REPORT

Results from the Swedish National Screening Programme 2005

Subreport 3: Perfluorinated Alkylated Substances (PFAS)

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B1698
November 2006

Rapporten godkänd
2006-11-20

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Report Summary

Project title

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Title and subtitle of the report

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Summary

IVL Swedish Environmental Research Institute has, in co-operation with NILU (Norwegian Institute for Air Research), on behalf of the Swedish EPA conducted a screening study on perfluorinated substances (PFAS).

Keyword

Screening, PFAS, perfluorinated substances, PFBS, PFHxS, PFOS, PFDS, PFBA, PFHxA, PFHpA, PFOA, PFNA, PFDcA, PFUnA, 6:2 FTS, PFOSA

Bibliographic data

IVL Report B1698

The report can be ordered via

Homepage: www.ivl.se, e-mail: publicationservice@ivl.se, fax+46 (0)8-598 563 90, or via IVL, P.O. Box 21060, SE-100 31 Stockholm Sweden

Sammanfattning

IVL Svenska Miljöinstitutet har, tillsammans med NILU (Norsk institutt for luftforskning), på uppdrag av Naturvårdsverket genomfört en screening av perfluorinerade ämnen (PFAS). Huvudsyftet med studien var att bestämma koncentrationer i olika matriser i miljön, att belysa viktiga transportvägar samt att bedöma sannolikheten för pågående emissioner i Sverige. Studiens resultat skall kunna bidra med underlag för beslut om vidare miljöövervakning av dessa ämnen. I den ursprungliga beställningen ifrån Naturvårdsverket var perfluorobutansulfonat (PFBS) det ämne som skulle undersökas men ytterligare 12 PFAS har inkluderats i studien.

PFAS har en omfattande användning. Under det senaste decenniet har PFAS blivit uppmärksammade som problematiska föroreningar i miljön. PFAS är som ämnesgrupp mycket toxisk och persistent.

En provtagningsstrategi utarbetades utifrån ämnenas möjliga källor. Potentiella punktkällor, diffusa källor (reningsverk) samt bakgrundsstationer valdes ut och provtagning utfördes i luft, nederbörd, vatten, slam, sediment och fisk. Tre länsstyrelser bidrog med ytterligare nio prover fördelat på ett sedimentprov, fyra slamprover samt fyra vattenprover.

Program	**Luft**	**Nederbörd**	**Slam**	**Vatten**	**Sediment**	**Biota (fisk)**	**Totalt**
Nationellt	11	9	11	17	8	4	**60**
Regionalt	-	-	4	4	1	**-**	**9**
Totalt	***11***	***9***	***15***	***21***	***9***	***4***	***69***

Variationen mellan koncentrationer av PFAS var stor både mellan olika substanser och mellan olika provtagningsplatser. Den mest frekvent detekterade PFAS var PFOS.

De olika ämnena inom PFAS-gruppen förekom frekvent i proverna från de olika reningsverken vilket indikerar betydelsen av dessa som källa till spridning i miljön. Skillnaderna i halter mellan de olika reningsverken var dock stor, både för utgående vatten och för slam. Förhöjda halter av PFAS detekterades även i lakvatten ifrån deponier varför även dessa typer av anläggningar bör betraktas som källor till spridning i miljön.

I de luftprover som analyserats var PFOS, PFOA och PFOSA de vanligast förekommande av de i studien ingående PFAS. För PFOS och PFOSA var halterna i prover ifrån urban miljö förhöjda jämfört med bakgrundsproverna medan luftprover insamlade i anslutning till utvald punktkälla ej var högre än de uppmätta bakgrundshalterna. Långväga transport föreslås som en viktig spridningsväg för PFAS. Även i nederbördsprover var PFOS och PFOA vanligt förekommande dock ej PFOSA .

Ett mönster som kunde skönjas var att sulfonamiden PFOSA företrädelsevis detekterades i luft samt fasta matriser (sediment, slam) emedan den telomera föreningen 1,1,2,2-tetrahydro-perfluorooktansulfonat detekterades vanligen i vattenprover (nederbörd, ytvatten).

Summary

IVL Swedish Environmental Research Institute has, in co-operation with NILU (Norwegian Institute for Air Research), on behalf of the Swedish EPA conducted a screening study on perfluorinated substances (PFAS). The main purposes of this study have been to determine the con9centrations of PFAS in different environmental matrices, investigate important transport pathways and assess the possibility of current emissions of PFAS in Sweden. The results of the study can be used as data for decision-making on further environmental surveillance on these substances. In the original tender by the Swedish EPA, perfluorobutane sulfonate (PFBS) was selected as the main substance to be screened, however another 12 PFAS have been included in the investigation.

The use of PFAS is extensive and diverse. During the last decade PFAS have been recognised as environmentally controversial since this group of compounds are both toxic and persistent.

Depending on possible PFAS sources, a sampling strategy was developed. Potential point sources, diffusive sources (STPs) as well as background locations were identified and air, precipitation, surface water, sludge, sediment and fish were sampled. Three county administrative boards contributed nine additional samples; one sediment sample, four sludge samples and four water samples.

Program	**Air**	**Precip.**	**Sludge**	**Water**	**Sediment**	**Biota (fish)**	**Total**
National	11	9	11	17	8	4	**60**
Regional	-	-	4	4	1	**-**	**9**
Total	***11***	***9***	***15***	***21***	***9***	***4***	***69***

The variation in PFAS-concentration between different compounds as well as between different sampling locations was large. The most frequently detected PFAS was PFOS.

The different PFAS were frequently detected in the STP-originating samples, indicating the importance of the STPs as a source for PFAS into the environment. However there were great differences in PFAS-concentration between different STPs both in effluent water and in sludge. Increased concentrations of PFAS were also encountered in leachate water from landfills and these types of facilities should be considered as sources for PFAS-emission to the environment.

In the air samples PFOS, PFOA and PFOSA were the most frequently detected of the PFAS. The concentration of PFOS and PFOSA were increased in the urban air samples compared to the samples from the background stations whereas concentrations in the air samples from the point sources were in the same level as the background air samples. Atmospheric long-range transport seemed to be an important pathway for PFAS. Also in precipitation samples PFOS and PFOA were the most frequently detected PFAS while PFOSA was seldom detected. PFOSA often occurred in air samples and solid matrices (sludge, sediment) while the telomeric 1,1,2,2-Tetrahydroperfluorooctane sulfonate was often detected in water samples (precipitation, surface water).

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1 Introduction

As an assignment from the Swedish Environmental Protection Agency, IVL has during 2005/2006 performed a "Screening Study" of selected chemicals within the groups of pharmaceuticals, biocides and perfluorinated alkylated substances (PFAS). The selected chemicals (Table 1) are emitted and distributed in the environment via a variety of sources, e.g. point sources and use in consumer products.

The overall objectives of the screening were to determine the concentrations of the selected substances in a variety of media in the Swedish environment, to highlight important transport pathways, and to assess the possibility of current emissions in Sweden. A further aim was to investigate the likelihood of atmospheric transport and uptake in biota.

This sub-report considers the screening of the selected perfluorinated alkylated substances (PFAS). Results for the other chemical groups included in the screening are given in sub-report 1 and 2.

Table 1. Chemicals selected for screening 2005

	Included substances	**Report nr.**
Pharmaceuticals	**Antibiotics:** Doxycycline, Lymecycline, Oxitetracycline, Tetracycline **Antiinflammatory substances;** Ibuprofen, Ketoprofen, Naproxen, Diclofenac **Hormones:** Ethinyl estradiol, Norethindrone, Estradiol, Estriol, Progesterone	1
Biocides	Bronopol,4-Chloro-3-cresol, Mercaptobenzothiazole, N-didecyl-dimethylammoniumchloride, Propiconazole, Resorcinol, 2-(Tiocyanomethylthio)benzothiazole, Methylparabene, Ethylparabene, Propylparabene, Butylparabene, Benzylparabene	2
PFAS	Perfluorobutane sulfonate (**PFBS**), Perfluorohexane sulfonate (**PFHxS**), Perfluorooctane sulfonate (**PFOS**), Perfluorodecane sulfonate (**PFDS**), Perfluorobutanoic acid (**PFBA**), Perfluorohexanoic acid (**PFHxA**), Perfluoroheptanoic acid (**PFHpA**), Perfluorooctanoic acid (**PFOA**), Perfluorononanoic acid (**PFNA**), Perfluorodecanoic acid (**PFDcA**), Perfluoroundecanoic acid (**PFUnA**), 1,1,2,2-Tetrahydroper-fluorooctane sulfonate (**6:2 FTS**), Perfluorooctane sulfonamide (**PFOSA**)	3

The industrial application and consumer use of PFAS has increased ever since the 1950s. Recently, concern about the environmental effects of these chemicals has arisen since they have been detected globally in different environmental matrices (KEMI, 2004). PFAS are considered highly toxic, extraordinarily persistent and concerns are especially focused on the most pervasive and toxic residues within the group that is considered to never degrade in the environment (Kallenborn et al., 2004).

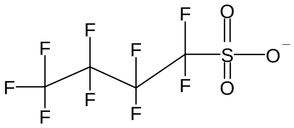
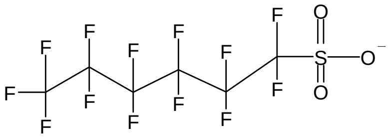
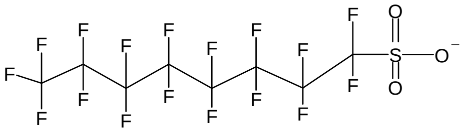
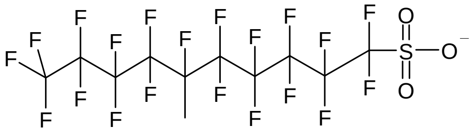
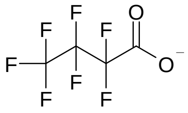
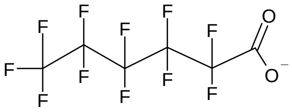
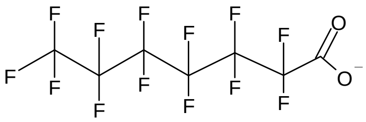
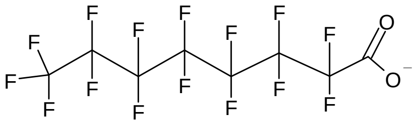
This screening includes a number of PFAS: perfluorinated sulfonates (C_4-C_{10}) as well as perfluorinated carboxylic acids (C_4-C_{11}). In addition, PFOSA (a perfluorinated C_8-sulfonamide) and 6:2 FTS (a fluorinated telomeric C_8-sulfonate) were included.

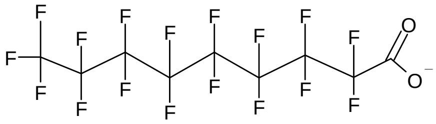
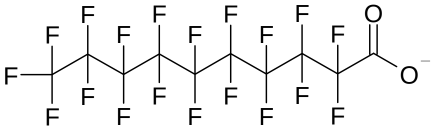
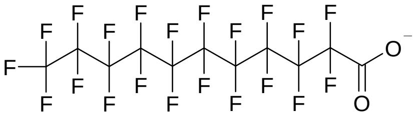
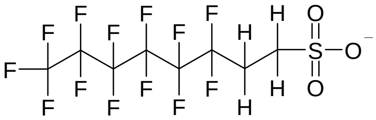
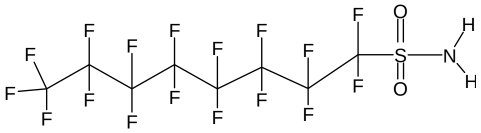
Originally, only perfluorobutane sulfonate (PFBS) was selected for this screening. However, the analytical method used allows for additional PFAS to be included. Thus, based on knowledge of use and environmental occurrence, 12 other substances belonging to this group were included (see Table 2).

2 Chemical properties, fate and toxicity

The abbreviations, full chemical names, CAS no and structures of the substances included in the screening are given in Table 2.

Table 2. CAS no and chemical structure of selected PFAS substances

Abbreviation	Chemical name	CAS-no	Structure
PFBS	Perfluorobutane sulfonate	29420-49-3	
PFHxS	Perfluorohexane sulfonate	432-50-7	
PFOS	Perfluorooctane sulfonate	2795-39-3	
PFDS	Perfluorodecane sulfonate	67906-42-7	
PFBA	Perfluorobutanoic acid	375-22-4	
PFHxA	Perfluorohexanoic acid	307-24-4	
PFHpA	Perfluoroheptanoic acid	375-85-9	
PFOA	Perfluorooctanoic acid	335-67-1	

Abbreviation	Chemical name	CAS-no	Structure
PFNA	Perfluorononanoic acid	375-95-1	
PFDcA	Perfluorodecanoic acid	335-76-2	
PFUnA	Perfluoroundecanoic acid	2058-94-8	
6:2 FTS	1,1,2,2-Tetrahydroperfluorooctane sulfonate	arbitrary	
PFOSA	Perfluorooctane sulfonamide	4151-50-2	

As the group PFAS contain a large number of compounds, with similar names and abbreviations, Figure 1 shows a scheme showing the terminology of the compounds included in this study.

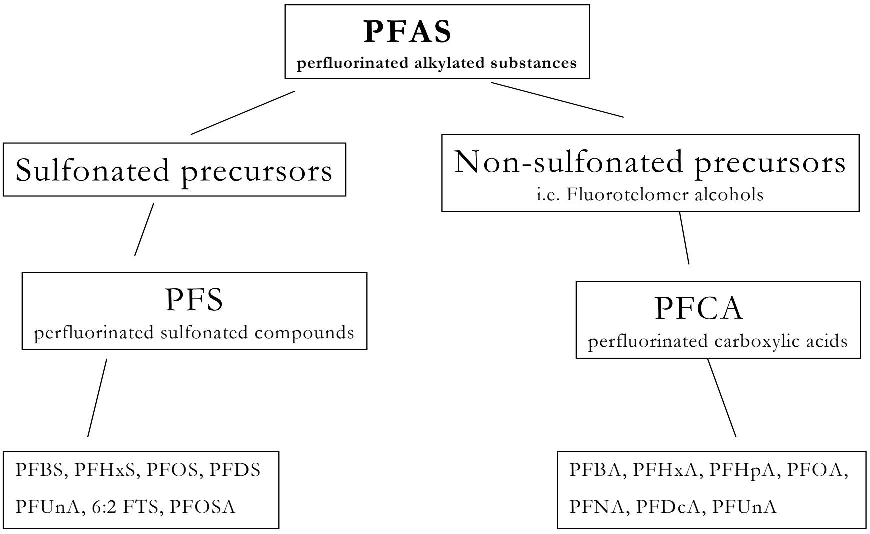


Figure 1. Scheme of perfluorinated alkylated substances

The PFAS are characterised by their carbon chains of varying length and by covalently bound fluorine atoms. The term perflurorinated means that all hydrogen atoms in the carbon chain are replaced with fluorine.

Perfluorinated substances in general are regarded as nearly insoluble in water and they have the ability to repel both water and oil, which makes them suitable as surface-active substances. However, PFOS is moderately soluble in water, 519 mg/l at 20 °C (for the potassium salt) and PFOA and PFHxA are probably even more water-soluble. (KemI, 2006). Perfluorinated substances have the possibility to reduce the surface tension of water, they resist degradation in both alkaline and acidic environments and they are stable at high temperatures.

The C-F bond is the intrinsic property that causes the exceptional stability of these compounds. It is extremely strong with a bond energy of 488 kJ/mol which can be compared to the bond energy of the C-C bond (348 kJ/mol) (OECD, 2002). A study on the hydrolysis of PFOS in water, using a temperature of 50 °C and a varying pH (1.5-11) to facilitate hydrolysis, did not indicate any degradation. Thus abiotic half-life of PFOS was set to 41 years (OECD, 2002).

