REPORT

Results from the Swedish National Screening Programme 2007

Sub-report 5:Silver

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Report Summary

Results from the Swedish National Screening Programme 2007
Sub report 5: Silver

Project sponsor

Naturvårdsverket

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Title and subtitle of the report

Results from the Swedish National Screening Programme 2007 Sub report 5: Silver

Summary

IVL has performed a "screening study" on release of silver in the Swedish environment on a commission from the Swedish Environmental Protection Agency.

Keywords

Silver, screening, monitoring, fate, ecotoxicity

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Please note

The measurements of silver in water described in this report were done on acidified samples where particles were allowed to settle before the water phase was analysed. Silver adsorbed to the surface of coarse particles were thus not included in the presented concentrations. Keep this in mind when comparing to results obtained for water samples after digestion with particles included.

The following sentence has been removed from Chapter 8.2.1:
The concentrations were much lower than the interval 600 - 36 000 ng/l reported in Sweden 1996 and also in the low range of recent Norwegian results (cf. Section 5) reflecting the decrease in consumption.

Observandum

Mätningar av silver i vatten som beskrivs i denna rapport gjordes på surgjorda prov där partiklar fick sedimentera innan vattenfasen analyserades. Silver adsorberat till grövre partiklar ingår alltså inte i resultatet. Tag hänsyn till detta om jämförelser görs med resultat från analys av vatten efter uppslutning där partiklarna inkluderats.

Summary

The Swedish Environmental Research Institute Ltd. (IVL) and the Norwegian Institute for Air Research (NILU) have performed a "screening study" of silver during 2007 as an assignment from the Swedish Environmental Protection Agency. Silver is a precious noble metal long used as jewellery, for ornament and as a coin metal. Silver may appear as solid waste from applications in electronic industry, in batteries, mirror glass etc. However, it is mainly the uses in photographic applications and as antiseptic for medical purposes and in consumer products, that are of environmental concern. While the use in photography will decrease due to the development of digital cameras, the use as antimicrobial agent in consumer products may increase.

The overall objective of the screening was to determine the concentrations of silver in some compartments of the Swedish environment, focusing on the release into the aquatic environment. The program included measurements in background areas and close to potential point sources and areas affected by diffuse sources. Sample types included untreated and treated municipal sewage wastewaters, landfill leakage waters, sludge, and surface water samples. In addition, samples of fish muscle were analysed.

The table shows ranges of silver concentrations in environmental matrices.

Sample type	Number of samples	Silver concentration
Background lakes, surface water	3	6 - 10 ng/l
Background lakes, sediment	3	5 - 22 mg/kg d.w.
Background lakes, fish muscle	3	< 0.21 µg/kg f.w.
Groundwater	3	5-7 ng/l
Untreated municipal sewage wastewater	43	< 9.0 - 280 ng/l
Treated municipal sewage wastewater	78	< 5.0 - 1400 ng/l
Municipal sewage sludge	41	0.12 - 46 mg/kg d.w.
Receiving water, surface water	10	< 5.0 - 25 ng/l
Receiving water, sediment	12	0.68 - 44 mg/kg d.w.
Receiving water, fish muscle	21	< 0.21 - 1.0 µg/kg f.w.
Storm water	4	71 - 480 ng/l
Landfill leachate	6	13 - 830 ng/l
Hospital wastewater	8	5.0 - 71 ng/l
Laundry wastewater	2	18 and 54 ng/l

Top layers of sediments from background area lakes contained from 2.1 to 22 mg/kg d.w. of silver, the latter concentration probably depending on the bedrock composition. Perch muscle contained no measurable concentrations of silver (< 0.21 µg/kg f.w.).

Influents to municipal sewage wastewater treatment plants (STPs) contained from 9.0 to 280 ng/l of silver. The median value was 41 ng/l obtained from analyses in 43 STPs. Treated effluents contained silver in concentrations with a median value of 13 ng/l as measured in 78 STPs. The median value of the retention of silver in STPs was 75 %. Sewage sludge contained 0.12 - 46 mg/kg d.w. of silver.

Water bodies receiving treated wastewaters (and storm waters) contained silver from below the detection limit of the analytical method to 25 ng/l. Silver was found in sediments of receiving waters bodies (0.68 - 44 mg/kg d.w.) supporting a statement that silver is bound to particulate material that eventually sediments from the water column. In most perch muscle samples the concentration of silver was below the detection limit (0.21 μg/kg f.w.); in three samples the concentration was between 0.3 and 1.0 μg/kg f.w.

Samples from four storm water wells in Stockholm city contained from 71 to 480 ng/l of silver. Aluminium precipitation had a limited effect on the silver concentration.

Landfills release silver that is transported by the landfill leachates. Samples from six deposit sites contained from 13 to 830 ng/l. At one site wastewater treatment reduced the concentrations from 520 to 290 ng/l.

Eight hospital wastewaters contained silver between 5.0 and 71 ng/l. Two laundry effluents contained 18 and 54 ng/l. The concentrations were in most cases not higher than untreated municipal wastewaters and do not contribute substantially to an increase in these flows if connected to the sewage net.

Sammanfattning

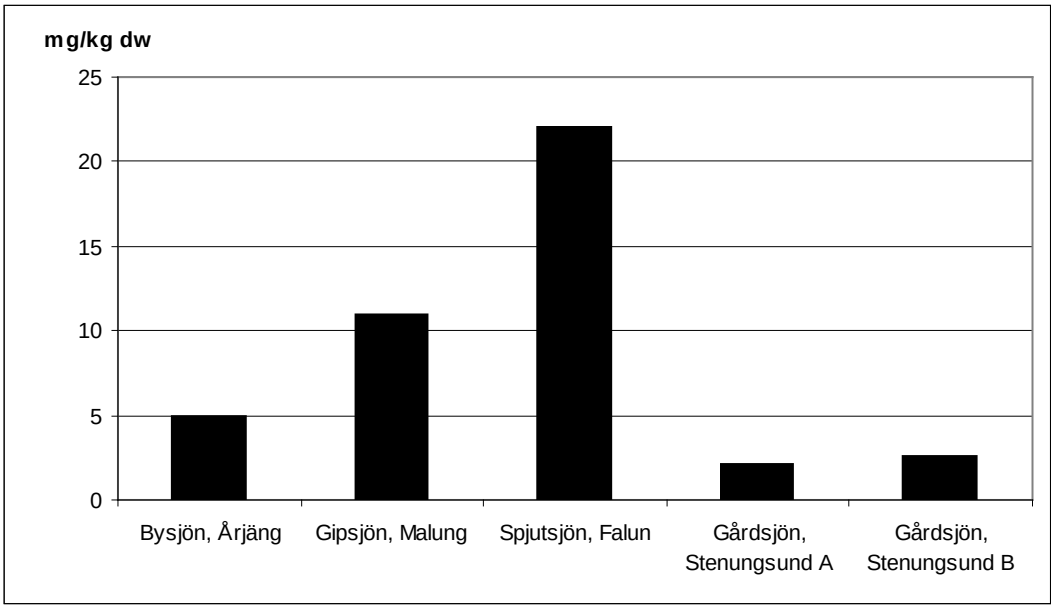
IVL Svenska Miljöinstitutet AB och Norsk Institutt for Luftforskning (NILU) har på uppdrag av Naturvårdsverket genomfört en översiktlig kartläggning av silver i svensk miljö 2007. Silver är en ädelmetall som förekommer sällsynt i jordskorpan. Silver ingår i vissa sällsynta mineral men utvinns framförallt ur koppar-, zink- och blyförande malmer. Silver har använts av människan under årtusenden och användningen har varierat från i ren metallisk form som smycken, prydnadsföremål, bordssilver och mynt till mer industriella användningar som elektriska ledare, fotografi och medicinska tillämpningar. Silverjoners antiseptiska egenskaper har utnyttjats inom läkekonsten och på senare tid även i konsumentprodukter. Bakteriers förmåga att utveckla resistens mot antibakteriella medel har givit anledning till oro i samband med användningen av silver i bakteriostatika.

Det huvudsakliga syftet med denna översiktliga kartläggning var att bestämma koncentrationer av silver i några olika matriser i miljön, framförallt för att belysa viktiga transportvägar i vattenmiljön i Sverige samt förekomst i fiskmuskel.

Nedan visas en tabell med uppmätta halter i olika provtyper.

Provmatris	Antal prov	Koncentration Ag
Referenssjöar, ytvatten	3	6 - 10 ng/l
Referenssjöar, sediment	3	5 - 22 mg/kg torrvikt
Referenssjöar, fiskkött	3	< 0,21 µg/kg våtvikt
Grundvatten	3	5-7 ng/l
Obehandlat kommunalt avloppsvatten	43	9,0 - 280 ng/l
Behandlat kommunalt avloppsvatten	78	< 5,0 - 1400 ng/l
Kommunalt avloppsslam	41	0,12 - 46 mg/kg torrvikt
Recipient, ytvatten	10	< 5,0 - 25 ng/l
Recipient, sediment	12	0,68 - 44 mg/kg torrvikt
Recipient, fiskkött	21	< 0,21 - 1,0 µg/kg våtvikt
Dagvatten	4	71 - 480 ng/l
Lakvatten från avfallsanläggning	6	13 - 830 ng/l
Avloppsvatten från tvätterier	2	18 och 54 ng/l
Avloppsvatten från sjukhus	8	5,0 - 71 ng/l

I bakgrundssjöars sediment (NVs referenssjöar och andra bakgrundssjöar) uppmättes silver i koncentrationer från 2,1 till 22 mg/kg torrvikt, den senare troligen påverkad av områdets berggrund. Silver såväl i jonform som i metallisk form binds till partiklar varför en anrikning i sediment kan förväntas. Fiskkött av abborre innehöll inga mätbara halter av silver (< 0,21 µg/kg våtvikt).



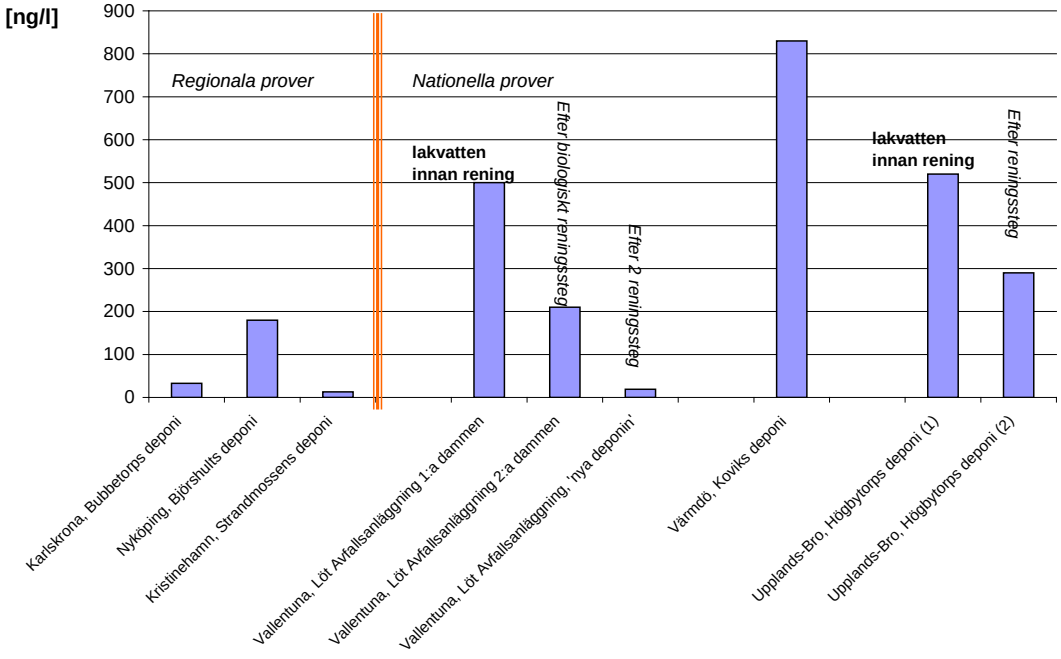
Figur A. Uppmätta silverkoncentrationer i sedimentprover från referens- och bakgrundssjöar.

I inkommande vatten till reningsverk transporteras silver. Från 9 till 280 ng/l, med ett medianvärde på 41 ng/l, uppmättes i 43 provtagna anläggningar. Vid avloppsvattenbehandling avlägsnas en del av silvret och medianvärdet för provtagna utgående avloppsvatten sjönk till 13 ng/l. Ett medianvärde för retentionen beräknades till 75 %. Avskilt silver ansamlas i reningsverksslam. Provtagning och analys av slam gav halter mellan 0,12 och 46 mg/kg torrvikt.

I recipienter till reningsverk (och till dagvatten) uppmättes halter av silver från mindre än detektionsgränsen (5,0 ng/l) till 25 ng/l. Även i denna miljö uppträder silver i sediment. Från 0,68 till 44 mg/kg torrvikt uppmättes i sedimentens översta skikt. I abborrkött från recipienter kunde silver i de flesta fall inte detekteras (detektionsgräns 0,21 µg/kg våtvikt). Tre prover innehöll emellertid mellan 0,3 och 1,0 µg/kg våtvikt av silver. I fiskprover ifrån Stockholms innerstad kunde silver ej detekteras.

Dagvatten från hårdgjorda ytor i stadsmiljö innehöll ansenliga halter av silver. I prov från fyra lokaler i Stockholm uppmättes 71 - 480 ng/l. Kemisk fällning som behandling av dagvatten från en lokal visade endast en begränsad minskning av silverhalten (ett fall av två!).

Från avfallsanläggningar transporteras silver via lakvatten. Prov från sex anläggningar gav värden från 13 till 830 ng/l. Behandling av lakvatten (aktivslambehandling) reducerade silverhalten från 520 till 290 ng/l i en undersökt anläggning.



Figur B. Koncentrationer av silver i lakvatten ifrån deponier och avfallsanläggningar. I några förekommande fall har prover tagits före och efter rening av lakvattnet.

Hantering av silverhaltiga produkter på sjukhus och i tvätterier motiverade undersökningar av avloppsvatten från sådana källor. Åtta analyserade sjukhusavlopp hade silverhalter mellan 5,0 och 71 ng/l, medianvärde 16 ng/l. Två analyserade tvätteriavloppsvatten innehöll 18 och 54 ng/l. Halterna var i de flesta fall i nivå med obehandlat kommunalt avloppsvatten och bidrar således inte till någon förhöjning vid anslutning till det kommunala nätet.

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 carried out 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. Several of them are included in consumer products.

The overall objectives of the screening studies 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.

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

The Swedish Environmental Research Institute (IVL) in collaboration with the Norwegian Institute has performed the screening of silver for Air Research (NILU).

Silver is a noble metal known for its use in jewellery, tableware, plating, coins and medals, electric conductors and as a catalyst. Silver salts are used in photography in developing film and photographic paper, especially before the introduction of digital cameras.

Free silver ion is highly toxic, only preceded by mercury of toxic heavy metals. This property has been used in bacteriostasis. Technical use of silver compounds, especially up to recent days in photographic industry, released silver into the aquatic environment. The antiseptic properties of silver have been used in medical care. Recently another technical application of silver has been introduced; as an antibacterial agent in consumer products such as washing machines, refrigerators and clothings. An increased flow of silver in the environment is thereby expected.

