REPORT

Results from the Swedish National Screening Programme 2007

Subreport 4: Linear alkyl benzene sulfonate (LAS)

Lennart Kaj, Karl Lilja, Mikael Remberger,
Ann-Sofi Allard, Brita Dusan, Eva Brorström-Lundén

B1808
October 2008

This report approved
2008-11-20

Lars-Gunnar Lindfors
Scientific Director

IVL Swedish Environmental Research Institute

Organization	Report Summary
IVL Swedish Environmental Research Institute Ltd.	**Project title** **Screening 2007**
Address P.O. Box 21060 SE-100 31 Stockholm	**Project sponsor** Environmental Monitoring, Swedish Environmental Protection Agency
Telephone +46 (0)8-598 563 00	

Authors

Lennart Kaj, Karl Lilja, Mikael Remberger, Ann-Sofi Allard, Eva Brorström-Lundén

Title and subtitle of the report

Results from the Swedish National Screening Programme 2007

Subreport 4: Linear alkyl benzene sulfonate (LAS)

Summary

LAS (linear alkylbenzene sulfonate) is an anionic sufactant mainly used in laundry- and dishwashing detergents and lubricant additives. The annual amount used in Sweden is about 900 tonnes. As an assignment from the Swedish Environmental Protection Agency, IVL has performed a screening study of LAS. The overall objective of the screening was to determine concentrations in a variety of media in the Swedish environment.

Keyword

LAS, linear alkylbenzene sulfonate, anionic sufactant, detergent, lubricant, sceening, water, sediment, sludge

Bibliographic data

IVL Report B1808

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

Summary

LAS (linear alkylbenzene sulfonate) is an anionic sufactant mainly used in laundry- and dishwashing detergents and lubricant additives. The annual amount used in Sweden is about 900 tonnes. As an assignment from the Swedish Environmental Protection Agency, IVL has performed a screening study of LAS. The overall objective of the screening was to determine concentrations in a variety of media in the Swedish environment. A national sampling program (50 samples) was combined with an extensive regional program administered by eight county administarive boards (72 samples). Sample types were waste water, sludge, storm water, ground water, surface water, soil and sediment.

LAS was not found in surface waters, sediments or soil from background areas.

LAS was found in the influents to all investigated sewage treatment plants (STPs). The median concentration was 360 µg/l. LAS was also found in all effluent waters from STPs. The median concentration was 2.7 µg/l. In 19 pairs of influent/effluent waters the removal efficiency was 95 - 99.9%. The median concentration in sludge was 670 mg/kg DW. As an average 33% of the LAS entering STPs ended up in sludge.

LAS was found in traffic related storm waters (0.2 – 6 µg/l) and land fill lechates (0.58 – 1.2 µg/l).

Sediments from the urban area Stockholm were contaminated with LAS (360 – 1 600 ng/g DW).

Commercial LAS consists of a mixture of chain lengths ranging from C10 to C14. An alteration in the distribution of chain lengths were noticed depending of sample types.

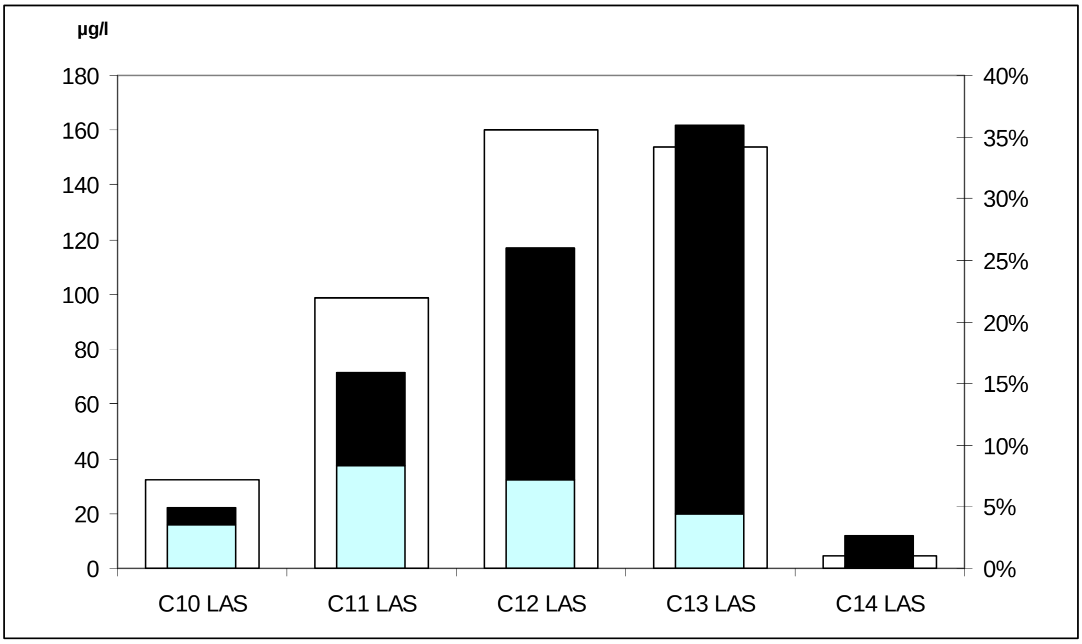
The concentrations of LAS measured in sediments from recipients and urban areas (270-1 600 ng/g DW) are lower than the PNEC-values, 8 100 ng/g DW and 4 900 ng/g DW for fresh water sediments and marine sediments respectively, found in the literature (Chapter 2.2). However, these values have been derived from limited sets of data and some studies indicate that they might not be protective.

The concentrations of LAS found in surface waters from urban areas and industrial recipients were lower than reported PNEC-values derived from extensive sets of toxicity data. Thus, LAS is not expected to cause adverse effects in the water phase of the recipients.

Sammanfattning

LAS (linjär alkylbensensulfonat) är en anjontensid som huvudsakligen används i tvätt- och diskmedel och som tillsats i smörjmedel. Den årliga användningen i Sverige är ca 900 ton. På uppdrag av Naturvårdsverket har IVL utfört en screeningundersökning av LAS. Det huvudsakliga syftet med studien var att bestämma koncentrationen i ett antal matriser i den svenska miljön. Ett nationellt provtagningsprogram (50 prov) kombinerades med ett omfattande regionalt program (72 prov) där åtta länsstyrelser bidrog. Provtyper var avloppsvatten, slam, dagvatten, grundvatten, ytvatten, jord och sediment.

LAS i kommersiell form är vanligen en teknisk blandning kallad natriumdodecylbenzensulfonat. Denna består av raka kolkedjor med 10 till 14 kolatomer som till något av kolen, ändkolen undantagna, binder en i paraställning sulfonerad bensenring. En typisk fördelningen av kolkedjornas längd illustreras i Figur A, ofyllda staplar.



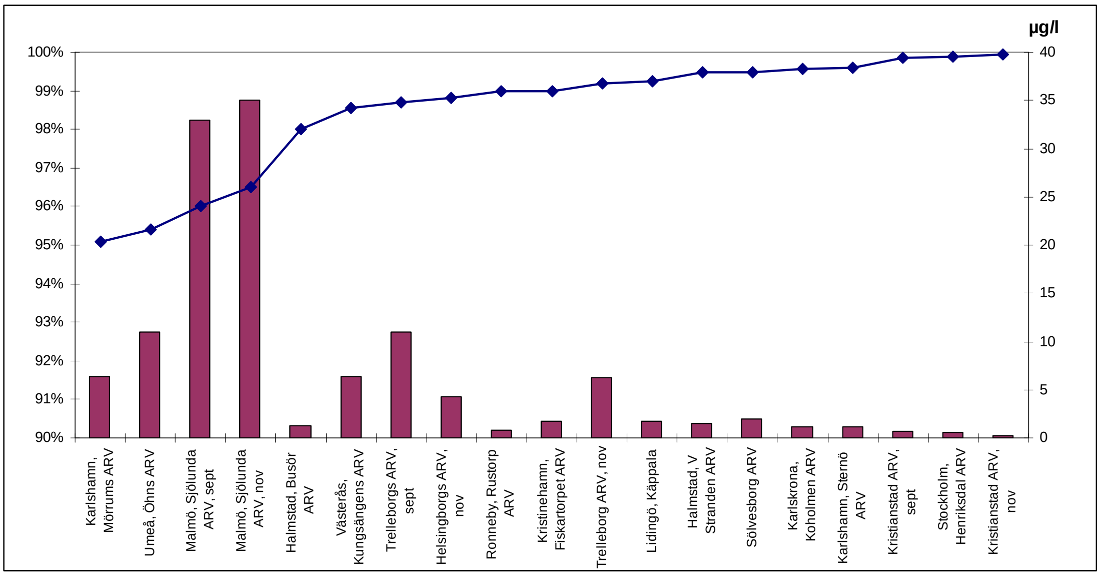
Figur A Procentuell fördelning av kolkedjelängd i teknisk blandning av LAS (ofyllda staplar, högra axeln) samt koncentration av LAS av olika kedjelängd i vattenfas (blå staplar) och partikelfas (svarta staplar) i inkommande avloppsvatten till Sölvesborg ARV (vänstra axeln).

LAS hittades inte i ytvatten, sediment eller jord från bakgrundsområden.

LAS uppmättes i samtliga analyserade inkommande vatten till avloppsreningsverk (ARV). Mediankoncentrationen (summa C10 – C14-LAS) i 19 prov var 360 µg/l. Högst koncentration hittades i Sjölundaverket, Malmö och lägst i Busör ARV, Halmstad. Ett typiskt exempel på fördelning av kolkedjelängder i inkommande avloppsvatten ges i Figur A, färgade staplar. Där framgår också att längre kolkedjor i högre grad binds till avloppsvattnets partikelfas.

LAS uppmättes också i samtliga utgående avloppsvatten (26 prov). Mediankoncentrationen var 2.7 µg/l. Koncentrationen var högst i Rimbo avloppsreningsverk (ARV) och i Sjölundaverket, Malmö.

Reningsgraden (19 par av inkommande/utgående avloppsvatten) varierade mellan 95 och 99.9%. Detta illustreras tillsammans med halterna i utgående vatten i Figur B.



Figur B Procentuell reningsgrad (punkter och linje, vänstra axeln) och koncentration (summa C10 – C14LAS) i utgående avloppsvatten (staplar) i olika reningsverk.

Mediankoncentrationen i reningsverksslam var 670 mg/kg TS. I medeltal 33% av till reningsverken inkommande LAS återfinns i slammet. Slammet från ett reningsverk överskred den haltgräns för spridning på jordbruksmark som föreslagits i EU.

LAS uppmättes i trafikdagvatten i koncentrationer mellan 0.2 och 6 µg/l och i deponilakvatten i halter mellan 0.58 och 1.2 µg/l.

Sediment från Mälaren vid St. Essingen, i Årstaviken och Riddarfjärden, alla i Stockholm, var kontaminerade med LAS i koncentrationer mellan 360 och 1 600 ng/g TS.

LAS-koncentrationen i sediment från recipienter för avloppsvatten och urbana områden (270-1 600 ng/g TS) är lägre än de PNEC-värden för sötvattensediment (8 100 ng/g TS) och marina sediment (4 900 ng/g TS) som återfunnits i litteraturen. Dessa värden är beräknade från ett begränsat antal mätdata och några studier tyder på att de kan vara underskattade.

De LAS-koncentrationer som uppmätts i ytvatten från urbana områden och industriella recipienter var lägre än de PNEC-värden som beräknats ur omfattande underlag av toxicitetsdata. Alltså förväntas inte LAS medföra några negativa effekter för organismer i vattenfasen.

Table of contents

1. Introduction

As an assignment from the Swedish Environmental Protection Agency, screening studies of amines, esters, pigments, linear alkyl benzene sulfonate (LAS) and silver have been performed during 2007/2008. These substances are emitted and distributed in the environment via a variety of sources, e.g. different point sources and/or diffusive sources. Some of them are used in consumer products.

The overall objectives of the screening studies are 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.

The results are given in five sub-reports according to Table 1.

Table 1 Substances / substance groups included in the screening

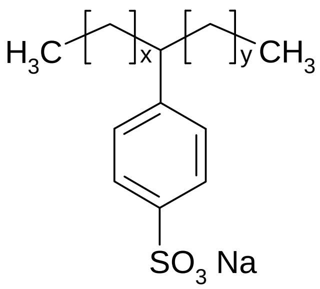
Substance / Substance group	Sub-report #
Amines:	1
3,6,9,12-Tetraazatetradecane-1,14-diamine	
N-cyclohexyl-2-benzothiazolamine (NCBA)	
N-isopropyl-N'-phenyl-p-phenylenediamine (IPPD)	
N-Phenyl-benzeneamine	
Dicyclohexylamine	
Esters:	2
Octadecyl 3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate	
Pigments:	3
Pigment yellow 1 (CI 11680)	
Pigment orange 5 (CI 12075)	
Pigment red 53:1 (CI 15585:1)	
Pigment red 170 (CI 12475)	
Linear alkyl benzene sulfonate (LAS)	4
Silver	5

This sub-report considers the screening of the linear alkyl benzene sulfonate (LAS). LAS is an anionic sufactant mainly used in chemical products such as laundry- and dishwashing detergents, allround cleaners, lubricant additives and biocides. It is also used as a surface active agent in industrial processes.

2. Chemical properties, fate and toxicity

2.1. Properties and fate

The most common form of commercial LAS is sodium dodecyl benzenesulfonate, often called sodium lauryl benzenesulfonate. It is a mixture of more than 20 different components, consisting of a para-sulphonated aromatic ring attached to a linear alkyl chain (10-14 carbon units) at any position except the terminal carbons, see Figure 1. The ratio of the different isomers and homologues is relatively constant in the various commercial products, with an average carbon number of 11.6-11.8 for the alkyl chain in products on the European market (OECD SIDS, 2005).



where x+y = n
and n = 7-11

Figure 1 Molecular structure of the sodium salt of LAS.

The physical-chemical properties of commercial LAS are presented in Table 2. LAS has a high water solubility, 250 g/l, but at concentrations above the critical micelle concentration, 0.65 g/l, micelles start to form. LAS has a low vapour pressure and is thus not predicted to volatize. Sorption to solids increases with carbon chain length, a K_{oc} value of 2500 L/kg has been calculated for $C_{11.6}$. In the environment the distribution of LAS homologues thus can differ in different environmental compartments. It has also been shown that sorption decreases with increasing concentrations of LAS (OECD SIDS, 2005)

Table 2 Physico-chemical properties of commercial LAS ($C_{11.6}$) or the pure C_{12} homologue (HERA 2007).

Property	Value	Comments
MW (g/mol)	342.4	$C_{11.6}$
Melting point (°C)	277	Calculated as C_{12}
Boiling point (°C)	637	Calculated as C_{12}
Vapour pressure (Pa)	$(3-17) * 10^{-13}$	Calculated as C_{12}
Water solubility (g/L)	250	Experimental
Critical micelle conc. (g/L)	0.65	Experimental
Henry's Law constant (Pa * m^3/mol)	$6.36 * 10^{-3}$	Calculated as C_{12}
Log Kow	3.32	Calculated as $C_{11.6}$
K_{oc} (L/kg)	2500	Calculated as $C_{11.6}$

LAS have been shown to be effectively removed, in the range 98-99.9%, in activated sludge sewage treatment plants (STPs). Mass balance studies indicate that 80-90% is degraded, 10-20% adsorbed to sludge, and 1% released to surface waters (HERA, 2007). The sludge adsorbed fraction can then enter the environment if sludge is used as a fertilizer in forestry or on agricultural soils, or through leakage from landfills. Due to the water solubility LAS could be expected to be mobile in soil with leakage to lower layers and ground waters as a consequence, but in a lysimeter study with LAS added incorporated in sludge by Jakobsen et al. (2004), no leakage from the top soil were found.

Once in the environment, LAS degrades relatively rapid (HERA, 2007). It is degradable under aerobic conditions, as evaluated by ready tests (OECD 301 A, B, D, E, F) inherent tests (OECD 302 A, B), and a simulation test (OECD 303 A), and no persistent degradation intermediates are formed. Anaerobic degradation of LAS is limited, but can continue if initiated under oxygen-limited conditions.

In the review by HERA (2007), half-lifes in the range of 1-12 hours for primary biodegradation, and 18 hours for ultimate biodegradation in aqueous mediums are reported. Other reported primary degradation half-lifes are in the range of 3.26 days for river water (Perales *et al.,* 2007), 3.4-13.8 days for coastal water (Vives-Rego *et al.,* 2000), and 0.3-8.2 days in sea water (León *et al.,* 2004: Perales *et al.,* 2007). Degradation rates are haltered by higher concentrations of LAS (Perales *et al.,* 1999; Lara-Martín *et al.,* 2007). Some studies also indicate slower degradation rates at lower water temperatures (León *et al.,* 2004: Perales *et al.,* 1999), thus degradation rates may vary seasonally and can be slower in colder climates.

In anaerobic marine sediments a half-life of approximately 90 days was determined by Lara-Martín *et al.* (2007), but significantly higher values, up to several years, expected at concentrations above 20 mg/kg dw due to microbial toxicity.

