ScorePP is a Specific Targeted Research Project (STREP) funded by the European Commission under the Sixth Framework Programme

Substance Flow Analysis for selected Priority Pollutants in Case Cities

Deliverable No: D2.5, Date: 2009-12-21

Dissemination level: PU

Arne Jamtrot[1], *Kemi Seriki*[2], *Maria Pettersson*[1]

[1] City of Stockholm, Environment and Health Administration, Sweden

[2] Anjou Recherche -Veolia Environnement, France

Source Control Options for Reducing Emissions of Priority Pollutants (ScorePP)
Sixth Framework Programme, Sub-Priority 1.1.6.3, Global Change and Ecosystems
Project no. 037036, www.scorepp.eu, Duration: 1 October 2006 – 31 March 2010

Deliverable number:	D2.5
Deliverable title:	Substance Flow Analysis for selected Priority Pollutants in Case Cities
Authors:	*Arne Jamtrot, Kemi Serikki, Maria Pettersson*
Review and assessment	*Lorenzo Benedetti*
Date submitted to project coordinator:	2009-12-21
Approved by (Work package leader) :	2010-03-31
Approved by (Project coordinator) :	2010-05-08

Abstract
The objective of this task has been to describe and analyse substance flows in two European case cities for selected priority pollutants. This was done by using information on sources and release factors from the ScorePP emission string database together with more local specific information. The substance flow analysis (SFA) results were compared to the results from the monitoring campaigns performed within the project.

The major sources to water and wastewater systems identified and quantified were:
Cadmium: Car wash, long range transport (case city A), contaminant in zinc (case city B).
DEHP: Abrasion particles ("waste in the environment"), floor and wall coverings, coated textiles and lacquers and paint.
Mercury: Dentists, human excrements (due to amalgam fillings), erosion of tires and roads (case city A), Manufactruring of chemicals (case city B)
B(a)P: Domestic greywater.
Penta(BDE): Abrasion particles from polyurethane articles.

In case city B a local emission register was used to quantify releases from different activities. However, it was found that the figures in the register probably referred not only to actual releases but to total use of the substances.

The results from the SFAs are generally in reasonable agreement with the findings of the monitoring at wastewater treatment plants in the cities.

Acknowledgement
The presented results have been obtained within the framework of the project ScorePP - "Source Control Options for Reducing Emissions of Priority Pollutants", contract no. 037036, a project coordinated by the Department of Environmental Engineering, Technical University of Denmark within the Energy, Environment and Sustainable Development section of the European Community's Sixth Framework Programme for Research, Technological Development and Demonstration.

The results presented in this report and the assumptions upon which they are based are the views of the authors, and should not be taken as official positions of the City of Stockholm or Anjou Recherche respectively.

Table of Contents

Figures

Tables

1 Introduction

1.1 Objective

This report was conducted within the scope of the project Source Control Option for Reducing Emissions of Priority Pollutants (ScorePP). The aim of the project is to develop comprehensive and appropriate source control strategies that authorities, cities, water utilities and chemical industries can use to reduce priority pollutants emissions to urban waterways. The project focuses on the 33 "priority" and "priority hazardous" substances identified in the European Water Framework Directive (WFD) (European Commission, 2000).

The objective of the task presented in this report has been to describe and analyse substance flows for selected priority pollutants in two European case cities. This was done by using information on sources and release factors from the ScorePP emission string database (Holten Lützhøft et al., 2009) together with more local specific information from the cities. The results have been compared to the results from the monitoring campaigns performed at wastewater treatment plants (WWTPs) in the case cities within another task of the project (Seriki et al., 2009). Apart from describing the flows of priority pollutants in the case cities, this is a way of evaluating if the ScorePP emission string database can be used as a basis for calculating flows of priority pollutants in cities.

2 Method

2.1 System definition in space and time

For the substance flow analyses (SFAs) presented here, the systems have been defined as the case cities, limited by their city borders. The time frame used is one year. The analysis does not refer to a specific year, but the most recent available data have been used, and sometimes older data have been updated to 2009 conditions. Since focus of the ScorePP project is on controlling emissions to the urban aquatic environment, the analysis has focused on flows that contribute to such emissions and their fate in the urban water environment, although emissions to air and urban soil have also been accounted for.

2.2 Case city characteristics

The two cities for which results are presented in this report have different characteristics. They will be referred to as city A and city B.

City A has a population of 802 600 inhabitants. Few industries are present in the city and economical activities mainly rely on financial, service and high technology fields. The traffic work in the city corresponds to 3.2 million vehicle-km/year). The city has both combined and separate stormwater and wastewater system. The majority of the wastewater is treated by two WWTPs using activated sludge processes. These WWTPs also treat wastewater from 230 000 person equivalents in neighbouring municipalities, and a small part of the wastewater in city A (80 000 person equivalents) is sent for treatment to a third wastewater treatment plant located outside the city. The fact that the substance flow analyses deal with the municipality, whereas the wastewater treatment plants receive wastewater from a somewhat larger area may result in somewhat higher flows indicated by monitoring at WWTPs relative to SFA.

City B has a population of 50 100 inhabitants that doubles and sometimes triples during the summer period. Industries operate within the city but the economy mainly relies on tourism and trade. The city is surrounded by few agricultural fields and has an important harbour activity (granite, wood, salt, fertilizer, paper and livestock importation). The city has a separate wastewater and stormwater

network system with the possibility of storing 120 000 m³ of stormwater for treatment. Wastewater is treated at a WWTP using an activated sludge process and then discharged to surface water.

2.3 Selection of substances

The following substances were selected for SFA:

Case city A: di(2-ethylhexyl)phthalate (DEHP), cadmium, mercury, benzo(a)pyrene and pentabromodiphenyl ether (pentaBDE)

Case city B: di(2-ethylhexyl)phthalate (DEHP), cadmium, mercury, nickel, lead and naphthalene.

The choice of substances was based on the results from the monitoring campaign in task 2.3 ("Improved monitoring in case cities", Seriki et al., 2009), on local information such as the possibility to acquire information on industry's use of priority pollutants, and on availability of data on releases and activities. Since different substances were identified as of interest in the two cities in previous tasks of the project, some of the substances were only selected for one of the cities. To facilitate a comparison between cities, some SFAs were however performed for the same compounds in both cities.
Based on the monitoring data from wastewater treatment plants (WWTPs) in case city A where nickel concentrations were high in both effluent and sludge, it could be argued that nickel also should be included in the SFA for this city. However, it has been shown (Sörme and Lagerkvist, 2002) that nickel loads to WWTPs in this city can largely be explained by precipitation chemicals used in the treatment process. No deeper analysis of sources to WWTPs was therefore found necessary.

In case city B attempts were made to make SFAs for pentachlorophenol and diuron, but due to lack of data they could not be completed.

2.4 General framework

An SFA is an analysis of the flows of a substance or substance group, including inflow, emissions to the environment and other outflows, such as exports of products or waste, within a defined system (usually a geographic region) during a specified time (usually a year) (Jonsson et. al. 2008). Sometimes an SFA also includes stock and environmental distribution. A schematic description of the relationships between these concepts is shown in Figure 2-1 and Figure 2-2.

The SFAs in this study focus on the releases from different sources and their redistribution within the urban water cycle. Therefore, only in the case of DEHP, a full analysis including inflow and stock has been performed.

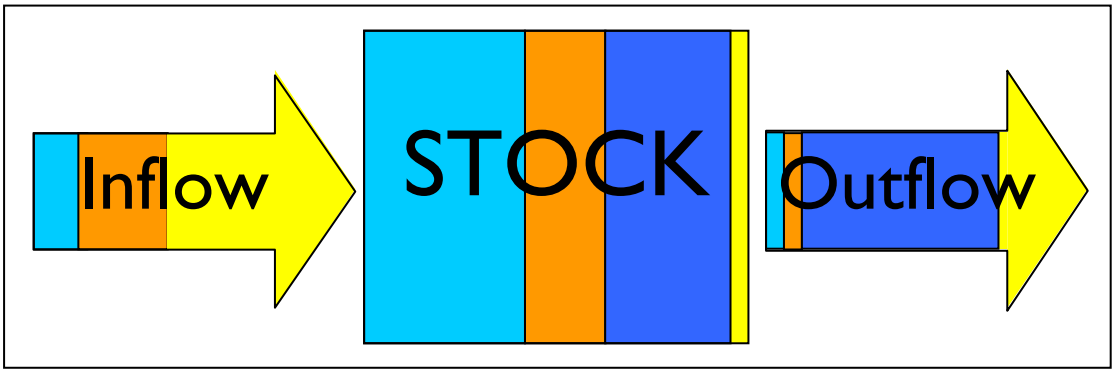


Figure 2-1: The general concepts of substance flow analysis. The different colours represent different applications of the substance, such as use in different goods, production processes etc.

2.4.1 Inflow

A substance may enter a city via different routes, for example with raw materials to industries within the city, with building materials to construction sites and with goods to consumers. Production of the substance within the city is another form of inflow. In the conceptual case in figure 2-1 there are three different routes (represented by the three different colours) which contribute to the total inflow.

2.4.2 Stock

If the products and materials in which the substance enters the city have a service life which is longer than the period which the analysis is based on, the substance will accumulate in the system. The accumulated amount present in the system is referred to as the stock of the substance. For the case in figure 2-1 it can be noted that there is one application of the substance that is represented in the stock, but not in the inflow. This could be because the use of the substance for this application has been phased out, but because the material or products in which the substance was used has a long service life, some of the amounts that accumulated in the system before the phase-out are still there.

There may also be applications with very short service lives, for which there is no stock, only inflow and outflow.

2.4.3 Outflow

The outflow of the substance consists of several fluxes: products may be exported from production facilities within the city or they may leave the city as waste, or the substance may be emitted to soil, water or air during different stages of the product's life-cycle. Also processes like combustion, wear of road pavement etc, result in releases that are part of the outflow of the substance.

The relative contributions from different applications of the substance may be different in the outflow than in the stock or the inflow. This is because different applications will be exposed differently, and hence different applications emit different amounts of the substance to the environment.

The SFAs included in this study focus on the load of priority pollutants on the aquatic environment, and hence the outflows discussed are the releases from products, materials and processes to the urban water cycle, but also to air and soil. These were calculated based on the emission string information in the ScorePP emission string database (Holten Lützhøft, 2009), or on more specific local information (annual reports from industries, existing software and questionnaires).

The emission strings in the database describe the distribution of releases on four principal compartments: water direct, water indirect, air and urban surface. When using these emission strings it has become clear that the compartments are not used in a consistent way throughout the database. However, based on how they are usually used we have decided to interpret them as follows:

- *Water direct:* Emissions to stormwater systems or directly to a lake, river or other aquatic recipient (very rarely). Stormwater systems may or may not be connected to municipal wastewater treatment plants (combined systems) or to other treatments.
- *Water indirect:* Sewage that will be treated at a municipal wastewater treatment plant (WWTP). For some sources, for example industrial facilities, there may be an on-site treatment before the wastewater is emitted onto the municipal sewer system. It has been assumed that the release factors found in the emission strings or elsewhere relate to what is emitted from these on-site treatments.
- *Urban surface:* Emissions to urban soil/unpaved areas. Deposition on paved areas is treated as emissions to stormwater.
- *Air:* It is not obvious how long emissions to air have to be air-borne not to be considered as emissions to urban surface/water etc. In this study, we have made the simplification not to

consider the possibility that emissions to air may be redistributed to water and soil within the system.

2.4.4 Environmental distribution

Emissions that were distributed to the primary compartments water direct (stormwater) and water indirect (wastewater) were redistributed using characteristics of the technical water systems of the respective cities. A comprehensive diagram is shown in Figure 2-2. Details are given below.