This survey aims to describe these flows, by sampling and analysis of silver in domestic and industrial wastewaters, sludge and sediments. Samples were also collected from water bodies receiving treated wastewaters and from background localities. A further aim is to investigate the uptake in fish muscle.

2 Production and use of silver compounds

2.1 Sources and production

The noble metal silver occurs sparingly in the earth crust especially in sulfide-rich ores and in combination with other noble metals and copper, lead, and zinc. It is found native as metallic silver and in minerals such as argentite, cerargyrite, horn silver, proustite, pyrargyrite, and stephanite. The main source however is usually as a by-product in copper and lead smelting. In 2001, 60 percent of the world production was from copper, lead, and zinc ores, 25 percent from silver ores, and 15 percent from gold ores (Butterman, Hilliard 2004). The total world production in 2006 was 18320 metric tonnes (Silverinstitute 2008). The most important producing countries are shown in Table 2.

In Sweden, silver has been mined at Sala silver mine in Västmanland since the beginning of the 16th century until the mine was closed in 1908. Nowadays silver is extracted in a copper mine at Aitik near Gällivare, a lead mine at Arjeplog, and in mines close to Skellefteå. The ore is transported to the smelt work at Rönnskär, Skellefteå. The Swedish production of silver in 2006 was 244 metric tonnes, i.e. 1.3 % of the world production (Table 2).

Table 2 Top 20 silver producing countries in 2006 (recalculated by 1 ounce = 28.35 g) (Silverinstitute 2008).

	Country	Production 2006, metric tonnes		Country	Production 2006, metric tonnes
1	Peru	3164	10	Kazakhstan	740
2	Mexico	2733	11	Bolivia	431
3	China	2138	12	Sweden	244
4	Australia	1576	14	Morocco	215
5	Chile	1460	15	Argentina	173
6	Poland	1145	16	Turkey	170
7	Russia	1123	17	Iran	91
8	United States	1040	18	South Africa	79
9	Canada	885	19	India	77
10	Kazakhstan	740	20	Uzbekistan	65

The flow of silver and silver compounds across the border of Sweden due to import and export is small in comparison with the annual production (http://apps.kemi.se/flodessok/floden). The import as raw material was 3 - 4 tonnes and as chemical products less than 1 tonne in 2003. The export as raw material was 3 tonnes and as chemical products less than 1 tonne. These values are in some discrepancy with previous data from 1994 (Naturvårdsverket 1996).

2.2 Use of silver and silver compounds

The most well known use of silver is in jewellery and ornament. Silver is used in tableware and utensils. Since ancient times silver coins have been used as currency. However, nowadays the metal has been largely replaced with other coin metals. Silver is used in high quality mirrors. Metallic silver alloyed with mercury and small amounts of some other metals is used in dental fillings (amalgam). Silver iodide has been used in cloud seeding to induce rainfall.

Several industrial applications use silver. Silver oxide is an important catalyst in chemical industry. The metal is used in electrical and electronic devices as electric contacts and conductors. Products like computer keyboards and audio hardware contain electrical contacts in silver. Silver is also used in batteries. Silver salts, mainly silver nitrate and silver halides, are used in photographic applications: photographic films and papers contain photosensitive cationic silver. Upon introduction of digital cameras, the silver consumption in photography is expected to decrease.

The bactericidal properties of silver compounds have been employed in the control of microbial infections. Lapis, a known antiseptic product, is a solution of silver nitrate. In Sweden, silver sulfadiazin in creams or aerosol sprays is used to combat infections in wounds, especially burn wounds.

Silver has recently found a new market in consumer products like washing machines, refrigerators, socks and shoes, and body lotions. The main application is as antiseptic and anti-odour agent. Micro granules of silver are incorporated in commercial clothing and will eventually appear in washing wastewater (Benn, Westerhoff 2008). Silver is also used in medical products because of its bactericidal properties. However, Apoteket stopped selling silver containing plasters in May 2006 (Kemivärlden Biotech) and Stockholm County Council (Stockholms läns landsting) has abandoned the use of silver containing products.

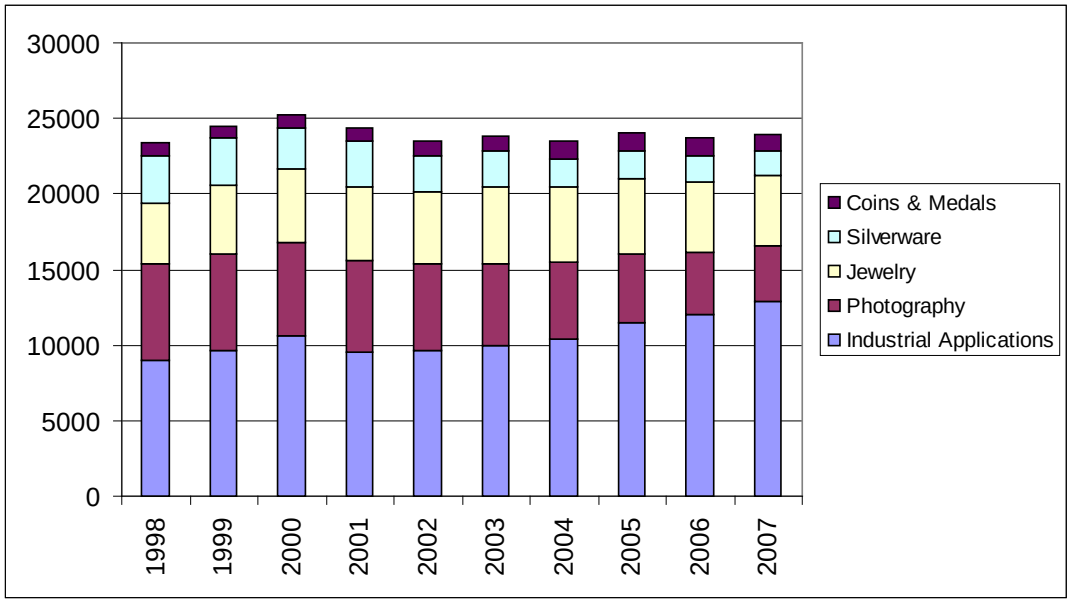


Figure 1. World silver demand for different applications for the years 1998 – 2007 (Silverinstitute 2008).

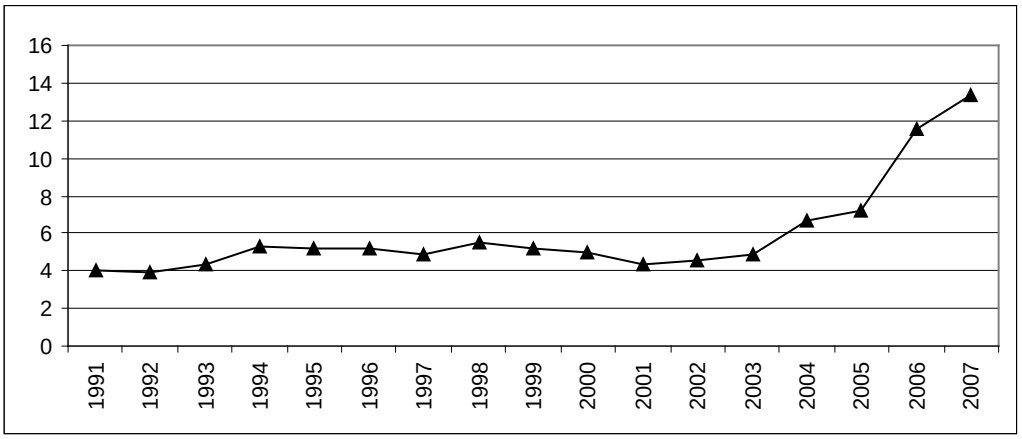


Figure 2. World silver price (constant 2007 US$/oz) for the years 1991 – 2007. (Silverinstitute 2008)

The annual global consumption of silver has been rather constant the latest decade, at 23 000-27 000 tonnes (800-900 million ounces, Figure 1). About one-third of the silver that was produced in 2001 went into jewellery and silverware, one-fourth into photography, and the main part of the remainder was used in industrial applications (Butterman, Hilliard 2004). Over the past decade the consumption in industrial applications has increased, the use in photography on the other hand has decreased (Figure 1). The price of silver in US $ has increased considerably since 2005 (Figure 2).

In Sweden, enterprises are not required to report the use of pure silver to the Products Register at the Swedish Chemicals Agency. However, silver compounds which are present in chemical products should be reported. Figure 3 shows the reported annual use of silver compounds in Sweden from year 1992 to 2005 (KemI-stat, May 2008). As can be seen the consumption has decreased considerably since the mid-1990s.

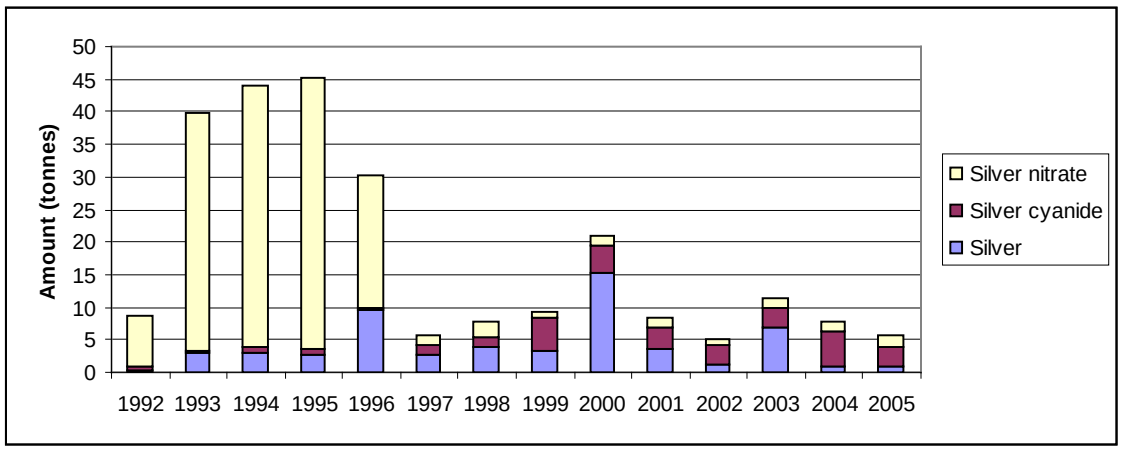


Figure 3. Swedish consumption of silver compounds as registered in the Products Register (KemI-stat, 2008)

3 Properties, fate, and toxicity

3.1 Chemical and physical properties

Silver is a white metallic element, a noble metal well known for its malleable, electric and thermal conductive properties. It has the highest electric and thermal conductivity of all elements. The metallic surface reflects almost 100 % of incident light. Silver has the chemical symbol Ag, derived from the Latin argentum, and the atomic number 47. Silver occurs in nature in two stable isotopes ^{107}Ag and ^{109}Ag with the proportions 51.8 and 48.2 %, respectively. Besides those two isotopes, 28 radioactive isotopes have been characterised with half-lives from less than three minutes to 41 days.

Being a noble metal silver is resistant to oxidation and corrosion except when in contact with sulphur. Silver is almost exclusively univalent in its compounds. Physical-chemical properties of metallic silver and four silver compounds are compiled in Table 3.

Table 3. Physical-chemical properties of silver and some silver compounds

	Silver, metallic Ag	Silver chloride AgCl	Silver nitrate $AgNO_3$	Silver sulphide Ag_2S	Silver thiosulphate $Ag_2S_2O_3$
MW (g/mol)	107.88	143.34	169.89	247.82	327.89
Specific gravity (g/mol)	10.5	5.56	4.35	7.32	
Melting point (°C)	960.8	455	212	825	decomp
Boiling point (°C)	1950	1550	444	decomp	decomp
Water solubility (mg/l)	Insoluble in water, soluble in HNO_3, KCN	0.089 - 2.1 (at 10–100 °C)	122 – 952 (at 0–100 °C)		slightly soluble
Solubility Product Constant		1.8×10^{-10}		6×10^{-51}	

As shown in the table, silver is soluble in nitric acid and forms univalent silver ions. Silver ions form more or less soluble complexes or salts with other ions such as nitrate, cyanide, thiosulfate, chloride, and sulphide. Silver ions may also form complexes with organic (sulphur-containing) compounds and colloids. Some complexes are insoluble in water.

3.2 Fate

The most important forms of silver in the environment are as elemental silver (oxidation state 0) or as monovalent cationic silver (oxidation state +1). The main part of silver resulting from photographic applications occurs as insoluble forms. The affinity for sulphide, (photo-induced) reduction to elemental silver or formation of less soluble organic and inorganic complexes reduce the contents in aquatic media. Most silver entering municipal sewage wastewater ends up in sludge (Naturvårdsverket 1996). Residual concentrations in the aquatic environment will sorb on particulate material, either planctic organisms or abiotic particles, and eventually appear in sediments.

Cationic silver is associated with structures in organisms containing sulphur and to some extent to nitrogen- and oxygen containing compounds. In liver and kidney tissue silver is bound to the cysteine-rich protein metallothionein.

Silver containing materials such as electronics, batteries and solders may appear in solid waste that is either deposited on landfills or burnt in waste incinerators. Residues may disperse in the environment by leakage or emissions to the air.

Silver is accumulated in plants, both terrestrial and aquatic species. A bioconcentration factor of 40 000 was reported for the phaeophyte *Fucus vesiculosus* (Langston, Burt 1994). Limnic and marine molluscs have been shown to accumulate silver (Berthet et al. 1992; Langston, Burt 1994). Uptake of silver in organisms is interfered by the presence of other heavy metals. The presence of zinc and copper may increase the uptake of silver in fish by induction of metallothionein production.

3.3 Environmental toxicity, health effects, and metabolism

3.3.1 Exotoxicity

Silver has no known biological function in living organisms. Silver compounds that dissociate to produce significant concentrations of silver ions in solution may be toxic to exposed organisms. The silver ion belongs to a group of the most toxic forms of heavy metals together with Cd, Cr (VI), Cu, and Hg.

Toxic effects of some silver compounds on a number of aquatic organisms are compiled in Table 4.

