7. REPORT SYNOPSIS, DISCUSSION AND CONCLUSIONS

7.1 Report Synopsis

7.1.1 Scope of the study

The European Union is introducing an integrated policy to promote sustainable water use through the Water Framework Directive-2000/60/EC (**WFD**) based on a long-term protection of water resources. A strategic aspect of this is the progressive decrease in contaminant discharges to the aquatic environment. Allied to this water policy is the amended proposal by the European Commission (COM/2001/17) listing 32 priority substances to be phased out and 11 hazardous substances that will be subject to emission controls and quality standards in accordance with Article 16 of the WFD. Furthermore, Directive 86/278EEC concerning the use of sewage sludge in agriculture (**USSA**) is undergoing major revision of the quality standards for potentially toxic elements and organic contaminants in sludge and metal concentrations in sludge-treated soil. The urban wastewater (UWW) collection system is one of the main facilities used for the disposal of many types of commercial and domestic wastes that contain potentially toxic elements and organic pollutants. It also receives unintentional diffuse inputs of contaminants in storm run-off from paved surfaces. However, wastewater treatment processes are effective in mitigating the discharge of many substances to surface waters with the treated effluent. This is achieved principally through aerobic biological transformations or because a significant proportion of the contaminant load is transferred to the sewage sludge. Centralised collection and treatment of urban wastewater and sewage sludge is therefore a pivotal link in defining the pathways and fate of contaminant releases to the environment.

A major review of scientific, operational and regulatory information and literature from published sources, research institutions, industrial operators and environmental agencies has pooled current knowledge and developed a data-base of the sources and pathways of pollutants in the wastewater treatment system (WWTS) within the European context.

The main objectives of this study were to determine the multiple sources of potentially toxic elements and organic pollutants entering UWW, to determine quantitatively the amounts of pollutants passing into the influent of wastewater treatment plant (WWTP), and to assess the effects of treatment processes on the fate of both inorganic and organic pollutants in sewage sludge and treated effluents. This information was to be used to identify problems, to make recommendations and enable optimum reduction of pollutant inputs, and to identify areas where data are lacking and where further research is required. The significance of the inputs and types of contaminants from different sectors connected to the wastewater collection system and potential opportunities and practical measures to reduce the extent of contaminant discharges to sewer are discussed. Potentially toxic elements are routinely measured in wastewater and sludge and an extensive data-base of information has accumulated on the concentrations and fate of these elements in environmental media. Several important groups of organic contaminant have also received considerable attention (eg PAHs, PCBs, PCDD/Fs), but, in general, the amount of published information on organics is limited compared with potentially toxic elements due to the high cost of analysis, and need for specialist analytical facilities and the absence of standardised methodologies.

More information has been identified for potentially toxic elements, which have been subject to more detailed monitoring, as they are relatively easy to analyse using routine and inexpensive tests and environmental or food chain impacts are much easier to quantify where high soil loadings have occurred. Much less information is available on organic pollutants where some six thousand or more compounds have been identified. Many of these cannot be routinely determined in the majority of laboratories due to lack of appropriate instrumentation, the absence of a unified methodology and expense.

The type of pollutants and the magnitude of loadings to the WWTS system are a complex function of:

- Size and type of conurbation (commercial, residential, mixed);
- Plumbing and heating systems;
- Domestic and commercial product formulation and use patterns;
- Dietary sources and faeces;
- Atmospheric quality, deposition and run-off;
- Presence and type of industrial activities;
- Use of metals, and other materials in construction;
- Urban land use;
- Traffic type and density;
- Urban street cleaning;
- Maintenance practices, for collecting systems and stormwater controls;
- Accidental releases.

Quantitative information on both metal and organic pollutants in urban runoff arising from anthropogenic activities is difficult to evaluate, due to the lack of information on background levels of these substances in the environment. Background concentrations relate to natural geochemical sources and biological sources, and include amounts in soils, dusts and waters derived from historical pollution.

The specific potentially toxic elements (PTEs) and organic contaminants considered in this report are listed in Table 7.1.

Table 7.1 Potentially toxic elements and organic contaminants examined in the review of pollutants in urban waste water and sewage sludge

Potentially toxic elements	Organic contaminants
Zinc (Zn)	Linear alkylbenzene sulphonates (LAS)
Copper (Cu)	Nonylphenolethoxylates (NPE)
Nickel (Ni)	Di-(2-ethylhexyl)phthalate (DEHP)
Cadmium (Cd)	Polycyclic aromatic hydrocarbons (PAHs)
Lead (Pb)	Polychlorinated biphenyls (PCBs)
Chromium (Cr) III and VI	Polychlorinated dibenzo-p-dioxins (PCDDs)
Mercury (Hg)	Polychlorinated dibenzo-p-furans (PCDFs)
Platinum group metals (PGMs)	Nitro musks (chloronitrobenzenes)
Other PTEs*	Pharmaceuticals
	Oestrogenic compounds:
	Endogenous forms: 17β-oestradiol, oestrone
	synthetic steroids: ethinyloestradiol
	Polyelectrolytes (polyacrylamide)
	Other organics**

*- such as Arsenic, Silver, Molybdenum and Selenium
**- such as Adsorbable organo halogens (AOX) and chlorinated paraffins

Specific case studies on the following key issues are included in greater detail in Section 6

- Platinum group metals (PGMs),
- Sustainable urban drainage,
- Artisanal activities,
- Pharmaceuticals,
- Body care products and fragrances,
- Surfactants,
- Polyelectrolytes in sludge treatment and dewatering,
- Influence of chemical phosphorus removal on potentially toxic element content in sewage sludge.

The review has emphasised that an assessment of the contaminants entering UWW and sludge cannot be divorced from an understanding of their potential impacts on the environment, and particularly in relation to the use of sewage sludge in agriculture, as this provides the context for defining the significance of UWW and sludge contamination.

Finally, areas where there is a deficit of information concerning particular sources or contaminant groups, or their behaviour in the WWTS are identified and recommendations for further investigations to inform decisions about the direction of future research requirements have been formulated.

7.1.2 Potentially toxic elements

Sources of potentially toxic elements entering the WWTS

The sources of potentially toxic element contamination in the wastewater system have been classified into three main categories:

- Domestic;
- Commercial;
- Urban runoff.

The information that was collected identified domestic inputs as the largest overall sources of Cu, Zn and Pb entering the UWW system, whereas commercial sources represent the major inputs of Hg and Cr (Table 7.2). Commercial discharges contribute moderately larger inputs of Cd (30 – 60 %) compared with domestic sources (20 – 40 %). Estimates of Ni loadings from domestic sources are highly variable and this contribution may be similar to, or greater than, the commercial input. The size of the run-off contribution depends on climate and traffic intensity, and can be a significant proportion (>20 %) of the total metal load for Cd and Pb, but it is a relatively minor source of Cu and Hg. However, storm discharge was identified as an important source of Hg in a survey of metal inputs to the river Rhine (French region), contributing 15 % of the total load of this element to the river. Chromium, Ni and Zn represent an intermediate group and run-off typically contributes <20 % of the total input of these elements to UWW.

There is a degree of uncertainty in the mass balance, however, and a significant proportion of the load is from unidentified sources, which represent ≥50 % of the total input of Cr, Ni and Zn. Unclassified inputs of Cu, Hg and Pb represent 20-40% of the total loading of these elements, whereas >80 % of the Cd is from identified sources. Nevertheless, the relative magnitude of the domestic and commercial inputs of metals to UWW is highly consistent with the estimated total loadings from these sources to major river systems in Europe (Table 7.3). Strategies to reduce discharges of metals to sewer can only focus on those sources that can be identified and quantified. Therefore, given the extent of the uncertainty in establishing the sources and inputs of certain elements, a priority area for research would be to determine these contributions and to develop a complete mass balance for potentially toxic elements entering to the UWW system in different European countries.

Cadmium and Hg have been proposed as priority hazardous substances by the European Commission and will be subject to the controls required by the WFD to end all releases of these elements to the water environment within a 20-year period. The status of Pb as a priority substance is currently under review. Nickel is not designated hazardous, but is classified as a dangerous substance and emission controls and quality standards will also apply to this element as required by the WFD.

