Statens forurensningstilsyn
Norwegian Pollution Control Authority

SCREENING OF POLYFLUORINATED ORGANIC COMPOUNDS AT FOUR FIRE TRAINING FACILITIES IN NORWAY

2444
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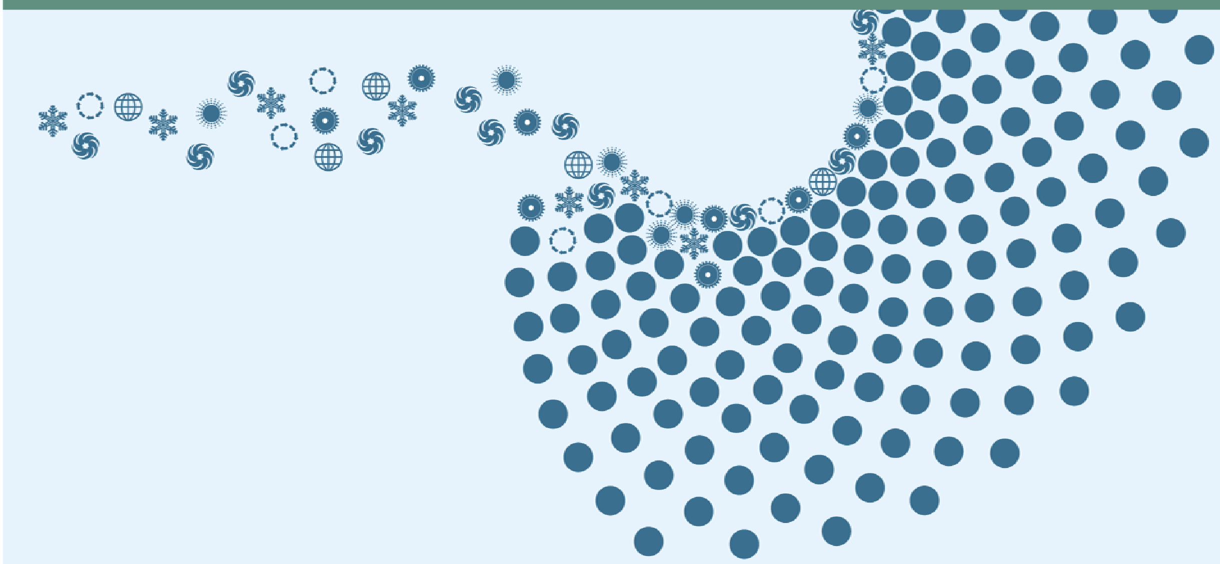

Forord

I 2007 ble det i Norge innført forbud mot bruk av PFOS i brannskum, tekstiler og impregnering. SFT har fått undersøkt jordsmonnet rundt fire brannøvingsfelt som et ledd i å fremskaffe et bedre kunnskapsgrunnlag om mulige miljøkonsekvenser som følge av bruk av PFOS og andre perfluorerte forbindelser. Hensikten med denne undersøkelsen har vært å få kartlagt om PFOS-holdig brannslukkingsskum som er anvendt frem til 2007 fortsatt er i nærområdet rundt brannøvingsfeltene. Undersøkelsen belyser også hvilke negative miljøkonsekvenser gjenværende rester kan ha.

Rapporten vil danne et grunnlag for vurdere hvorvidt andre brannøvingsfelter bør undersøkes nærmere med hensyn på perfluorerte forbindelser, samt å vurdere mulige tiltak mot fremtidig forurensning.

Bioforsk, med prosjektleder Carl Einar Amundsen, har utført undersøkelsen på vegne av SFT. NIVA har vært underleverandør på de marine undersøkelsene, og NILU har utført de kjemiske analysene.

Oslo 2. desember 2008

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Content

1. Summary

Several polyfluorinated organic compounds are considered toxic and persistent, and bioaccumulate in the environment. It is known that compounds like perfluorsulphonates (PFS) and perfluorcarboxylic acids (PFCA) have been emitted to the environment through the use aqueous film forming foams (AFFF) at fire training facilities at airports and oil refineries since the early 1970s. Soil, water, sediments and biota in the vicinity of these sites may have been affected by this activity. The use of AFFFs containing perfluoroctansulphonate (PFOS) was banned in Norway in 2007, but the knowledge on how these compounds are spread in the environment during the last 20-30 years are very limited, both in Norway and in other countries.

To investigate if the terrestrial and aquatic environments at previous and active training facilities are affected, SFT has taken the initiative of carrying out environmental screening at four selected fire training facilities in Norway (Mongstad oil refinery, Solberg Scandinavian AS, Gardermoen airport and Rygge Air Station). Bioforsk Soil and Environmental division has planned and implemented the investigation.

The main focus of this investigation has been on the terrestrial environment. The main objectives have been to determine the concentrations of relevant perfluorinated organic compounds (PFCs) in soils at the four selected fire training facilities in Norway and assess their dispersion potential from these sites. Another important aspect of the investigation has been to determine to what degree selected organisms in soil and water are influenced by PFCs from fire training facilities. The risks PFCs pose to the local environment are assessed in the report.

The concentrations of PFCs found in the vicinity of the four fire training facilities in this project show that soils in these areas are severely contaminated by PFCs coming from AFFFs, and the soil may be an important source for long term environmental pollution of PFCs. Measurements of PFOS in most soil samples exceed the proposed Norwegian guideline value for PFOS in soil (100 ng/g). Rough estimations of the total amounts of PFCs in soils around two of the investigated facilities show that 10-40% of PFOS used in AFFFs may still be present in the soil. These figures are uncertain.

Based upon estimated PNEC (predicted no effect concentration) for 6:2 FTS, PFOS and PFOA in soils, soil organisms living within about 100 meters from these sites may be at risk. More information is however needed on the effects of PFCs on soil living organisms to make better predictions of effects.

Exposing earthworms to soils from the four fire training facilities in this project resulted in mean bioaccumulation factors (BAFs) for 6:2 FTS, PFOS and PFOA of 2.4 (0.76-6.7), 2.6 (0.49-6.4) and 5.9 (0.31-14.0), respectively. For PFSs and PFCAs, BAF increases with increasing chain length. The PFOS precursor N-Et-FOSA had BAFs for earthworms in the range 188-770. Also N-Me-FOSA and PFOSA had considerable higher BAFs than 6:2 FTS, PFOS and PFOA.

The results show that increasing silt and clay content in soils reduces PFC uptake in earthworms and leaching in the soil profile. PFCs with long carbon chains (C_9-C_{14}) are less mobile than PFCs with chain lengths, C_4-C_8. Due to leaching in the soil profile, high concentrations of PFCs have been found in the groundwater at Gardermoen.

High concentrations of PFOS and N-Et-FOSA in sea snails (*Patellidae*) downstream the industrial area at Solberg Scandinavian AS, were due to runoff from the industrial area. The sediments in Radsundet also contained elevated concentrations of PFCs relative to other fjords (e.g. Oslofjorden), and seemed to be influenced by the activity at the firm.

This investigation shows that continued fire training over years locally has resulted in quite severe contamination with PFOS, in particular, but also with other PFCs in the environment. High mobility in some soils (sandy soils), high bioaccumulation potential of some PFCs, make these contaminants an environmental risk that should be assessed.

Sammendrag

Flere polyfluorerte organiske forbindelser (PFC) er giftige, persistente og bioakkumulerer i miljøet. Det er kjent at perfluorsulfonater (PFS) og perfluorkarboksylsyrer (PFCA) blant annet er sluppet ut til miljøet ved bruk i brannslukningsmidler på flyplasser og oljeraffinerier siden begynnelsen av 1970-tallet. Jord, vann, sedimenter og biota i nærheten av slike steder kan være forurenset av PFC på grunn av denne aktiviteten. Bruken av brannslukningsmidle som inneholder perfluoroktansulfonat (PFOS) har vært forbudt brukt i Norge siden 2007, men kunnskapen i Norge og internasjonalt om hvordan PFOS og andre PFC har blir spredt i miljøet de siste 30-40 årene er begrenset.

For å øke kunnskapen om i hvilken grad det terrestriske og akvatiske miljøet ved brannøvingsfelter i Norge er påvirket, har SFT tatt initiativ til å gjennomføre en screening-undersøkelse ved fire brannøvingsfelter i Norge (Mongstad oljeraffineri, Solberg Scandinavian AS, Gardermoen flyplass, Rygge flystasjon v/Forsvarsbygg). Bioforsk Jord og miljø har planlagt og gjennomført undersøkelsene.

Hovedfokus i undersøkelsen har vært undersøkelser i det terrestriske miljøet fordi kunnskapen har er mest begrenset. Hovedmålene har derfor vært å bestemme konsentrasjoner i jord av relevante PFC rundt disse brannøvingsfeltene for dermed å kunne bestemme horisontal og vertikal spredning (mobilitet) i jord. Bioakkumulering av ulike PFC i jord er bestemt ved å analysere meitemark fra felt og ved gjennomføring av tester i laboratoriet på jord som er samlet inn lokalt rundt brannøvingsfeltene. Mobilitet og potensialet for bioakkumulering er også undersøkt ved å ta prøver av bekkevann, grunnvann, marine sedimenter og albueskjell i sjø. Den lokale miljørisikoen er vurdert på bakgrunn av resultatene.

Konsentrasjonene av PFC i jord rundt de fire brannøvingsfeltene er svært høyt og innholdet er opptil 700 ganger høyere enn foreslåtte normverdier for PFOS. Innholdet av PFOS i alle jordprøver er høyere enn normverdien på 100 ng/g. Grove estimater over mengder PFC i jord rundt brannøvingsfeltene på Mongstad og Gardermoen viser at 10-40% av PFC som er brukt i brannskum ligger lagret i jord på disse områdene. Basert på sammenligninger med estimerte effekt-nivåer (predicted no-effect concentration, PNEC) for 6:2 FTS, PFOA og PFOS i jord kan det (basert på dagens kunnskap) antas at jordlevende organismer som lever innenfor 100 meter fra brannøvingsfeltene er påvirket. Mer kunnskap om effekter av PFC på jordlevende organismer er imidlertid nødvendig for å gi sikrere svar på miljørisikoen i jord.

Bioakkumuleringsforsøk med meitemark i jord samlet inn ved de fire brannøvingsfeltene gir gjennomsnittlige bioakkumuleringsfaktorer (BAF) for 6:2 FTS, PFOS og PFOA på hhv. 2.4 (0.76-6.7), 2.6 (0.49-6.4) og 5.9 (0.31-14.0). For PFSs og PFCAs øker bioakkumuleringen ettersom lengden på karbonkjeden øker. N-etyl-heptadecafluoroktan sulfonamid (N-Et-FOSA) viser svært høy akkumulering i meitemark (BAFs på flere hundre). Også andre sulfonamider (N-Me-FOSA og PFOSA) har høyere BAF for meitemark enn 6:2 FTS, PFOS and PFOA.

Resultatene fra prosjektet viser at økende silt- og leirinnhold i jord reduserer opptaket av PFC i meitemark fra jord og reduserer mobiliteten av PFC i jord. Perfluorkarboksylsyrer (PFCA) med kjedelengde C_9-C_{14} er mindre mobile i jord enn PFCA med kjedelengde C_4-C_8. Generelt er PFC relativt mobile i jord og høye konsentrasjoner er funnet i bekkevann ved Solberg Scandinavian og i grunnvann på Gardermoen. Høye konsentrasjoner av PFOS og N-Et-FOSA i albueskjell (*Patellidae*) i sjøkanten i Radsundet nedenfor Solberg Scandinavian skyldes

trolig avrenning fra området til sjøen. Sedimentene i Radsundet har et høyere innhold av PFOS enn sedimenter fra for eksempel Oslofjorden og selv om tilstanden i sedimentene kan klassifiseres som god ifølge klassifiseringsystemet for marine sedimenter, viser dette at sedimentene i Radsundet er påvirket av aktiviteten ved bedriften.

Undersøkelsen viser at miljøet rundt brannøvingsfelter som har vært brukt over lang tid (10-20 år), vil være forurenset med PFOS og andre PFC som er brukt i brannskum. Relativt høy mobilitet i jord og høyt bioakkumuleringspotensiale for enkelte PFC, gjør at disse forbindelsene kan utgjøre et miljøproblem som bør utredes videre.

Abbreviations

AFFF	Aqueous film forming foams (also aqueous fire fighting foams)
BAF	Bioaccumulation factor: ratio between the concentration in biota and concentration in soil. Here: concentration in biota (ww)/concentration in soil (ww).
FTS	Fluoroteleomer sulphonate
LC_{50}	Concentration that leads to death of 50% of test species
LOQ	Limit of quantification
NOEC	No observed effect concentration
ng/g	Nanograms per gram = parts per billion (ppb) (equal to µg/kg)
PEC	Predicted environmental concentration
PFC	Polyfluorinated organic compounds
PFCA	Perfluor carboxylic acid
PFOA	Perfluor octanoic acid
PFOS	Perfluoroctyl sulphonate
PFS	Perfluor sulphonates
PNEC	Predicted no effect concentration
TGD	Technical Guidance Document

2. Background

One of the main sources for PFCs in the environment, at least locally, is the application of aqueous film forming foams (AFFF) at fire training facilities at airports and oil refineries, where PFCs have been used since early 1970's (SFT 2005, Posner *et al.* 2007). Soil, water, sediments and biota in the vicinity of these sites may have been affected by this activity. In the Norwegian screening for environmental contaminants relatively high concentrations of PFOS and other polyfluorinated organic compounds were found in the drainage system at a fire training facility in Haugesund, Western Norway, and PFOS was also found in Blue mussels in the recipient downstream of this site (Green *et al*. 2008).

Accumulation experiments using standard soil (OECD-soil) have shown that earthworm bioaccumulate PFOS, PFOA and 6:2 fluoroteleomer sulphonate (FTS) encountering bioaccumulation factors (BAF) of about 1-3 (Stubberud 2006). 6:2 FTS had somewhat higher BAFs than PFOS and PFOA. Biodegradation experiments for 6:2 FTS and 10:2 FTOH have shown that 6:2 FTS do not degrade under anaerobic conditions, while a quite high degradation rate was found for 10:2 FTOH. During a 42 week period at 25 ºC 11 450 ng/g 10:2 FTOH was reduced to 66 ng/g. PFDcA was found to be a major degradation product in the process (Eggen 2007). These experiments show that 6:2 FTS, which is a possible substitute for PFOS-related compounds, bioaccumulate in soils and degrade slowly.

In May 2000 the 3M Company announced that it would voluntarily cease manufacturing materials based on perfluoroctanesulphonyl fluoride (POSF) after a metabolite of this compound (PFOS) was found to be widespread. AFFFs containing PFOS have not been manufactured by 3M since 2003.

The use of AFFFs containing PFOS was banned in Norway in 2007, but the knowledge of how these compounds are spread in the environment during the last 20-30 years at fire training facilities is limited, both in Norway and in other countries. To investigate if the terrestrial and aquatic environments at previous and active training facilities pose an environmental threat SFT has taken the initiative to carry out environmental investigations at four fire training or testing facilities in Norway. The fire training facilities to be included in the investigation were selected by SFT. Bioforsk Soil and Environmental division has planned and implemented the investigation.

2.1 Objectives

The main focus in this investigation is on the terrestrial environment. This is both due to the limited knowledge on how PFCs behave in soils and how soil living invertebrates respond to these pollutants. Soil act both as a source and a sink for pollutants and to evaluate soil as a future source for PFCs for soil living organisms and the aquatic environment the vertical and horizontal distribution of PFCs at and around these training facilities need to be investigated.

Objectives for the investigation

- Investigate the concentrations of relevant PFCs in soil at four fire training or testing facilities in Norway and, by sampling soil in horizontal and vertical gradient at the sites, evaluate the dispersion potential for PFCs from these sites
- Investigate to what degree selected organisms in soil and water are affected by PFCs from fire training facilities

- Evaluate the risks previous use of PFCs at these training facilities pose on the local environment

3. Polyfluorinated organic compounds in fire fighting foams

Perfluoralkanesulphonate salts and perfluorcarboxylates are present in fire-fighting foam formulations, such as aqueous film forming foams (AFFFs). AFFFs are proprietary mixtures used to extinguish hydrocarbon fuel fires and are often found where there are large volumes of flammable liquids and the potential for a fire exists (e.g. airports, oil refineries, fire departments etc). They are complex mixtures of surfactants and other components that have been available for fire-fighting applications since their development by the United States Navy and 3M Company in the mid-1960s (Moody and Field 1999). Due to the business confidential nature of AFFF formulations, the chemical structure and of the actual perfluorinated surfactants used in commercial AFFFs are not known outside the companies that manufacture them.

Two different methodologies have been used for the production of PFCs. In the electrochemical fluorination process (ECF) used by the 3M Company since 1956, the organic compound is dissolved or dispersed in anhydrous hydrogen fluoride. A direct electrical current is passed through the HF, causing all the hydrogen atoms on the organic compound to be replaced by fluorine (Hekster *et al.* 2003). This process produces 1-perfluorooctane sulphonylfluoride (POSF) which is the starting product for the range of products based on Perfluorooctyl sulphonates (PFOS). POSF reacts with methyl or ethylamine to form N-methyl (N-MeFOSE) or N-ethylperfluorooctanesulphonamidoethanol (N-EtFOSE) which is the primary building blocks of the perfluorochemistry of 3M (Hekster *et al*. 2003). The ECF process produces only 35-40% n-POSF; the rest is impurities like perfluorinated alkanes and ethers, branched and linear C8-perfluorinated sulphonates, and tars (Hekster *et al.* 2003). As mentioned 3M decided in 2000 to phase out the production based upon the perfluoroctyl chemistry. The perfluorooctyl group has been replaced by the perfluorobutyl equivalent (Hekster *et al.* 2003; Herzke *et al.* 2007).

Another method for producing PFCs is telomerisation. This process was developed by Haszeldine in 1949. It produces only linear products, which can contain small amounts of shorter carbon chain compounds (Hekster *et al.* 2003). Linear substances are generally more degradable than branched substances. The chemical structure of teleomer sulphonates is characterised by a perfluorinated carbon chain which is followed by a CH_2-CH_2-group connected to the sulphonate group.

The main producer of PFOS-related substances, 3M, decided to phase out the production of these substances in 2000 and since 2003 these substances have not been produced by 3M. A number of industry sectors also have taken voluntary measures to reduce the potential emissions and risk from PFOS-related substances.

4. Regulations regarding PFCs

In Norway there is a national goal to reduce the emissions of PFOA- and PFOS-related compounds significantly at the latest within 2010 and completely eliminate emissions before 2020 (Stortingsmelding no. 21, 2004-2005). In the national action plan for PFOS- and PFAS-related compounds from 2005, the substitution and phasing out of PFOS-related compounds in fire fighting foams is one of several actions that is suggested by SFT (http://www.sft.no/arbeidsomr/kjemikalier/pfos/pfas_handlingsplan.pdf). In a Norwegian inventory of remaining quantities of fire extinguisher foam containing PFOS in 2005, it was estimated that there were approximately 22 tons of PFOS present in the 1,4 million litres of foam in stock (SFT 2005). Since then most of the fire extinguishing foam has been delivered for destruction. From April 2007, it is forbidden to be in possession of, use, sell or export AFFF containing PFOS in Norway.

The inventory from 2005 showed that it was difficult to quantify the historic emissions of PFOS, especially from airports and fire training sites. Even if it is difficult to quantify the amounts of PFOS released from fire training facilities, it is estimated that considerable amounts have been dispersed into the nearby surroundings of these sites. Based on information obtained from these sites, as well as from estimates from other countries (e.g. UK, Brooke *et al.* 2004), it seems obvious that the amount of PFOS-related compounds released from fire fighting activities during the last two-three decades is considerable. According to Prevedouros *et al.* (2006) 50-100 tons of PFCA were emitted in the period 1965-1974 from AFFFs, while 3-30 tons were emitted indirectly through POSF-based AFFFs in the period 1970-2002.

Recently the Norwegian Pollution Control Authority has proposed a guideline value for PFOS in soils of 100 ng/g based upon effect studies on earthworms (Stubberud 2006 and 3M 2003).

5. Selection of fluorocarbons for analysis

5.1 Chemical properties of PFCs

6:2 Fluorotelomer sulphonate (6:2 FTS)

Fluoroteleomer sulphonates (FTS) are produced by the telomerisation process, and thereby consists only of linear products and even numbered FTS, which can contain small amounts of shorter carbon chain compounds (Hekster *et al.* 2003). 6:2 FTS is susceptible to biodegradation under sulphur-limiting and aerobic conditions (see references in literature review by Herzke *et al.* 2007). 6:2 FTS is now used as substitute for PFOS in fire extinguishing foams (Herzke *et al.* 2007) and the analysis of these compounds in environmental samples at fire training sites is expected to give important information about the environmental behaviour of these compounds.

Perfluorooctane sulphonamide and sulphonamidoethanol

The fluorooctanesulphonamides (FOSA) and fluorooctanesulphonamideoethanols (FOSE)-type substances are suspected to be potential sources of PFOS in the environment through degradation (Källqvist 2007). These substances are intermediary products in the production of PFOS-related compounds (Brooke *et al.* 2004). According to Brooke *et al.* (2004) there is evidence for this for N-EtFOSE, but little or none for the other substances.

Both FOSA and FOSE-compounds have higher vapour pressure than PFOS and it has been demonstrated that they can be subject to atmospheric long range transport (Stock *et al.* 2004; Martin *et al.* 2006) and that FOSA can be oxidized in the atmosphere to PFCA (e.g. Martin *et al.* 2006). In water N-EtFOSE and N-MeFOSE can be degraded by indirect photolysis. In degradation experiments using activated sludge 84-90% of N-EtFOSE has been shown to degrade during 18-35 days (see Källqvist 2007). In these experiments PFOA was shown to be one of the degradation products. The degradation of FOSA using active sludge seems to be slower than for FOSE (see Källqvist 2007).

Since both FOSA and FOSE are known to be intermediary products in the production of PFOS-related compounds, these compounds are included in the analysis of PFCs in the project.

Perfluoralkylsulphonates (PFS)

Perfluoroalkylsulphonates (PFS) are a range of compounds that contain perfluorinated carbon chains connected to sulphonate groups. The most studied and widely applied PFS is perfluorooctanesulphonate (PFOS). In the environment PFOS is resistant to chemical and biological changes and does not degrade under any observed conditions except for combustion (3M 2003). PFOS has been widely used in fire fighting foams throughout the world and in 2000 the global volume for fire fighting foams was approximately 151 tons (OECD 2002).

Less is known about shorter chain PFS (butane and hexane sulphonates, PFBS and PFHxS), but according to Herzke *et al.* (2007) they probably have the same mode of action as regards toxicity, but are less toxic and bioavailable. As mentioned, octane is replaced by butane in the production of PFC at the 3M Company.

According to Herzke *et al.* (2007) longer chained PFS (C_9-C_{15}) are relevant both for human exposure (toxic characteristics) and accumulation. In this project PFS with 4, 6, 8 and 10 carbons are quantified in the environmental samples (Table 1).

Perfluoralkylcarboxylates (PFCA)
Commercial PFCA products consist mainly of linear C8- and C9-PFCA, but homologues with chain length between C_4 and C_{13} can also be found (Herzke *et al.* 2007). In the period from 1947 to 2002 the ECF process was used to produce the majority of perfluoroctanoate (Prevederous *et al.* 2006). As mentioned the use of fire fighting foams have emitted substantial amounts of PFCs worldwide. The new generation fire fighting foams mainly based on C_6-fluoortelomers, however, will contain only traces of PFOA.
For more detailed information on chemistry and application of PFOA in Norway, see Posner *et al.* (2007).

5.2 Chemical analysis of environmental samples

5.2.1 Biota, soil and sediment

Soil and sediment samples were air dried and then treated with acid. After neutralization the samples were extracted with methanol in an ultrasonic bath. Internal standard was added to all samples prior to extraction. Biota samples were homogenised and extracted by the same procedure. All soil, sediment and biota samples were analysed twice: the first time the extracts were concentrated (about 200 times), the second time (due to high concentrations) the extracts were not pre-concentrated. In the clean-up process graphitised carbon (EnviCarb) was used.

5.2.2 Water

Water samples were filtered prior to analysis i.e. only dissolved PFCs were included in the analytical determination.

5.2.3 Analytical determination

The quantification of PFCs was done by high performance liquid chromatograph coupled to mass spectrometer (HPLC-Q-TOF-MS) for methanol extracts. Quantification was performed using the internal standard method.
Quality control measures included determination of method detection limits for all analytes on the basis of blank extraction experiments. Analysis of reference material was carried out for each 10th sample. The recovery rates for all internal standards were controlled.

Table 1: List of PFCs analysed in soil, sediment, water and biota in the project.

Compound	Short name
6:2 Fluorotelomer sulphonate	6:2 FTS
Perfluorooctane sulphonamide	PFOSA
N-Methyl-heptadecafluorooctane sulphonamide	N-Me-FOSA
N-Ethyl-heptadecafluorooctane sulphonamide	N-Et-FOSA
N-Methyl-heptadecafluorooctane sulphonamidoethanol	N-Me-FOSE
N-Ethyl-heptadecafluorooctane sulphonamidoethanol	N-Et-FOSE
Perfluorobutane sulphonate	PFBS
Perfluorohexane sulphonate	PFHxS
Perfluorooctane sulphonate	PFOS
Perfluorodecane sulphonate	PFDcS
Perfluorohexanoic acid	PFHxA
Perfluoroheptanoic acid	PFHpA
Perfluorooctanoic acid	PFOA
Perfluorononanoic acid	PFNA
Perfluorodecanoic acid	PFDcA
Perfluoroundecanoic acid	PFUnA
Perfluorododecanoic acid	PFDoA
Perfluorotridecanoic acid	PFTriA
Perfluorotetradecanoic acid	PFTeA

pH, total organic carbon (TOC), and fraction of soil less than 63µm where determined in the soil samples. TOC was determined in the sediment samples.

An overview of CAS-numbers and chemical structure for PFCs analysed in soil, sediment, water and biota in the screening project is showm in Appendix I.

5.2.4 General remarks to chemical analyses

When quantification of PFCs in the samples was not possible, the values were given as less than the detection limit (defined as 3x noise in the LC/MS spectra) or as less than the limit of quantification (defines as 10 x noises in the LC/MS spectra). Limit of quantification is then higher and more accurate than the limit of detection. All values less than the detection limit or limit of quantification is denoted by <.

An accurate measure of the uncertainty in analyses requires laboratory intercalibration excercices for all measured sample types and matrices. This has not been done, but a rough estimate of the measurement uncertainty is ±30-40%.

6. Description of localities and sampling

Four localities have been selected for investigation in this screening project: Mongstad oil refinery, Solberg Scandinavian AS, Gardermoen airport and Rygge Air Station (Figure 1).