Table 4. Ecotoxicity of silver compounds

	Species	Endpoint	Toxicity [mg/l]	Compound	Reference
Fish	*Pimephales promelas,* Fathead minnow	Acute toxicity 4 d LC50	0.0025-0.338	$AgNO_3$	Several refs.
		Acute toxicity 4 d NOEC	0.010	$AgNO_3$	Klaine et al. 1996
		Acute toxicity, flow-through 4 d LC50	0.0092	$AgNO_3$	Nebeker et al. 1993
	Oncorhynchus mykiss, Rainbow Trout	Acute toxicity, static 4 d LC50	0.012	$AgNO_3$	Hogstrand et al. 1996
		Acute toxicity, static 7 d LC50	0.0032	Ag^+	Hogstrand, Wood 1998
		Acute toxicity, flow-through 4 d LC50	0.0065-0.013	$AgNO_3$	Davies, Ginneverl 1979
	Oncorhynchus mykiss, Rainbow Trout, embryo-larvae	Acute toxicity, >6 d LC50	0.01	$AgNO_3$	Birge, Zuiderveen 1995
Amphi-bians	*Rana palustris, R. pipiens, Gastrophryne carolinensis*	Acute toxicity, LC50	0.01	$AgNO_3$	Birge, Zuiderveen 1995
Inverte-brates	*Daphnia magna,* Crustacea	Acute toxicity 96 h IC50	0.02	Ag_2S	Ewell et al. 1993
		Acute toxicity 96 h IC50	0.005	$AgNO_3$	Ewell et al. 1993
		Reproduction 21 d EC50	0.0029-0.0039	$AgNO_3$	Nebeker et al. 1993
	Ceriodaphnia dubia, Crustacea	Reproduction NOEC	0.0045	$AgNO_3$	Birge, Zuiderveen 1995
	Chironomus tentans, 3rd instar larvae, Insecta	Acute toxicity 10 d IC50	0.035-0.063	$AgNO_3$	Call et al. 1997
	Planorbella trivolis, Mollusca	Acute toxicity 4 d LC50	0.3	$AgNO_3$	Ewell et al. 1993
		Acute toxicity 4 d EC50	>1.3	$NaAgS_2O_3$	Ewell et al. 1993

	Species	Endpoint	Toxicity [mg/l]	Compound	Reference
		Acute toxicity 4 d LC50	>1000	Ag_2S	Ewell et al. 1993
	Aplexa hypnorum, Mollusca	Acute toxicity 4 d LC50	0.4	$AgNO_3$	Holcombe et al. 1983
	Dugesia dorotocephala, Turbellaria	Acute toxicity 4 d LC50	0.03	$AgNO_3$	Ewell et al. 1993
		Acute toxicity 4 d EC50	>1.3	$NaAgS_2O_3$	Ewell et al. 1993
		Acute toxicity 4 d LC50	>1000	Ag_2S	Ewell et al. 1993
Algae	*Selenastrum capricornutum*, green alga	Growth inhibition 7 d NOEC	10	$NaAgS_2O_3$	Ewell et al. 1993
		Growth inhibition EC50	>0.125	$AgNO_3$ Ag_2SO_4	Schmittschmitt et al. 1997
	Gymnodium sp., dinoflagellate	Growth inhibition 2 d NOEC	0.002-0.010	Ag^+	Wilson, Freeberg 1980

According to the table, silver nitrate is the most toxic form of silver. Silver ions are dissociated upon dissolution of the salt in water. Free silver ions are the most toxic species of silver. The ions readily form complexes or are sorbed by other constituents in an exposure medium. Therefore continuous flow exposure is necessary to maintain concentrations in solution when investigating the toxicity of free silver ions.

No toxicity was observed upon exposure of various aquatic organisms to silver sulphide, Ag_2S. Concentrations of up to 1 g/l (apparently not dissolved in water) were ineffective. From the extremely low solubility and dissociation of the sulphide follows a low concentration of free silver ion, the toxic form of silver.

Exposure of fish to silver results in induction of production of the metal-binding protein metallothionein (Hogstrand, Wood 1993; Cosson 1994).

3.3.2 Health effects

There are in general no severe adverse health effects of silver. Silver may enter the human body through breathed air, ingestion with food or skin contact. In the past, workers who were manufacturing silver compounds like silver nitrate and silver oxide, were exposed to silver containing dust (Butterman, Hilliard 2005). Symptoms included breathing complaints, irritated throat and lungs, and stomach pain. The condition argyria, which is caused by silver deposits in subepithelial cells in skin, results in a discolouration, which is irreversible but otherwise not harmful to the subject. Another condition, argyrosis, occurs when excessive silver is deposited in the conjunctiva and cornea of the eye, which may impair vision. Of greater concern to human health is the possible antimicrobial resistance caused by excessive use of silver (cf. below).

3.3.3 Nano silver, 'nAg'

Nano-sized Ag particles (sometimes referred to as 'biocidal Ag' or 'nAg') have rapidly become an important human health issue as well as an environmental issue. Among the products listed in the Inventory of Nanotechnology Consumer Products (WWI, 2006), silver nanoparticles are the most prevalent nanomaterial. The number of registered products in the WWI-listing rose from 67 products (April 2007) to 93 products (May 2007) by 50% in one month. 'nAg 'has antibacterial, antimicrobial, antibiotic antifungal and partially antiviral properties (American elements, 2007). Nano silver powders further offer potential for protective coatings including paints and varnishes, scratch resistant coatings, charge dissipating coatings, drug delivery identification units, solar energy collection components, and water purification systems (Etris, 2006). Typical sizes of nAg range

from 10 nm to 80 nm with a specific surface area between 30-60 m2/g. nAg is available in different purity, coated and in dispersed forms (American elements 2007).

According to calculations from Blaser et al., 110-230 tonnes of nAg is currently used within EU annually. Furthermore, this amount is claimed to (from material flow modelling) correspond to 9-20 tonnes of nAg emitted to the environment from STP effluents.

A key issue regarding nano seized silver and its corresponding toxicity is whether nAg emitted from products like textiles upon washing, are completely dissolved or remains in the nano-sized particle form also when entering and leaving the WWTP. If nAg were completely dissolved when immersed, in water then no specific toxicity would be expected from the particles aprat from the toxicity associated with ordinary silver salts (such as silver nitrate or sulphide). Morones et al. (Morones et al., 2005) and Sondi and Salopek-Sondi (Sondi and Salopek-Sondi, 2004) examined whether the toxic effect resulting from nanoparticles was actually caused by the nanoparticles and not by ions released from the nanoparticles. It was shown that ions were released immediately (1 μM) after the nanoparticles were given in the medium (Morones et al., 2005). After 24 h this concentration had decreased considerably (0.2 μM). No further dissolution occurred. Morones et al. figured that Ag^+ may be reduced to Ag(0) or re-associated with the nanoparticles. Sondi and Salopek-Sondi confirmed the incorporation of nAg (elementary silver) in the membrane structure by TEM (Transmission electron microscopy) analysis and EDAX (energy-dispersive X-ray spectroscopy).

There are now several studies on the toxicity of nAg to bacteria (Sondi and Salopek-Sondi, 2004), a few studies with rats/rat cell lines, but no studies with algae, daphnia or fish. The studies identify different factors that influence the toxic concentration of nAg: size and shape of nAg, initial number of colony forming units (CFUs), nAg concentration and the medium. All studies report nano silver to be toxic independent of the organism/cell used in the tests. Sondi and Salopek-Sondi (Sondi and Salopek-Sondi, 2004) found that nAg was present in the bacterial cell wall prohibiting a proper regulation of the transport through the membrane of the bacteria and thus causing cell death.

Morones et al. (Morones et al., 2005) suggest that silver reacts preferably with sulphur-containing proteins among others in the membrane and with phosphorus containing compounds such as DNA. Nanoparticulate silver with a size ranging from 75-250 nm were found to interrupt the RNA replication and prevent microbes from reproducing (Tűrk et al., 2005).

In rat liver cells (in vitro) exposed to 10-50 mg/l nAg (15, 100 nm), the mitochondrial function decreased whereas LDH (lactate dehydrogenase) leakage increased significantly (Hussain et al., 2005). Cells became irregular in size and showed cellular shrinkage, significant depletion of GSH (reduced glutathione) level, reduced mitochondrial membrane potential and a significant increase in ROS (reactive oxygen species). Hussain et al. disclosed that the cytotoxicity is likely to be mediated through oxidative stress (Hussein et al., 2005). In a study with E. coli, nAg was shown to destabilize the outer membrane, collapse the plasma membrane potential, specifically stimulate 8 proteins and deplete the levels of intracellular ATP (Lok et al., 2005). Lok et al. found the mode of action to be similar to ionic silver. However, Morones et al. disclosed a different effect of ions and nAg. According to Morones et al., ions produce a formation of a low molecular weight region in the centre of the bacteria (a mechanism of that defence where bacteria conglomerate its DNA to protect it). For nanoparticles no low density region was found but a large number of small silver nanoparticles inside the bacteria (Morones et al., 2005).

Pal et al. (Pal et al., 2007) showed that the antibacterial activity of nAg also depends on the shape. Truncated triangular silver nanoplates with a lattice plane as the basal plane displayed the strongest biocidal action (EC_{100} at 1.2 mg/l) compared with spherical and rod-shaped nAg (EC_{100} at 12.5-50 mg/l) and with Ag^+.

Nanosilver has also recently been found at concentrations as low as 0.14 μg/mL to be toxic to several species of nitrifying bacteria, which play an important role in the environment by converting ammonia in the soil to a form of nitrogen that can be used by plants (Benn et al., 2008). Nitrifying bacteria are used in also sewage treatment plants (STPs) to convert raw sewage into less harmful products. The toxicity of nAg to these organisms has raised concerns that release of nanosilver to the environment may disrupt the operation of STPs as well as natural processes in the ecosystem that support plant life. However, estimated that concentrations of nanosilver are expected to be released would not likely reach high enough levels to threaten microbes important to STP operation (Benn et al., 2008, Mueller et al., 2008).

Furthermore, very recent findings indicate that single Ag nano particles diffuse through pores in chorion surrounding Zebra fish embryos (Nallathamby et al., 2008). In the study the authors could frequently detect Ag nano particles also in tissue like retina, brain, gill arches, heart, tail of the mature fish. Exposure to the nano particles was believed by the authors to have caused deformations in the adult fish (effect observed at a 0.19 nM ≈ 20 ng/l).

4 National and international legislation

Silver is not included among the metals that are controlled in the assessment of environmental quality in lakes and other watercourses (Naturvårdsverket 2000).

A tolerable daily intake of silver has been given as five μg/kg body weight (IRIS 1991). A critical concentration for the protection of groundwater, based on a WHO recommendation, was reported as 50 μg/l (WHO 2004). There is no regulation of silver in drinking water in the USA, but the EPA recommends a limit of 10 mg/l to avoid the possibility of skin discolouration (Butterman, Hilliard 2004). Their Occupational Safety and Health Administration recommend a limit of 10 μg/m^3 for workplace air for an 8-h workday and a 40-h workweek. Workplace air was furthermore recommended to contain no more than 100 μg/m^3 of metallic silver and 10 μg/m^3 of soluble silver compounds in 1999 by the American Conference of Governmental Industrial Hygienists.

5 Previous measurements in the environment

Few data are available from Swedish localities, except for sewage wastewaters and sludge. Environmental concentrations of silver have been compiled mainly from analyses in different matrices abroad in remote, possibly unpolluted areas and areas with expected pollution (Naturvårdsverket 1996).

Air contained 1-3 pg/m^3 and 11-25 pg/m^3 in two investigations of air from remote areas, presumably representing background values (Bowen 1985; Jalkanen, Häsenen 1994). Air analysed in polluted areas contained 30-1000 pg/m^3 (Bowen 1985). In a background document for a WHO

Guideline for drinking water quality, ambient air concentrations were given as low ng/m^3 levels, based on information from a report issued by the US EPA (Anon. 1996, US EPA 1980).

Possibly uncontaminated freshwater contained 1-5 and <8 ng/l in previous investigations (Shafer et al. 1994; Benoit 1994; Mukherjee, Lahermo 1995). Higher concentrations were measured in contaminated freshwater, 50-100 ng/l. Concentrations of silver in seawater from remote areas were lower, only 0.08-0.10 ng/l were measured, whereas seawater collected close to pollution sources contained 0.3-4.2 ng/l (Flegal, Sanudo-Wilhelmy 1993, Flegal et al. 1995; Martin et al. 1983).

Sediments contained 0.28 mg/kg d.w. in unpolluted lakes, whereas 154 mg/kg d.w. has been measured in polluted areas (Dissanayake, Tobschall 1983). In Sweden, silver concentrations in four background lake sediments varied within 0.16- 0.66 mg/kg d.w. (Grahn et al. 2006).

In a recent screening in Norway influents to three STPs contained silver in the range 180-530 ng/l. In effluents from the same STPs the concentration was <10 ng/l (SFT 2008).

In two studies from earlier than 1996 untreated sewage wastewater from Swedish STPs contained 600-2 000 and 10 000 -36 000 ng/l (unpublished sources cited in Naturvårdsverket (1996)). The same investigations report 60 -200 and 3 000 – 12 000 ng/l in wastewaters after treatment.

The silver concentration in sewage sludge from Henriksdal and Bromma STPs in Stockholm has decreased from 28 and 27 mg/kg d.w. in 1995 to 6.6 and 3.8 mg/kg d.w. respectively in 2006 (Stockholm Vatten AB 2008). The concentration in sludge from three Norwegian STPs 2008 were 7.6, 4.0 and 0.48 mg/kg d.w. (SFT 2008).

Concentrations in soil have been measured at 0.01-1 mg/kg d.w. in remote, uncontaminated areas (Jones et al. 1984). Higher concentrations 1-10 mg/kg were found in contaminated soil. In Sweden, analyses have shown that background values of silver were 0.07 mg/kg in the fine particulate fraction of moraine (< 0.063 mm) and 0.2 mg/kg in a fine fraction (< 2 mm) of sediment soils (SGU 2006).

Silver has also been found in birds (44 mg/kg liver) and snails (0.1-10 mg/kg) with a maximum concentration of 320 mg/kg (Eisler 1996; US EPA 1980).

6 Sampling strategy and study sites

A sampling strategy was developed in order to survey the total concentrations of silver in different environmental matrices in Sweden and to identify major emission sources as well as important transport pathways. The program included both measurements in background areas and close to potential sources.

In order to determine background levels, background sites were chosen in lakes with no known impacts from wastewater effluents. The sampling program is summarised in Table 5.

Table 5. Sampling program

Site	Surface water	Sedi-ment	Ground water	Fish	In-fluent	Effluent	Sludge	Storm-water	Total
Background									
Background sites	**3**	**5**	**3**	**3**					**14**
Diffuse sources									
Municipal STP					**3**	**4**	**2**		**9**
Lakes receiving effluents	**3**	**3**		**2**					**8**
Urban runoff								**7**	**7**
Point sources									
Landfill leachates						**6**			**6**
Laundry wastewater						**1**			**1**
Human exposure									
Total	**6**	**8**	**3**	**5**	**3**	**11**	**2**	**7**	**45**

Individual samples are listed in Appendix 1.

A regional screening program included sewage wastewater and sludge samples (42 untreated influents, 78 treated effluents and 48 sludge samples from STPs, as well as 1 power plant condensate effluent, and 1 industrial process effluent). In some of them matched samples were collected before and after sewage treatment, and from liquid and solid phases in the treatment plants. Water bodies receiving treated wastewater was sampled both in the water column (9 samples, with an additional 5 samples affiliated to drinking water production) and in sediments (40 samples). The regional program also included fish samples from receiving waters (18 samples).

The program also included sampling of landfill leachates (3 samples) and hospital wastewaters (8 samples).

7 Methods

7.1 Sampling procedures

7.1.1 Liquid samples

Lake surface water samples were collected at 0-1 m depth in 1 l polyethylene bottles. Storm water (1 l samples) was collected directly in runoff wells. At Eugenia-tunneln samples were taken before and after a chemical precipitation treatment unit.

Laundry wastewater was collected flow proportionally for 24 h.