For soil, half-lifes in the range 1-26 days have been reported from laboratory and field studies (reviewed in OECD SIDS, 2005)

2.2. Toxicity

Mammalian toxicity of LAS is reviewed in the OECD SIDS Initial Assessment Report where it is concluded that LAS is of low hazard potential to humans (OECD SIDS, 2005). Animal studies have shown low or moderate acute toxicity, that LAS is not genotoxic nor carcinogenic, and do not cause reproductive toxicity. It is not eye irritating at low concentrations (0.5-2.5%), but can be reversibly irritating at higher concentrations.

The toxicity of LAS is caused by the surfactant properties it is used for; it causes perturbation of cell membranes, and the toxicity has been shown to increase exponentially with carbon chain length (HERA 2007).

The ecotoxicity of LAS has been extensively studied and PNECs (predicted no-effect concentrations) for most environmental compartments can be found in the literature, see Table 3. The values have been derived by the use of application factors (safety margins) on NOECs (no observed effect concentration) or LC10-values when limited numbers of chronic toxicity data have been available, or by the use of species sensitivity distributions (SSDs) for environmental compartments more extensively studied. PNEC values are dependent on the toxicity data available and methodology used, and should not be considered true no-effect concentrations.

Table 3. PNEC (predicted no-effect concentration) values for different environmental compartments found in the literature.

Environmental compartment	PNEC	Method	Comment	Reference
Fresh water	0.293 mg/l	Ecosystem NOEC	Model stream ecosystem exposed for 56 days.	Belanger *et al.*, 2002
	0.32 mg/l 0.25 mg/l	SSD[a], lower value adjusted according to results from field studies.		Plassche van de *et al.*, 1999
	0.36 mg/l	SSD on NOEC values	Same data set as for SSD by van de Plassche	Temara *et al.*, 2001
Fresh water sediment	8.1 mg/kg dw	AF=10 on most sensitive chronic NOEC	3 evertebrate species tested	Comber *et al.*, 2006
Marine/brackish waters	0.031 mg/l	SSD on NOEC values		Temara *et al.*, 2001
	0.0021 mg/l	SSD on NOEC values		Selck *et al.*, 2002
Marine sediment	4.9 mg/kg dw	AF=10 on most sensitive sub-chronic LC10	3 sediment dwelling organisms tested	Hampel *et al.*, 2007
Soil	35 mg/kg dw	SSD on NOEC and EC10 values		Jensen *et al.*, 2007

[a]SSD: Species Sensitivity Distribution

Using the SSD approach, the PNEC represents a value for which 95% of all species, can be assumed not to be exposed to concentrations exceeding their EC10 or NOEC (Jensen *et al.,* 2007). In the data used for the determination of the PNEC value for soil (35 mg/kg dw) by Jensen *et al.* (2007), most values found in the lower part of the species sensitivity distribution are EC10 values for reproduction or growth. The PNEC thus represents a value for which 5% of all species are likely to be exposed to concentrations exceeding their EC10. The EC10 reproduction for the oligochaete *Enchytraeus albidus* is for example 6.2 mg/kg dw.

For fresh waters PNEC values based on SSDs and NOEC values from model ecosystems in the range 0.25 mg/l to 0.36 mg/l can be found (Belanger *et al.,* 2002; Plassche van de *et al.,* 1999; Temara *et al.,* 2001). In rainbow trout, these concentration levels have been shown to affect growth rate and non-specific immune responses (Bakirel *et al.,* 2005), and to affect swimming capacity and cause gill hypertrophy in fry (Hofer *et al.,* 1995).

For marine waters, two PNEC values derived by the SSD approach differing by a factor of 10 can be found, 0.031 mg/l in the work by Temara *et al.* (2001) and 0.0021 mg/l in the work by Selck *et al.* (2002). In the article by Selck *et al.* (2002), LOEC values from enclosure experiments in the same range as the PNEC calculated by Temara *et al.* (2001) are reviewed. At concentrations ten times higher, several acute toxicity values can be found. Hampel and Blasco (2002) reported a LC50 of 0.5 mg/l for seabream embryos, Debelius *et al.* (2008) reported EC50 values for growth inhibition in the range 0.242-1.84 mg/l for 5 different species marine microalgae, and Christoffersen *et al.* (2003) found a LC50 of 1.23 mg/l and an EC50 for egg production of 0.74 mg/l for the copepod *Acartia tonsa*.

For sediments, toxicity data is limited. The PNEC value 8.1 mg/kg dw found for fresh water sediments is based on the lowest NOEC value for the most sensitive of three evertebrates using an application factor of 10 (Comber *et al.,* 2006). The PNEC value 4.9 mg/kg dw for marine sediments is derived from a LC10 value for the snail *Hydrobia ulvae* using an application factor of 10 (Hampel *et al.,* 2007). This value is in the same range as concentrations causing growth inhibition of marine microalgae; an EC50 for *Cylindrotheca clostridium* of 4.18 mg/kg dw were found by Moreno-Garrido *et al.* (2003), and a 63% growth inhibition of *Phaeodactylum tricornutum* at 4.77 mg/kg dw by Moreno-Garrido *et al.* (2007). At concentrations above 20 mg/kg dw, inhibition of microbial degradation of LAS in marine sediments have been shown (Lara-Martín *et al.,* 2007).

2.3. Human exposure and metabolism

Human exposure to LAS may occur through skin contact, direct during products use and indirect due to residues that may remain on textiles, through inhalation of aerosols from cleaning sprays, and through ingestion of residues deposited on dishes (HERA, 2007).

Animal studies have shown that LAS is readily absorbed in the gastro-intestinal tract (80-90%), whereas absorption through skin is poor (0.1-0.6%) (HERA, 2007). After absorption, LAS is distributed to most organs and metabolized in the liver to sulfophenyl carboxylic acids, with subsequent elimination through urine and faeces.

3. Production, consumption and regulations

LAS is produced by sulphonation of linear alkyl benzenes (LAB) (HERA, 2007). Today, SO_3 gas is the main sulphonating agent, but fuming sulphuric acid is also used to some extent. The sulphonation results in the formation of alkylbenzene sulphonic acid, which is then neutralised with a base to generate the final LAS salt. The choice of neutralizing base is dependent on the final products use. Sodium neutralized LAS is most predominant and used for water-based products, calcium hydroxide can be used for oilbased products, whereas the use of ammonium ions generate LAS salts with emulsifying properties in both water and oil (HERA, 2007; KEMI, 2003).

On the European market, a consumption of approximately 430000 tonnes of LAS has been estimated for 2005, with more than 80% in household products (HERA, 2007). The content of LAS in different consumer products used on the European market range between 1-37%, see Table 4.

Table 4 LAS content in consumer products on the European market.

Product group	LAS content
Laundry powders, liquids and tablets	3-22%
Laundry bleach additives	3-11%
Hand dishwashing liquids	2-30%
All-purpose cleaning powders, liquids, sprays and tablets	1-37%

(HERA, 2007)

In Sweden, usage of LAS has decreased in consumer products due to successful opinion making by environmental NGOs. The usage of LAS in laundry detergents has decreased from 10000-15000 tonnes during the eighties, to approximately 80 tonnes 2001, but in 2003 the imported amount in laundry detergents had increased to 180 tonnes and in 2004 it was 151 tonnes (KEMI, 2003; KEMI, 2006).

In 2004, the Swedish import of LAS was 806 tonnes in chemical products and 248 tonnes as raw material (KEMI, 2006). LAS is/was also manufactured in Sweden, but data on amounts are not available due to secrecy reasons (KEMI, 2006). The raw material were either exported or used in the manufacture of chemical products, amounts in different product types imported or manufactured in Sweden are presented in Table 5. Export in chemical products were 115 tonnes, thus the total use in chemical products in Sweden 2004 can be estimated to almost 900 tonnes (866). Most of the chemical can be found in lubricants, lubricant additives, coolants and transmission fluids, in detergents and degreasing and cleaning agents. LAS is also used in pesticides, paints and varnishes, and in surface active agents.

Table 5. LAS content (tonnes pure substance) in chemical products imported or manufactured in Sweden 2004 (KEMI, 2004).

Product type	**Imported**	**Manufactured**
Lubricant additives	363	-
Detergents	151	1
Degreasing and cleaning agents	82	50
Lubricants, coolants and transmission fluids	49	45
Surface active agents, emulsifiers	46	18
Washing-up detergents	36	4
Car care products	7	25
Pesticide, biocide	29	< 1
Paints and varnishes	< 1	28
Metal treatment agents	4	1
Other types of products	38	3
Total	**806**	**175**

Within the EU, Regulation (EC) No 648/2004 on detergents entered into force in October 2005 and was updated with the Regulation (EC) No 907/2006. These regulations do not deal with the anaerobic degradation of detergents, but state that the Commission shall review, submit a report, and if justified present legislative proposals on this issue by 8 April 2009.

Anaerobic degradation is however one of the required criteria for surfactants used in laundry detergents to qualify for several ecolabellings such as the European Union Flower, the Nordic Swan (the Nordic Council of Ministers), and Bra Miljöval (The Swedish Society for Nature Conservation).

Approximately 10-20% of the LAS entering sewage treatment plants end up in the sludge. Sludge is used on agricultural soil in many parts of Europe. A limit value for LAS in sludge used on agricultural soil of 2 600 mg/kg DW has been proposed for the European Union (Environment DG, 2000). In Denmark, a stricter value of 1 300 mg/kg DW is written in the national legislation.

4. Previous measurements in the environment

Table 6 summarizes some of the measurements of LAS in different environmental compartments found in the literature. Most of the measurements have been done in urban areas; in harbors, or close to industrial or waste water outflows. For Sweden, only measurements in STP sludge could be found.

Table 6. Measured LAS concentrations in different environmental compartments.

Compart-ment	**Content**	**Comment**	**Reference**
Water	10-30 µg/L (but occ. exceeding 1500 µg/L close to an untreated ww discharge)	Cadiz Bay area	González-Mazo *et al.*, 1998
	2.4-92 µg/L	Spanish mediterrian and atlantic coasts. Harbours and close to ind. and ww outflows. 35 samples analysed 1999-2000.	Petrovic *et al.*, 2002
Sediment	<0.039-0.106 mg/kg dw	German Baltic and North Sea coasts	Bester *et al.*, 2001
	0.2-28 mg/kg dw	Danish harbours, Copenhagen area	Nerpin *et al.*, 2005
	0.3-8.4 mg/kg dw Above LOD (0.2) in 10/12 harbours studied	Danish harbours	Jensen & Gustavson 2001
	0.03-17.76 mg/kg dw (July) 0.09-9.57 (December) Most values below 1	Tagus estuary (Lissabon area, Portugal), 40 stations sampled 2004	Hampel *et al.*, 2008
	1.2-67.6 mg/kg dw	Cadiz Bay area (Spain), 5 stations sampled in 2002. Highest conc. close to an untreated waste water discharge.	Lara-Martín *et al.*, 2006
	< 1- <10 mg/kg dw	Cadiz Bay area, 11 stations sampled in 2002. Highest conc. same station as Lara-Martín et al., 2006, but half year after WWTP start.	Lara-Martín *et al.*, 2005
	0.1-238 mg/kg dw	Spanish mediterrian and atlantic coasts. Harbours and close to ind. and ww outflows. 39 samples analysed 1999-2000.	Petrovic *et al.*, 2002
Ground water	0.003 mg/L	500 m downstream a sewage infiltration.	HERA, 2007
Soil, sludge amended	0.7-1.4 mg/kg dw 30 days after application < 20 mg/kg dw depending on application rate and time of sampling.		Reviewed in Jensen *et al.*, 2007
Sludge	Mean: 176 mg/kg dw, max value below 1000 (aerobic) Mean: 5564 mg/kg dw, 490 and 15070 for the 5th and 95th percentiles (anaerobic)	Available data found for all European countries, covering 1988-2006	Schowanek *et al.*, 2007
	13-13725 mg/kg dw (1995) 50-1507 mg/kg dw (2002)	Denmark 1995-2002 Average dropped 40% 1997-2002	Jensen & Jepsen, 2005
	<50-840 mg/kg dw	ReVAQ 2004-2007	Wahlberg 2008
	<50-920 mg/kg dw	Västra Götaland 2001-2002	Svensson 2002
	<50-560 mg/kg dw, municipal STPs 300-2300 mg/kg dw small scale sewage treatment	Jämtland 2005	Nilsson 2006

5. Sampling strategy and study sites

5.1. National screening program

A national sampling strategy was developed in order to determine concentrations of LAS in different matrices in the Swedish environment, see Table 7.

Table 7. National sampling program

Site	STP water	STP Sludge	Industrial waste water	Storm water	Surface water	Sedi-ment	Soil	Ground water	Total
Background									
Backgrund lakes					**3**	**3**	1		**7**
Groundwater								**4**	**4**
Diffuse sources									
Municipal STPs	2	3							**5**
Stockholm area	4	3		7	3	3			**20**
Point source									
Paper & pulp industry			6			3			**9**
Laundry related	1				3	3			**7**
Total	**7**	**6**	**6**	**7**	**9**	**12**	**1**	**4**	**50**

Details of the samples are given in Appendix 1.

5.2. Regional screening program

A regional screening program was carried out by different Swedish county administrative boards that had the possibility to collect and send samples to IVL for analysis. In the case of LAS, 8 county administrative boards participated with a total of 72 samples consisting of 18 sludge and 41 water samples from sewage treatment plants, 4 surface waters, 2 landfill leachate waters, 2 public laundry effluents, 5 drinking waters (including raw waters). Details of the samples are shown in Appendix 2.

6. Methods

6.1. Sampling

The staff at the different sewage treatment plants collected **sludge** samples from the anaerobic chambers. The sludge was transferred into polyethylene jars, stored in a freezer (-18°C) and freeze dried. **Influent** and **effluent waters** were sampled in 1l polyethylene bottles.

Surface **sediment** (0-2 cm) samples were collected by means of a Kajak sampler. The sediment was transferred into perheated (400°C) glass jars and stored in a freezer (-18°C) and freeze dried. Three sediment samples from the national background lakes were provided from the Swedish Museum of Natural History.

Surface water samples from background lakes and from the urban area of Stockholm were collected in glass or polyethylene bottles.

Storm water samples was collected during periods of sufficient precipitation.

Leachate water samples were collected in 1l polyethylene bottles.

A pooled sasmple of surface **soil** (0-2 cm) from a background area was collected in a polyethylene jar.

Groundwater was collected in polyethylene bottles and stored in a freezer (-18°C). Sampling was kindly managed by Lotta Lewin-Pihlblad, SGU, Geological Survey of Sweden.

6.2. Analysis

Internal standard (4-Octylbenzene sulfonic acid, n-C8-LAS, Aldrich) was added to all samples.

Freeze dried sludge was extracted with methanol. The extract was diluted in equal parts 10 mM NH_4Ac in water and methanol.

Untreated waste water (10 ml) was acidified and, without filtration, extracted on a graphitized carbon black SPE column (Supelclean ENVI-Carb, Supelco), washed with acidified dichloromethane/methanol and eluted with dichloromethane/methanol containing tetramethylammoniumhydroxide (CEN, 2007). After evaporation the extract was redisolved in equal parts 10 mM NH_4Ac in water and methanol..

For effluent waste water, surface water and other low concentration waters the ENVI-Carb column was more extencively washed using the eluting solvent, methanol and acidified water. A sample volume of 50 – 1 000 ml was used. If needed the sample was filtered on a glass fiber filter prior to SPE extraction. The filter was extracted using methanol and the extract added to the SPE column after extraction of the filtrate.

Freeze dried sediments were extracted with methanol. After centrifugation the extract was treated the same way as discribed for extracts of the particulate phase of water samples above.

Liquid chromatography was performed on a Prominence UFLC system (Shimadzu) with two pumps LC-20AD, degasser DGU-20A5, autosampler SIL-20ACHT and column oven CTO-20AC. The analytical column was an Thermo HyPurity C8 50 mm x 3 mm, particle size 5 µm (Dalco Chromtech). The solvent was 10 mM NH_4Ac in water mixed with methanol in a linear gradient from 30% to 100%. The column temperature was 50°C and the flow rate 0.5 ml/min. The effluent was directed to an API 4000 triple quadrupole mass spectrometer (Applied Biosystems). Electrospray ionisation in negative mode was used. Precurser ion was the molecular ion. Product ions were m/z 170 and 80 for n-C8-LAS and m/z 183 and 80 for C10-LAS – C14-LAS.

Quantification was done using dodecylbenzenesulfonic acid, sodium salt, tech. (Aldrich). The C8 column separates LAS with different chain lenghts but differently branched chains are all found in the same peak (CEN, 2007). The sensitivity for the MRM transition molecular ion to m/z 170 was assumed to be the same for the different chain lengths C10 to C14. By this assumption a distribution of chain lengths in the technical blend was obtained, Figure 2. The average carbon number was 12.0.

Several procedural blanks were run among the samples. The possibility to correctly measure low concentrations is not limited by instrument sensitivity but by the careful control of blank values.