Figure 1: Geographic localisation of investigated sites.

6.1 Mongstad oil refinery

6.1.1 Location of testing platform and site history

Mongstad is an industrial site located in the municipalities of Lindås and Austrheim in Hordaland, Norway, about 80 km north of Bergen (Figure 1). The site features an oil refinery for StatoilHydro and other oil companies, including Shell. The first use of the site was in 1975 when Statoil opened its refinery. At the end of the 1980s the refinery was expanded and is today the largest oil refinery in Norway.

The fire training platform at Mongstad has been used regularly (February-November) since 1988. About 200 litres of foam has been used annually. Assuming a concentration of perfluorinated compounds of 1-4 percent (mean 3%), this amounts to 6 kg PFCs per year or about 120 kg totally in the period. About 80% of the foam used has been produced by National foam (US company that produces foam concentrates) and 20% by 3M (delivered by Solberg Scandinavian). Since 2006 ATC foam and fluoroprotein foam, which do not contain PFOS, have not been used at Mongstad.

The fire training platform has a concrete floor and a drainage system collects excess hydrocarbons and AFFFs from the platform. It is located quite far from the ocean shore; about 200 meters from Mongstadvågen. Therefore it was decided not to collect samples of sediment and biota in the marine environment in this project.

6.1.2 Soil sampling

Soils were sampled in an area south of the training platform at Mongstad (Figure 3). It was not possible to sample soils closer than 26m from the platform. At this distance samples were taken at five depths (0-5cm, 5-10cm, 10-30cm, 30-50cm and 50-60cm, Appendix II). The next samples were all taken from the topsoil (0-5cm) at distances 30m, 40m, 52m, 91m and 200m from the training platform (see Figure 3).

The samples Soil 26m, Soil 30m, Soil 40m and Soil 52m were collected at or inside a Salix grove south from the platform, while Soil 91m and Soil 200m were collected in open grass-covered areas with quite thin soil layers.

Figure 2: Left: The fire training platform at ***Mongstad*** *oil refinery. Right: View towards platform which is situated by red building (behind trees) in the back. People (orange spot) can be seen at 91m sampling point.*

6.1.3 Earthworms

At the sampling points Soil 25m and Soil 52m earthworms were collected at Mongstad. At both sites several species were found (*Lumbricus rubellus, Aporrectodea rosea, Dendrobaena octaedra, Dendrodrilus rubidus).* These species have different ways of living (feeding, depth of living, burrowing etc) but it is not known that the uptake mechanisms for organic contaminants vary between species which may be the case for e.g. heavy metals (different metallothionin production between species).

The worms from each site were pooled and analysed as one sample.

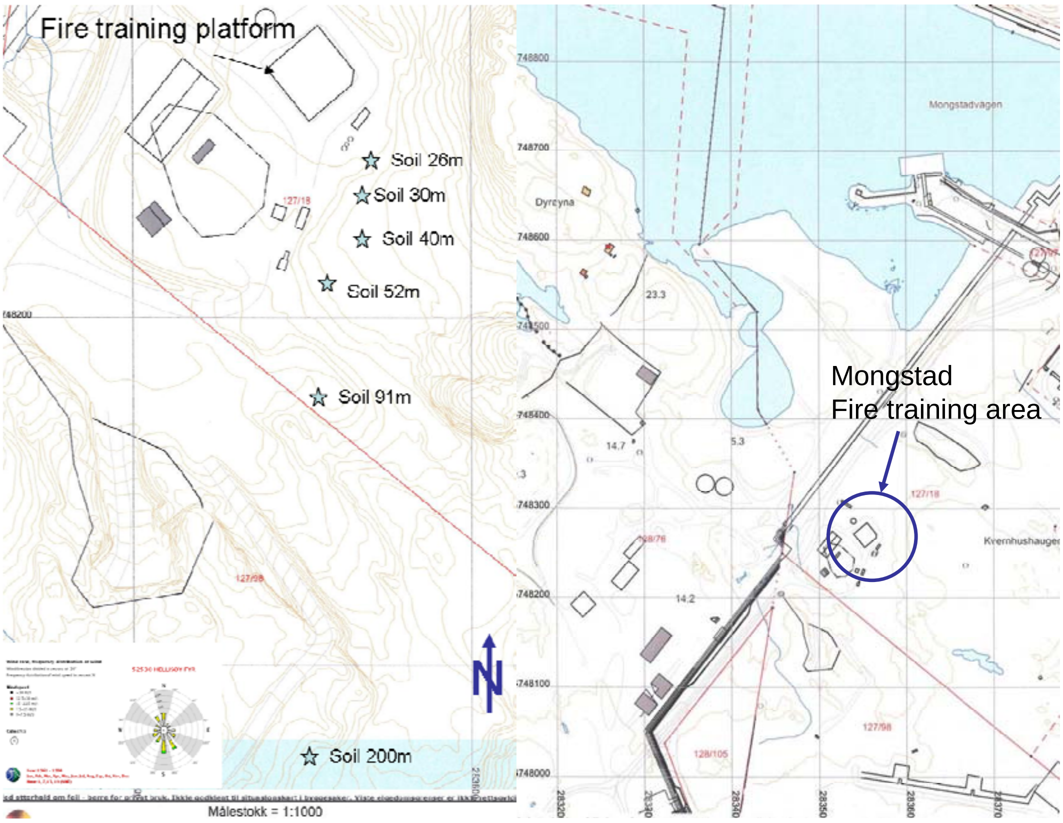

Figure 3: Overview of soil sampling locations at Mongstad oil refinery.

6.2 Solberg Scandinavian AS

6.2.1 Testing platform location and site history

Solberg Scandinavian AS is a company which manufactures and sells of high quality fire fighting foam agents – ARCTIC FOAM. The headquarters are located at Olsvollstranda in Radøy municipality about 50 km north of Bergen. At the site there is a platform for fire testing were various fire fighting foams have been tested over the years. Today the platform is located about 20 meters from the main building (Figure 4 and 5) on an asphalted area. In the testing only fire drill equipment exerting moderate power (short range) has been used. The spreading of fire fighting foam from the area during testing is therefore assumed to be caused by wind.

The fire extinguishing activity at the site has been a part of the quality control of AFFFs foams since 1982. In the period 1990-2001 Solberg Scandinavian AS made AFFFS on licence from 3M which involved the use of PFOS-related products. Since 2001 only AFFFs without PFOS have been tested at the site. It has not been possible to quantify the amount of AFFFs that has been used at the site in the period from 1982.

The sampling of soil, stream sediment and stream water at Solberg Scandinavian was performed by personnel from Bioforsk Soil and Environment Division 18.June 2008, while the marine samples were collected on 19.June (sediment) and 1.July 2008 (Sea snails) by personnel from Norwegian Institute for Water Research (NIVA).

6.2.2 Soil sampling

The soil thickness in the area was generally lower than 30cm and the soil was dominated by a thick layer of only slightly decomposed organic material (Oi-horizon, mainly mosses).
The soil samples were collected in a gradient heading north-northwest from the testing platform. At the 16m and 25m sampling points soils from three and two horizons were collected, respectively, while at the other locations only topsoils were collected (Appendix II). At all locations the Oa- or A-horizon was sampled as the uppermost layer because these layers have higher densities and presumably better binding properties for PFCs than the Oi-horizon.

The samples at 16m and 25m from the testing platform were collected inside the fence surrounding the area, while the samples at 38m, 84m and 155m were taken outside the fence in a north-northwest direction (the prevailing wind direction in the area) from the testing platform (Figure 5). The area from sample point 38m to sample point 155m consists of dense coniferous forest (*Picea* and *Pinus* species). 0.5-1 litres were collected for each soil sample. The fence surrounding the industrial area is not shown on the map.

Earthworms were not found during soil sampling in the area.

*Figure 4: Left: testing platform at **Solberg Scandinavian AS**. Right: sampling of Sea snails at the seashore in Radsundet below Solberg Scandinavian.*

6.2.3 Water and sediment samples from stream

In the stream running from the drainpipe (Figure 5) to the fjord one water sample (volume 0.5 litre PE-bottle) was collected. The bottle was rinsed twice in the stream water prior to sample collection. The water flow was roughly/approximately 1 litre per second at the time of sampling.

In the stream a composite sample of sediments was collected. This was carried out by collecting about 100 ml of sedimented material from different locations in the stream, starting from the drainage outlet extending to the seashore. The sediment was collected in a PE-container with a screw-cap.

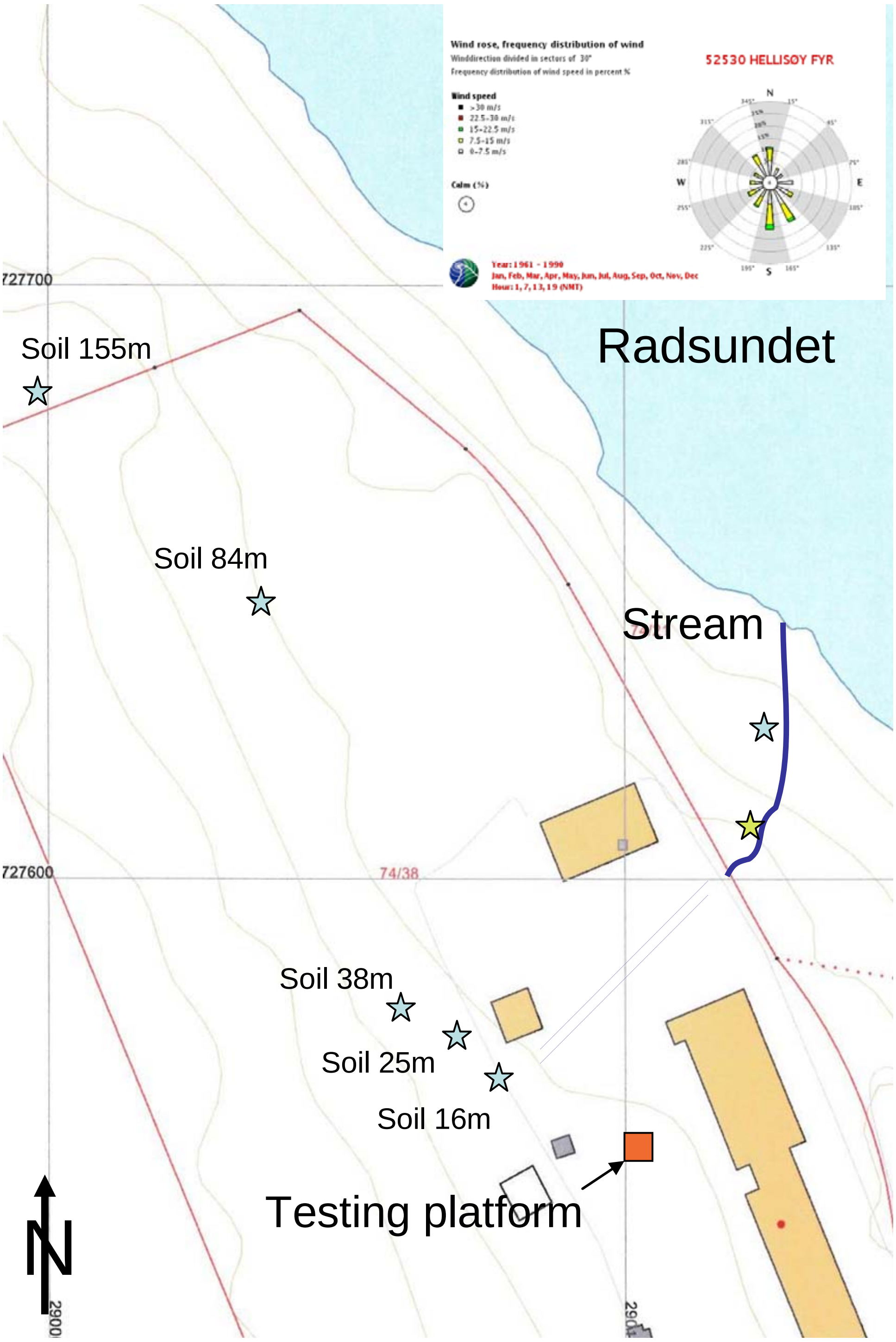

Figure 5: Overview of sampling points for soil and stream sampling at Solberg Scandinavian performed 18.June 2008.

6.2.4 Marine sediments

The seabed outside Solberg Scandinavian declined steeply from the seashore which made it difficult to collect sediments for analysis. Sediments were sampled from five out of nine locations using a grab-sampler. The sediments from the shallowest water consisted of relatively coarse material, while the two sediments from deeper waters had finer texture (Appendix II).

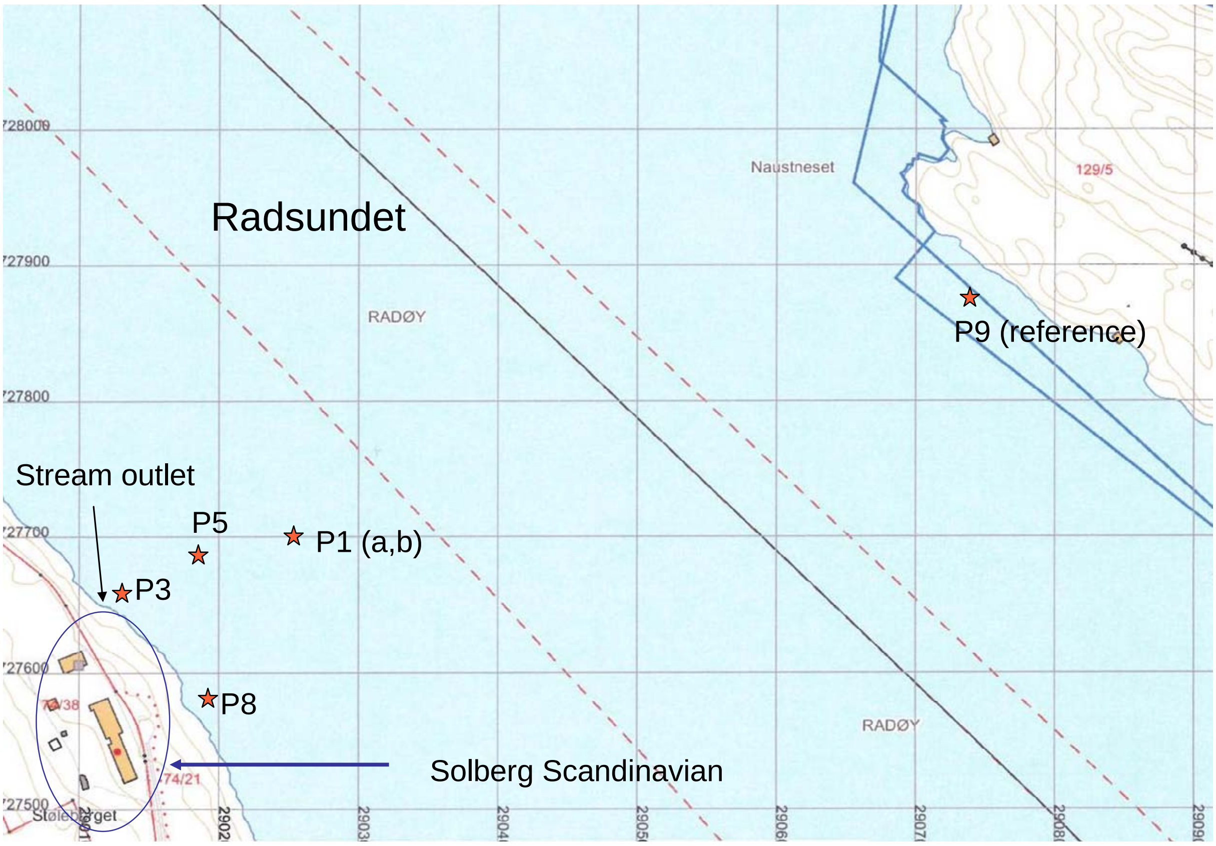

Figure 6: Overview of sediment sampling points at Solberg Scandinavian (see Appendix II).

6.2.5 Sea snails

Sea snails (*Patellidae*) were collected at seven seashore locations outside Solberg Scandinavian on 1.July 2008 by personnel from NIVA. Three sampling locations were situated north of the stream outlet (Appendix II) and three were located south of this outlet. The sea snails from sample point 7 were taken at the outlet of a stream south of the stream that was selected for water and sediment analysis (see above).

All sea snails were collected from stones in the tidal sone. The locations are therefore different from the sediment locations and no direct connection between sediment and biota exists.

6.3 Rygge Air Station

6.3.1 Platform location and site history

Rygge Air Station by The Norwegian Defence Estates Agency is operated by the Royal Norwegian Air Force, which also owns the land and the runway. The Air Station is located 60 km south of Oslo (Figure 1) and is co-located with Moss Airport, Rygge, which is owned and operated by Rygge Sivile Lufthavn.

The old training facility at Rygge Air Station was used for a period of at least 20 years (about 1980-2000), probably longer. Today there is a new road passing through the area and it was not possible to establish exactly were the old platform (concrete, 10x10m) had been located. The distances used in the sample description therefore are approximate distances from the old training site (Appendix II and Figure 8).

The area is dominated by deciduous trees. In northeast and southwest directions there are small gravelled roads, while in the east-west direction there is a new road heading towards the new terminal building at Moss Airport, Rygge. These roads make the area today relatively open. After a quite extensive soil investigation in 2002, 144m^3 soil polluted with hydrocarbons, halogenated fire extinguisher foams was removed from the site and landfilled (Aase 2002). After removal of polluted soil the area was levelled, probably using both local and new (delivered) soil. Areas that were clearly disturbed by the remediation at the site were avoided.

The new fire training facility has been used since 2000/2001 when the new fire station was built. This platform is located about 600m northeast of the old site on the other side of the airfield (Figure 8).

Based on the site history, and inspection of the site with former users, location of the sampling areas was decided. Since the area at and close to the old platform had been significantly disturbed since the platform was in use, soils were sampled in the forested areas northwest and northeast from the platform since there were no signs of disturbance at these sites. It was also decided to take some samples at the new fire training site.

6.3.2 Soil and sediment sampling

Soil and sediment samplings at Rygge were performed on 12th.June 2008 by personnel from Bioforsk Soil and Environment Division.

Soil samples were collected at distances 26m, 31m, 38m, 54m and 174m northwest from the approximate platform location (Figure 8). At 26m samples were collected from 0-3cm, 5-10cm, 10-30cm, 30-50cm and 50-55cm (Figure 7), while at the other locations the upper 5cm was sampled (Appendix II). There was no distinct horizon development at the 26m location profile which was sampled. The top soil was a typical A-horizon, while the four other soil samples were transitions from E- to C-horizons.

One soil sample was also taken northeast of the old platform area (Soil 19m). Between the old fire training platform and the grove of deciduous trees northwest of the platform there was a shallow ditch which may have received drainage from the platform area. Three samples were taken from this ditch at two locations (Sed 18m, depth 0-5cm and 20-22cm and Sed 39m 0-4cm).

*Figure 7: Left: location of the old fire training site at **Rygge**. Right: soil profile at Soil 26m.*

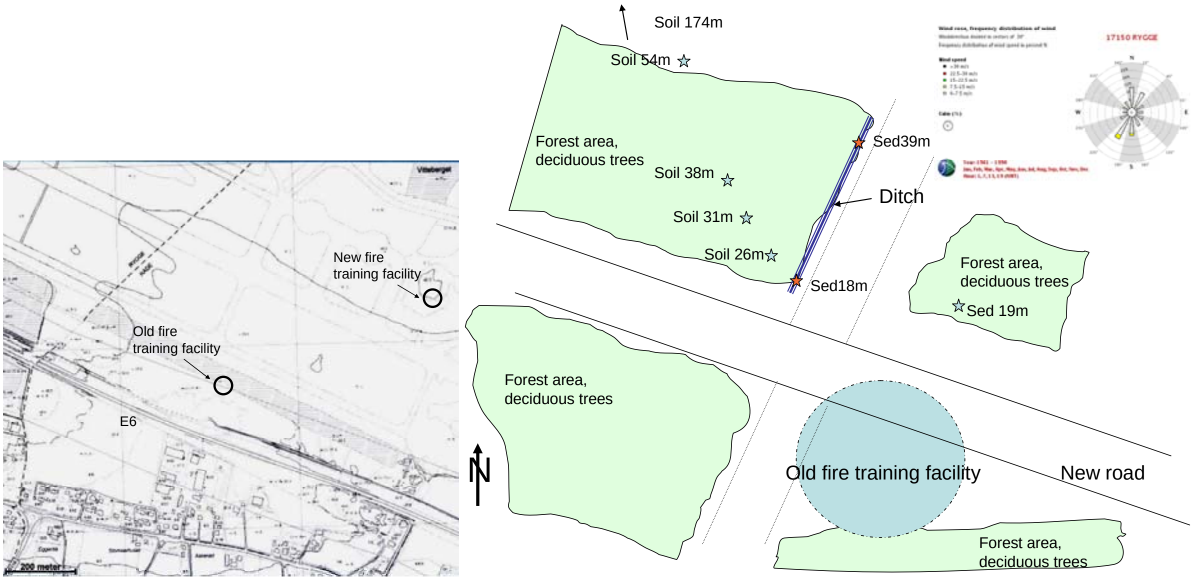

Figure 8: Overview of the area at the old fire training facility at Rygge Air Station. Locations for soil and sediment samples are shown. The proportions and scale in the map is just approximate.

Two soil samples were taken from 0-5cm depth, at the 27m and 56m locations situated south of the new fire training platform at Rygge. There were no trees at this site and the area was covered with grass.
During the sampling of the soil profile at location Soil 26m some earthworms were found. The sample size was however not considered sufficient for chemical analysis.

6.4 Gardermoen airport

6.4.1 Site history and testing platform location

The Gardermoen area was originally used as a military airport (from about 1912). From 1998 the area has been the main airport for Southeastern Norway and is situated 50 km northeast of Oslo (Figure 1).
There are five platforms at Gardermoen being used for fire training since 1990-91. Platform 1 and 4 have been used more frequently compared to the other platforms and are the sites were most of the perfluorinated fire foam have been used. These two training platforms have been used for airplane fire extinguishing using quite powerful foam canons (range up to 80m). In this investigation the area around platform 4 was selected for investigation. Platform 1 is the largest of the training platforms at Gardermoen, and is located about 40m south of platform 4. The activity at platform 1 therefore also may influence on the pollution PCF-levels around platform 4.

Between 5000-7000 litres of AFFFs have been used annually at Gardermoen, and approximately 500-700 litres, (10%), of this were used at platform 4. In 2001-2002 AFFFs containing PFOS were phased out.

The groundwater magazine at Gardermoen is the largest in Norway and is a very important water resource. However, the groundwater is not currently used for drinking water purposes. Emissions of pollutants like de-icing agents based upon acetate and formiat, as well as hydrocarbons from Gardermoen airport, constitute a potential threat to groundwater quality. Extensive monitoring programs are therefore carried out in the area. At the fire training platforms there are two monitoring wells close to platform 4 that is regularly sampled and the water analysed for e.g. hydrocarbons. Analysis for PFCs have, however, not been carried out in these wells on a regular basis.

6.4.2 Soil sampling

Soil sampling at Gardermoen was performed by personnel from Bioforsk Soil and Environment division on11th.June 2008.

The soil samples were collected north of training platform 4 which coincide with the prevailing wind direction in the area (Figure 10). A soil profile was made 1m from the edge of the training platform in a low sandbank surrounding the platform. The top of the bank was vegetated with grass. Samples were taken from 0-5cm, 5-10cm, 10-30cm, 30-50cm and 65-80cm (Appendix II, Figure 9). Two samples were collected at a deciduous grove 7,5m (0-5cm and 10-12cm) from the border of the platform. The two last samples (70m and 200m) were taken in the coniferous forest heading north from the training area.

*Figure 9: Left: fire training platform 4 at **Gardermoen**. Right: soil profile in the sandbank by the platform.*

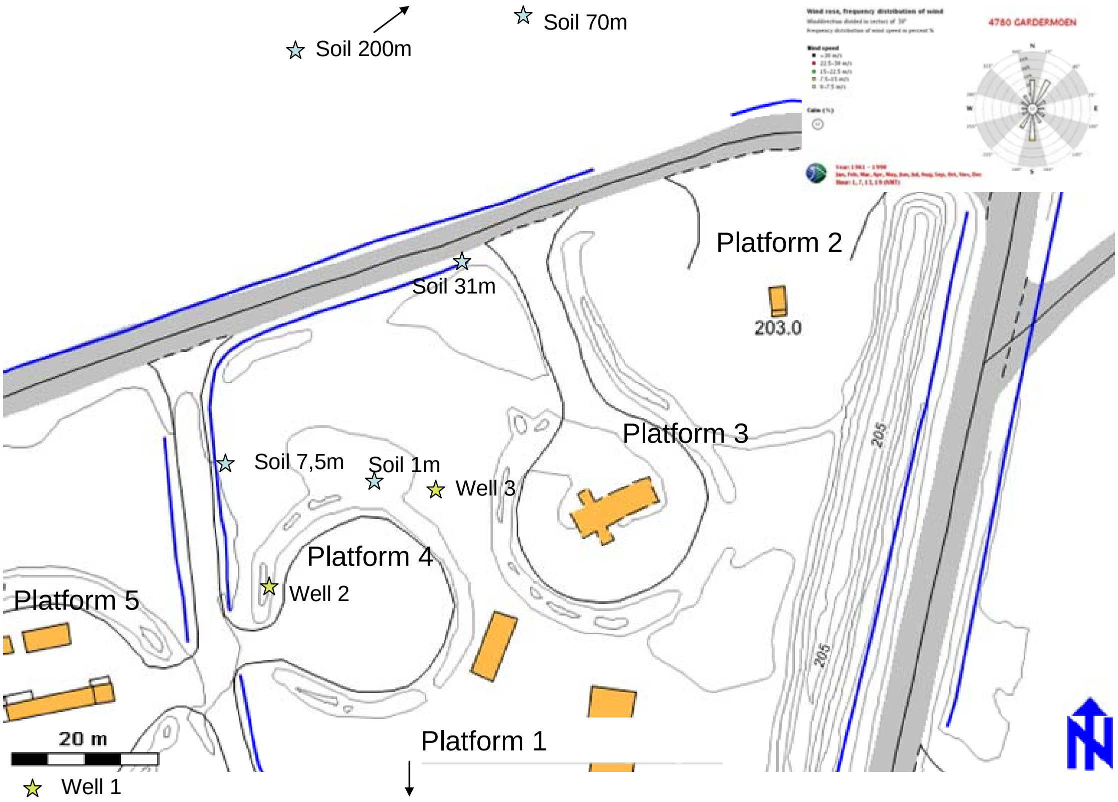

Figure 10: Overview of sampling locations at the fire training platforms at Gardermoen airport. The reference soil sample (Soil 200m) is located outside the map.