Flow proportional 24 hour composite samples of untreated and treated municipal sewage wastewaters were collected in 100 ml acid-rinsed polyethylene bottles. Weekly samples were composed of consecutive daily samples. In some treatment plants, only grab samples were taken. In these cases the effluent water was sampled about 20 h after the influent samples, compensating for the hydraulic retention time. Samples of landfill leachates (100 ml) were taken at the inlet and outlet of leachate treatment ponds.

The liquid samples were frozen at -18 °C and delivered frozen to the laboratory.

7.1.2 Solid and semisolid samples

Anaerobic sludge (about 100 g wet weight) was collected from sewage treatment plants. Sludge was collected in the top 5 cm on the bottom of landfill leachate treatment ponds using a scraper. Samples of lake sediment were collected in background lakes and lakes receiving treated municipal sewage wastewater using a sediment collector of the kajak-type.

Perch (*Perca fluviatilis*) was caught in background lakes and lakes receiving wastewaters using gill nets.

7.2 Sample processing procedures and analysis

7.2.1 Lake water and wastewater samples

Lake water samples were conserved to 1 % (v/v) nitric acid. Aliquots of 10 ml from each sample were analysed. Wastewater samples were conserved to 1 % (v/v) nitric acid and left on the bench for sedimentation of coarse particles. Aliquots of 10 ml from the water phase were analysed. ^{185}Re was added to all standards, blanks and samples as internal standard.

7.2.2 Sediment and sludge samples

Sediment and sewage sludge samples were extracted in aqua regia using a microwave oven (Ethos plus, Milestone, Italy). Digested samples were diluted to 100 ml with ion-exchanged water. A

dilution of 1:10 was used for analysis. ^{185}Re was added to all standards, blanks and samples as internal standard.

Dry weights were determined by drying 0.1 g of all sediments and sewage sludge samples at 105 ˚C over night.

7.2.3 Fish samples

Tissue samples were dissected from the dorsal muscle of Perch (*Perca fluviatilis*). Samples were extracted in nitric acid and hydrogen peroxide using a microwave oven.

7.2.4 ICP-HRMS analysis

The concentration of silver for all matrices were determined using a high-resolution plasma mass spectrometer (ELEMENT2, Thermo Inc., Germany) at NILU. The plasma generator was operated at 1250 W. The silver isotope ^{107}Ag was determined in low resolution mode (R ≅ 300). The flow rate of plasma gas and auxiliary gas used were 15 l/ min and 1 l/min, respectively. Nebulizer gas flow was around 0.9 l/min and optimised daily. The spray chamber assembly consisted of a Meinhard concentric nebulizer and a glass spray chamber of type Scott. Nickel-tipped cones were used for both sampler and skimmer. The data processing and instrument control were performed by the ELEMENT software SWv 3.06.

7.2.5 Analytical Quality Control

The accuracy of the method was verified by analysis of different reference materials. The results are presented in Table 6. The calibration curve was verified by analysis of control samples. To discover possible contamination during sample preparation, blank samples were prepared using the same preparation procedure as with the samples.

Table 6. Analysis of reference materials

Reference material	Sample type	Certified value	NILU average	Recovery, %
NCSZC76309	Water	1000 µg/ml	994 µg/ml	99
NIST-1566b	Oyster tissue	0,666 mg/kg	0,730 mg/kg	110
CRM-018-050	Sewage sludge	72,1 mg/kg	42,8 mg/kg	59

8 Results and Discussion

The concentrations of silver in individual samples within the national and regional screening programs are given in the Appendices 1 and 2 together with sample characteristics.

8.1 Background areas

Surface water from the lakes Bysjön (Årjäng), Gipsjön (Malung) and Spjutsjön (Falun) represent background localities with no known sources of contamination. The silver concentration was 10, 9

and 6 ng/l respectively. These concentrations are in accordance to previous reports on freshwater (Figure 4).

In Figure 4 also results from the ground water sampling are plotted. The ground water stations in Vimmerby, Hallsberg and Lerum may not always represent 'pristine' background localities but the concentrations of silver therein corresponds to the concentrations found in background water.

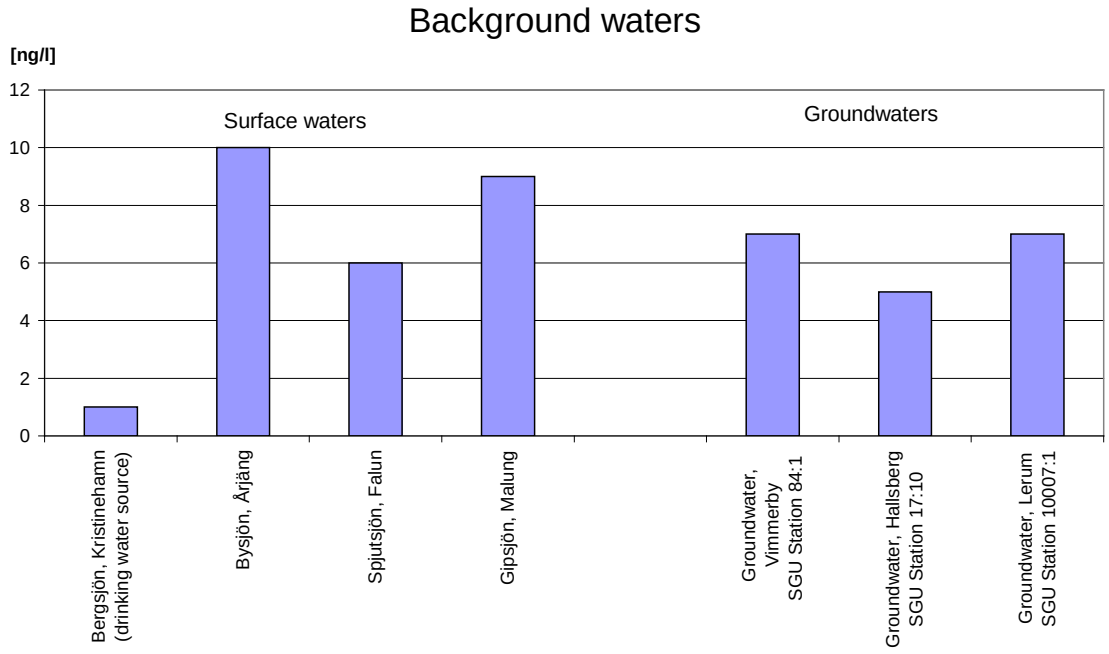


Figure 4. Surface and groundwater's from background areas.

Sediments from the same lakes as in Figure 4, and from Lake Gårdsjön (Stenungsund), contained from 2.1 to 22 mg/kg d.w. (Figure 5). The levels are higher than those previously reported, both nationally and internationally (cf. Section 5). Falun is located in a sulfide-mineralised area containing the Falun copper mine. This may explain the high silver concentrations in Spjutsjön and probably also in Gipssjön at Malung (cf. 2.1)

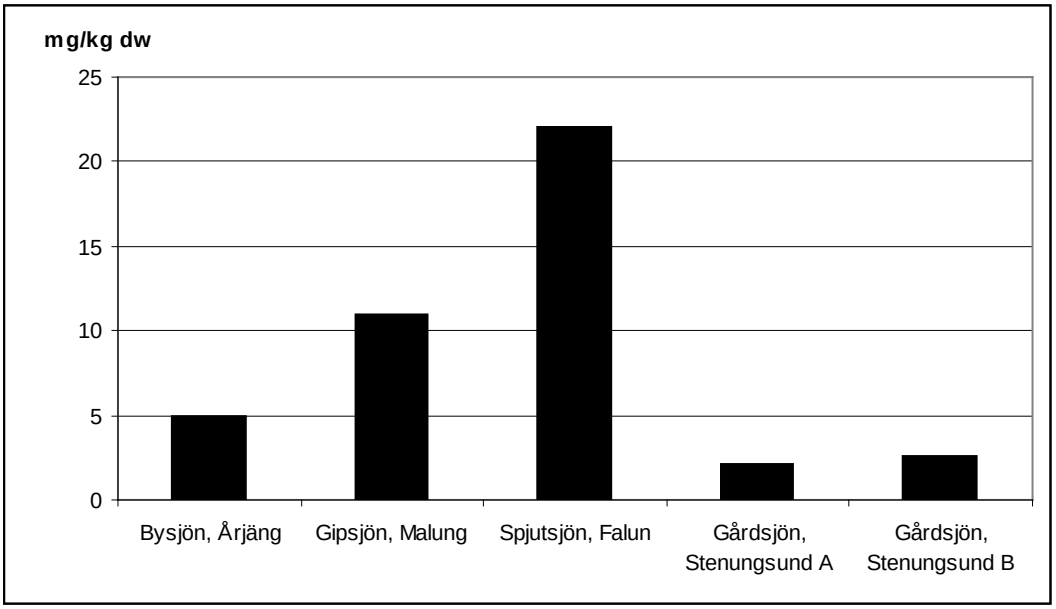


Figure 5. Silver concentrations in sediments from background lakes

The silver contents in muscle tissue of Perch, *Perca fluviatilis*, caught in four background lakes were < 0.21 µg/kg f.w.

8.2 Silver in sewage treatment plants and their receiving water bodies

8.2.1 Municipal sewage wastewaters and sludge

Box plots of the total data distribution of silver concentrations in untreated influent and treated effluent wastewater is presented in Figure 6 and individual results from analysis of wastewater, sludge as well as the retention in STPs are presented in Figure 7.

Untreated sewage wastewaters were collected from 43 STPs. The silver concentrations varied from 9.0 to 280 ng/l. The median value was 40 ng/l and the average 65 ng/l (Figure 6).

Treated sewage wastewaters contained from less than the detection limit (5.0 ng/l) to 74 ng/l in 78 investigated STPs. One extremely high value, 1 400 ng/l, was obtained at Kiruna STP (Figure 7). Regarding the sample from Kiruna, no matching sample of untreated wastewater was collected. The median concentration was 13 ng/l while the arithmetic mean concentration was 35 ng/l (due to the impact of the Kiruna sample). The concentrations are also considerably lower than those reported from Swedish STPs 1996 (cf. Section 5).

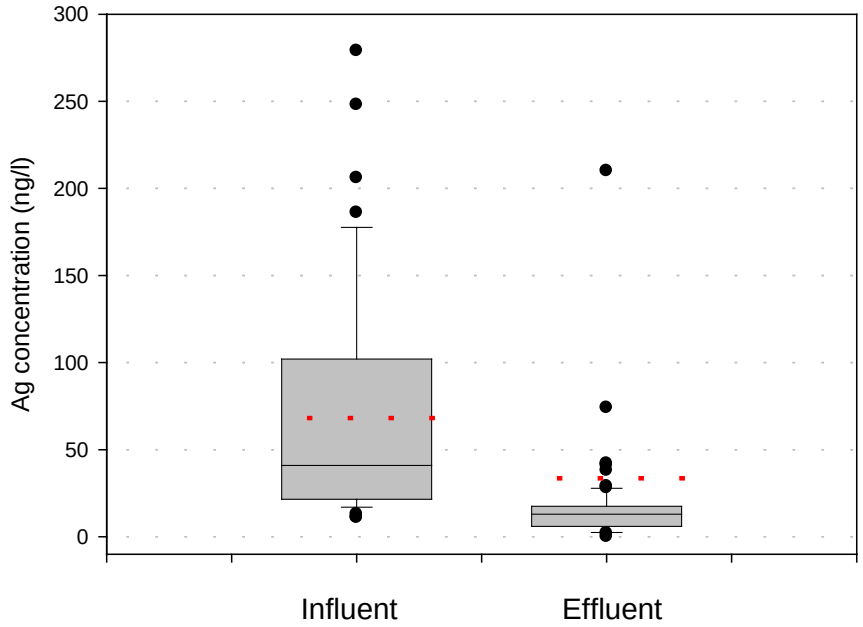


Figure 6. Box plots of silver concentrations in untreated and treated sewage wastewaters (ng/l). Values below the detection limit were assigned half the detection limit value in the figure. One extreme value of effluent concentration is omitted in the graph (The Kiruna STP, see Figure 7, middle pane). Solid lines represent median values, 40 and 13 ng/l respectively for influent and effluent, hatched lines represent average values 65 and 35 ng/l respectively.

Municipal sewage sludge contained silver in concentrations between 0.12 and 46 mg/kg d.w. in 40 investigated STPs (Figure 7). The median was 12 mg/kg d.w and the mean concentration was 14 mg/kg d.w. There is a proposed limit value of 15 mg/kg d.w. of silver in sludge for use in soil applications (Naturvårdsverket 2002). That value was exceeded by 28% of the samples in this study. The highest silver concentrations were found in sludges from Borlänge, Katrineholm, Bygdeå (outside Robertsfors) and Finspång. The lowest concentrations were found in sludges from Örnsköldsvik, Kungsbacka and Laholm. Thus, it is not possible to deduce any geographic predisposition in the occurrence pattern of silver in sludge.

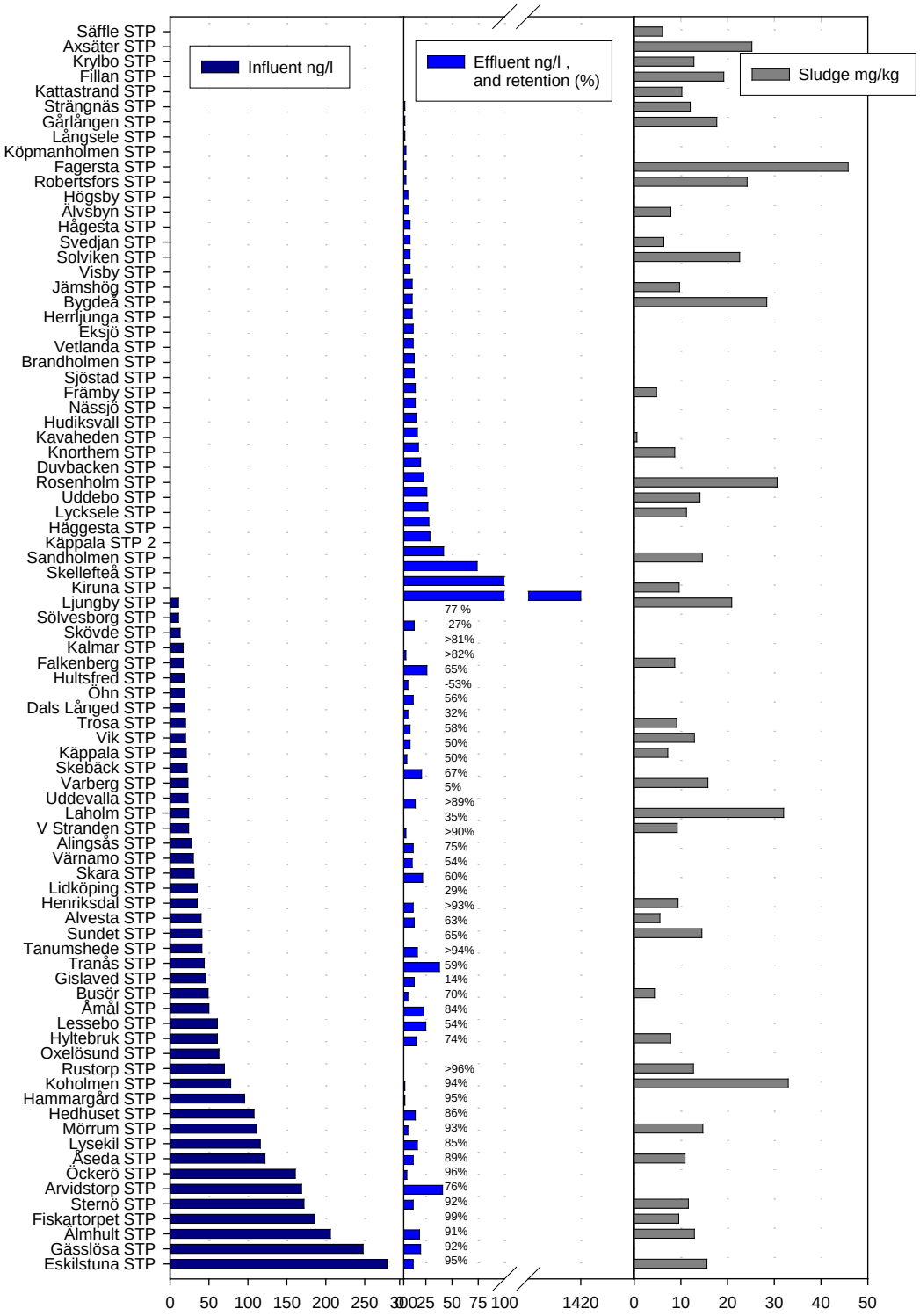


Figure 7. Silver concentrations in sewage wastewater (ng/l) and sludge mg/kg d.w) and its retention (%) in STPs where both influent and effluent water have been analysed.