Table 7.2 Provisional potentially toxic element load from different sources entering UWW in EU countries (% of total input)

PTE	Domestic Wastewater	Commercial Wastewater	Urban Runoff
Zn	30-50	5-35	10-20
Cu	30-75	3-20	4-6
Ni	10-50	30	10-20
Cd	20-40	30-60	3-40
Pb	30-80	2-20	30
Cr	2-20	35-60	2-20
Hg	4-5	50-60	1-5

The ranges in Table 7.2 are estimates from various sources in this study and may not add up to 100%. Quite a high proportion of the Zn, Ni and Cr are not identified and attributed to certain sources, and more research is needed in calculating the mass balances of these PTEs in the urban environment.

Table 7.3 Diffuse and point sources of potentially toxic elements entering the river Rhine reported in 1999 (% of total input)

PTE	Point sources[(1)]		Total diffuse sources[(2)]
	Domestic	Industry	
Zn	30	10	60
Cu	20	15	65
Ni	20	20	60
Cd	10	10	80
Pb	15	10	75
Cr	15	25	60
Hg	20	20	60

[(1)]Points sources include discharges through the UWW system
[(2)]Diffuse inputs enter surface water directly

Despite uncertainties in identifying all the metal inputs there is ample evidence demonstrating the significant reduction in metal discharges to the WWTS, principally due to implementation of effective trade effluent controls, more efficient processes and change in industrial base. This is reflected in the declining concentrations of metals present in sewage sludge and in influent wastewaters (Section 2.1) and was reported in all countries where data could be abstracted on temporal trends (The Netherlands, France, UK and Sweden). Examples of the general declining trends in metal concentrations in sludge over the past 20 years in European countries are shown in Figure 7.1 for Zn and Cd for a major WWTP in the UK. In Sweden, Cd inputs declined by 60 % during the period 1992 – 1998 and Cr, Hg and Pb were reduced by 40 – 50 %. Zn and Ni declined by 10 % during the same period, and there was no change in Cu generally reflecting the importance of the domestic contribution of these elements in UWW. Metal concentrations in rivers receiving treated UWW have also shown a marked decline. For example, concentrations in the river Thames have declined on average by 50 % in the period 1986 – 1995.

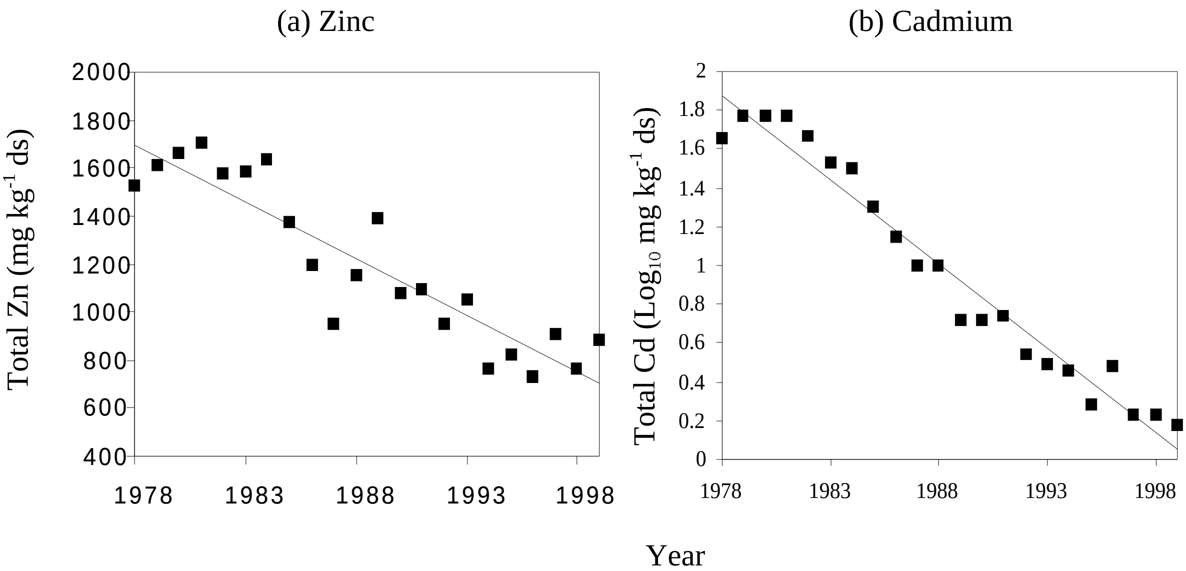

Figure 7.1 Reduction in (a) zinc and (b) cadmium concentrations (untransformed and log_{10} transformed data, respectively) in sewage sludge from Nottingham STW, UK during the period 1978 – 1999

Measures to reduce metals discharges from domestic sources

Faeces comprise a significant proportion (>20 %) of the load of Cd, Cu, Zn and Ni (equivalent to 60-70 % of the total amount of these elements in domestic contribution to wastewater). Faeces typically contain 250 mg Zn kg^{-1}, 70 mg Cu kg^{-1}, 5 mg Ni kg^{-1}, 2 mg Cd kg^{-1} and 11 mg Pb kg^{-1} dry solids. The residual sewage sludge from WWTS generally has significantly larger concentrations of metals than those present in human faeces because of the contributions from other sources.

For Cd, however, which is the most labile zootoxic element in UWW and sludge and its release is of particular concern in the environment, the weighted average content in sludge is comparable to the concentration in human faeces. Whilst other sources of this important element can be identified, solids inputs and secondary sludge production during WWT may have a significant dilution effect on the mass input and transfer to the sewage sludge. Consequently, a critical balance between input concentration in wastewater and dilution processes may control the final Cd content in sludge to within the normal range for faeces, which represents the minimum potential background concentration value. The precise nature of these mechanisms could be identified to better understand the behaviour of Cd in WWTS and in relation to effects of measures to reduce Cd inputs on sludge quality. Whilst the opportunities for further reducing Cd inputs would generally appear to be limited, removing phosphate from detergent formulations has successfully reduced Cd discharges from domestic sources in The Netherlands and Sweden (Section 2.1.2).

However, the principal sources of metals in domestic wastewater are body care products, pharmaceuticals, cleaning products and liquid wastes (eg paint). Plumbing is the main source of Cu in hard water areas, contributing >50 % of the Cu load. It may also be a principal source of Pb where this was used historically as a means of drinking water conveyance, accounting for 25 % of the input to WWTS. Lead solder in copper pipes may also be an important source.

One approach to reducing the domestic input of contaminants is for homeowners to be advised on the proper disposal of household wastes, for example the 'bag it and bin it' campaign run by some UK water companies . This will require co-operation between the wastewater collector and regional authority responsible for municipal waste disposal to establish and publicise schemes and accessible facilities for the disposal of liquid wastes by homeowners. Metals (eg Zn) are also important active ingredients in other commonly used household products, but it may be impracticable to eliminate these although manufacturers minimise their excessive use, for example in packaging. An assessment and survey of the practical implementation of voluntary collection schemes for liquid waste and a programme of pilot studies is recommended to assess attitudes and the extent of homeowner participation.

Commercial sources and inputs of potentially toxic elements to UWW

Regional studies of metal emissions from commercial premises indicate that further reductions in discharges of most elements of concern could be potentially achieved from this sector (Section 2.1.2). The main sources that may be the focus of further investigation include health establishments, manufacturing industry and hotel/catering. Approximately 30 % of medical establishments and 20 % of the other activities may be discharging significant amounts of potentially toxic elements in wastewater. In particular, Hg in UWW and sludge is largely attributable to dental and medical practices. Dental amalgam separators are effective at reducing Hg emissions where their use is compulsory and there is evidence, for example following the Danish ban, that alternatives to Hg used in thermometers and other products can reduce discharges to the WWTS.

Large industrial installations are required to treat wastewater to an appropriate standard before discharging to the WWTS and are subject to rigorous trade effluent control standards. However, small commercial, artisanal enterprises that are connected to WWTS may also be a potentially significant source of contaminants. One of the largest agglomerations of artisanal activities in Italy was investigated in Case Study (c) . This Case Study identified vehicle repair shops, metal processing and jewellery manufacturers as principal artisanal activities potentially responsible for discharging significant amounts of PTEs to the UWW system (table 7.4). However, many small enterprises pretreat wastewater before discharge and this was found to markedly reduce the extent of actual metal discharges to sewer. In the Vicenza Case Study, for example, pretreatment reduced the input of Zn, Cu and Pb from artisanal activities to <10 % of the total load entering the WWTS and Cr and Ni inputs were reduced to <2 and 0.5 % of the total input. Cadmium achieved the smallest overall reduction and approximately 40 % of the total load of this element to the WWTS, was identified as coming from artisanal and commercial activities, principally goldsmiths and car repairers. Further detailed assessment of wastewater management by these types of small enterprises is necessary in other European countries to determine the extent and effectiveness of wastewater treatment prior to discharge and whether specific measures and requirements are necessary and warranted to reduce potentially toxic element contamination from these sources.