6.4.3 Groundwater sampling

Sampling of groundwater was done by personnel from Gardermoen airport using the same equipment used in the regular monitoring of groundwater quality at Gardermoen. About 20 litres of water were pumped from each well. One-litre polyethylene (PE) bottles were rinsed twice using the well water before being filled. New PE-hoses were used for the water sampling.

Well 2 and 3 are located close to platform 4, while well 1 is located 40-50 meters southwest of platform 4 (Figure 10). The groundwater flow is from east to west i.e. from wells 3 towards well 2 and 1. The groundwater table was at -3meters at the time of sampling. One sample was collected from each well.

6.5 Overview of samples for analysis

Altogether 75 samples have been analysed in the project and the majority of these samples are soil and earthworm (Table 2). Noted that 12 of the earthworm samples are from accumulation experiments in the laboratory (se chapter 7) and only two are earthworms collected in the field.

Table 2: Overview of samples analysed in the project

Sample medium	Soil	Earth-worm*	Sediment	Stream water	Ground-water	Marine sediments	Marine biota
Site							
Solberg Scandinavian	8	3	1	1		6	7
Monstad oil refinery	10	5					
Gardermoen airport	10	3			3		
Rygge Air Station	11	3	4				
Total	39	14	5	1	3	6	7

*12 out of 14 samples are from laboratory accumulation experiment

7. Earthworms collected in field and accumulation experiments

During soil sampling earthworms were collected in those cases were these could be found. As shown in the previous chapter, earthworms which were suitable for chemical analysis were found only at Mongstad, at locations 26m and 52m from the platform. At location 26m the worms were collected through the entire profile (0-60cm); while at location 52m worms were collected down to 30cm i.e. 25cm below the sampling depth. Different species of worms were collected (*Lumbricus rubellus*, *Aporrectodea rosea, Dendrobaena octaedra, Dendrodrilus rubidus*). All worms from one site were pooled before analysis.

At Rygge and Gardermoen the soil was very dry and only a few worms could be found at the 26m location at Rygge, while at Gardermoen no worms were found. At Solberg Scandinavian the soil conditions with respect to humidity was good, but no worms were found.

To investigate how PFCs emitted from the training facilities to local soils can be transported in the terrestrial food chain, accumulation experiments using sampled soils from the four sites were performed. Three soil samples from each of the four investigated sites were selected for investigations of uptake of PFCs in earthworms. 400 ml of air dried soil was added to 500 ml PE containers (and moisturised to a suitable condition for accumulation tests. The amount of water added to soils with similar characteristics (texture, organic matter) was the same, assuring comparable moisture conditions.

The accumulation experiment was performed for tree weeks. Ten earthworms (total weight of minimum 3 grams) *Eisenia fetida,* all with clitellum were added to each container. The earthworm gut was emptied keeping the worms on wet filter paper for 24 hours. They were fed with about 15 grams of wetted horse manure (air dried and frozen at -20 C), added on top of each container at the start of the experiment. The feeding was repeated after 1 and 2 weeks with the same amount of rewetted horse manure.

The exposure was performed at 20-23°C in a light:dark cycle of 16:8 hours. After three weeks the earthworms were weighed after emptying of the gut for 24 hours. The worms were frozen (-20 ºC) immediately after weighing and kept frozen until analysis.

By using soil and earthworm concentrations, the bioaccumulation factors (BAF) for the various PFCs will be calculated. BAF is calculated according to Technical Guidance Document (TGD), EU (2003)

$$BAF = \frac{Concentration\ \ earthworm\ (ng / g\ wetweight)}{Concentration\ \ soil\,(ng / g\ wetweight)} \qquad \text{Eq. 1}$$

8. Results

8.1 Mongstad oil refinery

8.1.1 Soil

The content of total organic carbon (TOC) were high in all samples from Mongstad (28.8-49.5%, Appendix III). pH varied in the range 5.1-5.6, with the exception of the sample from Soil 91m which had a pH of 4.3. It was not possible to quantify the mineral fraction less than 63µm in organic soils.

6:2 fluoroteleomer sulphonates were found in 6 out of 10 soil samples at Mongstad oil refinery (Figure 11, Appendix III). In the 52m sample 6:2 FTS constituted 20.5% of the total PFCs while in the topsoil at 26m from the training platform it constituted 8.6% of total perfluorcarbons in the soil (Appendix III).
6:2 fluoroteleomer sulphonates was detected only in the upper 10 cm of the soil profile at the sampling point closest to the training platform. The limit of quantification in the samples below 10 cm is quite high, and it can therefore not be concluded that no leaching of this compound occurs. The concentration of 6:2 fluoroteleomer sulphonates increased from the 26m sampling point to 52m from the platform (2365 ng/g dm), i.e. a concentration increase of about 30 times up to this point. This increase is somewhat surprising since there is a wooded area between the platform and the 52m sampling point. The concentration of 6:2 fluoroteleomer sulphonates at 91m was also higher than at 26m (Appendix III).

PFOSA and the fluoroctane sulphonamides- and sulphonamidoethanols (FOSA and FOSE-compounds) have not been detected in any of the soil samples from Mongstad.

Among the perfluorosulphonates, PFOS was the dominating compound (more than 90% of the PFS) (Figure 11, Appendix III). The mean ratio between the perfluorsulphonates with 4, 6, 8 and 10 carbons in the soil samples from Mongstad was 1:15:172:1.3. The concentrations of perfluorsulphonates in the soil profile at 26m from the platform increase with depth and the highest concentrations occur in the samples at 10-50 cm depth (Figure 11). Leaching from the surface seems to be highest for PFBS and PFHxS and least for PFDcS. At 50-60 cm in the soil profile from 26m the concentration of PFOS is 1439 ng/g dm indicating that the leaching down the soil profiles may be substantial, even in soils with a high content of organic carbon (29-50%).

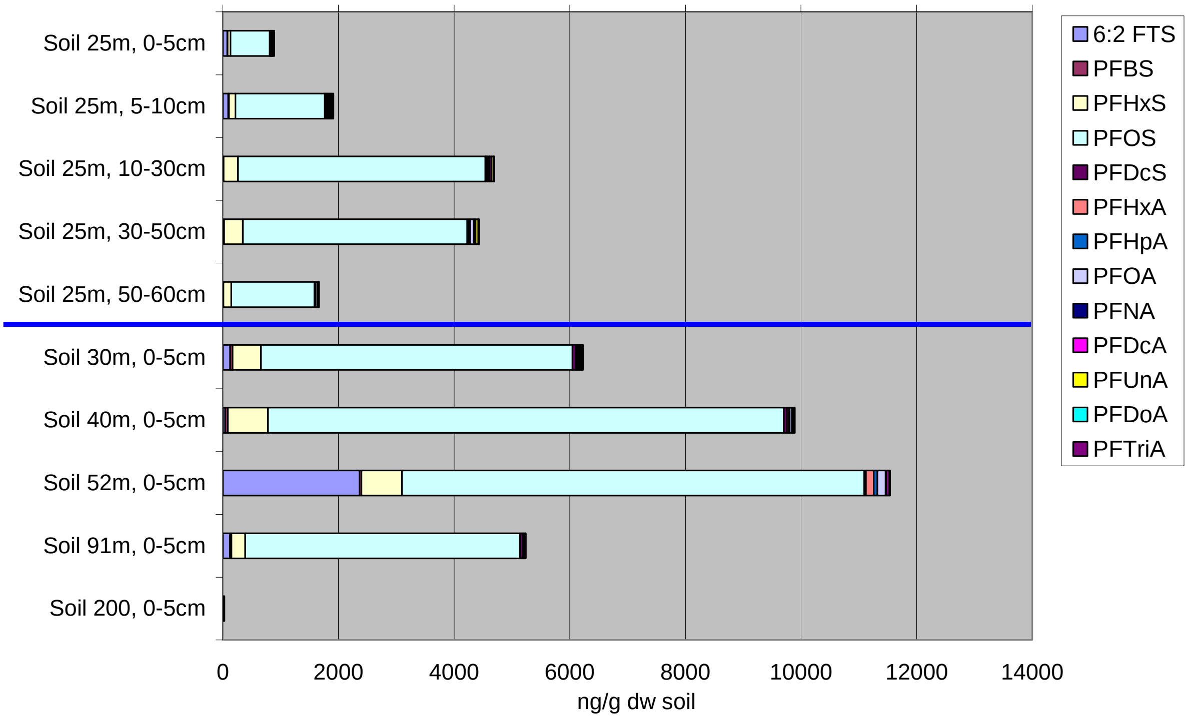

Figure 11: PFCs in soil samples (ng/g dw) from Mongstad oil refinery. Only the PFCs quantified in one or more samples are included in the Figure.

All soil samples (except from the reference sample at 200m) exceed the proposed Norwegian guideline value for PFOS (100 ng/g), at most with a factor of 90.The surface samples (0-5cm) taken at 30, 40, 52 and 91 meters from the platform all have higher concentrations of PFOS than at the sampling point 26m (Appendix III). The soil from 30 and 40m are sampled within a Salix grove, while this grove is between the platform and the 52m sample. The sampling point at 91m was somewhat elevated compared to the sampling points 26, 30, 40 and 52meters from the platform, which may explain the high concentrations found at this point. The 91m location is however out of sight from the training platform due to a grove of deciduous trees (*Salix*) and it is therefore surprising that the concentration of PFOS at this distance is that high (4756 ng/g dw). In the soil sample taken at 200m from the platform only PFOS has been detected in concentrations above the detection limit (28.6 ng/g dw).

Among the perfluorcarboxylic acids the compounds having 6, 8, 10, 11 and 12 carbons in the alkylchain are the dominating, with PFOA somewhat higher in concentration than the other acids in most samples (Appendix III). The content of perfluorcarboxylic acids range from 0% (sample point 200m) to 8.3% (top soil at 26m) of the total perfluorcarbons in the soil samples from Mongstad. In the soil profile (26m) the concentrations of perfluorcarboxylic acids are highest at depth 10-50cm, with most other compounds being found in highest concentrations at depth 30-50cm (Figure 12). The data clearly indicate that there is a downwards movement of these compounds in the soil. As for the perfluorsulphonates the movement seems to decrease with increasing length of the carbon chain (Appendix III), but this is not consistent for all compounds. Deca and dodecane acids (PFDcA and PFDoA) are higher in 10-30 cm and 5-10cm samples than in the 30-50cm samples, while PFUnA (11 carbons) is highest in the 30-50cm sample.
The highest concentrations of PFCAs (C_6-C_{10}) in the surface samples are at the 52m location, while the PFCAs with longer chains (C_{12}-C_{14}) are not detected at this location (Appendix III).

This may indicate that longer chain PFAS are less volatile and are transported to a lesser degree than short chain PFCAs.

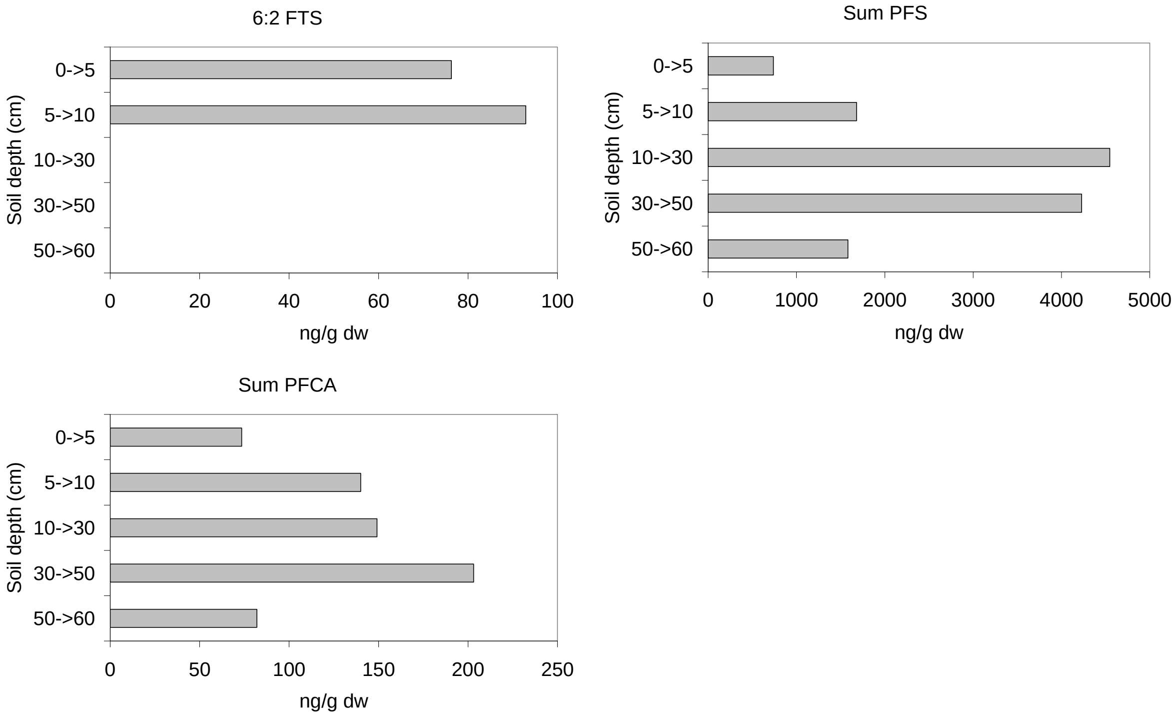

Figure 12: Concentrations of 6:2 FTS, sumPFS and sumPFCA at different depths in soil profile at 26m from fire training platform at Mongstad oil refinery.

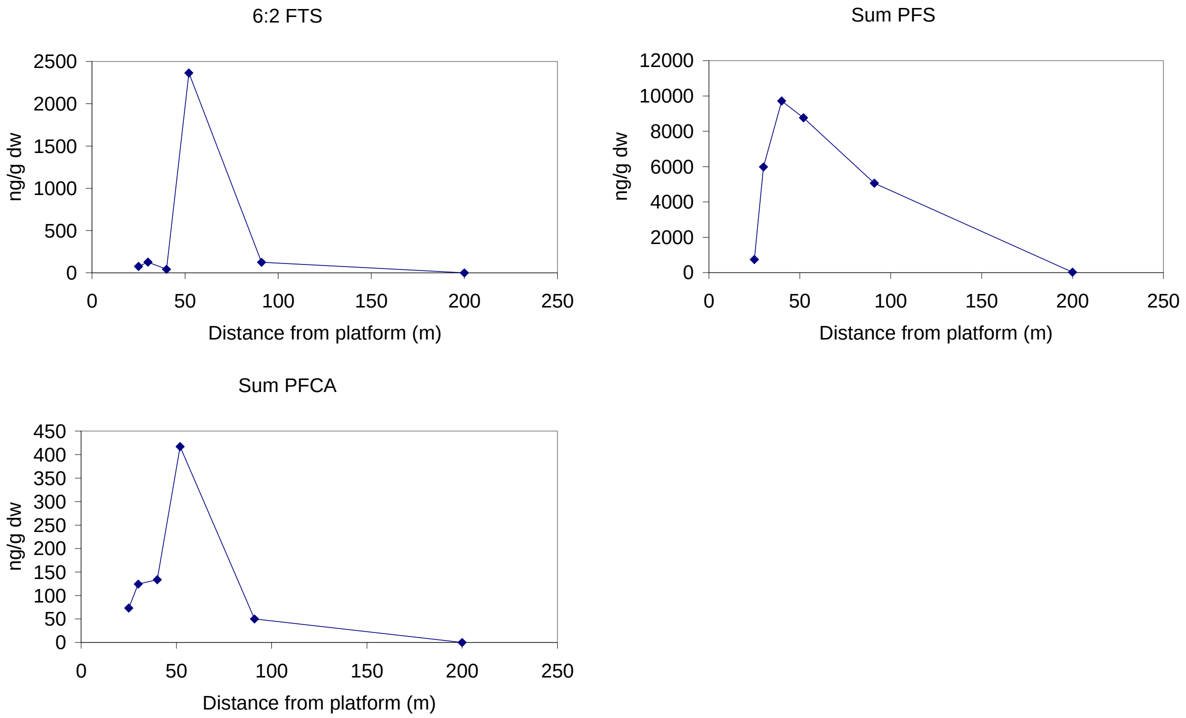

Figure 13: Concentrations in surface soils (0-5cm) of 6:2 FTS, sumPFS and sumPFCA with increasing distance to fire training platform at Mongstad oil refinery.

8.2 Solberg Scandinavian AS

8.2.1 Soils

Eight soil samples were collected and analysed from Solberg Scandinavian AS.
The pH in the soils varied from 4.3 to 5.3 which is quite typical for Spodosols in this region. TOC in the Oa-samples from 16m and 155m are high (28.1% and 46.2%), while TOC in samples from the E and B –horizons are lower (7.3 and 7.7%). The fraction of the soils being less than 63µm varies from 11.6% to 16.2% (Appendix III) showing that a majority of the soils consists of sandy material.

6:2 fluorteleomersulphonate was quantified in only two of the samples (20-30cm at the 16m location and 5-15cm at the 25m sampling point).
The data do not give any indication of leaching in the soil profiles or of any significant horizontal dispersion of this compound (Figure 14, 15).

Perfluoroctane sulphonamid is quantified in four of the eight soil samples and the highest concentrations is found in the bottom horizon in the soil profiles at 16m and 25m from the training platform (Appendix III, Figure 14). In the surface soil at the 16m location Perfluoroctane sulphonamid is not quantified. Increasing concentrations with depth indicate that there is a downwards movement of this compound in these soils.

The fluoroctane sulphonamides- and sulphonamidoethanols (FOSA and FOSE-compounds) were detected in the reference sample at 155m from the testing area (23.2 ng/g dw; Appendix III). This is surprising since these compounds were not detected in any of the soil samples closer to the testing platform.

There is a quite clear tendency that the PFS increase with depth at both 16m and 25m profiles (Figure 14, 15) indicating that a substantial leaching of these compounds occur in the soils in the vicinity of the testing platform. At sampling points 16m and 25m from the platform all four PFS are found in at least three of the samples, with PFOS and PFHxS as quantitatively the most important (Figure 14). PFOS and PFHxS are also found in the soil samples 84 and 155m from the platform but then at lower concentrations (Appendix III).

Closest to the platform PFOSA constitute up to 19% of the PFCs (sample 25m, depth 5-15cm) and in the sample 16m, depth 20-30cm PFCAs constitute 48% of the PFCs, but in general, the composition of PFCs in the soil samples is dominated by PFS which constitute 74-85%.

Most samples exceed the proposed guideline values for PFOS (100 ng/g).

The decrease in soil concentrations from the platform testing area (16m and 25m samples) to the background area (155m) is quite distinct, clearly showing that nearby soils are influenced by the testing activity at the site (Figure 16). The concentrations in soils outside the fence in the prevailing wind direction (distance 38-155m) are more than a factor 10 lower than in soils at 16m and 25m. Since the concentration of the sum of the PFCs is about the same in the soils from 38m, 84m, and 155m, it may be concluded that the dispersion through air from the training facility is important.

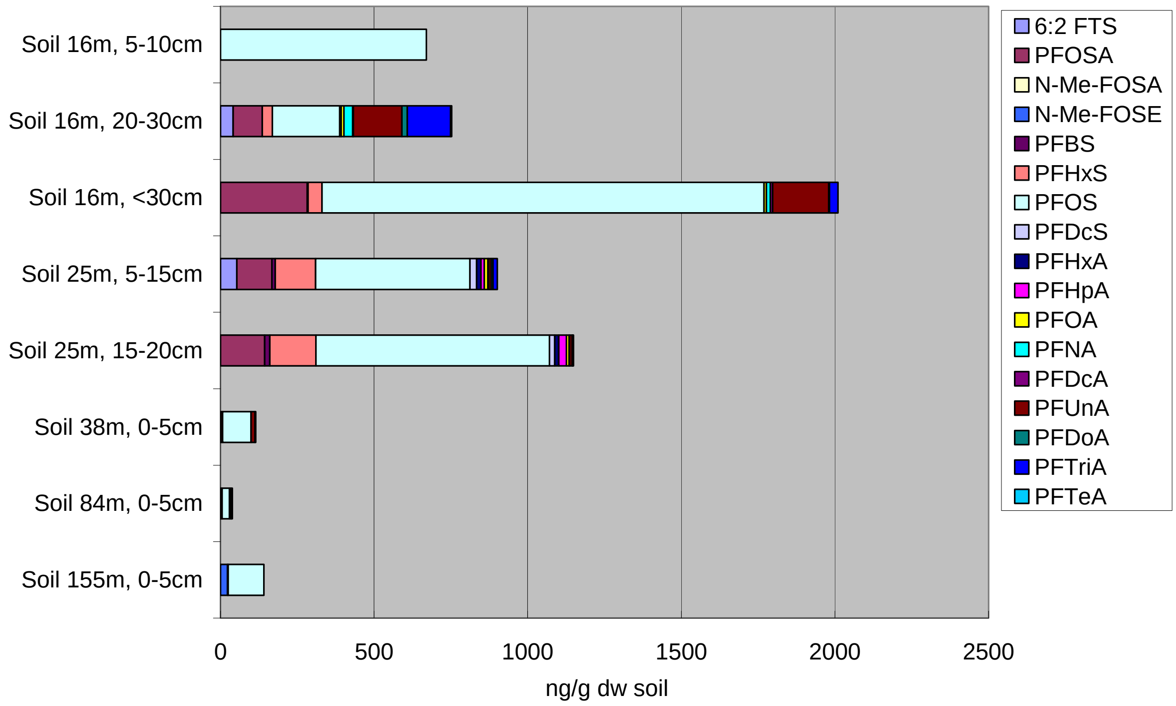

Figure 14: PFCs in soil samples from Solberg Scandinavian. Only the PFCs quantified in one or more samples are included in the Figure.

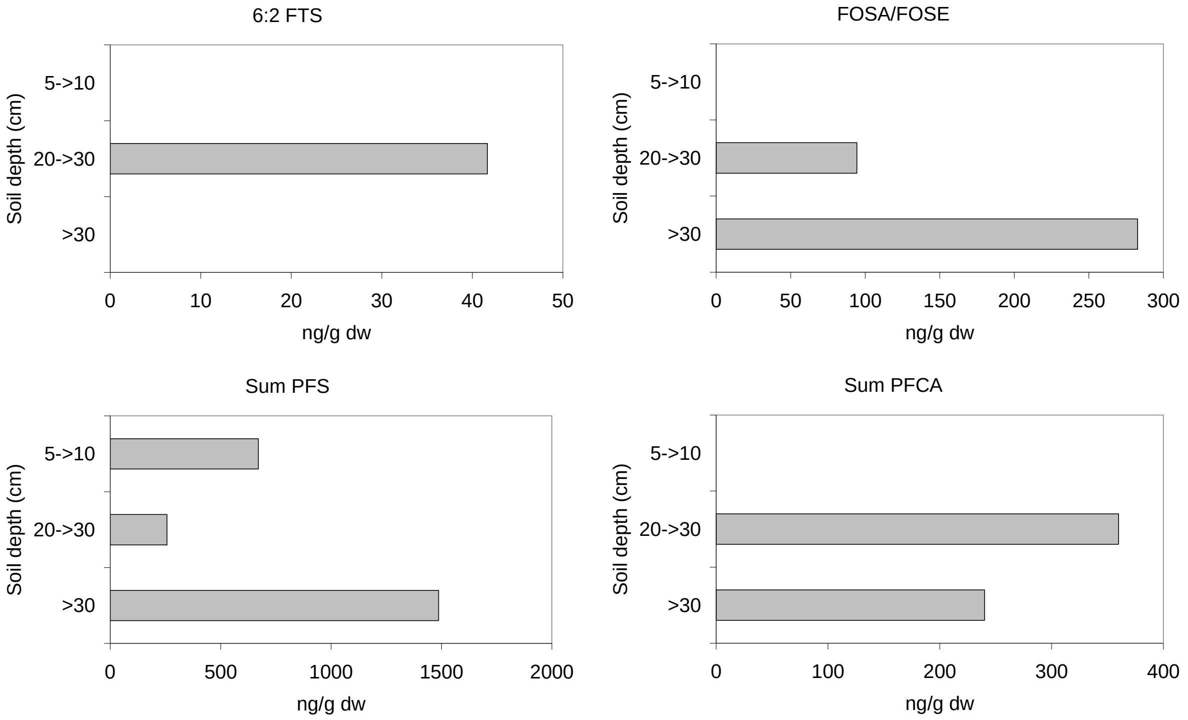

Figure 15: Concentrations of 6:2 FTS, FOSA/FOSE (including PFOSA), sumPFS and sumPFCA at different depths in soil profile at 16m from fire training platform at Solberg Scandinavian AS.

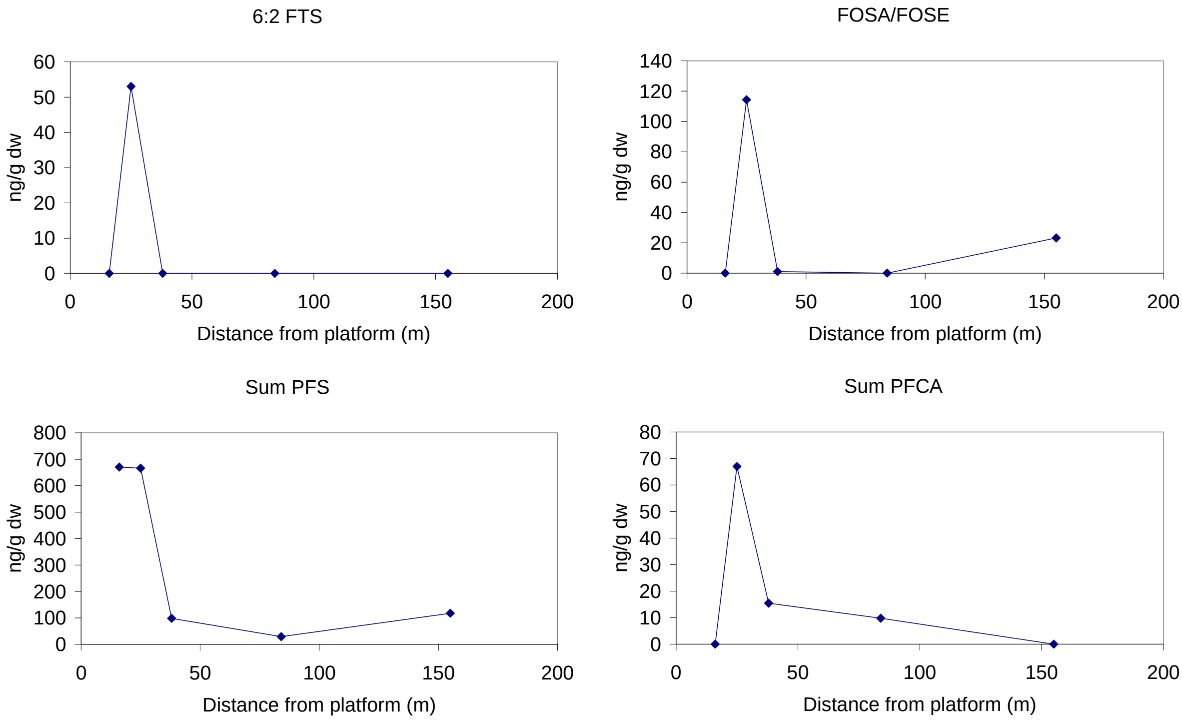

Figure 16: Concentrations in surface soils (0-5cm) of 6:2 FTS, FOSA/FOSE (including PFOSA), sumPFS and sumPFCA with increasing distance to fire testing platform at Solberg Scandinavian AS.