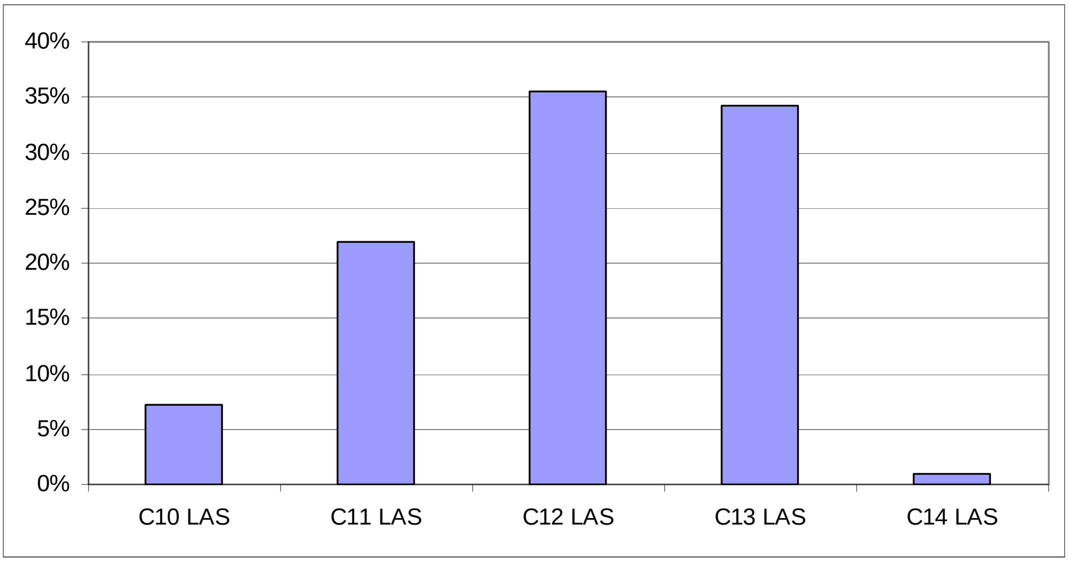


Figure 2 Distribution of chain lengths in the C12-LAS technical mixture

7. Results and discussion

Individual results for all samples are given in Appendix 3 (National sample program) and Appendix 4 (Regional sample program). Results are given for the different chain lenghts C10 to C14 and summed. The sum should be used when comparing results to sources where LAS is not further specified.

7.1. Background areas

Surface water and sediment were sampled in three lakes representing background areas. Soil was sampled at one of the lakes. LAS was not detected in any of the samples. Detection limits are given in Table 8. The water at Gipsjön contained colloidal matter making it impossible to use as large a water volume as for the other lakes thus raising the detection limit.

Table 8 Background samples and results

Site	Municipality	Matrix	Unit	C10 LAS	C11 LAS	C12 LAS	C13 LAS	C14 LAS	Sum LAS (C10-C14)
Spjutsjön	Falun	surface water	µg/l	<0.002	<0.01	<0.02	<0.03	<0.002	<0.06
Gårdsjön	Stenungsund	surface water	µg/l	<0.002	<0.01	<0.02	<0.03	<0.002	<0.06
Gipsjön	Malung	surface water	µg/l	<0.01	<0.05	<0.09	<0.13	<0.007	<0.29
Spjutsjön	Falun	sediment	ng/g DW	<5	<21	<40	<54	<4	<130
Gårdsjön	Stenungsund	sediment	ng/g DW	<5	<22	<42	<58	<4	<130
Gipsjön	Malung	sediment	ng/g DW	<5	<27	<42	<90	<4	<170
Gårdsjön	Stenungsund	soil	ng/g DW	<7	<34	<63	<89	<5	<200

7.2. Sewage treatment plants

7.2.1. Influent waste water

The distribution of LAS between the aqueous and particulate phases was studied in some of the influent waters to sewage treatment plants. LAS were measured separately on filtered and unfiltered samples. The percentage of LAS of different chain lengths in the aqueous phase of three samples are illustrated in Figure 3. It can be seen that the relative content of short chain lengths is somewhat higher than in the technical mixture, Figure 2.

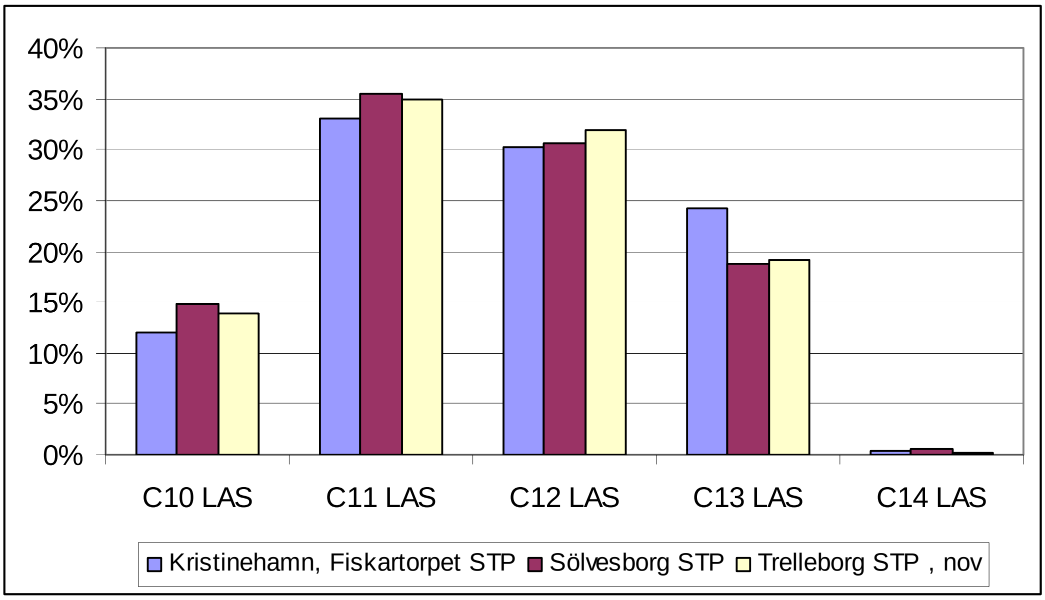


Figure 3 The percentage of LAS of different chain lengths in the aqueous phase of three untreated waste water samples.

For LAS sorbed to particles in the sample the situation is reversed, Figure 4. The concentration of C13-LAS is higher than that of C12-LAS. This is consistent with what has been said (Chapter 2.1) about increased sorption of LAS to sludge, soil and sediments with increasing carbon chain length.

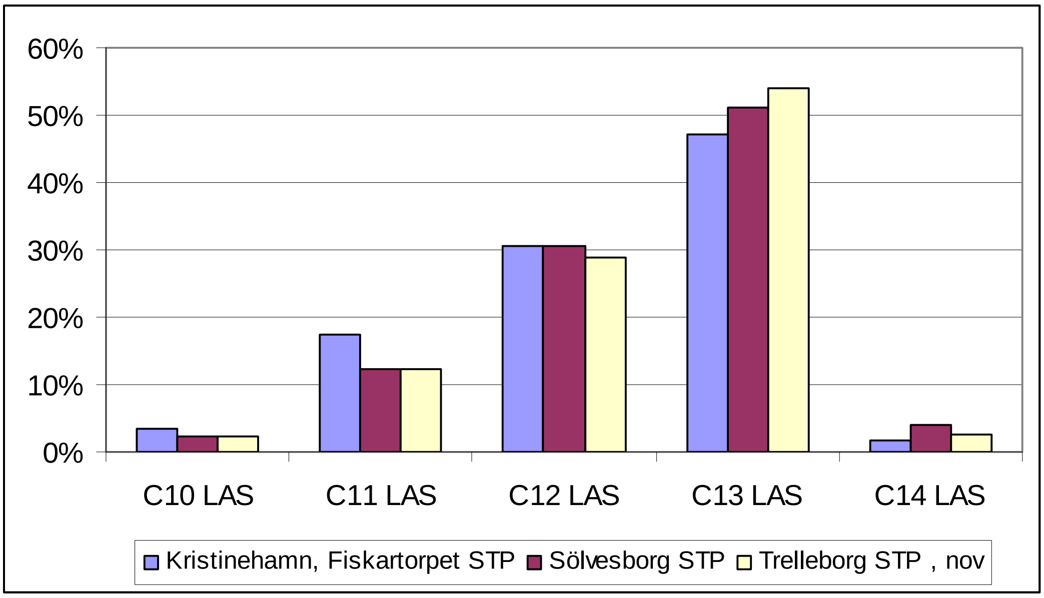


Figure 4 The percentage of LAS of different chain lengths in the particle phase of three untreated waste water samples.

The relative concentration of LAS of different chain lenght in the sample as a whole (sum of aqueous and particle phases) is shown in Figure 5. The concentration in influent to Sölvesborg STP in absolute concentration units (µg/l) is illustrated in Figure 6.

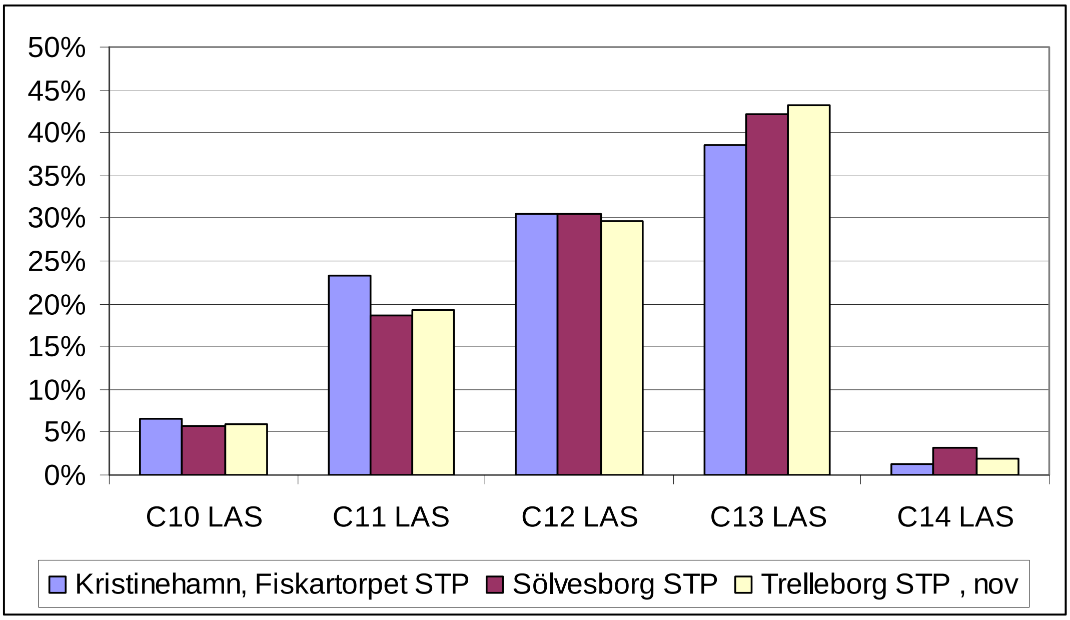


Figure 5 The percentage of LAS of different chain lengths in three untreated waste water samples (sum of aqueous and particle phases).

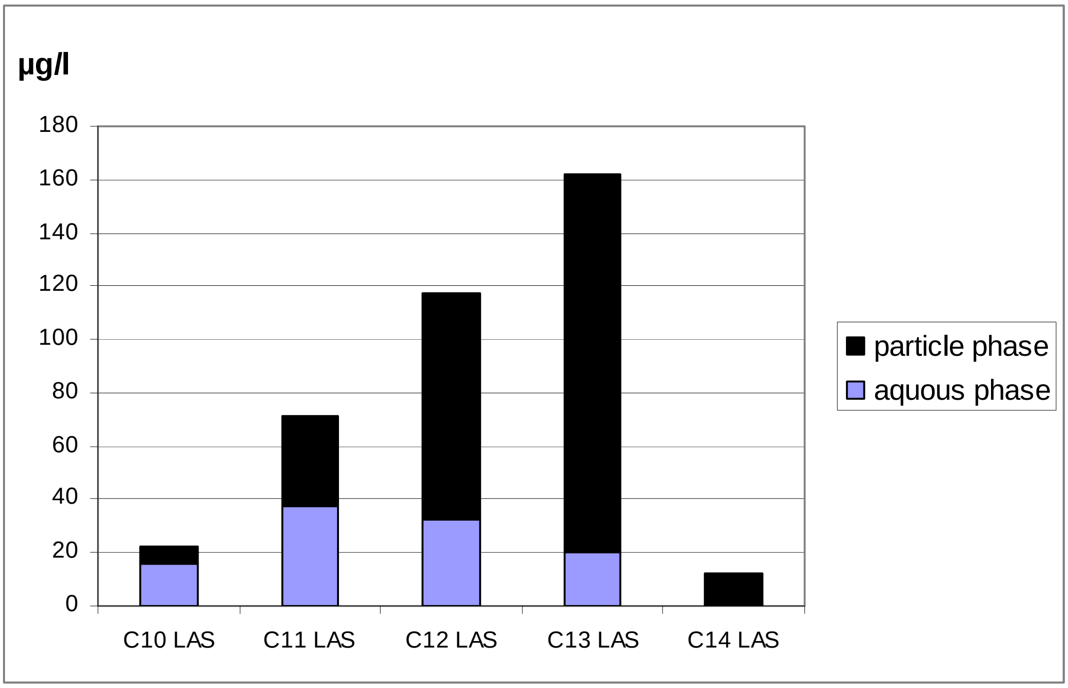


Figure 6 Concentration of LAS of different chain lenghts in particle phase and aquous phase in influent water to Sölvesborg STP.

The summed concentration of C-10 – C14-LAS in influent waste waters to different STPs varied considerably (Figure 7). The highest concentration, 1 000 µg/l, was found in Sjölundaverket, Malmö and the lowest (65 µg/l) in Busör STP, Halmstad. The average and median concentrations of 19 samples were 410 and 360 µg/l respectively.

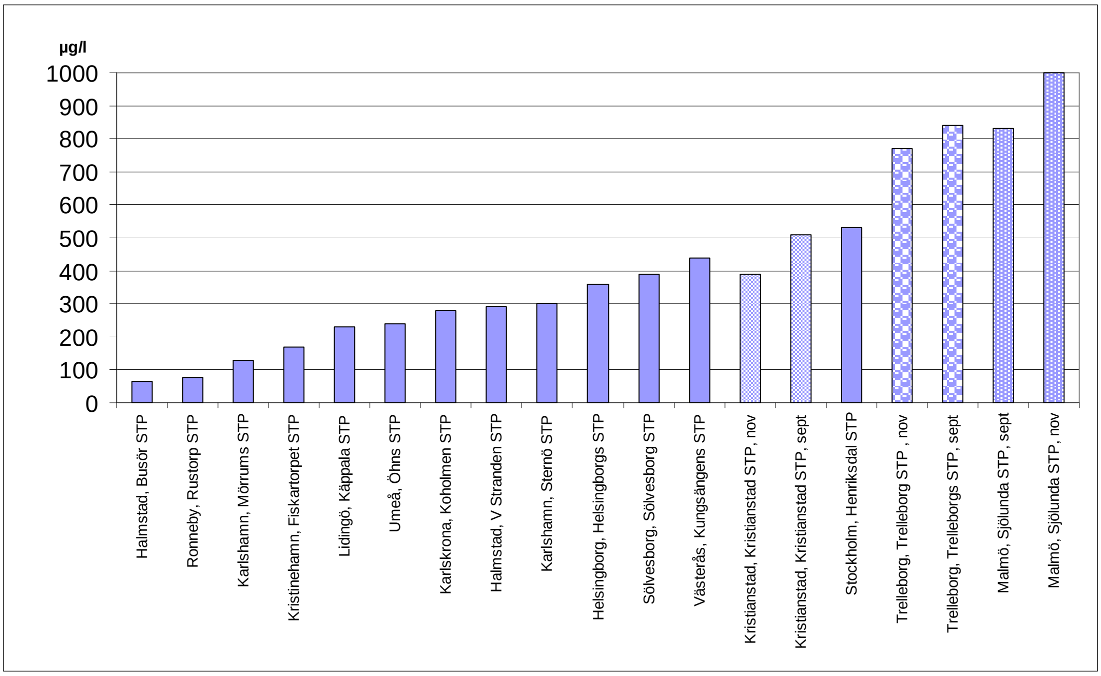


Figure 7 Summed concentration of C-10 – C-14 LAS in influent waters to STPs. Samples from the same STPs are shown with identical patterns.

7.2.2. Effluent waste water

The summed concentration of C-10 – C14-LAS in treated effluent waters were measured in 27 samples, Figure 8. The concentration was highest in Rimbo STP, Norrtälje (85 µg/l). Industrial laundry water makes up 20% of the influent to this STP; the remaining 80% comes mainly from households. The next highest concentration was found in Sjölundaverket, Malmö (33 and 35 µg/l). The lowest concentrations were found in Kristianstad STP (0.75 and 0.23 µl) and Henriksdal STP, Stockholm (0.55 µg/l). The average and median concentrations of all 26 samples were 9.3 and 2.7 µg/l respectively.