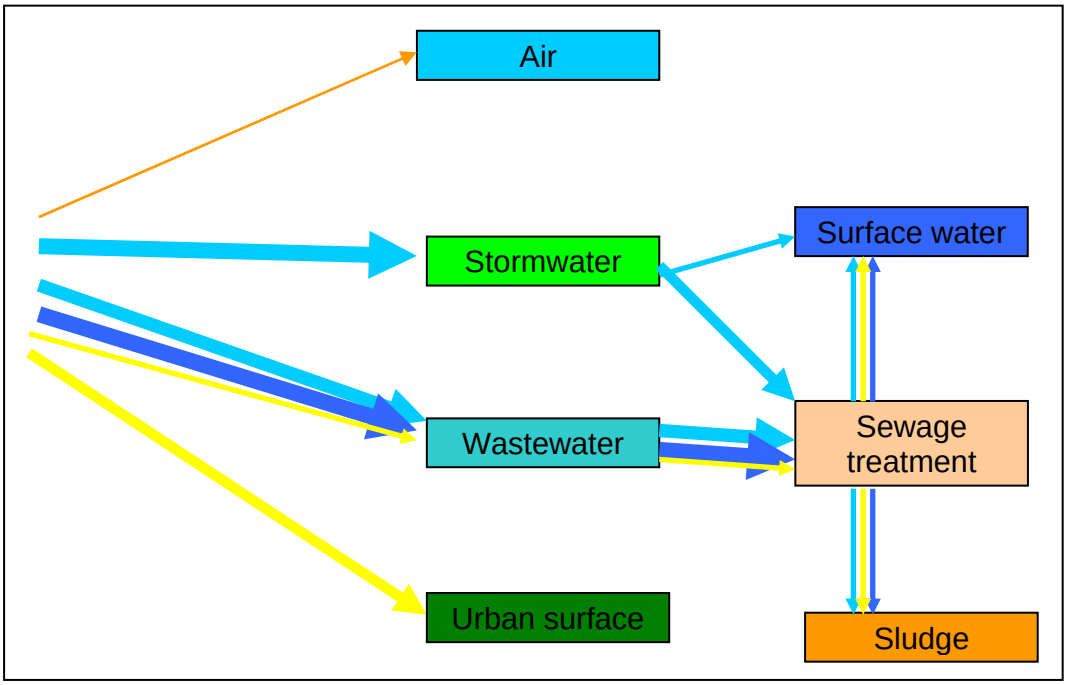


Figure 2-2: The principles for environmental distribution used in the SFAs in this study. The different colours of the arrows represent releases from different applications of the substance, such as use in different goods, production processes etc, and follow the distribution from each source.

Stormwater was distributed between surface water and wastewater treatment according to the actual distribution of separated and combined stormwater systems in the cities (see 2.5.4 below). There was the possibility to assume different distributions for different release sources, for example if they are mainly present in areas where combined systems are more frequent than in the city as a whole. For each emission to separate stormwater systems it was also possible to assign a removal in the treatment facilities.

The fate of priority pollutants in ***wastewater*** treatment was estimated in three ways:

i) For organic substances it was based on results from the STPWIN model calculations presented in Task 5.4 of this project ("Priority pollutants behaviour in end of pipe wastewater treatment plants", Seriki et al., 2008). These give the relative contributions of different processes to the removal of priority pollutants in primary and secondary treatment stages at WWTPs, resulting in estimated loads to air, sludge and effluent water.

ii) For mercury and cadmium the fate was estimated based on the effluent/influent concentration ratios found at the WWTPs in the case cities during the monitoring campaigns presented by Seriki et al., (2009). These ratios are more appropriate for estimating the distribution between sludge and effluent in the specific WWTPs than the more general modelling results. Not all the data needed for calculating the fate of the pollutants at the WWTPs could be obtained from the monitoring for case city B, since

concentrations were often below detection limits. In these cases data from case city A were used when possible.

iii) The most recent literature data presented by Seriki et al. (2008) were used when none of the above methods were applicable. This was the case for nickel and lead.

Finally the total loads to air, surface water, urban soil and sludge were summarized and the calculated total amounts in WWTP influent, effluent and in sludge were compared to measured loads from Seriki et al., (2009). It should be noted that data from these monitoring campaigns may not be in all cases sufficiently representative for the situation in the WWTPs. In case city A two sampling campaigns were conducted at each WWTP, in spring and autumn. At each campaign, time proportional sampling were performed during a seven day period and composite samples representing this period were analysed. The sampling periods were chosen to be as representative as possible of normal flow to the WWTPs, i.e. not extremely dry or rainy periods. In case city B, four 24 hours flow proportional samples were collected. Four samples may not be sufficient to represent the average situation in the WWTP over a year as many factors influence its functioning (rain events, pollution, water storage before treatment etc.), and the conditions during these campaigns may not be representative for the situation in the city. In addition, city B has a storm water retention basin that may have hold important levels of priority pollutants which were never measured during the campaigns.

2.5 Collection of data

Data were either based on local information or on general information from the literature or from previous work within the project.

2.5.1 Identification of release sources

Relevant release sources were identified by crosschecking the ScorePP emission string database for the chosen substances with local information on what activities are represented in the cities.

In case city B this information was supplemented with information from a local emission register, including NACE-codes for activities in the city that release the selected substances.

2.5.2 Quantification of releases

The release factors included in the emission strings were used in combination with local information about the release factor multipliers, such as population, traffic, number of dentists etc. Some emission strings were identified as relevant in the above step, but could not be included because of lack of release factors or of information about the release factor multipliers.

For DEHP a revised estimation for some of the release factors was made, taking into consideration the gradual phase-out of some applications. See Appendix 1 for details.

Specific local emission data were taken from emission registers, questionnaires, annual reports of power plants etc.

Data on priority pollutants specific to all economic activities in city B were not possible to acquire over the period of time given for this task. To evaluate the mass of priority pollutants discharged by activities known to release them, the ACTIPOL® software was used in the city. The software enables users to identify potential discharge sources of pollutants in the collection network that may represent potential threat for the wastewater treatment plant and the environment. Each source of pollutants connected to the sewerage network is affiliated to a Nace code.

2.5.3 Distribution of releases

The releases were distributed on the receiving compartments according to the data in the emission strings, or according to more detailed numbers in underlying information, such as EU risk assessment reports.

The ACTIPOL® software can be used to diagnose a given situation, provide elements for better decision making or just to identify the main sources of pollutants in an urban area. However, the media (water, air, solid wastes, sludge…) in which the pollutants are discharged was not specifically described for priority pollutants of interest in city B. For the purpose of the substance flow analysis, the choice of possible routes of priority pollutants was done based on the type of activities, the city's sewer systems and on the physical-chemical properties of the pollutants. These routes are proposition that were judged the most probable based on the collected data and knowledge of the city.

2.5.4 Re-distribution of stormwater

Local data on the relative occurrence of combined and separate stormwater systems were used to re-distribute the releases attributed to stormwater to wastewater treatment and to surface water respectively. In case city A there are 50 percent each of separate and combined systems. In case city B 75 percent of stormwater systems are combined and 25 percent separate. In city B the first flush is stored into retention basin for later treatment at the WWTP. When the retention capacity is reached, the additional storm water is discharged into the surface water. No treatment of stormwater was included in the calculations for any of the cities. This is not because there are no treatment installations for stormwater, but because it could not be approximated how much of the releases from each source end to such treatment. Generally stormwater treatment is most frequently applied for traffic stormwater, and hence ignoring stormwater treatment may lead to an over-estimation of traffic-related sources.

2.5.5 Re-distribution of pollutants in waste-water

As noted above the fate of pollutants at WWTPs was estimated in three different ways. The factors that were used are presented in Table 2-1.

Table 2-1: Distribution factors (percent) between degradation, adsorption, volatilisation and effluent at WWTPs predicted by the STPWIN model, local monitoring and literature data.

Priority pollutant	Degradation	Adsorption (→ sludge)	Volatilisation (→ air)	Remainder (→effluent)	Ref.
Naphthalene	25.6	11.38	11.30	52	STPWIN[1]
Benzo(a)pyrene	12.13	86.67	0	1.2	STPWIN[1]
DEHP	75	25	0	0	STPWIN[1]
PentaBDE	0.48	97	0	2.5	STPWIN[1]
Cadmium	0	84	0	16	Monitoring[2] case city A
Mercury	0	88	0	12	Monitoring[2] case city A
Nickel	0	50	0	50	Literature[1]
Lead	0	70	0	30	Literature[1]

[1]Seriki et al. (2008); [2]Seriki et al. (2009)

3 Results and discussion

3.1 Cadmium

The identified and quantified cadmium sources for both cities and their distribution to different environmental compartments are shown in Table 3-1.

The dominating cadmium sources in case city A are *Long range transport, Traffic* and *Car washes* (11, 10 and 8 kg/y respectively). Cadmium from traffic is distributed to air according to the emission strings, whereas the other two sources affect the aquatic and soil environment. Other important sources to wastewater are *Artists' paints, Food* and *Detergents* (4, 3.5 and 2 kg/y respectively). According to the calculations based on emission strings, *Waste incineration* would be an additional important source to air (20 kg/year), but according to the annual report of the incineration plant in question the emissions are only 0.25 kg/year. Cadmium from *Long range transport* is distributed between stormwater and urban soil according to the relative occurrence of paved and non-paved areas in the city (55 and 45 percent respectively). The fact that some of the cadmium is deposited directly on the water surface is dealt with by assigning a larger proportion to separate stormwater systems relative to combined systems – deposition on water will in effect be equal to deposition on paved areas with separate systems.

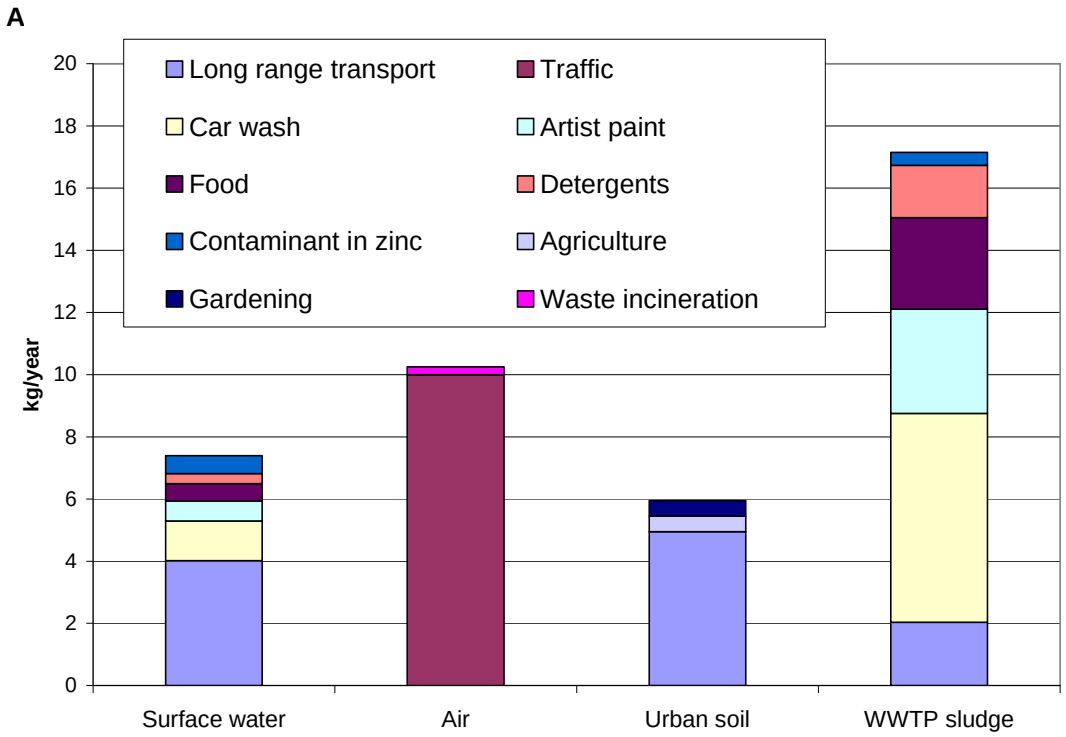
Table 3-1: Cadmium sources identified and quantified in the two case cities. Releases in kg/year.