Incomplete information regarding these sources could account for a major proportion of the unidentified inputs of metals to UWW (Table 7.2). The identification and control of these inputs is practiced in a number of regions in France by operating registration schemes and inventories of all discharging business premises/activities connected to the WWTS within specific catchment areas. Premises are inspected and the necessary levels of remedial action are agreed with the owner. Small business enterprises may be an important source of potentially toxic elements and the extent of these inputs to UWW, and the level of process wastewater treatment or segregation, should be examined in other European countries to assess the effectiveness and practicability of targeting artisanal activities for specific remedial action.

Other investigations in Sweden and Norway confirm the importance of motor industries, vehicle workshops and washing facilities (particularly heavy goods vehicles) as major sources of potentially toxic elements in UWW. Oil separating devices may be fitted as a measure to reduce wastewater contamination from these activities. However, the formation of stable emulsions in the wastewater by detergent microemulsion formulations used for vehicle washing tend to limit the effectiveness of these systems at reducing pollutant emissions.

Table 7.4 Total metal loads (mean values) from artisanal activities (in discharged and segregated wastewater) in Northern Italy

Activity (number of enterprises[1])	Zn % total load to WWTS (mean)	Cu % total load to WWTS (mean)	Ni % total load to WWTS (mean)	Cd % total load to WWTS (mean)	Pb % total load to WWTS (mean)	Cr(III)[4] % total load to WWTS (mean)
Food (52)	0.28	0.09	<LOD	<LOD	<LOD	<LOD
Car repair (174)	**6.4**	**8.5**	0.3	**6.3**	**34.0**	1.0
Ceramic (24)	0.01	0.001	<LOD	0.14	3.1	1.1
Galvanic (17)	0.07	0.84	0.67	0.39	1.5	0.15
Printing (141)	0.24	2.0	< LOD	2.8	0.59	0.6
Wood (92)	0.29	0.46	<LOD	<LOD	**5.5**	0.76
Metallurgist (155)	**8.7**	**5.3**	**15.6**	2.3	**25.7**	4.7
Dental (88)	0.16	0.02	<LOD	0.25	<LOD	0.05
Gold (253)	2.1	**7.6**	<LOD	**32.2**	<LOD	0.14
Hairdressing (316)	0.99	0.69	<LOD	<LOD	<LOD	<LOD
Laundry (88)	0.49	0.09	0.04	2.3	0.45	<LOD
Total[2]	19.9	25.5	16.6	46.6	71.1	8.9
Total[3]	8.8	9.5	0.46	36.9	7.9	1.8

[1]Total number = 1579 enterprises [2]Calculated on basis of no pre-treatment and discharge directly to UWW system.

[3]Based on discharge of pre-treated wastewater to the UWW system (car repair, ceramic, galvanic, printing, wood processor and metallurgy enterprises usually segregate and pre-treat process water to comply with the standards for discharge of industrial wastewater in Italy).

[4] Cr VI was discharged in the effluent from galvinising shops, but was not detected any other sample or in the influent to the WWTS. Cr VI is rapidly transformed to Cr III on contact with organic matter in sewage and sludge. Therefore the Cr VI input from galvanising shops was calculated as a proportion of the total Cr load to the UWWS (as Cr III). Loadings >5 % of the total input to the UWWS system are highlighted in bold and <LOD=below limit of detection

Urban run-off
Metal inputs to WWTS in urban run-off are highly variable and depend on traffic, surface and roofing materials and age, and environmental factors (Section 2.1.3). The principal sources of PTEs in urban run-off include:

- Wet and dry atmospheric deposition;
- Degradation of roofing materials;
- Construction;
- Road and vehicle related pollution;
- Litter, vegetation and associated human activities;
- Soil erosion.

Urban run-off is potentially a significant source of Cd and Pb, contributing up to 40 % of the total load of these elements entering the WWTS (Table 7.2). The removal of Pb from fuel additives has significantly reduced runoff inputs of this element. Precipitation represents a comparatively small proportion of the total bulk input of metals in urban run-off. Rainfall contributes approximately 10 % of the Cd, Pb and Cu and only about 1 % of the Zn load in run-off. The majority of elemental inputs are derived from dry deposition onto paved surfaces, surface degradation processes as well as from vehicle emissions.

Roads and vehicles have been investigated as potential sources of PTEs entering WWTS. Lead, Cu, Cd and Zn are present in high concentrations in brake linings and amounts of Cd and Zn are also significant in tyre rubber. Tyre abrasion and brake-lining wear appear to be more important as sources of Cd and Zn transfer to runoff water. Whilst these metals may be released during brake-lining wear, the amounts of Pb and Cu entering the drainage system in runoff is relatively small. Run-off is a minor source of Cu entering the UWW compared with the domestic load from plumbing. Nickel is the main element released from the abrasion of road surfaces. Roofing materials influence concentrations in runoff and Zn is significantly increased by galvanised surfaces. Lead in window frames and roof sheeting and also Pb painted surfaces can contribute significant amounts of this element to runoff water. Interestingly, the concentrations of Cd, Cu, Pb and Zn in roof runoff may be comparable to, or greater than, those in road run-off suggesting that atmospheric deposition onto paved surfaces may be more important as a source of metals in run-off than vehicle or road related inputs. Concrete structural materials transfer negligible amounts of potentially toxic elements to run-off. The relative size of the inputs of different potentially toxic elements to UWW in run-off can be ranked in increasing order as: Cd<<Ni<Cu<Pb<<Zn. Although there is more Zn in urban run-off than any other metal, this represents a relatively minor input to the WWTS (<20 %) compared with domestic (50 %) and commercial (<35 %) discharges of Zn to sewer (Table 7.2).

The available mass balance information suggests that the overall contribution of urban run-off to the metal flux in UWW is generally comparatively small, and intermittent depending on rainfall, relative to other sources (Table 7.2). However, the variable nature and uncertainty about the extent of these inputs could partly explain the apparent discrepancy between the identified sources of PTEs and the actual load entering the WWTS. The significance of potentially toxic elements in urban run-off could be quantitatively examined by relating rainfall frequency, duration and intensity with temporal trends in the metal content of sewage sludge sampled from WWTS serving different catchments types (industrial, domestic, mixed). There are a number of possible measures that can potentially reduce contaminant entry into UWW from run-off. For industrial and other paved areas, for example, where it is practicable, interception systems to remove contaminants bound to suspended solids by sedimentation or filtration can reduce inputs to the WWTS. However, these are only moderately effective because the smallest particles containing the largest concentrations of metals do not settle efficiently. The design and management of these systems are described in Case Study (b). In general, however, it is difficult to practically control or minimise run-off contamination due to the diffuse nature of the sources of metals, although targeting Pb painted surfaces for source preventive action would further curtail inputs of this element into the environment.

Metal transfers to sewage sludge during WWT

The majority of the polluting load in UWW, including potentially toxic elements, is transferred to the sewage sludge during WWT and a relatively small soluble or suspended fraction may be discharged to the environment in the treated effluent.

Empirical and mechanistic models of metal transfer (TOXCHEM) have been developed. Both modelling approaches can be used to predict the metal concentration in wastewater on the basis of the content in sludge. Metal removal during primary sedimentation is a physico-chemical process, dependent on the settlement of precipitated, insoluble metal or the association of metals with settleable particulate matter. The removal of metals during secondary wastewater treatment is dependent upon the uptake of metals by the microbial biomass and the separation of the biomass during secondary sedimentation. Approximately 60 – 80 % of most elements in raw sewage are removed and transferred to the sludge. Nickel is the most soluble element and removals of 40 % are more typical for this element. The arithmetic mean metal concentrations in sewage sludge in European countries are listed in Table 7.5.

Mass balance of metals in the WWTS must take into account metal contents and their fates in sewage sludge. Detailed environmental, toxicological and ecotoxicological assessments of metals provide assurance that the concentrations of Cd, Cu, Ni, Cr, Hg and Pb in sewage sludge are well below values that constitute a potential risk to soils and the environment when sludge is applied to agricultural land. Zinc, on the other hand, presents the principal potential risk to crop yields from phytotoxicity to affecting soil microbial processes. However, it is also an important trace element and the environment can be protected from the potentially toxic effects of Zn in sludge by technically based, but precautionary soil limits.