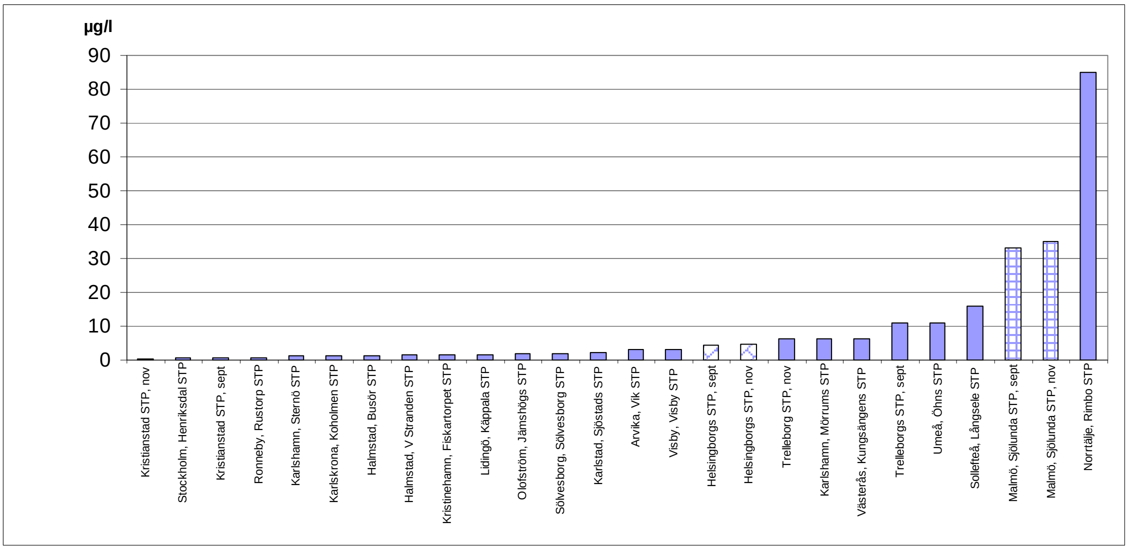


Figure 8 Summed concentration of C-10 – C-14 LAS in effluent waters from STPs. Samples from the same STPs are shown with identical patterns.

7.2.3. Removal efficiency

Removal efficiency for the summed concentration of C-10 – C-14 LAS was calculated for 19 pairs of influent/effluent samples. The results were all in the range 95 – 99.9%. In Figure 9 the results are illustrated together with the effluent concentration. As an exception to the other influent/effluent pairs the samples from Henriksdal STP are not from the same time period.

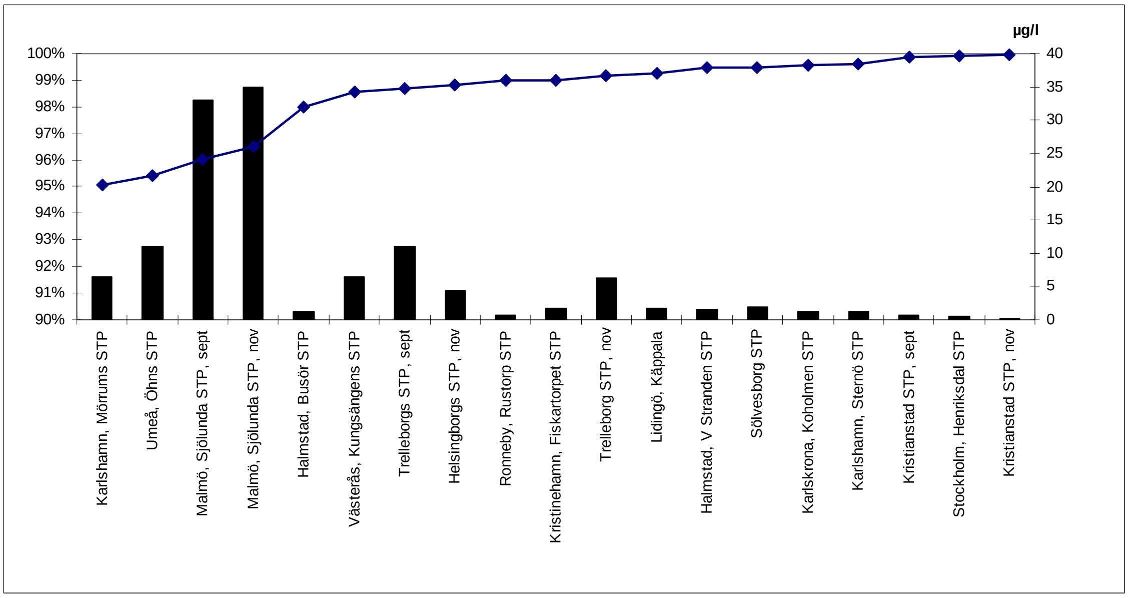


Figure 9 Removal efficiency (diamonds and line, left axis) and summed concentration of C10 – C14 LAS in effluent water (bars, right axis).

7.2.4. Sludge

The percentage of LAS of different chain lengths in sludge is shown in Figure 10. The curve shows average values for 24 samples. The distribution was very consistent between the samples and was similar to what was measured for the particulate phase of influent waste water (Figure 4).

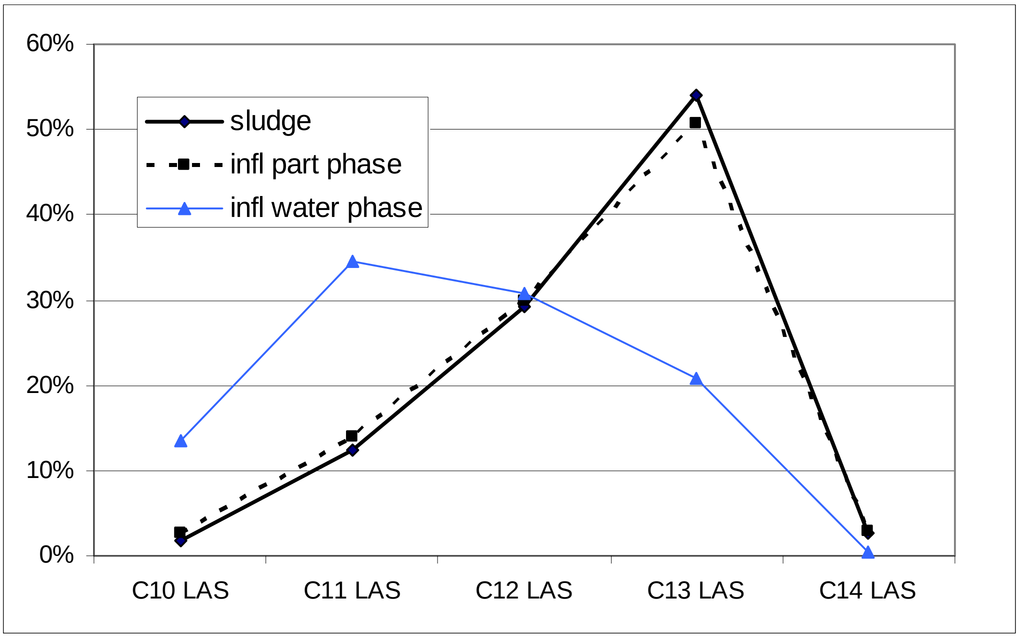


Figure 10 The percentage of LAS of different chain lengths in STP sludge (squares, solid line). For comparison the corresponding curves for influent water, particle phase (dotted line) and influent water, aqueous phase (triangles, solid line) are shown).

The summed concentrations of C-10 – C14-LAS in sludge from different STPs are illustrated in Figure 11. The highest concentration in sludge, 2 700 mg/kg DW, was as for influent water found in samples from Sjölundaverket, Malmö. Also Helsingborg and Trelleborg had concentrations above 1 000 mg/kg DW. The lowest concentrations (9 and 24 mg/kg DW) was measured in samples from Karlskrona and Ronneby. Six STPs were sampled twice. With these duplicate measurements represented by their mean the average and median concentration of measurements from 16 different STPs were 710 and 670 mg/kg DW.

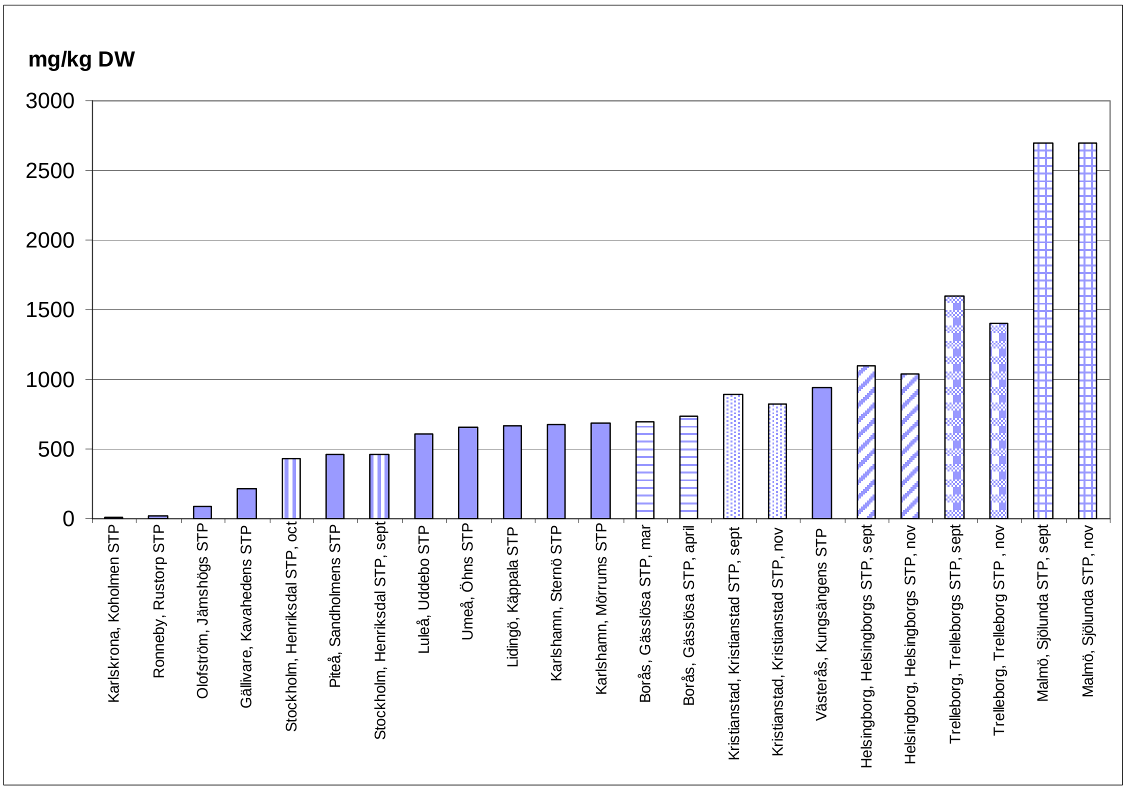


Figure 11 Summed concentration of C-10 – C-14 LAS in sludge. Samples from the same STPs are shown with identical patterns.

The concentration of LAS in sludge from Stockholm (Henriksdal) 2004 – 2007 has been reported as 150 -540 mg/kg DW with an average of 410 mg/kg DW (Wahlberg 2008). This agrees well with the results from the present investigation (460 and 430 mg/kg DW).

The concentration in the two sludge samples from Sjölunda STP, Malmö just exceeds the limit value for use on agricultural soil proposed by the EU. Compared to the stricter limit used in Denmark also the sludges from Trelleborg STP would be ruled out for agricultural use (Chapter 3).

The correlation between concentrations in paired influent water and sludge samples from the same STPs is illustrated in Figure 12. The r^2 value is 0.74.

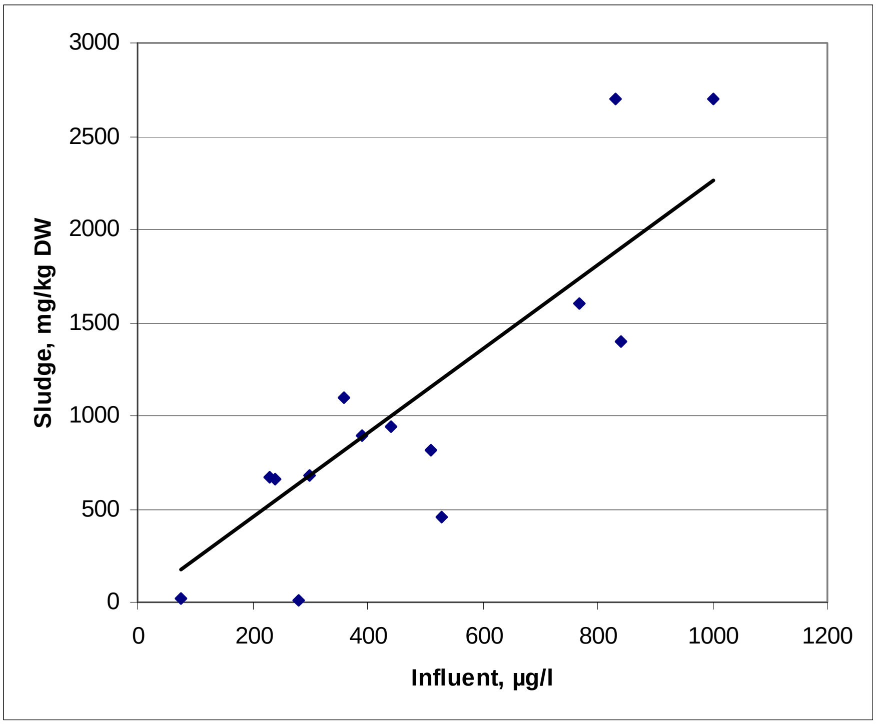


Figure 12 Correlation between C-10 – C-14 LAS concentration in paired influent water and sludge samples from the same STPs

7.3. Traffic storm water

Traffic storm water from two locations in Stockholm were analysed. Water from the traffic tunnel Eugeniatunneln were sampled November, February and Mars before and after PAX-treatment. PAX is a flocculating chemical containing aluminumchloride. The results (sum of C10 – C14 LAS) is shown in Figure 13. The concentrations are in the range 0.2 – 6 µg/l, the same range as most STP effluent waters.

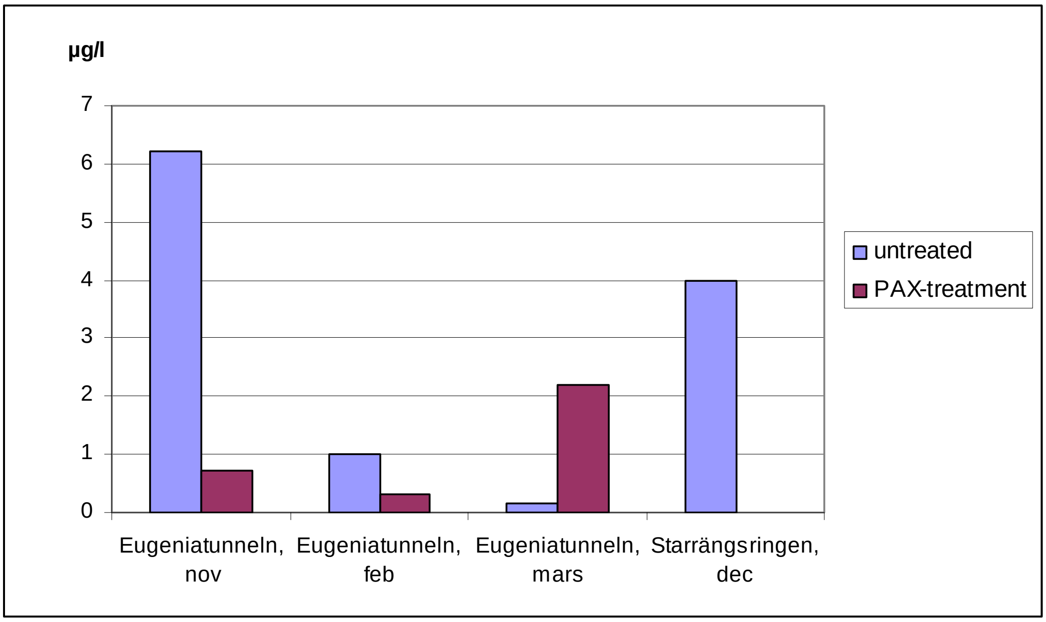


Figure 13 Sum of C10 – C14 LAS in traffic storm water.

7.4. Urban areas

Traces of C10 LAS could be found in surface water from the Stockholm area (Stora Essingen, Årstaviken and Riddarfjärden) but not from LAS of longer chain length (Figure 15). Sediments from the same sampling stations were on the other hand clearly contaminated. Summed concentrations of C10 –C14 LAS at Stora Essingen, Årstaviken and Riddarfjärden were 1600, 360 and 530 ng/g DW respectively. Concentrations of individual chain lenghts are illustrated in Figure 14.