There was no apparent correlation between concentrations in sewage sludge and the content of silver in untreated influents (Figure 8). A high concentration of silver in the influent wastewater could have caused a higher content in sludge, but obviously, the correlation analysis do not support this hypothesis. Similarly, there was no correlation between concentrations in sewage sludge and treated effluents (not shown).

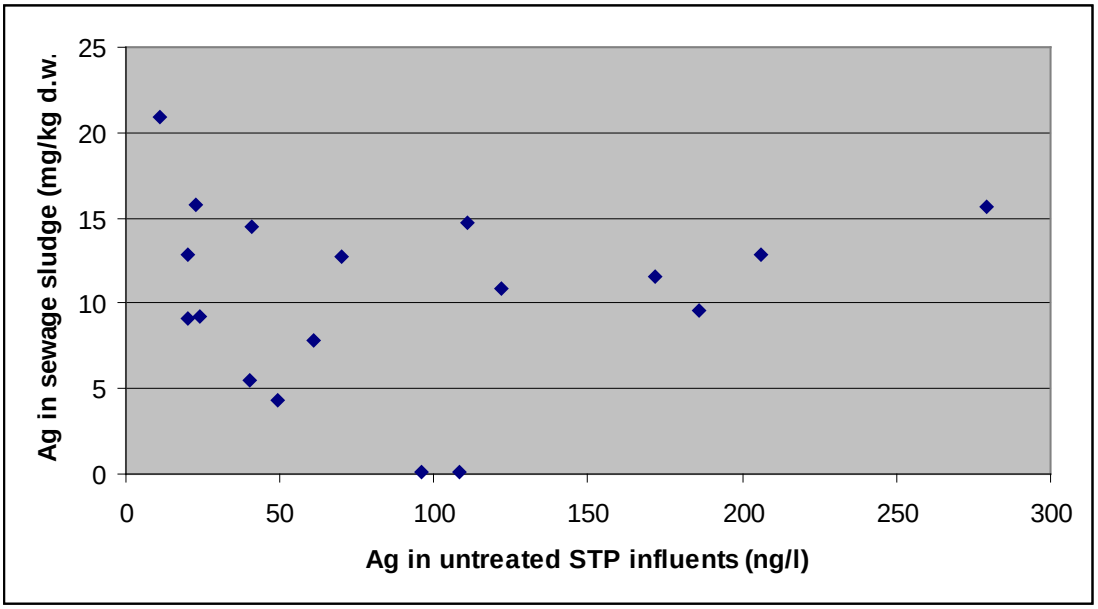


Figure 8. Plot of silver concentrations in sewage sludge against concentrations in incoming, untreated wastewater

The retention of silver in the treatment processes, i.e. the percentage of influent concentration retained in the STPs also varied from almost complete removal, i.e. effluent concentrations below the detection limit to STPs with higher effluent concentration than in the influent (Figure 7). A median value for the retention in 43 STPs was 75 %. Higher retention, usually more than 75 %, was obtained in STPs where influent concentrations exceeded 50 ng/l.

8.2.2 Surface waters and sediments in wastewater receiving lakes and rivers

Silver was analysed in surface waters in lakes and rivers receiving treated wastewaters. The results are shown in Figure 9.

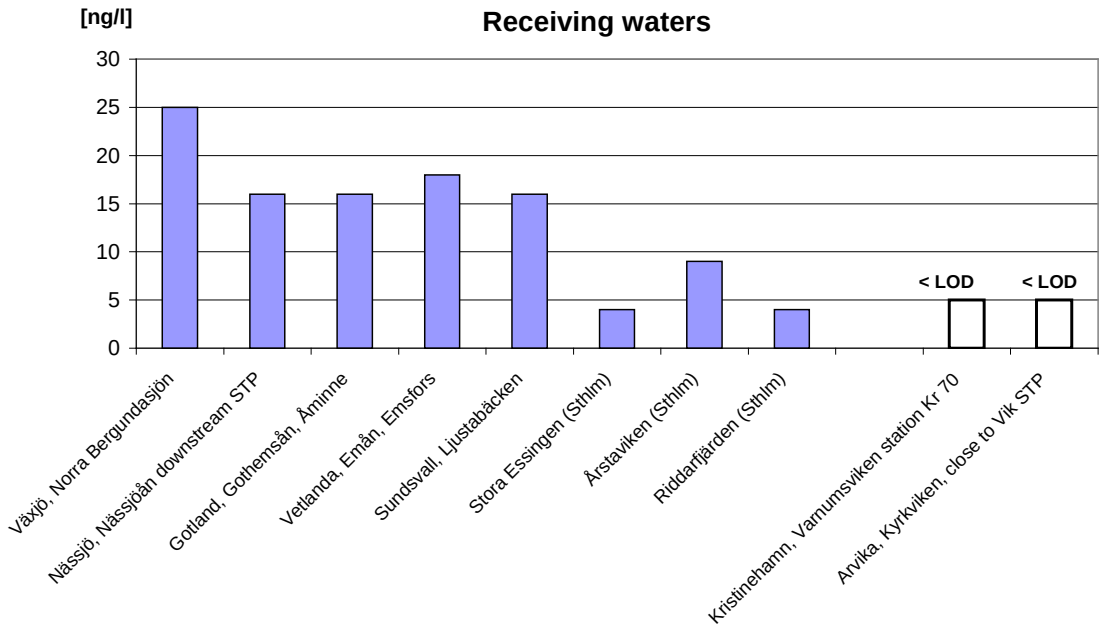


Figure 9. Silver in surface water of wastewater receiving water bodies. The concentration in samples from Arvika and Kristinehamn were lower than the detection limit (LOD indicated by height of unfilled bars).

Silver concentrations varied from lower than the detection limit (5.0 ng/l) to 25 ng/l. There was no correlation between the concentrations in STP effluents and the surface water concentrations. The levels found in this study were lower than those previously reported, 50 - 100 ng/l (cf. Section 5), probably reflecting the dilution of wastewater when entering the receiving waters.

Lake sediments contained from 0.68 to 44 mg silver/kg d.w. in 12 investigated receiving waters (Figure 10).

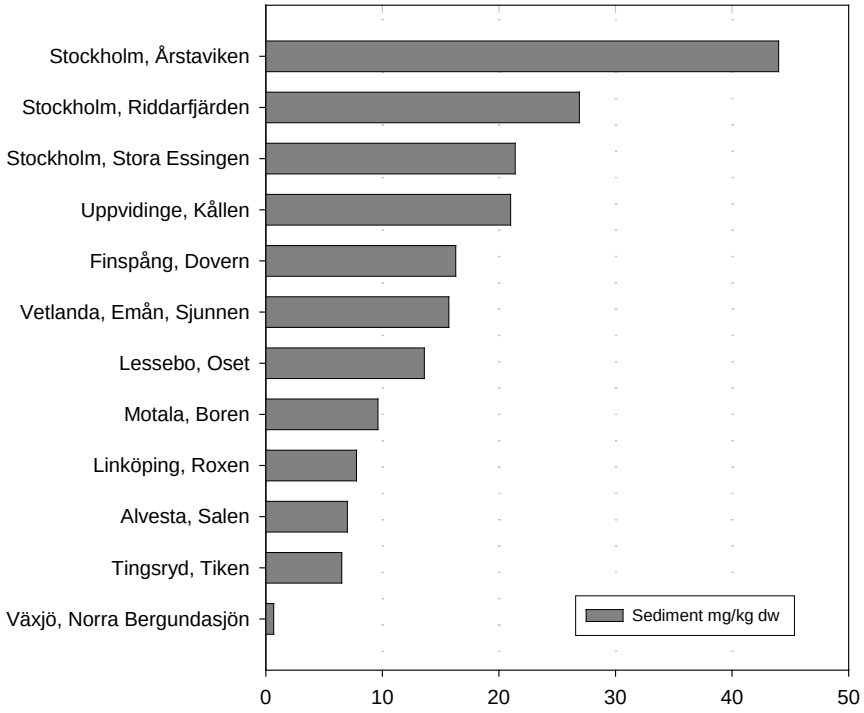


Figure 10. Silver concentrations in sediments of lakes and rivers receiving municipal wastewater effluents

The median concentration was 15 mg/kg d.w. The lakes or rivers were expected to receive treated wastewater upstreams in the water courses. In comparison to previous data, the sediment from the Lake Bergundasjön in Växjö, coincided with the concentration levels found in background lakes, whereas all other analysed sediments contained higher concentrations, indicating silver contamination probably from sewage wastewater and storm water outlets. The low concentration in sediment from Norra Bergundasjön was also lower than expected, with respect to the concentration in its corresponding surface water.

Brackish water sediments were taken in the Stockholm archipelago and the Slätbaken Bay in Östergötland. The concentrations of silver in the Stockholm area (30 sediment samples from 30 different sampling locations throughout the archipelago) varied from 0.10 to 27 mg/kg d.w. with a median concentration of 1 mg/kg d.w. The lower value of 0.1 mg/kg d.w (in one sample) of the series probably representing uncontaminated conditions.

The silver concentration in sediment from Slätbaken was 4.5 mg/kg d.w., i.e. close to the concentrations in sediments from background sites.

8.3 Urban runoff, diffuse sources

Considerable concentrations of silver were detected in storm water from four locations in Stockholm. The concentrations varied between 71 and 480 ng/l (Figure 11).

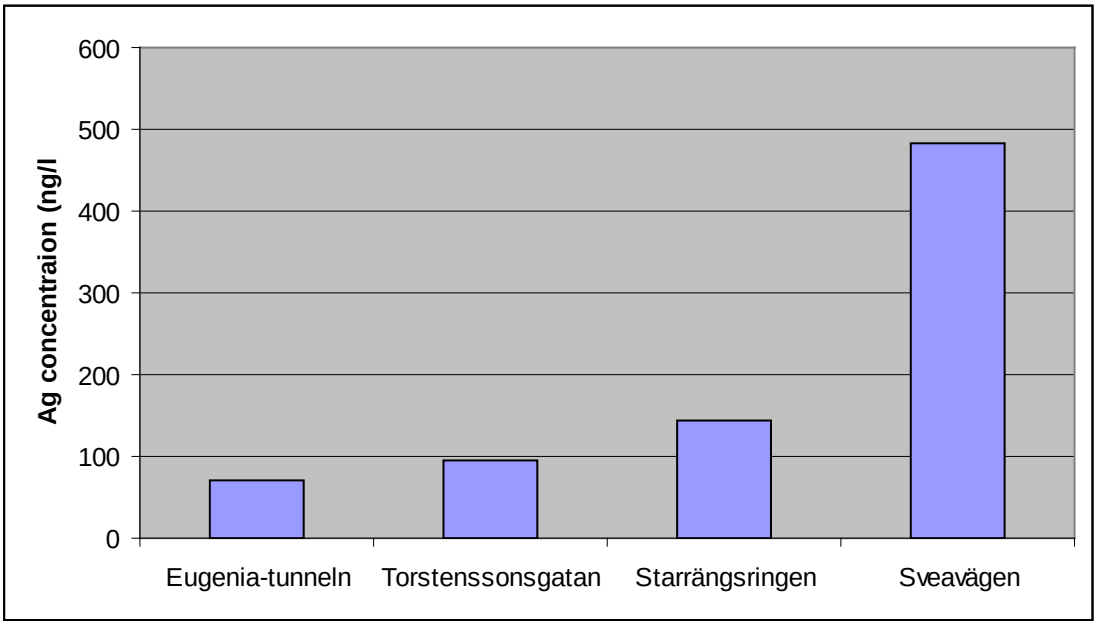


Figure 11. Silver concentrations in urban run-off at four places in Stockholm

Collected storm water from Eugenia-tunneln was treated with aluminium precipitation (PAX). The silver concentration increased from 71 to 1900 ng/l by this treatment. Apparently silver was introduced into the water upon this purification treatment. A second sampling four months later at Eugenia-tunneln revealed 34 and 18 ng/l, respectively before and after PAX treatment. Concentration of silver (and other substances) in urban storm water collecting magazines can be expected to vary tremendously over the year due to variations in the precipitation.

8.4 Laundry effluents, etc., point sources

Two treated laundry effluents were analysed. They contained 18 and 54 ng/l, respectively, the former within the range and the latter somewhat higher than most treated municipal effluents. Increases in silver concentrations due to wash-off of silver containing clothing have apparently not affected these wastewaters significantly.

A condensate from a power plant contained 49 ng/l of silver, indicating that silver is transported in incinerator gas flows and stripped off in treatment processes.

8.5 Hospital effluents, point sources

Hospital effluents were included in the survey of silver. The concentrations in eight effluents are shown in Figure 12.