8.2.2 Sediment sample from stream

The composite sample of sediment taken from the stream northwest of the testing platform contain relatively high concentrations of all analysed PFCs except for N-Me-FOSA, N-Me-FOSE and N-Et-FOSE (Table 3, Appendix III). The sum of the PFCs in the sediment sample was 4357 ng/g dw which was higher than in any of the soil samples analysed. The highest concentration, 2010 ng/g dw, was detected at the 16m location at The 30-35cm depth. The sediment sample also has higher concentrations of 6:2 FTS and PFCA relative to PFS compared with the soil samples at 16m and 25m. This indicates that the leaching of PFS and PFCA from the area is higher than for PFCs.

8.2.3 Stream water

The concentration of PFCs in the stream sample seems high and clearly shows that there is a significant leaching of these compounds from the area.

Compared to the sediment sample and especially the soil samples (Appendix III), the concentration of 6:2 FTS seems high in the stream water (Table 3). This may be due to low adsorption to soils and sediments. The concentrations of PFBS and PFHxS are also high in the stream water compared to the soil samples. This is also the case for PFHxA and PFOA. Both observations may be attributed to higher mobility of short chain PFCs in soils.

Table 3: Concentration of PFCs in stream sediment and stream water sampled at Solberg Scandinavian 18.June 2008.

Compound	Stream sediment (ng/g dw)	Stream water (ng/l)
6:2 FTS	1090	9388
PFOSA	226	< 70.5
N-Me-FOSA	<1.0	< 70.5
N-Et-FOSA	7.0	< 6
N-Me-FOSE	<3.0	< 2.7
N-Et-FOSE	<1.5	< 2.7
PFBS	118	8284
PFHxS	465	37312
PFOS	1340	68886
PFDcS	23.5	< 7.4
PFHxA	112.9	17260
PFHpA	39.9	5746
PFOA	101.0	16430
PFNA	39.9	1045
PFDcA	25.8	796
PFUnA	326.7	4158
PFDoA	49.3	< 16.2
PFTriA	369.0	< 10
PFTeA	23.5	< 14.8
SumPFC	4357	**169305**

8.2.4 Marine sediments

The concentrations of PFCs in the sediment samples from Radsundet outside Solberg Scandinavian AS is low compared to the concentrations found in soils and stream sediments (see above). Both concentrations in stream water and in the sediments from the stream indicate, however, that PFCs are transported from the industrial area to the sea.
PFOS is the only PFC that is found in concentrations above the detection limit in the sediment samples (Figure 17).

The concentrations in sediments at distance 73m and 127m from the outlets are quite similar and distance from the stream outlet (seashore) therefore does not seem to influence sediment concentrations of PFOS.
The conditions for sedimentation outside the stream outlet are not conducive, both because of quite heavy currents in the fjord and because of the steep slope from the seashore. No sedimentation for finer particles may also be the reason for the coarse textured sediment samples which have a low capacity for binding PFCs. The samples taken 73m and 127m from the stream outlet are the two most fine textured of the sediments.

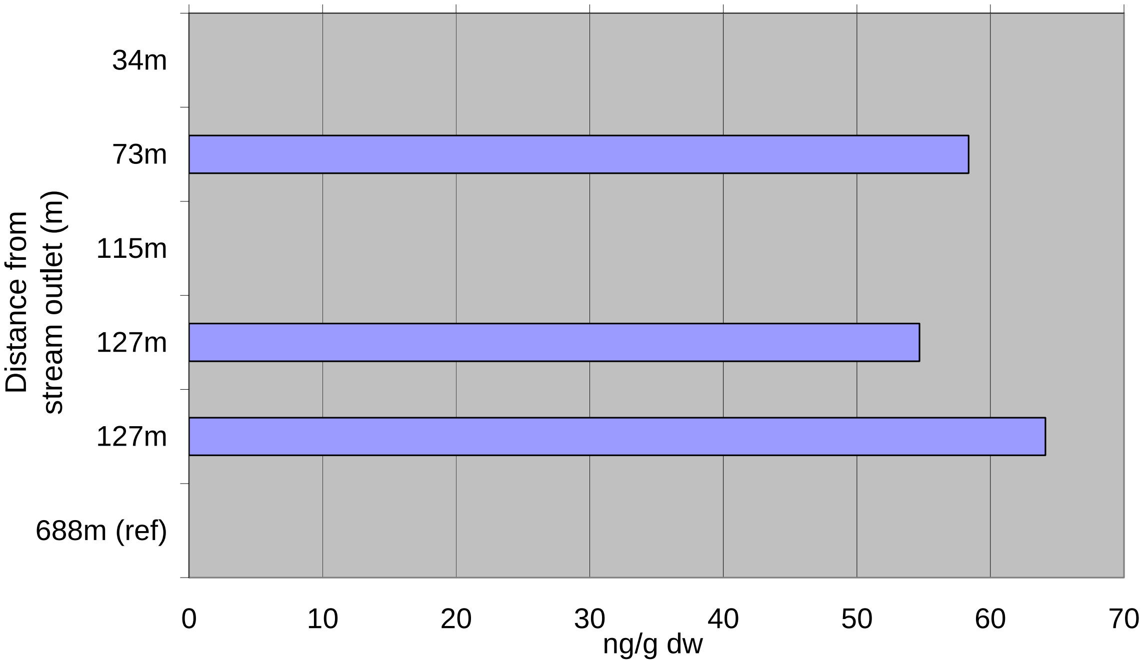

Figure 17: Concentrations of PFOS in sediments from Radsundet outside Solberg Scandinavian AS. Unit: ng/g dw.

8.2.5 Marine biota

Three PFCs (6:2 FTS, N-Et-FOSA and PFOS) were found in Sea snails (*Patellidae*) at all seven seashore locations outside Solberg Scandinavian (Figure 18, Appendix IV). In addition some PFCAs were detected in samples 40m and 115m south from the stream outlet (Figure 18). 6:2 FTS, PFOS and some PFCAs are all found in the stream water from the industrial area, but N-Et-FOSA is not detected (Table 3). Both in the stream water and stream sediment (Table 3) PFBS, PFHxS, PFHxA, PFHpA are found in relatively high concentrations, but these compounds are not quantified in the Sea snails (Figure 18). In general these shorter chain PFCs (C_5-C_7) seem to accumulate to a lesser degree than longer chain PFS and PFCAs.

There is no clear concentration gradient with increasing distance north or south from the stream outlet (Figure 18). Sea snail sample 115m was taken at a stream outlet south of the stream that was sampled for water analysis. The high concentration of PFOS in sea snail at this location compared to the other locations clearly indicates that other streams running through the industrial area at Solberg Scandinavian are more important sources for PFCs in Radsundet.

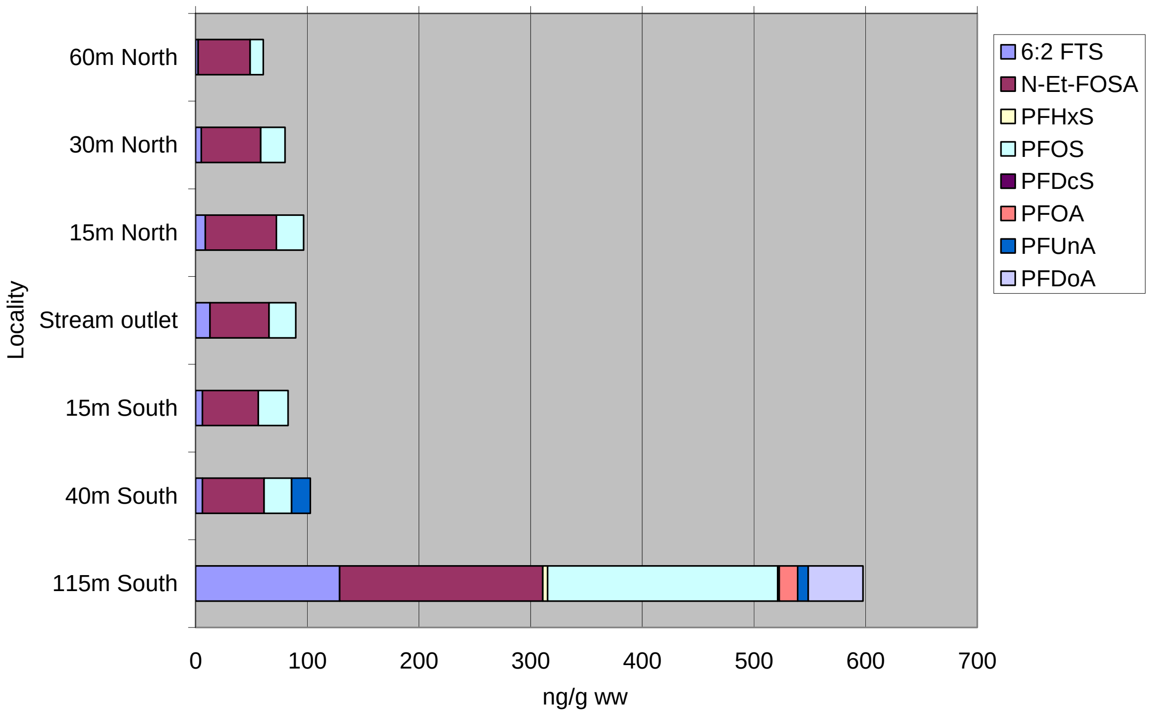

Figure 18: Concentrations of PFCs in Sea snail (<u>Patellidae</u>) collected at the seashore in Radsundet at Solberg Scandinavian AS.

8.3 Gardermoen airport

8.3.1 Soil

The samples taken from the sandbank (Soil 1m) at Gardermoen have a low content of TOC and contains about 90% sand (i.e. fraction <63µm is about 10%). pH ranges from 6.4-7.0 (Appendix III). The content of TOC is higher in the samples farther away from the platform. In the most distant samples (Soil 70m and Soil 200m) the content is 41.2 and 37.4%. The two soils, taken from the coniferous forest north from platform 4, are also quite acidic (pH 4 and 3.6, respectively). The content of silt and clay is highest in the sample from the 7.5m location at a depth 10-12cm, (23.5%) and from the 31m location (18.2%).

6:2 FTS is found in all soil samples from Gardermoen, except in soil sample taken from 200m (reference sample) (Figure 19, Appendix III). The highest concentrations are found in Soil 7.5m (depth 0-5cm) (2155 ng/g dw) and at 30-50cm depth in the sandbank close to platform 4 (1241 ng/g dw). The concentrations in the sandbank increase from the surface (0-5cm) down to 30-50cm (Figure 20). There is also quite an evident decrease in surface soil concentrations for 6:2 FTS from Soil 7.5m to Soil 31m (Figure 21). The soil at 70m north of the platform also has a quite high concentration of 6:2 FTS. In the surface horizon (0-5cm) in the sandbank, as well as in the topsoil at 31m, nearly 40% of PFCs are 6:2 FTS (Figure 19, Appendix III).

Perfluoroctanolesulphonamid (PFOSA) is also found in quite high concentrations in the soil samples collected within 7,5m from the platform with concentrations of, 966 ng/g dw at the 10-12cm depth. In soil samples taken further away from the platform PFOSA is not quantified (Figure 19, Appendix III). N-MeFOSA is only quantified (1.5 and 1.6 ng/g dw) in samples 70m and 200m from the platform.
In Soil 7.5m (0-5cm) PFOSA constitutes as much as 9% of the total PFCs in the sample. In the other samples this percentage is lower and varies in the range 0-6.8%. Still, this is quite high compared to the samples from Mongstad and Solberg Scandinavian AS.

Perfluorsulphonates (PFS), and especially PFOS, occur in quite high concentrations in the closest area to the platform (Figure 19). The highest level of PFOS (11923 ng/g dw) was found in Soil 7.5m (depth 10-12cm). High values of PFOS are also found in the sandbank close to the platform where the concentrations are highest at 30-50cm depth (Figure 19). Also PFBS and PFHxS are found in the highest concentrations at 30-50cm, while PFDcS are not detected below 10cm (Appendix III).

Among the PFCAs, PFUnA (C_{11}) is found in highest concentrations in the sandbank and as for the PFS, the concentration increases with increasing depth (Figure 19). This is also the case for the sum of PFCAs (Figure 20), whose sum in the topsoil (0-5cm) also decreases markedly from the platform area to the background in the coniferous forest north of the platform (Figure 21). If PFUnA is excluded, however, this trend is not that obvious.
PFCAs in the soil at Gardermoen constitute a relatively low fraction of the total content of PFCs, generally in the range 2-5% (Appendix III).

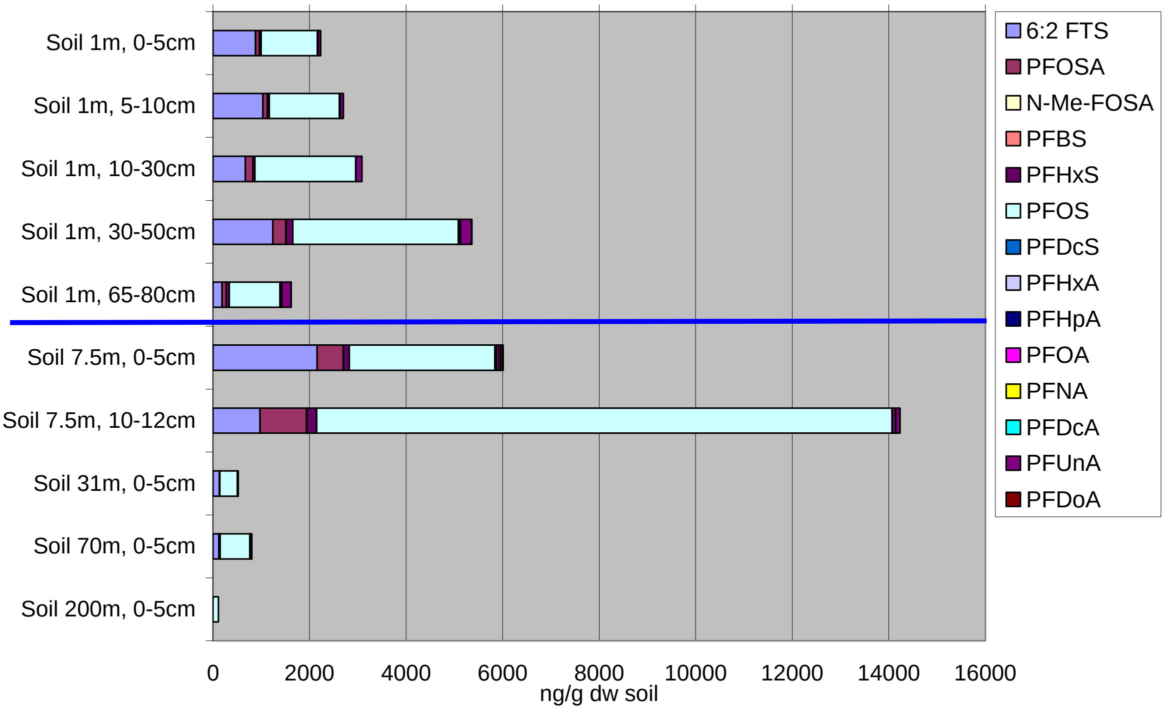

Figure 19: Concentrations of PFCs (ng/g dw) in soil samples from fire training facility at Gardermoen airport. Only PFCs quantifies in the soil samples are included in the Figure. The soils above the blue line are from the soil profile at 1m.

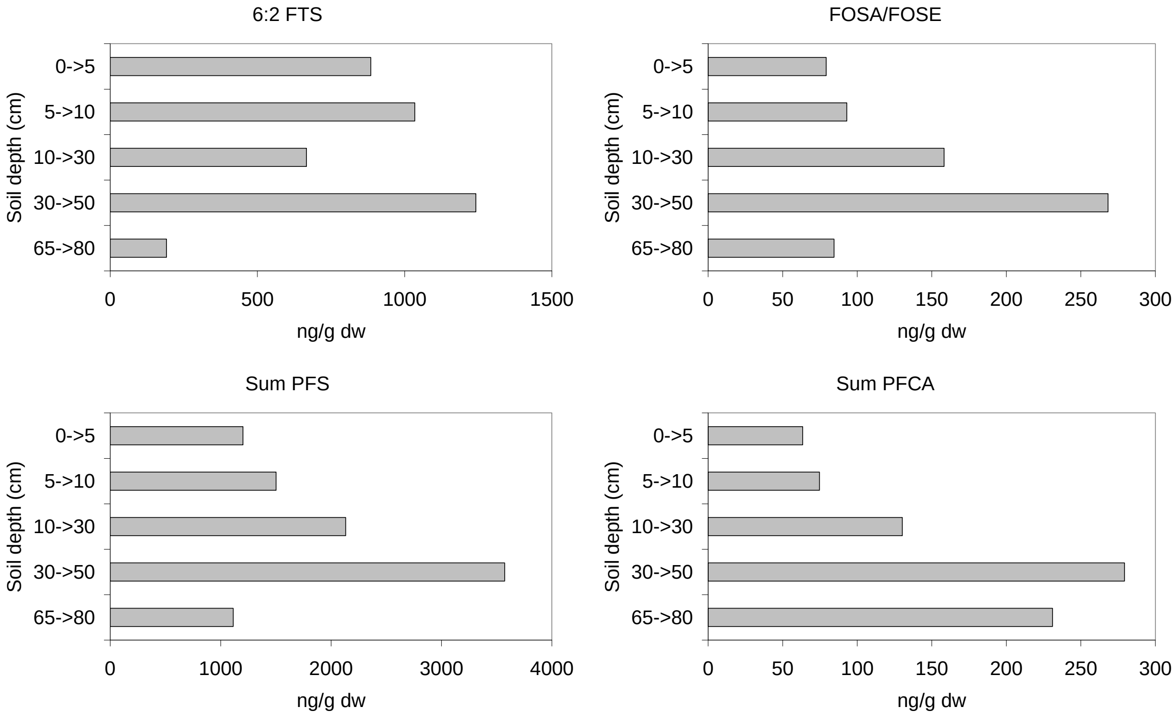

Figure 20: Concentrations of 6:2 FTS, FOSA/FOSE (including PFOSA), sumPFS and sumPFCA at different depths in soil profile at 1m from fire training platform at Gardermoen airport.

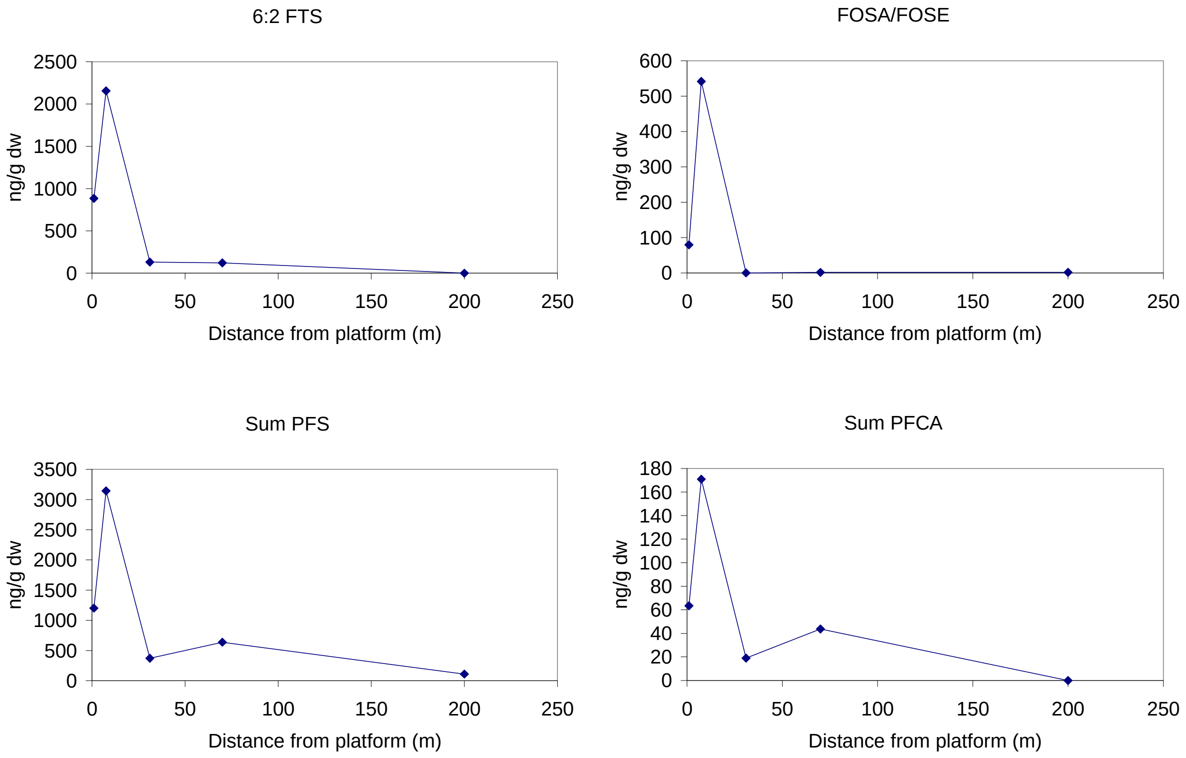

Figure 21: Concentrations in surface soils (0-5cm) of 6:2 FTS, FOSA/FOSE (including PFOSA), sumPFS and sumPFCA with increasing distance to fire practice platform at Gardermoen airport.

8.3.2 Groundwater

6:2 FTS is determined in all three well samples from Gardermoen with the highest concentration found in wells BV-3 and BV-1.

PFOSA, FOSE- and FOSA-compounds are not detected in any of the three groundwater samples.

PFBS, PFHxS and PFOS are all found in high concentrations in the groundwater (Appendix V, Figure 22). The mean ratio between concentration of these three PFS in the soils at Gardermoen was 1:5.5:183, while in groundwater the ratio is 1:3.7:19. This indicates that PFBS (and to some degree PFHxS) is more mobile in the soil than PFOS.

The same trend can be seen for the PFCAs. Short chained PFCAs are found in relatively higher concentrations in groundwater compared to soil at Gardermoen. In the groundwater PFHxS is found in highest concentrations (1585 ng/l in well BV-3, Appendix V), while PFUnA which was the dominant PFCA-homologue in the soil is not detected in the groundwater.

Calculations of the ratio between concentrations in soil and in groundwater show that this ratio increases with increasing chain length both for PFS and PFCAs (Table 4). In other words: the soil sorption of PFS and PFCAs increase with increasing chain length. Of the PFCs analysed in this project, 6:2 FTS seems to bind most strongly to the sandy soils at Gardermoen.

Groundwater wells BV-3 and BV-2 is situated closest to platform 4, while groundwater well BV-1 is situated southwest of platform 4 and it was therefore not surprising that the concentration of PFCs was highest in groundwater (BV-3). The generally high concentrations of PFCs in all groundwater samples, also in BV-1 which is situated about 40m downstream from platform 4, clearly show that PFCs are mobile in soils at Gardermoen and possibly are widespread in the aquifer.

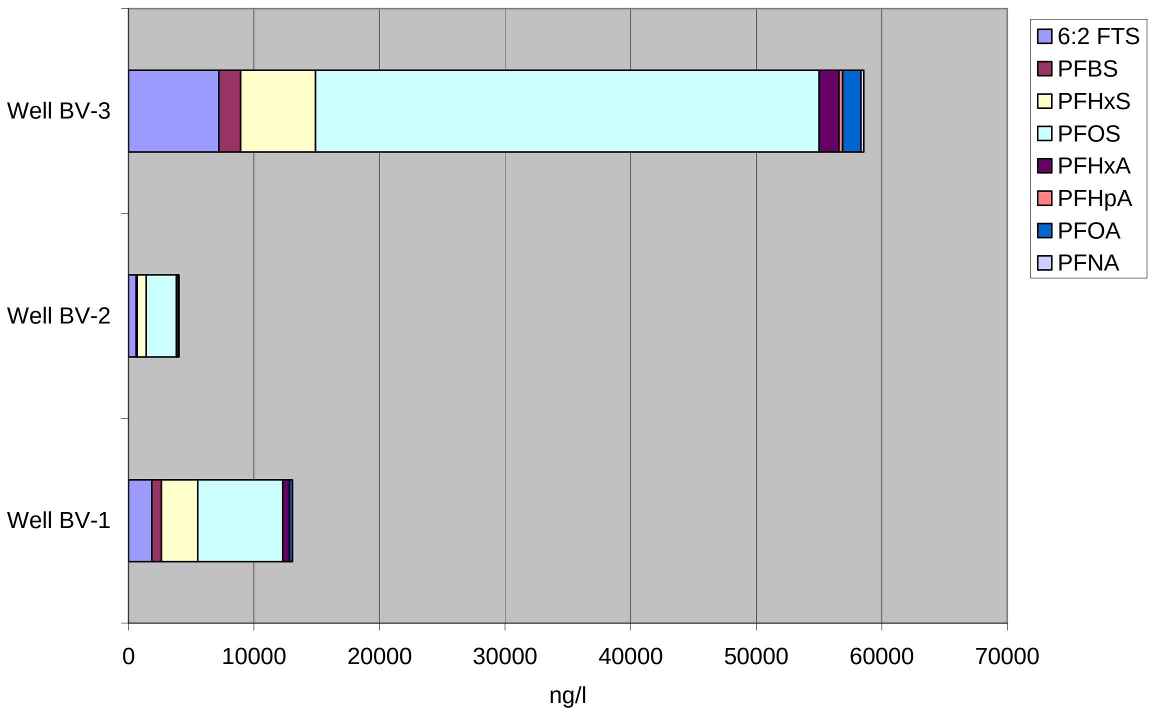

Figure 22: Concentrations of PFCs in groundwater from three wells in the vicinity of fire training platform 4 at Gardermoen airport. Only PFCs quantified in the groundwater samples are shown in the Figure.

Table 4: Ratio (Kd, l/kg) between mean concentration in soils (all soil samples from 1-7.5 from platform 4) and groundwater (mean concentrations in well BV-1, BV-2, BV-3).