Until recently, perfluorinated compounds were also thought of being biologically inert and thus not bioavailable. However, PFOS has been shown to be toxic to mammals (rats; Rusch et al, 1979, monkeys; Goldenthal et al., 1979). PFOS has also recently been shown to bioaccumulate in fish and mammals (Martin et al., 2003 and 2004) as well as to have the propensity of biomagnification in fish, birds and mammals (Martin et al., 2004, Giesy and Kannan, 2001a-d). PFOS fulfils the criteria for a PBT substance (KEMI 2004; OECD, 2002). It should also be considered as a POP (persistent organic pollutant with the potential for long range transboundary air pollution)(KEMI, 2004). Bioaccumulation factors are given in Table 3 and some ecotoxicological data are summarised in Table 4.

Despite several similarities with PFOS, PFOA is not considered as a PBT substance, mainly because of studies that indicate low bioaccumulation in fish. However, the low elimination rate of the substance indicates uncertainties about whether this statement is generally applicable in the environment (KEMI 2004).

Table 3. BCF values for PFOS (OECD 2002)

Carp	**Bluegill sunfish**
1124-4013	200-1500

Table 4. Ecotoxicological data for PFOS reported in the litterature. (OECD 2002)

	Species	Endpoint	Concentration	Duration
Fish	Pimephalis promelas	LC50	4.7 mg/l	96h
Fish	Pimephalis promelas	NOEC (survival)	0.3 mg/l	42 d
Fresh water organism	Daphnia magna	EC50	27 mg/l	48h
Fresh water organism	Daphnia magna	NOEC(reproduction)	7 mg/l	28 d
Salt water organism	Mysidopsis Bahia	LC50	3.6 mg/l	96 h
Salt water organism	Mysidopsis Bahia	NOEC(reproduction)	0.25 mg/l	35 d
Algae	Skeletonema Costatum	NOEC	>3.2 mg/l	96 h
	Lemna Gibba (duck weed)	NOEC (inhibition of frond production)	15.1 mg/l	7 d

Since many PFAS are lipophobic (lipid-repellent), hydrophobic (water-repellent) and also express strong surface-active properties, conventional dispersion modelling and risk calculation approaches based on K_{ow}-values, often very useful for other POPs, is not applicable for the evaluation of their environmental fate.

Mechanisms of global transport of PFAS to remote arctic regions are unclear (Verreault et al, 2005). Recently, Ellis et al. suggested that atmospheric oxidative degradation of fluorotelomer alcohols, is likely to contribute to the widespread occurrence of perfluorocarboxylic acids (PFCA) in arctic animals (Ellis et al., 2004). If transported in the atmosphere, PFOS itself is assumed to be predominantly bound to particles, because of its surface-active properties, rather than in the gaseous state. (OECD, 2002) Prevedouros et al. (2006) suggest that transport in ocean surface water accounts for the majority of PFCA (especially PFOA) found in the Arctic (transport 2-12 tonnes/year) and that transport in the atmosphere is of less importance.

3 Production, use and emissions

The environmental persistence of some of the substances in the PFAS group together with their suspected toxicity has recently raised concern (Berthiaume et al., 2000, Hu et al., 2002). In 2000, the US Environmental Protection Agency (EPA) banned PFOS from the US market and shortly thereafter, one of the major manufacturers announced a production phase-out of carboxylated and sulfonyl-based perfluorochemicals from December 2000 (Fed. Regist., 2000). However, PFOA and other long-chain perfluorinated carboxylic acids continue to be manufactured. Prevedouros et al. (2006), estimated the global, historical emissions of total perflourocarboxylates (PFCAs) to 3200-7300 tonnes, with 80% deriving from fluoropolymer manufacture and use.

There is no primary production of PFAS in Sweden. Emissions are considered to derive from consumer use of products containing the substances or secondary reemission from the environment.

Table 5. Consumption of PFAS in Sweden (SPIN, 2006)

Cas no	
29420-49-3	No registered use in Sweden
432-50-7	No registered use in Sweden
2795-39-3	Confidential use
67906-42-7	Confidential use
307-24-4	No registered use in Sweden
375-85-9	Confidential use
335-67-1	Confidential use
375-95-1	No registered use in Sweden
4151-50-2	Confidential use

Because of only a few registered users there is no publicly available information about the use of PFAS in Sweden (Table 5). A survey of the Swedish product registry performed by KEMI (2004) showed 39 users of PFOS or other PFAS (17 and 22, respectively) with a total quantity of 1175 kg (862 and 313 kg, respectively) registered in 73 different products. There is no obligation to register products containing less than 5% of the substance unless it contributes to the dangerous properties of the product. Many of the products that were registered contained less than 1% of the substance implying that there might be a large quantity of the substance not included in these figures.

Important applications of PFAS in Sweden were impregnation of leather and textiles as well as cleaning agents. The substances were also used for surface treatment of metals and as a flame-retarding component in hydraulic oils for aeroplanes.

4 Previous measurements in the environment

Measurements of the occurrence of PFAS show that they are widespread contaminants in the environment and even in the Arctic areas (Martin et al., 2004, Holmström et al., 2005, Boulanger et al., 2004, Giesy and Kannan 2001). However the highest concentrations are found in more industrialised areas e.g. in the North American Great Lakes, Mediterranean Sea and the Baltic Sea. Concentration data of PFAS found in international reports are summarised in Appendix 1.

PFAS have frequently been found in many different environmental matrices e.g. air, surface waters, human blood and biota: mammals, birds, fish, turtles and frogs, invertebrates (Boulanger et al., 2005b). They have been detected both in top predator fish as well as in lower trophic levels e.g. invertebrates. In a study from the Baltic Sea it was found that the concentrations in fish highly influenced the human body burden of PFAS (Falandysz et al., 2006).

When human blood, serum and plasma samples were analysed, PFOS were found to be the predominant compound (Kannan et.al. 2004). The highest concentrations occurred in samples collected in Portland, USA (>30 ng/ml), moderate levels were found in Korea, Belgium, Malaysia, Brazil, Italy and Colombia (3-29 ng/ml) and the lowest level was found in India (< 3 ng/ml) (Kannan et al., 2004). PFOA was the second most abundant perfluorinated compound in blood samples.

A study of Guillemot eggs from Stora Karlsö showed an increasing temporal trend of PFOS concentrations, suggesting increasing occurrence in the environment. The results from this study showed that the concentration of PFOS had increased almost 30 times from 1968 to 2003, from 25 ng/g w.w. to 614 ng/g w.w (Holmström K. et al., 2005).

A screening study on the occurrence, distribution and fate of PFAS in the Nordic environment has previously been carried out (Kallenborn et al., 2004). Measurable amounts of the selected PFAS occurred in all analysed sample matrices, see Table 6. The biota samples collected in the Nordic countries showed signs of species dependent distribution of the PFAS. High concentrations occurred in sewage sludge and in landfill effluents, suggesting that these are important pathways of PFAS into the environment. PFOS and PFOA dominated in sewage sludge samples (Kallenborn et al., 2004).

Table 6. Measured PFAS levels in Nordic Countries (LOQ equals limit of quantification) (Kallenborn et al. 2004).

Sample type	Unit	PFOS	PFOSA	SUM PFAS (8 comp.)
Sea water	ng/l	<LOQ-22	<LOQ-0.007	4.4-37
Fresh water	ng/l	<LOQ-0.48	<LOQ	9-10
Rain water	ng/l	0.24-2.97	<LOQ-0.14	11.2-22
Sediment	pg/g ww	<LOQ-892	<LOQ	69-1147
Sewage sludge	pg/g ww	55-2644	<LOQ-0.94	150-3793
Sewage effluent	ng/l	1.2-62.6	<LOQ-0.48	5-105.4
Landfill effluent	ng/l	30.1-187	<LOQ-3.28	199-11537
Marine mammals	pg/g ww	19-977	0.9-364	36-1060
Marine fish	pg/g ww	0.9-62	<LOQ-30	1.7-83.3
Freshwater fish	pg/g ww	4.7-551	0.6-141	8-707
Sea birds (egg)	pg/g ww	31-37.5	<LOQ-0.5	39-40

5 Sampling strategy and study sites

5.1 National

A national sampling strategy was developed in order to determine the environmental concentrations of selected PFAS in different environmental matrices in Sweden. An additional aim of the sampling programme was to identify major emission sources as well as important transport pathways. The sampling programme was based on identified possible emission sources and the behaviour of the substances in the environment.

Atmospheric transport and deposition were identified as an important pathway for the occurrence of PFAS in the ecosystem and the sampling program included measurements in air and precipitation at remote and backgrounds sites. The sampling stations used were Råö at the Swedish West Coast and Pallas in Northern Finland. These stations are used in the national monitoring program for air pollutants and included in the Co-operative Programme for Monitoring and Evaluation of Long-Range Transmission of Air Pollutants in Europe (EMEP) and in the Arctic Monitoring and Assessment Programme (AMAP).

Environmental background levels in water, sediment and biota were determined in samples from three reference lakes where the influence from human activities was considered minor. Marine water samples were collected at the shoreline close to Råö at the Swedish West Coast.

Sewage systems and urban areas were identified as important sources for diffuse emissions from the society. Measurements of PFAS were carried out at municipal sewage treatment plants (STPs) and at landfills. As diffuse sources eleven STPs and one urban area, central Stockholm, were selected.

The chosen STPs are included in the Swedish Environmental Protection Agency's monitoring programme for environmental pollutants in sludge (Naturvårdsverkets miljöövervakningsprogram av miljögifter i slam). Stockholm was used for measurements of PFOS in an urban area where sampling was undertaken in air, water and sediments.

In order to identify additional potential point sources the programme included samples from two industrial laundries, and from an airport where air, sediment, and water samples were collected. PFAS could be emitted from the airport because of the frequent use of fluoropolymer-based lubricants as well as the use of fire fighting foams containing PFAS.

The sampling programme is summarised in Table 7. Site information and sample characteristics of the samples collected within the national program are given in Appendix 2.

Table 7. Number of samples from different localities

	Site	Air	Precipi-tation	Sedi-ment	Sludge	Water	Biota	Total
Background	Lilla Öresjön			1		1	1	3
	Stensjön			1		1	1	3
	Tärnan			1		1	1	3
	Pallas	3	3					6
	Råö	3	4			3		10
Diffuse	Municipal STP				11	2		13
	Landfill					3		3
	Stockholm	3						3
	Riddarfjärden			1		1		2
	Stora Essingen			1		1		2
	Årstaviken			1		1		2
Point source	Airport	2	2	2		1	1	8
	Laundry					2		2
Total		**11**	**9**	**8**	**11**	**17**	**4**	**60**

5.2 Regional

Regional screening was carried out by different Swedish county administrative boards that had the possibility to collect samples for analysis. Different counties have chosen different strategies for their own regional sampling scheme. The selection of the "regional" samples was meant to increase the number of samples for substances connected to their environmental programmes i.e. substances that have been regulated or included in the national priority database. Another strategy has been to choose substances where environmental levels are expected to differ from national levels because of intense use within the county i.e. local industrial areas or because of geographic proximity to European industrial areas.

Three different county administrative boards participated in the regional sampling programme of PFAS with a total of nine extra samples: one sediment sample, four sludge samples, and four water samples.

Detailed information about sampling sites and sample characteristics of the samples included in the regional programme are given Appendix 3.

6 Methods

6.1 Sampling

As a guideline for adequate and consequent sampling, a manual was developed. Detailed instructions for sampling, storing and transport were given. Sampling protocols for all sample types were included in the manual. The overall aim of the sampling protocols was to:

1. Guide the responsible personnel on how to avoid contamination when sampling

2. Ensure documentation of the sampling procedure, quality of the sample and environmental and physical circumstances during the sampling.

The guidelines were used both internal at IVL and of persons collecting samples within the regional program. The samples from the regional county administrative boards were sent to IVL for analysis.

6.1.1 Air and Precipitation

Urban air samples (particle phase) were collected using a low volume air sampler (LVS) with a flow of approximately 1 m^3/hour. Particles were collected on a glass fibre filter (MG160, Munktell).

Air samples (particle phase) at the background stations were collected using a high volume air sampler (HVS) with a flow of approximately 25 m^3/hour. The substances in the particle phase were collected on a glass fibre filter (MG160, Munktell).

The sampling was carried out for one week and four weekly samples were pooled to represent an average for one month. Prior to sampling the filters were heated to 350°C.

After sampling the filters were wrapped in aluminium foil and sent to the laboratory where it was stored in a freezer (-18°C) until analysis. An additional filter used as a field blank was sent back to the laboratory unexposed.

The precipitation samples were collected using an inert funnel connected to a 5-liter bottle. The samples were stored frozen until analysis.

6.1.2 Water

Water samples were collected in pre-cleaned plastic bottles and stored frozen until analysed.

6.1.3 Sediment

Sediment samples from lakes were collected by means of a Kajak sampler. Sediment was transferred into plastic jars and stored frozen until analysed.

6.1.4 Sludge

The staff at the different treatment plants collected the sludge samples from the anaerobic chambers. The sludge was transferred into plastic jars and stored at 4°C or -18°C until analysed.

6.1.5 Fish

The fish samples were collected by means of fishing net, hoop net or fishing rod. Samples of herring from background sites were supplied from The Environmental Specimen Bank and the Museum of Natural History (A. Bignert and colleagues). Fish samples were individually wrapped in aluminium foil and stored in a freezer (-20°C).

6.2 Analysis

6.2.1 Water

Sample preparation: Water samples were extracted with methanol using a SPE method. Dispersive clean-up was performed with graphitised carbon.

6.2.2 Sediments

Sample preparation: The sediments were treated with sodium hydroxide prior to extraction with methanol. Clean-up was performed with graphitised carbon.

6.2.3 Biota

Sample preparation: Extraction with acetonitrile, concentration, clean-up was performed with graphitised carbon.

6.2.4 Air (particles)

Sample preparation: Extraction with methanol, concentration, clean-up using graphitised carbon can be applied for highly contaminated samples.

6.2.5 Analytical method

High performance liquid chromatograph coupled to mass spectrometer (HPLC-MS). Quantification of perfluorinated alkyl substances (FAS) was performed using the internal standard method. For further details of the analytical method see Kallenborn (2004).

7 Results and discussion

The concentrations of PFAS found in the different samples from the national and regional screening are given in tabular form in Appendix 4. In the plots below, perfluorinated sulfonates and perfluorinated carboxylic acids have been grouped separately in order to reveal variations among homologues series of compounds.

7.1 Concentrations in air and precipitation

7.1.1 Air

PFAS occurred in the atmosphere (particle phase) at all sites were air was sampled. The sampling sites represented background, diffusive sources and a point source. PFOS was the most frequently detected substance. It was found in all the samples while the corresponding carboxylic acid PFOA was found more occasionally (Figure 2 and Figure 3). The highest PFOS concentrations were measured in the urban atmosphere in Stockholm, but PFOS was also found at the background sites, reflecting the propensity of long-range transport. The air concentration of PFAS at Landvetter airport, which was selected as a possible point source, was similar to the levels found at the background site at the Swedish West Coast.

The concentrations of PFOS at Pallas varied between 0.08 and 1 pg/m^3 and at Råö between 0.8 and 1.2 pg/m^3, which is in the same concentration range as for individual PCBs (IVL-Luftdatabas). No seasonal variation was found for PFOS at the background sites. The concentrations of PFOS found in the urban area (Stockholm) were somewhat higher and varied between 2.6 and 3.9 pg/m^3. The highest concentration occurred during the sampling period with the highest ambient temperatures.

PFBS, which was the substance to bee screened originally, was only detected in one air particle sample which was taken at the background station Råö (0.10 pg/m^3). Of the other perfluorinated sulfonates (C_4-C_{10}), PFHxS occurred at Råö and Landvetter in concentrations below 0.1 pg/m^3 and in Stockholm at 0.21 pg/m^3. PFDS was found in one sample from Råö (0.02 pg/m^3) and one from Stockholm (0.38 pg/m^3).

Surprisingly, PFOA was detected in the highest concentration at the most remote sampling site Pallas. In a previous screening and in the "National monitoring program for air pollutants", chemicals such as octachlorostyrene and PBDE have also been found in higher concentration in Pallas compared to Råö at the Swedish West Coast. However, we can not exclude a contamination of this sample. Except PFOA, the only perfluorinated carboxylic acid detected on the air particles was PFDcA. It was found in one sample from Pallas (12 pg/m^3).