Source	Release kg/year Case city A	Release kg/year Case city B	Distribution to compartments, %			
			Storm-water	Waste-water	Air	Urban soil
Long range transport	11	0.12	55			45
Traffic	10				100	
Car wash	8	0.51		100		
Artist paint	4			100		
Food	3.5			100		
Detergents	2	0.13		100		
Contaminant in zinc	1	0.66	100			
Agriculture	0.5	0.07				100
Gardening	0.5	0.07				100
Waste incineration	0.25				100	
Manufacturing of chemicals		55000		100		
Manufacturing of fertilizers		360		100		
Metal treatment		220		100		
Non dangerous waste collecting		40		100		
Other cleaning activities		40		100		
Manufacture of electronic components		10		100		

In case city B additional sources were identified using the local emission register: *Manufacture of fertilizers and nitrogen compounds, Manufacturing of other inorganic basic chemicals, Treatment and coating of metals, Manufacture of electronic valves and tubes and other electronic components, Non dangerous waste collecting* and *Other cleaning activities*. However, the amounts given in the register

were several orders of magnitude greater than the ones calculated for other sources. For example, the annual emissions from *Manufacture of other inorganic basic chemicals* were said to be 55 tonnes, which is almost as much as the total stock of cadmium in products and articles in the much greater case city A. Such an emission would have been noticed in the WWTP. It was assumed that the figures given in the register refer not only to emissions, but probably to the total usage of cadmium in these activities. Thus, these activities were excluded from the further analysis. Among the remaining sources are *Contaminant in zinc* and *Car wash* the dominating with 0.7 and 0.5 kg/year respectively.

The contributions from different sources to the final recipients Surface water, Air, Urban soil and WWTP sludge in case city A and B are shown in Figure 3-1. The calculated amounts in WWTP influent, effluent and sludge are compared to measured values from Seriki et al. (2009) in Table 3-2. The calculated loads from the SFAs in case city A are in good agreement with what is found in the monitoring. In case city B, the detection limits for the analyses of the influent and effluent were too high to evaluate the calculations, but the calculated load to sludge agreed well with the monitoring result.



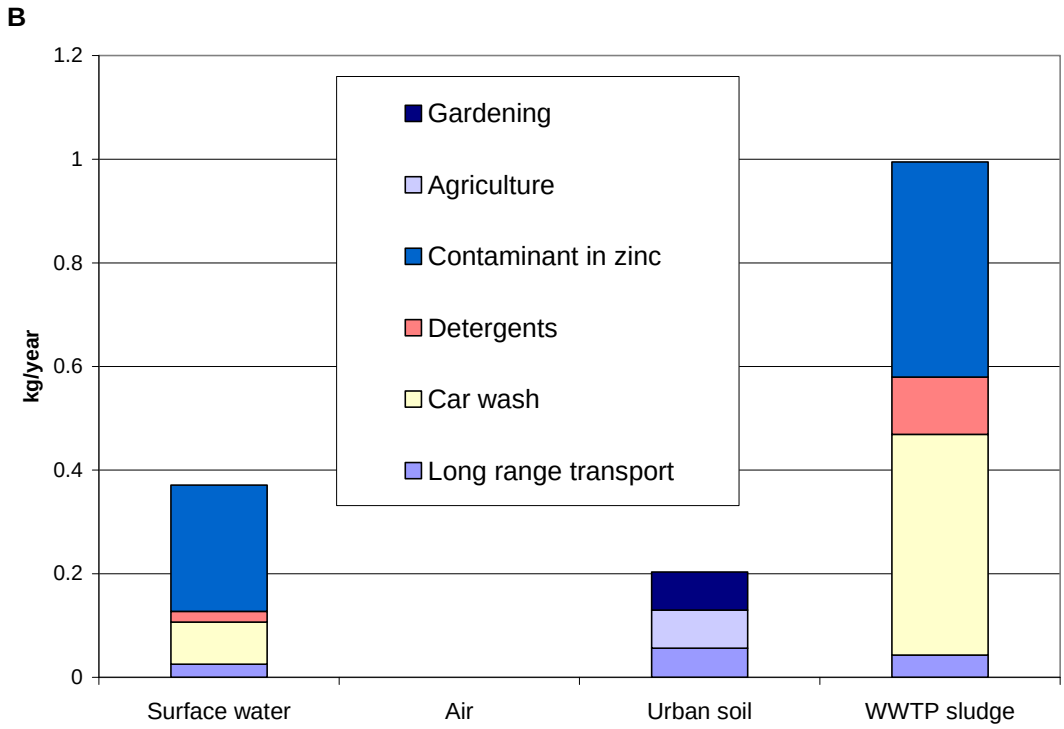


Figure 3-1: Cadmium loads (kg/year) on Surface water, Air, Urban soil and WWTP sludge in case city A (above) and B (below). Underlying numbers can be found in Appendix 3.

Table 3-2: Cadmium loads (kg/year) to WWTP influent, effluent and sludge calculated in the SFA, compared to results from monitoring in the two case cities.

	Case city A		Case city B	
	Calculated kg/year	Measured kg/year	Calculated kg/year	Measured kg/year
Influent	20	24	1.2	<13
Effluent	3.3	4	0.19	<13
Sludge	17	19	1	1.6

3.2 DEHP

The identified and quantified DEHP sources in both cities and their distribution to different environmental compartments are shown in Table 3-3.

For both cities the dominant source by far is *Waste in the environment*, contributing to 60-70 percent of the releases (38 and 2.4 tonnes/year in cities A an B respectively). During use and disposal of products and articles, particles and fragments are abraded from them (European Commission, 2008). These particles are mainly deposited in the urban soil and stormwater compartments, but smaller particles may be transported with air and water. In this study the dispersion of these particles forms an

emission string of its own, separate from the use of products from which the particles originate. The distribution of releases from waste in the environment is calculated given the figures presented in the risk assessment report (European Commission, 2008, table 3.37). It should be noted that the DEHP emitted from this source is in particulate form, which means it is much less bioavailable than the molecular releases coming from most other sources. Some of it is likely to still be in this particulate form when it ends up in sewage sludge, and may therefore not be included in the chemical analysis of the sludge. Thus the calculated loads to sludge which include the particulate fraction, are not necessarily comparable to the measured amounts, which do not.

Table 3-3: DEHP sources identified and quantified in the two case cities

Source	Release kg/year Case city A	Release kg/year Case city B	Distribution to compartments, %			
			Storm-water	Waste-water	Air	Urban soil
Waste in the environment	38000	2380	14		0.05	86
Distribution of electricity, electrical cables outdoor in soil.	8800	950				100
Use of floor and wall covering (floor and wall carpets) in buildings, diffusion to indoor air.; Release during use, cleaning of floor and wall covering, (floor and wall carpets) in buildings, mainly particle bound.	4000	252		97	3	
Manufacture of non-metallic mineral products (non-polymer products); mainly sealants and inks, also paint and ceramics		56	44		36	20
Use of lacquers and paint	803	51	24.9	49.7	0.5	24.9
Use of coated textiles*	550		50		0.5	49.75
Use of coated textiles in households*		44		95	5	
Use of sealants and adhesives	470	30	24.9	49.8	0.4	24.9
Distribution of electricity, electrical cables outdoor in air.	220	24	50		0.5	49.7
Use of other building installation, coated metal sheets	200	13	50		0.4	49.8
Use of clothing and footware, shoes (soles), households	150	9.5	50		0.2	49.9
Use of films, sheets and coated products*	140			75	25	
Cargo handling. Release during distribution of pure DEHP - transportation - cleaning of transport vessels. Other tank cleaning	131	8.3		100		
Transports. Use of motorvehicles, undersealing paste	100	6.7	50		1	49.5
Release from undersealing paste during washing of cars, emissions from car washes	100	6.3		100		
Tubes and profiles used for construction	60	3.8	26		48.2	25.9
Production of electricity; combustion processes; production of heat and electricity; municipal waste incineration; flue gases; Deposition of fly ash/bottom ash on landfills for hazardous waste	50	3.1			100	
Distribution of electricity, electrical cables indoor	37	2.3			100	
Use of printing ink	34	2.1			100	

*In case city A, use of coated textiles in households is included in *Release during use of films, sheets and coated products.*

The second most important source in both cities is *Buried cables* (8.8 and 1 tonnes/year in case city A and B respectively). The releases from these however affect deeper soil layers than usually included when calculating loads to urban or industrial soil. The EU risk assessment report (European Commission, 2008) therefore excludes this source from the general calculations.

It is therefore interesting to look further for sources that are important also for the aquatic environment and in shorter time. Then *Floor and wall coverings* are the most important in both cities (4 and 0.25 tonnes/year respectively), although it should be noted that, like *Waste in the environment* this source includes particulate abrasion products that are fully available neither to organisms nor to chemical analysis.

In case city A these sources are followed by *Lacquers and paint* with approximately 0.8 tonnes/year, whereas in case city B *Manufacture of non-metallic products* is in the same size as *Lacquers and paint*, both emitting some 50 kg/year.

The contributions from different sources to the final recipients Surface water, Air, Urban soil and WWTP sludge in case city A and B are shown in Figure 3-2. Since the contributions from *Waste in the environment* and *Cables outdoors in soil* are so dominant, making it difficult to distinguish the other sources, Figure 3-3 shows the same results with these two sources excluded.

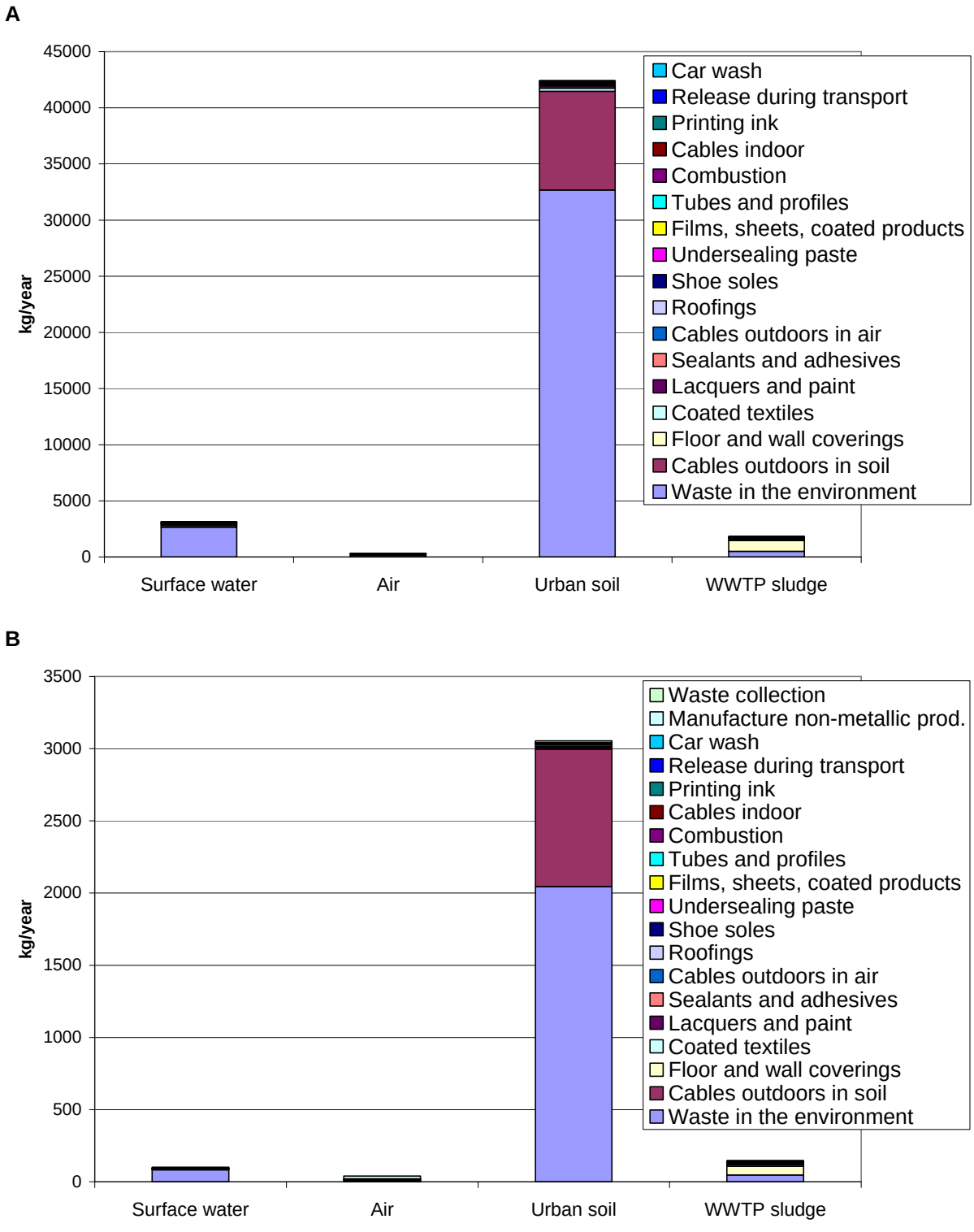


Figure 3-2: DEHP loads (kg/year) on Surface water, Air, Urban soil and WWTP sludge in case city A and B. Underlying numbers can be found in Appendix 3.