Compound	**Groundwater (ng/l)**	**Soil (ng/kg)**	**Kd (l/kg)**
6:2 FTS	3220	1020688	317
PFOSA	< 70.5	312968	-
N-Me-FOSA	< 70.5	<80	-
N-Et-FOSA	< 70.5	<1300	-
N-Me-FOSE	< 70.5	<2500	-
N-Et-FOSE	< 70.5	<1200	-
PFBS	865	6138	7
PFHxS	3187	91236	29
PFOS	16424	3444777	210
PFDcS	< 7.4	8236	-
PFHxA	762	12775	17
PFHpA	291	10400	36
PFOA	849	18097	21
PFNA	135	15891	117
PFDcA	< 13.9	5238	-
PFUnA	< 18.7	112189	-
PFDoA	< 16.2	3684	-
PFTriA	< 10	<60	-
PFTeA	< 14.8	<80	-
SumPFS	25211	5035000	200

8.4 Rygge Air Station

8.4.1 Soil and sediment

The upper soil horizon at Soil 26m contains relatively high levels of TOC, while the rest of the soil profile has a low content (0.5% or less, Appendix III). The fraction of clay and silt in the profile was nearly 50% (measured only in 5-10cm, but the lower horizons were similarly textured). The surface soil at 31m, 38m, 54m and 174 had TOC contents of 2.6-4.8% and a pH of 5.4-6.7. The highest pH is measured in the deciduous forest area (Appendix III).

6:2 FTS was not determined in any of the soil samples from Rygge (Figure 23, Appendix III), but was found to be present in all the sediment samples (Figure 26, Appendix III). The highest concentration was found in the surface layer of the ditch northwest of the platform (Sed 18m, 252 ng/g dw).

Among the PFOSA, FOSA and FOSE-compounds only N-Me-FOSE was determined and that was in the soil sampled closest to the new platform (7.8 ng/g dw) (Appendix III). These compounds were not detected in any of the sediment samples.

PFOS was quantified in all soil samples both at the old and the new training platform (Figure 23, Appendix III). The concentrations of PFOS in soils in the vicinity of the old training platforms were somewhat higher than at the new, but the differences were not big. The PFS in the soils from the new training have been emitted in the period from 2002 to 2005.
In the soil profile from sample point 26m the concentrations of both PFHxS and PFOS in the surface were found to be 6-10 times higher than in the lower. Leaching to the lower horizons of these compounds seems to have been limited (Figure 24). The concentration of PFS at sample point 174m was about 10 times lower than at 26m (Figure 25). This clearly indicates reduced aerial deposition with increasing distance from the platform. In the soils almost 100% of PFCs was PFS.

The concentration of PFS in the sediment samples was very high (Figure 26), far higher than any of the soil samples in the area. The upper 5 cm at the sampling point closest to the old platform (Sed 18m) had PFOS levels of 47 743 ng/g dw. Also the other sediment samples had concentrations which far exceeded nearby soils.

PFOA was quantified in the upper horizon at Soil 26m and was found in relatively low concentrations (3.8 ng/g dw, Appendix III). In the other samples, however, PFCA was not present above the detection limit. In the sediments, relatively high concentrations of PFCAs occurred. Even though the concentration of PFOA dominated, the concentrations of PFHxA and PFHpA were also quite high. Minor traces of C_9-C_{12} also exist in the samples (Appendix III).

There may be several reasons why the concentrations of PFCs are so much higher in the sediment samples than in the soil samples in the area. The most obvious explanation is, of course, that the sediments are located closer to the old platform than the soils. Another reason may be attributed to the high content of fine material in the sediments which may be efficient in the adsorption of PFCs.

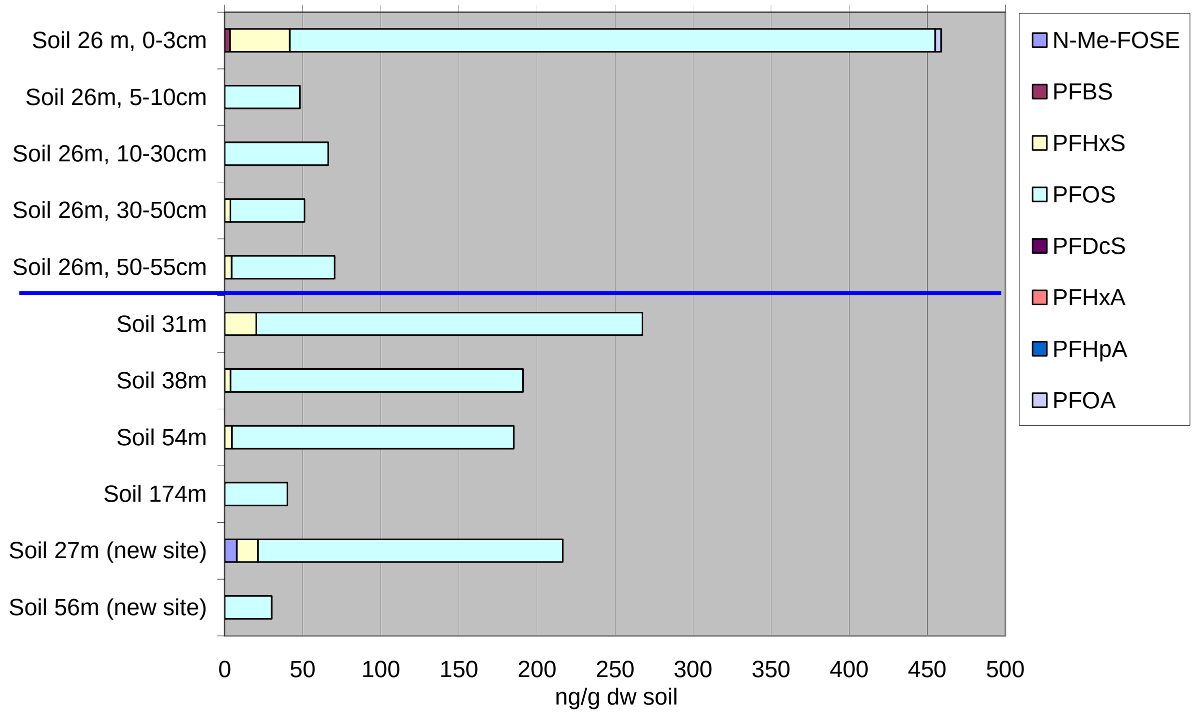

Figure 23: Concentrations of PFCs in soil at the old and new fire training facilities at Rygge Air Station. Only PFCs quantified in the soil samples are shown in the Figure. Soils above the blue line in the Figure are from the soil profile at Soil 26m.

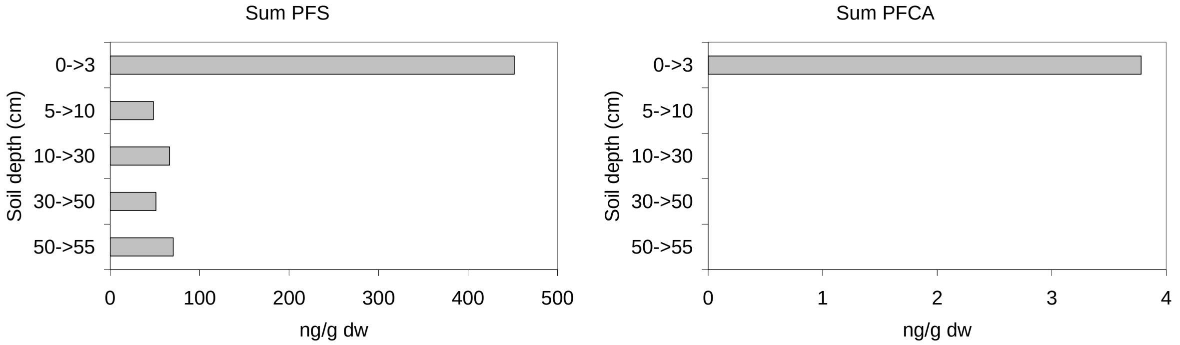

Figure 24: Concentrations of sumPFS and sumPFCA at different depths in soil profile at 26m from the old fire training platform at Rygge Air Station.

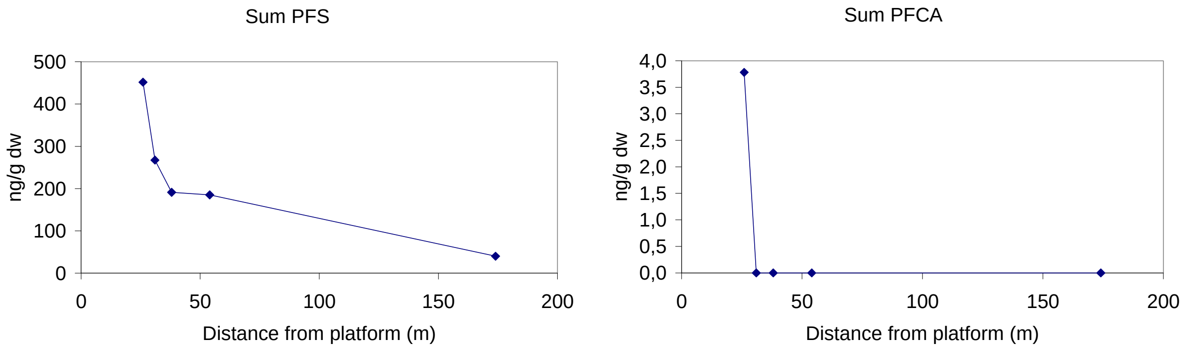

Figure 25: Concentrations in surface soils (0-5cm) of sumPFS and sumPFCA with increasing distance to the old fire training platform at Rygge Air Station.

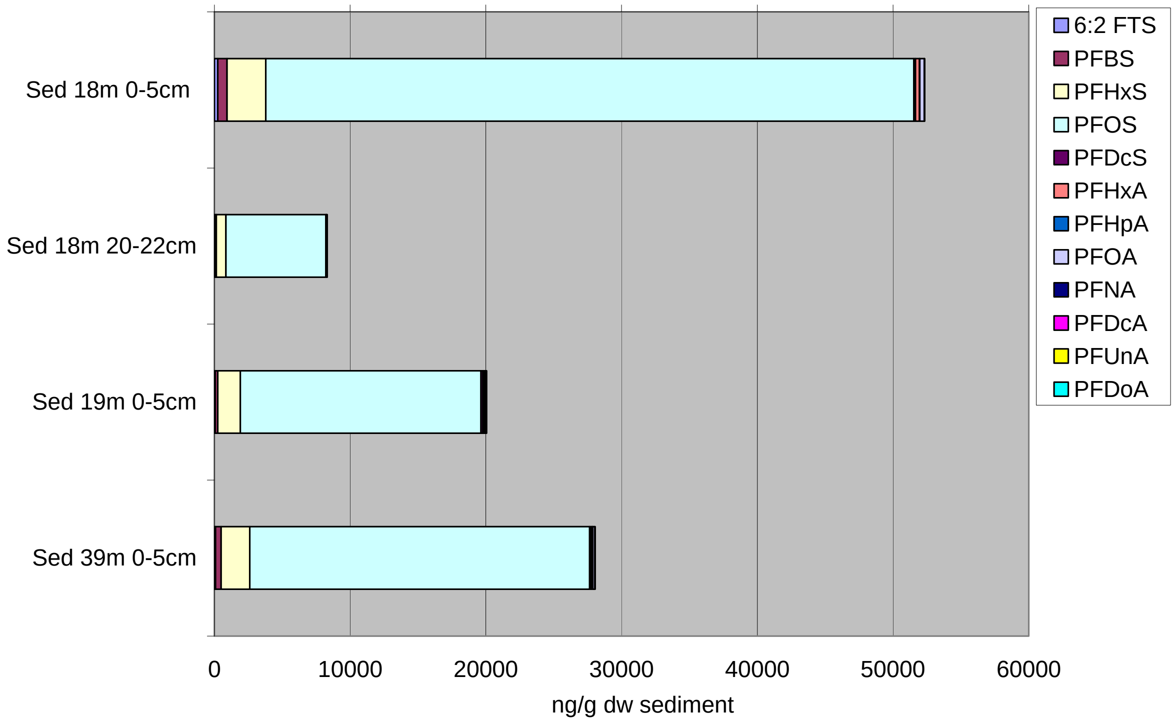

Figure 26: Concentrations of PFCs (ng/g dw) in sediment samples in the vicinity of old fire training site at Rygge Air Station. Only PFCs quantified in the soil samples are shown in the Figure.

8.5 Bioaccumulation of PCFs in earthworms

As mentioned in chapter 7, earthworms from the field were only found at Mongstad and two earthworm samples from the field were analysed to calculate bioaccumulation factors for earthworms. To calculate BAFs for earthworm for the field soil at all locations (also Mongstad), bioaccumulation experiments were performed in the laboratory using three soils from each locality. In these experiments the earthworm species *Eisenia fetida* was used.

Since most PFCs were not determined in either earthworms or soils, the detection limits (or limits of quantification) have been used in the calculations. When this is the case, the BAFs are shown in italics.

8.5.1 Mongstad

There were considerable concentration variations of PFCs in earthworms from Mongstad. The highest concentrations were measured in the sample from Soil 52m (35582 ng/g dw) while the lowest concentration was measured in the accumulation experiment using soil from the reference site at Mongstad (Soil 200m) (Table 5). The high concentrations in the worms collected at locality Soil 52m agrees well with the high soil concentrations at this site.

6:2 FTS was found in all earthworms except from the worms exposed to the reference soil at Mongstad (Soil 200m). The calculated bioaccumulation factor (BAF) for the worms sampled in the field was considerably higher than for the worms from the laboratory experiment.
One or all of the compounds PFOSA, N-Me-FOSA and N-Et-FOSA were found in all earthworms analysed, even though they were not detected in the soil samples. One explanation for this may be the extremely high BAF. According to Environment Canada (2006) BAF for N-Me-FOSEA and N-Et-FOSEA are calculated to 26000 and 5543, respectively, after emission of fire fighting foam.
In particular, N-Et-FOSA was found in high concentrations in the earthworms. Using the detection limit for these compounds in soils (see Table 5), the BAF for N-Et-FOSA in earthworm from Mongstad can be as high as 380.

For the PFS there was a trend that the BAF increased with increasing carbon chain length (Table 5). PFOS is the only PFC quantified in all earthworm samples and the BAF for PFOS varies in the range 0.7-6.4 (highest BAF in the soil with lowest PFOS-concentration). PFBS and PFHxS were not determined in the sampled earthworms.

For PFCAs the same trend as for PFCs was evident, i.e. increasing BAFs with increasing length of the carbon chain (Table 5). Even PFTeA (C_{14}) which was not detected in any of the soils was found to be present in the earthworms. Using the detection limits for the soil samples, the BAF for PFTeA varies in the range 5-55 which is considerably higher than for e.g. PFOS and PFOA.

A vague trend in the BAF-calculations for laboratory and field data is that the BAFs calculated for the two field samples are somewhat higher, but in general there are only minor differences between the BAFs calculated from the laboratory and field data (Table 5).

8.5.2 Solberg Scandinavian AS

The trends in BAFs for the accumulation experiments performed for the three soils from Solberg Scandinavian are more or less the same as for the Mongstad-experiments. PFOSA, N-Me-FOSA and N-Et-FOSA were detected in most earthworm samples (Table 6), but not in the soils. Very high BAFs can be assumed for N-Et-FOSA. That is to say that if the detection limits for the soils are used, BAF may vary from 50-180 for this compound.

The trend that increasing carbon-chain length increases BAF for PFCs is not that obvious in the experiments from Solberg Scandinavian. Actually, in these experiments PFHxS had the highest BAF for earthworms (24.8 in the reference soil).

For PFCAs the same trend can be seen as for the accumulation experiment from Mongstad: the uptake in earthworms increase with increasing chain length. In the sample from 16m, the BAF for PFUnA, PFDoA and PFTeA may be assumed to be 100-200 if the detection limits for soil is used.

8.5.3 Gardermoen airport

The BAF for 6:2 FTS was somewhat higher in the samples from Gardermoen (Table 7) compared to the samples from Mongstad and Solberg Scandinavian. This is probably due to the low content of silt, clay and TOC in the samples from Gardermoen.

PFOSA, N-Me-FOSA and N-Et-FOSA were detected in all earthworm samples from Gardermoen but not be detected in the soils, Table 7). Again, using the detection limits for the soils, BAF for N-Et-FOSA varied in the range 365-516.

Also the BAFs for PFOS in earthworm from the three Gardermoen soils were higher than in earthworm from the Mongstad and Solberg Scandinavian soils. BAF for PFBS seemed to be much higher than that for PFHxS (based on the detection limit for soils). BAF for PFDcS was considerably higher than for the other PFCs in the soils from Gardermoen.

The bioaccumulation in earthworm increases drastically with chain length of the PFCAs in the soils at Gardermoen (Table 7). In the earthworms exposed to soils 0-5cm and 10-30cm, the concentrations of PFUnA and PFTriA exceeded 1000 ng/g ww. For PFTriA this results in a BAF of 930 (using the soil detection limit).

8.5.4 Rygge Air Station

The content of 6:2 FTS was not detectable in any of the earthworm samples from Rygge, while N-Et-FOSA was found in all three samples in the same high concentrations as in earthworms exposed to soil from the other localities. PFOS was also detected in all earthworm samples (Table 8), which resulted in BAFs in the range 1.5-4.1. The earthworm accumulation experiment using soils from Rygge showed no clear tendency of increasing BAF with increasing chain length for the PFS.

Among the PFCAs only PFUnA was found in the earthworms with BAF of about 16 using the detection limit for soil.

Table 5: Concentrations in earthworms (ng/g ww), soils (ng/g ww) and calculated BAFs for laboratory experiments and after field sampling of earthworms. Data from Mongstad oil refinery. BAFs calculated involving the detection limit for soil or earthworm is shown in italics.

Compound	Laboratory									Field					
	25m			40m			200m			25m			52m		
	Earth-worm	Soil	BAF	Earth-worm	Soil	BAF	Earth-worm	Soil	BAF	Earth-worm	Soil	BAF	Earth-worm	Soil	BAF
6:2 FTS	82	42.3	1.9	64	20.4	3.1	<6.6	<4.8	*1.4*	1126	67.6	16.7	14834	2034	7.3
PFOSA	40	<21.9	*3.3*	229	<10.5	*21.9*	<1.9	<8.3	*0.2*	54	< 19.4	*2.8*	210	< 19.4	*10.8*
N-Me-FOSA	4.30	<0.9	*8.6*	5.57	<0.4	*12.7*	< 0.8	<0.3	*2.3*	7.20	< 0.8	*9.0*	< 0.8	< 0.8	*1.0*
N-Et-FOSA	392	<1.5	*472*	528	<0.7	*773*	210	<0.6	*379*	289	< 1.3	*222*	441	< 1.3	*339*
N-Me-FOSE	<12.0	<2.7	*8.0*	<12.0	<1.3	*9.4*	<12.0	<1.0	*11.5*	<12.0	< 2.4	*5.0*	<12.0	< 2.4	*5.0*
N-Et-FOSE	<11.5	<1.4	*14.8*	<11.5	<0.6	*18.1*	<11.5	<0.5	*22.1*	<11.5	< 1.2	*9.6*	<11.5	< 1.2	*9.6*
PFBS	< 0.8	3.1	0.3	<0.8	22.2	*0.036*	< 0.8	<0.3	*2.3*	13.40	4.90	2.7	63.30	30.3	2.1
PFHxS	<1.7	26.8	0.1	<1.7	338.3	*0.005*	<1.7	<0.5	*3.3*	84.0	42.9	2.0	2528	599	4.2
PFOS	265	377	0.7	4882	4359	1.1	64	9.9	6.4	1838	603	3.0	16814	6880	2.4
PFDcS	9.5	2.6	3.7	58.3	26.5	2.2	< 0.9	<0.4	*2.4*	7.6	4.1	1.9	265	23.7	11.2
PFHxA	<5.2	6.4	*0.8*	<5.2	15.3	*0.3*	<5.2	<1.1	*4.7*	16.4	10.3	1.6	81.9	114.7	0.7
PFHpA	<6.8	3.2	*2.1*	<6.8	6.7	*1.0*	<6.8	<0.4	*16.3*	<6.8	5.1	*1.3*	<6.8	55.9	*0.1*
PFOA	<6.4	3.9	*1.6*	<6.4	20.8	*0.3*	<6.4	<0.6	*11.5*	26.6	6.3	4.2	38.2	121.7	0.3
PFNA	<7.2	2.8	*2.6*	<7.2	2.0	*3.5*	<7.2	<0.4	*18.9*	10.0	4.5	2.2	<7.2	14.4	*0.5*
PFDcA	22.3	5.8	3.8	16.6	4.9	3.4	<3.9	<0.2	*16.1*	76.0	9.3	8.2	49.1	37.7	1.3
PFUnA	52.5	7.1	7.4	56.3	6.9	8.2	<6.2	<0.2	*25.5*	112	11.4	9.8	41.0	14.3	2.9
PFDoA	79.1	9.6	8.3	37.4	3.7	10.2	<4.1	<0.2	*16.9*	148	15.3	9.7	172	< 0.6	*287*
PFTriA	<2.4	1.8	*1.3*	<2.4	5.0	*0.5*	<2.4	<0.2	*9.9*	<2.4	2.9	*0.8*	<2.4	< 0.6	*4.0*
PFTeA	12.8	<2.5	*9.3*	8.70	<0.4	*19.8*	<3.0	<0.3	*8.6*	17.8	<2.2	*8.1*	43.7	< 0.8	*54.6*
SumPFC	960	492	2.0	5886	4831	1.2	274	30.6	11.6	3826	787	4.9	35582	9925	3.6

Table 6: Concentrations in earthworms (ng/g ww), soils (ng/g ww) and calculated BAFs after laboratory accumulation experiments. Data from Solberg Scandinavian. BAFs calculated involving the detection limit for soil or earthworm is shown in italics.

	16m			**38m**			**155m**		
	Earthworm	**Soil**	**BAF**	**Earthworm**	**Soil**	**BAF**	**Earthworm**	**Soil**	**BAF**
6:2 FTS	18	<5.5	*3.2*	<6.6	<8.1	*0.8*	<6.6	<6.8	*1.0*
PFOSA	126	<9.6	*13.1*	7	<14.1	*0.5*	< 1.5	<11.9	*0.1*
N-Me-FOSA	2.52	<0.4	*6.5*	1.88	0.6	3.2	< 0.8	<0.5	*1.6*
N-Et-FOSA	316	<0.6	*499*	206	<0.9	*217*	149	<0.8	*188*
N-Me-FOSE	<12.0	<1.2	*10.0*	<12.0	<1.7	*7.0*	<12.0	<6.3	*1.9*
N-Et-FOSE	<11.5	<0.6	*19.2*	<11.5	<0.9	*12.9*	<11.5	<0.7	*15.6*
PFBS	1.30	<0.4	*3.4*	<0.7	<0.6	*1.2*	<0.7	<0.5	*1.4*
PFHxS	<1.7	<0.5	*3.7*	<1.7	3.6	*0.5*	13.7	0.6	24.8
PFOS	116	236	0.5	75	54.8	1.4	22	31.7	0.7
PFDcS	9.6	<0.5	*21.0*	< 0.9	<0.7	*1.4*	<0.4	<0.5	*0.7*
PFHxA	<5.2	<1.3	*4.0*	<5.2	<1.9	*2.7*	<5.2	<1.6	*3.2*
PFHpA	<6.8	<0.5	*13.8*	<6.8	<0.7	*9.5*	<6.8	<0.6	*10.8*
PFOA	<6.4	<0.5	*14.0*	<6.4	<1.8	*3.5*	<6.4	<0.5	*11.7*
PFNA	25.3	<0.5	*55.3*	<7.2	<0.7	*11.0*	<7.2	<0.5	*13.2*
PFDcA	7.0	<0.3	*24.9*	3.2	<0.4	*7.7*	<3.6	<0.4	*9.4*
PFUnA	198	<0.3	*704*	91.1	7.3	12.4	16.5	<0.4	*43.2*
PFDoA	81.7	<0.3	*290*	6.6	<0.4	*15.9*	<3.6	<0.4	*9.4*
PFTriA	<2.4	<0.3	*8.5*	<2.4	<1.8	*1.3*	<2.4	<0.4	*6.3*
PFTeA	112	<0.4	*290*	7.50	<0.6	*12.6*	<3.0	<0.5	*6.1*
SumPFC	1013	236	4.3	397	68.2	5.8	201	38.5	5.2

Table 7: Concentrations in earthworms (ng/g ww), soils (ng/g ww) and calculated BAFs after laboratory accumulation experiments. Data from Gardermoen airport. BAFs calculated involving the detection limit for soil or earthworm is shown in italics.

	1m, 0-5cm			**1m, 10-30cm**			**1m, 65-80cm**		
Compound	**Earthworm**	**Soil**	**BAF**	**Earthworm**	**Soil**	**BAF**	**Earthworm**	**Soil**	**BAF**
6:2 FTS	2355	729.8	3.2	2823	550.2	5.1	1036	153.7	6.7
PFOSA	311	65.3	4.8	153	130.6	1.2	26	67.8	0.4
N-Me-FOSA	4.12	<0.7	*6.2*	5.89	<0.7	*8.9*	5.23	<0.7	*7.2*
N-Et-FOSA	498	<1.1	*464.4*	671	<1.1	*625.0*	512	<1.1	*455.4*
N-Me-FOSE	<12.0	<2.0	*6.1*	<12.0	<2.1	*5.8*	<12.0	<2.1	*5.7*
N-Et-FOSE	<11.5	<1.0	*11.6*	<11.5	<1.0	*11.6*	<11.5	<1.0	*11.0*
PFBS	7.38	2.2	3.4	6.40	<1.5	*4.3*	16.10	<1.4	*11.8*
PFHxS	<1.7	26.2	*0.1*	<1.7	38.4	*0.0*	<1.7	51.3	*0.0*
PFOS	5938	959	6.2	6317	1721	3.7	2086	845	2.5
PFDcS	182	5.5	33.3	68.5	<0.7	*92.2*	15.9	<0.8	*19.8*
PFHxA	<5.2	<3.3	*1.6*	<5.2	<3.1	*1.7*	<5.2	<2.7	*1.9*
PFHpA	<6.8	4.4	*1.6*	<6.8	4.6	*1.5*	<6.8	5.6	*1.2*
PFOA	<6.4	4.4	*1.5*	<6.4	3.1	*2.1*	32.7	9.7	3.4
PFNA	<7.2	<0.7	*9.7*	<7.2	<0.7	*9.7*	124	9.7	12.8
PFDcA	32.4	1.1	30.2	31.5	<1.5	*21.2*	106	5.6	19.0
PFUnA	1001	43.6	23.0	1391	99.9	13.9	792	152	5.2
PFDoA	105	<1.1	*98.4*	59.6	<1.5	*40.1*	62.0	2.7	22.6
PFTriA	1206	<1.1	*1150*	<2.4	<0.5	*4.8*	<2.4	<0.5	*5.0*
PFTeA	41.9	<0.7	*63.5*	19	<0.7	*28.0*	24	<0.7	*33.2*
SumPFC	11682	1235	6.4	11545	1507	4.5	4838	562.8	3.7

Table 8: Concentrations in earthworms (ng/g ww), soils (ng/g ww) and calculated BAFs after laboratory accumulation experiments. Data from Rygge Air Station. BAFs calculated involving the detection limit for soil or earthworm is shown in italics.