Table 7.5 Arithmetic mean metal content in sludge and maximum permissible limits in soil and sludge (mg kg^{-1}ds) in the EU[(1)]

Element	Mean	86/278/EEC maximum in sludge (range)	Proposed EU maximum in sludge	86/278/EEC maximum in soil (range)	Proposed EU maximum in soil (pH 6-7)
Zn	863[(2)]	2500-4000	2500	150-300	150
Cu	337	1000-1750	1000	50-140	50
Ni	37	300-400	300	30-75	50
Cd	2.2[(3)]	20-40	10	1-3	1
Pb	124	750-1200	750	50-300	70
Cr	79[(4)]		1000		60
Hg	2.2	16-25	10	1-1.5	0.5

[(1)]Data are reported for 13 countries: Austria, Denmark, Finland, France, Germany, Greece (Athens), Ireland, Luxembourg, Norway, Poland, Sweden, The Netherlands and UK.
[(2)]Excludes Poland and Greece (represented by Athens WWTS); the mean Zn content in Polish sludge and sludge from Athens WWTP is 3641 and 2752 mg kg^{-1} ds, respectively. The mean European value including Poland and Greece is 1222 mg Zn kg^{-1}.

(3)Excludes Poland; the mean Cd content in Polish sludge is 9.9 mg kg^{-1} value. The mean European value including Poland is 2.8 mg Cd kg^{-1} ds.
(4)Excludes Greece; the mean Cr content in sludge from Athens WWT**P** is 886 mg kg^{-1}. The mean European value including Greece is 141 mg Cr kg^{-1}.

Variations in metal concentrations in sewage sludges observed between different countries are difficult to reconcile because all European governments, local environmental agencies, water utilities and municipal authorities actively enforce trade effluent control. Metal concentration data are most widely reported for sludge that is used in agriculture and lower values may be apparent where national regulations enforce stringent metal limits for sludge, although this approach tends to diminish the opportunities for utilising sludge on agricultural land. These data are therefore specific to particular sludge sources and do not provide an overall assessment of sludge contamination with potentially toxic elements disposed of by alternative routes such as incineration. However, certain countries report lower metal contents in sludge than in other states, even when sludge limit values do not appear to be generally restrictive of sludge recycling to land.

A possible explanation may be related to the statistical characteristics of metal concentrations and whether data are reported as arithmetic or weighted averages. The data are usually skewed and the median values are usually lower than the means. This would give rise to large discrepancies in amalgamated data from different member states. Variations could also be related to the efficiency of different analytical methods at extracting metals from the sludge matrix. The size of WWTP may also be important since sludges from large works contain more metals than from smaller works. This could be interpreted as the result of higher industrial inputs of metals to large works, although it may also be explained by the greater interception of atmospheric deposition of metals by paved areas in urban centres served by the largest sewage treatment works. A more detailed assessment and examination of the sludge qualities and quantities from different types of treatment centre in relation to disposal outlet in European Member States is necessary, and a consistent statistical format should be developed, for the comparative analysis of concentration data from different countries.

Enhancing metal partitioning between treated wastewater and sewage sludge
The chemical treatment of wastewater to remove phosphorus is increasingly practiced to control P discharges in the treated effluent as a measure to reduce eutrophication of sensitive water courses. Chemical precipitation with Al or Fe salts can also enhance the efficiency of metal removal and transfer to the sewage sludge, thus potentially increasing the metal content of the sludge (Case Study (i)). For example, Cu and Zn removal from UWW can be raised by 50 % compared to conventional sedimentation without chemical enhancement; Pb removal may increase by 80 % and a 3-fold increase in Cr (III) removal by chemical precipitation has been reported. However, potentially the most important effect of chemical precipitants on metal concentrations in sewage sludge is associated with the actual quality and metal content of commercially available precipitant formulations themselves. For example, Fe-based precipitants marketed for use in wastewater treatment can be industrial by-products from titanium oxide production and may contain significant amounts of potentially toxic elements.

Theoretical calculations (Case Study (i)) suggest that typical dosing rates of $FeSO_4$ salt may increase the Cd content of sludge by 4.5 mg kg^{-1}. The Ni concentration in sludge may increase by 130 % compared with national weighted average values and Zn and Pb contents may be typically raised by 10 %. Indeed, the use of low-grade precipitants could erode the significant progress that has been achieved in reducing metal emissions to sewer through controlling trade effluent discharge. In response to these concerns, certain European countries (e.g. Germany) have introduced controls on the composition of Fe and Al-based coagulants used for UWW treatment and potable water grade Fe salts are recommended to avoid potential problems associated with potentially toxic elements. However, relatively pure sources of Fe and Al salts can be recovered from other types of waste, such as acid mine drainage, and are also effective P precipitants. The use of secondary resources for P precipitation during UWW treatment is intuitively attractive and also alleviates other potential environmental problems associated with the disposal of those wastes. However, the metal content of waste-derived products should be established, and the potential consequences of their use on sludge quality determined, before a particular product is accepted for use as a chemical precipitant in UWW treatment.

Significance of Platinum Group Metals in UWW

The platinum group metals (PGMs) are a group of rare elements including platinum (Pt), palladium (Pd), rhodium (Rh), ruthenium (Ru), iridium (Ir) and osmium (Os) and the current status of the sources and knowledge of the fate and environmental consequences of PGMs are described in Case Study (a). The commercial use of Pt and Pd in particular has expanded significantly in recent years in the manufacture of catalytic converters to reduce atmospheric emissions of carbon monoxide, hydrocarbons and nitrous oxide from internal combustion engines. The discharge of Pt from excreted anti-neoplastic drugs used in the treatment of cancers is another identified source entering the WWTS. However, reliable quantitative estimates of major Pt and Pd sources are available and show that hospitals contribute a relatively minor input, equivalent to 6 – 12 % of Pt discharged to sewer, compared with vehicle exhaust catalysts. Glass, electronics and jewelery manufacturing are other potential sources of PGMs and can represent important local inputs of these elements entering particular WWTS. The rate of removal of PGMs from UWW by sewage treatment processes is generally within the range of most other potentially toxic element species and approximately 70 % of the Pt in wastewater is transferred to the sewage sludge. Reported concentrations of Pt in sludge from 2 WWTP in Munich were in the range 86 – 266 μg kg^{-1} ds.

Platinum group metals emitted as autocatalyst particles behave inertly and have limited mobility in soil so there would appear to be negligible risk to health, groundwater and the environment. However, it is possible for transformations to soluble, bioactive forms to occur and as the commercial use of PGMs continues to rise, there is a case for a limited investigation of their environmental significance. These studies should focus on the factors controlling the solubility and bioavailability of PGMs and on the behaviour of PGMs in surface waters receiving treated sewage effluents. Information is also needed on the uptake of PGMs by crops from the agricultural use of sludge and direct deposition onto urban garden soils to quantify the potential transfer by multiple exposure routes to the human foodchain.

7.1.3 Organic compounds

General

Compared with the small number of PTEs of concern in wastewater and sludge which are routinely monitored and controlled, the range of organic contaminants present in these media, with the potential to exert a health or environmental hazard, are significantly more diverse. For example, approximately 140 organic compounds have been identified in UWW in Sweden and more than 330 organic substances have been determined in German sewage sludge. Forty two organic compounds are regularly detected in sludge.

Persistent organic contaminants
Source and emission controls on persistent organic contaminants were introduced between 1980-90 to curb the extent of environmental releases as concern increased about the extent of their occurrence and potential toxicity. This legislation has been relatively effective and there are several reliable examples in the literature illustrating significant reductions in the primary sources of PAHs, PCBs and PCDD/Fs and this has lowered inputs to the UWW system and reduced concentrations in sewage sludge (Table 7.6). For example, discharges of PCBs to UWW declined by >99 % in the Rhine region of France between 1985 to 1996 due to stricter industrial source control and PAHs were also reduced by >90 % over the same time period. The principal inputs of these contaminants to UWW are from atmospheric deposition onto paved surfaces and run-off.