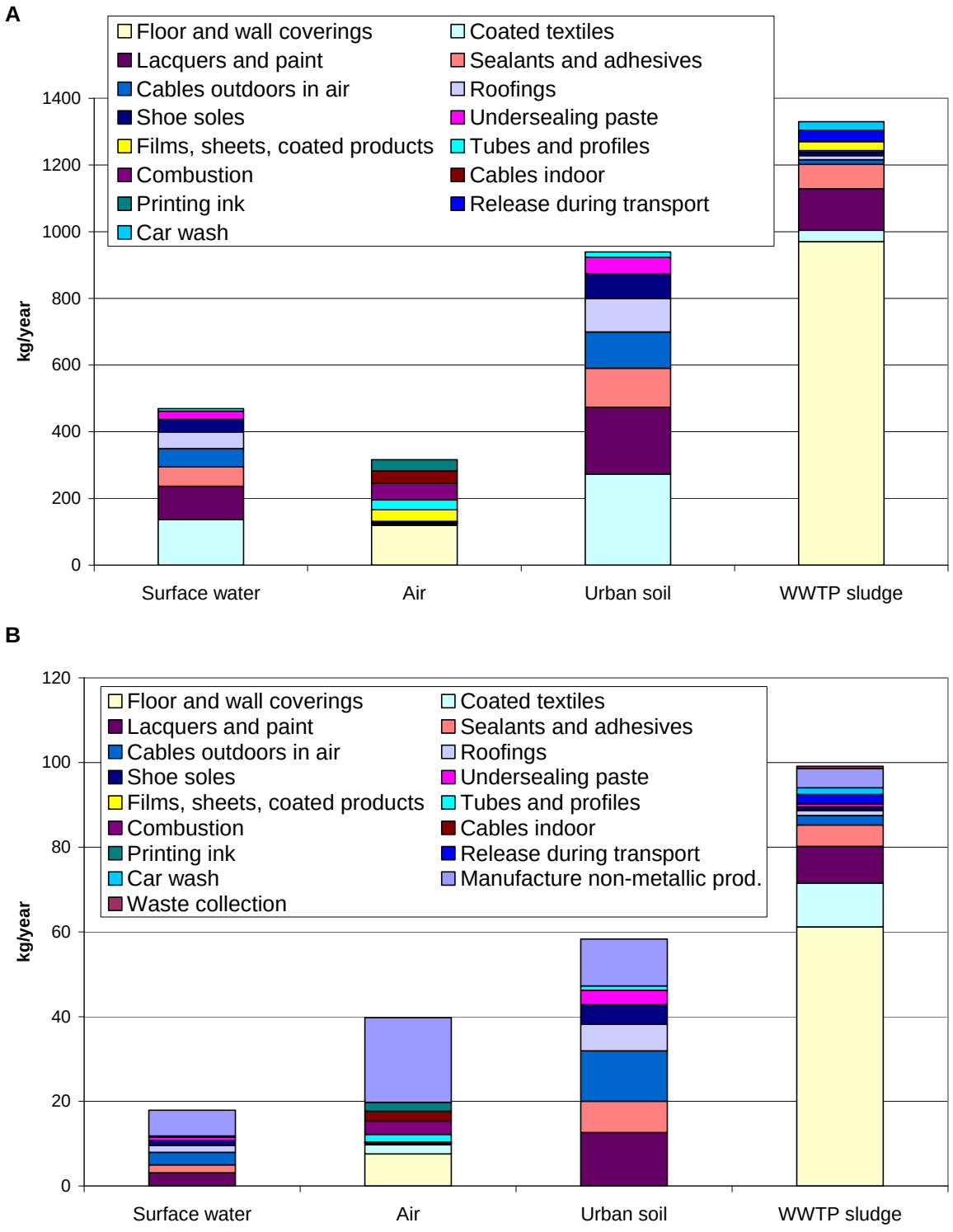


Figure 3-3: DEHP loads (kg/year) on Surface water, Air, Urban soil and WWTP sludge in case city A and B with releases from *waste in the environment* and *cables outdoors in soil* excluded. Underlying numbers can be found in Appendix 3.

The calculated amounts in WWTP influent, effluent and sludge are compared to measured values from Seriki et al. (2009) in Table 3-4. In both cities, the calculated inflow is significantly higher than what is found in the monitoring campaigns. This is probably because DEHP is mostly occurring adsorbed to

particles, or as abrasion particles from PVC products, and the analysis was made on filtrated water, thus not including the particulate fraction. It should also be noted that according to the STPWIN model used for predicting the partitioning of pollutants at WWTPs, DEHP is totally removed from the wastewater stream during the secondary sedimentation stage in the process. This of course means that the predicted effluent load from WWTPs will be zero.

Table 3-4: DEHP loads (tonnes/year) to WWTP influent, effluent and sludge calculated in the SFA, compared to results from monitoring in the two case cities.

	Case city A		Case city B	
	Calculated kg/year	Measured kg/year	Calculated kg/year	Measured kg/year
Influent	8000	<80-1050	650	100
Effluent	0	100	0	100
Sludge	1800	1200*	150	50

* From annual report for the two WWTPs

3.3 Mercury

The identified and quantified mercury sources in both cities and their distribution to different environmental compartments are shown in Table 3-5.

Table 3-5: Mercury sources identified and quantified in the two case cities

Source	Release kg/year Case city A	Release kg/year Case city B	Distribution to compartments, %			
			Storm-water	Waste-water	Air	Urban soil
Erosion of tyres	77		60			40
Erosion of roads	16		60			40
Non-hazardous waste	8.6		0.4		99.6	
Coal combustion installations (>50MW)	6.8		7		93	
Dentists, old dental filling	6.4	0.12		100		
Human excrements due to amalgam fillings	5.0	0.31		100		
Crematoria	1				100	
Energy plants - heavy fuels	0.037				100	
Energy plants - distilled fuels	0.00046				100	
Transportation - distilled fuels		0.56			100	
Transportation - heavy fuels		0.048			100	
Manufacturing of chemicals		0.11		100		
Manufacturing of motor vehicle accessories		0.01		100		
Cleaning activities		0.01		100		

In both cities traffic-related sources were found to be the most important. In case city A the most important source was found to be *Erosion of tyres* (77 kg/year). *Erosion of roads* was the second most important. In case city B *Distilled fuels for transportation* was the major source. All of these are based on release factors from the ScorePP emission string database combined with local figures on annual traffic work or fuel consumption. Due to differences in the availability of supporting information (traffic work and fuel consumption, respectively) all of these could not be calculated in both cities, although they were found to be significant.

In case city A *Incineration of non-hazardous waste* and *Incineration of coal at power plants* followed. These figures were based on the annual reports of the plants, except the smaller part going to water from coal combustion, which was based on the emission string data. Using the release factors in the emission string database gave much higher values: 624 and 29 kg/year respectively. Releases related to dental amalgam were also found to be significant in both cities: *Dental practices*, *Releases via human excrements* and from *Crematoria* (in case city A). The value for the latter was based on the annual report of the crematorium; using emission string data gave 7.5 kg/year.

In case city B *Manufacturing of other inorganic basic chemicals* was also found to be a significant source, based on the local emissions register.

The partitioning of releases on different compartments follows the information in the emission strings and the local specific information respectively. For the traffic related sources – *erosion of tyres and roads* – the emission strings state that in urban areas 100 percent is released to stormwater whereas in non-urban areas 80 percent is emitted to urban soil. Since approximately half of the total area of case city A is urbanized a partitioning of 60 percent to stormwater and 40 percent to urban soil was used.

The contributions from different sources to the final recipients Surface water, Air, Urban soil and WWTP sludge in case city A and B are shown in Figure 3-4. The calculated amounts in WWTP influent, effluent and sludge are compared to measured values reported by Seriki et al. (2009) in Table 3-6.

Table 3-6: Mercury loads (kg/year) to WWTP influent, effluent and sludge calculated in the SFA, compared to results from monitoring in the two case cities.

	Case city A		Case city B	
	Calculated kg/year	**Measured kg/year**	**Calculated kg/year**	**Measured kg/year**
Influent	40	11-23	0.44	<3.3
Effluent	4.7	1.1-3.2	0.053	<0.35
Sludge	35	16*	0.39	1.4

* From the annual report for the two WWTPs

In case city A, calculated loads are higher than measured. This may be related to the calculated releases from traffic. These have not been identified as important sources in previous SFAs in the city (Sörme et al., 2001, Månsson et al., 2009). Excluding these releases from traffic gives calculated loads which are in better agreement with the measurements. It also results in contributions from different sources that are in better agreement to what has been reported in the mentioned references.

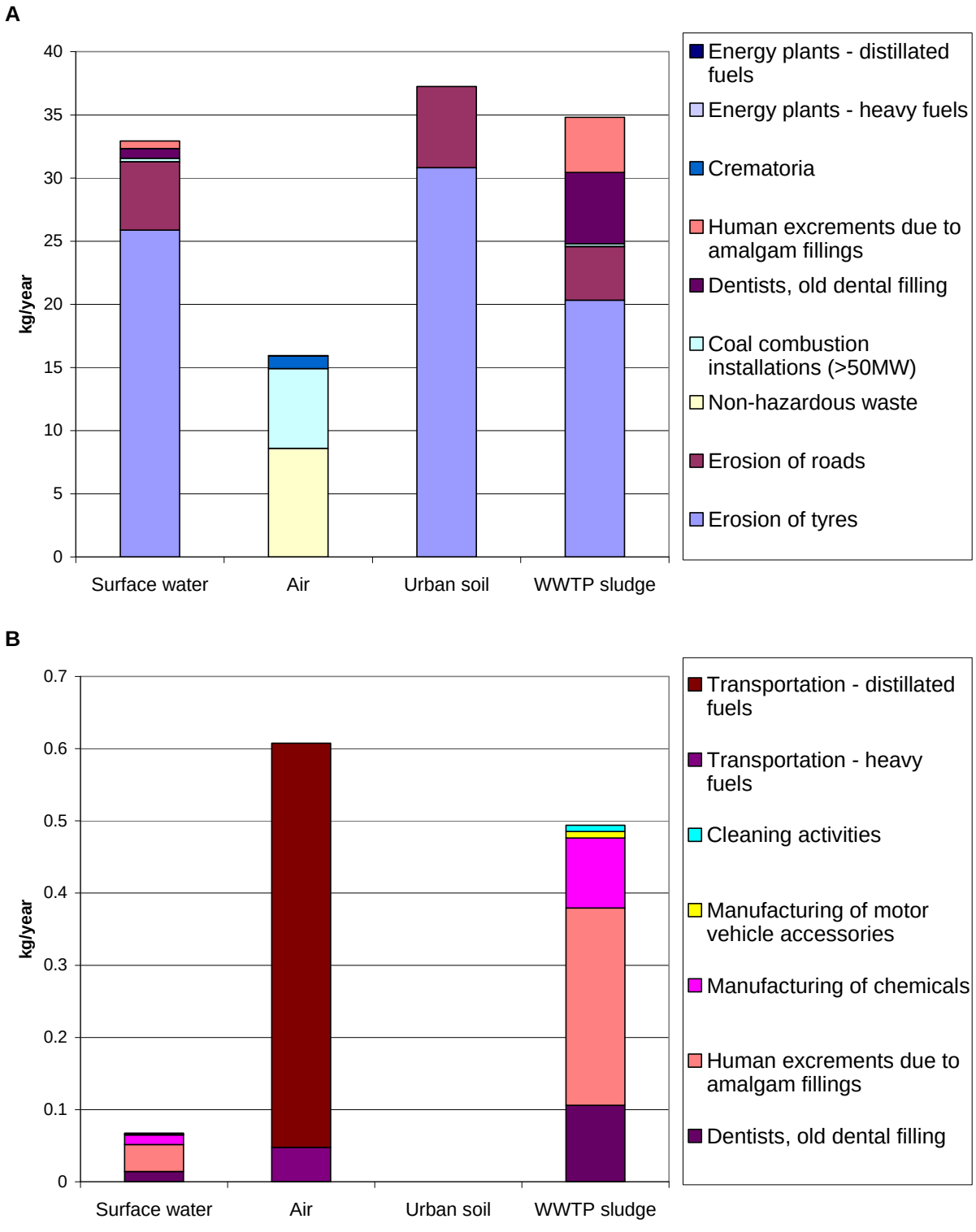


Figure 3-4: Mercury loads (kg/year) on Surface water, Air, Urban soil and WWTP sludge in case city A and B. Underlying numbers can be found in Appendix 3.