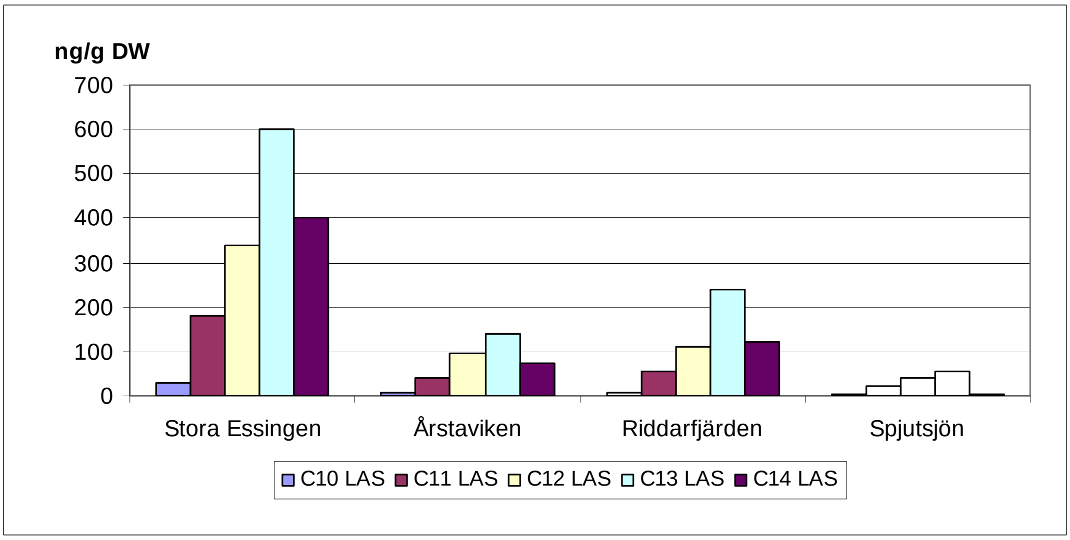


Figure 14 LAS concentration in sediments from the Stockholm area and a background location. Unfilled bars indicate that LAS was not found; the heights of the bars indicate detection limits.

The summed concentrations are in the range of what has been reported from sediments in Danish harbors; <200 – 8 400 ng/g DW with a median of 350 ng/g DW (Jensen & Gustavson 2001)

Two surface water samples from the regional program represents the same type of location; urban areas influenced by STP effluents. Varnumsviken, Kristinehamn is recepient for Fiskartopet STP and Kyrkviken, Arvika for Viks STP. Traces of C10 and C11 LAS was measured at Kyrkviken. LAS was not detected at Varnumsviken. The results are illustrated in Figure 15.

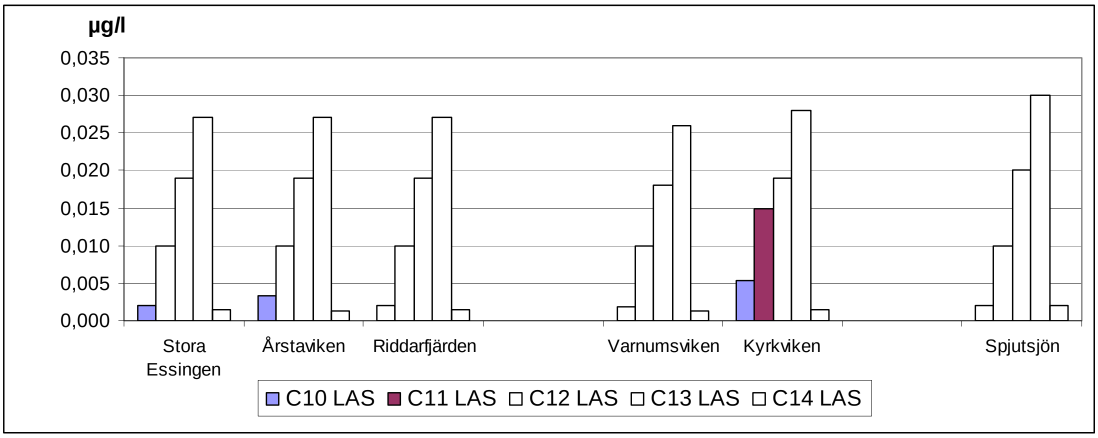


Figure 15 LAS concentration in surface waters from the Stockholm area, Kristinehamn (Varnumsviken), Arvika (Kyrkviken) and a background location. Unfilled bars indicate that LAS was not found; the heights of the bars indicate detection limits.

Surface water and sediment were sampled in Vallbyån upstream, 5 m and 500 m downstream of the discharge point of the Rimbo STP. The influent to this STP holds a large proportion of industrial laundry water (Chapter 7.2.2). A summed concentration (C10 – C14 LAS) of 0.28 µg/l was found upstream of the discharge point. Five and 500 m downstream the summed concentration was 2.9 and 0.77 µg/l respectively. Individual concentrations are illustrated in Figure 16. LAS was not found in the sediment upstream or five m downstream. 500 m downstream the summed concentration (C10 – C14 LAS) in the sediment was 320 ng/g DW. The water flow rate at this point is lower than near the dicharge permitting sedimentation.

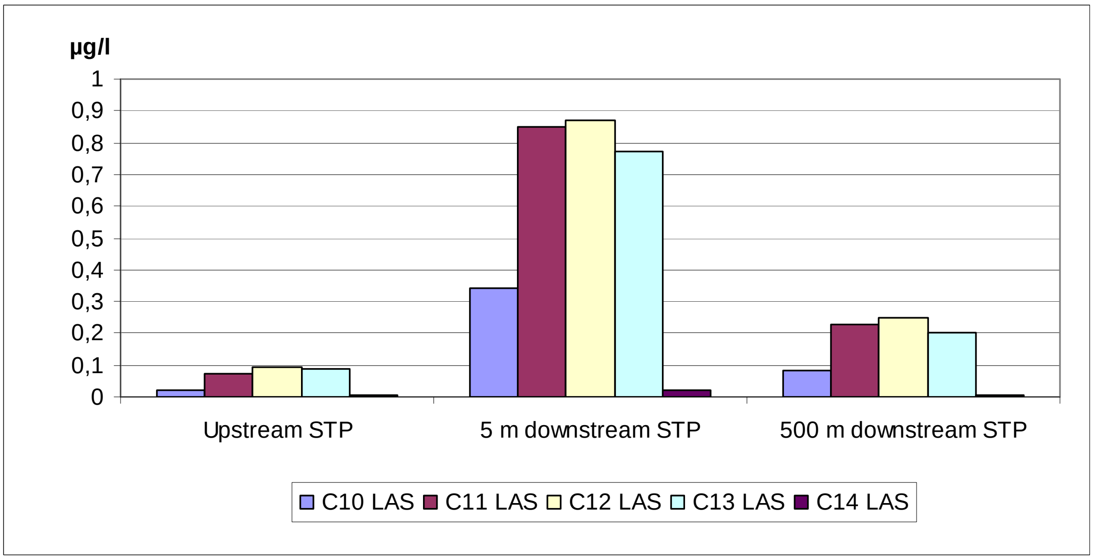


Figure 16 Surface water upstream, 5m downstream and 500m downstream of the discharge point of Rimbo STP.

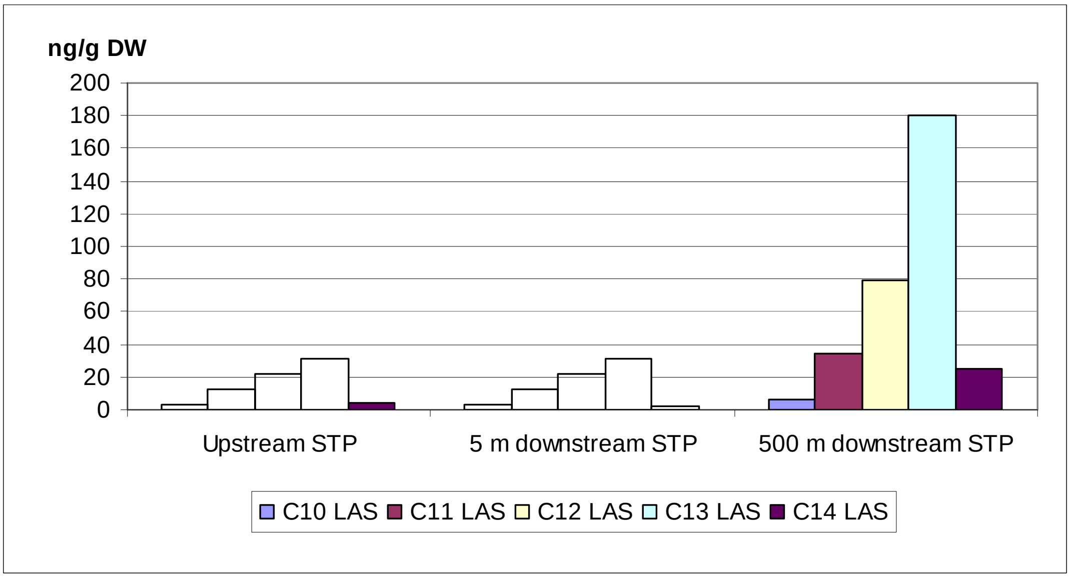


Figure 17 Sediment upstream, 5m downstream and 500m downstream of the discharge point of Rimbo STP.

7.5. Groundwater

Groundwater was sampled at four locations according to Table 9. LAS was found in one of the groundwater samples, Vimmerby, at a summed concentration of 0.31 µg/l. The results are also illustrated in Figure 18.

Table 9 Groundwater samples

Municipality	SGU Stn #	Comment	Sum LAS (C10-C14) µg/l
Lerum	10007:1	Skallsjö ängar, municipal water source, heavy traffic nearby	< 0.06
Hallsberg	17:10	Heavy traffic nearby	< 0.06
Arjeplog	42:13	Natural spring. Influenced only by air borne deposition	< 0.06
Vimmerby	84:1	Natural spring. Influenced only by air borne deposition	0.31

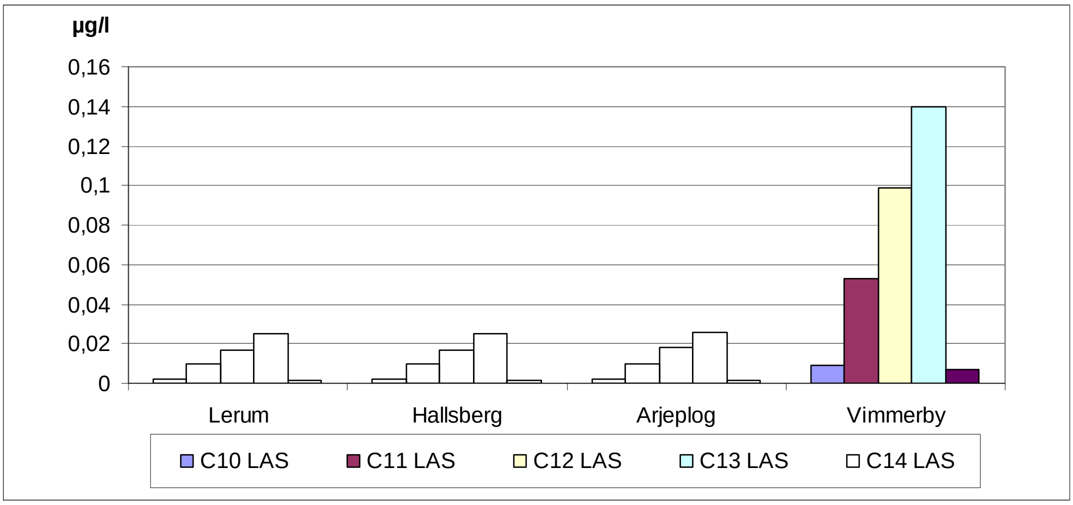


Figure 18 Concentration of LAS of different chain lengths in groundwater. Unfilled bars indicate that LAS was not found; the heights of the bars indicate detection limits.

7.6. Drinking water

Seven raw and drinking waters were included in the regional program. The results are illustrated in Figure 19. LAS was found in raw water from Lyckeby water works, Karlskrona, and was barely detected in drinking water from the same water work. The summed concentration was 0.18 µg/l in raw water and 0.084 µg/l in drinking water. In drinking water prior to carbon filter LAS was not detected (<0.07 µg/l). This indicates that LAS may be leaking from an overused carbon filter. LAS was not found in the remaining samples. The detection limit was higher in the raw waters from Långasjön, Karlshamn and Gothemsån, Gotland due to colloidal matter making it impossible to use as large a water volume as for the other samples.

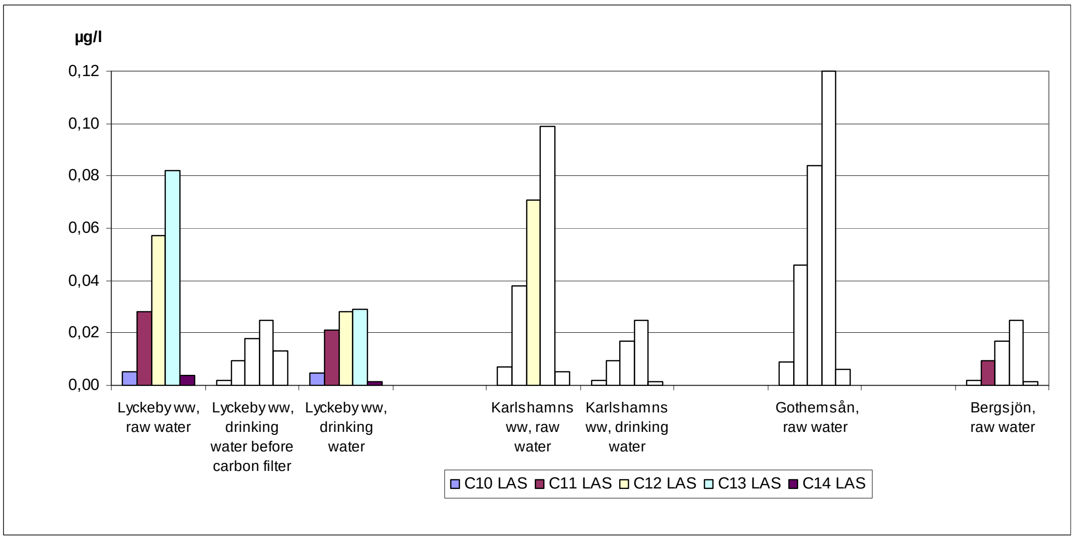


Figure 19 Concentration of LAS of different chain lengths in raw water and drinking water.

7.7. Lechate

Lechate water from two landfills was analyzed. The summed concentration of C-10 – C-14-LAS in lechate water from Bubbetorp landfill, Karlskrona was 1.2 µg/l and from Strandmossen landfill, Kristinehamn 0.58 µg/l. The concentration of individual compounds is illustrated in Figure 20.

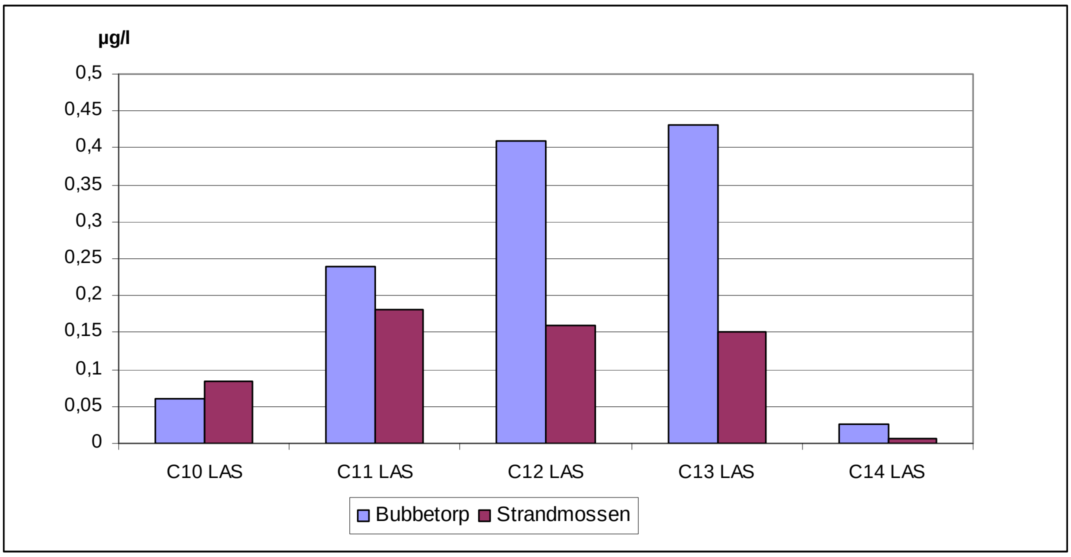


Figure 20 Concentration of LAS of different chain lengths in leachate waters from two landfills.

7.8. Industrial sources

7.8.5. Industrial laundry

Two effluent water samples (September and November) from an industrial laundry in Kristianstad showed summed concentrations of C-10 – C-14 LAS of 220 and 160 µg/l. Concentrations of individual chain lengths are illustrated in Figure 21. These waters become influents to a municipal STP. The LAS concentrations in these industrial waters are not higher than what was found as typical for ordinary influent waters to STPs (Chapter 7.2.1).