Compound	**26m**			**38m**			**174m**		
	Earthworm	**Soil**	**BAF**	**Earthworm**	**Soil**	**BAF**	**Earthworm**	**Soil**	**BAF**
6:2 FTS	<6.6	<8.0	*0.8*	<6.6	<8.7	*0.8*	<6.6	<8.5	*0.8*
PFOSA	28	<13.9	*2.0*	13	<15.1	*0.9*	<2.6	<14.8	*0.2*
N-Me-FOSA	< 0.8	<0.5	*1.5*	< 0.8	<0.7	*1.2*	< 0.8	<0.6	*1.4*
N-Et-FOSA	383	<0.9	*410.5*	368	<1.0	*363.1*	235	<1.0	*233.9*
N-Me-FOSE	<12.0	<1.7	*7.1*	<12.0	<1.9	*6.4*	<12.0	<1.8	*6.7*
N-Et-FOSE	<11.5	0.9	*13.1*	<11.5	<0.9	*12.2*	<11.5	<0.9	*12.3*
PFBS	7.50	1.9	4.0	<0.8	<0.7	*1.2*	<0.8	<0.6	*1.4*
PFHxS	<1.7	21.0	*0.1*	<1.7	2.8	*0.6*	<1.7	<0.7	*2.4*
PFOS	649	226.9	2.9	209	135.6	1.5	117	28.8	4.1
PFDcS	4.5	<0.7	6.8	<0.9	<0.7	*1.2*	<1.3	<0.7	*1.8*
PFHxA	<5.2	<1.9	*2.8*	<5.2	<2.0	*2.6*	<5.2	<2.0	*2.6*
PFHpA	<6.8	<0.7	*9.5*	<6.8	<0.8	*8.5*	<6.8	<0.8	*8.6*
PFOA	<6.4	2.1	*3.1*	<6.4	<0.7	*8.8*	<6.4	<0.7	*8.9*
PFNA	<7.2	<0.7	*10.9*	<7.2	<0.7	*9.9*	<7.2	<0.7	*10.0*
PFDcA	<3.6	<0.4	*8.2*	<3.9	<0.4	*9.0*	<3.9	<0.4	*9.1*
PFUnA	13.0	<0.4	*29.6*	<9.3	<0.7	*12.8*	<8.2	<0.4	*19.0*
PFDoA	<3.6	<0.4	*8.2*	<3.5	<0.4	*8.1*	<5.5	<0.4	*12.8*
PFTriA	<2.4	<0.4	*5.5*	<2.4	<0.4	*5.5*	<2.4	<0.4	*5.6*
PFTeA	<3.0	<0.5	*5.5*	<3.0	<0.7	*4.6*	<3.0	<0.6	*5.2*
SumPFC	1085	251.9	4.3	590	138.4	4.3	352	28.8	12.2

There is an apparent trend that bioaccumulation of PFCs and PFCAs in earthworms increase with increasing chain length (Table 9). Another important finding from the bioaccumulation experiments was that N-Et-FOSA was found in nearly all earthworm samples in quite high concentrations, but was detected in only one of the soil samples. Using the detection limit for N-Et-FOSA in the soils, BAFs of several hundred was calculated.

The variation in calculated BAFs also was quite large. These variations may be explained by differences in soil pH, TOC and silt+clay content, and possibly by different concentrations of PFCs in the soil.

Table 9: Summary of calculated BAFs for laboratory experiments and field sampling.

Compound	BAF Laboratory eksperiments (n=12) Min	Mean	Max	BAF Field Mongstad (n=2) Mong 25m	Mong 52m
6:2 FTS	0.76	2.4	6.7	16.7	7.3
PFOSA	0.13	4.0	21.9	2.8	10.8
N-Me-FOSA	1.23	5.1	12.7	9.0	1.0
N-Et-FOSA	188	423	773	222	339
N-Me-FOSE	1.90	7.1	11.5	5.0	5.0
N-Et-FOSE	11.0	14.6	22.1	9.6	9.6
PFBS	0.04	2.9	11.8	2.7	2.1
PFHxS	0.01	3.0	24.8	2.0	4.2
PFOS	0.49	2.6	6.4	3.0	2.4
PFDcS	0.73	15.6	92.2	1.9	11.2
PFHxA	0.34	2.4	4.7	1.6	0.7
PFHpA	1.02	7.1	16.3	1.3	0.1
PFOA	0.31	5.9	14.0	4.2	0.3
PFNA	2.56	14.0	55.3	2.2	0.5
PFDcA	3.35	13.5	30.2	8.2	1.3
PFUnA	5.20	75.3	704	9.8	2.9
PFDoA	8.06	45.1	290	9.7	287
PFTriA	0.48	98.2	1125	0.8	4.0
PFTeA	4.60	40.5	290	8.1	54.6
SumPFC	1.23	4.7	11.6	2.3	3.6

Figure 27 shows that the fraction of the soil less than 63µm (silt, clay) is negatively correlated with the BAF for PFOS, The implication is that higher silt and clay in the soil results in lower bioaccumulation if PFOS. The highest BAFs for PFOS occur in soils with low content of TOC, with the exception of Mongstad Soil 200m which had a BAF of 6.4 and a TOC value of 42.9%. The three Mongstad soil samples used in the bioaccumulation experiment all contain high levels of TOC (31.3-42.9%), but the sample Soil 200m results in a much higher BAF for PFOS than the other two samples (6.4 vs. 1.1 and 0.7). pH is quite similar in the samples, but the concentration of PFOS in sample 200m (9.9 ng/g ww), is considerably lower than in the other two samples (334 and 3958 ng/g ww). Bioaccumulation experiments performed by Stubberud (2007, se below) suggest that BAF is reduced with increasing concentration of PFC in the soil. This study, however, shows no relationship between soil concentration of PFOS and the BAF (Figure 27).

The content of TOC in soil could be expected to reduce the bioaccumulation of PFOS due to binding to organic carbon. However, soil TOC does not seem to have any effect on BAF for PFOS (Figure 27).

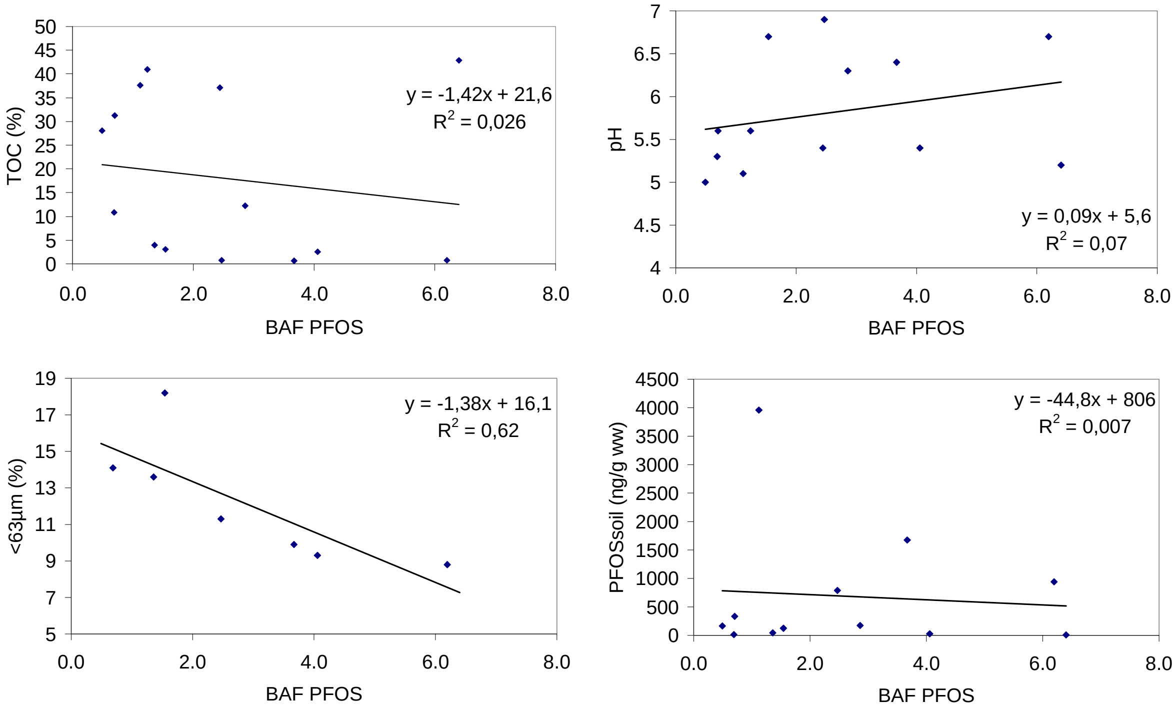

Figure 27: Correlations between BAF for PFOS and pH, TOC, fraction <63µm and concentration of PFOS in soil.

9. Discussion

9.1 Soils

9.1.1 Concentrations in soils vs. sediments and sewage sludge

The concentration of PFOS in most soil samples from the four fire training facilities exceeds the proposed guideline values for PFOS in soils (100 ng/g).

No measurements of concentrations of PFCs in natural or contaminated soils have been found in the literature. In a risk evaluation of PFOS in UK, Brooke *et al*. (2004) also stated that measured concentrations were not available. In UK risk evaluation therefore, soil concentrations of PFOS by the use of fire-fighting foams were calculated. In these calculations it was assumed that 114 kg of PFOS-acid was used annually in the UK and that 1% of this amount was used in a fire. Two scenarios were made. The first (A) involved no containment of foam and water and so 50% of the release goes to surface water without treatment and 50% to soil. In the second scenario (B) it was assumed that foam and water were collected and passed to a waste water treatment plant and that PFOS thereafter was applied to soil through the use of sewage sludge. After 30 days soil concentration for scenario A were calculated to 0.53 ng/g ww, and for scenario B 5360 ng/g ww. These PECs were used in a risk evaluation for PFOS. In the risk assessment PECs for soils were also calculated for other use areas: chromium plating, aviation, photolithography, paper treatment, coatings etc. Even though the predicted soil concentrations from the UK risk evaluation can not be used for comparison with measured concentrations in this project, the predictions show that use of fire fighting foams results in much higher PECs (scenario B) compared to other uses and that the soil concentrations (if the scenario in some way is relevant) may be high.

The concentrations of PFOS in soils at or in the vicinity of the four fire training facilities investigated in this project is 10-10000 times higher than concentrations found in sewage sludge from the Nordic countries (Table 10).

Table 10: Concentrations of PFCs in Norwegian sewage sludge (ng/g dw unless otherwise specified).

Sewage sludge	PFOSA	PFHxS	PFOS	PFHxA	PFOA	PFNA	Reference
Sewage sludge (n=3)	n.d.	0.09	1.2-5.2	n.d	n.d.	n.d.	Norwegian Screening 2007[1]
Norwegian sewage sludge* (n=2)	<LOQ	0.018-0.025	0.45-1.02	<LOQ-0.13	0.38-0.39	0.10-0.19	Nordic screening[2]
Swedish sewage sludge (n=11)*	<0.05-1.0	<0.06-0.67	0.43-35	<2	<1-4.3	<1-14	Swedish screening[3]

1 Green *et al*. (2008); 2 Kallenborn *et al*. (2004); 3 Woldegiorgis *et al*. (2006); * wet weight

The high concentrations found in soils at the fire training facilities clearly indicate that PFCs from AFFFs in fire fighting foams severely contaminate nearby soils. At all sites PFOS, which has not been used in fire fighting foam at these localities since 2005, is dominating.

At Mongstad and Rygge PFS in general constitute more than 90% of the PFCs in the soil samples, at Solberg Scandinavian this percentage was smaller (70-85%, but even lower in some samples, i.e. 34-44%). At some samples close to the testing platform at Solberg Scandinavian, the fraction of 6:2 FTS, PFOSA and PFCAs were 5.5%, 13%, and 48%, respectively.

At Gardermoen the percentage of PFSs in the soil samples closest to the training platform was 50-70%, while the fraction of PFOSA and PFCA generally were low (<10%). At Gardermoen 6:2 FTS constituted 10-40% of the PFCs in the soil samples.

The highest concentration of PFOS in any samples were found in the ditches at the old fire training site at Rygge where PFOS-concentrations as high as 47743 ng/g dw were determined. This is much higher than was determined in soil samples from the site and show that drainage systems and ditches at fire training facilities may accumulate PFCs. At the time of sampling the ditches at Rygge were dried out, but in e.g. high rainfall periods these systems may be flushed with water and may possibly mobilise PFCs.

9.1.2 Leaching in soils

Analysis of soil profiles at the four fire training sites show that 6:2 FTS, most PFS and PFCAs determined in this project are mobile in soils and may leach to the groundwater through the soil profile. Similar findings have been reported by e.g. Murakami *et al.* 2008. At Mongstad and Gardermoen the concentrations at 30-60cm depth are higher for most PFS and PFCAs than at the soil surface. This clearly indicates leaching in the soil profile. The soils at Mongstad and Gardermoen are very different with respect to organic carbon content (40% at Mongstad, and 1 % at Gardermoen). Both organic and inorganic soil constituents have been shown to influence the fate and transport of PFOS in soils (Johnson *et al.* 2006) and the high leaching in the Mongstad soil therefore may be attributed to low silt and clay content.
The soils at Gardermoen also were low in clay and silt, and low sorption may be expected.

Lower concentrations in the surface soil may also indicate a reduction in the emission of these compounds during the last years. The front of PFCs which seems to move downwards in the soils at all sites, shows that the soils in the vicinity of the fire training or testing facilities will be a source for PFCs still for many more years even though emissions are reduced.
Even if most PFCs are mobile in soils, sorption may still be sufficient to hold back most of the PFCs emitted.

At Gardermoen, the leaching of 6:2 FTS seems to be similar to PFS and PFCAs, but much less than the leaching of these compounds in the organic soil at Mongstad. In general, the leaching of PFCs seem to be highest in the sandy soils at Gardermoen which also have a low content of silt, clay and organic carbon, and lowest in the soil profile from Rygge where about 50% of the soil consist of silt and clay.

9.1.3 Horizontal dispersion from training sites

The application of AFFFs at the fire training platforms has led to quite severe contamination in the vicinity of these sites. The areas, influenced by the activity, vary considerably depending on the type of training equipment used, frequency of training and weather conditions. At Gardermoen and Mongstad quite powerful equipment has been used. At Gardermoen airport cannons with a firing range of 80m have been used in the area at or close to platform 4. The sandbank just outside the paved platform has, on several occasions, been damaged by the high foam-cannon pressure. At Mongstad the soils in the prevailing wind direction are severely contaminated (more than 100 times the background concentration) up to

90m from the training platform. Also at Gardermoen the soil at 70m from the platform has concentrations of the sum of PFCs which are 7-8 times the background concentration. The equipment used at the testing platform at Solberg Scandinavian has been much less powerful, and at this site the aerial transport seems to have been much less than at the other sites.

9.1.4 Background soil concentrations of PFCs?

At all four sites investigated in this project, soil samples that were assumed not to be influenced by the fire fighting activity were collected. The levels of PFCs in these soils were supposed to give an indication of the background level of PFCs in natural soils in Norway (Table 11). In these “reference” soils the concentrations of PFOS varied from 28.6 to 116 ng/g dw, while N-Me-FOSA and N-Me-FOSE occurred in concentrations of 1,6 and 23.2 ng/g dw at Gardermoen and Solberg Scandinavian, respectively. As can be seen PFOS was the only PFCs detected in concentrations above the detection limit or limit of quantification in all samples (Table 11).

Table 11: Concentrations of PFCs (ng/g dw) in soils taken 150-200 meters from training or testing platforms for AFFFs.

	Site	Mongstad	Rygge	Solberg Scandinavian	Gardermoen
Compound	Distance from platform (m)	200	174	155	200
6:2 FTS		<13.8	<11.8	<25.0	<21.9
PFOSA		<24	<20.6	<43.7	<38.3
N-Me-FOSA		<1.0	<0.8	<1.8	1.6
N-Et-FOSA		<1.6	<1.4	<2.9	<2.6
N-Me-FOSE		<3.0	<2.5	23.2	<4.7
N-Et-FOSE		<1.5	<1.3	<2.7	<2.4
PFBS		<1.0	<0.8	<1.8	<1.6
PFHxS		<1.5	<1.0	2.0	<1.8
PFOS		28.6	40.2	116.0	109.9
PFDcS		<1.1	<1.0	<2.0	<1.8
PFHxA		<3.2	<2.8	<5.9	<5.1
PFHpA		<1.2	<1.1	<2.3	<2.0
PFOA		<1.6	<1.0	<2.0	<1.8
PFNA		<1.1	<1.0	<2.0	<1.8
PFDcA		<0.7	<0.6	<1.4	<1.2
PFUnA		<0.7	<0.6	<1.4	<1.2
PFDoA		<0.7	<0.6	<1.4	<1.2
PFTriA		<0.7	<0.6	<1.4	<1.2
PFTeA		<1.0	<0.8	<1.8	<1.6
SumPFC		29	40	141	111
TOC		42.9	2.6	46.2	37.4

The concentration levels of PFCs found in the background soils were 6-30 times higher than the concentrations found in e.g. sewage sludge in the Nordic screening project (Kallenborn *et al.* 2004). This fact clearly indicates that the reference soil samples also are influenced by the fire training activity and that atmospheric transport may disperse PFCs (at least PFOS) more than 200 meters from the training platforms.

9.2 Marine sediments and biota

9.2.1 Sediments from Radsundet

The concentrations found for PFOS in Radsundet (54-64 ng/g dw) outside Solberg Scandinavian AS are comparable to the concentrations of PFOS found in sediments (28-31 ng/g dw PFOS) from sedimentation basins downstream a fire drill site in Haugesund (West Coast of Norway). (Source: Results from the Norwegian environmental screening investigation 2007; Green *et al*. 2008). The concentrations of PFOS in the sedimentation basin at the fire drill site in Haugesund were at the most ten times higher than in sediments from a landfill leachate sedimentation pond (3.8-7.5 ng/g dw) analysed in the same screening project (Green *et al* 2008). Sediments sampled outside Bekkelaget sewage treatment plant (Oslofjorden), in Drammensfjorden and in Loselva (freshwater) varied in the range 0.63-6.7 ng/g dw with the highest concentrations in sediments outside Bekkelaget wastewater treatment plant (Green *et al*. 2008). The concentrations in sediments outside Bekkelaget, in Drammensfjorden and Loselva were all considerably higher than in the reference sample from Lista (0.34 ng/g dw).

Despite the heavy currents and steep slope from the seashore at Solberg Scandinavian AS to Radsundet, the sediments in Radsundet seem to be heavily contaminated with PFOS. Other PFCs were not detected in the sediments in the area.

9.2.2 Sea snails from Radsundet

The concentrations of 6:2 FTS, N-Et-FOSA and PFOS found in Sea snails (*Patellidae*) are considerably higher than concentrations for these compounds found in Blue mussels (*Mytilus edulis*) and Atlantic cod (*Gadus morhua*) liver in the Norwegian environmental screening from 2007 (Green *et al*. 2008) (Table 12). In this screening the concentrations of PFOS in Blue mussels were in the range 0.17-1.89 ng/g ww, with the highest concentration found in the recipient downstream the fire training facility in Haugesund

Table 12: Concentrations of selected PFCs in marine organisms determined in Norwegian screening experiments. Unless otherwise specified, the highest detection limit and highest concentration quantified is shown.

Organism	6:2 FTS	N-Et-FOSA	PFOS	PFOA	PFDoA	Reference
Sea snail (*Patellidae*)	2.4-129	50-182	12-206	<3.4-16.4	<2.8-49.1	This project
Blue mussel (Mytilus edulis)	n.d.	n.d.	0.17-1.89	n.d.	n.d.	Screening 2007[1]
Blue mussel (Mytilus edulis)			<0.06-0.56			Screening 2006[2]
Blue mussel (Mytilus edulis)			0.034-0.165			Screening 2004[3]
Atlantic cod (*Gadus morhua*) liver	n.d.	n.d.	4.41-28	n.d.	n.d.	Screening 2007[1]
Atlantic cod (*Gadus morhua*) liver			37-63[4]			Screening 2006[2]

1 Green *et al*. (2008); 2 Bakke *et al*. (2007); 3 Fjeld *et al*. (2005); 4 Inner Oslofjord, Norway

Also PFHxS, PFDcS, PFUnA were found in concentrations above the detection limit in Sea snail at the seashore at Solberg Scandinavian AS.

9.3 Groundwater and surface water

The concentration levels of PFCs found in stream water at Solberg Scandinavia AS are 1000 times higher than concentrations found in landfill effluent in the Nordic screening from 2004 (Table 13). However, compared the maximum concentrations found in surface water after an accidental release of fire-fighting foam in USA (Moody *et al*. 2002), the concentrations in the stream from Solberg Scandinavia AS, however, are low (Table 13). Moody *et al* (2003) analysed groundwater samples at a former fire-training site at Wurtsmith Air Force Base (WAFB) in northeastern Michigan. The concentrations of PFOS ranged from 110 000 ng/l closest to the platform to 4000 ng/l in the wells down gradient from the training site. The gradient concentrations for PFHxS, PFOA and PFHxA were 9000-120 000 ng/l, not detected to 105 000 ng/l, and not detected to 20 000 ng/l, respectively (Moody *et al*. 2003). The concentrations found in the groundwater at Gardermoen are in the lower end of the concentration ranges found in groundwater for these four compounds at the former fire-training site at WAFB (Table 13). The groundwater samples from WAFB were sampled at least five years (possibly as much as 15 years) after the closedown of the training site clearly indicating that PFCs from AFFFs are slowly degraded and may be present in the groundwater many years after use (Moore *et al*. 2003).

Concentrations in groundwater samples from Gardermoen are also high compared to those in sewage effluent water from the Nordic screening (Kallenborn et al. 2004), and also much higher than water from the Rhine and drinking water in the Rhine area (Skutlarek *et al.* 2006).

The levels found in the groundwater at Gardermoen are comparable with the highest concentrations found in the highly polluted Moehne river in Germany (Skutlarek *et al.* 2006) (Table 13).

Table 13: Comparison of concentrations (ng/l) of selected PFCs in water samples from this project with concentrations obtained for different surface waters and groundwater from other countries (ref 2; Germany, ref3; Nordic countries; ref 4, 5; USA).

		N	PFBS	PFOS	PFHxA	PFHpA	PFOA	Sum
1	Well BV-1	1	758	6762	532	114<LOQ	241	8293
	WellBV-2	1	94	2394	169	39.7<LOQ	97.6<LOQ	2657
	Well BV-3	1	1743	40116	1585	291	1457	45192
	Stream water	1	8284	68886	17260	5746	16430	116606
2	Surface water, Ruhr area	29	33-71	4-193	3-1248	25-148	11-3640	3-4268
	Rhine river	38	2-46	2-26	2-77	2-11	2-48	2-178
	Moehne river	12	17-1450	2-5900	73-3040	50-989	11-33900	11-43348
	Drinking water, Ruhr area	28	3-26	3-22	3-56	2-23	22-519	26-598
3	Lake water	5	<LOQ	<LOQ-0.48	0.76-1.68		4.8-8.2	6-10
	Landfill effluent	3	5.6-112	33-187	44-697		91-516	199-1537
	Sewage effluent water	6	1-3.1	6.9-63	8.0-14.5		20-23	48-105
4	Stream water	55		<det lim-2210000			<det.lim-2270000	
5	Groundwater	10		4000-110000	nd-20000		nd-120000	
6	Sewage effluent water	3	nd	0.94-1.07	nd	nd	nd	

1 This investigation; 2 Skutlarek *et al.* 2006; 3 Kallenborn *et al.* 2004; 4 Moody *et al.* 2002; 5 Moody *et al.* 2003; Greene *et al.* 2008; nd-not detected

It is not possible to quantify the amounts of PFCs that is leaching from Solberg Scandinavian AS. The water flow in the sampled stream is not known. Observations made during the sampling of sediments and biota in Radsundet, indicate that there are also other streams leading from the industrial area to the sea. The relatively high concentrations of PFCs in biota at the outlet of one of these streams clearly show that transport of PFCs from the industrial area also occurs in other streams leading to Radsundet. These streams were not sampled.

As mentioned, the area around the industrial area at Solberg Scandinavian is dominated by shallow soils with low the capacity for sorption of pollutants. The soil in the industrial area consists of coarse textured material (gravel, blasted rock used as filler material) with no organic material. In a humid climate, with excess precipitation, these factors will promote leaching. More information on size of catchment area, water flow through the area, as well as concentration measurements in the water seems necessary to draw any conclusions.

9.4 Earthworms

The BAFs found for the 6:2 FTS, PFOS and PFCA in this project (summarised in Table 9) are comparable to the BAFs found by Stubberud (2006) (Table 14).

Table 14: BAF calculated from laboratory experiments where three concentrations of PFOS, PFOA and 6:2 FTS were added to OECD soil. Exposure time: 28 days. (Stubberud, 2006)

Soil conc. (mg/kg)	BAF PFOS	BAF PFOA	BAF 6:2 FTS
10	2.8	1.0	4.3
20	2.2	1.0	1.8
40	1.8	0.7	3.1
Mean	2.3 ± 0.5	0.9 ± 0.2	3.0 ± 1.2

The accumulation of longer chained PFSs and PFCAs was not investigated by Stubberud (2006) and other investigations on accumulation of these compounds in soil organisms have not been reported by others. Analysis of PFCA in eggs, plasma, liver and brain in Glaucous Gull from Bjørnøya, indicated that the dominating acids were PFUnA and PFTriA. C_5-C_8 or C15 PFCAs were not detected in any samples. This clearly shows that the bioaccumulation potential for, at least, some of the longer chained PFCAs is higher than for e.g. PFOA.

High accumulation factors have, however, been reported for N-Et-FOSA and N-Me-FOSA (Environment Canada 2006), which is in agreement with the results found for earthworms in this project.

9.5 Amount of PFCs in soils at fire training sites

Soil sampling at the training sites were carried out in increasing distance from the site to get an indication of the horizontal dispersion of PFCs. Sampling was done only in the prevailing wind direction and sampling in other directions from the training site is sparse or totally lacking. At the same time, sampling has been performed only down to 50-80cm (except from at Solberg Scandinavian where soil thickness was only 30cm). Both at Mongstad and Gardermoen the concentrations of PFCs at 60-80cm were quite high, indicating that leaching occurred below this depth, also clearly indicated by the high concentrations of PFCs in the groundwater at Gardermoen. This means that the overview of both the horizontal and vertical distribution of PFCs at the various sites is not complete. Still, the analysed soil samples can be used in simple calculations to get an impression on the amount of PFCs that is contained in the soils in the vicinity of the fire training platforms.