3.4 Benzo(a)pyrene (B(a)P)

The identified and quantified B(a)P release sources in case city A are shown in Table 3-7.

Table 3-7: Benzo(a)pyrene sources identified in case city A

Source	Release kg/year Case city A	Distribution to compartments, %			
		Storm-water	Waste-water	Air	Urban soil
Domestic wood burning	8000			100	
Road transport (with catalist)	3400			100	
Road transport (without catalist)	1200			100	
Domestic greywater (bath, shower, kitchen sink, wash basin, dish washer, washing machine) due to human activities	526		100		
Municipal waste incineration	45			100	
Cigarette smoke	43			100	
Fuel burning in large coal burning stoves and furnaces for power supply	19			100	
Bitumen and asphalt production plants, use of asphalt	7,8			100	
Fuel burning in oil burning stoves and furnaces	7,0			100	
Crematoria	0,22			100	

The largest source is *Domestic wood burning*. This figure is taken from Sundkvist (2004), and the author notes that it is likely to be an over-estimation. Releases from road traffic are the next important sources; vehicles with catalysts contribute more than those without, because of their larger number. Sundkvist (2004) gives a total release of 4 kg/year from road traffic , which is in good agreement with results based on the emission strings in combination with the total traffic work. The latter information has been used because it differentiates between vehicles with and without catalysts, and because it is based on more recent traffic data.

Release from domestic grey water is not really a source, but more of a distribution route. No information has been found about what causes the B(a)P-content in the grey water. Cooking (especially barbequing), smoked food-stuffs and cigarette ashes are some possible explanations.

Two sources that were identified as potentially important but could not be quantified due to lacking release factor multiplier information are *Leaching of B(a)P from bitumen (e.g. Roofing) and asphalt,* and *Leaching of BaP from creosote treated wood.*

Most of the identified and quantified releases are emitted to air, and only the domestic grey-water affects the aquatic environment, which can be seen in Figure 3-5. The calculated amounts in WWTP influent, effluent and sludge are compared to measured values from Seriki et al. 2009 in Table 3-8.

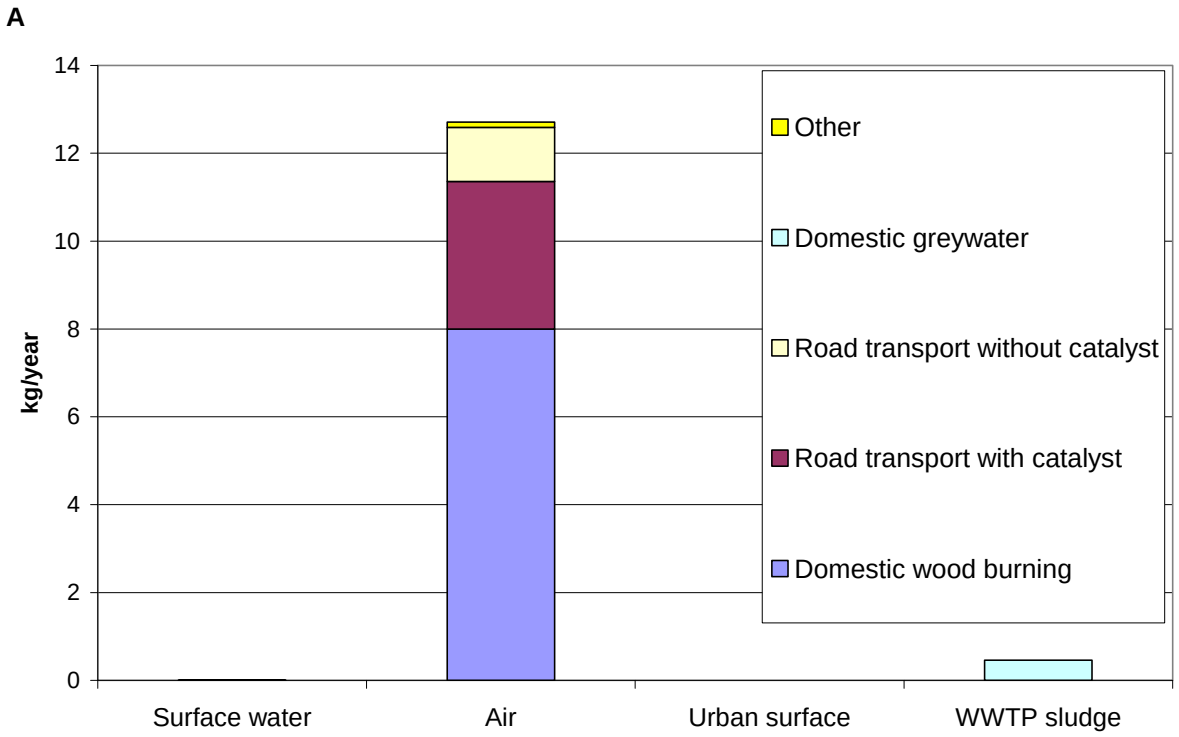


Figure 3-5: Benzo(a)pyrene loads (kg/year) on Surface water, Air, Urban soil and WWTP sludge in case city A. Category *Other* includes *Municipal waste incineration, Cigarette smoke, Fuel burning in large coal burning stoves and furnaces for power supply, Bitumen and asphalt production plants, use of asphalt, Fuel burning in oil burning stoves and furnaces* and *Crematoria.* Underlying numbers can be found in Appendix 3.

Table 3-8: Benzo(a)pyrene loads (kg/year) to WWTP influent, effluent and sludge calculated in the SFA, compared to results from monitoring in case city A.

	Case city A	
	Calculated kg/year	**Measured kg/year**
Influent	0.5	<3
Effluent	0.006	<3
Sludge	0.5	3.7*

* From the annual report for the two WWTPs

It is obvious that the chemical analyses of water phases are not sensitive enough to facilitate a comparison with the estimated amounts. The sludge concentrations however indicate that there are important sources to the wastewater systems that have been neglected in this SFA. This is not surprising since some emission strings that were found to be present in the city and thus potentially important had to be omitted because of lacking background data. It is also clear that some of the releases that are assigned as releases to air in this study (for example road traffic) will be deposited shortly after emission, and will contribute to the aquatic pollution.

3.5 PentaBDE

PentaBDE is a technical product consisting of a number of isomers. The SFA is mainly based on the EU risk assessment report (European Commission, 2001) or local adoptions hereof (Thuresson, 2007). These data refer to the technical product, which mainly consists of tetra and penta-bromoderivatives. In the comparison with monitoring data, concentrations for the two main constituents of the technical product – BDE-47 and BDE-99 (Thuresson, 2007) – have been used.

The identified and quantified pentaBDE release sources in case city A are shown in Table 3-7.

Table 3-9: PentaBDE sources identified and quantified in case city A

Source	Release kg/year Case city A	Distribution to compartments, %			
		Storm-water	Waste-water	Air	Urban soil
Use of PU foam	66			100	
Particulate waste from PU foam	55	14		0.06	86
Waste handling	54			100	

Only three sources could be quantified using the emission string data together with local release factor multiplier information or local specific data. Apart from these, *Manufacture of furniture (office, kitchen and other)* was found to be possibly relevant since a few such industries were found in the city, but no information was found on the use of polyurethane foam in these industries. Thus these releases could not be calculated. However, since 2004 pentaBDE must not be used in production of polyurethane within the EU, which may imply that these sources may be less important. This phase-out has also resulted in a significant decrease in the inflow of pentaBDE in articles (Thuresson, 2007; Jonsson et al., 2008) in turn reducing the stock and the lifetime releases from polyurethane-containing articles. Based on import data in the mentioned publications, it was estimated that both stock and releases have decreased by 40 percent since 2005, the year for which the release estimation was made. As for DEHP, there is a source related to "waste remaining in the environment" referring to abrasion particles from polyurethane materials. As was the case for DEHP discussed in Appendix 1, this was not reduced due to phase-out, since the stock of waste was not assumed to have reached steady state, and thus these delayed emissions are still increasing.

The release from *Waste handling* was based on the release factor associated with the emission string and the population number.

Most of the pentaBDE is emitted to air, only abrasion particles contribute to the load to the aquatic environment. According to the distribution of releases reported in the emission string (based on the risk assessment report), these particles are mainly emitted to urban soil, following the same distribution as the corresponding emissions of DEHP. In practice, however, it may be argued that polyurethane foam articles are to a greater extent used indoor, and the releases of abrasion particles should be more distributed to waste-water, compared to DEHP. In this study however, we have used the emission string data without attempting to revise them according to these assumptions.

The resulting loads to Surface water, Air, Urban soil and WWTP sludge are shown in Figure 3-6. The calculated amounts in WWTP influent, effluent and sludge are compared to measured values reported in Seriki et al. (2009) in Table 3-10.

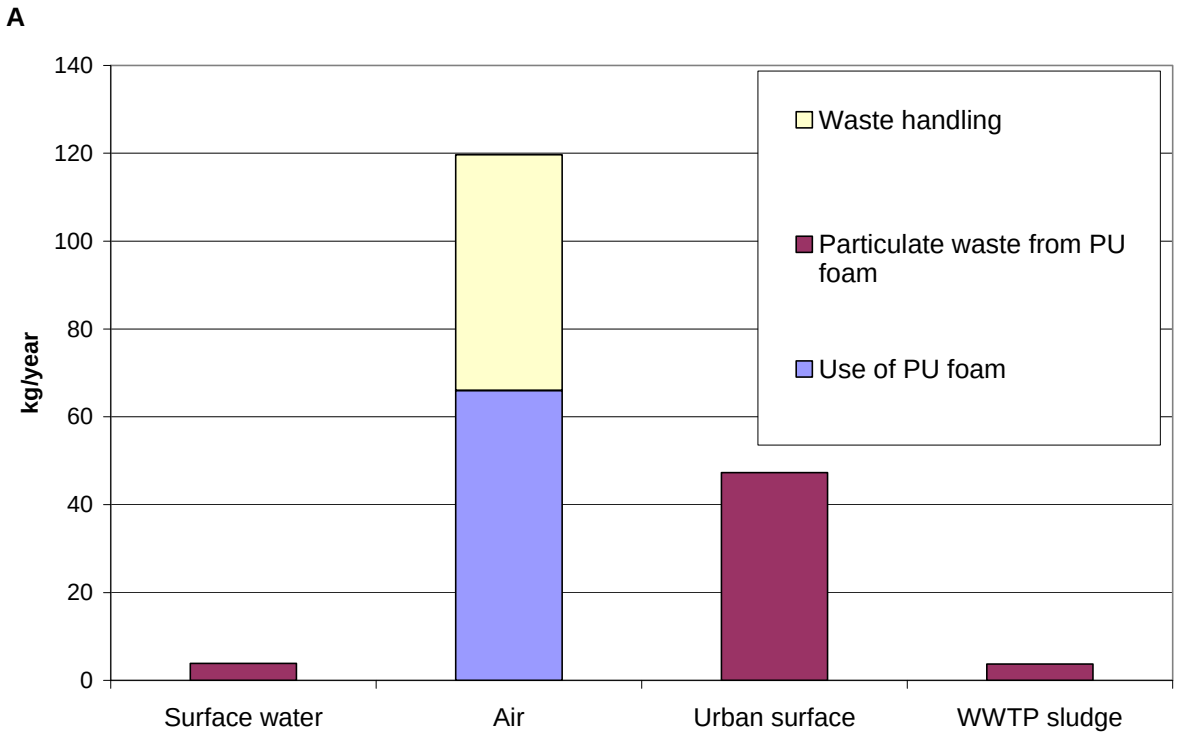


Figure 3-6: PentaBDE loads (kg/year) on Surface water, Air, Urban soil and WWTP sludge in case city A. Underlying numbers can be found in Appendix 3.