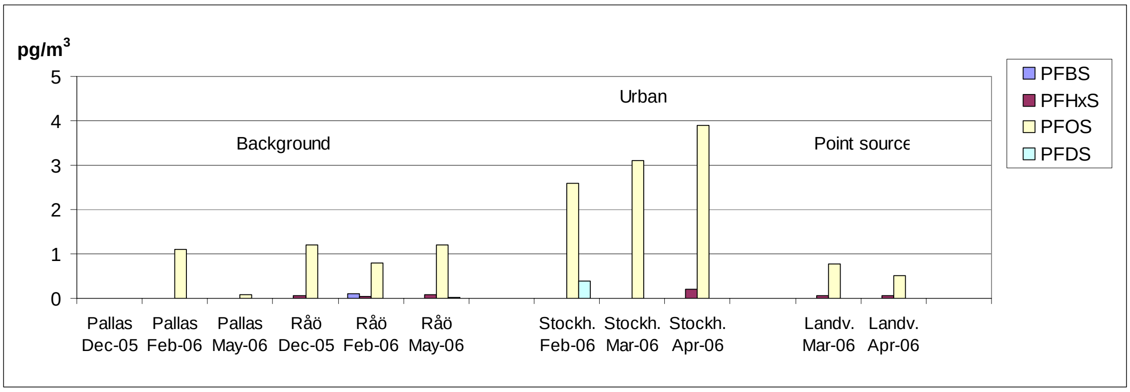


Figure 2. Concentrations of perfluorinated sulfonates (C_4-C_{10}) in air.

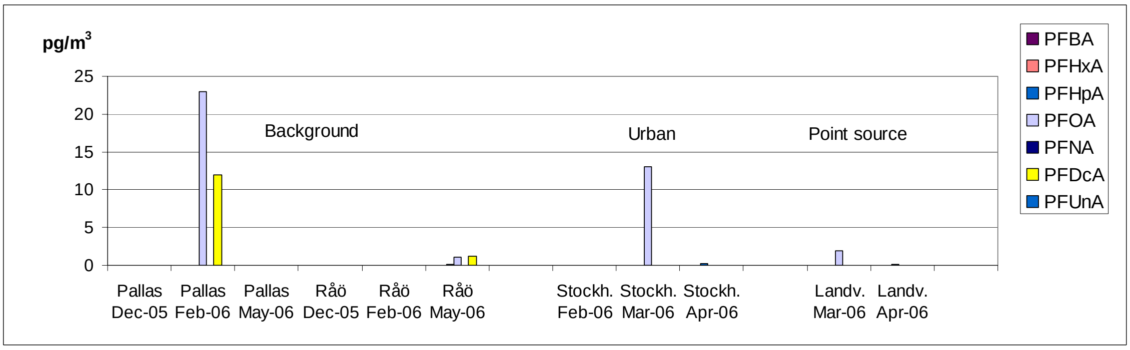


Figure 3. Concentrations of perfluorinated carboxylic acids (C_4-C_{11}) in air.

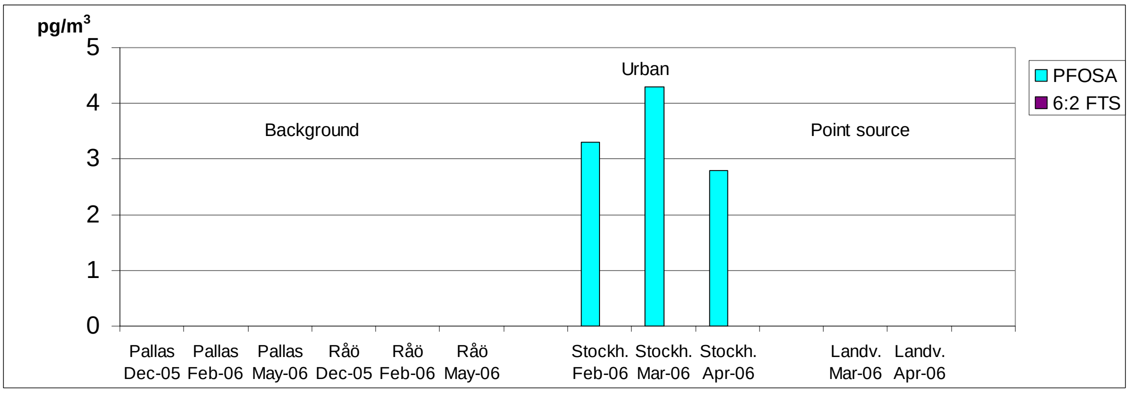


Figure 4. Concentrations of PFOSA (a perfluorinated C_8-sulfonamide) and 6:2 FTS (a fluorinated telomeric C_8-sulfonate) in air.

The perfluorinated C_8-sulfonamide, PFOSA, occurred in the urban air in similar concentrations as PFOS, but it was not found in the samples from the background sites (Figure 4). The telomeric C_8-sulfonate 6:2 FTS was not detected in any of the air samples.

The detection limits of the different PFAS in the air samples varied depending on instrument sensitivity and the sampled air volumes. For the perfluorinated sulfonates it was 0.6 pg/m^3 or less, for the perfluorinated acids 9 pg/m^3 or less, for PFOSA 0.1 pg/m^3 or less and for 6:2 FTS 2.5 pg/m^3 or less. Detection limits for individual samples are given in Appendix 5.

7.1.2 Precipitation

PFAS was found in the precipitation from both the background sites Pallas and Råö and at the point source Landvetter. PFOS and PFOA were, as was the case in air, the most frequently found substances. The concentration of PFAS found in the precipitation collected close to Landvetter airport were lower than at Råö, the background station at the Swedish West Coast (Figure 5 - Figure 7).

PFOS occurred in all nine precipitation samples and PFHxS (the C_6-sulfonate) was found in five of the samples. The concentration of PFOS was significantly higher at Råö than at Pallas. There was no relationship between the concentrations in air and the concentrations in precipitation neither at Råö or Pallas; the highest concentration detected in precipitation samples did not coincide with the air samples having the highest concentration. The concentrations of PFOS were highest in the samples collected during the winter periods, December and January. PFBS was found in one of the precipitation samples from Råö (Figure 5).

PFOA was detected in seven out of nine samples while the C_6-perfluorinated carboxylic acid, PFHxA, was not found in any of the precipitation samples, which was in contrast to the sulfonated counterpart (Figure 6). However the highest concentrations of PFOA at Pallas occurred in precipitation samples collected when also the highest concentration was found in the air samples.

Kallenborn et al. have previously reported PFOS concentrations of 0.83 - 2.97 ng/l and PFHxA concentrations of 0.62 - 1.08 ng/l in precipitation at Råö (Kallenborn et al., 2004). The concentrations found in this screening were thus somewhat higher compared to the results reported by Kallenborn et al.

Notable was the frequent detection of the fluorinated telomeric C_8-sulfonate, 6:2 FTS, which was found in seven of the samples. The highest concentration was found in one of the samples from the remote site Pallas, which co-incided with increased concentrations of PFOA in both preciptation and air (Figure 7).

The detection limits for precipitation samples were for the perfluorinated sulfonates 0.4 ng/l or less, for the perfluorinated carboxylic acids 10 ng/l or less (in one case 82 ng/l), for PFOSA 0.2 ng/l or less and for 6:2 FTS 2 ng/l or less. Detection limits for individual samples are given in Appendix 5.

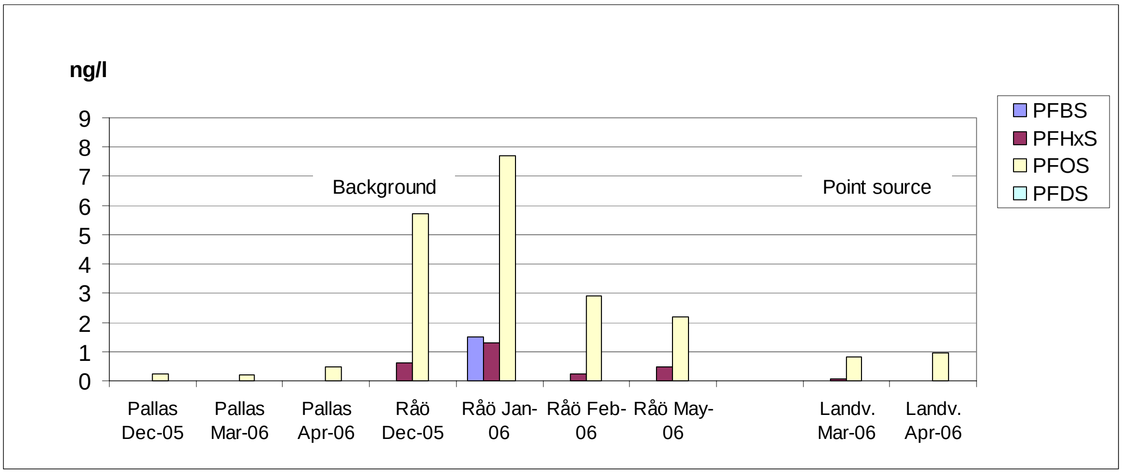


Figure 5. Concentrations of perfluorinated sulfonates (C_4-C_{10}) in collected precipitation samples.

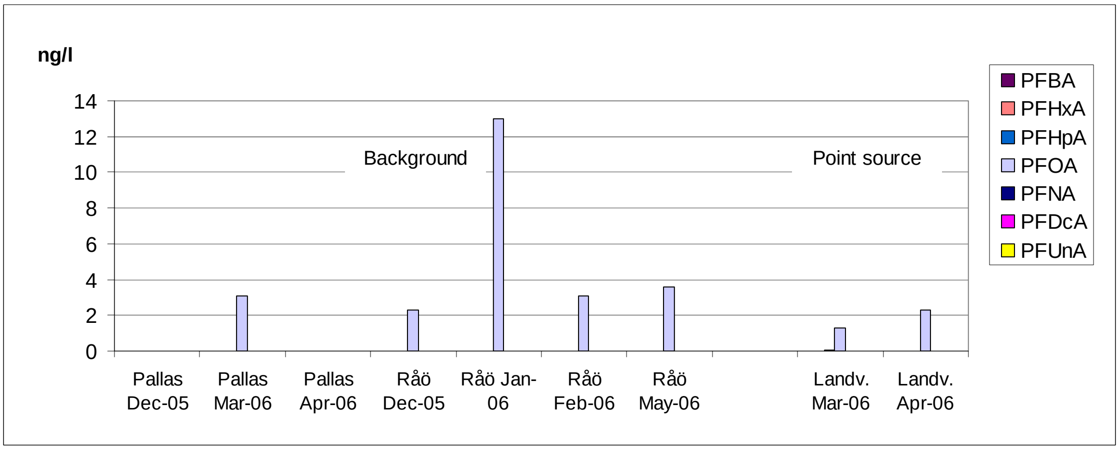


Figure 6. Concentrations of perfluorinated carboxylic acids (C_4-C_{11}) in collected precipitation samples.

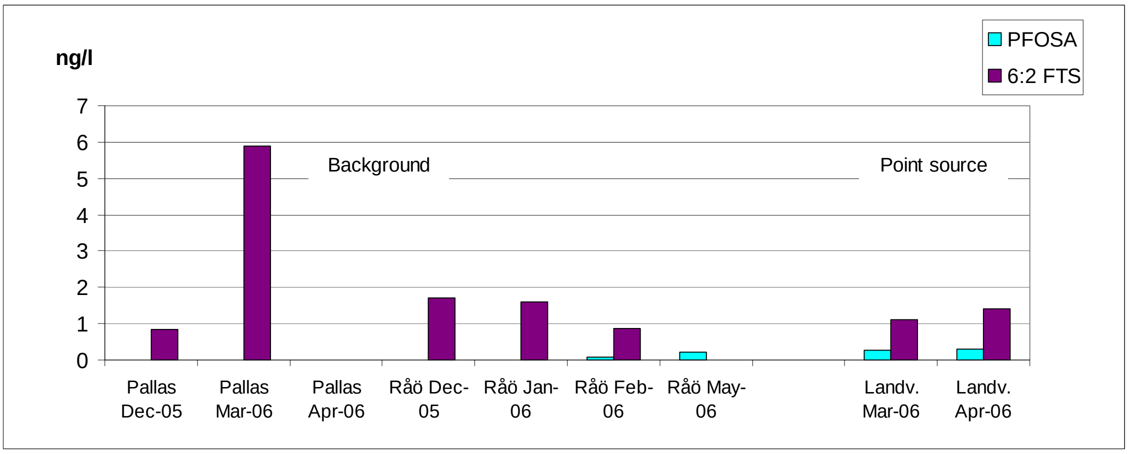


Figure 7. Concentrations of PFOSA (a perfluorinated C_8-sulfonamide) and 6:2 FTS (a fluorinated telomeric C_8-sulfonate) in collected water precipitation samples.

7.2 Concentrations in surface water

PFOS, PFHxS, PFOA and 6:2 FTS were the most frequently detected compounds in surface water and they occurred in higher concentrations compared to the other analysed substances, which is shown in Figure 8 - Figure 10. The surface water samples represent marine background, background lakes, an urban area and a lake close to the point sources, Landvetter (see sampling strategy).

PFOS and PFOA were found in the marine water samples from the Swedish West Coast in the same order of magnitude or in somewhat lower concentrations than in the precipitation collected at the shore line, Råö. The concentrations of PFBS and PFHxS occurred in the marine water in significantly lower concentrations than PFOS and PFOA.

Compared to the marine water samples, lower PFAS concentrations occurred in the samples from two of the background "reference" lakes. However, the sample from one of the background lakes, Lilla Öresjön, contained increased concentrations of PFOA (14 ng/l). Notable is that the increased concentration of PFOA was found in the same lake where also increased concentrations of pharmaceuticals previously have been reported (Andersson et al., 2006). Lilla Öresjön stood out as a lake, which may be more affected by human activities than the geographical position initially would suggest (Andersson et al., 2006).

The concentrations of PFOS and PFHxS found in the water samples from the urban area were higher than in the reference samples (background lakes) while the concentrations of PFOA were similar or even lower.

The water sample from Landvetter airport contained elevated concentrations of PFOS (39 ng/l) compared to both the water samples from the background lakes (average 3.3 ng/l) and the urban area (average 12 ng/l). Also regarding the concentration of the perfluorinated C_6-sulfonate, PFHxS, the Landvetter sample was elevated, 3.4 ng/l compared to the other samples.

In comparison with the data in this study, Kallenborn et al., has previously reported PFOS concentrations of 0.43 - 0.48 ng/l, PFOA concentrations of 4.82 - 8.23 ng/l and PFHxA concentrations of 0.76 - 1.68 ng/l in lake water from the South Eastern part of Norway (Kallenborn et al., 2004).

As was the case for precipitation 6:2 FTS was found frequently in surface water samples (Figure 10). No clear distribution pattern regarding the concentrations in the different locations could be seen. The median concentration was 1.9 ng/l.

The detection limit for surface water was for perfluorinated sulfonates 0.2 ng/l or less, for the perfluorinated acids 6 ng/l or less, for PFOSA 0.2 ng/l or less and for 6:2 FTS 0.9 ng/l or less. Detection limits for individual samples are given in Appendix 5.