Controls on combustion and incineration emissions and the production of certain potentially contaminated chlorinated pesticides have also markedly reduced the release of PCDD/Fs to the environment. A review of PCDD emissions in Austria in 1998 show small consumers including household, trade and administration activities are the principal sources of release contributing almost 60 % of the total contemporary load to the environment (Figure 7.2). In the UK, incineration of municipal waste is the largest emitter of PCDD/Fs representing about 40 % of total emissions to the environment. The emission controls have had a positive effect on the quality of sewage and PCDD/F concentrations have declined significantly. For example, the average PCDD/F concentration in sludge sampled from Spanish WWTS declined from an average value of 620 ng kg^{-1} TEQ reported for the period 1979 – 1987 to 55 ng kg^{-1} TEQ in 1999. In the case of sludge from a major London WWTS (Figure 7.3), PCDD/F concentrations decreased by >97 % in the past 40 years from 166 ng kg^{-1} TEQ in 1960 to 4.2 ng kg^{-1} TEQ in 1998. Typical PCDD/F concentrations reported in sewage sludge are significantly below the highly precautionary standard for agricultural utilisation (100 ng kg^{-1} TEQ) proposed by the EU (Table 7.6). Indeed the numerical limit is unlikely to restrict land application yet the cost of PCDD/F analysis is high and routine monitoring of sludge for its PCDD/F content is impractical. The implementation of quality standards for PCDD/Fs in sewage sludge should be reviewed in terms of environmental effects, analysis frequency and cost.

Historic pollution levels are important for organic pollutants as well as potentially toxic elements. For example PCBs, which are no longer used, largely result from volatilisation from soil and are found in similar concentrations in all the WWTS. This suggests either that sources are diffuse and spread evenly or that this is due to general background concentrations. Soil is an effective scavenger and sorptive medium for organic pollutants and acts as a long-term and major repository, although biodegradation also takes place. Contemporary remobilisation by volatilisation from soil and redeposition onto surfaces and consequential collection by UWW systems is a major source of these compounds entering sewage sludge.

Controls on the use and emissions of persistent organic contaminants have significantly reduced industrial inputs of these substances to sewer. Therefore, the concentrations present in sludge principally reflect:

- Background inputs to the sewer from normal dietary sources ;
- Background inputs by atmospheric deposition due to contemporary remobilisation/volatilisation from soil and cycling in the environment (eg PCBs, PCDD/Fs and PAHs);
- Atmospheric deposition from waste incineration (eg PCDD/Fs);

- Atmospheric deposition from domestic combustion of coal;
- The extent of biodegradation of organic contaminants during sludge treatment, which is limited for most of these compound types;
- The extent of volatile solids destruction during sludge treatment, which increases the concentration of conservative persistent organic compounds in sludge.

Polycyclic aromatic hydrocarbons are proposed as priority hazardous substances (COM(2001) 17 final) within the European Water Framework Directive and the aim will be to achieve cessation of emissions, discharges and losses of these compounds by 2020. However, curbing the emissions of PAHs and PCDD/Fs from domestic coal burning would be technically difficult and incinerators are already subject to stringent air quality emission standards. Consequently, there is probably little opportunity to further reduce the inputs and concentrations of PAHs, PCDD/Fs as well as PCBs in UWW and sewage sludge. Furthermore, the compounds are effectively removed by wastewater treatment processes because they strongly bind to the sludge solids minimising the discharge in treated effluent. The increasing amount of scientific investigation also shows there are no significant environmental consequences from PAHs, PCBs or PCDD/Fs when sludge is used on farmland as a fertiliser. In the light of such developments and their physico-chemical behaviour, it may be argued that the importance of these substances as major pollutants of UWW and sludge has been significantly diminished. Soil is a major repository for persistent organic contaminants and further investigations are necessary to improve understanding of the remobilisation and cycling processes in the environment that control diffuse inputs of these organic compounds to UWW.

Table 7.6 Concentrations and proposed limit values of selected organic contaminants in sewage sludge (mg kg^{-1} ds)

Organic compounds	Mean content mg kg^{-1} ds	Proposed EU maximum in sludge mg kg^{-1} ds
Halogenated organics (AOX)	200[(1)]	500
Linear alkylbenzene sulphonates (LAS)	6500	2600
Di(2-ethylhexyl)phthalate (DEHP)	20 – 60	100
Nonylphenol and ethoxylates (NPE)	26 (UK: 330 – 640)	50
Total polycyclic aromatic hydrocarbons (PAH)	0.5 – 27.8	6
Total polychlorinated biphenyls (PCB)	0.09	0.8
Polychlorinated dibenzo-dioxins and –furans (PCDD/Fs)	36[(2)]	100[(2)]

[(1)]German sludge only [(2)]Units ng kg^{-1} TEQ

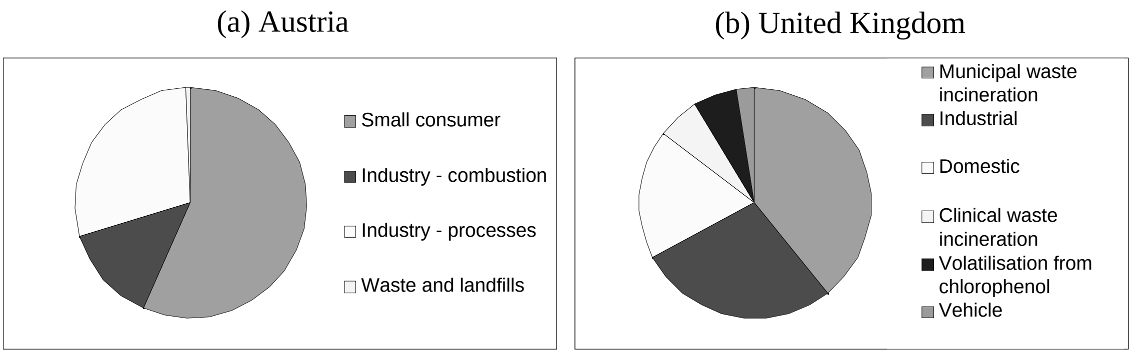

Figure 7.2 Sources of dioxin emissions (% of total emitted) in (a) Austria in 1998 and (b) UK in 1991

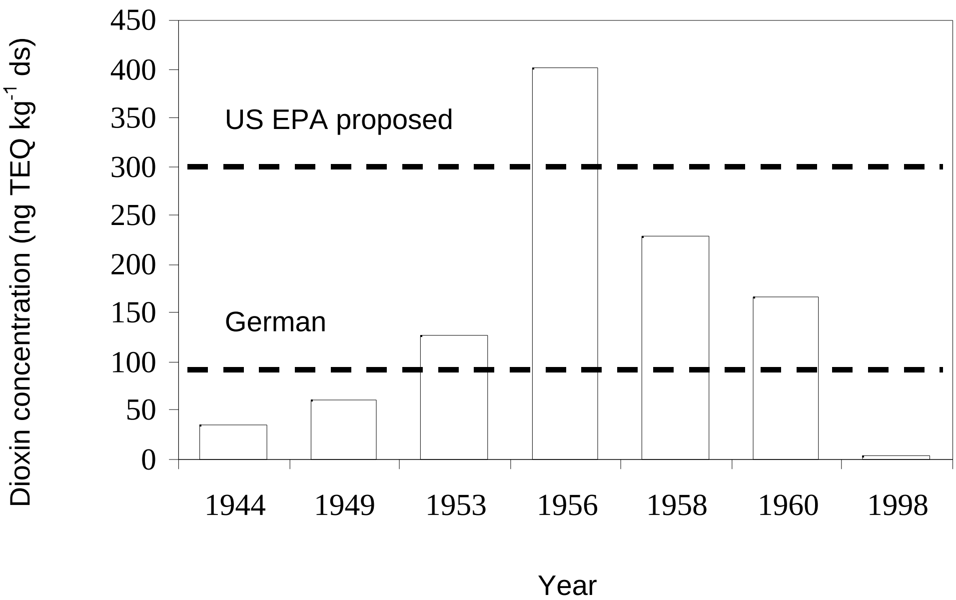

Figure 7.3 Dioxin content of archived samples of sewage sludge from a WWTS in West London, UK

Other organic contaminants

Emissions of other organic contaminants and entry to the WWTS are associated with direct or indirect discharges resulting from their use in commercial and domestic activities. For example, the principal emissions of DEHP occur from the use of finished products and major domestic inputs to UWW are floor and wall coverings and textiles with PVC prints. In Sweden, for example the domestic contribution was equivalent to approximately 70 % of the total load of phthalates to Gothenburg WWTS. Numerically, detergent surfactants and residues (LAS and NPE) are the most significant contaminants in sewage sludge and the LAS content is typically more than twice the proposed European limit for this pollutant in sludge (Table 7.6). Unless action is taken to reduce the use of the surfactant LAS in detergent formulations, the proposed standard will prevent use of sludge on agricultural land. The UK also appears to have a particular problem with NP and NPEs as concentrations of these compounds in UK sludge are an order of magnitude larger than those reported in average sludges in other European countries Non-

Governmental organisations in Sweden and Denmark have been successful in independently introducing eco-labelling schemes persuading consumers against detergents containing LAS or NPE.