Table 3-10: PentaBDE loads (kg/year) to WWTP influent, effluent and sludge calculated in the SFA, compared to results from monitoring in case city A.

	Case city A	
	Calculated kg/year	**Measured kg/year**
Influent	3.8	<13
Effluent	0.1	<2.6
Sludge	3.7	1

Again, it is obvious that the chemical analyses of influent and effluent waters are not sensitive enough for a proper comparison of the results. For sludge, however, it seems that although the distribution of abrasion particles did not take wastewater into account, the load seems overestimated in the SFA. It may be that the phase-out of pentaBDE has been more effective than was assumed in the calculations, leading to lower releases from the included sources.

3.6 Nickel

The information on release sources in case city B presented in Table 3-11 is based on the local release register. As noted above, it is not clear whether these data always refer to actual releases, or if also use of the substances was included. The distributions on different compartments are based on the authors' own estimations.

Table 3-11: Nickel sources identified and quantified in case city B. Details including all sources covered by the category *Other* can be found in Appendix 4.

	Release kg/year Case city B	Distribution to compartments, %			
		Storm-water	Waste-water	Air	Urban soil
Photocopying, document preparation and other specialised office support activities	33390		50	50	
Manufacture of fertilizers and nitrogen compounds	6660		100		
Postal activities under universal service obligation	5670			100	
Manufacture of other chemical products	1110		100		
Other specialized construction activities n.e.c.	950				100
Joinery installation	930				100
Roof activities	800			100	
Manufacture of other plastic products	760		100		
Machining	660		100		
Construction of residential and non residential buildings	650				100
Manufacture of other inorganic basic chemicals	640		100		
Manufacture of other furniture	640		100		
Manufacture of other parts and accessories for motor vehicles	570		100		
Construction of other civil engineering projects n.e.c.	500				100
Other	5080				

Sources that dominate the reported releases are *Photocopying, document preparation and other specialised office support activities*; *Manufacture of fertilizers and nitrogen compounds* and *Postal activities under universal service obligation*, together accounting for 75 percent of the reported releases.

The fate of nickel at WWTPs could not be calculated from monitoring results from case city B, since the concentrations in both influent and effluent were below the quantification limits. Neither could results from case city A be used, since most of the nickel concentrations in effluent and sludge from its WWTPs are explained by precipitation chemicals used in the treatment process. The distribution is therefore based on the most recent literature data reported in Seriki et al (2008), with 50 percent each to sludge and effluent.

Comparing the calculated loads to wastewater treatment with measured values from Seriki et al. (2009) as in Table 3-12 shows that the releases based on the release register are overestimated by several orders of magnitude. It was therefore concluded that they do not in fact only cover releases from the activities. As it was not easily identified which release data were mostly flawed, the SFA could not be corrected for this, and no detailed data are shown about the distribution to different recipients.

Table 3-12: Nickel loads (kg/year) to WWTP influent, effluent and sludge calculated in the SFA, compared to results from monitoring in T2.3 for case city B.

	Case city B	
	Calculated kg/year	**Measured kg/year**
Influent	31000	<66
Effluent	15500	<66
Sludge	15500	30

3.7 Lead

The information on release sources in case city B presented in Table 3-13 is based on the local release register. As noted above, it is not clear whether these data only refer to actual releases, or to use of the substances included. The distributions on different compartments are based on the authors' own estimations.

Table 3-13: Lead sources identified and quantified in case city B. Details including all sources covered by the category *Other* can be found in Appendix 4.

	Release, kg/year	Distribution to compartments, %			
Source	**Case city B**	**Storm-water**	**Waste-water**	**Air**	**Urban soil**
Machining	33780		100		
Wholesale of chemical products	5200		100		
Sewerage	5140		100		
Other specialized construction activities n.e.c.	760				100
Other publishing	720		100		
Roofing activities	640	100			
Joinery installation	630	50	50		
Construction of residential and non residential buildings	520				100
Manufacture of luggage, handbag and the like saddlery and harness	420		100		
Construction of other civil engineering projects	400				100
Other	3160				

Two thirds of the reported emissions come from *Machining* and another 20 percent are equally distributed on *Wholesale of chemical products* and *Sewerage.*

As for nickel, the fate of lead at WWTPs is based on the most recent information reported in Seriki et al. (2008), with 70 percent predicted to end up in sludge and 30 percent in effluent.

As for the other results based on the local release register, comparing calculated flows of lead to and from WWTPs with monitoring results shows a great discrepancy (Table 3-14). It is not likely that all the reported releases are truly releases; some of them may well be figures of the total use at the industries. For example a release of 34 tonnes of lead to the wastewater system from *Machining* would be noticed at the treatment plant. Since it cannot be distinguished which numbers are not referring to

actual releases it was decided not to carry through the whole procedure of calculating loads from different sources to different recipients.

Table 3-14: Lead loads (kg/year) to WWTP influent, effluent and sludge calculated in the SFA, compared to results from monitoring in case city B.

	Case city B	
	Calculated kg/year	**Measured kg/year**
Influent	50000	<33
Effluent	14000	<33
Sludge	34000	60

3.8 Naphthalene

The information on release sources in case city B presented in Table 3-15 is based on the local release register. As noted above, it is not clear whether these data always refer to actual releases, or if also use of the substances was included. The distributions on different compartments are based on the authors' own estimations.

Table 3-15: Naphthalene sources identified and quantified in case city B

	Release,	Distribution to compartments, %			
Source	**kg/year Case city B**	**Storm water**	**Waste water**	**Air**	**Urban surface**
Finishing of textile	3420		100		
Sawmilling and planing of wood	2000		100		
Manufacture of perfumes and toilet preparation	1590		100		
Cigarettes sidestream	64,58			100	
Manufacture of other parts and accessories for motor vehicles	30		100		
Manufacture of other chemical products n.e.c.	10		100		
Cigarettes mainstream	0,561			100	

The fate of naphthalene at WWTPs was predicted using the results from the STPWIN-model presented in Seriki et al (2008), giving the following distribution: degradation 26 %; sludge 11 %; volatilisation 11 % and effluent 52 %.

It is clear from the monitoring results presented in Table 3-16 that the releases to wastewater reported in Table 3-15 are not reliable release data.

Table 3-16: Naphthalene loads (kg/year) to WWTP influent, effluent and sludge calculated in the SFA, compared to results from monitoring in T2.3 for case city B.

	Case city B	
	Calculated kg/year	**Measured kg/year**
Influent	7000	0.40
Effluent	3700	<0.35
Sludge	800	0.16

3.9 SFA versus monitoring results

Figure 3-7 shows the available calculated and monitored flows of cadmium, DEHP, mercury, B(a)P and pentaBDE in the two cities. The results for nickel, lead and naphthalene are not shown, because the release values from the local register were found not realistic, as discussed above.

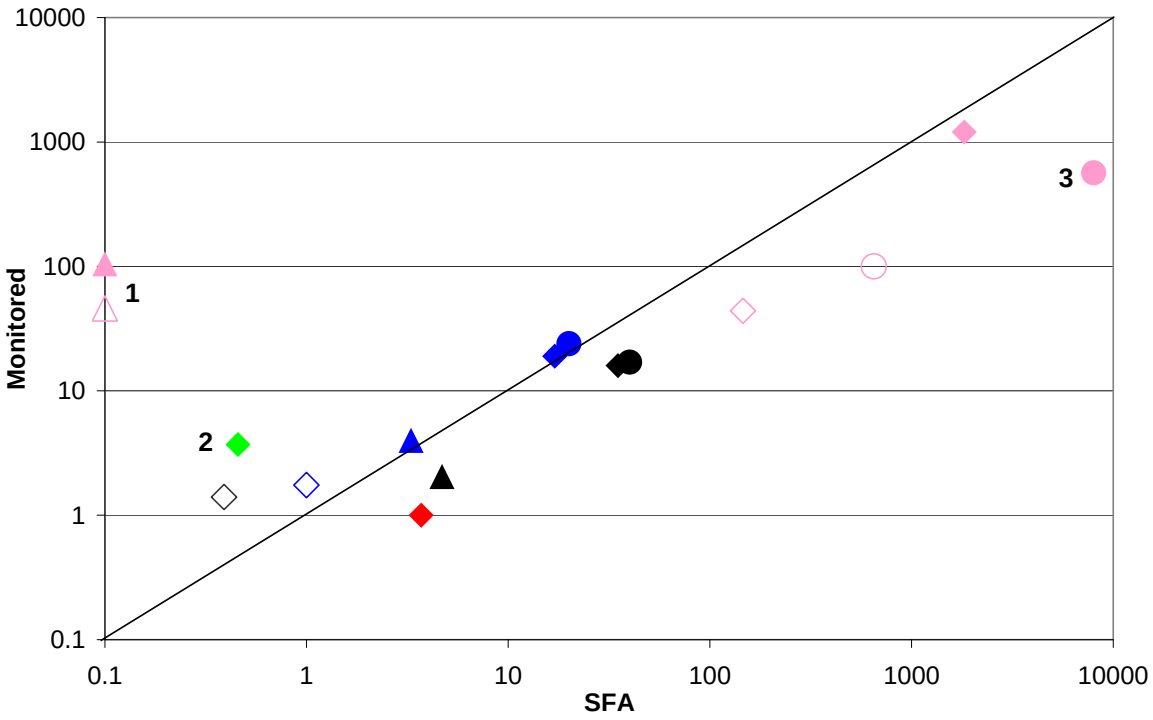


Figure 3-7: An overview of the comparison between calculated and measured flows at WWTPs in the two cities (kg/year). Circles indicate influent, triangles effluent and squares sludge. Filled symbols refer to case city A and empty to case city B. Different colours refer to the different substances included in the study: blue: cadmium, pink: DEHP, black: mercury, green: benzo(a)pyrene, red: penta-BDE. Data points where measured values are below quantification limits have not been included. Numbers next to data points refer to comments in the text.

In most cases the predicted values based on the SFA are in good agreement with what is found in the monitoring. However, a few major discrepancies deserve commenting on:

1. The model used to predict the fate of DEHP at wastewater treatment plants predicts a total (100 percent) removal in the treatment process. This means that the predicted effluents in both cities are zero (shown as 0.1 in the logarithmic diagram), which it clearly is not.

2. For B(a)P the SFA clearly under-estimated the load to WWTPs (only sludge is shown in the diagram, since the concentrations in influent and effluent were below the quantification limits). This indicates that there are some missing sources that contribute to the load on WWTPs. An explanation can be found in the fact that the SFA does not account for deposition of B(a)P released to air within the city. Releases from road traffic are for example likely – at least partly – to be deposited and redistributed with stormwater to the WWTPs.
3. The influent value for DEHP in case city A is an average of two measurements, approximately six months apart. They differed significantly, leading to the large span shown in Table 3-4 (80-1050 kg/year). The fact that the load in the influent is smaller than the flows to sludge, and that they are both lower than predicted by the SFA can be explained by what was mentioned above about the DEHP-containing abrasion particles from different materials and articles. These contribute significantly to the load, but their DEHP content may not be detected in the chemical analysis. DEHP is also a hydrophobic substance which will largely be associated to particles in the wastewater. Since the chemical analysis of WWTP influent is made on filtrated samples this particulate fraction will be missed, and the inflow will be under-estimated.