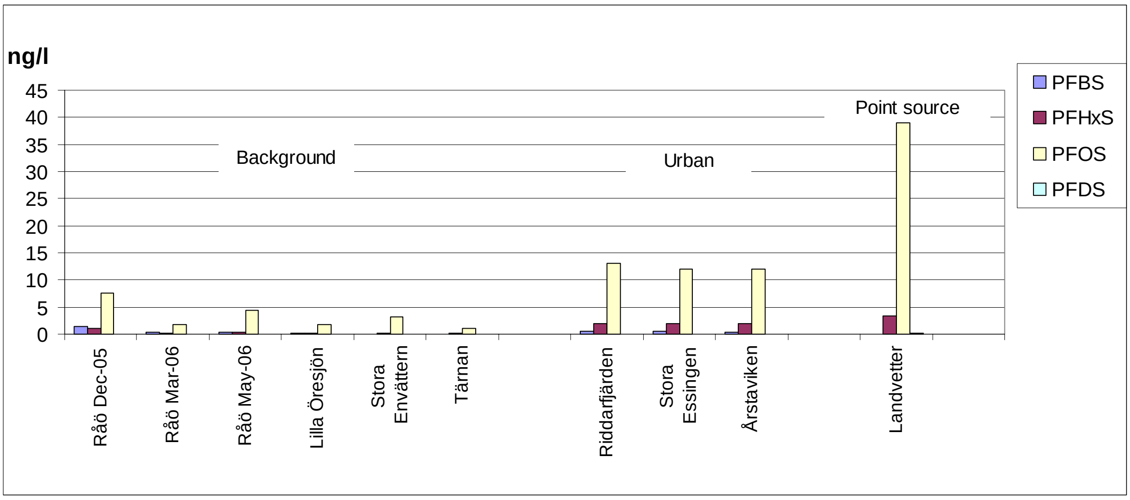


Figure 8. Concentrations of perfluorinated sulfonates (C_4-C_{10}) in surface water samples.

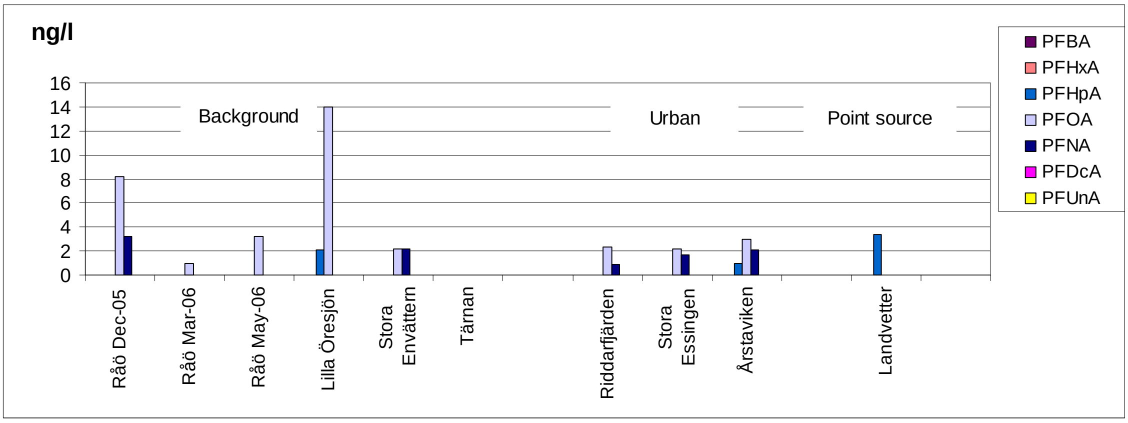


Figure 9. Concentrations of perfluorinated carboxylic acids (C_4-C_{11}) in surface water samples.

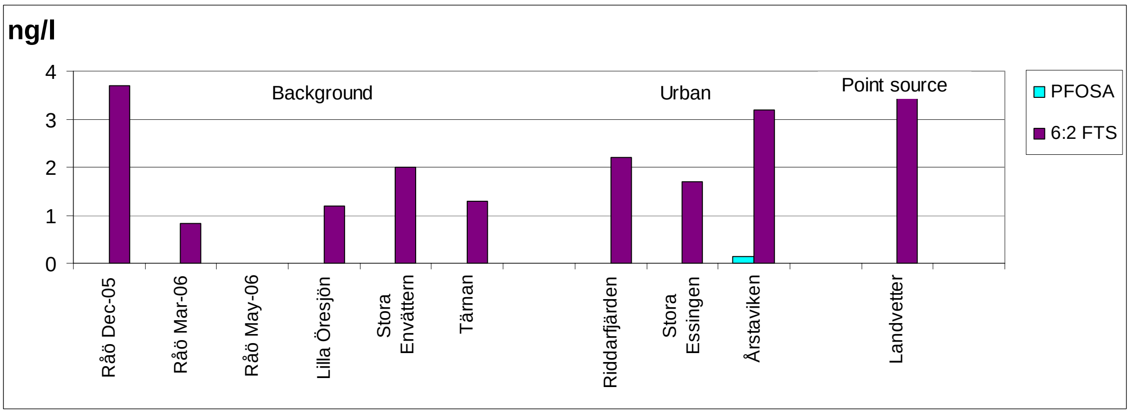


Figure 10. Concentrations of PFOSA (a perfluorinated C_8-sulfonamide) and 6:2 FTS (a fluorinated telomeric C_8-sulfonate) in collected surface water samples.

To facilitate comparison between concentrations found in precipitation and surface water, the results from Råö and Landvetter are shown together in Figure 11. Concentrations in precipitation and surface water were noticeably similar at Råö. At Landvetter the concentration of PFOS was much higher in surface water than in precipitation.

Concentrations of PFOS and PFOA in precipitation and surface water from all stations are shown together in Figure 12. Concentrations of PFBS, PFHxS, PFHpA and PFNA in the same samples are shown in Figure 13.

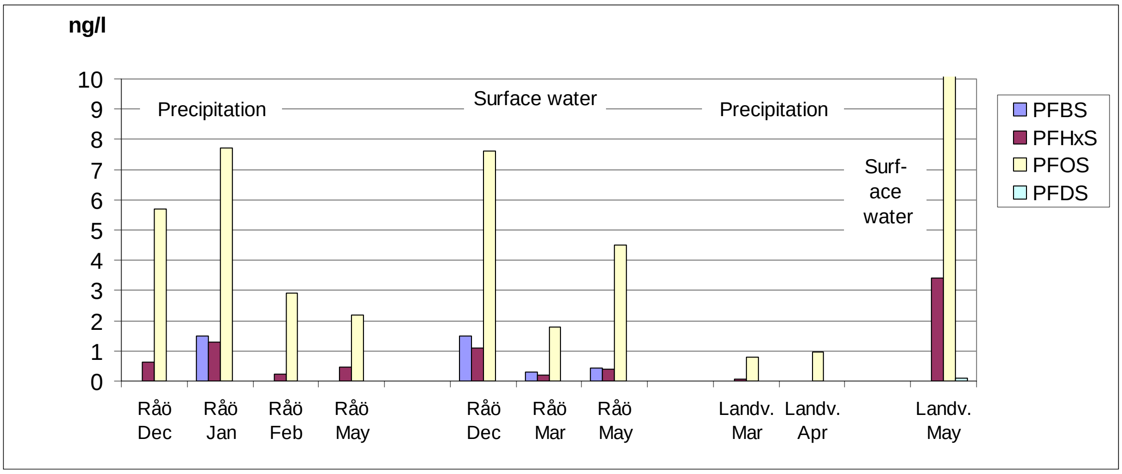


Figure 11. Concentrations of perfluorinated sulfonates in precipitation and surface water from Råö and Landvetter showing similar concentrations in precipitation and surface water at Råö. (PFOS in surface water from Landvetter is 39 ng/l).

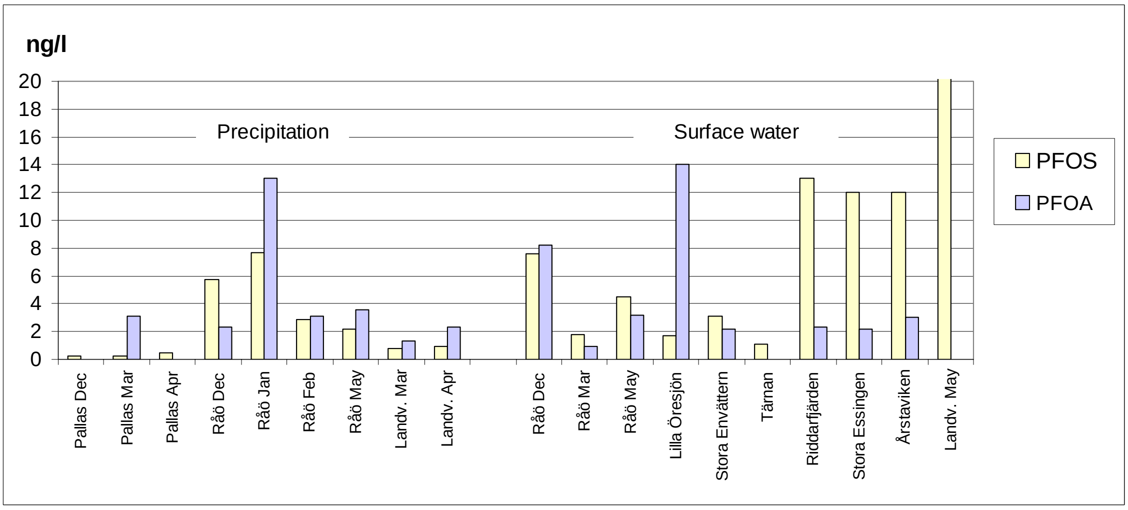


Figure 12. Concentrations of PFOS and PFOA in precipitation and surface water from all stations (PFOS in surface water from Landvetter is 39 ng/l).

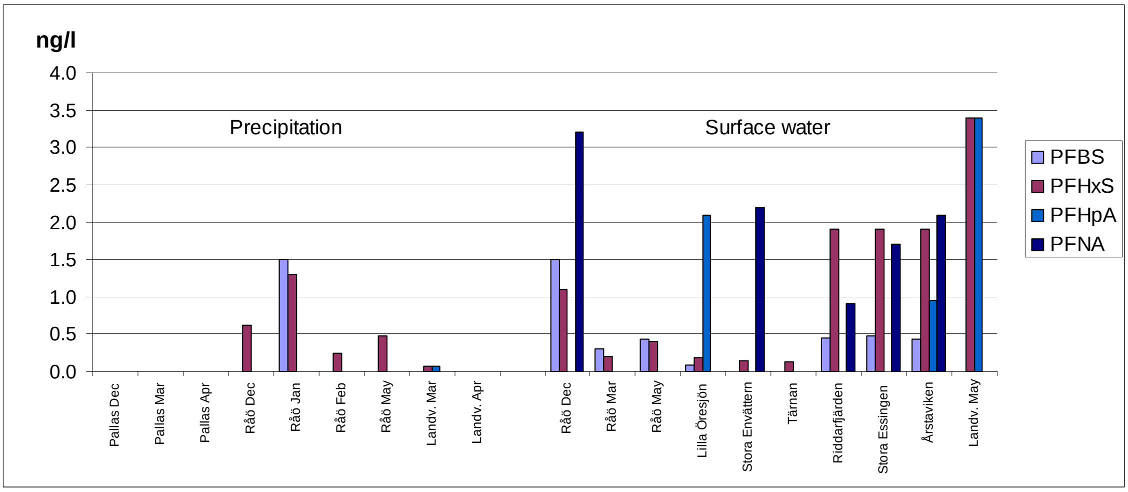


Figure 13 Concentrations of PFBS, PFHxS, PFHpA and PFNA in precipitation and surface water from all stations.

7.3 Concentrations in sediment

The concentrations of perfluorinated sulfonates found in sediments are illustrated in Figure 14. In most sediment samples only PFOS occurred in detectable amounts (8 out of 9 samples). PFOS was also detected in sediment samples from the background lakes, where the highest concentration, in agreement with the water samples, was found in Lilla Öresjön. The concentrations of PFOS in sediments collected at the urban sites (average 1.0 ng/g ww) were elevated compared to the background sediments (average 0.02 ng/g ww). The perfluorinated C_{10}-sulfonate, PFDS, was found in two samples from the urban area. The concentrations of PFOS were lower in the sample collected close to Landvetter compared to the concentrations found in sediments from the Stockholm area (0.16 ng/g ww).

Notably, the perfluorinated C_8-carboxylic acid, PFOA, was not detected in any sediment sample included in the national screening. However in a sediment sample from lake Tärnsjön (north of Karlstad) included in the regional screening program, the perfluorinated C_{10}-carboxylic acid, PFDcA, occurred at an elevated concentration (30 ng/g ww), while all the other analysed PFAS were below the detection limit. A textile industry is situated in the area.

Kallenborn et al. has reported a PFOS concentration of 0.069 ng/g ww in a background lake sediment sample from the Northern part of Sweden. In that particular sample all other PFAS concentrations were below the limit of detection (Kallenborn et al., 2004).

Detection limit in sediment samples was for the perfluorinated sulfonates 0.2 ng/g ww or less, for the perfluorinated acids 8 ng/g ww or less, for PFOSA 0.1 ng/g ww or less and for 6:2 FTS 1.1 ng/g ww or less. Detection limits for individual samples are given in Appendix 5.

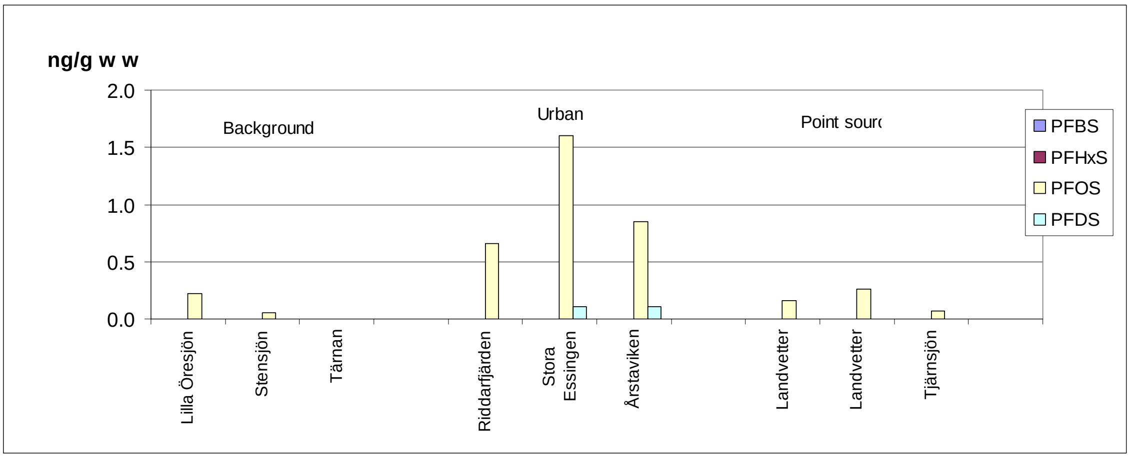


Figure 14. Concentrations of perfluorinated sulfonates (C_4-C_{10}) in sediment samples.

7.4 Diffuse sources - Municipal sewage treatment plants

7.4.1 Concentrations in sludge

The results of the analyses of PFAS in sludge from sewage treatment plants (15 samples in total) indicated that there are large differences in the distribution of PFAS among the different STPs. No geographically influenced pattern could be identified.

PFOS was found in all samples, however there was a great variation in concentration: range 0.52 - 35 ng/g ww, median 2.2 ng/g ww. The perfluorinated C_{10}-sulfonate, PFDS, was also frequently detected (in all samples but three): range <0.05 – 3.3 ng/g ww, median 0.32 ng/g ww. The C_6-sulfonate PFHxS was occasionally found while the low molecular weight C_4-sulfonate, PFBS, was not detected in any of the sludge samples (Figure 15). Thus the concentrations of PFOS in sludge were in several of the samples in the same levels as was found in sediments from urban sources. Like the sediment samples, the sludge contained mostly non-volatile substances.

The perfluorinated carboxylic acids were only detected occasionally in the sludge but they occurred in rather high concentrations (0.7- 44 ng/g ww). The sludge sample from Borås was untypical as it contained several of the perfluorinated carboxylic acids. PFDcA occurred in the sample from Skellefteå and PFBA in sludge from Stockholm and Eslöv (Figure 16).

The perfluorinated C8-sulfonamide PFOSA, was detected in eleven sludge samples with a median concentration of 0.16 ng/g ww (range <0.05 - 1.0 ng/g ww) while the telomeric C8-sulfonate, 6:2 FTS only was found in the sample from the Landskrona STP (Figure 17).