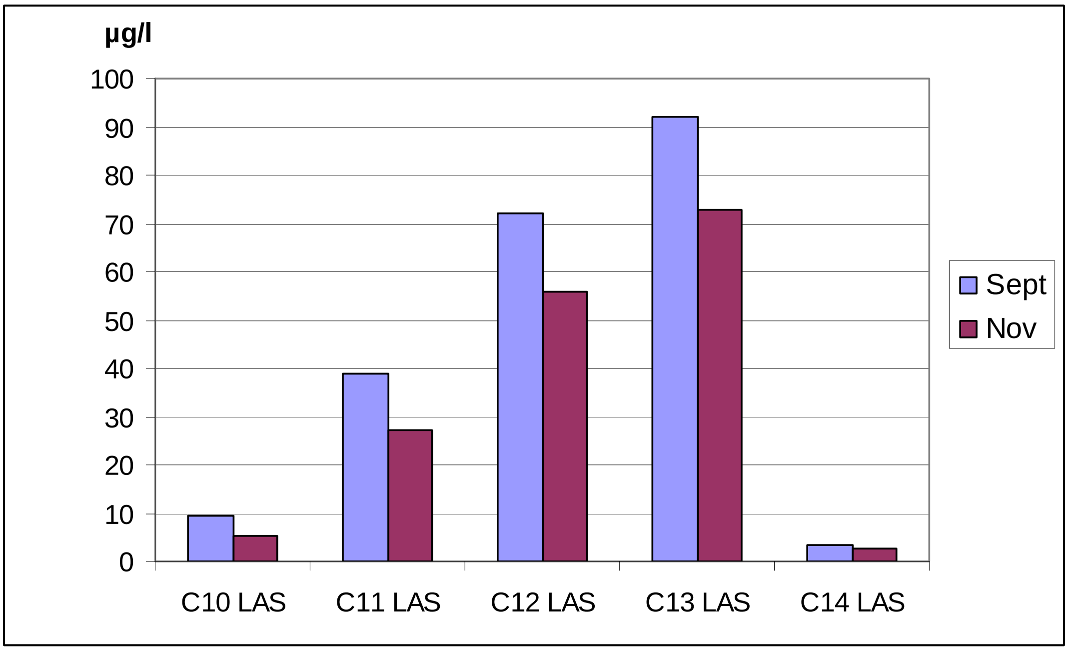


Figure 21 Concentrations of LAS of different chain lengths in two effluent waters from an industrial laundry.

7.8.6. Pulp and paper production

The effluent water from a combined pulp and paper factory is emitted to a large lagoon and then to a receiving lake. Grab samples from two consecutive days from water going in to the lagoon, coming out of the lagoon and sludge settling on the bottom was analyzed for LAS. The summed concentration of C-10 – C-14 LAS was 46 and 83 µg/l for water going in, <6 µg/l for water coming out and 50 and 46 µg/l for sludge. Concentration of individual compounds is illustrated in Figure 22. Due to the complexity of the water coming out of the lagoon the detection limit is higher than for many other water types.

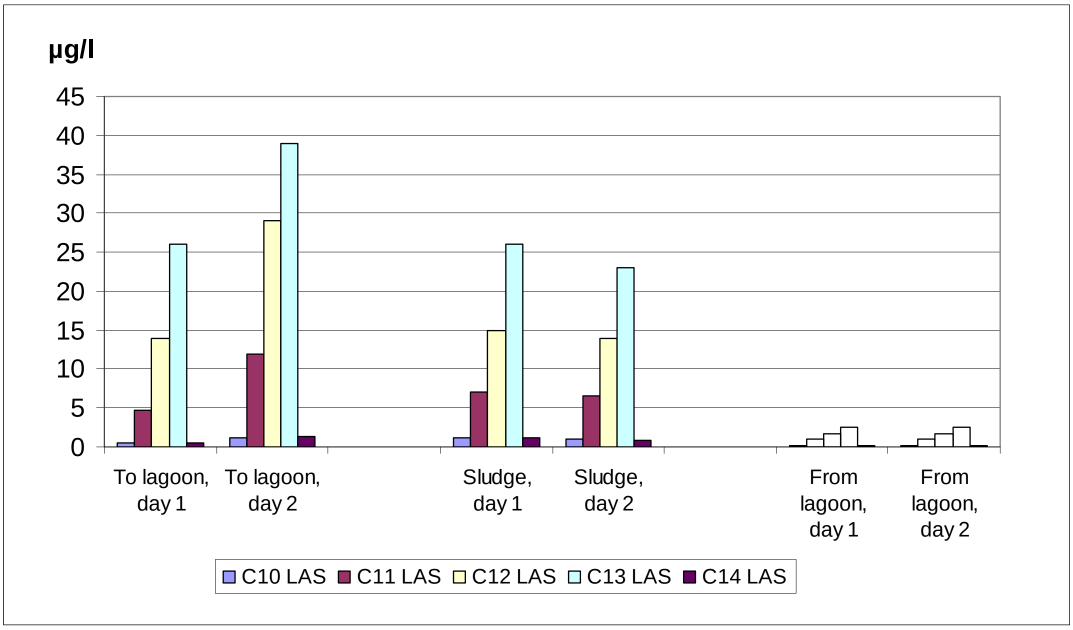


Figure 22 Concentration of LAS of different chain lengths in waters from pulp and paper production, see text. In water "From lagoon" LAS was not detected, the unfilled bars indicate limits of detection.

Sediment from the recieving lake at distances of approximately 1km, 4 km and 12 km from the discharge point was analyzed. As illustrated in Figure 23 C12, C13 and C14 LAS was found in the sediment nearest to the discharge point (summed concentration 270 ng/g DW), traces of C14 LAS was found in the sediment from the more distant locations.

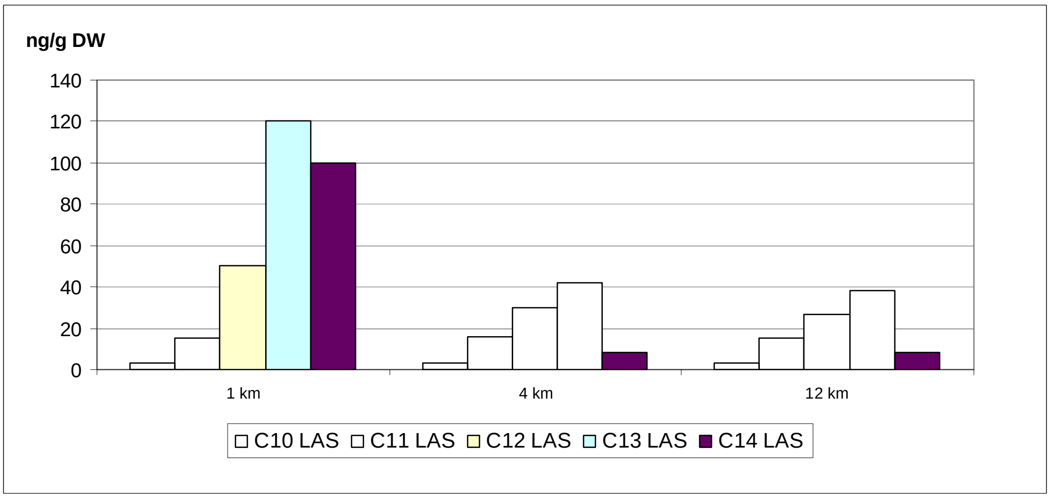


Figure 23 Concentration of LAS of different chain lengths in lake sediments at different distances from the discharge point of water from pulp and paper production. Unfilled bars indicate that LAS was not found; the heights of the bars indicate limits of detection.

8. Conclusions

LAS was not found in surface waters, sediments or soil from background areas.

LAS was found in the influent to all investigated STPs. If the median LAS concentration found in STP influent (360 µg/l) is typical for all STPs in Sweden the total annual amount entering the STPs is 490 tonnes (total waste water volume 1.36E9 m3 ;SCB 2004). This seems reasonably compaired to the 900 tonnes estimated to be used.

The removal efficiency in the STPs was 95 – 99.9% but LAS was found in all effluent waters.

The median concentration in effluents from STPs (2,7 µg/l) corresponds to a total annual load emmitted to water of 3.6 tonnes.

The median result 670 mg/kg DW for LAS in sludge corresponds to a total of 160 tonnes of LAS in all Swedish sludge produced each year (240 000 tonnes DW, SCB 2004). Thus, as an average 33% of the LAS entering STPs ends up in sludge.

LAS was measured in Vallbyån, recipient for the Rimbo STP treating water from households and an industrial laundry.

LAS was found in traffic related storm waters (0.2 – 6 µg/l) and land fill lechates (0.58 – 1.2 µg/l).

All three sediments from the urban area Stockholm were contaminated with LAS (360 – 1 600 ng/g DW). LAS was also found in lake sediment in the vicinity of the discharge point from a pulp and paper industry (270 ng/g DW).

Commercial LAS consists of a mixture of chain lengths ranging from C10 to C14. The distribution of chain lengths has a maximum of around C12. It is displaced towards shorter chain lengths in the dissolved fraction of environmental water samples is analyzed and towards longer chain lengths in the particulate phase and in sludge. In sediment the displacement is even more pronounced. C14 LAS, which is a minor component in the commercial mixture, was the next most abundant component in one of the analyzed sediments. This implies that C14 LAS is selectively enriched due to higher affinity to solids.

The concentrations of LAS (270-1 600 ng/g DW) measured in sediments from recipients and urban areas are lower than the PNEC-values, 8 100 ng/g DW and 4 900 ng/g DW for fresh water sediments and marine sediments respectively, found in the literature (Chapter 2.2). However, these values have been derived from limited sets of data and some studies indicate that they might not be protective.

The concentrations of LAS found in surface waters from urban areas and industrial recipients were lower than reported PNEC-values derived from extensive sets of toxicity data. Thus, LAS is not expected to cause adverse effects in the water phase of the recipients.

9. References

Bakirel, T., Keleş, O., Karataş, S., Özcan, M., Türkmen, G., Candan, A. 2005. Effect of linear alkylbenzene sulphonate (LAS) on non-specific defence mechanisms in rainbow trout (*Oncorhynchus mykiss*). Aquat. Toxicol. 71: 175-181.

Belanger, S. E., Bowling, J. W., Lee, D. M., LeBlanc, E. M., Kerr, K. M., McAvoy, D. C., Christman, S. C., Davidson, D. H. 2002. Integration of aquatic fate and ecological responses to linear alkyl benzene sulfonate (LAS) in model stream ecosystems. Ecotox. Env. Safety. 52: 150-171.

Bester, K., Theobald, N., Schröder, H. 2001. Nonylphenol-ethoxylates, linear alkylbenzenesulfonates (LAS) and bis (4-chlorophenyl)-sulfone in the German Bight of the North Sea. Chemosphere, 45: 817-826.

CEN, European Committee for Standardization (2007) Soils, sludges and treated bio-waste — Determination of LAS — Method by HPLC with fluorescence detection (LC-FLD) and mass selective detection (LC-MSD) CEN/TC BT WI CSS99041 European Standard, Working document http://www.ecn.nl/docs/society/horizontal/BT_TF151_WI_CSS99041_LAS_(E)_2862007.pdf

Christoffersen, K., Hansen, B.W., Johansson, L.S., Krog, E. 2003. Influence of LAS on marine calanoid copepod population dynamics and potential reproduction. Aquat. Toxicol. 63: 405-416.

Comber, S. D. W., Conrad, A. U., Höss, S., Webb, S., Marshall, S. 2006. Chronic toxicity of sediment-associated linear alkylbenzene sulphonates (LAS) to freshwater benthic organisms. Env. Pollut. 144: 661-668.

Debelius, B., Forja, J.M., Del Valls, A., Lubián, L.M. 2008. Effect of linear alkylbenzene sulfonate (LAS) and atrazine on marine microalgae. Mar. Poll. Bull. In Press

Environment DG. 2000. Working Document on Sludge. 3rd Draft, April 27. http://ec.europa.eu/environment/waste/sludge/workingdoc3.htm

Gonzáles-Mazo, E., Forja, J. M., Gómez-Parra, A. 1998. Fate and distribution of linear alkylbenzene sulfonates in the littoral environment. Environ. Sci. Technol. 32: 1636-1641.

Hampel, M., Blasco, J. 2002. Toxicity of linear alkylbenzene sulfonate and one long-chain degradation intermediate, sulfophenyl carboxylic acid on early life-stages of Seabream (Sparus aurata). Ecotox. Env. Safety. 51: 53-59.

Hampel, M., Gonzáles-Mazo, E., Vale, C., Blasco, J. 2007. Derivation of predicted no effect concentrations (PNEC) for marine environmental risk assessment: Application of different approaches to the model contaminant Linear Alkylbenzene Sulphonates (LAS) in a site-specific environment. Environ. Int. 33: 486-491.

Hampel, Canário, J., Branco, V., Vale, C., Blasco, J. 2008. Environmental levels of linear alkylbenzene sulfonates (LAS) insediments from the Tagus estuary (Portugal): environmental implications. Environ. Monit. Assess. DOI 10.1007/s10661-008-0190-0

HERA. 2007. Human & environmental risk assessment on ingredients of European household cleaning products. LAS, Linear Alkylbenzene Sulphonate. October 2007. Version 3.0.

Hofer, R., Jeney, Z., Bucher, F. 1995. Chronic effects of linear alkylbenzene sulfonate (LAS) and ammonia on raibow trout (*Oncorhynchus mykiss*) fry at water criteria limits. Wat. Res. 29: 2725-2729.

Jacobsen, A. M., Mortensen, G. K., Hansen, H. C. B. 2004. Degradation and mobility of linear alkylbenzene sulphonate and nonylphenol in sludge-amended soil. J. Environ. Qual. 33: 232-240.

Jensen, A., Gustavson, G. 2001. Havnesedimenters indhold af miljøfremmede organiske forbindelser. Kortlægning af nuværende og fremtidige behov for klapning og deponering. Miljøprojekt Nr. 627. Miljøstyrelsen, Miljø- og Energiministeriet.

Jensen, J., Jepsen, S-E. 2005 The production, use and quality of sewage sludge in Denmark. Waste Management. 25: 239-247.

Jensen, J., Smith, S.R., Krogh, P.H., Versteeg, D.J., Temara, A. 2007. European risk assessment of LAS in agricultural soil revisited: Species sensitivity distribution and risk estimates. Chemosphere, 69: 880-892.

KEMI. 2003. Information on substances: Linear alkyl benzene sulfonates. http://apps.kemi.se/flodessok/floden/kemamne_eng/LAS_eng.htm

KEMI, 2006. Flow analyses for chemical substances. Linear alkylbenzene sulfonates. The substance flow in chemical products within Sweden 2004. http://apps.kemi.se/flodessok/floden/_flodenbild/floden.cfm?lang=eng&Id=810

Lara-Martín, P.A., Gómez-Parra, A., González-Mazo, E. 2005. Determination and distribution of alkyl ethoxylates and linear alkylbenzene sulfonates in coastal marine sediments from the bay of Cadiz (southwest of Spain). Env. Toxicol. Chem. 24:2196-2202.

Lara-Martín, P.A. Petrovic, M., Gómez-Parra, A., Barceló, D., González-Mazo, E. 2006. Presence of surfactants and their degradation intermediates in sediment cores and grabs from the Cadiz Bay area. Env. Pollut. 144: 483-491.

Lara-Martín, P. A., Gómez-Parra, A., Köchling, T., Sanz, J. L., Amils, R., González-Mazo, E. 2007. Anaerobic degradation of linear alkylbenzene sulfonates in coastal marine sediments. Environ. Sci. Technol. 41: 3571-3579.

Léon, V. M., Gómez-Parra, A., González-Mazo, E. 2004. Biodegradation of linear alkylbenzene sulfonates and their degradation intermediates in seawater. Environ. Sci. Technol. 38: 2359-2367.

Moreno-Garrido, I., Hampel, M., Lubián, L. M., Blasco, J. 2003. Marine benthic microalgae Cylindrotheca closterium (Ehrenberg) Lewin and Reimann (Bacillariophyceae) as a tool for measuring toxicity of linear alkylbenzene sulfonate in sediments. Bull. Environ. Contam. Toxicol. 70: 242-247.

Moreno-Garrido, I., Lubián, L. M., Blasco, J. 2007. Sediment toxicity tests involving immobilized microalgae (Phaeodactylum tricornutum Bohlin). Environ. Int. 33: 481-495.

Nerpin, L., Nordell, O., Burgdorf Nielsen, J., Hein, M., Carlsson, C., Bjerre, F., Brøns-Hansen, J. 2005. Miljögifter i Öresund, en översikt. Öresundsvattensamanbetet. www.oresundvand.dk

Nilsson, K. 2006. Förekomst av organiska miljöföroreningar i slam och utgående avloppsvatten från avloppsverk och i slam från enskilda avloppsbrunnar. Länsstyrelsen Jämtlands län.

OECD SIDS Initial Assessment Report for Linear Alkylbenzene Sulfonate (LAS). 2005-08-15. http://www.chem.unep.ch/irptc/sids/OECDSIDS/LAS.pdf

Perales, J.A., Manzano, M. A., Sales, D., Quiroga, J. A. 1999. Biodegradation kinetics of LAS in river water. Int. Biodeter. Biodeg. 43: 155-160.

Perales, J. A., Manzano, M. A., Garrido, C., Sales, J., Quiroga, J. M. 2007. Biodegradation kinetics of linear alkylbenzene sulphonates in sea water. Biodegradation. 18: 63-70.

Petrovic, M., Fernández-Alba, A.R., Borrull, F., Marce, R.M., González-Mazo, E., Barceló, D. 2002. Occurence and distribution of nonionic surfactants, their degradation products, and linear alkylbenzene sulfonates in coastal waters and sediments in Spain. Env. Toxicol. Chem. 21: 37-46.