It is also noticeable that – apart from the ones commented on above – most calculated wastewater flows from the SFAs are slightly higher than the corresponding loads found in the monitoring (most data points are below the 1:1 line in Figure 3-7). This indicates either that the SFAs overestimate the flows, possibly because release factors are based on old data and too high, or that the concentrations in wastewater fractions are in fact higher, but could not be found by the methods applied for the chemical analysis.

4 Conclusions

Measuring priority pollutants in influent, effluent and sludge from domestic WWTPs confirmed that some priority pollutants are important to survey. Therefore, substance flow analyses were made for several pollutants in two case cities. In most cases the predicted values based on the SFA were in good agreement with what was found by monitoring. However, it was noticed that the calculated and measured data did not always comply. Reasons for these differences may be:

- The data gathered to produce the SFAs was too general or could not be used because of lack of essential supporting information.
- The release factors developed in the ScorePP emission string database provided average releases factors that were too high. These release factors were created after an extended literature research on priority pollutants releases from diverse activities (domestic, economic). They are specific to given situations and applying them to the ScorePP case cities may have overestimated or underestimated the real situation.
- The uncertainty linked to measurements and the small number of measuring points could have resulted in over- or underestimation of the priority pollutants flows in the WWTPs.
- In case city A, the system analysed in the SFA was not exactly the same as the area from which wastewater is treated at the two WWTPs.

For some of the priority pollutants the limits of quantifications were too high to detect the substance and it was therefore not possible to compare measured and calculated data.

It clearly appears that despite the differences in size, activities, population and environmental commitment, substances like DEHP and metals still remain a problem in both cities.

Due to its universal use, DEHP is even more difficult to phase out than many other substances as many appliances and objects in the domestic sector and in sanitary facilities contain the compound, and as these often are long-lived and will remain important sources for decades after the use of DEHP has been phased out from production of these goods and materials. It is therefore most unlikely that the releases of DEHP will be ceased by 2015. Reducing the use of DEHP will take several emission control options as its uses affect different environmental compartments. A number of emission control strategies including different control options for DEHP were proposed for both cities in Task 2.4 of this project "Identification of appropriate emission control strategies in case cities".

Concerning metals, they are emitted either via transportation activities (emission from cars, fuel burning and roads) or industrial activities. Decreasing emissions from some of these sources could be possible once the responsible processes are identified and emission control strategies are developed and applied.

The making of SFA required the involvement of several important contributors: local authorities, industries, businesses and local shop owners. An important barrier encountered during this task was the distrust these stakeholders had towards the project and that they did not wish to communicate information that could have improved the assessment of data concerning uses, stocks and emissions of priority pollutants in the case cities. A lesson learned is that when planning this type of work the involvement of the municipality from the project proposal phase is of utmost importance. Informing the municipality (in the case of city B) after the project had been approved lead to a lack of support from the municipality and almost no tangible data gathering from the concerned party. As a result, the data acquired mainly relied on literature reviews that may or may no longer represent the actual situation. In case city A, on the contrary, the SFAs was performed by staff at the municipal environment administration, which meant that the access to available release and activity information was good. Still, however, information about releases of priority pollutants are sometimes lacking in the reports from smaller industries and other activity data may also be hard to get.

Measurements made at the WWTPs enabled highlighting problematic priority pollutants for which SFAs were made using existing data. The next step would be to verify how accurate SFAs (and thus release factors) and local data are by more extensive measurements of emissions to different media (water, emission from industrial WWTP, stormwater, etc.) on a longer period of time, at higher frequencies, and during different conditions (rain, holidays, weekdays, week ends etc.) for given activities.

5 References

European Commission (2000). Directive 2000/60/EC of the European Parliament and the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, Official journal of the European Commission L 327/1-72.

European Commission (2001). "European Union Risk Assessment Report: Diphenyl ether, pentabromoderivative (Pentabromodiphenyl ether)". European Chemicals Bureau. EUR 19730 EN.

European Commission (2008). "European Union Risk Assessment Report: bis(2-ethylhexyl)phthalate (DEHP)". European Chemicals Bureau. EUR 23384 EN.

Holten Lützhøft, H.C., Eriksson, E., Donner, E., Wickman, T., Banovec, P., Mikkelsen, P.S., Ledin, A. (2009). "Quantifying Release of Priority Pollutants from Urban Sources." Proceedings WEFTEC 09, 82nd Annual Water Environment Federation Technical Exhibition and Conference, Orlando, Florida, USA, pp. 5873-5891.

Jonsson, A., Fridén, U., Thuresson, K., Sörme, L. (2008). "Substance flow analysis of organic pollutants in Stockholm". Water, Air and Soil Pollution: Focus 8:433-443.

Månsson, N., Bergbäck, B., Sörme, L. (2009) "Phasing out cadmium, lead and mercury: Effects on urban stocks and flows." Journal of Industrial Ecology 13(1): 94-111

Sandström, H. (2005). "DEHP i Stockholm – en substansflödesanalys" [DEHP in Stockholm – a substance flow analysis"] Report, City of Stockholm Environment and Health Administration. In Swedish with abstract in English.

Seriki, K., Pettersson, M., Jamtrot, A., Castillo, L., Wickman, T., Trouvé, E. (2009). "Measuring priority pollutants and proposing emission control strategies in two European case cities." Proceedings WEFTEC 09, 82nd Annual Water Environment Federation Technical Exhibition and Conference, Orlando, Florida, USA, pp. 5892-5911.

Seriki, K., Gasperi, J, Castillo, L, Scholes, L., Eriksson, E., Revitt, M., Meinhold, M., Atanasova, N. (2008). "Priority pollutants behaviour in end of pipe wastewater treatment plants". ScorePP Deliverable No: D5.4. www.scorepp.eu

Sundqvist, P. (2004) "Polycykliska aromatiska kolväten i stadsluftkällor" ["Polycyclic aromatic hydrocarbons in urban air sources"]. Master thesis, Stockholm University, Department of Physical Geography and Quaternary Geology. In Swedish with abstract in English.

Sörme, L., Bergbäck, B., Lohm, U. (2001). "Goods in the anthroposphere as a metal emission source – A case study of Stockholm, Sweden" Water, Air and Soil Pollution: Focus 1(3-4): 213-227

Sörme, L. and Lagerkvist, R. (2002). "Sources of heavy metals in urban wastewater in Stockholm" Science of the Total Environment 298:131-145.

Thuresson, K. (2007). "Substansflödesanalys av polybromerade difenyletrar i Stockholms stad 2005" ["Substance flow analysis of polybrominated diphenyl ethers in the City of Stockholm 2005"]. Report, City of Stockholm Environment and Health Administration. ISSN 1653-9168. www.stockholm.se/nyagifter

6 Appendix 1: Calculation of updated release factors for DEHP

These calculations are based on data from Sandström (2005) which in turn is an adjustment of data from draft versions of the EU risk assessment report (RAR) (European Commission, 2008) based on local information.

6.1 Coated textiles, films etc

Includes both technical textiles (*coated textiles*) and textiles for indoor use (*films, sheets and coated products*) but it is difficult to know from the risk assessment report what articles belong to what category. Data from Sandström were updated in the following way:

- The average annual inflow of both categories for the period 2002-09 was assumed to be half of the inflow reported for 2002, since Sandström has found indications that DEHP is being phased out.

  Inflow(2002-09)=Inflow(-2002)*0,5

- The lifetime of *films, sheets and coated products* was assumed to be 7 years. For *coated textiles*, the lifetime was assumed to be 10 years. (ref RAR)

- The stock in 2009 was calculated as the accumulated inflow over the lifetime period for the two categories; i.e.:

  Stock(films)=Inflow(films 2002-09)*7

  Stock(textiles)=Inflow(textiles 2002-09)*7 + Inflow(textiles -2002)*3

- A release coefficient was calculated as release/stock based on RAR data:

  EC(films)=$2{,}8*10^{-4}$

  EC(textiles)=$2{,}1*10^{-3}$

- Releases for 2009 were calculated as Stock(2009)*EC

6.2 Shoe soles

No changes were made to the use reported for 2002 (Sandström), i.e. the inflow, stock and outflow were assumed to be the same.

6.3 Floor and wall covering

According to Sandström's contacts with Swedish flooring manufacturers the use of DEHP ceased in 2000-01. The lifetime of floor and wall cover materials is reported to be 20 years (Sandström). It was assumed that half of the stock has been replaced since 2002 with materials without DEHP, and that releases have consequently also been reduced to half. Sandström uses the figure 16 tonnes, which includes abrasion particles that are collected by for example vacuum cleaning. Here, that fraction is not included, which means that the release has been calculated to be 4 tonnes/year.

6.4 Cables

According to Sandström the use of DEHP in cables ceased in 1998, at least for larger manufacturers. The lifetime of cables is reported to be 30 years (Sandström). It was assumed that one third of the stock has been replaced since 1998 with materials without DEHP.

Release coefficients were calculated in the same way as for textiles and films:

EC(Outdoor)=$1,3*10^{-3}$

EC(Indoor)=$5,3*10^{-6}$

6.5 Undersealing paste

We have found no newer data, or any information that suggests a change in this application since Sandström's calculations (based on the RAR).

6.6 Production of electricity

According to the RAR DEHP releases from incineration of municipal waste in Europe is 5.5 t/year, or 0.015 g/person,year. However, the incineration rate is higher in Stockholm than in Europe in general (100% of the municipal waste is incinerated compared to 24% in Europe) so the per capita release is adjusted to 0.060 g/person and year. This gives a release in Stockholm of 50 kg/year.

6.7 Coated metal sheets

According to Sandström's contacts with Swedish roofing manufacturers the use of DEHP ceased in 1997-98. The lifetime of PVC and coil coated roofing materials is reported to be 5-25 years (Sandström). Based on information in RAR an average of 12 years was assumed. This would mean that the present stock contains DEHP-free materials from 1998-2008 and two annual inflows from the period before that, i.e. 2*12 tonnes=24 tonnes. This is one fifth of the stock presented by Sandström based on RAR figures, and hence the releases should also be one fifth; 0.2 tonnes/year.

6.8 Tubes and profiles

We have found no newer data, or any information that suggests a change in this application since Sandström's calculations (based on the RAR).

6.9 Waste remaining in the environment

Unlike the stock of articles and materials within the society, the stock of abrasion particles dispersed in the environment has not reached steady state, i.e. there is still a delayed accumulation corresponding to the accumulation that has been going on in the society. Thus, recent phase-outs of DEHP in articles and materials is not expected to have reduced the emissions with "waste remaining in the environment"

7 Appendix 2: Questionnaire (examples)

7.1 Shoes/Clothes shops

1. What is the volume of shoes sold in 2008? (DEHP)
2. Do you sell clothes made in other countries (PCP)?
    a. If yes, what is their volume (PCP)?
    b. From which country do they come from? (PCP)
3. Do you sell leather products (PCP)?
    a. If yes, where are they made (PCP)?

7.2 Hospitals

1. What is the volume of plastic device used by the hospital in 2008 (DEHP)?
    a. How is the used plastic material in the hospital disposed of (DEHP)?
    b. How much has been thrown away in 2008 (DEHP)?
    c. Is this value stable year to year?
    d. Is it possible to have the address of the company taking care of medical device disposal (DEHP)?