In the calculations the most contaminated area in the vicinity of the training platform was selected. The soil concentrations (ng/g or mg/ton) in this area were the mean value of all soil samples analysed inside this area both horizontally and vertically. Selection of soil depth used in the calculations for the different sites was based upon observations at the sites and results from soil analysis. Soil mass (tons) was then calcultaed by multiplying distance from the platform by soil depth and the multiplying with soil density (for simplicity assumed to be 1000 kg/m^3).

The calculated amounts of PCFs in soils at the training sites (Table 15) are just indications on the amount that may be present in the soils.

9.5.1 Solberg Scandinavian AS

As mentioned, the fire platform at Solberg Scandinavian has been used as a testing site for quality control of different formulations of AFFFs and large amounts of AFFFs have, not been used, according to the firm. The equipment used has also been relatively small compared to what has been used at the other sites. The calculations indicate that about 1.3 kg is stored in soils within about 40meters from the platform. Since the firm has no records or has not made any assumptions on the amount of PFCs that has been used in the testing activity, it is not possible to predict what fraction of the used PFCs that is still in the soil and how much has leached to the resipients in the area. Concentrations of PFCs found in the stream running from the area, high concentrations in Sea snails at the seashore, as well as high concentrations in sediments inRadsundet, indicate however that the leaching from the site has been and is quite extensive. It is unlikely that the polluted natural soils at the site are responsible for the high concentrations in the stream and in the sea snails. The most plausible explanation is that there is a reservoir of old PFC at the industrial site that is “flushed” during rainstorms.
Actions should be taken to reduce the measured leaching of PFCs from Solberg Scandinavian.

9.5.2 Mongstad

According to information about the activity at the site, about 100 kg of PFOS-related PFCs may have been used at the fire training facility in the periode 1988-2005. If we assume that at least 50 % of the AFFFs used are collected in the drainage systems from the platform, about 50kg is emitted to the environment around the platform during this period. The calculated amount (22 kg) still present in the soils then represents 40% of the used amount of PFCs in the period. In large areas around the platform there is no soil, just large open gravelled and asphalted areas for roads and industrial activity. In these areas the binding capacity for PFCs are poor and PFCs spread from the training activity may have leached to Mongstadbukta, the closest marine area about 200 meters from the platform (Figure 3).

It is recommended to analyse sediments and Blue mussels (or other types of biota) from this area to investigate possible spreading of PFCs to the marine environment from the fire training activity at Mongstad.

9.5.3 Gardermoen airport

At platform 4 at Gardermoen about 500-700 liters of AFFFs have been used annually for about 10 years. Assuming a content of PFOS of 1-4 % (mean 3 %), in the AFFFs, this amount to 150-210 kg PFOS during the 10-year period. If we assume that at least 50 % of the AFFFs used are collected in the drainage systems from the platform, 75-105 kg is emitted to soils from platform 4 in the 10-year period. The calculated amount of PFOS (13 kg, Table 15) remaining in the soil in the vicinity of platform 4, then constitutes only 9-17 % of the emitted PFOS in this period. This indicates that a relatively large fraction of the PFCs emitted at the fire training site at Gardermoen has leached to the groundwater.

The analysis of groundwater samples at Gardermoen confirmed this. A substantial fraction of the AFFFs used at the platfor has escaped the concrete cover and drainage systems during fire extinguishing training and has reached the groundwater. It is recommended to analyse more groundwater samples in order to get an overview of the distribution of PFCs in the groundwater at Gardermoen.

9.5.4 Rygge Air Station

The soils at Rygge seemed to contain relatively small amounts of PFCs (calculated amount 0.7 kg, Table 15), at least relative to the other sites. The soils at Rygge contain large fractions of silt and clay, which increase sorption of e.g. PFOS and reduce bioaccumulation. The concentrations of PFCs found in the ditches close to the old platform were high, but this constituted only a relatively small area. During periods of high precipitation or snowmelt these ditches may be flushed and PCFs may be mobilised. The ditches do not seem to drain to specific recipients and the risk for transport of PFCs from the ditches seems to be low.

Table 15: Amount (kilo) of different PCFs in soils in the vicinity of investigated fire training sites.

	Mongstad	Solberg Scandinavian AS	Gardermoen	Rygge
Soil depth (m)	0.5	0.3	1	0.5
Radius from platform (m)	52	38	31	54
Compound				
6:2 FTS	2.30	0.06	2.7	n.d.
PFOSA	n.d.	0.22	0.9	n.d.
N-Me-FOSA	n.d.	0.001	n.d.	n.d.
N-Et-FOSA	n.d.	n.d.	n.d.	n.d.
N-Me-FOSE	n.d.	n.d.	n.d.	n.d.
N-Et-FOSE	n.d.	n.d.	n.d.	n.d.
PFBS	0.10	0.014	0.02	0.02
PFHxS	1.46	0.099	0.25	0.06
PFOS	18.12	0.84	9.23	0.63
PFDcS	0.11	0.020	0.02	n.d.
PFHxA	0.15	0.018	0.04	n.d.
PFHpA	0.07	0.025	0.03	n.d.
PFOA	0.19	0.012	0.05	0.02
PFNA	0.04	0.028	0.04	n.d.
PFDcA	0.09	0.005	0.01	n.d.
PFUnA	0.09	0.100	0.30	n.d.
PFDoA	0.06	0.009	0.01	n.d.
PFTriA	0.03	0.051	n.d.	n.d.
PFTeA	n.d.	0.006	n.d.	n.d.
SumPFC	22	1.3	13	0.68

10. Risk characterisation and recommendations

10.1 Soil and earthworms

In an experiment performed by 3M (3M, 2003), PFOS was incorporated into an artificial soil substrate at five different concentrations in which adult earthworms (*Eisenia fetida*) were exposed to the soil for 14 days. The 14-day LC50 was determined to be 373 mg/kg soil (316-440, 95% CI). The 14-day NOEC, based on survival, was determined to be 77 mg/kg soil.

Stubberud (2006) performed reproduction tests where number of cocoons, hatching success, number of juveniles and weight of juveniles were registered or calculated (Table 16). The results clearly indicated that, especially for PFOS and PFOA, parameters based upon reproduction were much more sensitive than endpoints like survival and weight loss by adult earthworms.
The experiments performed by Stubberud (2006) resulted in NOEC-values of 10 and 16 mg/kg soil PFOS and PFOA, respectively. For 6:2 FTS an EC_{10} of 21 mg/kg was calculated (Table 16).

Table 16: EC50 (95% conf.int) mg/kg dw for PFOS, PFOA and 6:2 FTS calculated from reproduction tests (Stubberud 2006)

Soil conc.	PFOS	PFOA	6:2 FTS
No of cocoons	103 (85-127)	383 (281-524)	566 (401-800)*
Hatching success		423 (365-491)	
No of juveniles	80 (62-103)	213 (173-261)	
Total weight of juvenile	29 (21-39)	50 (40-61)	253 (164-392)
Weight per juvenile	131 (65-262)	115 (60-223)	

*Extrapolated values; should be used with caution

PNEC-values have not been calculated for the soil environment. According to TGD (EU 2003) an assessment factor of 100 should be used if NOEC for one-long-term toxicity test exists (as is the case here). The resulting PNEC-values for PFOS, PFOA and 6:2 FTS is shown in Table 17.

Table 17: PNEC-values for PFOS, PFOA and 6:2 FTS in soil.

Soil conc.	NOEC (mg/kg)	EC_{10} (mg/kg)	Assessment factor	**PNEC (ng/g dw)**
PFOS	10		100	**100**
PFOA	16		100	**160**
6:2 FTS		21	100	**210**

If data from a short-term test is used (e.g. LC_{50}, earthworm, plant, microorganism), an assessment factor of 1000 should be applied. Using the data from the acute test performed by 3M, a PNEC-value of 0.077 mg/kg (77 ng/g) is achieved.

The TGD states that "if only one terrestrial test result is available (earthworms or plants), the risk assessment should be performed both on this test result and on the basis of the outcome of the aquatic toxicity data to provide an indication on the risk".

Based upon the calculated PNEC-values (Table 17) it may be concluded that PFOS in most soils analysed in the project may pose a risk to earthworms (PEC/PNEC>1). At Solberg

Scandinavian AS and Gardermoen this is also the case for earthworms at the background areas (150-200 m from the training platforms).

The soil concentrations of 6:2 FTS are higher than the PNEC-value for all soil samples taken within 7.5m of the platform at Gardermoen and at the sample point Soil 52m at Mongstad. At Solberg Scandinavian and Rygge no soil samples exceed PNEC for 6:2 FTS. At Rygge, however, the concentration of 6:2 FTS in the sediment from Sed 18m exceeds PNEC (252 ng/g dw in sediment). For PFOA, PNEC is exceeded for the sample point Soil 52m at Mongstad and at Sed 18m and Sed 39m sampled at Rygge Air Station.

The large uncertainty in the soil PNEC-values for PFCs in general urge for more investigations on effects of these compounds in soil living organisms.

10.2 Stream water and groundwater

10.2.1 Stream water at Solberg Scandinavian AS

The concentration of PFOS found in stream water at Solberg Scandinavian was 69000 ng/l, which according to the classification given in Table 18, may result in chronic effects after long-term exposure. Since the classification is based on results from ecotoxicological studies and on the use of assessment factors (25000 ng/l is equal to the PNEC-value calculated by 3M (3M 2003)), one might expect chronic effects at this level.

Table 18: Classification based upon concentrations of PFOS in water. Unit: ng/l (SFT 2007).

	Background	Good	Moderate	Bad	Very bad
	Background values	No toxic effects	Chronic effects by long-term exposure	Acute toxic effects by short-term exposure	Severe acute effects
PFOS water (ng/l)		<25000	25000-72000	72000-360000	>360000

The stream water from Solberg Scandinavian AS runs into Radsundet which contain a large volume of water and quite strong currents. The dilution of water will be enormous and chronic effects on biota in Radsundet due to elevated concentrations of PFOS in the water, is very unlikely. At the seashore, however, Sea snails contain high concentrations of PFOS which might give toxic effects.

10.2.2 Groundwater at Gardermoen

The groundwater at Gardermoen contained 40116 ng/l (BV-3), 6762 ng/l (BV-1) and 2393 ng/l (BV-2) PFOS and 241 ng/l, <LOQ and 1457 ng/l PFOA, respectively.

Quality criteria have not been set for PFCs in Norwegian drinking water, but comparison with drinking water criteria from e.g. Germany, UK and Minnesota, US, show that the concentrations of PFOS and PFOA in the groundwater samples at Gardermoen exceed one or more of these quality criteria. It should be emphasised, however, that the groundwater at Gardermoen is not used for drinking water purposes.

In Germany different quality criteria has been set for drinking water involving the sum of PFOS and PFOA. These quality criteria varies from 100 to 5000 ng/l (Table 19). 100 ng/l is the health based *precautionary* value (long term minimum quality goal) for non-genotoxic

substances and 5000 ng/l is the Precautionary *action* value for adults i.e. drinking water inadmissible for food processing and preparation. The concentration of PFOS in groundwater from well BV-1 and BV-3 exceed the limit of 5000 ng/l.
Minnesota Department for Health (MDH) has issued 300 ng/l PFOS and 500 ng/l PFOA as a Health Based Value (HBV) (established in March 2007). This is the amount of a chemical in drinking water considered to be safe for people to drink daily for up to a lifetime. All three groundwater samples from Gardermoen exceed the HBV for PFOS, but only groundwater from well BV-3 (closest to the platform) exceeds the HBV for PFOA.
In UK maximum acceptable concentrations in drinking water has been set to 300 ng/l for PFOS and 10000 ng/l for PFOA (Table 19). The value for PFOS is thus similar to the health based quality criteria from Germany and Minnesota (Table 19).

Table 19: Drinking water "quality criteria" for PFOS and PFOA from different countries.

Type of max value		Composite PFOS, PFOA (ng/l)	PFOS (ng/l)	PFOA (ng/l)
Germany[1]	Health based *precautionary* value (long term minimum quality goal) for non-genotoxic substances	100		
	Strictly *health based* guide value for safe lifelong exposure of all population groups	300		
	Precautionary *action* value for infants	500		
	Precautionary *action* value for adults	5000		
UK[2]	Maximum acceptable concentration in drinking water		300	10000
US (Minnesota)[3]	Health Based Value (HBV)		300	500

1 GMH (2006); 2 HPS 2007; 3 MDH 2007

10.3 Marine sediments and biota

The concentrations of PFOS found in the marine sediments outside Solberg Scandinavian AS varied in the range 34-41 ng/g ww (or 55-64 ng/g dw). Comparison with the classification system for sediments (SFT 2007) shows that the sediment quality with respect to PFOS can be classified as good (Table 20). The concentrations of PFOS found in sediments in Radsundet outside Solberg Scandinavian are however up to ten times higher than the concentrations found at assumable polluted sediments (chapter 9.2) and the sediments in Radsundet seem to be heavily contaminated with PFOS.

Table 20: Classification based upon concentrations of PFOS in sediments. Unit: ng/g (SFT 2007).

	Background	Good	Moderate	Bad	Very bad
	Background values	No toxic effects	Chronic effects by long-term exposure	Acute toxic effects by short-term exposure	Severe acute effects
PFOS sediment (ng/g)	<0.17	0.17-220	220-630	630-3100	>3100

As shown in chapter 9.2.2, the concentrations in Sea snails from Radsundet outside Solberg Scandinavian are considerably higher than the concentrations found in Blue mussels from sites that may be affected by PCFs in AFFFs. The significance of the high concentrations found in the Sea snails should be evaluated comparing with effect concentrations for this species. However, since no effect data exist for this species, effect concentrations of PFOS for other species can be used to give an indication on possible effects.

The effects of PFOS on aquatic organisms have been quite extensively studied during the last 20-years. 3M (2003) has summarised the available data on toxic effects of PFOS and calculated PNEC-values for several ecological receptor groups (Table 21).

The PNEC-value for Mollusc tissue has been calculated to73 ng/g, referring to concentration in the whole body. The concentration of PFOS in Sea snail *(Patellidae)* at the seashore from Solberg Scandinavian varied in the range 11.8-206 ng/g fw. This means that the concentration of PFOS in Sea snail at the stream outlet is higher than the PNEC for Molluscs.
Molluscs and Sea Snails are different species, and it is not possible to predict if the PNEC-value for molluscs will be representative also for sea snail. The comparison, however, indicates that effects might occur in Sea snail at this sampling point.

Table 21: Predicted no effect concentrations for PFOS (from 3M 2003).

Ecological Receptor Group	Toxicity test	Endpoint	NOEC	**Uncertainty factor***	**PNEC**
Aquatic life	35-d *M.bahia*	Reproduction and growth	0.25 mg/l	**10**	**0.025 mg/l**
Fish	62-d *L macrochirus*	Survival	80.6 µg/g (ww)	**10**	**8** µg/g (ww)
Molluscs	96-h *U.complamatus*	Survival	7.3 µg/g (ww)	**100**	**0.073** µg/g (ww)
Mammals	2-generation rat study	Reproduction	107 µg/g (liver)	**10**	**10.7** µg/g (liver)
			47.1 ppm (serum)	**10**	**4.7 ppm (serum)**
Birds	19-wk Bobwhite quail	Reproduction	Not determined	**N/A**	Not determined
	19-wk Mallard duck	Reproduction	Not determined	**N/A**	Not determined

* 10 for chronic NOECs and 100 for acute NOECs.

10.4 Recommendations for further investigations

This investigation shows that continued fire training over years using AFFF containing PFCs has resulted in quite severe contamination with PFOS, in particular, but also with other PFCs in the local environment. High mobility in some soils and high bioaccumulation potential of some PFCs, make these contaminants an environmental risk that should be further assessed.

Comparison of measured soil concentrations at the investigated fire training facilities with estimated PNEC-values (predicted no effect concentration) for 6:2 FTS, PFOA and PFOA in soils, indicated that soil organisms living within about 100 meters of these sites may be at risk. More information is however needed on the effects of PFCs on soil living organisms to make better predictions of effects. The high uncertainty in the soil PNEC-values for PFCs in general calls for more investigations on effects of these compounds in soil living organisms.

Mongstad
Soils at Mongstad oil refinery in the vicinity of the fire training site contain considerable amounts of PFCs after about 17 years of activity. Since large areas close to the platform consist of coarse textured materials (gravel, blasting rocks), leaching of PFCs to the sea may have occurred. It is therefore recommended to analyse sediments and Blue mussels (or other types of biota) from Mongstadvågen to investigate possible spreading of PFCs to the marine environment from the fire training activity at Mongstad.

Solberg Scandinavian AS
Analysis of stream water, sea snails at the seashore in Radsundet beneath Solberg Scandinavian AS, and sediments from Radsundet revealed that the industrial area is an active source to PFCs to the surrounding environment. It is recommended that actions be taken to reduce leaching of PFCs from Solberg Scandinavian AS.

Gardermoen airport

High concentrations of PFCs in the groundwater in the vicinity of the fire training platform 4 were observed at Gardermoen. This indicated that a substantial fraction of the AFFFs used at the fire training platforms has escaped the concrete cover and drainage systems during fire extinguishing training and has reached the groundwater. It is recommended to analyse more groundwater samples in order to get an overview of the distribution of PFCs in the groundwater at Gardermoen.

Rygge Air Station

The concentrations of PFCs found in dried out ditches close to the old fire training platform at Rygge were high. Since PFCs are very concentrated at these locations, it is recommended to remove sediments from the ditches.

11. Conclusions

The concentrations of PFCs found in the vicinity of the four fire training facilities in this project show that soils in these areas may be severely contaminated by PFCs coming from AFFFs. Concentrations in most soil samples taken within 200 meters of the training facilities exceed the proposed Norwegian guideline value for PFOS (100 ng/g). Based upon predictions of no effect concentrations (PNEC) for 6:2 FTS, PFOS and PFOA in soils, soil organisms living within about 100 meters from these four sites may be at risk. Since the PNEC-value for these three PFCs is based on testing of just one organism (earthworm), more information is needed on the effects of PFCs on soil living organisms in order to make better predictions of no effect concentrations and for assessing the environmental risks at fire training facilities in Norway.

Exposing earthworms to soils from the four fire training facilities in this project resulted in mean bioaccumulation factors (BAFs) for 6:2 FTS, PFOS and PFOA of 2.4 (0.76-6.7), 2.6 (0.49-6.4) and 5.9 (0.31-14.0), respectively. This is consistent with findings in a previous investigation performed by SFT and Bioforsk. 6:2 FTS which seems to replace PFOS-related compounds in e.g. AFFFs, therefore accumulates to the same extent as PFOS and PFOA. Bioaccumulation of PFDcS has a tendency of having a higher BAF than PFOS. For PFCAs, the bioaccumulation experiments showed that increasing length of the carbon chain increased BAF substantially. The experimental data for PFUnA, PFDoA and PFTeA (C_{11}-C_{14}) indicated that BAFs of 100-1000 can be predicted. The PFOS precursor N-Et-FOSA had BAFs for earthworms in the range 188-770. Also N-Me-FOSA and PFOSA had considerable higher BAFs than 6:2 FTS, PFOS and PFOA.

The results showed that increasing silt and clay content in soils reduces both bioaccumulation in earthworms and leaching in the soil profile. Leaching of PFCs in soils occurred at all the investigated sites. Increasing carbon-chain length of PFS and PFOA reduced leaching in most of the investigated soils. PFBS (C_5) which is a potential replacement for PFOS-related products therefore has a higher leaching potential compared to PFOS, but a lower bioaccumulation potential.

At Gardermoen high concentrations of PFCs have been found in the groundwater. The levels of PFOS and PFOA in the groundwater were far higher than for drinking water criteria from UK, US and Germany. Further measures should be taken to clarify the extent of PFC-pollution in the groundwater at Gardermoen. At present, however, the groundwater at Gardermoen is not used for human consumption.

Marine sediments and biota have been investigated at Radsundet outside Solberg Scandinavian AS. The high concentrations of PFOS and N-Et-FOSA recorded in sea snail at the seashore, downstream of the industrial area, are attributed to runoff from the industrial area. The level of PFOS in sea snail was higher than the PNEC for molluscs, indicating that the runoff from Solberg Scandinavian may pose a risk to seashore marine organisms.

The sediment quality in Radsundet, outside Solberg Scandinavian, is characterised as good according to guidelines for sediment quality. The concentrations of PFCs were, however, found to be up to ten times higher than the concentrations found in e.g. Oslofjorden. Runoff from Solberg Scandinavian AS to the sea, therefore, seemed to have influenced sediment quality in the fjord. Actions to reduce the future runoff from the industrial area to the sea are recommended to be taken.

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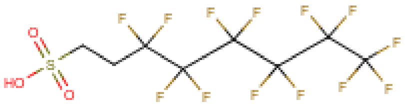
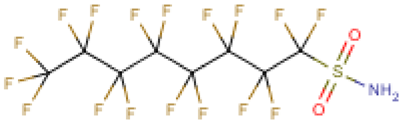
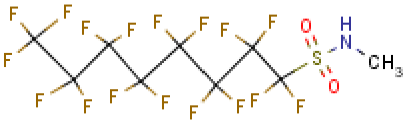
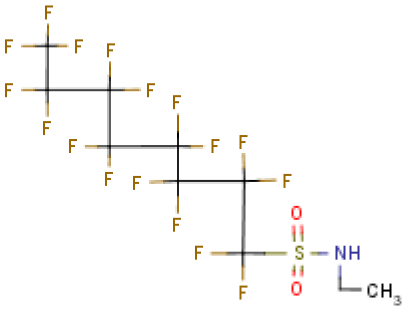
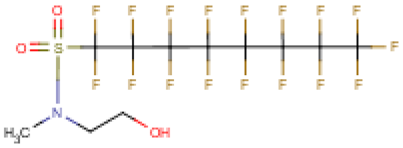
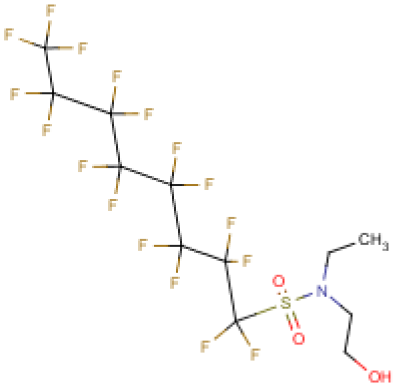
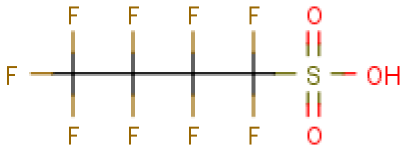
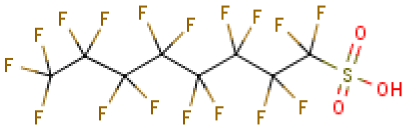
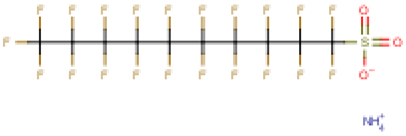
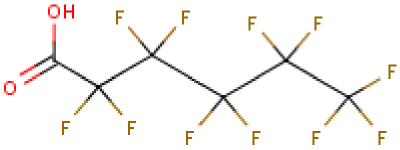
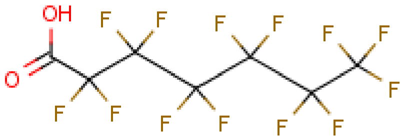
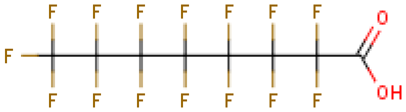
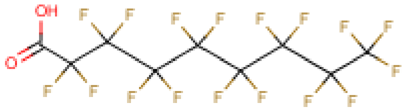
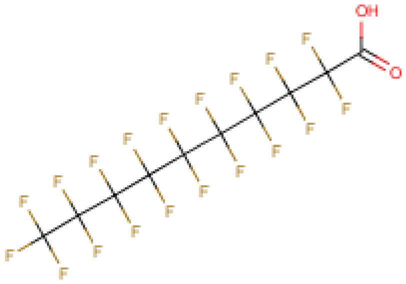
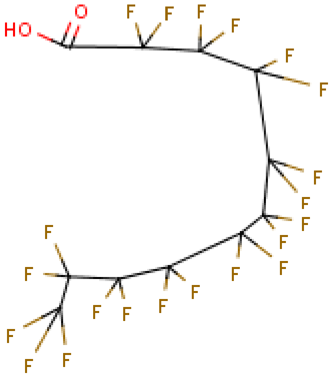
Appendix I

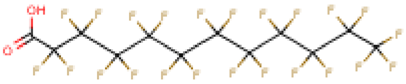
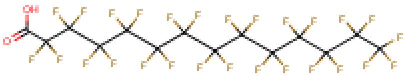
Overview of chemical structure for PFCs analysed in soil, sediment, water and biota in the screening project.

Compound	Short name	CAS-nr	Structure
6:2 Fluorotelomer sulphonate	6:2 FTS	27619-97-2	
Perfluorooctane sulphonamide	PFOSA	754-91-6	
N-Methyl-heptadecafluorooctane sulphonamide	N-Me-FOSA	31506-32-8	

N-Ethyl-heptadecafluorooctane sulphonamide	N-Et-FOSA	4151-50-2	
N-Methyl-heptadecafluorooctane sulphonamidoethanol	N-Me-FOSE	24448-09-7	
N-Ethyl-heptadecafluorooctane sulphonamidoethanol	N-Et-FOSE	1691-99-2	
Perfluorobutane sulphonate	PFBS	375-73-5	
Perfluorohexane sulphonate	PFHxS	Not found	

Perfluorooctane sulphonate	PFOS	1763-23-1	
Perfluorodecane sulphonate	PFDcS	67906-42-7	
Perfluorohexanoic acid	PFHxA	307-24-4	
Perfluoroheptanoic acid	PFHpA	375-85-9	

Perfluorooctanoic acid	PFOA	335-67-1	
Perfluorononanoic acid	PFNA	375-95-1	
Perfluorodecanoic acid	PFDcA	335-76-2	
Perfluoroundecanoic acid	PFUnA	2058-94-8	

Perfluorododecanoic acid	PFDoA	307-55-1	
Perfluorotridecanoic acid	PFTriA	Not found	
Perfluorotetradecanoic acid	PFTeA	376-06-7	

Appendix II

Overview of soil, sediment, groundwater, stream water and biota samples collected in the project.

Soil samples collected at Mongstad oil refinery 17.June 2008.