Detection limits in STP sludge samples were for perfluorinated sulfonates 0.4 ng/g ww or less, for the perfluorinated acids 16 ng/g ww or less, for PFOSA 0.2 ng/g ww or less and for 6:2 FTS 1.5 ng/g ww or less. Detection limits for individual samples are given in Appendix 5.

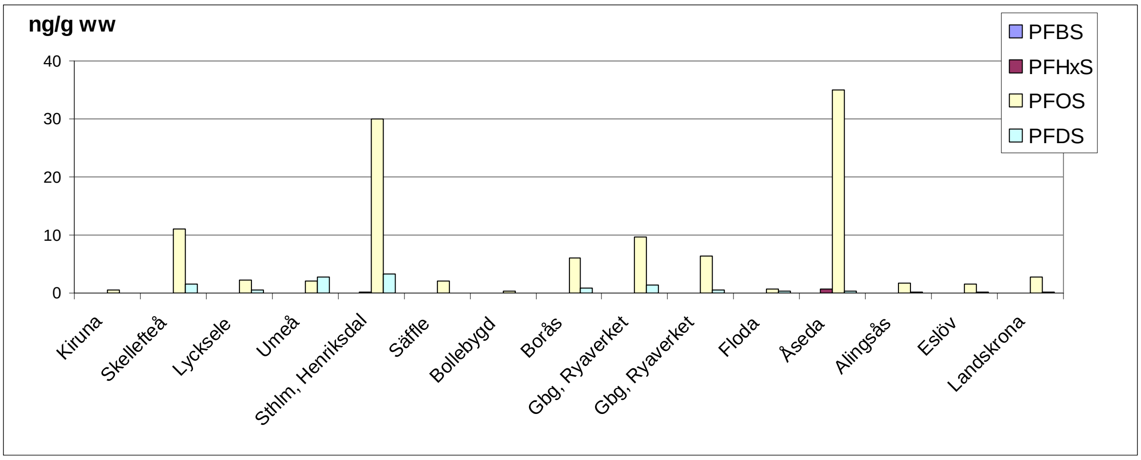


Figure 15. Concentrations of perfluorinated sulfonates (C_4-C_{10}) in STP sludge samples.

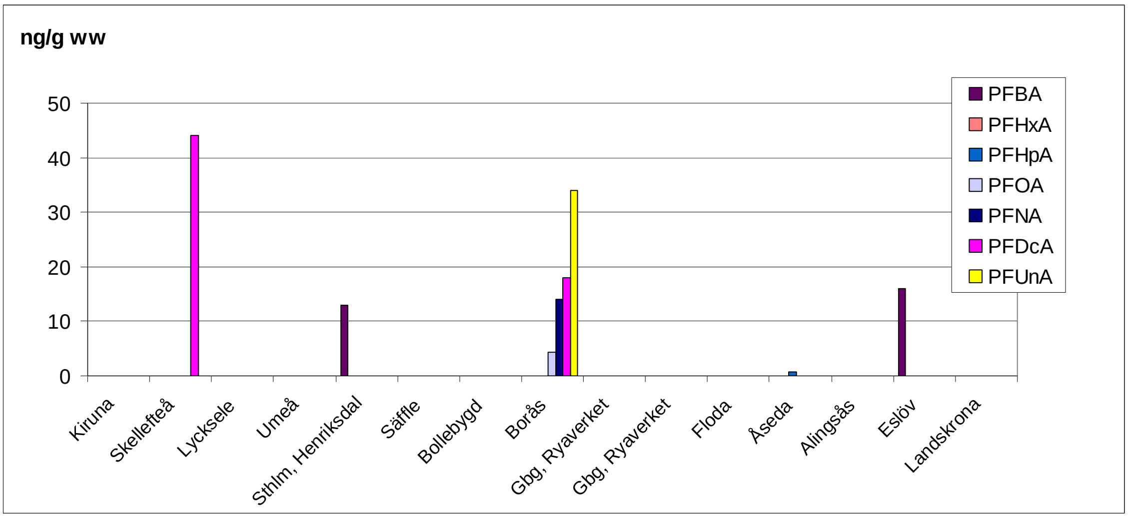


Figure 16. Concentrations of perfluorinated carboxylic acids (C_4-C_{11}) in STP sludge samples.

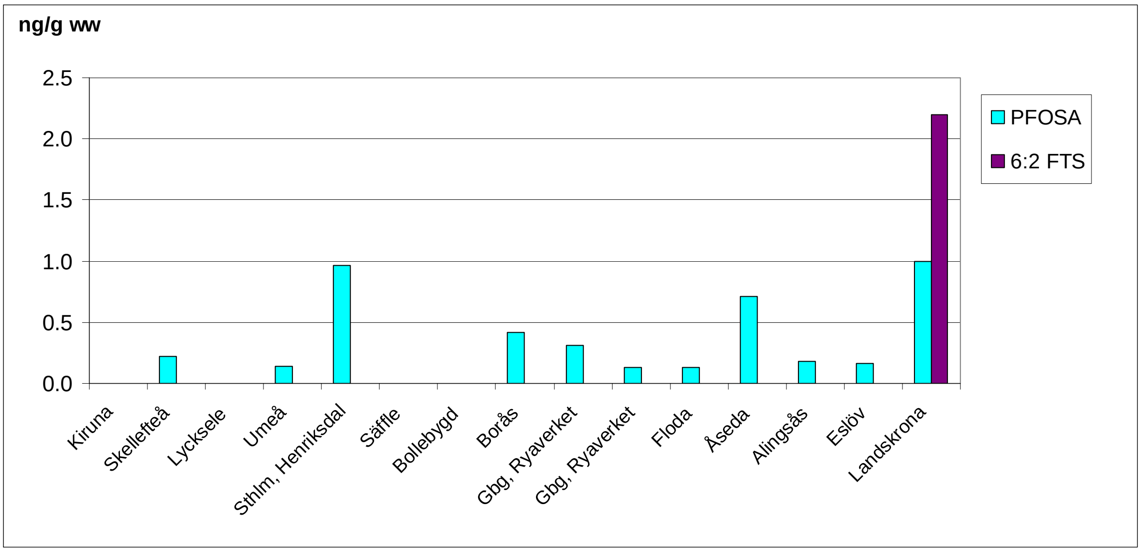


Figure 17. Concentrations of PFOSA (a perfluorinated C8-sulfonamide) and 6:2 FTS (a fluorinated telomeric C_8-sulfonate) in STP sludge samples.

Kallenborn et al. has previously reported PFOS concentrations of 0.17 - 2.6 ng/g ww and PFHxS concentrations of 0.017 - 0.046 ng/g ww, in STP sludge samples from the Southern part of Sweden (Kallenborn et al., 2004) which are lower compared to the present results.

As mentioned above seven of the STPs selected for this screening are also included in the National monitoring program of chemicals in sludge which is carried out by Umeå University as an assignment from the Swedish EPA. The PFOS concentrations found in 2004 in that program (Haglund and Olofsson 2006) are compared to the concentrations found (samples from 2005) in the present study in Figure 18. The concentrations have been converted to dry weight basis. The results agree quite well. The sludge samples from Stockholm, Göteborg and Borås contained the highest PFOS concentrations in both studies.

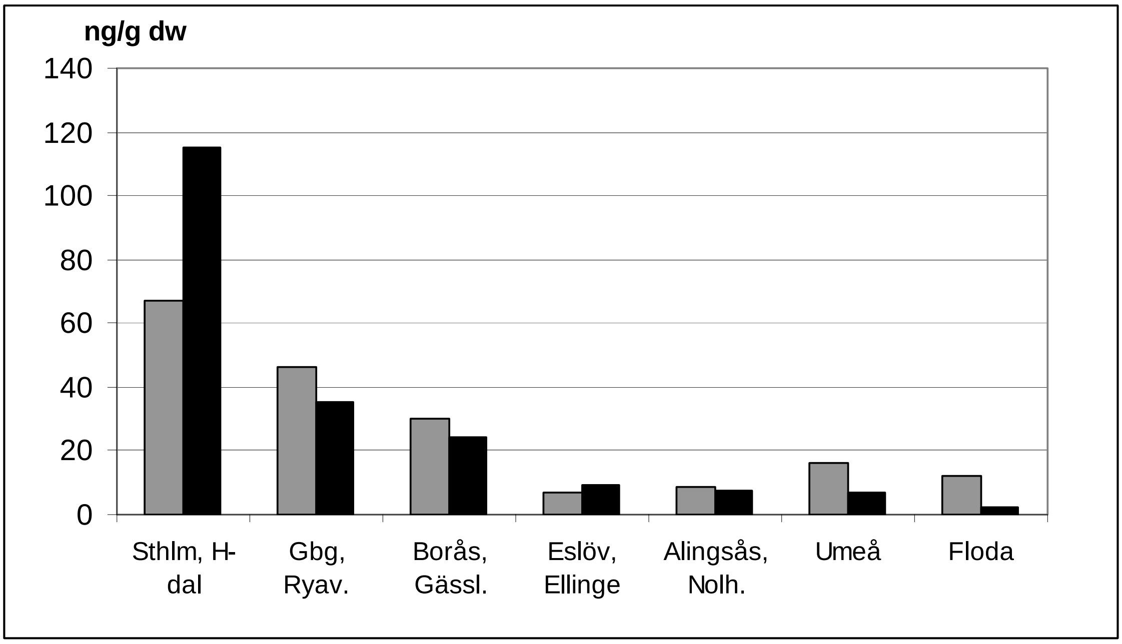


Figure 18. PFOS concentrations in STP sludge from a study by Umeå University (samples from 2004, gray) and from the present study (samples from 2005, black).

7.4.2 Effluent water from STPs

The concentrations of PFAS found in the effluent water samples from STPs were for many of the substances significantly higher compared to the concentrations in the recipient water samples. However the concentration varied substantially among the different STPs and no geographically influenced pattern could be identified.

All perfluorinated sulfonates except the C_{10}-variant (PFDS) were detected in all the samples in the following median concentrations: PFBS 1.7 ng/l, PFHxS 6.0 ng/l and PFOS 43 ng/l (Figure 19). PFOS was the dominating substance, but in contrast to the sludge samples, the substances with lower molecular weight (shorter carbon chain) occurred in the effluent water samples. Thus the distribution of the perfluorinated sulfonates differed between the water and sludge.

PFOS concentrations of 6.89 - 18.3 ng/l in STP effluent water from the South East part of Norway has previosly been reported (Kallenborn et al., 2004).

The perfluorinated carboxylic acids were not as frequently encountered as their sulfonated counterparts but there was a great variation among the different STPs. PFBA did not occur in any effluent water sample. The C_{11}-carboxylic acid was only found in the sample from the STP in Borås (Figure 20). The C_6-C_{10} perfluorinated carboxylic acids (PFHxA, PFHpA, PFOA, PFNA and PFDcA) were detected in two, four, five, four and three samples respectively. The median concentrations of the C_7-C_9 carboxylic acids (PFHpA, PFOA and PFNA) were 3.2, 9.0 and 2.8 ng/l respectively.

The effluent water from Borås STP contained, as did the corresponding sludge, increased concentrations of the perfluorinated carboxylic acids. The effluent water sample from Kiruna STP also contained several of these substances but the distribution pattern differed from the Borås sample.

Similar to the perfluorinated sulfonates, the perfluorinated carboxylic acids showed different distribution patterns comparing sludge and effluent water. A detection frequency histogram for the perfluorinated carboxylic acids reveals an almost Gaussian profile (Figure 22). The median concentrations of the C_7-C_9 carboxylic acids (PFHpA, PFOA and PFNA) were 3.0, 9.0 and 1.5 ng/l respectively.

Kallenborn et al. has previously reported PFHxA concentrations of 13.9 - 14.5 ng/l (compared to this study, <2-22 ng/l) and PFOA concentrations of 20.2 - 22.5 ng/l (this study, median 9.0 ng/l) in STP effluent water from the South East part of Norway (Kallenborn et al., 2004).

The perfluorinated C8-sulfonamide, PFOSA was detected in three of the samples while the telomeric 6:2 FTS was detected in all effluent samples but one, with a median concentration of 11 ng/l. When comparing STP sludge and STP effluent samples it is interesting to note that PFOSA seems to preferentially distribute to the solid phase whereas 6:2 FTS probably is less surface active and thus ends up in the water phase (Figure 21).

The detection limits for effluent water samples were for perfluorinated sulfonates 2 ng/l or less, for the perfluorinated acids 46 ng/l or less, for PFOSA 3 ng/l or less and for 6:2 FTS 5 ng/l or less. Detection limits for individual samples are given in Appendix 5.

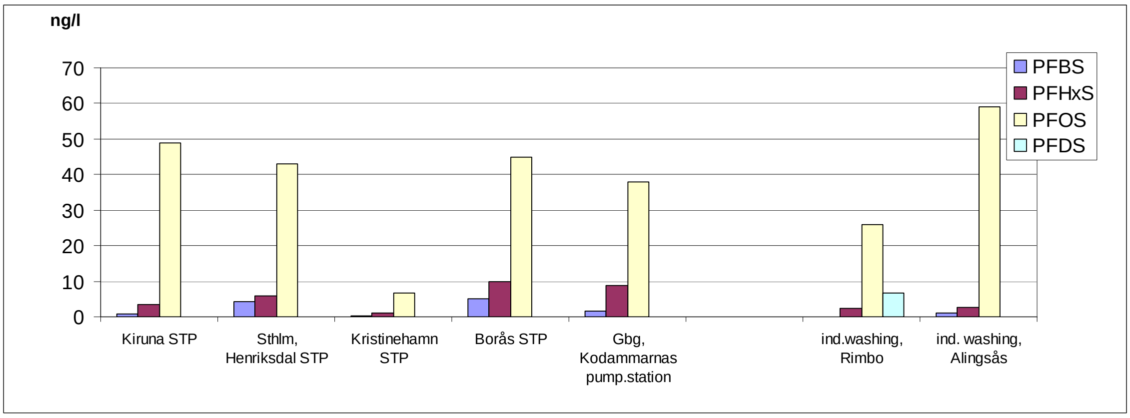


Figure 19. Concentrations of perfluorinated sulfonates (C_4-C_{10}) in STP effluent water samples.

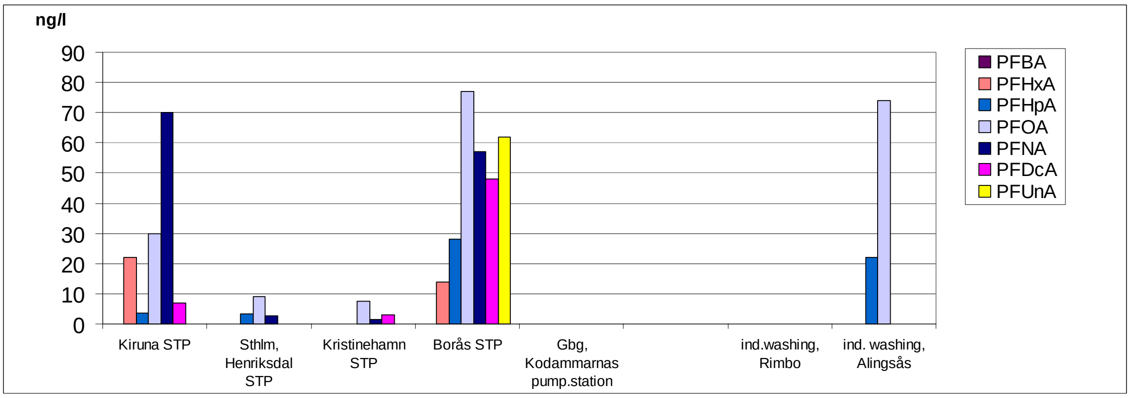


Figure 20. Concentrations of perfluorinated carboxylic acids (C_4-C_{11}) in STP effluent water samples.