7.3 Construction industry, building industry

1. Do you sell PVC products (Window frames, door frames...)?
2. What sealing material do you use in construction (waterproof)? (Tar, bitumen, asphalt)?
3. What was the volume of PVC products installed in xxx (Case city B) in 2008 (DEHP)?
4. Are there records of previous years mentioning the volume of PVC products installed in xxx (Case city B) (DEHP)?
5. Do you dispose of old PVC products from facilities changing PVC products (DEHP)?
    a. If yes, do you know the volume it represents (DEHP)?
    b. If no, who can we contact (DEHP)?
6. Do you install plastic flooring (DEHP)?
    a. If yes, what was the volume installed in 2008 (DEHP)?
7. Do you have previous records on flooring installed before 2008 (DEHP)?
8. Do you have storing facilities for PVC material in xxx (Case city B) (DEHP)?
    a. If yes, what volume does it represent (DEHP)?
9. Do you sell and or store cable and wiring?
    a. If yes, what was the volume sold in 2008 (DEHP)?
10. Do you store cables and wiring (DEHP)?
    a. If yes, what volume does it represent (DEHP)?
11. Are you entitled to use pentachlorophenol?
    a. If yes, what volume each year?
    b. Do you use textiles treated with pentachlorophenol?
    c. What are those textiles treated with?
    d. What are the textiles used for?

7.4 Supermakets

1. What volume of moth balls was sold last year (Naphthalene)?
    a. What are the brand names (DEHP)?
2. What was the volume of herbicide sold last year (Diuron)?
    a. What herbicides brands did you sell in 2008 (Diuron)?

7.5 Wood selling companies for heating purposes

1. What volume of wood was sold for burning purposes in 2008 (Naphtalene)?

   a. How many homes does it represent (Naphtalene)?
   b. Has this volume increased, decreased or is more or less the same (Naphtalene)?

7.6 Companies selling fuel for heating purposes

1. What volume of fuel was sold for heating purposes in 2008 (Naphtalene)?
   a. How many homes does it represent (Naphtalene)?
   b. Has this volume increased, decreased or is more or less the same (Naphtalene)?

7.7 Wood selling companies for construction

1. What volume of wood was sold for construction purposes in 2008 (PCP)?
2. Do you know how the wood is treated (PCP)?

7.8 Dumping ground (all components)

1. What is your volume of solid waste brought each year?
2. Do you have selective solid wastes sort out (e.g. paper, plastic, glass, green waste and domestic waste?
   a. If yes, what is the volume for each sort out in 2008?
3. Do you burn solid waste?
   a. If, yes what type of solid waste do you burn?
   b. What was the volume of solid waste burnt in 2008?
4. Do you collect special wastes and redirect them to another facility (e.g. oil, batteries…)?
   a. If yes, what type of waste are those?

7.9 Tobacco sellers

1. How many packets of cigarettes did you sell in 2008 (Naphtalene)?
   a. Is this number stable from year to year (Naphtalene)?

7.10 Railroad company

1. What herbicides do you use against invasive grass along railways?
   a. What was the volume used in 2008 on the railway of xxx (Case city B) (Diuron)?

7.11 Petrol selling companies

1. What is the volume of sold petrol in 2008 for (Naphtalene):
   a. GPL?
   b. Without lead 95?
   c. Without lead 98?
   d. Gasoline?
2. Are those values stable compared to previous years (Naphtalene)?
3. Is it possible to get approximations of volume sold the last 5 years per carburant (Naphtalene)?

8 Appendix 3: Loads of priority pollutants to surface water, air, urban soil and WWTP sludge, based on SFA calculations.

Cd, kg/year	Case city A					Case city B				
Source	**Surface water**	**Air**	**Urban soil**	**WWTP sludge**	**Total emissions**	**Surface water**	**Air**	**Urban soil**	**WWTP sludge**	**Total emissions**
Long range transport	4.0		4.95	2.0	11	0.025		0.056	0.043	0.125
Traffic		10			10					
Car wash	1.28			6.72	8	0.081			0.426	0.507
Artist paint	0.64			3.36	4					
Food	0.56			2.94	3.5					
Detergents	0.32			1.68	2	0.021			0.11	0.13
Contaminant in zinc	0.58			0.42	1	0.24			0.415	0.666
Agriculture			0.5		0.5			0.0735		0.0735
Gardening			0.5		0.5			0.0735		0.0735
Waste incineration		0.25			0.25					

DEHP, kg/year	Case city A					Case city B				
Source	**Surface water**	**Air**	**Urban soil**	**WWTP sludge**	**Total emissions**	**Surface water**	**Air**	**Urban soil**	**WWTP sludge**	**Total emissions**
Waste in the environment	2660	19	32680	500	35900	83	1.19	2045	46.8	2177
Cables outdoors in soil			8800		8800			950		950
Floor and wall coverings		120		970	1090		7.6		61.2	69
Coated textiles	137	2.75	274	34.2	447		2.2		10.3	12.5
Lacquers and paint	100	3.9	200	125	429	3.16	0.25	12.6	8.66	24.7
Sealants and adhesives	58.5	2	117	73	251	1.85	0.13	7.4	5.08	14.4
Cables outdoors in air	54.7	1.1	109	13.7	179	3.0	0.12	11.9	2.2	17.3
Roofings	49.8	0.8	100	12.5	163	1.57	0.050	6.28	1.18	9.1
Shoe soles	37.4	0.3	75	9.36	122	1.18	0.019	4.7	0.886	6.8
Undersealing paste	25	1	50	6.2	81.4	0.827	0.067	3.3	0.62	4.82
Films, sheets, coated products		35		26.25	61.25					
Tubes and profiles	7.8	29	15.5	1.9	54	0.25	1.8	0.98	0.18	3.25
Combustion		50			50		3.14			3.14
Cables indoor		37			37		2.33			2.33
Printing ink		33.7			33.7		2.12			2.12
Release during transport				32.7	32.7				2.06	2.06
Car wash				25	25				1.58	1.58
Manufacture non-metallic prod.						6.1	20.0	11.1	4.6	41.7
Waste collection									0.52	0.52

Hg, kg/year	Case city A					Case city B				
Source	**Surface water**	**Air**	**Urban soil**	**WWTP sludge**	**Total emissions**	**Surface water**	**Air**	**Urban soil**	**WWTP sludge**	**Total emissions**
Erosion of tyres	25.9		30.8	20.3	77.0					
Erosion of roads	5.4		6.4	4.2	16.0					
Non-hazardous waste	0.019	8.6		0.015	8.6					
Coal combustion installations (>50MW)	0.266	6.3		0.209	6.8					
Dentists, old dental filling	0.769			5.64	6.41	0.0145			0.106	0.120
Human excrements due to amalgam fillings	0.60			4.37	5.0	0.0373			0.274	0.311
Crematoria		1.0			1.0					
Energy plants - heavy fuels		0.037			0.037					
Energy plants - distillated fuels		0.000456			0.000456					
Manufacturing of chemicals						0.0132			0.0968	0.11
Manufacturing of motor vehicle accessories						0.0012			0.0088	0.01
Cleaning activities						0.0012			0.0088	0.01
Transportation - heavy fuels							0.0476			
Transportation - distillated fuels							0.56			

B(a)P, kg/year	Case city A				
Source	**Surface water**	**Air**	**Urban soil**	**WWTP sludge**	**Total emissions**
Domestic wood burning		8			8
Road transport with catalyst		3.4			3.4
Road transport without catalyst		1.2			1.2
Domestic greywater	0.0063			0.457	0.46
Waste incineration		0.045			0.045
Cigarettes		0.043			0.043
Coal burning		0.0189			0.0189
Bitumen and asphalt production		0.00778			0.00778
Oil burning		0.0070			0.0070
Crematoria		0.000225			0.000225

PentaBDE, kg/year	Case city A				
Source	**Surface water**	**Air**	**Urban soil**	**WWTP sludge**	**Total emissions**
Use of PU foam		66			66
Particulate waste from PU foam	3.9	0.027	47	3.7	55
Waste handling		53.6			53.6

9 Appendix 4: Details about nickel and lead sources in case city B

9.1 Nickel

Source	Release kg/year Case city B	Distribution to compartments, %			
		Storm-water	Waste-water	Air	Urban soil
Photocopying, document preparation and other specialised office support activities	33390		50	50	
Manufacture of fertilizers and nitrogen compounds	6660		100		
Postal activities under universal service obligation	5670			100	
Manufacture of other chemical products	1110		100		
Other specialized construction activities n.e.c.	950				100
Joinery installation	930				100
Roof activities	800			100	
Manufacture of other plastic products	760		100		
Machining	660		100		
Construction of residential and non residential buildings	650				100
Manufacture of other inorganic basic chemicals	640		100		
Manufacture of other furniture	640		100		
Manufacture of other parts and accessories for motor vehicles	570		100		
Construction of other civil engineering projects n.e.c.	500				100
Manufacture of perfumes and toilet preparations	450		100		
Joinery installation	450				100
Manufacture of luggage, handbag s and the like saddlery and harness	360		100		
Repair and maintenance of ships and boats	340			100	
Repair of other personal and household goods	330		100		
Manufacture of medical and dental instruments and supplies	280		100		
Distribution of electricity	240			100	
Other specialized construction activities n.e.c.	200				100
Manufacture of engines and turbines, except aircraft, vehicle and cycle engine	180		100		
Construction of residential and non residential buildings	150				100
Finishing of textiles	140		100		
Weaving of textiles	120		100		
Manufacture of other textiles n.e.c.	120		100		
Manufacture of other plastic products	120		100		
Manufacture of metal structures and parts of structures	120		100		
Treatment and coating of metals	120		100		
Other manufacturing n.e.c.	120		100		
Installation of industrial machinery and equipment	120		100		
Manufacture of fluid power equipment	110		100		
Construction of utility projects for electricity and telecommunication	100				100
Installation of industrial machinery and equipment	90		100		
Other printing	80		100		
Collection of non hazardous waste	80				100
Other cleaning activities	80			100	
Repair of furniture and home furnishing	80		100		
Manufacture of tools	70		100		

Nickel cont.					
Manufacture of electricity distribution and control apparatus	70		100		
Building of pleasure and sporting boats	60			100	
Manufacture of doors and windows in metal	50		100		
Repair of electrical equipment	50			100	
Manufacture of other electronic and electric wires and cables	40		100		
Manufacture of kitchen furniture	40		100		
Manufacture of imitation jewellery and related articles	40		100		
Production of electricity	40			100	
Other specialized construction activities n.e.c.	30				100
Agents involved in the sale of furniture , household goods, hardwater and ironmongery	10		100		

9.2 Lead

Source	Release, kg/year Case city B	Distribution to compartments, %			
		Storm-water	Waste-water	Air	Urban soil
Machining	33780		100		
Wholesale of chemical products	5200		100		
Sewerage	5140		100		
Other specialized construction activities n.e.c.	760				100
Other publishing	720		100		
Roofing activities	640	100			
Joinery installation	630	50	50		
Construction of residential and non residential buildings	520				100
Manufacture of luggage, handbag and the like saddlery and harness	420		100		
Construction of other civil engineering projects	400				100
Cargo handling	370			100	
Installation of industrial machinery and equipment	340			100	
Operation of gravels and sand pits extraction of clay and kaolin	220			100	
Manufacture of other furniture	160		100		
Other specialized construction activities n.e.c.	160				100
Manufacture of other parts and accessories for motor vehicles	150		100		
Manufacture of medical and dental instruments and supplies	140		100		
Other manufacturing n.e.c.	140		100		
Repair of electrical equipment	130		50	50	
Manufacture of fertilizers and nitrogen compounds	120		100		
Installation of industrial machinery and equipment	120		100		
Construction of residential and non residential buildings	120				100
Manufacture of other inorganic basic chemicals	100		100		
Manufacture of engines and turbines except aircrafts, vehicle and cycle engines	100		100		
Research and experimental development on biotechnology	90		100		
Other research and experimental development on social sciences and humanities	90		100		
Construction of utility projects for electricity and telecommunications	80				100
Manufacture of doors and windows in metal	70		100		
Manufacture of loaded electronic boards	70		100		
Manufacture of other chemical products	60		100		
Distribution of electricity	60			100	
Collection of non hazardous waste	60				100
Manufacture of fluid power equipment	40		100		
Repair of machinery	40		50	50	
Roofing activities	40	100			
Treatment and metallic coating	20		100		
Manufacture of other electronic and electric wires and cables	20		100		
Manufacture of jewellery and related articles	20		100		
Manufacture of communication equipment	10		100		
Manufacture of kitchen furniture	10		100		
Repair of fabricated products	10		100		