Linear alkylbenzene sulphonate and NPE can be substituted in detergent formulations and alternatives may also need to be sought for DEHP in plastics manufacture if emissions of this substance to water are to be controlled. Nonylphenol is a proposed priority hazardous substance within the Water Framework Directive and the use of NPEs in detergents is therefore likely to end with the implementation of European legislation to phase out discharges, losses and emissions of alkylphenolic compounds to the aquatic environment. A comprehensive independent review, also involving the detergent and plastics manufacturers, regarding the fate, behaviour, degradability, toxicity and environmental consequences of these and the alternatives compounds would provide information on the advantages and disadvantages of product substitution in detergent formulations and plastics manufacture.

A group of emerging compounds of potential significance in UWW were identified by the review due to their persistence during sewage or sludge treatment, persistence in soil or toxicity in the environment:

1. Little is known about the fate and behaviour in UWW of the large number (>200) of **commercial chlorinated paraffin** formulations in use as plasticisers in PVC and other plastics, extreme pressure additives, flame retardants, sealants and paints.

2. The **brominated diphenyl ethers** (PBDEs) are a group of compounds used for flame retardation in furnishings, textiles and electrical insulation and their use has expanded due to fire regulation requirements and the increased use of plastic material and synthetic fibres. A survey in Sweden indicated concentrations of PBDE congeners in sludge were between 15 and 19 μg kg^{-1}, respectively. PBDEs are on the list of proposed priority hazardous substances.

3. **Polychlorinated naphthalenes** (PCNs) are released into the environment by waste incineration and landfill disposal of items containing PCNs. Concentrations in sewage sludge may be in a similar range to individual PCB congeners. A survey of Swedish sludges indicated that PCN concentrations were in the range 1.6 mg kg^{-1} ds. Some PCN congeners have dioxin like activity and have been assigned TCDD toxic equivalent values similar to those for coplanar PCBs and so have toxicological interest.

4. A small amount of **Quintozene (pentachloronitrobenzene)** is produced in the EU (21.5 t y^{-1}) and it is registered for use in the UK, Spain, Greece and Cyprus. It has low water solubility and half-lives in soil are reported to be in the range 5 – 10 months.

5. **Polydimethylsiloxanes** (PDMS) are nonvolatile silicone polymers used in industrial and consumer products including lubricants, electrical insulators and antifoams. They are hydrophobic and partition onto the sludge solids and concentrations in N American sludge reported to be in the range 290 – 5155 mg kg^{-1}. However, PDMS do not bioconcentrate or exhibit significant environmental toxicity, but they are relatively persistent in soil and can take months to years to degrade.

6. **Nitro musks** (chloronitrobenzenes) are a group of synthetic dinitro- trinitro-substituted benzene derivatives used as substitutes for natural musk in perfumed products (Case Study (e)). In Europe, current consumption is estimated to be 124 t y^{-}

[1] for musk ketone and 75 t y^{-1} for musk xylene and the release of these compounds to the environment is dominated by domestic discharges to WWTS.

Further studies on the biodegradation and transformations of these compounds during secondary wastewater and sludge treatment are required as a preliminary stage in understanding whether the release of musk compounds to the environment is significant from WWT.

7. **Endogenous oestrogens** (17b-oestradiol and oestrone) and synthetic steroids such as ethinyloestradiol, which is the active oestrogenic component in oral contraceptives, are discharged in trace amounts in the effluent from WWTS and are primarily a concern due to the possible impact on the aquatic ecosystem. These compounds also partition onto particulates and may be associated with sewage sludge, but this is unlikely to have significant environmental implications for use of sludge in agriculture. Recent investigations show that approximately 90 % of potential oestrogenic activity (based on 17b-oestradiol equivalency) in UWW is reduced by sewage treatment and that <3 % may be transferred to the sewage sludge.

8. **Pharmaceutical compounds**, designed for specific biological effects in medical and veterinary practice, can enter the wastewater system by excretion or residues and metabolites in urine and from intentional disposal (Case Study (d)). Disposal into the UWW system is common practice, although the rationale for justifying this on the grounds of the dilution received within the sewer system should be reviewed in context of subsequent environmental fate and behaviour of individual compounds. Significant amounts of administered drugs are excreted from the body and 30 – 90 % of antibiotic doses to humans and animals enter UWW in active forms in the urine. The potential toxicological and ecotoxicological activities of these substances in the wider environment are generally unknown, but, because of their biological function, they are generally designed to be rapidly metabolised and degraded, although they are often lipophilic and potentially bioaccumulate. Removal efficiencies during WWT of >60 % are typical for most types of drug, although a wide range of removal rates is reported (7 – 96 %) and drug compounds are routinely found in treated effluents and surface waters. Many commonly used analgesic drugs are rapidly biodegraded during sewage treatment including aspirin, ibuprofen and paracetamol. Most of these are soluble and exist primarily in the aqueous phase and transfer to sewage sludge is probably of only minor concern, although it is not possible to predict partitioning and fate during sewage treatment due to the absence of physico-chemical data for many of the compounds. The occurrence of drugs in soil is widespread from veterinary administration to livestock. A risk assessment on the fate and biodegradation of drug compounds could form an integrated part of the approval procedure for pharmaceutical products. This would improve understanding of their behaviour and fate to balance the benefits to health with the potential consequences of their release into the environment. Collection systems for unwanted drugs should be encouraged to reduce disposal into the wastewater system.

Polyelectrolytes and sludge treatment

Polyelectrolytes based on polyacrylamide and cationic copolymers are used extensively in sludge treatment to aid dewatering, see Case Study (g). The polyelectrolyte concentration in mechanically dewatered cakes is relatively large typically in the range 2500 – 5000 mg kg^{-1} ds and they only degrade relatively slowly by abiotic processes in cultivated soil at a rate of 10 % per year. Acrylamide is a common monomer associated with polyelectrolytes and is potentially toxic to humans and is a reported carcinogen. Concern that residual monomers in polyelectrolytes used in drinking water treatment may have implications for human health has resulted in their withdrawal from this application in Japan and Sweden, and stringent controls on their use are also in place in Germany and France. These factors have drawn attention to the possible environmental implications of sludge dewatering practices with polyelectrolytes and long-term accumulation in sludge-treated soil.

Attenuation and transformations during wastewater and sludge treatment
Sewage sludge is treated to reduce its fermentability, nuisance and vector attraction and to aid its management and acceptability for use on agricultural land. These processes include physical, chemical and microbiological treatment of the sludge that may influence the loss, or potential formation, of organic contaminants (Section 3.2). Loss mechanisms include:

- Volatilisation;
- Biological degradation;
- Abiotic/chemical degradation (e.g. hydrolysis);
- Extraction with excess liquors;
- Sorption onto solid surfaces and association with fats and oils.

The sorption of organic contaminants onto the sludge solids is determined by physico-chemical processes and can be predicted for individual compounds by the octanol-water partition coefficient (K_{ow}). During primary sedimentation, hydrophobic contaminants may partition onto settled primary sludge solids and compounds can be grouped according to their sorption behaviour based on the Kow value as follows:

Log K_{ow} < 2.5	low sorption potential
Log K_{ow} > 2.5 and < 4.0	medium sorption potential
Log K_{ow} > 4.0	high sorption potential

Many sludge organics are lipophilic compounds that adsorb to the sludge matrix and this mechanism limits the potential losses in the aqueous phase in the final effluent. A proportion of the volatile organics in raw sludge, including benzene, toluene and the dichlorobenzenes, may be lost by volatilisation during wastewater and sludge treatment at thickening, particularly if the sludge is aerated or agitated, and by dewatering. As a general guide, compounds with a Henry's Law constant $>10^{-3}$ atm (mol^{-1} m^{-9}) can be removed by volatilisation. The significance of volatilisation losses of specific organic compounds during sewage treatment can be predicted based on Henry's constant (Hc) and K_{ow}:

$Hc > 1 \times 10^{-4}$ and $Hc/K_{ow} > 1 \times 10^{-9}$ high volatilisation potential
$Hc < 1 \times 10^{-4}$ and $Hc/K_{ow} < 1 \times 10^{-9}$ low volatilisation potential

Biodegradation may be more important than air-stripping in removing volatile organic contaminants during secondary biological WWT.