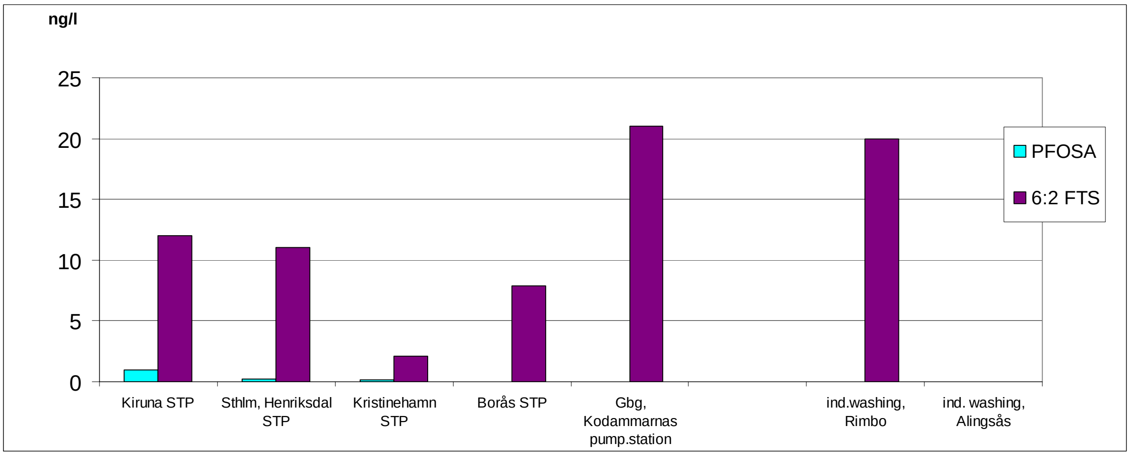


Figure 21. Concentrations of PFOSA (a perfluorinated C_8-sulfonamide) and 6:2 FTS (a fluorinated telomeric C_8-sulfonate) in STP effluent water samples.

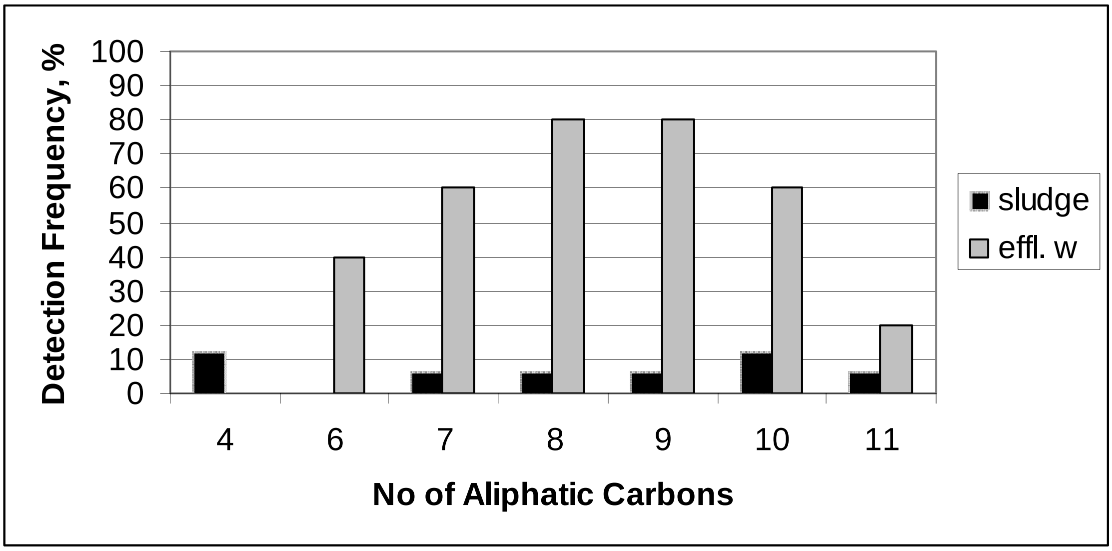


Figure 22. Detection frequency histogram for PFCAs as a function of carbon chain length for sludge (16 samples) and effluent water (5 samples).

7.5 Effluent water from point sources

PFAS concentrations in effluent water from two industrial laundries were measured. The results are shown together with results for effluent water from STPs in Figure 19 - Figure 21. The concentration of perfluorinated sulfonates were similar to what was found for the effluent water samples from the STPs and with PFOS as the dominating substance. Also the perfluorinated carboxylic acids were detected, but only in the water sample from Alingsås where PFNA and

PFOA occurred in increased concentrations. 6:2 FTS (a fluorinated telomeric C8-sulfonate) occurred in the effluent water sample from Rimbo.

7.6 Concentrations in leachate water

The concentrations of PFAS in leachate water from landfills were significantly higher compared to both recipent water and STP effluent water concentrations, indicating that landfills constitute an important junction in the life cycle of PFAS.

In the case of perfluorinated sulfonates, PFHxS (C6) and PFOS (C8) were found in all the leachate water samples. PFDS (C10) were found in two samples. The PFHxS-concentration varied between 12 - 1800 ng/l with an average of 550 ng/l. The corresponding figures for PFOS were 32-1500 ng/l with an average of 520 ng/l (Figure 23). Even higher concentrations occurred in the untreated leachate water sample from the Högbytorp landfill (Figure 26), where also increased concentrations of pharmaceuticals were found (Andersson et al., 2006).

Regarding the perfluorinated carboxylic acids a similar pattern was identified as in the case of effluent water: the C7-C9 acid analogues (PFHpA, PFOA and PFNA) were most frequently encountered. PFOA was found in all four samples while PFHpA and PFNA occurred in three samples. The concentration of PFOA varied between 38 and 1000 ng/l (Figure 24 and Figure 26). For the other two C8-compounds, PFOSA and the telomeric 6:2 FTS, the pattern identified in the other aqueous phase samples was sustained further; 6:2 FTS was detected in all five samples in concentrations of 19 - 2000 ng/l (Figure 25). The C8-sulfonamide PFOSA was detected in two leachate water samples (4 -7 ng/l).

The detection limit for leachate water was for perfluorinated sulfonates 2 ng/l or less (for one sample 34 ng/l), for the perfluorinated acids 85 ng/l or less (for one sample 1300 ng/l) and for PFOSA 2 ng/l or less (for one sample 26 ng/l). Detection limits for individual samples are given in Appendix 5.

PFAS have previously been analysed in landfill leachate water samples from the southern part of Norway (Kallenborn et al., 2004). The concentrations of PFOS found in those samples varied between 33 and 108 ng/l, which is lower than the findings in this study. In the same study Kallenborn et al reported concentrations of PFHxA between 26.4 - 697 ng/l and PFOA between 91.3 - 516 ng/l.

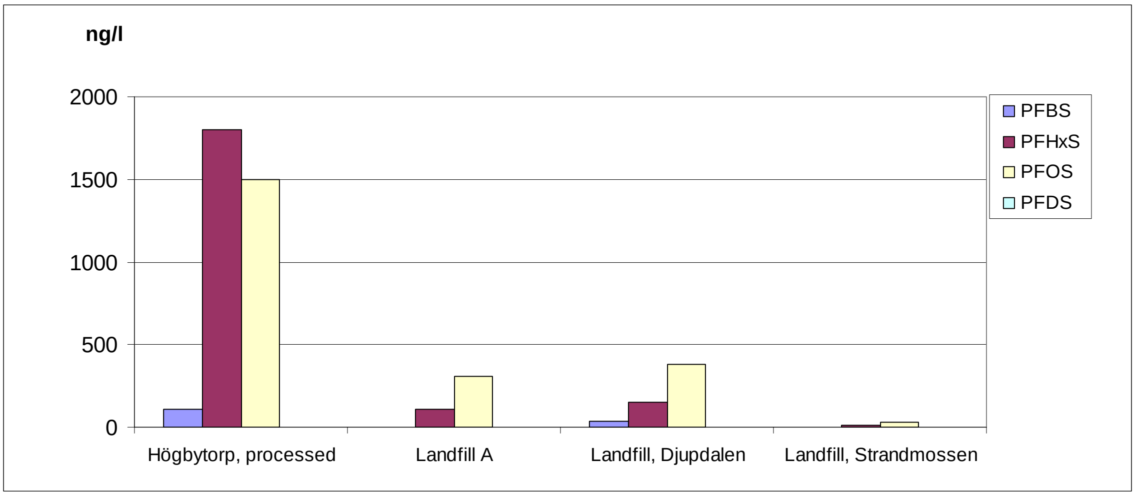


Figure 23. Concentrations of perfluorinated sulfonates (C_4-C_{10}) in leachate water samples.

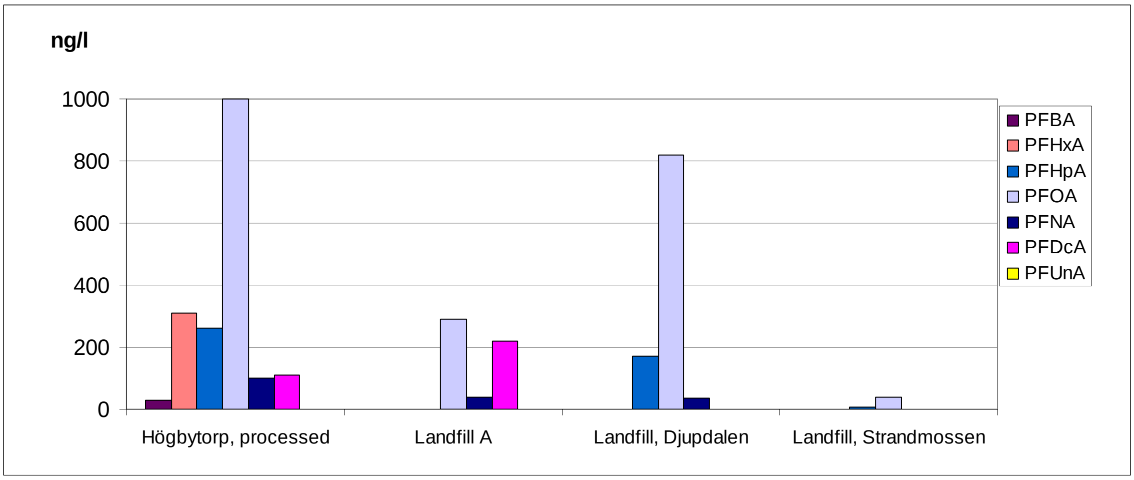


Figure 24. Concentrations of perfluorinated carboxylic acids (C_4-C_{11}) in leachate water samples.

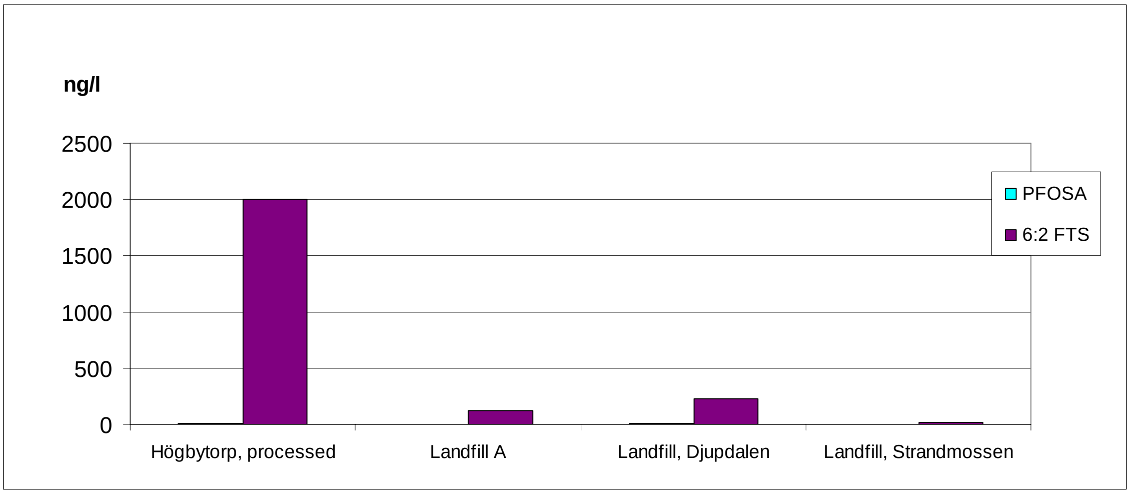


Figure 25. Concentrations of PFOSA (a perfluorinated C_8-sulfonamide) and 6:2 FTS (a fluorinated telomeric C_8-sulfonate) in leachate water samples.

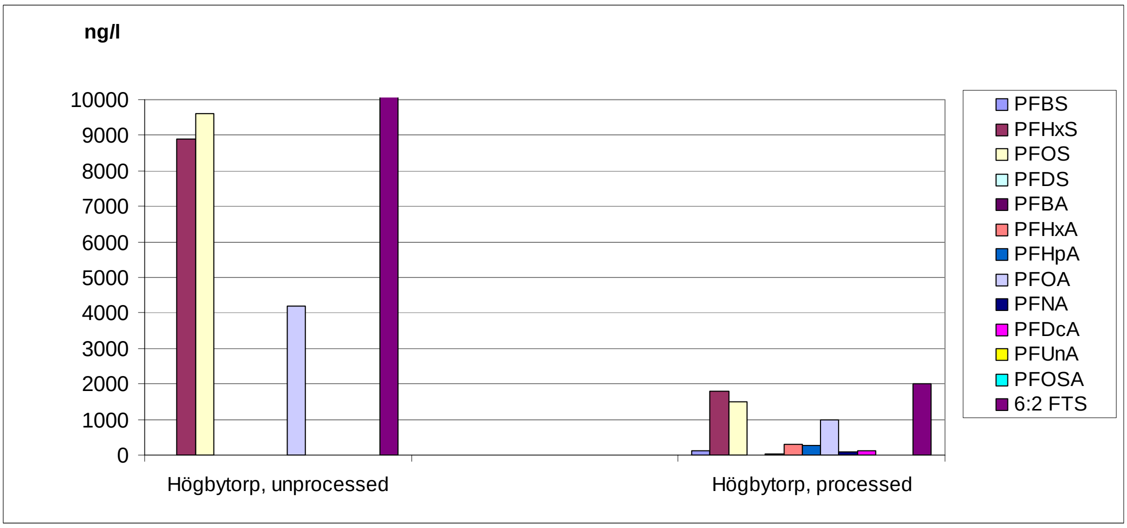


Figure 26. Concentration of PFAS in leachate water before and after the internal treatment process at Högbytorp landfill. Some components found in the processed water could not be quantified in the unprocessed water due to interference problems.

7.7 Concentrations in fish

Fish samples (perch) from the background lakes, Lilla Öresjön, Stora Envättern and Tärnan, as well as from Västra Ingsjön in the proximity to the Landvetter airport (point source) were included in the screening.

PFOS was found in fish from all three background lakes, in concentrations between 1.2-1.4 ng/g ww, which gives an indication how dispersed this compound is in the environment. Increased concentration of PFOS (98 ng/g ww) compared to the background levels occurred in the fish originating from Västra Ingsjön. Also the C_{10}-sulfonate, PFDS, was detected in this fish sample in a concentration of 0.23 ng/g ww. The fish sample from the Landvetter area also contained PFOSA, in a concentration of 2.4 ng/g ww. Perfluorinated carboxylic acids or telomeric C8-sulfonate, 6:2 FTS were not detected, neither in samples from the background lakes nor from the point source.

The detection limits for fish samples were for the perfluorinated sulfonates 0.3 ng/g ww or less, for the perfluorinated acids 7 ng/g ww or less, for PFOSA 0.2 ng/g ww or less and for 6:2 FTS 2.4 ng/g wwl or less. Detection limits for individual samples are given in Appendix 5.

Kallenborn et al. has previously reported PFOS concentrations of 172 - 432 ng/g ww, PFHxA concentrations of 0.62 - 1.08 ng/g and PFOSA concentrations of 0.6 - 6.1 ng/g ww in fish samples (Perch) from the North part of Sweden (Kallenborn et al., 2004).

8 Conclusions

PFAS are widespread contaminants in the Swedish environment. Perflourinated sulfonates were most frequently detected. From this group PFOS was found in most matrices and occurred in the highest concentrations. Internationally, there is an ongoing discussion in the industry whether the C4-sulfonate PFBS is a suitable replacement chemical for PFOS. PFBS was only found occasionally in this study.