Sample no	Distance from platform (m)	Sample depth (cm)	Coordinates Grid 32 V Longitude	Latitude	Horizon*
1	26	0-5	0283567	6748243	Oa
2	26	5-10	0283567	6748243	A
3	26	10-30	0283567	6748243	A
4	26	30-50	0283567	6748243	A
5	26	50-60	0283567	6748243	A
6	30	0-5	0283566	6748249	Oa
7	40	0-5	0283564	6748222	Oa
8	52	0-5	0283552	6748122	Oa
9	91	0-5	0283553	6748176	Oa
10	200	0-5	0283550	6748071	Oa

*Oa-organic horizon, residues (plants and animals) highly decomposed
A-topmost mineral horizon, containing a strong admixture of humified organic matter, which tends to impart a darker color than that of the lower horizon.

Soil samples collected at Solberg Scandinavian 18.June 2008.

Sample no	Distance from platform (m)	Soil depth (cm)	Coordinates Grid 32 V Longitude	Latitude	Horizon*
1	16	5-10	0290076	6727570	Oa
2	16	20-30	0290076	6727570	AE
3	16	30-35	0290076	6727570	BC
4	25	5-15	0290070	6727575	Oa
5	25	15-20	0290070	6727575	E
6	38	5-10	0290058	6727572	AE
7	84	5-10	0290035	6727647	AE
8	155	5-10	0289991	6727681	Oa

*E-horizon of maximum eluviation of clay, iron, and aluminium oxides and a corresponding concentration of resistant minerals. It is generally lighter in colour than the A horizon.
AE-horizon: transition layer between A and E with properties more like those of A than of E.
B-horizon of maximum accumulation of materials such as iron and aluminium oxides and silicate clays.
BC-horizon: transition layer between B and C with properties more like those of B than those of C.

Positions for sediment sampling in Radsundet outside Solberg Scandinavian AS. It was not possible to collect samples from locations P3, P4, P6 and P7-positions not shown).

Pos	Latitude	Longitude	Depth	Distance from outlet	Texture
Stream outlet	60`37.775	5`09.764	0	0	
P1 (a,b)	60`37.802	5`09.892	64	127	Fine material
P3	60`37.780	5`09.778	12	15	Sand/gravel
P5	60`37.802	5`09.824	46	73	Fine material
P8	60`37.733	5`09.858	10	115	Sand/gravel
P9 (reference)	60`37.878	5`10.492	25	688	

Positions for sampling of Sea snails (Patellidae) in the tidal sone in Radsundet outside Solberg Scandinavian AS.

Sampling point	Latitude	Longitude	Distance from stream outlet (m)
1 (stream outlet)	60` 37.760	5`09.956	0
2	60` 37.774	5`09.742	15 north
3	60`37.776	5`09.723	30 north
4	60`37.796	5`09.705	60 north
5	60`37.760	5`09.770	15 south
6	60`37.743	5`09.794	40 south
7	60`37.722	5`09.836	115 south

Soil and sediment samples collected at Rygge old and new fire training facilities 12.June 2008.

Site	Samples no	Sample type	Distance from platform (m)	Depth (cm)	Coordinates Grid 32 V		Horizon*
					Longitude	Latitude	
Rygge old fire training facility	1	Soil	19	0-5	0601936	6582988	A
	2	Soil	26	0-5	0601914	6583016	A
	3	Soil	26	5-10	0601914	6583016	AE
	4	Soil	26	10-30	0601914	6583016	AE
	5	Soil	26	30-50	0601914	6583016	BC
	6	Soil	26	50-55	0601914	6583016	C
	7	Soil	31	0-5	0601886	6583018	A
	8	Soil	38	0-5	0601871	6583009	A
	9	Soil	54	0-5	0601890	6583037	A
	10	Soil	174	0-5	0601833	6583143	A
	11	Sediment	18	0-5	0601890	6583006	
	12	Sediment	18	0-5	0601890	6583006	
	14	Sediment	39	0-4	0601901	6583028	
Rygge new training facility	15	Soil	27	0-5	0602529	6583256	A
	16	Soil	50	0-5			A

*See above for explanation

Soil samples collected at fire training facility (platform 4) at Gardermoen airport 11.June 2008.

Sample no	Distance from Platform (m)	Soil depth (cm)	Coordinates Longitude	Grid 32 V Latitude	Horizon*
1	1	0-5	0615376	6676827	Sandy material¤
2	1	5-10	0615376	6676827	Sandy material
3	1	10-30	0615376	6676827	Sandy material
4	1	30-50	0615376	6676827	Sandy material
5	1	65-80	0615376	6676827	Sandy material
6	7.5	0-5	0615350	6676827	A
7	7.5	10-12	0615350	6676827	AE
8	31	0-5	0615377	6676853	Oa
9	70	0-5	0615387	6676894	Oa
10	200	0-5	0615432	6677026	Oa

*See above for explanation; ¤sandy embankment, not natural soil

Appendix III

Soil concentrations (ng/g dw) of PFCs in samples from Mongstad, Solberg Scandinavian, Gardermoen and Rygge.

*Concentrations of PFCs in soil samples in the vicinity of fire training site at **Mongstad oil refinery**. Unit: ng/g dm.*

Dist. from platform (m)	25	25	25	25	25	30	40	52	91	200
Compound / Soil depth (cm)	0-5	5-10	10-30	30-50	50-60	0-5	0-5	0-5	0-5	0-5
6:2 FTS	76	93	<51.6	<49.5	<43.6	128	42	2365	125	<13.8
PFOSA	<21.9	<26.5	<31.3	<34.4	<34.5	<27.0	<21.4	<22.6	<22.9	<24
N-Me-FOSA	<0.9	<1.1	<1.3	<1.4	<1.4	<1.1	<0.9	<0.9	<0.9	<1.0
N-Et-FOSA	<1.5	<1.8	<2.1	<2.3	<2.3	<1.8	<1.4	<1.5	<1.5	<1.6
N-Me-FOSE	<2.7	<1.3	<3.9	<4.3	<4.3	<3.3	<2.6	<2.8	<2.8	<3.0
N-Et-FOSE	<1.4	<1.6	<1.9	<2.1	<2.1	<1.7	<1.3	<1.4	<1.4	<1.5
PFBS	5.5	9.3	15.0	20.6	9.43	39.6	45.4	35.2	23.4	<1.0
PFHxS	48.4	115	247	324	135	492	693	697	237	<1.5
PFOS	680	1547	4278	3883	1439	5390	8924	8000	4756	28.6
PFDcS	4.6	9.7	5.6	<1.6	<1.6	57.4	54.2	27.6	45.7	<1.1
PFHxA	11.6	18.6	18.1	30.0	16.2	17.7	31.4	133.4	14.8	<3.2
PFHpA	5.8	8.2	11.8	18.3	8.2	10.0	13.7	65.0	4.6	<1.2
PFOA	7.1	13.4	29.0	60.5	33.8	26.7	42.5	141.5	20.1	<1.6
PFNA	5.1	8.2	9.2	12.2	9.3	4.6	4.2	16.7	4.7	<1.1
PFDcA	10.5	28.6	32.4	24.5	5.7	16.6	10.1	43.8	3.3	<0.7
PFUnA	12.9	28.6	31.9	44.5	8.9	20.8	14.1	16.6	<1.3	<0.7
PFDoA	17.3	27.3	10.3	4.1	<1.1	17.7	7.5	<0.7	2.6	<0.7
PFTriA	3.3	7.1	6.5	9.2	<1.1	10.3	10.2	<0.7	<0.7	<0.7
PFTeA	<2.5	<2.6	<1.3	<1.4	<1.4	<1.1	<0.9	<0.9	<0.9	<1.0
SumPFC	**889**	**1913**	**4695**	**4431**	**1665**	**6231**	**9891**	**11541**	**5236**	**29**
Dry matter	88.6	73.3	62	56.4	56.2	71.8	90.8	86	84.7	80.7
TOC	31.3	40.2	39.8	44.3	49.5	41.2	37.6	37.1	28.8	42.9
pH	5.6	5.5	5.1	5.4	5.1	5.6	5.1	5.4	4.3	5.2
<63um	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
% 6:2FTS	8.6	4.9	0.0	0.0	0.0	2.0	0.4	20.5	2.4	0.0
% PFOSA, FOSA, FOSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% PFS	83.1	87.8	96.8	95.4	95.1	96.0	98.2	75.9	96.7	100.0
% PFCA	8.3	7.3	3.2	4.6	4.9	2.0	1.4	3.6	1.0	0.0

Concentrations of PFCs in soil samples in the vicinity of tesing site for AFFF at ***Solberg Scandinavian AS****. Unit: ng/g dm.*

Distance from platform (m)	16	16	16	25	25	38	84	155	Sed stream
Compound Soil depth (cm)	5-10	20-30	30	5-15	15-20	0-5	0-5	0-5	0
6:2 FTS	<15.7	41.7	<17.7	53.0	<27.4	<13.6	<12.6	<25.0	1090
PFOSA	<27.4	94.4	283	114	143.6	<23.8	<31.7	<43.7	226
N-Me-FOSA	<1.1	<0.8	<0.8	<0.9	<0.8	1.0	<0.9	<1.8	<1.0
N-Et-FOSA	<1.8	<1.4	<1.3	<1.4	<1.3	<1.6	<1.5	<2.9	7.0
N-Me-FOSE	<3.4	<2.5	<2.5	<2.6	<2.5	<2.9	<4.9	23.2	<3.0
N-Et-FOSE	<1.7	<1.3	<1.2	<1.3	<1.2	<1.5	<1.4	<2.7	<1.5
PFBS	<1.1	<2.2	2.6	11.1	16.9	<1.0	<0.9	<1.8	118
PFHxS	<1.3	32.9	45.4	131	150	6.1	4.9	2.0	465
PFOS	671	220	1439	502	761	92.4	24.5	116	1340
PFDcS	<1.3	4.4	<0.9	22.3	16.9	<1.1	<1.0	<2.0	23.5
PFHxA	<3.7	<2.7	<5.0	14.0	12.7	<3.2	<2.9	<5.9	113
PFHpA	<1.4	<2.2	<2.6	11.1	25.4	<1.2	<2.8	<2.3	39.9
PFOA	<1.3	8.8	7.6	11.1	8.5	<3.1	4.9	<2.0	101
PFNA	<1.3	28.5	12.7	<2.8	<2.1	<1.1	4.9	<2.0	39.9
PFDcA	<0.8	2.2	7.6	2.8	2.1	<0.7	<0.7	<1.4	25.8
PFUnA	<0.8	158.0	181.8	8.3	8.5	12.4	<0.7	<1.4	327
PFDoA	<0.8	17.5	2.6	5.6	2.1	<0.7	<0.7	<1.4	49.3
PFTriA	<0.8	140.5	27.8	14.0	2.1	3.1	<0.7	<1.4	369
PFTeA	<1.1	4.4	<0.8	<0.9	<0.8	<1.0	<0.9	<1.8	23.5
SumPFC	671	753	2010	901	1149	115	39.1	141	4357
Dry matter	70.7	95.3	97.1	92.4	97.0	81.6	88.3	44.4	80.9
TOC	28.1	14.7	7.3	24.8	7.7	4.0	6.3	46.2	10.8
pH	5.0	n.a.	4.9	4.3	4.9	n.a.	4.4	5.3	n.a.
<63um	n.a.	n.a.	16.2	n.a.	11.6	13.6	14.1	n.a.	n.a.
% 6:2FTS	0.0	5.5	0.0	5.9	0.0	0.0	0.0	0.0	25.0
% PFOSA, FOSA, FOSE	0.0	12.5	14.1	12.7	12.5	0.9	0.0	16.4	5.3
% PFS	100.0	34.1	74.0	74.0	82.2	85.7	75.1	83.6	44.7
% PFCA	0.0	47.8	11.9	7.4	5.3	13.4	24.9	0.0	25.0

Concentrations of PFCs in soil samples in the vicinity of fire training facilities at ***Gardermoen airport****. Unit: ng/g dm*

Distance from platform (m)	1	1	1	1	1	7.5	7.5	31	70	200
Compound Soil depth (cm)	0-5	5-10	10-30	30-50	65-80	0-5	10-12	0-5	0-5	0-5
6:2 FTS	885	1034	667	1241	191	2155	971	131	122	<21.9
PFOSA	79	93.0	158	268	84	542	966	<21.2	<36.3	<38.3
N-Me-FOSA	<0.8	<0.8	<0.8	<0.8	<0.9	<0.9	<0.9	<0.9	1.5	1.6
N-Et-FOSA	<1.3	<1.3	<1.3	<1.3	<1.4	<1.5	<1.4	<1.4	<2.4	<2.6
N-Me-FOSE	<2.4	<2.5	<2.5	<2.5	<2.6	<2.8	<2.6	<2.6	<4.5	<4.7
N-Et-FOSE	<1.2	<1.2	<1.2	<1.2	<1.3	<1.4	<1.3	<1.3	<2.2	<2.4
PFBS	2.7	2.8	<1.8	8.3	<1.7	8.7	8.3	<2.1	<1.5	<1.6
PFHxS	31.7	38.1	46.6	135	63.8	122	201	12.7	26.2	<1.8
PFOS	1162	1451	2085	3429	1051	3013	11923	360	611	110
PFDcS	6.6	9.8	<0.9	<0.9	<1.0	<1.0	<1.0	<1.0	<1.7	<1.8
PFHxA	<4.0	<4.2	<3.7	11.1	<3.4	14.5	<5.6	<2.8	<4.9	<5.1
PFHpA	5.3	4.2	5.5	13.9	6.9	23.2	13.8	4.3	8.8	<2.0
PFOA	5.3	4.2	3.7	11.1	12.1	43.5	46.9	<2.1	17.4	<1.8
PFNA	<0.9	<0.9	<0.9	2.8	12.1	37.7	11.0	4.3	8.8	<1.8
PFDcA	<1.3	<1.4	<1.8	5.5	6.9	5.8	2.7	2.1	<1.1	<1.2
PFUnA	52.8	66.3	121	232	190	40.6	82.8	6.3	8.8	<1.2
PFDoA	<1.3	<1.4	<1.8	2.8	3.4	5.8	2.7	2.1	<1.1	<1.2
PFTriA	<1.3	<1.4	<0.6	<0.6	<0.6	<0.7	<0.7	<0.7	<1.1	<1.2
PFTeA	<0.8	<0.8	<0.8	<0.8	<0.9	<0.9	<0.9	<0.9	<1.5	<1.6
SumPFC	2230	2703	3087	5361	1622	6011	14230	523	805	111
Dry matter	98.1	97.5	97.3	96.7	93.6	86.3	91.5	91.6	53.5	50.6
TOC	0.8	0.9	0.7	0.8	0.8	9.3	2.6	8.3	41.2	37.4
pH	6.7	7.0	6.4	6.7	6.9	6.3	6.5	6.3	4	3.6
<63um	8.8	10.5	9.9	10.6	11.3	5.9	23.5	18.2	5.5	5
% 6:2FTS,	39.7	38.2	21.6	23.2	11.8	35.9	6.8	25.1	15.2	0.0
% PFOSA FOSA, FOSE	3.6	3.4	5.1	5.0	5.2	9.0	6.8	0.0	0.2	1.4
% PFS	53.9	55.5	69.1	66.6	68.8	52.3	85.3	71.3	79.2	98.6
% PFCA	2.8	2.8	4.2	5.2	14.2	2.8	1.1	3.6	5.4	0.0

Concentrations of PFCs in soil samples in the vicinity of old and new fire training site at ***Rygge Air Station****. Unit: ng/g dw.*

	Rygge old									Rygge new	
Dist. from platform (m)	26	26	26	26	26	31	38	54	174	27	56
Compound Soil depth (cm)	0-3	5-10	10-30	30-50	50-55	0-5	0-5	0-5	0-5	0-5	0-5
6:2 FTS	<14.5	<12.0	<12.0	<12.2	<12.4	<13.0	<12.0	<12.6	<11.8	<21.5	<16.5
PFOSA	<25.3	<20.9	<20.9	<21.3	<21.7	<22.7	<20.9	<22.0	<20.6	<20.8	<28.9
N-Me-FOSA	<1.0	<0.9	<0.9	<0.9	<0.9	<0.9	<0.9	<0.9	<0.8	<0.9	<1.2
N-Et-FOSA	<1.7	<1.4	<1.4	<1.4	<1.5	<1.5	<1.4	<1.5	<1.4	<1.4	<1.9
N-Me-FOSE	<3.1	<2.6	<2.6	<2.6	<2.7	<2.8	<2.6	<2.7	<2.5	7.8	<3.6
N-Et-FOSE	<1.6	<1.3	<1.3	<1.3	<1.3	<1.4	<1.3	<1.4	<1.3	<1.2	<1.8
PFBS	3.4	<0.9	<0.9	<0.9	<1.0	<1.8	<0.9	<0.9	<0.8	<1.9	<1.2
PFHxS	38.3	<1.9	<1.4	3.7	4.5	20.2	3.9	4.8	<1.0	13.6	<1.3
PFOS	413	48.3	66.3	47.4	66.0	247	187	180	40.2	195	30.1
PFDcS	<1.2	<1.0	<1.0	<1.0	<1.0	<1.1	<1.0	<1.0	<1.0	<1.9	<1.3
PFHxA	<3.4	<2.8	<2.8	<2.9	<2.9	<3.0	<2.8	<3.0	<2.8	<2.8	<3.9
PFHpA	<1.3	<1.1	<1.1	<1.1	<1.1	<1.2	<1.1	<1.1	<1.1	<1.9	<1.5
PFOA	3.8	<1.0	<1.0	<1.0	<1.0	<2.2	<1.0	<1.0	<1.0	<1.9	<1.3
PFNA	<1.2	<1.0	<1.0	<1.0	<1.0	<1.1	<1.0	<1.0	<1.0	<1.9	<1.3
PFDcA	<0.8	<0.6	<0.6	<0.7	<0.7	<0.7	<0.6	<0.7	<0.6	<0.6	<0.9
PFUnA	<0.8	<0.6	<0.6	<0.7	<0.7	<0.7	<1.0	<1.0	<0.6	<1.9	<0.9
PFDoA	<0.8	<0.6	<0.6	<0.7	<0.7	<0.7	<0.6	<0.7	<0.6	<0.6	<0.9
PFTriA	<0.8	<0.6	<0.6	<0.7	<0.7	<0.7	<0.6	<0.7	<0.6	<0.6	<0.9
PFTeA	<1.0	<0.9	<0.9	<0.9	<0.9	<0.9	<0.9	<0.8	<0.8	<0.9	<1.2
SumPFC	459	48	66	51	70	268	191	185	40.2	217	30.1
Dry matter	76.7	92.8	92.7	90.9	89.6	85.5	92.7	88	94.3	93.2	67.2
TOC	12.3	0.5	0.2	0.1	0.2	4.8	3	3.7	2.6	2.1	5.1
pH	6.3	n.a.	n.a.	n.a.	n.a.	6	6.7	5	5.4	n.a.	n.a.
<63um	n.a.	46.3	n.a.	n.a.	n.a.	32.8	18.2	9.7	9.3	n.a.	n.a.
% 6:2FTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% PFOSA, FOSA, FOSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	0.0
% PFS	99.2	100	100	100	100	100	100	100	100	96.4	100
% PFCA	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Concentrations of PFCs in sediment samples (dried out ditch) in the vicinity of old fire training site at Rygge Air Station. Unit: ng/g dw.

	Rygge old			
Distance from platform (m)	18	18	19	39
Compound Depth (cm)	0-5	20-22	0-4	0-4
6:2 FTS	252	43.8	61.2	81.1
PFOSA	<27.0	<21.2	<25.0	<26.5
N-Me-FOSA	<1.1	<0.9	<1.0	<1.1
N-Et-FOSA	<1.8	<1.4	<1.7	<1.8
N-Me-FOSE	<3.3	<2.6	<3.1	<3.3
N-Et-FOSE	<1.7	<1.3	<1.5	<1.6
PFBS	688	98.1	190	422
PFHxS	2849	702	1663	2111
PFOS	47743	7375	17734	25035
PFDcS	120	18.8	135	105
PFHxA	289	50.2	67.2	111
PFHpA	40.1	6.2	101	16.3
PFOA	309	31.3	97.8	157
PFNA	14.3	<2.1	<3.1	10.8
PFDcA	8.6	<0.7	3.1	2.7
PFUnA	2.9	<0.7	3.1	2.7
PFDoA	8.6	<0.7	3.10	<0.8
PFTriA	<0.8	<0.7	<0.8	<0.8
PFTeA	<1.1	<0.9	<1.0	<1.1
SumPFC	52326	8325	20058	28055
Dry matter	71.8	91.7	77.5	73.1
TOC	10	0.4	13.7	5.9
pH	4.9	6	5.6	4.8
<63um	n.a.	44.6	n.a.	90.8
% 6:2FTS	0.5	0.5	0.3	0.3
% PFOSA FOSA, FOSE	0.0	0.0	0.0	0.0
% PFS	98.2	98.4	98.3	98.6
% PFCA	1.3	1.1	1.4	1.1

Appendix IV

Concentrations of PFCs in marine sediments and biota (Sea snails) from Radsundet at Solberg Scandinavian.

Concentrations of PFCs in sediments from Radsundet outside Solberg Scandinavian AS. Unit: ng/g dw. The sediment numbers refer to Appendix II and Figure 6

Distance from stream outlet (m)	34	73	115	127	127	688
Water depth (m)	30	46	10	64	64	25
	Sediment P3	**Sediment P5**	**Sediment P8**	**Sediment P1a**	**Sediment P1b**	**Sediment P9**
6:2 FTS	<6.6	<6.9	<5.7	<6.6	<6.4	<5.7
PFOSA	<0.2	<0.2	<0.1	<0.2	<0.2	<0.1
N-Me-FOSA	<0.2	<0.2	<0.1	<0.2	<0.2	<0.1
N-Et-FOSA	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
N-Me-FOSE	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
N-Et-FOSE	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
PFBS	<0.5	<0.5	<0.4	<0.5	<0.5	<0.4
PFHxS	<0.2	<0.2	<0.1	<0.2	<0.2	<0.1
PFOS	<0.3	58.3	<0.3	54.6	64.1	<0.3
PFDcS	<2.1	<2.2	<1.8	<2.1	<2.0	<1.8
PFHxA	<0.05	<0.05	<0.04	<0.05	<0.05	<0.04
PFHpA	<0.05	<0.05	<0.04	<0.05	<0.05	<0.04
PFOA	<0.06	<0.07	<0.06	<0.06	<0.06	<0.06
PFNA	<0.16	<0.17	<0.14	<0.16	<0.16	<0.14
PFDcA	<0.06	<0.07	<0.06	<0.06	<0.06	<0.06
PFUnA	<0.02	<0.02	<0.01	<0.02	<0.02	<0.01
PFDoA	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
PFTriA	<0.16	<0.17	<0.14	<0.16	<0.16	<0.14
PFTeA	<0.05	<0.05	<0.04	<0.05	<0.05	<0.04
SumPFS	0	58	0	55	64	0

Concentrations (ng/g ww) av PFCs in Sea snail (Patellidae) from seven locations outside Solberg Scandinavian AS.

Distance from stream outlet (m)	0 Sea snail 1	15 Sea snail 2	30 Sea snail 3	60 Sea snail 4	15 Sea snail 5	40 Sea snail 6	115 Sea snail 7
6:2 FTS	12.9	8.7	5.2	2.4	6.0	6.0	129
PFOSA	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3
N-Me-FOSA	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2
N-Et-FOSA	52.9	63.8	53.2	46.4	50.2	55.3	182
N-Me-FOSE	<11.2	<11.2	<11.2	<11.2	<11.2	<11.2	<11.2
N-Et-FOSE	<4.6	<4.6	<4.6	<4.6	<4.6	<4.6	<4.6
PFBS	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
PFHxS	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	4.2
PFOS	23.9	24.1	21.7	11.8	26.5	24.7	206
PFDcS	< 0.9	< 0.9	< 0.9	< 0.9	< 0.9	< 0.9	1.5
PFHxA	< 2.6	< 2.6	< 2.6	< 2.6	< 2.6	< 2.6	< 2.6
PFHpA	<3.3	<3.3	<3.3	<3.3	<3.3	<3.3	<3.3
PFOA	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	16.4
PFNA	<4.3	<4.3	<4.3	<4.3	<4.3	<4.3	<4.3
PFDcA	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6
PFUnA	<4.2	<4.2	<4.2	<4.2	<4.2	16.7	9.4
PFDoA	<2.8	<2.8	<2.8	<2.8	<2.8	<2.8	49.1
PFTriA	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4
PFTeA	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
SumPFC	**90**	**97**	**80**	**61**	**83**	**103**	**598**

Appendix V

Concentrations of PFCs in groundwater from three wells in the vicinity of fire traning platform 4 at Gardermoen airport.

Compound	**Well BV-1**	**Well BV-2**	**Well BV-3**
6:2 FTS	1857	611	7194
PFOSA	< 70.5	< 70.5	< 70.5
N-Me-FOSA	< 70.5	< 70.5	< 70.5
N-Et-FOSA	< 6	< 6	< 6
N-Me-FOSE	< 2.7	< 2.7	< 2.7
N-Et-FOSE	< 2.7	< 2.7	< 2.7
PFBS	758	94	1743
PFHxS	2904	705	5952
PFOS	6762	2394	40116
PFDcS	< 7.4	< 7.4	< 7.4
PFHxA	532	169	1585
PFHpA	<114	<39.7	291
PFOA	241	<97.6	1457
PFNA	<12.4	51.7	219
PFDcA	< 13.9	< 13.9	< 13.9
PFUnA	< 18.7	< 18.7	< 18.7
PFDoA	< 16.2	< 16.2	< 16.2
PFTriA	< 10	< 10	< 10
PFTeA	< 14.8	< 14.8	< 14.8
SumPFS	**13054**	**4024**	**58557**

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Tittel - norsk og engelsk
Norway
Screening of polyfluorinated organic compounds at four fire training facilities in Norway
Screening av polyfluorerte organiske forbindelser ved fire brannøvingsfelter i Norge

Sammendrag – summary

This report summarises the results from analysis of environmental samples collected at four fire training facilities in Norway: Mongstad oil refinery, Solberg Scandinavian, Gardermoen airport and Rygge Air Station. 40 soil samples including surface and subsoils, 14 samples of earthworm, 3 groundwater samples, 1 stream sample, 4 freshwater sediment samples (dried out ditches), 6 marine sediment samples and 7 samples of Sea snails (*Patellidae*) were collected. Concentrations of 19 polyfluorinated organic compounds including 6:2 fluorotelomer sulphonate, 4 perfluorsulphonates (C_4-C_{10}, including PFOS) and 9 perfluorcarboxylic acids (C_6-C_{14}, including PFOA) were determined in the samples.

4 emneord	4 subject words
Nasjonal screeningsundersøkelse	National screening
Brannøvingsfelter	Fire training sites
AFFF	AFFF
Polyfluorerte organiske forbindelser	Polyfluorinated organic compounds

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