Plassche van de, E. J., De Bruijn, J. H. M., Stephenson, R. R., Marshall, S. J., Feijtel, T. C. J., Belanger, S. E. 1999. Predicted no-effect concentartions and risk characterization of four surfactants: Linear alkyl benzene sulfonate, alcohol ethoxylates, alcohol ethoxylated sulfates, and soap. Env. Toxicol. Chem. 18: 2653-2663

SCB 2004 Discharge to water and sludge production in 2002. Sveriges officiella statistik. Statiskiska meddelanden MI 22 SM 0401.

Schowanek, D., David, H., Francaviglia, R., Hall, J., Kirchmann, H., Krogh, P.H., Schraepen, N., Smith, S., Wildemann, T. 2007. Probabilistic risk assessment for lineas alkylbenzene sulfonate (LAS) in sewage sludge used on agricultural soil. Reg. Toxicol. Pharmacol. 49: 245-259.

Selck, H., Riemann, B., Christoffersen, K., Forbes, V.E., Gustavson, K., Hansen, B.W., Jacobsen, J.A., Kusk, O.K., Petersen, S. 2002. Comparing sensitivity of ecotoxicological effect endpoints between laboratory and field. Ecotox. Env. Saf. 97-112.

Svensson, A. 2002. Miljögifter i avloppsslam – en studie omfattande 19 reningsverk i Västra Götaland. Rapport 2002:39. Länsstyrelsen Västra Götaland.

Temara, A., Carr, G., Webb, S., Versteeg, D., Feijtel, T. 2001. Marine risk assessment: Linear Alkylbenzenesulponates (LAS) in the North Sea. Mar. Poll Bull. 42: 635-642.

Vives-Rego, J., López-Amorós, R., Guindulain, T., García, M. T., Comas, J., Sánchez-Leal, J. 2000. Microbial aspects of linear alkylbenzene sulfonate degradation in coastal water. Jour. Surfact. Deter. 3 (3): 303-308.

Wahlberg, C. 2008 Sammanställning av slamanalyser inom ReVAQ år 2004-2007. Rapport R nr 8-2008. Stockholm Vatten AB.

Appendix 1 National program, Sample characteristics

Sample#	Type	City/Municipality	Site	Matrix	Sampling date	RT90, X	R90, Y
6228	Background	Malung	Gipsjön	sediment	2007 sept		
6225	Background	Malung	Gipsjön	surface water	2007 sept		
6227	Background	Falun	Spjutsjön	sediment	2007 sept		
6224	Background	Falun	Spjutsjön	surface water	2007 sept		
6037	Background	Stenungsund	Gårdsjön	sediment	2007 sept		
6038	Background	Stenungsund	Gårdsjön	surface water	2007 sept		
6036	Background	Stenungsund	Gårdsjön	soil	2007 sept		
6738	Background	Lerum	SGU Stn 10007:1	groundwater	2007-11-21	6412857	1294478
6735	Background	Hallsberg	SGU Stn 17:10	groundwater	2007-11-12	6546701	1454844
6551	Background	Arjeplog	SGU Stn 42:13	groundwater	2007 nov	7318516	1602028
6732	Background	Vimmerby	SGU Stn 84:1	groundwater	2007-11-09	6408158	1496211
7480	Diffuse, STP	Stockholm	Henriksdal STP	effluent	2008-05-29		
6767	Diffus, ARV	Lidingö	Käppala STP	effluent	2007-12-06		
6892	Diffus, ARV	Umeå	Umeå STP	effluent	2008-03-27		
6035	Diffus, ARV	Stockholm	Henriksdal STP	sludge	2007 sept (v. 36)		
6584	Diffus, ARV	Stockholm	Henriksdal STP	sludge	2007-10-25		
6844	Diffus, ARV	Lidingö	Käppala STP	sludge	2007-12-20		
6896	Diffus, ARV	Umeå	Umeå STP	sludge	2008-04-02		
6909	Diffus, ARV	Borås	Gässlösa STP	sludge	2008 mars		
6936	Diffus, ARV	Borås	Gässlösa STP	sludge	2008-04-18		
6559	Diffus, ARV	Stockholm	Henriksdal STP	influent	2007-10-25		
6766	Diffus, ARV	Lidingö	Käppala STP	influent	2007-02-05		
6891	Diffus, ARV	Umeå	Umeå STP	influent	2008-03-27		
6615	Diffuse, urban	Stockholm	Eugeniatunneln untreated	storm water	2007-11-07		
6618	Diffuse, urban	Stockholm	Eugeniatunneln PAX treated	storm water	2007-11-07		
6812	Diffuse, urban	Stockholm	Starrängsringen	storm water	2007-12-13		
6856	Diffuse, urban	Stockholm	Eugeniatunneln untreated	storm water	2008-02-05		
6857	Diffuse, urban	Stockholm	Eugeniatunneln PAX treated	storm water	2008-02-05		
6889	Diffuse, urban	Stockholm	Eugeniatunneln untreated	storm water	2008-03-19		

Sample#	Type	City/Municipality	Site	Matrix	Sampling date	RT90, X	R90, Y
6890	Diffuse, urban	Stockholm	Eugeniatunneln PAX treated	storm water	2008-03-19		
6358	Diffuse, urban	Stockholm	Stora Essinge	sediment	2007-10-03		
6361	Diffuse, urban	Stockholm	Årstaviken	sediment	2007-10-03		
6364	Diffuse, urban	Stockholm	Riddarfjärden	sediment	2007-10-03		
6357	Diffuse, urban	Stockholm	Stora Essinge	surface water	2007-10-03		
6360	Diffuse, urban	Stockholm	Årstaviken	surface water	2007-10-03		
6363	Diffuse, urban	Stockholm	Riddarfjärden	surface water	2007-10-03		
6750	Point source	Norrtälje	Rimbo STP	effluent	2007 nov.		
6745	Point source	Norrtälje	Vallbyån, upstream Rimbo STP	sediment	2007-11-29		
6746	Point source	Norrtälje	Vallbyån, 5 m downstream Rimbo STP	sediment	2007-11-29		
6747	Point source	Norrtälje	Vallbyån, 500 m dowmstream Rimbo STP	sediment	2007-11-29		
6742	Point source	Norrtälje	Vallbyån, upstream Rimbo STP	surface water	2007-11-29		
6743	Point source	Norrtälje	Vallbyån, 5 m downstream Rimbo STP	surface water	2007-11-29		
6744	Point source	Norrtälje	Vallbyån, 500 m dowmstream Rimbo STP	surface water	2007-11-29		
6911	Point source		Pulp & paper ind.	water to lagoon	2008-04-14		
6912	Point source		Pulp & paper ind.	water to lagoon	2008-04-15		
6913	Point source		Pulp & paper ind.	effluent from lagoon	2008-04-14		
6914	Point source		Pulp & paper ind.	effluent from lagoon	2008-04-15		
6915	Point source		Pulp & paper ind.	sludge from lagoon	2008-04-14		
6916	Point source		Pulp & paper ind.	sludge from lagoon	2008-04-15		
4771	Point source		Vänern, Ås 9	sediment	2006-05-08	6581849	1348253
4773	Point source		Vänern, Ås 141	sediment	2006-05-09	6579050	1349651
4775	Point source		Vänern, Ås 190	sediment	2006-05-08	6571600	1349700

Appendix 2 Regional program, Sample characteristics

Sample#	County	City/ Municipality	Site	Matrix	Sampling date	RT90, X	R90, Y	Dimension of STP, pe	Connected to STP, pe
6590	Blekinge (K)	Karlshamn	Blekingesjukhuset Karlshamn	effluent	2007-10-31				
6219	Blekinge (K)	Karlshamn	Karlshamns w w (Långasjön)	drinking water	2007-09-25				
6215	Blekinge (K)	Karlshamn	Karlshamns w w (Långasjön)	raw water	2007-09-25				
6086	Blekinge (K)	Karlshamn	Mörrums STP	effluent	2007-09-04--05				
6085	Blekinge (K)	Karlshamn	Mörrums STP	influent	2007-09-04--05				
6087	Blekinge (K)	Karlshamn	Mörrums STP	sludge	2007-09-04--05				
6092	Blekinge (K)	Karlshamn	Sternö STP	effluent	2007-09-04	622560	144002	30000	22000
6091	Blekinge (K)	Karlshamn	Sternö STP	influent	2007-09-04	622560	144000	30000	22000
6093	Blekinge (K)	Karlshamn	Sternö STP	sludge	2007-09-04	622560	144004	30000	22000
6073	Blekinge (K)	Karlskrona	Bubbetorp deponi	lechate	2007-09-05--12				
6247	Blekinge (K)	Karlskrona	Koholmen STP	effluent	2007-09-18--25	622523	148848	57000	40000
6246	Blekinge (K)	Karlskrona	Koholmen STP	influent	2007-09-18--25	622523	148846	57000	40000
6249	Blekinge (K)	Karlskrona	Koholmen STP	sludge	2007-09-18--25	622523	148850	57000	40000
6161	Blekinge (K)	Karlskrona	Lyckeby w w (Lyckebyån)	drinking water prior to carbon filter	2007-09-25	6229872	1490913		
6164	Blekinge (K)	Karlskrona	Lyckeby w w (Lyckebyån)	drinking water	2007-09-25	6229872	1490913		
6156	Blekinge (K)	Karlskrona	Lyckeby vattenverk (Lyckebyån)	raw water	2007-09-25	6229872	1490913		
6713	Blekinge (K)	Karlskrona	Tvätteri Gullberna	effluent	2007-11-20				
6554	Blekinge (K)	Olofström	Jämshögs STP	effluent (after wetland)	2007-10-22	6233651	1420545	19500	12000
6556	Blekinge (K)	Olofström	Jämshögs STP	sludge	2007-10-22	6233651	1420547	19500	12000
6052	Blekinge (K)	Ronneby	Rustorp STP	effluent	2007-09-11	6228468	1468366	24000	19000
6048	Blekinge (K)	Ronneby	Rustorp STP	influent	2007-09-11	6228468	1468364	24000	19000
6054	Blekinge (K)	Ronneby	Rustorp STP	sludge	2007-09-11	6228468	1468368	24000	19000
6574	Blekinge (K)	Sölvesborg	Sölvesborg STP	effluent	2007-10-22--28	6213461	1423579	19500	8600
6571	Blekinge (K)	Sölvesborg	Sölvesborg STP	influent	2007-10-22--28	6213461	1423577	19500	8600
6577	Blekinge (K)	Sölvesborg	Sölvesborg STP	sludge (från vassbädd)	2007-10-22--28	6213461	1423581	19500	8600
6309	Gotland (I)	Gothem	Gothemsån	surface water	2007-10-01				

Sample#	County	City/ Municipality	Site	Matrix	Sampling date	RT90, X	R90, Y	Dimension of STP, pe	Connected to STP, pe
6306	Gotland (I)	Visby	Visby STP	effluent	2007-09-25--10-02	6391515	1647282	60000	41 457
6322	Halland (N)	Halmstad	Busör STP	effluent	07-09-24-10-02			13350	6100
6321	Halland (N)	Halmstad	Busör STP	influent	07-09-24-10-02			13350	6100
6332	Halland (N)	Halmstad	V Stranden STP	effluent	07-09-24-1001			140000	80000
6331	Halland (N)	Halmstad	V Stranden STP	influent	07-09-24-1001			140000	80000
6231	Norrbotten (BD)	Gällivare	Kavahedens STP	sludge	2007-09-20--26			20000	15500
6757	Norrbotten (BD)	Luleå	Uddebo STP	sludge	2007-11-26--12-03			85000	61000
6179	Norrbotten (BD)	Piteå	Sandholmens STP	sludge	2007-09-19--25			35000	30500
6099	Skåne (M)	Helsingborg	Helsingborgs STP	effluent	2007-09-17				
6595	Skåne (M)	Helsingborg	Helsingborgs STP	effluent	2007-10-29--11-04				
6098	Skåne (M)	Helsingborg	Helsingborgs STP	influent	2007-09-17				
6101	Skåne (M)	Helsingborg	Helsingborgs STP	sludge	2007-09-17				
6596	Skåne (M)	Helsingborg	Helsingborgs STP	sludge	2007-10-29--11-04				
6139	Skåne (M)	Kristianstad	Kristianstad STP	effluent	2007-09-11--09-17				
6690	Skåne (M)	Kristianstad	Kristianstad STP	effluent	2007-11-05				
6138	Skåne (M)	Kristianstad	Kristianstad STP	influent	2007-09-11--09-17				
6688	Skåne (M)	Kristianstad	Kristianstad STP	influent	2007-11-05				
6142	Skåne (M)	Kristianstad	Kristianstad STP	sludge	2007-09-11--09-17				
6686	Skåne (M)	Kristianstad	Kristianstad STP	sludge	2007-11-05				
6144	Skåne (M)	Kristianstad	Kristianstad STP	effluent from laundry	2007-09-11--09-17				
6689	Skåne (M)	Kristianstad	Kristianstad STP	effluent from laundry	2007-11-05				
6125	Skåne (M)	Malmö	Sjölunda STP	effluent	2007-09-13				
6606	Skåne (M)	Malmö	Sjölunda STP	effluent	2007-11-01				
6123	Skåne (M)	Malmö	Sjölunda STP	influent	2007-09-13				
6604	Skåne (M)	Malmö	Sjölunda STP	influent	2007-11-01				
6128	Skåne (M)	Malmö	Sjölunda STP	sudge	2007-09-13				
6608	Skåne (M)	Malmö	Sjölunda STP	sludge	2007-11-01				
6705	Skåne (M)	Trelleborg	Trelleborg STP	effluent	2007-11-20				

Sample#	County	City/ Municipality	Site	Matrix	Sampling date	RT90, X	R90, Y	Dimension of STP, pe	Connected to STP, pe
6706	Skåne (M)	Trelleborg	Trelleborg STP	influent	2007-11-20				
6707	Skåne (M)	Trelleborg	Trelleborg STP	sludge	2007-11-20				
6168	Skåne (M)	Trelleborg	Trelleborgs STP	effluent	2007-09-25				
6167	Skåne (M)	Trelleborg	Trelleborgs STP	influent	2007-09-25				
6172	Skåne (M)	Trelleborg	Trelleborgs STP	sludge	2007-09-25				
6067	Värmland (S)	Arvika	Kyrkviken, outside Viks STP	surface water	2007-09-12	6618500	1319500		
6189	Värmland (S)	Arvika	Vik STP	effluent	v 38				
6282	Värmland (S)	Karlstad	Sjöstads STP	effluent	2007-09-28				
6433	Värmland (S)	Kristinehamn	Bergsjön raw water source	surface water	2007-10-08	6586800	1408540		
6442	Värmland (S)	Kristinehamn	Fiskartorpet STP	effluent	2007-10-02--08				
6438	Värmland (S)	Kristinehamn	Fiskartorpet STP	influent	2007-10-02--08	6578124	1401080		
6445	Värmland (S)	Kristinehamn	Strandmossens deponi	lechate	2007-10-08				
6017	Värmland (S)	Kristinehamn	Varnumsviken, stn Kr70	surface water	2007-08-28	6579403	1401200		
6187	Västernorrland (Y)	Sollefteå	Långsele STP	effluent	2007-09-17--24			5000	2550
6373	Västmanland (U)	Västerås	Kungsängens STP	effluent	2007-10-03				
6372	Västmanland (U)	Västerås	Kungsängens STP	influent	2007-10-03				
6376	Västmanland (U)	Västerås	Kungsängens STP	sludge	2007-10-03				