Of the the perfluorinated carboxylic acids PFOA was the most frequently detected substance and occurred in highest concentrations. It was mainly found in water samples. Perfluorinated carboxylic acids were however less frequently found compared to the perflourinated sulfonates.

The sulfonamide PFOSA was more frequently encountered in solid matrices while the telomeric C8-sulfonate 6:2 FTS was often detected in the aqueous based matrices.

PFOS occurred in air both at the Swedish West Coast and in Northern Finland, which indicates that atmospheric long-range transport contributes to the remote occurrence of this substance. Somewhat increased air concentrations occurred in the urban area, while the PFOS levels found at Landvetter airport were in the same level as background air. PFOSA occurred in air samples from the urban site.

The importance of atmospheric transport of PFAS was also indicated by the precipitation samples where PFOS and PFOA were the most frequently found substances. The concentration of PFOS was significantly higher at the Swedish West Coast compared to the northern parts of Finland. PFOA was found in increased concentration in one of the samples from Pallas.

The concentrations of PFOS and PFOA in the marine water samples from the Swedish West Coast were in the same order of magnitude as in the precipitation while lower PFAS concentrations was found in the background lakes. However, the sample from one of the background lakes, Lilla Öresjön, contained increased concentrations of PFOA.

PFAS especially PFOS, was detected in **sediment samples** from both urban and background sites.

PFOS occurred **in fish** from all three background lakes, which gives an indication how dispersed this compound is in the environment.

PFAS was found in all samples **from the STPs**, both in effluent water and sludge, indicating that diffusive spreading of PFAS via STPs may occur. However there was a great variation in both the concentration and the distribution of the different PFAS. Leachate water from **landfills** may also be a source for diffuse emission of PFAS.

The high abundance of PFAS in effluent water, landfill leachate and various surface water samples indicates that water phase may be an important transport medium for these substances.

Increased concentrations of PFAS in e.g. surface water and fish samples collected close to Landvetter indicate that the activities at the airport may affect the concentration of PFAS.

9 Acknowledgements

The persons assisting in the sample collection phase of the work is acknowledged;

All the staff at the county administrative boards and different municipalities that have contributed to the sampling.

Billy Sjöwall and Tage Jonson at the Stockholm Environmental Administration for assistance in the urban area Stockholm sampling.

Thomas Helin at the Swedish Civil Aviation Administration for assisting in the sampling at the Landvetter airport.

The study has been financed by the Swedish EPA together with the Swedish County Administration Boards

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Appendix 1. Concentration data of PFAS from international reports

Table A 1. Reported concentrations in literature of PFAS in invertebrates and fish in Lake Ontario (Martin et.al. 2004).

	Invertebrates Mysis	Invertebrates Diporeia	Fish forage alewife	Fish forage smelt	Fish forage sculpin	Fish trout
Analyte	ng g^{-1}	ng g^{-1}	ng g^{-1}	ng g^{-1}	ng g^{-1}	ng g^{-1}
PFOS	13 ± 1.8	280 ±33	46 ± 15	110 ± 55	450 ± 98	170 ± 64
FOSA	130 ± 4.2	180 ± 26	4.0 ± 3.2	72 ± 23	150 ± 17	16 ± 9.6
PFOS	143	460	50	182	600	186
PFOA	2.5 ± 0.4	90 ± 8.5	1.6 ± 1.5	2.0 ± 1.1	44 ± 12	1.0 ± 0.1
PFNA	2.7 ± 0.1	57 ± 4.4	0.8 ± 0.8	6.8 ± 5.1	33 ± 23	4.2 ± 3.0
PFDA	1.3 ± 0.1	32 ± 1.1	1.4 ± 1.4	6.1 ± 3.9	29 ± 8.4	6.1 ± 4.5
PFUnA	1.3 ± 0.1	41 ± 2.9	1.3 ± 0.9	7.0 ± 4.5	39 ± 9.5	8.3 ± 6.0
PFDoA	1.8 ± 0.2	14 ± 1.5	2.1 ± 1.8	3.9 ± 1.6	14 ± 3.0	3.9 ± 2.5
PFTrA	1.5 ± 0.2	15 ± 0.8	1.5 ± 0.3	3.8 ± 1.5	13 ± 2.7	4.6 ± 2.6
PFTA	<0.5	7.3 ± 0.6	<0.5	0.6 ± 0.5	4.0 ± 1.0	1.3 ± 1.3
PFPA	<0.5	1.9 ± 1.4	<0.5	<0.5	0.9 ± 0.5	<0.5
ΣPFCA	12	260	9.2	30	180	30
ΣPFOS/ PFCA	12	1.8	5.4	6.1	3.3	6.2

Table A 2. Reported concentrations in literature of PFAS in Surface Water in Canada (Boulanger B. et.al. 2004).

Location	PFOA ng l^{-1}	N-EtF OSAA ng l^{-1}	PFOSulfinate ng l^{-1}	FOSA ng l^{-1}
Lake Erie, Canada/USA	21-47	3-11	2.5-18	0.5-1.3
Lake Ontario, Canada/USA	15-70	<0.3-10		<0.3-2.3

Table A 3. Reported levels of PFOS in Biota at different locations around the world (Giesy and Kannan 2001).

Species	Location	Tissue	PFOS	Number of samples
Aquatic mammals			ng g^{-1} w.w for liver and muscle tissue and ng ml^{-1} for blood plasma (mean values in brackets)	
ringed seal	Canadian Arctic	plasma	<3-12	24
ringed seal	Baltic Sea	plasma	16-230 (110)	18
ringed seal	Norwegian Arctic	plasma	5-14 (9)	18
gray seal	Baltic seal	plasma	14-76 (37)	26
gray seal	Canadian Arctic	plasma	11-49 (28)	12
Califonia Sea lion	Coastal California	liver	<35-49	6
elephant seal	Coastal California	liver	<35	5
harbour seal	Coastal California	liver	<35-57	3
river otter	Northwestern USA	liver	34-990 (330)	5
sea otter	Coastal California	liver	<35	8
northern furseal	Coastal waters of Alaska	liver	<35-120	14
polar bear	Alaska, USA	liver	180-680 (350)	17
mink	Midwestern USA	liver	970-3680 (2630)	18
bottlenose dolphin	Mediterranean	liver	170-430 (270)	5
striped dolphin	Mediterranean	liver	65-160 (100)	4
weddel Seal	Terra Nova Bay, Antarctica	liver	<35	1
Ganges river dolphin	Ganges river India	liver	<35-81	2
Birds				
double-crested cormorant	Lake Huron, Great lakes	plasma	1-270 (170)	6
herring gull	Lake Huron, Great lakes	plasma	66-79 (73)	2
polar skua	Terra Nova Bay, Antarctica	plasma	<1-1.4	2
black-tailed gull	Hokkaido, Japan	plasma	2-12 (6)	24
double-crested cormorant	Lake Winnipeg, Canada	egg yolk	130-320 (210)	4
ring-billed gull	Lake Huron, Great lakes	egg yolk	<35-150	3
Laysan and black-footed albatrosses	Midway Atoll, North Pacific	liver	<35	9
common loon	North Carolina, USA	liver	35-690 (290)	8
brown pelican	Mississippi, USA	liver	290-620 (460)	2
common cormorant	Italy	liver	33-470 (96)	12
black-tailed gull	Korea	liver	70-500 (170)	15
Laysan and black-footed albatrosses	Midway Atoll, North Pacific	plasma	9-26 (18)	3

Species	**Location**	**Tissue**	**PFOS**	**Number of samples**
double-crested cormorant	Lake Huron, Great Lakes	plasma	110-430 (260)	3
herring gull	Lake Huron, Great Lakes	plasma	280-450 (370)	2
bald eagle	Midwestern USA	plasma	1-2570 (360)	26
Laysan and black-footed albatrosses	Midway Atoll, North Pacific	plasma	3-39 (9)	10
Fish				
lake whitefish	Michigan waters, USA	eggs	150-380 (260)	2
brown trout	Michigan waters, USA	eggs	49-75 (64)	3
Chinook salmon	Michigan waters, USA	liver	33-170 (110)	6
lake whitefish	Michigan waters, USA	liver	33-81 (67)	5
brown trout	Michigan waters, USA	liver	<17-26	10
yellow-fin tuna	Northern North Pacific Ocean	liver	<7	12
blue-fin tuna	Mediterranean Sea	liver	21-87 (48)	8
carp	Saginaw Bay, Michigan USA	muscle	60-300 (120)	10
Chinook salmon	Michigan waters, USA	muscle	7-190 (110)	6
lake whitefish	Michigan waters, USA	muscle	97-100 (130)	5
brown trout	Michigan waters, USA	muscle	<6-46	10
Turtles and frogs				
yellow-blotched map turtle	Mississippi, USA	liver	39-700 (190)	6
green frogs	Southwest Michigan, USA	liver	<35-290	4
snapping turtle	Lake St. Clair, Michigan, USA	plasma	1-170 (72)	5

Table A 4. Measured concentrations of PFAS in air, Lake Ontario Canada (Boulanger et.al. 2005b).

	Concentration
	pg m^{-3}
PFOS particulate-phase	6.4 ±3.3
N-EtFOSE gas-phase (N-ethylperflourooctane sulfonamidoethanol)	0.5 ± 0.32
N-EtFOSA gas-phase	1.1 ± 0.9

Appendix 2. Sample information national samples

MR-no	County/National	City	Site	Matrix	Coordinates	Sampling date	DW, %
4597	National, Background		Pallas A	air		2005-12-20 - 2006-01-09	
4703+4704+4705	National, Background		Pallas B	air		2006-02-22 - 2006-03-22	
4795	National, Background		Pallas C	air		2006-05-02 - 2006-05-08	
4496+4498+4500+4503	National, Background		Råö A	air		2005-12-19 - 2006-01-16	
4620+4621+4638+4648	National, Background		Råö B	air		2006-01-31 - 2006-03-01	
4757+4782+4796	National, Background		Råö C	air		2006-05-04 - 2006-06-01	
4593	National, Background		Pallas A	precipitation		2005-12-19 - 2006-01-16	
4708	National, Background		Pallas B	precipitation		2006-03-01 - 2006-03-22	
4799	National, Background		Pallas C	precipitation		2006-04-13 - 2006-05-08	
4507	National, Background		Råö A1	precipitation		2005-12-19 - 06-01-02	
4493	National, Background		Råö A2	precipitation		2006-01-02 - 2006-01-19	
4676	National, Background		Råö B	precipitation		2006-01-31 - 2006-03-01	
4800	National, Background		Råö C	precipitation		2006-05-03 - 2006-06-01	
4509	National, Background		Råö A	surface water		2005-12-19	
4678	National, Background		Råö B	surface water		2006-03-01	
4802	National, Background		Råö C	surface water		2006-05-04	
4686	National, Background	Göteborg	Lilla Öresjön	perche, muscle, 10 indiv. median 7 years, 70 g, 19 cm		2004-08-31	
4504	National, Background	Göteborg	Lilla Öresjön	sediment		2004-08-31	11.9
4483	National, Background	Göteborg	Lilla Öresjön	surface water		2006-01-12	
4688	National, Background	Södertälje	Stensjön	perche, muscle 10 indiv. median 7 years, 35 g, 16 cm		2004-08-12	

MR-no	**County/National**	**City**	**Site**	**Matrix**	**Coordinates**	**Sampling date**	**DW, %**
4506	National, Background	Södertälje	Stensjön	sediment		2004-08-12	15.1
4367	National, Background	Södertälje	Stora Envättern	surface water		2005-11-13	
4687	National, Background		Tärnan	perche, muscle 10 indiv. median 9 years, 72 g, 19 cm		2004-10-06	
4505	National, Background		Tärnan	sediment		2004-10-06	24.8
4368	National, Background		Tärnan	surface water	6608828; 1645102	2005-11-19	
4631+4640+4649+4679	National, Diffuse		Stockholm A	air		2006-02-15 - 2006-03-15	
4690+4697+4711+4716	National, Diffuse		Stockholm B	air		2006-03-15 - 2006-04-12	
4724+4734+4733+4745+4752	National, Diffuse		Stockholm C	air		2006-04-12 - 2006-05-11	
4484	National, Diffuse		Riddarfjärden	sediment	6580118; 1627286	2005-11-23	27.9
4485	National, Diffuse		Stora Essingen	sediment	6579225; 1623638	2005-11-23	20.9
4486	National, Diffuse		Årstaviken	sediment	6578147; 1628330	2005-11-23	23.9
4398	National, Diffuse		Ellinge	sludge		2005-10-20	15.9
4399	National, Diffuse	Alingsås	Nolhaga	sludge		2005-10-18	22.1
4400	National, Diffuse	Borås	Gässlösa STP	sludge		2005-10-19	25.4
4401	National, Diffuse	Umeå	Umeå	sludge		2005-10-19	27.7
4402	National, Diffuse	Göteborg	Ryaverket	sludge		2005-10-19	27.3
4403	National, Diffuse		Floda	sludge		2005-10-20	30.7
4404	National, Diffuse		Bollebygd	sludge		2005-10-17	11.8
4414	National, Diffuse	Landskrona	STP	sludge		2005-11-30	21.9
4481	National, Diffuse	Uppvidinge	Åseda STP	sludge		2006-01-01	18.0
4572	National, Diffuse	Kiruna	Kiruna STP	sludge		2006-01-22	19.2
4586	National, Diffuse	Stockholm	Henriksdal STP	sludge		2006-01-25	26.0
4386	National, Diffuse	Stockholm	Stora Essingen	surface water	6579225; 1623638	2005-11-23	
4387	National, Diffuse	Stockholm	Årstaviken	surface water	6578147; 1628330	2005-11-23	
4388	National, Diffuse	Stockholm	Riddarfjärden	surface water	6580118; 1627286	2005-11-23	
4573	National, Diffuse	Borås	Gässlösa STP	effluent		2006-01-24	

MR-no	**County/National**	**City**	**Site**	**Matrix**	**Coordinates**	**Sampling date**	**DW, %**
4585	National, Diffuse	Stockholm	Henriksdal STP	effluent		2006-01-25	
4689+4696+ 4702+4728	National, Point source		Landvetter A	air		2006-03-08 - 2006-04-06	
4729+4743+ 4744+4759	National, Point Source		Landvetter B	air		2006-04-06 - 2006-05-04	
4936	National, Point source		Landvetter, Västra Ingsjön, perch,	fish		2006-06-01	
4761	National, Point source		Landvetter	sediment		2006-05-10	12.9
4763	National, Point source		Landvetter	sediment		2006-05-10	14.0
4730	National, Point source		Landvetter	precipitation		2006-03-08 - 2006-04-06	
4760	National, Point source		Landvetter	precipitation		2006-04-05 - 2006-05-04	
4762	National, Point source		Landvetter	surface water		2006-05-10	
4381	National, point source	Bro	Högbytorp	leachate before treatment		2005-11-20	
4382	National, point source	Bro	Högbytorp	leachate after treatment		2005-11-20	
4420	National, Point source	Alingsås	Industrial washing	effluent		2005-12-05	
4599	National, Point source	Rimbo	Industrial washing	effluent		2006-02-07	
4609	National, point source		Landfill A	leachate			

Appendix 3. Sample information regional samples

County	City	Site	Information	Matrix	Dimension (STP)	Affiliated (STP) pe	STP-treatment	Site information	Coordinates	DW (%)	Samping date	Sample ID
Värmland	Kristinehamn	Fiskartorpet STP	effluent	water	18000	16300	mech/chem/biol and nitrogen reduction	Hospitals, metal industries(mainly metal industries			2005-10-18	4248
	Karlstad	Landfill Djupdalen	leachate after aeration pond	water					6578124; 1401080		2005-10-26	4279
	Kristinehamn	Landfill Strandmossen	leachate	water							2005-11-01	4323
	Säffle	Säffle STP		sludge	15000	7750	mech/chem/biol and nitrogen reduction	Hospital		31	2005-10-18	4263
	Karlstad	Tjärnsjön	Textile industy	sediment						34	2005-11-07	4352
Västerbotten	Lycksele	STP		sludge		9000		industrial, hospital		23	2005-11-02	4344
	Skellefteå	Tuvan STP		sludge		43000			175009; 719024	23	2005-10-24	4305
Västra Götaland	Göteborg	Ryaverket STP		sludge						34	2005-10-12	4202
	Göteborg	Kodammarnas pumpstation		water							2005-12-20	4472