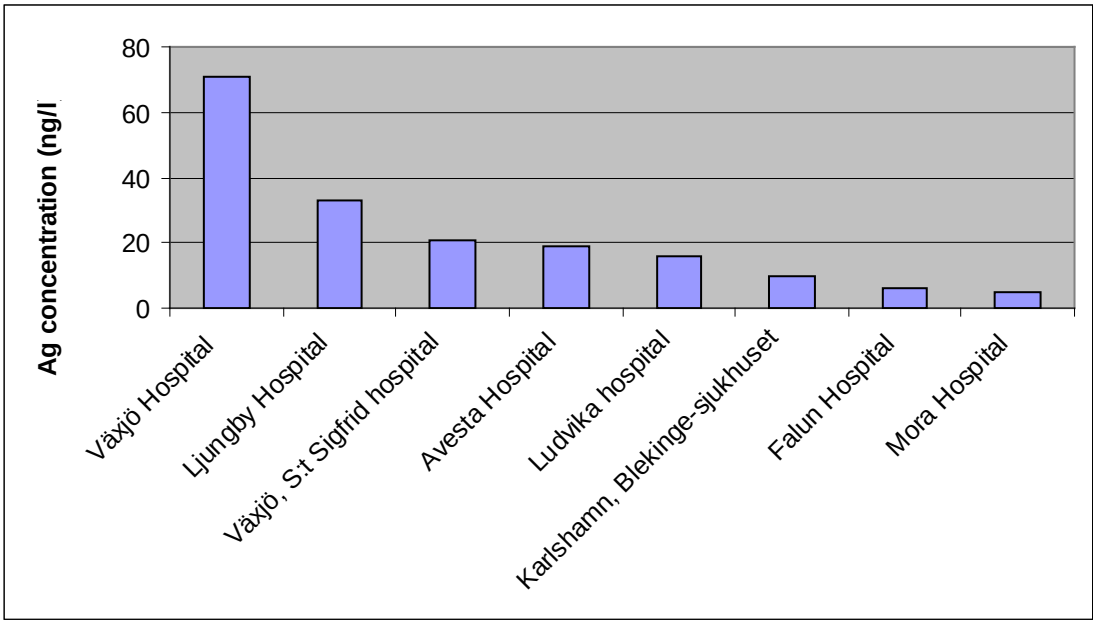


Figure 12. Silver concentrations in hospital wastewaters

Most hospital effluents contained silver within the ranges of treated municipal effluents. The median concentration was 18 ng/l and the average 23 ng/l. One effluent however, from Växjö Hospital contained 71 ng/l, which rather coincided with levels in untreated municipal waste water.

8.6 Landfill leachates, point sources

Silver were determined in leachates from six landfills (Figure 13). The landfill leachate from Strandmossen landfill at Kristinehamn and Bubbetorp at Karlskrona contained small concentrations of silver close to the range of treated municipal effluents (see Figure 7, middle pane). Four other landfill leachates contained higher concentrations, from 180 to 830 ng/l.

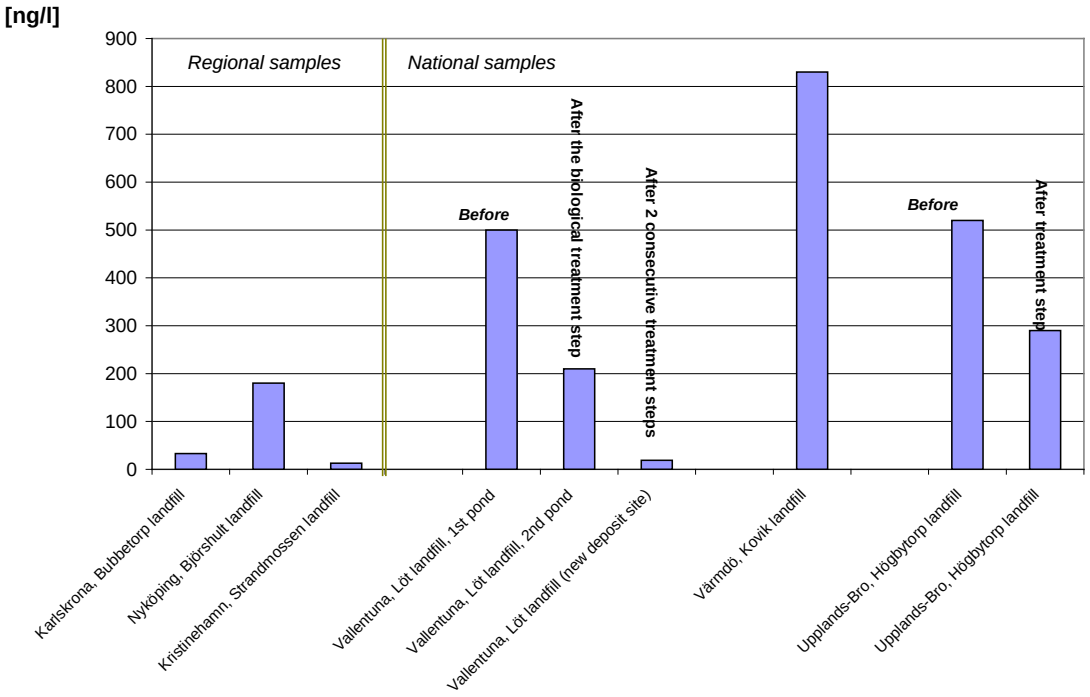


Figure 13. Silver concentrations in landfill leachates after wastewater treatment. In two locations, at the Löt landfill and at the Högbytorp landfill, data on silver concentrations both before and after treatment is included.

At two locations sampling before and after passage of the treatment system for leachate water of the landfill, indicates that concentrations were reduced by a factor of two or more in the treatment steps employed (the Löt landfill and the Högbytorp landfill). The treatment procedure at Högbytorp landfill reduced the silver concentration from 520 to 290 ng/l while the two consecutive treatment steps of the Löt landfill leachate reduces the silver concentration from 500 ng/l to 19 ng/l (the intermediate step concentration was 210 ng/l).

The elevated (comparably) concentration of the Kovik municipal landfill may be attributable to the large fraction of building materials being sent there.

8.7 Fish

Silver was not detected in muscle tissue from Perch, *Perca fluviatilis,* from Årstaviken and Riddarfjärden in the center of Stockholm (<0.21 µg/kg f.w).

In the regional program fish samples were collected in the Stockholm archipelago, where some contamination from municipal (and industrial) wastewaters could be expected. Out of 15 muscle tissue samples silver was detected in four (0.3 - 1.0 µg/kg f.w). Silver accumulated in fish from the surrounding aquatic environment is expected to be located in liver and kidney as with the soft heavy metals Zn, Cd, and (inorganic) Hg. The investigations show that consumption of fish muscle from these sites does not pose any human health risk due to silver.

9 Conclusions

Silver is released into the aquatic environment through municipal sewage wastewater, urban storm water, and landfill leachates.

Silver in sewage sludge exceeded the proposed limit value for agricultural use (15 mg/kg d.w.) in 28 % of the analysed samples (13 out 46 analysed sludge samples). However, the concentrations detected in the sludge samples did not correlate positively with concentrations in untreated wastewater or negatively with concentrations in treated wastewater.

Surface water from lakes and rivers receiving wastewater and storm water contained silver and silver was also detected in sediment samples. No positive correlation was found between the concentrations in surface water and effluent concentrations in nearby STPs, nor any correlation between surface water and sediment concentration of silver.

Fish muscle from studied Perch populations contained measurable silver concentration in a few cases only (maximum concentration 1.0 µg/kg f.w.).

Hospital wastewaters and wastewater from laundries may contribute only a minor part of silver released into the aquatic environment.

10 Acknowledgements

We thank staff members at the local municipalities that took part in the sampling of wastewater effluents and sludge. The study was funded by the Environmental Monitoring Program at the Swedish Environmental Protection Agency and by participating county administrations.

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Appendix 1 Sample Characteristics and Results of Silver Analysis. National screening program

Category	Sample ID	Site	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
Background								
Background lake	6223	Årjäng, Bysjön	Surface water	2007-09-06	658086	130264	10	ng/l
Background lake	6226	Årjäng, Bysjön	Sediment	2007-09-06	658086	130264	5.0	mg/kg dw
Background lake	6872	Årjäng, Bysjön	Perch muscle	2007-09-06	658086	130264	< 0.21	µg/kg fw
Background lake	6224	Falun, Spjutsjön	Surface water	2007-09-03	672467	148031	6	ng/l
Background lake	6227	Falun, Spjutsjön	Sediment	2007-09-03	672467	148031	22	mg/kg dw
Background lake	6874	Falun, Spjutsjön	Perch muscle	2007-09-03	672467	148031	< 0.21	µg/kg fw
Background lake	6225	Malung, Gipsjön	Surface water	2007-09-04	672729	138082	9	ng/l
Background lake	6228	Malung, Gipsjön	Sediment	2007-09-04	672729	138082	11	mg/kg dw
Background lake	6873	Malung, Gipsjön	Perch muscle	2007-09-04	672729	138082	< 0.21	µg/kg fw
Background lake	6036	Gårdsjön	Sediment	2007-09-13	6443047	1276602	2.1	mg/kg dw
Background lake	6037	Gårdsjön	Sediment	2007-09-13	6444157	1276465	2.6	mg/kg dw
Background site	6733	SGU Station 84:1, Vimmerby	Ground water	2007-11-09	6408158	1496211	7	ng/l
Background site	6736	SGU Station 17:10, Hallsberg	Ground water	2007-11-12	6546701	1454844	5	ng/l
Background site	6739	SGU Station 10007:1, Lerum	Ground water	2007-11-21	6412857	1294478	7	ng/l
Diffuse sources								
Sewage wastewater	6881	Lidingö, Käppala STP	Untreated influent	2007-12-13			21	ng/l
Sewage	6882	Lidingö, Käppala STP	Treated effluent				7.0	ng/l

Category	Sample ID	Site	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
wastewater								
Sewage wastewater	6767	Lidingö, Käppala STP	Treated effluent	2007-12-13			42	ng/l
Sewage sludge	6844	Lidingö, Käppala STP	Sludge				7.2	mg/kg dw
Sewage wastewater	6558	Stockholm, Henriksdal STP	Untreated influent	2007-10-25			35	ng/l
Sewage wastewater	6561	Stockholm, Henriksdal STP	Treated effluent	2007-10-25			13	ng/l
Sewage sludge	6584	Stockholm, Henriksdal STP	Sludge	2007-10-25			9.4	mg/kg dw
Sewage wastewater	6891	Umeå, Öhn STP	Untreated influent	2008-03-19			19	ng/l
Sewage wastewater	6892	Umeå, Öhn STP	Treated effluent	2008-03-19			13	ng/l
Receiving water	6357	Stockholm, Stora Essingen	Surface water	2007-09-20	6579241	1623643	4.0	ng/l
Receiving water	6358	Stockholm, Stora Essingen	Sediment	2007-09-20	6579241	1623643	21	mg/kg dw
Receiving water	6360	Stockholm, Årstaviken	Surface water	2007-09-20	6578147	1628330	9.0	ng/l
Receiving water	6361	Stockholm, Årstaviken	Sediment	2007-09-20	6578147	1628330	44	mg/kg dw
Receiving water	6362	Stockholm, Årstaviken	Perch, muscle	2007-09-20	6578147	1628330	< 0.21	µg/kg fw
Receiving water	6363	Stockholm, Riddarfjärden	Surface water	2007-09-20	6580141	1627276	4.0	ng/l
Receiving water	6364	Stockholm, Riddarfjärden	Sediment	2007-09-20	6580141	1627276	27	mg/kg dw
Receiving water	6365	Stockholm, Riddarfjärden	Perch, muscle	2007-09-20	6580141	1627276	< 0.21	µg/kg fw
Urban runoff	6889	Stockholm, Eugenia-tunneln	Storm water, untreated	2008-03-19	6583266	1627181	34	ng/l
Urban runoff	6890	Stockholm, Eugenia-tunneln	Storm water, PAX-treated	2008-03-19	6583266	1627181	18	ng/l
Urban runoff	6612	Stockholm, Eugenia-tunneln	Storm water	2007-11-07	6583266	1627181	71	ng/l
Urban runoff	6613	Stockholm, Eugenia-tunneln	Storm water, PAX-treated	2007-11-07	6583266	1627181	1900	ng/l

Category	Sample ID	Site	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
Urban runoff	6810	Stockholm, Starrängsringen	Storm water	2007-12-13	6582672	1629716	150	ng/l
Urban runoff	6811	Stockholm, Sveavägen	Storm water	2007-12-13	6582795	1627895	480	ng/l
Urban runoff	6809	Stockholm, Torstenssonsgatan	Storm water	2007-12-13	6581298	1629972	94	ng/l
Point sources								
Landfill runoff	6398	Vallentuna, Löt landfill (new deposit site)	Landfill leachate		6615315	1641725	19	ng/l
Landfill runoff	6447	Vallentuna, Löt landfill, 1st pond	Landfill leachate		6615315	1641725	500	ng/l
Landfill runoff	6448	Vallentuna, Löt landfill, 2nd pond	Landfill leachate	2007-10-10	6615315	1641725	210	ng/l
Landfill runoff	6462	Värmdö, Kovik landfill	Landfill leachate		6583454	1645162	830	ng/l
Landfill runoff	6542	Upplands-Bro, Högbytorp landfill	Landfill leachate, untreated		6604110	1603252	520	ng/l
Landfill runoff	6543	Upplands-Bro, Högbytorp landfill	Landfill leachate, treated		6604110	1603252	290	ng/l
Wastewater	6751	Laundry, Östra Svealand	Treated effluent				18	ng/l

Appendix 2 Sample Characteristics and Results of Silver Analysis. Regional screening program

County	Site	Category	Sample ID	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
Blekinge	Karlshamn, Blekinge-sjukhuset	Hospital wastewater	6591	Effluent	2007-10-31			10	ng/l
Blekinge	Karlshamn, Långasjön	Drinking water supply	6221	Treated drinking water	2007-09-25			< 5.0	ng/l
Blekinge	Karlshamn, Långasjön	Drinking water supply	6218	Untreated raw water	2007-09-25			< 5.0	ng/l
Blekinge	Karlshamn, Mörrum STP	Sewage sludge	6090	Sludge	2007-09-04 - 2007-09-05			15	mg/kg
Blekinge	Karlshamn, Mörrum STP	Sewage wastewater	6089	Treated effluent	2007-09-04 - 2007-09-05			8.0	ng/l
Blekinge	Karlshamn, Mörrum STP	Sewage wastewater	6088	Untreated influent	2007-09-04 - 2007-09-05			110	ng/l
Blekinge	Karlshamn, Sternö STP	Sewage sludge	6096	Sludge	2007-09-04			12	mg/kg dw
Blekinge	Karlshamn, Sternö STP	Sewage wastewater	6095	Treated effluent	2007-09-04			170	ng/l
Blekinge	Karlshamn, Sternö STP	Sewage wastewater	6094	Untreated influent	2007-09-04			13	ng/l
Blekinge	Karlskrona Lyckeby drinking water plant (Lyckebyån)	Drinking water supply	6163	Raw water, before active carbon filtration	2007-09-25			< 5.0	ng/l
Blekinge	Karlskrona Lyckeby drinking water plant (Lyckebyån)	Drinking water supply	6166	Treated drinking water	2007-09-25			< 5.0	ng/l
Blekinge	Karlskrona Lyckeby drinking water plant (Lyckebyån)	Drinking water supply	6159	Untreated raw water	2007-09-25			11	ng/l