Mesophilic anaerobic digestion is the principal sludge stabilisation process adopted in most European countries and many organic contaminants are biodegraded under anaerobic conditions and this is enhanced by increasing retention time and digestion temperature. Biodegradation during anaerobic digestion may eliminate certain organic contaminants from sewage sludge, but in general the destruction achieved is typically in the range of 15 – 35 %. Aromatic surfactants including LAS and 4-nonylphenol polyethoxylate (NP_nEO) are not fully degraded during sewage treatment and there is significant accumulation in digested sludge. For example, mass balance calculations suggest that approximately 80 % of LAS is biodegraded during the activated sludge process and 15-20 % is transferred to the raw sludge, although near complete biodegradation (97-99 %) is also reported in some cases. Approximately 20

% of LAS in raw sludge may be destroyed by mesophilic anaerobic digestion. The compounds, nonylphenol monoethoxylate (NP_1EO) and nonylphenol diethoxylate (NP_2EO) are formed during sewage treatment from the microbial degradation of NPnEO. These metabolites are relatively lipophilic and accumulate in sludge and are also discharged in the treated effluent from WWT. Approximately 50 % of the NPnEO in raw sewage is transformed to NP by sludge digestion.

Lower molecular weight phthalate esters and butyl benzyl phthalate are completely degraded in 7 days by anaerobic digestion at 35°C and should be removed by most municipal anaerobic digesters. The extent and rate of biodegradation of organic compounds during anaerobic digestion is apparently related to the size of alkyl side chains and compounds with larger C-8 groups are much more resistant to microbial attack. Therefore, di-n-octyl and DEHP are more persistent and are not removed by conventional anaerobic treatment of sludge. Phthalate esters are rapidly destroyed under aerobic conditions, however, and biological WWT (eg activated sludge process) can usually achieve >90% removal in 24 h. In soil, the reported half-life of DEHP is <50 d.

Composting is a thermophilic aerobic stabilisation process and has the potential to biodegrade relatively persistent organic compounds in sludge. Thermophilic aerobic digestion processes and sludge storage for three months can achieve similar overall removal rates for organic contaminants as those obtained with mesophilic anaerobic digestion. Thermal hydrolysis conditioning of sludge prior to conventional anaerobic stabilisation may have a significant influence on the removal of organic contaminants from sludge, but this is a comparatively new enhanced treatment process and effects on the destruction of organic contaminants have yet to be investigated.

Table 7.7 Assessment of the significance of PTEs entering UWW and SS

PTE	Trade effluent control (Yes, Y; No, N)	[1]Priority hazardous substance (Yes, Y; No, N)	[2]Environmental significance in sludge-treated soil (short –term) (Yes, Y; No, N)	[3]Significance of input sources (L, Low; Moderate, M; High, H)					
				[4]Commercial		Run-off		Domestic	
				Relative importance	Opportunity to reduce	Relative importance	[5]Opportunity to reduce	Relative importance	[6]Opportunity to reduce
Zn	Y	N	N*	M	M	L - M	L	H	M
Cu	Y	N	N	L - M	M	L	L	H	L
Ni	Y	N	N	M	M	L – M	L	M	L
Cd	Y	[7]Y	N	M - H	M	L – M	L	[8]M	L
Pb	Y	(Y)	N	L – M	M	M	L	H	L - M
Cr	Y	N	N	M - H	M	L – M	L	L	L
Hg	Y	Y	N	H	H	L	L	L	L
Pt	N	N	N	M	L	H	L	L	L
Pd	N	N	N	M	L	H	L	L	L

[1]Proposed priority hazardous substance in COM(2001) 17 final: Amended proposal for a Decision of the European Parliament and of the Council establishing the list of priority substances in the field of water policy. Lead is in parentheses as a proposed priority substance under review.
[2]Reported environmental effects at current maximum permissible limit concentrations in sludge-treated agricultural soil (86/278/EEC) for Zn, Cu, Ni, Cd, Pb, Hg; There are no reported environmental effects of Cr, Pt or Pd in sludge-treated soil. *Long-term potential for Zn, to soil microbial community at maximum limit.
[3]Relative to total identified inputs according to the following approximate ranges: L = <10 %, M = 10 – 50 %; H > 50 %.
[4]Medical activities, manufacturing industries and small artisanal enterprises including: car repair, galvanising, metal work and goldsmiths are identified as sources of metals discharging to sewer, where further reductions may be achieved.
[5]Run-off is difficult to mitigate in practice; sedimentation ponds capturing run-off from paved areas of known deposition risk (eg industrial sites) can reduce pollutant inputs bound to suspended solids.
[6]Mainly voluntarily through product ecolabelling and education concerning appropriate use and disposal of liquid wastes, body care products, cleaning agents and detergents by homeowners. A reduction in Pb may be possible in the long-term by replacing historical leaded pipework used for water conveyancing.
[7]Discharges may be indirect as Cd is an impurity associated with P (eg used in detergent formulations) and Zn used in industrial processes and roofing materials.
[8]Human faeces are the main domestic source of Cd representing the background concentration in UWW and sewage sludge.

Table 7.8 Assessment of the significance of organic contaminants entering urban wastewater and sewage sludge

Contaminant	(1)Content in WW/sludge	(2)Priority hazardous substance	(3)Destruction in treatment		Accumulation (Yes, Y; No, N)		Background inputs	(4)Overall significance (Yes, Y; No, N)	
			Wastewater	Sludge	Biological	Soil	(Yes, Y; No, N)	Wastewater	(5)Sludge
LAS	H	N	H	L Anaerobic H Aerobic	N	N	N	H	L
NPE	M - H	Y	M	L Anaerobic H Aerobic	N	N	N	H	L
DEHP	M	(Y)	M	L Anaerobic M Aerobic	N	N	N	H	L
PAHs	L - M	Y	L	L	Y	Y	Y	L	L
PCBs	L	N	L	L	Y	Y	Y	L	L
PCDD/Fs	L	N	L	L	Y	Y	Y	L	L
Pharmaceuticals	L	N	M	M	N	N	N	M	L
Oestrogenic:									
Endogenous	L	N	M - H	M - H	Y	N	Y	H	L
Synthetic	L	N	L - M	L - M	Y	N	N	H	L

(1)Concentration ranges for sludge: L< 1 mg kg-1 ds; M<100; H >100 mg kg^{-1} ds. Concentrations in wastewater are small (mg l-1) and highly variable, but will follow a similar general pattern to sewage sludge; published values are listed in Table 3.14 in the Main Report.
(2)European Commission Amended Proposal for a European Parliament and Council Decision establishing the list of priority substances in the field of water policy (COM(2001)17 final of 16 January 2001).
(3)Approximate indicative ranges: L < 20 %; M = 20 – 60 %; H > 60 %
(4)Significance rating: Low, L; Moderate, M; High, H

LAS	Linear alkylbenzene sulphonates
NPE	Nonylphenolethoxylates
DEHP	Di-(2-ethylhexyl)phthalate
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
PCDDs	Polychlorinated dibenzo-p-dioxins
PCDFs	Polychlorinated dibenzo-p-furans

Table 7.9 Sources and control of organic contaminants entering urban waste water and sewage sludge

Contaminant	Commercial		Run-off		Domestic	
	Relative importance	Opportunity to reduce	Relative importance	Opportunity to reduce	Relative importance	Opportunity to reduce
LAS	H	M	L	L	H	M
NPE	H	M	L	L	H	L
DEHP	H	M	L	L	M	M
PAHs	L	L	H	L	L	L
PCBs	L	L	H	L	L	L
PCDD/Fs	L	L	H	L	L	L
Pharmaceutical	H	M	L	L	H	M

LAS Linear alkylbenzene sulphonates
NPE Nonylphenolethoxylates
DEHP Di-(2-ethylhexyl)phthalate
PAHs Polycyclic aromatic hydrocarbons
PCBs Polychlorinated biphenyls
PCDDs Polychlorinated dibenzo-p-dioxins
PCDFs Polychlorinated dibenzo-p-furans

7.2 COMMENTS, CHALLENGES AND STRATEGIES FOR THE NEXT 5 TO 10 YEARS

The significance of the identified sources of metals entering the UWW system has been reviewed and opportunities for further reducing metal inputs are considered. This may be possible through, for example, controlling discharges from a number of specified commercial sectors and the introduction of remedial measures to reduce inputs from certain domestic and diffuse sources. Therefore, a feasibility study of the most effective approaches to further reducing metal inputs is recommended so that appropriate remedial strategies can be implemented.