Appendix 4. List of samples and results

MR-no	**County /National**	**City**	**Site**	**Matrix**	**Unit**	**PFBA**	**PFHxA**	**PFHpA**	**PFOA**	**PFNA**	**PFDcA**	**PFUnA**	**PFBS**	**PFHxS**	**PFOS**	**PFDS**	**PFOSA**	**6:2 FTS**
4597	National, Background		Pallas A	air	pg/m3	<0.035	<0.11	<0.0037	<0.11	<0.077	<0.057	<0.063	<0.005	<0.0037	0.0047	<0.0015	<0.0016	<0.027
4703+4704+4705	National, Background		Pallas B	air	pg/m3	<7.9	<12	<0.27	23	<7.3	12	<5.7	<0.29	<0.27	1.1	<0.1	<0.12	<2.4
4795	National, Background		Pallas C	air	pg/m3	<1	<1.8	<0.021	<0.83	<1.1	<0.69	<0.74	<0.041	<0.021	0.08	<0.018	<0.021	<0.33
4496+4498+4500+4503	National, Background		Råö A	air	pg/m3	<1.6	<1	<1.6	<1.5	<1.2	<0.96	<0.58	<0.071	0.07	1.2	<0.03	<0.045	<0.69
4620+4621+4638+4646	National, Background		Råö B	air	pg/m3	<1.1	<2.1	0.04	<1.5	<0.96	<0.88	<0.92	0.10	0.04	0.79	<0.017	<0.025	<0.38
4757+4782+4796+4797	National, Background		Råö C	air	pg/m3	<0.8	<1.6	0.08	1.10	<0.92	1.2	<0.81	<0.023	0.08	1.2	0.02	<0.023	<0.23
4593	National, Background		Pallas A	precipitation	ng/l	<0.63	<1	<0.6	<2	<0.6	<1.9	<1	<0.04	<0.01	0.23	<0.04	<0.04	0.85
4708	National, Background		Pallas B	precipitation	ng/l	<1.3	<2	<2	3.1	<2	<3.6	<1.9	<0.05	<0.03	0.22	<0.07	<0.1	5.9
4799	National, Background		Pallas C	precipitation	ng/l	<4.1	<7.3	<0.23	<6.6	<4.2	<10	<3.7	<0.4	<0.23	0.47	<0.11	<0.12	<1.6
4507	National, Background		Råö A1	precipitation	ng/l	<2.2	<3	<2	2.3	<2	<3.8	<3.5	<0.1	0.62	5.7	<0.1	<0.1	1.7
4493	National, Background		Råö A2	precipitation	ng/l	<5.8	<2	<2	13	<3	<6.8	<4.8	1.50	1.30	7.7	<0.1	<0.2	1.6
4676	National, Background		Råö B	precipitation	ng/l	<0.7	<0.7	<0.3	3.1	<1	<2.2	<1.7	<0.04	0.24	2.9	<0.04	0.07	0.88
4800	National, Background		Råö C	precipitation	ng/l	<4	<4	<2.9	3.6	<2.3	<2.7	<2	<0.22	0.47	2.20	<0.12	0.21	<1.1
4509	National, Background		Råö A	surface water	ng/l	<1	<2	<2	8.2	3.2	<3.3	<3.6	1.5	1.1	7.6	<0.2	<0.2	3.7
4678	National, Background		Råö B	surface water	ng/l	<0.54	<0.6	<0.5	0.94	<0.8	<1.7	<1.7	0.30	0.20	1.8	<0.07	<0.1	0.82
4802	National, Background		Råö C	surface water	ng/l	<2	<1.9	<1.6	3.2	<2.6	<2.3	<1.1	0.44	0.400	4.5	<0.059	<0.079	<0.86
4686	National, Background		Lilla Öresjön	fish	ng/g w w	<3	<6.8	<0.073	<3.7	<4	<3.5	<2.9	<0.11	<0.074	1.4	<0.13	<0.13	<1.9
4688	National, Background		Stensjön	fish	ng/g w w	<2.8	<5.8	<0.13	<3.9	<5.8	<4.7	<3.6	<0.15	<0.13	1.2	<0.13	<0.094	<1.3
4687	National, Background		Tärnan	fish	ng/g w w	<3.3	<5.5	<0.13	<3.8	<3.2	<3.6	<2.4	<0.17	<0.13	1.4	<0.072	<0.2	<1.1

MR-no	County /National	City	Site	Matrix	Unit	PFBA	PFHxA	PFHpA	PFOA	PFNA	PFDcA	PFUnA	PFBS	PFHxS	PFOS	PFDS	PFOSA	6:2 FTS
4504	National, Background		Lilla Öresjön	sediment	ng/g w w	<1.4	<3	<2	<1	<2	<1.4	<1	<0.04	<0.2	0.22	<0.05	<0.03	<0.41
4506	National, Background		Stensjön	sediment	ng/g w w	<8.4	<1	<2	<1	<0.5	<3	<2	<0.03	<0.1	0.05	<0.03	<0.03	<1.1
4505	National, Background		Tärnan	sediment	ng/g w w	<1.3	<4	<5	<3	<3	<2.4	<0.44	<0.2	<0.3	<0.2	<0.08	<0.1	<0.36
4483	National, Background		Lilla Öresjön	surface water	ng/l	<1.2	<1	2.1	14	<2	<2.9	<3.3	0.093	0.190	1.7	<0.09	<0.1	1.200
4367	National, Background		Stora Envättern	surface water	ng/l	<1.5	<2	<1	2.20	2.20	<3.2	<4.8	<0.1	0.15	3.1	<0.2	<0.2	2.00
4368	National, Background		Tärnan	surface water	ng/l	<1.8	<1	<0.8	<2	<0.8	<5.1	<3.6	<0.05	0.13	1.1	<0.2	<0.2	1.3
4631+4640+4649+4679	National, Diffuse	Stockholm	Stockholm A	air	pg/m3	<6.7	<11	<0.37	<11	<8.2	<7.9	<7.2	<0.57	<0.37	2.6	0.38	3.3	<2.4
4690+4697+4711+4716	National, Diffuse	Stockholm	Stockholm B	air	pg/m3	<4.5	<8.5	<0.28	13	<6.7	<4.9	<4.4	<0.31	<0.28	3.1	<0.12	4.3	<2.1
4724+4733+4745+4752	National, Diffuse	Stockholm	Stockholm C	air	pg/m3	<7.6	<14	0.21	<7.2	<8.9	<6.7	<7	<0.19	0.210	3.9	<0.17	2.8	<2.5
4388	National, Diffuse	Stockholm	Riddarfjärden	surface water	ng/l	<1.5	<0.8	<1	2.3	0.91	<6.8	<3.4	0.45	1.90	13	<0.1	<0.2	2.20
4386	National, Diffuse	Stockholm	Stora Essingen	surface water	ng/l	<1.2	<0.8	<0.7	2.2	1.7	<2.7	<3	0.47	1.90	12	<0.1	<0.2	1.70
4387	National, Diffuse	Stockholm	Årstaviken	surface water	ng/l	<0.82	<0.8	0.95	3.0	2.1	<4.9	<2.9	0.43	1.90	12	<0.1	0.14	3.20
4484	National, Diffuse	Stockholm	Riddarfjärden	sediment	ng/g w w	<1.1	<2	<2	<1	<1	<2.5	<0.52	<0.03	<0.06	0.66	<0.08	<0.04	<0.5
4485	National, Diffuse	Stockholm	Stora Essingen	sediment	ng/g w w	<1.8	<2	<3	<1	<1	<2.1	<1.1	<0.1	<0.1	1.60	0.11	<0.04	<0.68
4486	National, Diffuse	Stockholm	Årstaviken	sediment	ng/g w w	<1.5	<3	<4	<1	<0.6	<1.4	<0.79	<0.04	<0.1	0.85	0.11	<0.03	<0.65
4398	National, Diffuse	Eslöv	Ellinge	sludge	ng/g w w	16	<2	<2	<2	<2	<1.3	<0.86	<0.1	<0.1	1.5	0.15	0.16	<0.48
4399	National, Diffuse	Alingsås	Nolhaga	sludge	ng/g w w	<2.4	<4	<7	<2	<3	<1.7	<1.7	<0.3	<0.1	1.7	0.12	0.18	<0.9
4400	National, Diffuse	Borås	Gässlösa STP	sludge	ng/g w w	<2.4	<2	<2	4.3	14	18	34	<0.2	<0.2	6.1	0.92	0.42	<0.87
4401	National, Diffuse	Umeå	Umeå	sludge	ng/g w w	<2	<3	<2	<2	<3	<2.6	<1.5	<0.3	<0.1	2.0	2.7	0.14	<0.77
4402	National, Diffuse	Göteborg	Ryaverket	sludge	ng/g w w	<1.9	<2	<2	<2	<3	<1.6	<1.5	<0.2	<0.2	9.7	1.3	0.31	<0.8
4403	National, Diffuse		Floda	sludge	ng/g w w	<1.4	<3	<2	<2	<2	<3.5	<0.83	<0.3	<0.06	0.66	0.29	0.13	<0.47
4404	National, Diffuse		Bollebygd	sludge	ng/g w w	<1.8	<2	<0.8	<1	<1	<0.89	<1.1	<0.2	<0.1	0.43	<0.04	<0.05	<0.56

MR-no	**County /National**	**City**	**Site**	**Matrix**	**Unit**	**PFBA**	**PFHxA**	**PFHpA**	**PFOA**	**PFNA**	**PFDcA**	**PFUnA**	**PFBS**	**PFHxS**	**PFOS**	**PFDS**	**PFOSA**	**6:2 FTS**
4572	National, Diffuse	Kiruna	Kiruna STP	sludge	ng/g w w	<1.9	<2	<2	<1	<1	<1.2	<1.6	<0.2	<0.1	0.52	<0.05	<0.2	<1.4
4586	National, Diffuse	Stockholm	Henriksdal STP	sludge	ng/g w w	13	<2.2	<2.6	<3.5	<1.8	<1.8	<1.3	<0.18	0.140	30	3.3	0.96	<0.91
4414	National, Diffuse	Landskrona	Landskrona	sludge	ng/g w w	<3.3	<8.2	<0.11	<3.6	<5.5	<4.3	<2.5	<0.18	<0.11	2.8	0.20	1.00	2.2
4481	National, Diffuse	Uppvidinge	Åseda STP	sludge	ng/g w w	<3.9	<11	0.67	<2.9	<3.3	<4.3	<3.5	<0.28	0.67	35	0.32	0.71	<1.5
4571	National, Diffuse	Kiruna	Kiruna STP	effluent water	ng/l	<5.7	22	3.6	30	70	7.0	<4.9	0.720	3.6	49	<0.1	0.98	12
4573	National, Diffuse	Borås	Gässlösa STP	effluent water	ng/l	<3.5	14	28	77	57	48	62	5.0	9.8	45	<0.3	<0.5	7.9
4585	National, Diffuse	Stockholm	Henriksdal STP	effluent water	ng/l	<3.5	<2	3.2	9.0	2.8	<6.7	<3.3	4.2	6.0	43	<0.14	0.2	11.0
4689+4696 +4702+4728	National, Point source		Landvetter A	air	pg/m3	<1.4	<2.3	0.052	1.9	<1.4	<1	<0.76	<0.058	0.052	0.78	<0.021	<0.029	<0.39
4729+4743 +4744+4759	National, Point source		Landvetter B	air	pg/m3	<1.1	<2.1	0.068	<1	<1.1	<1.1	<0.86	<0.037	0.068	0.51	<0.02	<0.027	<0.38
4730	National, Point source		Landvetter	precipitation	ng/l	<0.72	<1.5	0.070	1.3	<0.72	<1.5	<0.64	<0.028	0.070	0.81	<0.014	0.28	1.1
4760	National, Point source		Landvetter	precipitation	ng/l	<1.4	<2.9	<0.07	2.3	<1.8	<1.8	<1.5	<0.06	<0.07	0.96	<0.051	0.31	1.4
4762	National, Point source		Landvetter	surface water	ng/l	<2	<6.4	3.4	<6.3	<5.4	<6.2	<4.3	<0.15	3.4	39	0.11	<0.098	3.7
4763	National, Point source		Landvetter	sediment	ng/g w w	<2.3	<5	<0.18	<3.9	<3.7	<5.9	<2.6	<0.096	<0.18	0.16	<0.088	<0.071	<0.86
4761	National, Point source		Landvetter	sediment	ng/g w w	<2.2	<7.1	<0.16	<2.1	<1.8	<2.6	<1.7	<0.093	<0.16	0.26	<0.046	<0.056	<0.64
4936	National, Point source		Landvetter, Västra Ingsjön	fish	ng/g w w	<4.4	<11	<0.24	<5.1	<6.2	<5.1	<10	<0.28	<0.24	98	0.23	2.400	<2.4
4599	National, Point source	Rimbo	Industrial textile washing	effluent water	ng/l	<26	<20	<26	<19	<28	<24	<21	<2	2.40	26	6.7	<2	20.0
4420	National, Point source	Alingsås	Industrial textile washing	effluent water	ng/l	<12	<13	22.0	74	<13	<8.2	<20	1.1	2.7	59	<0.3	<1	<5.1
4381	National, Point source		Högbytorp, före rening	leachate	ng/l	<1300	<300	<600	4200	<680	<410	<430	<34	8900	9600	<11	<26	14000
4382	National, Point source		Högbytorp, efter rening	leachate	ng/l	30.0	310	260	1000	100	110	<5.9	110	1800	1500	0.28	7	2000
4609	National, Point source		Landfill A	leachate	ng/l	<85	<16	<20	290	40	220	<37	<2	110	310.0	<1	<2	120
4352	Värmland	Karlstad	Tjärnsjön	sediment	ng/g w w	<1.4	<3	<3	<2	<3	30	<2	<0.05	<0.07	0.072	<0.06	<0.04	<0.43
4263	Värmland	Säffle	Säffle STP	sludge	ng/g w w	<1.6	<3	<3	<1	<3	<1.1	<1.1	<0.2	<0.06	2.1	<0.04	<0.1	<0.49
4248	Värmland	Kristinehamn	Fiskartorpet STP	effluent water	ng/l	<3.2	<2	<2	7.4	1.5	3.0	<1.8	0.34	1.20	6.7	<0.06	0.13	2.1

MR-no	**County /National**	**City**	**Site**	**Matrix**	**Unit**	**PFBA**	**PFHxA**	**PFHpA**	**PFOA**	**PFNA**	**PFDcA**	**PFUnA**	**PFBS**	**PFHxS**	**PFOS**	**PFDS**	**PFOSA**	**6:2 FTS**
4279	Värmland	Karlstad	Landfill Djupdalen	leachate	ng/l	<19	<18	170	820	34	<69	<59	39	150	380	<2	4	230
4323	Värmland	Kristinehamn	Landfill Strandmossen	leachate	ng/l	<12	<7	7.70	38	<18	<20	<38	<0.5	12	32	<1	<2	19
4305	Västerbotten	Skellefteå	Tuvan STP	sludge	ng/g w w	<2	<3	<3	<2	<2	44	<1.5	<0.2	0.08	11	1.50	0.22	<1.5
4344	Västerbotten	Lycksele	Lycksele STP	sludge	ng/g w w	<2	<2	<3	<2	<2	<2	<1.4	<0.3	<0.2	2.2	0.56	<0.1	<0.75
4202	Västra Götaland	Rya	GRYAAB	sludge	ng/g w w	<2.6	<4	<3	<2	<2	<1.2	<1.4	<0.4	<0.07	6.3	0.55	0.13	<0.67
4472	Västra Götaland	Göteborg	Kodammarnas pumpstation	effluent water	ng/l	<46	<21	<25	<13	<18	<15	<14	1.7	8.7	38	<0.6	<3	21