County	Site	Category	Sample ID	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
Blekinge	Karlskrona, Bubbetorp landfill	Landfill runoff	6076	Landfill leachate	2007-09-05 - 2007-09-12			33	ng/l
Blekinge	Karlskrona, Gullberna	Laundry effluent	6711	Effluent	2007-11-20			54	ng/l
Blekinge	Karlskrona, Koholmen STP	Sewage sludge	6253	Sludge	2007-09-18 - 2007-09-25			33	mg/kg dw
Blekinge	Karlskrona, Koholmen STP	Sewage wastewater	6252	Treated effluent	2007-09-18 - 2007-09-25			5.0	ng/l
Blekinge	Karlskrona, Koholmen STP	Sewage wastewater	6251	Untreated influent	2007-09-18 - 2007-09-25			78	ng/l
Blekinge	Olofström, Jämshög STP	Sewage sludge	6557	Sludge	2007-10-22			9.7	mg/kg dw
Blekinge	Olofström, Jämshög STP	Sewage wastewater	6555	Treated effluent	2007-10-22			12	ng/l
Blekinge	Ronneby, Rustorp STP	Sewage sludge	6056	Sludge	2007-09-11			13	mg/kg dw
Blekinge	Ronneby, Rustorp STP	Sewage wastewater	6053	Treated effluent	2007-09-11			< 5.0	ng/l
Blekinge	Ronneby, Rustorp STP	Sewage wastewater	6049	Untreated influent	2007-09-11			70	ng/l
Blekinge	Sölvesborg STP	Sewage sludge	6577	Sludge	2007-10-22 - 2007-10-28			Sample missng	mg/kg dw
Blekinge	Sölvesborg STP	Sewage wastewater	6576	Treated effluent	2007-10-22 - 2007-10-28			14	ng/l
Blekinge	Sölvesborg STP	Sewage wastewater	6572	Untreated influent	2007-10-22 - 2007-10-28			11	ng/l
Dalarna	Avesta Hospital	Hospital wastewater	6057	Effluent	2007-09-17 - 2007-09-21			19	ng/l
Dalarna	Avesta, Krylbo STP	Sewage sludge	6105	Sludge	2007-09-10 - 2007-09-14			12	mg/kg dw
Dalarna	Avesta, Krylbo STP	Sewage wastewater	6106	Treated effluent	2007-09-10 - 2007-09-14			< 5.0	ng/l
Dalarna	Borlänge, Fagersta STP	Sewage sludge	6120	Sludge	2007-09-18			46	mg/kg dw
Dalarna	Borlänge, Fagersta STP	Sewage wastewater	6118	Treated effluent	2007-09-11 - 2007-09-17			6.0	ng/l
Dalarna	Falun Hospital	Hospital wastewater	6183	Effluent	2007-09-17 - 2007-09-21			6.0	ng/l

County	Site	Category	Sample ID	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
Dalarna	Falun, Främby STP	Sewage sludge	6292	Sludge	2007-09			4.8	mg/kg dw
Dalarna	Falun, Främby STP	Sewage wastewater	6291	Treated effluent	2007-09			15	ng/l
Dalarna	Ludvika hospital	Hospital wastewater	6449	Effluent				16	ng/l
Dalarna	Ludvika, Gårlången STP	Sewage sludge	6383	Sludge	2007-09-26 - 2007-10-03			18	mg/kg dw
Dalarna	Ludvika, Gårlången STP	Sewage wastewater	6382	Treated effluent	2007-09-26 - 2007-10-03			5.0	ng/l
Dalarna	Mora Hospital	Hospital wastewater	6097	Effluent	2007-09-03 - 2007-09-07			5.0	ng/l
Dalarna	Mora, Solviken STP	Sewage sludge	6381	Sludge	2007-09-27 - 2007-10-03			23	mg/kg dw
Dalarna	Mora, Solviken STP	Sewage wastewater	6380	Treated effluent	2007-09-27 - 2007-10-03			10	ng/l
Gävleborg	Bollnäs, Häggesta STP	Sewage wastewater	6131	Treated effluent	2007-09-11 - 2007-09-17			29	ng/l
Gävleborg	Gävle, Duvbacken STP	Sewage wastewater	6350	Treated effluent	2007-09-24 - 2007-09-30			23	ng/l
Gävleborg	Hudiksvall STP	Sewage wastewater	6184	Treated effluent	2007-09-17 - 2007-09-23			17	ng/l
Gävleborg	Sandviken, Hedåsens ARV	Sewage wastewater	6585	Treated effluent	2007-10-31			<5	ng/l
Gotland	Gotland, Gothemsån, Åminne	Receiving water	6312	Surface water	2007-10-01	6391370	1676270	16	ng/l
Gotland	Visby STP	Sewage wastewater	6308	Treated effluent	2007-09-25 - 2007-10-02			12	ng/l
Halland	Falkenberg STP	Sewage sludge	6268	Sludge	2007-09-19 - 2007-09-25			8.7	mg/kg dw
Halland	Falkenberg STP	Sewage wastewater	6267	Treated effluent	2007-09-19 - 2007-09-25			26	ng/l
Halland	Falkenberg STP	Sewage wastewater	6266	Untreated influent	2007-09-19 - 2007-09-25			17	ng/l
Halland	Halmstad, Busör STP	Sewage sludge	6315	Sludge	2007-09-24 - 2007-10-02			4.4	mg/kg dw

County	Site	Category	Sample ID	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
Halland	Halmstad, Busör STP	Sewage wastewater	6316	Treated effluent	2007-09-24 - 2007-10-02			8.0	ng/l
Halland	Halmstad, Busör STP	Sewage wastewater	6314	Untreated influent	2007-09-24 - 2007-10-02			49	ng/l
Halland	Halmstad, V Stranden STP	Sewage sludge	6329	Sludge	2007-09-24 - 2007-10-01			9.2	mg/kg dw
Halland	Halmstad, V Stranden STP	Sewage wastewater	6324	Treated effluent	2007-09-24 - 2007-10-01			6.0	ng/l
Halland	Halmstad, V Stranden STP	Sewage wastewater	6323	Untreated influent	2007-09-24 - 2007-10-01			24	ng/l
Halland	Hylte, Hyltebruk STP	Sewage sludge	6453	Sludge	2007-09-26			7.8	mg/kg dw
Halland	Hylte, Hyltebruk STP	Sewage wastewater	6451	Treated effluent	2007-09-26			< 5.0	ng/l
Halland	Hylte, Hyltebruk STP	Sewage wastewater	6692	Treated effluent	2007-10-31			16	ng/l
Halland	Hylte, Hyltebruk STP	Sewage wastewater	6691	Untreated influent	2007-10-31			61	ng/l
Halland	Kungsbacka, Hammargård STP	Sewage sludge	6235	Sludge	2007-09-19 - 2007-09-25			0.12	mg/kg dw
Halland	Kungsbacka, Hammargård STP	Sewage wastewater	6234	Treated effluent	2007-09-19 - 2007-09-25			5.0	ng/l
Halland	Kungsbacka, Hammargård STP	Sewage wastewater	6233	Untreated influent	2007-09-19 – 2 007-09-25			96	ng/l
Halland	Laholm STP	Sewage sludge	6239	Sludge	2007-09-18 - 2007-09-24			32	mg/kg dw
Halland	Laholm STP	Sewage wastewater	6238	Treated effluent	2007-09-18 - 2007-09-24			< 5.0	ng/l
Halland	Laholm STP	Sewage wastewater	6237	Untreated influent	2007-09-18 - 2007-09-24			24	ng/l
Halland	Laholm, Hedhuset STP	Sewage sludge	6244	Sludge	2007-09-18 - 2007-09-24			0.12	mg/kg dw
Halland	Laholm, Hedhuset STP	Sewage wastewater	6242	Treated effluent	2007-09-18 - 2007-09-24			15	ng/l
Halland	Laholm, Hedhuset STP	Sewage wastewater	6241	Untreated influent	2007-09-18 - 2007-09-24			110	ng/l
Halland	Varberg STP	Sewage sludge	6065	Sludge	2007-09-10			16	mg/kg dw

County	Site	Category	Sample ID	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
Halland	Varberg STP	Sewage wastewater	6062	Treated effluent	2007-09-04 - 2007-09-10			< 5.0	ng/l
Halland	Varberg STP	Sewage wastewater	6061	Untreated influent	2007-09-04 - 2007-09-10			23	ng/l
Jönköping	Eksjö STP	Sewage wastewater	6545	Treated effluent	2007-10-15 - 2007-10-22			13	ng/l
Jönköping	Gislaved STP	Sewage wastewater	6548	Treated effluent	2007-10-23			14	ng/l
Jönköping	Gislaved STP	Sewage wastewater	6546	Untreated influent	2007-10-23			46	ng/l
Jönköping	Nässjö STP	Sewage wastewater	6286	Treated effluent	2007-09-24 - 2007-09-30			16	ng/l
Jönköping	Nässjö, Nässjöån downstream STP	Receiving water	6288	Surface water	2007-09-26	6393795	1431036	16	ng/l
Jönköping	Tranås STP	Sewage wastewater	6583	Treated effluent	2007-10-22 - 2007-10-29			38	ng/l
Jönköping	Tranås STP	Sewage wastewater	6582	Untreated influent	2007-10-22 - 2007-10-29			44	ng/l
Jönköping	Värnamo STP	Sewage wastewater	6471	Treated effluent	2007-10-08 - 2007-10-14			12	ng/l
Jönköping	Värnamo STP	Sewage wastewater	6469	Untreated influent	2007-10-08 - 2007-10-14			30	ng/l
Jönköping	Vetlanda STP	Sewage wastewater	6484	Treated effluent	2007-10-11 - 2007-10-16			14	ng/l
Jönköping	Vetlanda STP	Sewage wastewater	6485	Treated effluent	2007-10-11 - 2007-10-16			< 5.0	ng/l
Jönköping	Vetlanda, Emån, Emsfors	Receiving water	6489	Surface water	2007-10-16	6335200	1539200	18	ng/l
Jönköping	Vetlanda, Emån, Sjunnen, downstream STP	Receiving water	6730	Sediment	2007-11-06			16	mg/kg dw
Kalmar	Högsby STP	Sewage wastewater	6356	Untreated influent				9.0	ng/l
Kalmar	Hultsfred STP	Sewage wastewater	6261	Treated effluent	2007-09-20 - 2007-09-27			8.0	ng/l
Kalmar	Hultsfred STP	Sewage wastewater	6260	Untreated influent	2007-09-20 - 2007-09-27			18	ng/l

County	Site	Category	Sample ID	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
Kalmar	Kalmar STP	Sewage wastewater	6209	Treated effluent	2007-09-22 - 2007-09-26			6.0	ng/l
Kalmar	Kalmar STP	Sewage wastewater	6208	Untreated influent	2007-09-22 - 2007-09-26			17	ng/l
Kronoberg	Älmhult STP	Sewage sludge	6603	Sludge	2007-11-06			13	mg/kg dw
Kronoberg	Älmhult STP	Sewage wastewater	6602	Treated effluent	2007-11-06			19	ng/l
Kronoberg	Älmhult STP	Sewage wastewater	6601	Untreated influent	2007-11-06			210	ng/l
Kronoberg	Alvesta STP	Sewage sludge	6763	Sludge	2007-12-05			5.5	mg/kg dw
Kronoberg	Alvesta STP	Sewage wastewater	6762	Treated effluent	2007-12-05			14	ng/l
Kronoberg	Alvesta STP	Sewage wastewater	6761	Untreated influent	2007-12-05			40	ng/l
Kronoberg	Alvesta, Salen	Receiving water	6824	Sediment	2007-12-12	6299791	1424511	7.0	mg/kg dw
Kronoberg	Lessebo STP	Sewage sludge	6880	Sludge				Sample missimg	mg/kg dw
Kronoberg	Lessebo STP	Sewage wastewater	6879	Treated effluent				25	ng/l
Kronoberg	Lessebo STP	Sewage wastewater	6878	Untreated influent				51	ng/l
Kronoberg	Lessebo, Oset	Receiving water	6823	Sediment	2007-11-26	6290705	1465690	14	mg/kg dw
Kronoberg	Ljungby Hospital	Hospital wastewater	6450	Effluent	2007-10-10			33	ng/l
Kronoberg	Ljungby STP	Sewage sludge	6151	Sludge	2007-09-20			21	mg/kg dw
Kronoberg	Ljungby STP	Sewage wastewater	6150	Treated effluent	2007-09-20			< 5.0	ng/l
Kronoberg	Ljungby STP	Sewage wastewater	6149	Untreated influent	2007-09-20			11	ng/l
Kronoberg	Tingsryd, Tiken	Receiving water	6822	Sediment	2007-12-12	6264702	1449376	6.5	mg/kg dw
Kronoberg	Uppvidinge, Åseda STP	Sewage sludge	6820	Sludge	2007-12-11			11	mg/kg dw
Kronoberg	Uppvidinge, Åseda STP	Receiving water	6819	Surface water	2007-12-11			15	ng/l

County	Site	Category	Sample ID	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
Kronoberg	Uppvidinge, Åseda STP	Sewage wastewater	6818	Treated effluent	2007-12-11			13	ng/l
Kronoberg	Uppvidinge, Åseda STP	Sewage wastewater	6817	Untreated influent	2007-12-11			120	ng/l
Kronoberg	Uppvidinge, Kållen	Receiving water	6821	Sediment	2007-11-26	6337895	1475030	21	mg/kg dw
Kronoberg	Växjö Hospital	Hospital wastewater	6199	Effluent	2007-09-26			71	ng/l
Kronoberg	Växjö, Norra Bergundasjön	Receiving water	6825	Sediment	2007-12-12	6305156	1436566	0.68	mg/kg dw
Kronoberg	Växjö, Norra Bergundasjön	Receiving water	6114	Surface water	2007-09-18			25	ng/l
Kronoberg	Växjö, S:t Sigfrid hospital	Hospital wastewater	6200	Effluent	2007-09-26			21	ng/l
Kronoberg	Växjö, Sundet STP	Sewage sludge	6117	Sludge	2007-09-10 - 2007-09-17			15	mg/kg dw
Kronoberg	Växjö, Sundet STP	Sewage wastewater	6115	Treated effluent	2007-09-10 - 2007-09-17			< 5.0	ng/l
Kronoberg	Växjö, Sundet STP	Sewage wastewater	6116	Untreated influent	2007-09-10 - 2007-09-17			41	ng/l
Norrbotten	Älvsbyn STP	Sewage sludge	6553	Sludge	2007-10-23			7.9	mg/kg dw
Norrbotten	Älvsbyn STP	Sewage wastewater	6552	Treated effluent	2007-10-23			10	ng/l
Norrbotten	Boden, Svedjan STP	Sewage sludge	6196	Sludge	2007-09-11 - 2007-09-17			6.4	mg/kg dw
Norrbotten	Boden, Svedjan STP	Sewage wastewater	6195	Treated effluent	2007-09-11 - 2007-09-17			10	ng/l
Norrbotten	Gällivare, Kavaheden STP	Sewage sludge	6230	Sludge	2007-09-20 - 2007-09-26			0.60	mg/kg dw
Norrbotten	Gällivare, Kavaheden STP	Sewage wastewater	6229	Treated effluent	2007-09-20 - 2007-09-26			18	ng/l
Norrbotten	Kiruna STP	Sewage sludge	6137	Sludge	2007-09-05 - 2007-09-11			9.6	mg/kg dw
Norrbotten	Kiruna STP	Sewage wastewater	6136	Treated effluent	2007-09-05 - 2007-09-11			1400	ng/l
Norrbotten	Luleå, Uddebo STP	Sewage sludge	6756	Sludge	2007-11-26 - 2007-12-03			14	mg/kg dw