Appendix 3 National program, Results

Sample#	Type	City/Municipality	Site	Matrix	Unit	C10 LAS	C11 LAS	C12 LAS	C13 LAS	C14 LAS	Sum LAS (C10-C14)	DW, %
6228	Background	Malung	Gipsjön	sediment	ng/g DW	<5	26	<42	86	3.8		5.6
6225	Background	Malung	Gipsjön	surface water	µg/l	0.0096	<0.051	<0.092	<0.13	<0.0067		
6227	Background	Falun	Spjutsjön	sediment	ng/g DW	<4	<21	<38	<54	<3	<120	6.4
6224	Background	Falun	Spjutsjön	surface water	µg/l	<0.0018	<0.0097	<0.018	<0.025	<0.0013	<0.056	
6037	Background	Stenungsund	Gårdsjön	sediment	ng/g DW	<5	<22	<42	<58	<4	<30	6.4
6038	Background	Stenungsund	Gårdsjön	surface water	µg/l	<0.002	<0.01	<0.019	<0.027	<0.0014	<0.059	
6036	Background	Stenungsund	Gårdsjön	soil	ng/g DW	<7	<34	<63	<89	<5	<200	
6738	Background	Lerum	SGU Stn 10007:1	groundwater	ug/l	<0.0018	<0.0095	<0.017	<0.025	<0.0012	<0.06	
6735	Background	Hallsberg	SGU Stn 17:10	groundwater	ug/l	<0.0018	<0.0094	<0.017	<0.025	<0.0012	<0.06	
6551	Background	Arjeplog	SGU Stn 42:13	groundwater	µg/l	<0.0019	<0.0098	<0.018	<0.026	<0.0013	<0.06	
6732	Background	Vimmerby	SGU Stn 84:1	groundwater	ug/l	0.009	0.053	0.099	0.14	0.0067	0.31	
7480	Diffuse, STP	Stockholm	Henriksdal STP	effluent	ug/l	0.12	0.23	0.2	<0.2	<0.01	0.55	
6767	Diffus, ARV	Lidingö	Käppala STP	effluent	ug/l	0.42	0.65	0.39	0.19	<0.0078	1.7	
6892	Diffus, ARV	Umeå	Umeå STP	effluent	ug/l	2.1	3.8	2.8	1.8	0.063	11	
6035	Diffus, ARV	Stockholm	Henriksdal STP	sludge	mg/kg DW	5.4	46	140	270	11	460	
6584	Diffus, ARV	Stockholm	Henriksdal STP	sludge	mg/kg DW	4.9	44	120	240	10	430	
6844	Diffus, ARV	Lidingö	Käppala STP	sludge	mg/kg DW	9.6	82	200	360	13	670	25
6896	Diffus, ARV	Umeå	Umeå STP	sludge	mg/kg DW	14.0	98	210	330	12	660	
6909	Diffus, ARV	Borås	Gässlösa STP	sludge	mg/kg DW	12.0	88	210	370	18	700	
6936	Diffus, ARV	Borås	Gässlösa STP	sludge	mg/kg DW	13.0	98	220	390	16	740	21
6559	Diffus, ARV	Stockholm	Henriksdal STP	influent	ug/l	32	110	160	220	7.8	530	
6766	Diffus, ARV	Lidingö	Käppala STP	influent	ug/l	14	52	74	91	2.8	230	
6891	Diffus, ARV	Umeå	Umeå STP	influent	ug/l	13	46	73	100	3.5	240	
6615	Diffuse, urban	Stockholm	Eugeniatunneln untreated	storm water	ug/l	0.3	1.3	2	2.5	0.13	6.2	
6618	Diffuse, urban	Stockholm	Eugeniatunneln PAX treated	storm water	ug/l	0.11	0.32	0.3	<0.23	<0.012	0.73	
6812	Diffuse, urban	Stockholm	Starrängsringen	storm water	ug/l	0.24	0.7	1	1.9	0.13	4.0	

Sample#	Type	City/Municipality	Site	Matrix	Unit	C10 LAS	C11 LAS	C12 LAS	C13 LAS	C14 LAS	Sum LAS (C10-C14)	DW, %
6856	Diffuse, urban	Stockholm	Eugeniatunneln untreated	storm water	ug/l	0.054	0.2	0.34	0.43	0.024	1.0	
6857	Diffuse, urban	Stockholm	Eugeniatunneln PAX treated	storm water	ug/l	0.037	0.11	0.16	<0.23	<0.012	0.31	
6889	Diffuse, urban	Stockholm	Eugeniatunneln untreated	storm water	ug/l	0.039	0.12	<0.18	<0.25	<0.013	0.16	
6890	Diffuse, urban	Stockholm	Eugeniatunneln PAX treated	storm water	ug/l	0.34	0.84	0.66	0.31	<0.013	2.2	
6358	Diffuse, urban	Stockholm	Stora Essinge	sediment	ng/g DW	31	180	340	600	400	1600	13
6361	Diffuse, urban	Stockholm	Årstaviken	sediment	ng/g DW	8	42	94	140	72	360	16
6364	Diffuse, urban	Stockholm	Riddarfjärden	sediment	ng/g DW	<8	55	110	240	120	530	17
6357	Diffuse, urban	Stockholm	Stora Essinge	surface water	µg/l	0.0021	<0.01	<0.019	<0.027	<0.0014	0.0021	
6360	Diffuse, urban	Stockholm	Årstaviken	surface water	µg/l	0.0034	<0.01	<0.019	<0.027	<0.0013	0.0034	
6363	Diffuse, urban	Stockholm	Riddarfjärden	surface water	ug/l	<0.002	<0.01	<0.019	<0.027	<0.0014	<0.06	
6750	Point source	Norrtälje	Rimbo STP	effluent	ug/l	5.1	32	48	<2.5	<0.13	85	
6745	Point source	Norrtälje	Vallbyån, upstream Rimbo STP	sediment	ng/g DW	<3	<12	<22	<31	4		57
6746	Point source	Norrtälje	Vallbyån, 5 m downstream Rimbo STP	sediment	ng/g DW	<3	<12	<22	<31	<2	<70	83
6747	Point source	Norrtälje	Vallbyån, 500 m dowmstream Rimbo STP	sediment	ng/g DW	6	34	79	180	25	320	18
6742	Point source	Norrtälje	Vallbyån, upstream Rimbo STP	surface water	ug/l	0.021	0.074	0.095	0.089	0.0035	0.28	
6743	Point source	Norrtälje	Vallbyån, 5 m downstream Rimbo STP	surface water	ug/l	0.34	0.85	0.87	0.77	0.02	2.9	
6744	Point source	Norrtälje	Vallbyån, 500 m dowmstream Rimbo STP	surface water	ug/l	0.081	0.23	0.25	0.2	0.0057	0.77	
6911	Point source		Pulp & paper ind.	water to lagoon	ug/l	0.47	4.7	14	26	0.56	46	
6912	Point source		Pulp & paper ind.	water to lagoon	ug/l	1.2	12	29	39	1.4	83	
6913	Point source		Pulp & paper ind.	effluent from lagoon	ug/l	<0.18	<0.95	<1.7	<2.5	<0.13	<5.5	
6914	Point source		Pulp & paper ind.	effluent from lagoon	ug/l	<0.18	<0.96	<1.7	<2.5	<0.13		
6915	Point source		Pulp & paper ind.	sludge from lagoon	ug/l	1.1	7	15	26	1.2	50	
6916	Point source		Pulp & paper ind.	sludge from lagoon	ug/l	0.99	6.6	14	23	0.91	46	
4771	Point source		Vänern, Ås 9	sediment	ng/g DW	<3	<15	50	120	100	270	18
4773	Point source		Vänern, Ås 141	sediment	ng/g DW	<3	<16	<30	<42	8		13
4775	Point source		Vänern, Ås 190	sediment	ng/g DW	<3	<15	<27	<38	8		23

Appendix 4 Regional program, Results

Sample#	County	City/ Municipality	Site	Matrix	Unit	C10 LAS	C11 LAS	C12 LAS	C13 LAS	C14 LAS	Sum LAS (C10<C14)	DW, %
6590	Blekinge (K)	Karlshamn	Blekingesjukhuset Karlshamn	effluent	µg/l	0.32	0.8	1.5	1.3	<0.07	3.9	
6219	Blekinge (K)	Karlshamn	Karlshamns w w (Långasjön)	drinking water	µg/l	<0.0017	<0.0095	<0.017	<0.025	<0.0013	<0.055	
6215	Blekinge (K)	Karlshamn	Karlshamns w w (Långasjön)	raw water	µg/l	<0.0072	<0.038	0.071	<0.099	<0.005	0.071	
6086	Blekinge (K)	Karlshamn	Mörrums STP	effluent	µg/l	1.3	2.3	1.8	0.98	0.02	6.4	
6085	Blekinge (K)	Karlshamn	Mörrums STP	influent	µg/l	9	28	41	54	2	130	
6087	Blekinge (K)	Karlshamn	Mörrums STP	sludge	mg/kg DW	12	91	210	360	15	690	22
6092	Blekinge (K)	Karlshamn	Sternö STP	effluent	µg/l	0.06	0.19	0.3	0.56	0.044	1.2	
6091	Blekinge (K)	Karlshamn	Sternö STP	influent	µg/l	18	61	92	130	4	300	
6093	Blekinge (K)	Karlshamn	Sternö STP	sludge	mg/kg DW	12	91	210	360	15	680	26
6073	Blekinge (K)	Karlskrona	Bubbetorp deponi	lechate	µg/l	0.061	0.24	0.41	0.43	0.026	1.2	
6247	Blekinge (K)	Karlskrona	Koholmen STP	effluent	µg/l	0.17	0.41	0.4	0.26	<0.0063	1.2	
6246	Blekinge (K)	Karlskrona	Koholmen STP	influent	µg/l	22	64	88	100	3	280	
6249	Blekinge (K)	Karlskrona	Koholmen STP	sludge	mg/kg DW	0.1	1.0	2.4	5.4	0.4	9.0	19
6161	Blekinge (K)	Karlskrona	Lyckeby w w (Lyckebyån)	drinking water prior to carbon filter	µg/l	<0.0018	<0.0096	<0.018	<0.025	<0.0013	<0.056	
6164	Blekinge (K)	Karlskrona	Lyckeby w w (Lyckebyån)	drinking water	µg/l	0.0047	0.021	0.028	0.029	0.0013	0.084	
6156	Blekinge (K)	Karlskrona	Lyckeby vattenverk (Lyckebyån)	raw water	µg/l	0.0052	0.028	0.057	0.082	0.0037	0.18	
6713	Blekinge (K)	Karlskrona	Tvätteri Gullberna	effluent	µg/l	4.0	21	42	61	6.4	130	
6554	Blekinge (K)	Olofström	Jämshögs STP	effluent (after wetland)	µg/l	0.4	0.67	0.48	0.22	0.0079	2.0	
6556	Blekinge (K)	Olofström	Jämshögs STP	sludge	mg/kg DW	1.3	8.4	21.0	52.0	3.9	86	22
6052	Blekinge (K)	Ronneby	Rustorp STP	effluent	µg/l	0.15	0.32	0.31	<0.12	<0.0061	0.78	
6048	Blekinge (K)	Ronneby	Rustorp STP	influent	µg/l	6.8	22	25	23	0.5	77	
6054	Blekinge (K)	Ronneby	Rustorp STP	sludge	mg/kg DW	0.4	2.5	6.2	14.0	0.9	24	18
6574	Blekinge (K)	Sölvesborg	Sölvesborg STP	effluent	µg/l	0.58	0.77	0.4	0.2	0.012	2	
6571	Blekinge (K)	Sölvesborg	Sölvesborg STP	influent	µg/l	22	71	120	160	12	390	
6577	Blekinge (K)	Sölvesborg	Sölvesborg STP	sludge (från vassbädd)	µg/l	2	14	34	76	8	130	

Sample#	County	City/ Municipality	Site	Matrix	Unit	C10 LAS	C11 LAS	C12 LAS	C13 LAS	C14 LAS	Sum LAS (C10<C14)	DW, %
6309	Gotland (I)	Gothem	Gothemsån	surface water	µg/l	<0.0087	<0.046	<0.084	<0.12	<0.006	<0.26	
6306	Gotland (I)	Visby	Visby STP	effluent	µg/l	0.81	1.2	0.69	0.42	0.019	3.1	
6322	Halland (N)	Halmstad	Busör STP	effluent	µg/l	0.17	0.35	0.39	0.33	0.015	1.3	
6321	Halland (N)	Halmstad	Busör STP	influent	µg/l	5	16	20	24	1	65	
6332	Halland (N)	Halmstad	V Stranden STP	effluent	µg/l	0.56	0.66	0.3	<0.24	<0.01	1.5	
6331	Halland (N)	Halmstad	V Stranden STP	influent	µg/l	18	60	90	120	4	290	
6231	Norrbotten (BD)	Gällivare	Kavahedens STP	sludge	mg/kg DW	3.0	25.0	66.0	120.0	5.7	220	17
6757	Norrbotten (BD)	Luleå	Uddebo STP	sludge	mg/kg DW	8.2	73.0	180.0	330.0	16.0	610	15
6179	Norrbotten (BD)	Piteå	Sandholmens STP	sludge	mg/kg DW	7.8	62.0	140.0	240.0	12.0	460	29
6099	Skåne (M)	Helsingborg	Helsingborgs STP	effluent	µg/l	0.46	1.2	1.3	1.3	0.059	4.3	
6595	Skåne (M)	Helsingborg	Helsingborgs STP	effluent	µg/l	0.61	1.6	1.6	1.0	0.022	4.8	
6098	Skåne (M)	Helsingborg	Helsingborgs STP	influent	µg/l	22	74	111	150	5	360	
6101	Skåne (M)	Helsingborg	Helsingborgs STP	sludge	mg/kg DW	15.0	130.0	330.0	600.0	23.0	1100	19
6596	Skåne (M)	Helsingborg	Helsingborgs STP	sludge	mg/kg DW	17.0	130.0	330.0	590.0	27.0	1100	19
6139	Skåne (M)	Kristianstad	Kristianstad STP	effluent	µg/l	0.19	0.35	0.21	<0.25	<0.012	0.75	
6690	Skåne (M)	Kristianstad	Kristianstad STP	effluent	µg/l	0.22	0.33	<0.17	<0.25	<0.013	0.22	
6138	Skåne (M)	Kristianstad	Kristianstad STP	influent	µg/l	32	110	160	200	8	510	
6688	Skåne (M)	Kristianstad	Kristianstad STP	influent	µg/l	25	79	120	160	7	390	
6142	Skåne (M)	Kristianstad	Kristianstad STP	sludge	mg/kg DW	22.0	140.0	280.0	440.0	18.0	890	21
6686	Skåne (M)	Kristianstad	Kristianstad STP	Sludge	mg/kg DW	21.0	130.0	250.0	400.0	18.0	820	19
6144	Skåne (M)	Kristianstad	Kristianstad STP	effluent from laundry	µg/l	9.4	39	72	92	3.4	220	
6689	Skåne (M)	Kristianstad	Kristianstad STP	effluent from laundry	µg/l	5.1	27	56	73	2.8	160	
6125	Skåne (M)	Malmö	Sjölunda STP	effluent	µg/l	5	11	9.7	6.9	0.18	33	
6606	Skåne (M)	Malmö	Sjölunda STP	effluent	µg/l	6.1	14	9.2	5.4	0.13	35	
6123	Skåne (M)	Malmö	Sjölunda STP	influent	µg/l	58	180	260	320	12	830	
6604	Skåne (M)	Malmö	Sjölunda STP	influent	µg/l	62	200	310	410	16	1000	
6128	Skåne (M)	Malmö	Sjölunda STP	sludge	mg/kg DW	42.0	340.0	830.0	1400.0	54.0	2700	28
6608	Skåne (M)	Malmö	Sjölunda STP	sludge	mg/kg DW	50.0	370.0	810.0	1400.0	59.0	2700	26
6705	Skåne (M)	Trelleborg	Trelleborg STP	effluent	µg/l	1.51	2.5	1.55	0.71	0.017	6.3	

Sample#	County	City/ Municipality	Site	Matrix	Unit	C10 LAS	C11 LAS	C12 LAS	C13 LAS	C14 LAS	Sum LAS (C10<C14)	DW, %
6706	Skåne (M)	Trelleborg	Trelleborg STP	influent	µg/l	45	150	230	330	14	770	
6707	Skåne (M)	Trelleborg	Trelleborg STP	sludge	mg/kg DW	16.0	130.0	360.0	830.0	41.0	1400	29
6168	Skåne (M)	Trelleborg	Trelleborgs STP	effluent	µg/l	2.5	4.2	2.7	1.2	0.027	11	
6167	Skåne (M)	Trelleborg	Trelleborgs STP	influent	µg/l	60	190	250	330	13	840	
6172	Skåne (M)	Trelleborg	Trelleborgs STP	sludge	mg/kg DW	23.0	170.0	440.0	950.0	39.0	1600	32
6067	Värmland (S)	Arvika	Kyrkviken, outside Viks STP	surface water	µg/l	0.0054	0.015	<0.019	<0.028	<0.0014	0.0054	
6189	Värmland (S)	Arvika	Vik STP	effluent	µg/l	0.57	1	0.87	0.5	0.02	3	
6282	Värmland (S)	Karlstad	Sjöstads STP	effluent	µg/l	0.92	0.94	0.39	<0.22	<0.011	2.3	
6433	Värmland (S)	Kristinehamn	Bergsjön raw water source	surface water	µg/l	<0.0018	0.0095	<0.017	<0.025	<0.0013		
6442	Värmland (S)	Kristinehamn	Fiskartorpet STP	effluent	µg/l	0.19	0.41	0.51	0.57	0.029	1.7	
6438	Värmland (S)	Kristinehamn	Fiskartorpet STP	influent	µg/l	11	40	52	66	2.1	170	
6445	Värmland (S)	Kristinehamn	Strandmossens deponi	Lechate	µg/l	0.084	0.18	0.16	0.15	0.0066	0.58	
6017	Värmland (S)	Kristinehamn	Varnumsviken, stn Kr70	surface water	µg/l	<0.0019	<0.01	<0.018	<0.026	<0.0012	<0.057	
6187	Västernorrland (Y)	Sollefteå	Långsele STP	effluent	µg/l	3.8	6.8	3.9	1.7	0.028	16	
6373	Västmanland (U)	Västerås	Kungsängens STP	effluent	µg/l	1.5	2.6	1.3	1	0.047	6.4	
6372	Västmanland (U)	Västerås	Kungsängens STP	influent	µg/l	23	82	130	190	8	440	
6376	Västmanland (U)	Västerås	Kungsängens STP	sludge	mg/kg DW	25.0	140.0	290.0	460.0	22.0	940	27