The contributions by the three major sources of pollutants to UWW is predicted to change. Commercial sources are expected to become less important as the regulatory control is more widely implemented and tightened, while the percentage contribution from domestic sources is expected to increase. This is important as it is less easy to regulate domestic discharges to UWW. However this can be achieved to some extent by controlling the products used in homes; for example cadmium emissions from households could be reduced by a ban on the use of phosphates in washing powders. Increasing consumer awareness of pollution in UWW, for example through eco labelling schemes, can lead to reductions in load to UWW from some sources such as the domestic use of LAS, however this requires much wider adoption by manufacturers of eco labelling schemes. Industry and stakeholder involvement need to be encouraged. Mechanisms to provide an incentive for reductions in pollution and alternative product development should be developed.

There is probably little scope for further reductions in the inputs and concentrations of persistent organic contaminant types in sewage sludge. For example, it is unlikely that much can be done to curb emissions of PAHs and PCDD/Fs from domestic coal burning, where this is widely practiced, and incinerators are already subjected to stringent air quality emission standards. Losses of PCBs from electrical transformers is rapidly declining as these are phased out of use. However, the importance of soil as a repository for persistent organic contaminants is emphasised and the focus of further investigations to minimise inputs to sludge could be directed towards better understanding of the remobilisation and cycling of these substances in the environment.

Due to the variability of existing data on potentially toxic elements and organic pollutants, common methodologies and standards of chemical and statistical analysis are necessary and should be implemented at a European level as soon as feasible.

Feasibility of reuse of treated wastewater for non-household purposes, such as for irrigation of agricultural crops, parkland, and golf courses needs to be considered but must involve assessment of risks to human , environmental and economic strategic issues. Reuse of domestic grey waters in the EU needs to be re-evaluated. Development of common standards are necessary.

Return of unused pharmaceuticals to dispensaries/hospitals needs to be encouraged and made more widespread throughout Europe. Hospitals and medical centres effluents should be monitored closely for discharge to the urban wastewater network. Possible segregation and pre-treatment of hospital, medical centre and laboratory effluents, for the reduction of PGMs, pharmaceuticals and potentially toxic elements is recommended.

Sustainable urban drainage, discussed in detail, Case Study (b), may have great potential in terms of reduction of urban runoff pollution. However it is recommended that each case should be assessed individually, and an incremental approach containing both high tech and low-tech solutions is the most likely development scenario (Butler and Parkinson, 1997).

Financial incentives/grants to encourage and facilitate removal of lead piping from households would reduce lead emissions to UWW and should initially target areas with soft water.

There are some areas where restrictions need to be tailored to specific uses: for example, the urban use of pesticides may need separate guidelines, than those applicable to agriculture. Urban use of pesticides and herbicides in gardens and allotments is often indiscriminate and can result in major uncontrolled inputs to the UWWS.

For mercury, dentists are important sources and improved dental practices may reduce this source, but other sources, such as chloralkali processes, can in some instances emit more. The use of thermo-reactive liquids in thermometers has been introduced in some regions as a replacement for mercury. Mercury recycling schemes have also been a success in many regions and could be extended to other potential pollutants used in domestic and commercial settings.

Adjusting the pH of tap water may be useful in reducing corrosion, for example, from domestic and commercial heating systems, but may be limited by practical and economic factors and it can still be a problem in drinking water in some regions. For example, lead passing into drinking water supplies from old lead piping and then into the sewage system can be controlled by adjusting the pH and hardness of the water supply.

This report benefits from the presentation of several specific case histories, which provide detailed information in support of the above conclusions. Some specific potential problem areas have been reviewed. For example, the differences in cadmium concentrations reported in sewage sludge in the United Kingdom and Germany have been shown to be due to different approaches to data treatment and presentation rather than real variations in composition. (see Section 2.3)

In the WWTS the fate of compounds often differs, for example, Ni is removed less well from treated wastewater than other metals. This means that more Ni will pass out in the effluent from the WWTS and less will be concentrated in the SS. The behaviour of compounds should be borne into consideration when considering acceptable levels in the influent.

It is also important to note that some of the metals in this study, for example zinc and copper, are essential trace elements to plants and animals in low concentrations. It is important that levels in treated UWW and SS are not set so low by regulation that mineral deficiency could arise due to removal of these sources where UWW and SS might have been used, for example, on nutrient deficient land.

Domestic and industrial product formulation can have an important role in determining the nature and amount of pollutants that are likely to enter the WWTS. Risk assessment of domestic products should be based on their input of pollutants to the urban wastewater and the biodegradability of the pollutants. Health and environmental effects should be considered in the risk assessment process. Efforts to remove phosphate in detergents have had a knock on effect in lowering the cadmium input to the WWTS. NPE bans and regional LAS reduction through eco-labelling schemes have also been proven effective. It would also be possible to pre-treat high LAS concentration in UWW from commercial sources, which would then reduce levels reaching the WWTP.

Advice on household refurbishment (e.g. for old lead paint, piping) and advice on disposal of potential pollutants (e.g. down sinks) and eco-labels and public education should be provided and extended where possible to raise awareness of ecological impacts of various processes and products in urban wastewater.

The inclusion of Cu, Zn and LAS on the proposed list of priority substances is recommended because they are the most limiting substances to utilising sludge in agriculture within the limits proposed in the revision of Directive 86/278/EEC and they are ubiquitous in wastewater. Therefore, these substances should also be the focus of measures to reduce discharges and emissions to further improve sludge quality and support the recycling route for sewage sludge.

In order to reduce inputs to UWW, it is important to target the sources contributing most to the system, especially the diffuse sources. Trade effluent discharge controls have been successful in lowering emissions but are still necessary for certain industries. Reductions of many pollutants including lead and dioxins have been seen in sewage sludge since the 1960s. Increasing control on emissions, not only to water but also to air and land, are likely to continue this reduction. This study concludes that small users, hospitals, garages and car washes, dental and medical practices need a close monitoring and control for connection to the urban wastewater systems.

7.3 INFORMATION GAPS AND RESEARCH RECOMMENDATIONS

Relatively few regional surveys of the sources and significance of potentially toxic element (PTE) inputs to UWW (Section 2.1) have been reported and recently published work, in some cases, quote data from considerably earlier studies. There is a general lack of recent, quantitative information regarding the sources and inputs of PTEs to UWW for the EU and this is identified as a priority area for further data gathering.

There are very few studies available on the mass balance of potentially toxic elements and organic pollutants through WWTS. More work is needed to understand the partitioning and speciation of pollutants, particularly for compounds, such as NPE, which may become more toxic through wastewater treatment. Some pollutant sources still need further identification. In fact there are also many instances where the majority of pollutants sources remain unidentified, for example the ADEME study in France estimated that over 50% of some of the metals came from unidentified sources.

Identification and monitoring of trace organics is still sparse and more detailed work, though costly, is urgently required. Better source inventory data is essential. In some cases specific industrial sources are difficult to locate. For example, platinum uses and losses from industry into the wastewater system are subject to the protection of commercial interests.

Information on organic pollutants comes mainly from France, the United Kingdom, Benelux, Scandinavia and Germany but is very limited from the other EU countries. More research is needed for estimates and quantification of diffuse sources of organic pollutants especially in Iberia, Italy and Greece. Some data especially from Iberia is not readily available and an integrated data collection system is needed across the EU 15 for PTEs and organic pollutants.

Information is still needed in order to asses health and environmental effects. UWW effluent and sewage sludge use on land usually involves exposure to very small quantities of mixed pollutants over a prolonged period of time, and there is little health data about chronic exposure, particularly to organic pollutants. A particular area of current concern is the possible impact of cocktail effects where several contaminants are present at the same time. Interactions between metals, organics, and metals and organics may be synergistic or antagonistic, are complex and far from clearly understood.

Another area where knowledge is lacking is that concerning the effects of both potentially toxic elements and trace organics on components of the ecosystem, both in soils and in surface and subsurface waters. The prime effects to be considered are those on sensitive receptors, including micro-organisms, invertebrates and plants. At present there is a lack of base line information in this area. Ecotoxocity tests that are applied are undertaken in laboratory conditions assuming 100% bioavailability of the pollutant, and are not appropriate for field conditions. Research into the transfer of organic pollutants through uptake into pasture plants and into crops and thus into the food chain is limited and should be considered.