County	Site	Category	Sample ID	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
Norrbotten	Luleå, Uddebo STP	Sewage wastewater	6755	Treated effluent	2007-11-26 - 2007-12-03			27	ng/l
Norrbotten	Piteå, Sandholmen STP	Sewage sludge	6178	Sludge	2007-09-19 - 2007-09-25			15	mg/kg dw
Norrbotten	Piteå, Sandholmen STP	Sewage wastewater	6177	Treated effluent	2007-09-19 - 2007-09-25			74	ng/l
Örebro	Skebeck STP	Sewage sludge	6683	Sludge	2007-11-06			Sample missing	mg/kg dw
Örebro	Skebeck STP	Sewage wastewater	6681	Treated effluent	2007-10-29 - 2007-11-04			21	ng/l
Örebro	Skebeck STP	Sewage wastewater	6680	Untreated influent	2007-10-29 - 2007-11-04			22	ng/l
Östergötland	Finspång, Axsäter STP	Sewage sludge	6155	Sludge	2007-09-17			25	mg/kg dw
Östergötland	Finspång, Dovern	Receiving water	6566	Sediment	2007-10-25	6504650	1500800	16	mg/kg dw
Östergötland	Linköping, Roxen	Receiving water	6586	Sediment	2007-10-31	6481470	1489210	7.8	mg/kg dw
Östergötland	Motala, Boren	Receiving water	6569	Sediment	2007-10-30	6494660	1460230	9.6	mg/kg dw
Östergötland	Norrköping, Slätbaken	Receiving water	6490	Sediment	2007-10-11	6482790	154166	4.5	mg/kg dw
Södermanland	Eskilstuna STP	Sewage sludge	6280	Sludge	2007-09-17 - 2007-09-21			16	mg/kg dw
Södermanland	Eskilstuna STP	Sewage wastewater	6276	Treated effluent	2007-09-17 - 2007-09-21			13	ng/l
Södermanland	Eskilstuna STP	Receiving water	6277	Treated effluent, (efter våtmark)	2007-09-17 - 2007-09-21			24	ng/l
Södermanland	Eskilstuna STP	Sewage wastewater	6272	Untreated influent	2007-09-17 - 2007-09-20			280	ng/l
Södermanland	Katrineholm, Rosenholm STP	Sewage sludge	6741	Sludge	2007-09-19 - 2007-09-26			31	mg/kg dw
Södermanland	Katrineholm, Rosenholm STP	Sewage wastewater	6740	Treated effluent	2007-09-19 - 2007-09-26			26	ng/l
Södermanland	Nyköping, Björshult landfill	Landfill runoff	6335	Landfill leachate	2007-10-01			180	ng/l
Södermanland	Nyköping, Brandholmen STP	Sewage wastewater	6334	Treated effluent	2007-09-25 - 2007-10-01			14	ng/l

County	Site	Category	Sample ID	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
Södermanland	Oxelösund STP	Sewage wastewater	6841	Untreated influent	2007-12-10 - 2007-12-17			63	ng/l
Södermanland	Strängnäs STP	Sewage sludge	6024	Sludge	2007-08-28			12	mg/kg dw
Södermanland	Strängnäs STP	Sewage wastewater	6021	Treated effluent	2007-08-20 - 2007-09-27			5.0	ng/l
Södermanland	Trosa STP	Sewage sludge	6342	Sludge	2007-10-02			9.1	mg/kg dw
Södermanland	Trosa STP	Sewage wastewater	6340	Untreated influent	2007-09-25 - 2007-10-01			20	ng/l
Södermanland	Trosa STP, wetland treatment	Sewage wastewater	6341	Treated effluent	2007-09-25 - 2007-10-02			10	ng/l
Stockholm	Stockholm archipelago	Receiving water	6403	Sediment				0.95	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6404	Sediment				0.62	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6405	Sediment				0.79	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6406	Sediment				0.96	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6407	Sediment				1.1	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6408	Sediment				0.98	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6409	Sediment				1.7	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6410	Sediment				0.10	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6411	Sediment				22	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6412	Sediment				12	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6413	Sediment				7.4	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6414	Sediment				27	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6415	Sediment				9.8	mg/kg dw

County	Site	Category	Sample ID	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
Stockholm	Stockholm archipelago	Receiving water	6416	Sediment				6.1	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6417	Sediment				5.0	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6418	Sediment				7.2	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6419	Sediment				5.6	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6420	Sediment				1.4	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6421	Sediment				0.86	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6422	Sediment				0.95	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6423	Sediment				0.91	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6424	Sediment				0.67	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6425	Sediment				1.0	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6426	Sediment				1.6	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6427	Sediment				0.74	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6428	Sediment				0.83	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6429	Sediment				1.0	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6430	Sediment				1.0	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6431	Sediment				1.1	mg/kg dw
Stockholm	Stockholm archipelago	Receiving water	6432	Sediment				12	mg/kg dw
Stockholm	Stockholm archipelago, Asköfjärden	Receiving water	6795	Perch muscle	2007-12-20			< 0.21	µg/kg fw

County	Site	Category	Sample ID	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
Stockholm	Stockholm archipelago, Asköfjärden	Receiving water	6796	Perch muscle	2007-12-20			< 0.21	µg/kg fw
Stockholm	Stockholm archipelago, Asköfjärden	Receiving water	6797	Perch muscle	2007-12-20			0.30	µg/kg fw
Stockholm	Stockholm archipelago, Asköfjärden	Receiving water	6798	Perch muscle	2007-12-20			< 0.21	µg/kg fw
Stockholm	Stockholm archipelago, Asköfjärden	Receiving water	6799	Perch muscle	2007-12-20			< 0.21	µg/kg fw
Stockholm	Stockholm archipelago, Asköfjärden	Receiving water	6800	Perch muscle	2007-12-20			< 0.21	µg/kg fw
Stockholm	Stockholm archipelago, Asköfjärden	Receiving water	6801	Perch muscle	2007-12-20			< 0.21	µg/kg fw
Stockholm	Stockholm archipelago, Asköfjärden	Receiving water	6802	Perch muscle	2007-12-20			< 0.21	µg/kg fw
Stockholm	Stockholm archipelago, Lagnö	Receiving water	6787	Perch muscle	2007-12-19			1.0	µg/kg fw
Stockholm	Stockholm archipelago, Lagnö	Receiving water	6788	Perch muscle	2007-12-19			< 0.21	µg/kg fw
Stockholm	Stockholm archipelago, Lagnö	Receiving water	6789	Perch muscle	2007-12-19			< 0.21	µg/kg fw
Stockholm	Stockholm archipelago, Lagnö	Receiving water	6790	Perch muscle	2007-12-19			0.90	µg/kg fw
Stockholm	Stockholm archipelago, Lagnö	Receiving water	6791	Perch muscle	2007-12-19			< 0.21	µg/kg fw
Stockholm	Stockholm archipelago,	Receiving water	6792	Perch muscle	2007-12-19			< 0.21	µg/kg fw

County	Site	Category	Sample ID	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
	Lagnö								
Stockholm	Stockholm archipelago, Lagnö	Receiving water	6793	Perch muscle	2007-12-19			0.30	µg/kg fw
Stockholm	Stockholm archipelago, Lagnö	Receiving water	6794	Perch muscle	2007-12-19			< 0.21	µg/kg fw
Värmland	Arvika, Kyrkviken, close to Vik STP	Receiving water	6068	Surface water	2007-09-12			< 5	ng/l
Värmland	Arvika, Vik STP	Sewage sludge	6192	Sludge	2007-09-26			13	mg/kg dw
Värmland	Arvika, Vik STP	Sewage wastewater	6191	Treated effluent	2007-09-17 - 2007-09-24			10	ng/l
Värmland	Karlstad, Sjöstad STP	Sewage wastewater	6283	Treated effluent	2007-09-28			15	ng/l
Värmland	Kristinehamn, Bergsjön, drinking water source	Background lake	6434	Surface water	2007-10-08	6586800	1408540	1.0	ng/l
Värmland	Kristinehamn, Fiskartorpet STP	Sewage sludge	6436	Sludge	2007-10-08			9.5	mg/kg dw
Värmland	Kristinehamn, Fiskartorpet STP	Sewage wastewater	6443	Treated effluent	2007-10-02 - 2007-10-08			2.0	ng/l
Värmland	Kristinehamn, Fiskartorpet STP	Sewage wastewater	6439	Untreated influent	2007-10-02 - 2007-10-08			190	ng/l
Värmland	Kristinehamn, Strandmossen landfill	Landfill runoff	6446	Landfill leachate	2007-10-08	6583113	1403583	13	ng/l
Värmland	Kristinehamn, Varnumsviken station Kr 70	Receiving water	6019	Surface water	2007-08-28	6579403	1401200	< 5.0	ng/l
Värmland	Säffle STP	Sewage sludge	6201	sludge	2007-09-18			6.1	mg/kg dw
Västerbotten	Bygdeå STP	Sewage sludge	6352	Sludge	2007-10-02			28	mg/kg dw
Västerbotten	Bygdeå STP	Sewage wastewater	6351	Treated effluent	2007-10-02			12	ng/l
Västerbotten	Lycksele STP	Sewage sludge	6153	Sludge	2007-09-17 -			11	mg/kg dw

County	Site	Category	Sample ID	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
					2007-09-20				
Västerbotten	Lycksele STP	Sewage wastewater	6152	Treated effluent	2007-09-17 - 2007-09-20			28	ng/l
Västerbotten	Robertsfors STP	Sewage sludge	6354	Sludge	2007-10-02			24	mg/kg dw
Västerbotten	Robertsfors STP	Sewage wastewater	6353	Treated effluent	2007-10-02			8.0	ng/l
Västerbotten	Skellefteå STP	Sewage sludge	6853	Sludge	2008-01-15			Sample missing	mg/kg dw
Västerbotten	Skellefteå STP	Sewage wastewater	6850	Treated effluent	2008-01-15			210	ng/l
Västerbotten	Umeå, Dåvamyran power plant	Condensate	6568	Effluent	2007-10-29			49	ng/l
Västernorrland	Härnösand, Kattastrand STP	Sewage sludge	6193	Sludge	2007-09-17 - 2007-09-24			10	mg/kg dw
Västernorrland	Härnösand, Kattastrand STP	Sewage wastewater	6194	Treated effluent	2007-09-17 - 2007-09-24			5.0	ng/l
Västernorrland	Örnsköldsvik, Bodtjärnen	Background site	6495	Perch muscle	2007-09-13			< 0.21	µg/kg fw
Västernorrland	Örnsköldsvik, Knorthem STP	Sewage sludge	6148	sludge	2007-09-18			8.7	mg/kg dw
Västernorrland	Örnsköldsvik, Knorthem STP	Sewage wastewater	6147	Treated effluent	2007-09-18			20	ng/l
Västernorrland	Örnsköldsvik, Köpmanholmen STP	Sewage sludge	6176	Sludge	2007-09-17 - 2007-09-21			0.12	mg/kg dw
Västernorrland	Örnsköldsvik, Köpmanholmen STP	Sewage wastewater	6175	Treated effluent	2007-09-17 - 2007-09-21			6.0	ng/l
Västernorrland	Örnsköldsvik, Ovansjösjön	Receiving water	6494	Perch muscle	2007-09-13			< 0.21	µg/kg fw
Västernorrland	Sollefteå, Hågesta STP	Sewage wastewater	6186	Treated effluent	2007-09-17 - 2007-09-24			10	ng/l
Västernorrland	Sollefteå, Långsele STP	Sewage wastewater	6188	Treated effluent	2007-09-17 - 2007-09-24			6.0	ng/l
Västernorrland	Sundsvall, Fillan STP	Sewage sludge	6182	Sludge	2007-09-17 - 2007-09-24			19	mg/kg dw

County	Site	Category	Sample ID	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
Västernorrland	Sundsvall, Fillan STP	Sewage wastewater	6181	Treated effluent	2007-09-17 - 2007-09-24			< 5.0	ng/l
Västernorrland	Sundsvall, Ljustabäcken	Reference site	6600	Surface water	2007-10-31			16	ng/l
Västra Götaland	Alingsås STP	Sewage wastewater	6071	Treated effluent	2007-09-04 - 2007-09-10			13	ng/l
Västra Götaland	Alingsås STP	Sewage wastewater	6070	Untreated influent	2007-09-04 - 2007-09-10			28	ng/l
Västra Götaland	Åmål STP	Sewage wastewater	6060	Treated effluent	2007-09-03 - 2007-09-10			23	ng/l
Västra Götaland	Åmål STP	Sewage wastewater	6059	Untreated influent	2007-09-03 - 2007-09-10			50	ng/l
Västra Götaland	Borås, Gässlösa STP	Sewage wastewater	6386	Treated effluent	2007-09-27 - 2007-10-04			20	ng/l
Västra Götaland	Borås, Gässlösa STP	Sewage wastewater	6385	Untreated influent	2007-09-27 - 2007-10-04			250	ng/l
Västra Götaland	Dals Långed STP	Sewage wastewater	6290	Treated effluent	2007-09-24 - 2007-09-28			8.0	ng/l
Västra Götaland	Dals Långed STP	Sewage wastewater	6289	Untreated influent	2007-09-24 - 2007-09-28			19	ng/l
Västra Götaland	Herrljunga STP	Sewage wastewater	6197	Treated effluent	2007-09-12 - 2007-09-19			13	ng/l
Västra Götaland	Lidköping STP	Sewage wastewater	6212	Treated effluent	2007-09-20 - 2007-09-26			< 5.0	ng/l
Västra Götaland	Lidköping STP	Sewage wastewater	6211	Untreated influent	2007-09-20 - 2007-09-26			35	ng/l
Västra Götaland	Lysekil STP	Sewage wastewater	6301	Treated effluent				17	ng/l
Västra Götaland	Lysekil STP	Sewage wastewater	6300	Untreated influent				120	ng/l
Västra Götaland	Öckerö STP	Sewage wastewater	6133	Treated effluent	2007-09-11 - 2007-09-17			7.0	ng/l
Västra Götaland	Öckerö STP	Sewage wastewater	6132	Untreated influent	2007-09-11 - 2007-09-17			160	ng/l
Västra Götaland	Skara STP	Sewage wastewater	6031	Treated effluent				22	ng/l
Västra Götaland	Skara STP	Sewage wastewater	6030	Untreated influent				31	ng/l

County	Site	Category	Sample ID	Matrix	Sampling date	N (RT90)	E (RT90)	Concentration	Unit
Västra Götaland	Skövde STP	Sewage wastewater	6257	Treated effluent	2007-09-17 - 2007-09-24			< 5.0	ng/l
Västra Götaland	Skövde STP	Sewage wastewater	6256	Untreated influent	2007-09-17 - 2007-09-24			13	ng/l
Västra Götaland	Tanumshede STP	Sewage wastewater	6694	Treated effluent				17	ng/l
Västra Götaland	Tanumshede STP	Sewage wastewater	6693	Untreated influent				41	ng/l
Västra Götaland	Trollhättan, Arvidstorp STP	Sewage wastewater	6455	Treated effluent	2007-09-24 - 2007-10-01			41	ng/l
Västra Götaland	Trollhättan, Arvidstorp STP	Sewage wastewater	6454	Untreated influent	2007-09-24 - 2007-10-01			170	ng/l
Västra Götaland	Uddevalla STP	Sewage wastewater	6474	Treated effluent	2007-09-25 - 2007-10-01			15	ng/l
Västra Götaland	Uddevalla STP	Sewage wastewater	6473	Untreated influent	2007-09-25 - 2007-10-01			23	ng/l