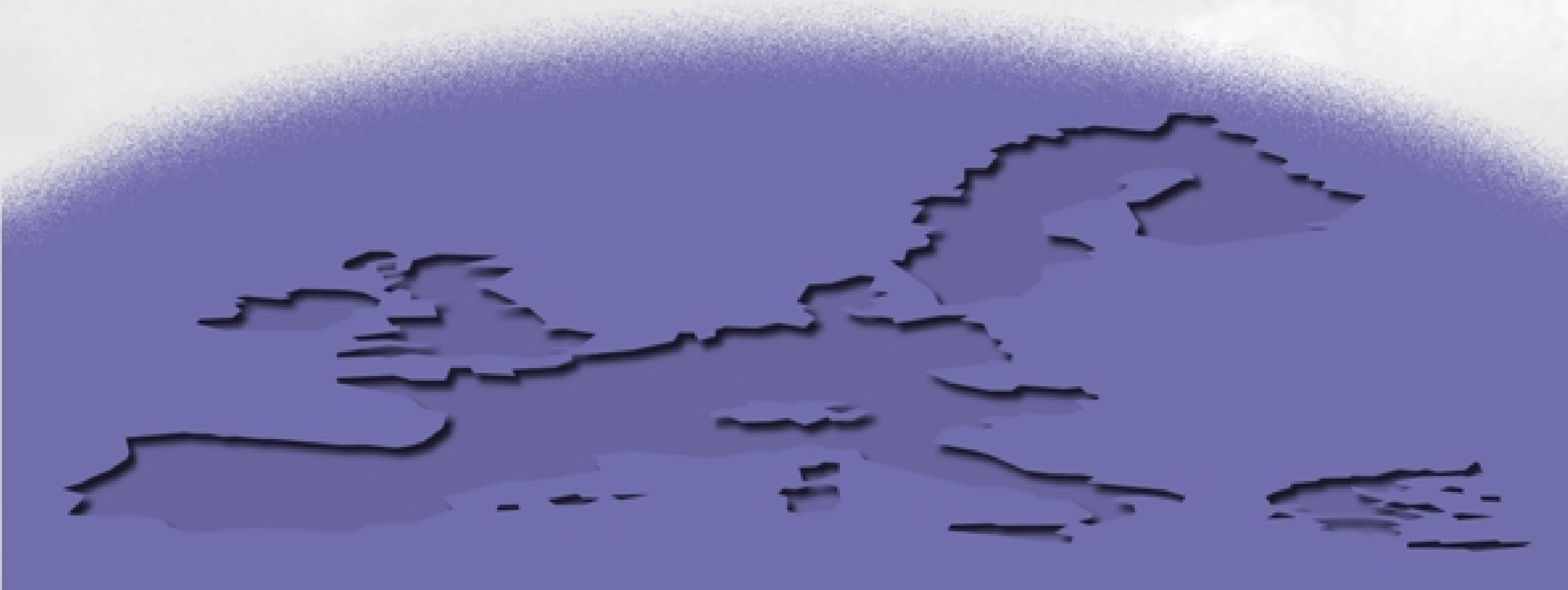
European Commission

Pollutants in urban waste water and sewage sludge



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POLLUTANTS IN URBAN WASTE WATER

AND SEWAGE SLUDGE

Final Report

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EXECUTIVE SUMMARY

Water policy in the European Union is aiming to promote sustainable water use and a major objective of the new Water Framework Directive (2000/60/EC) is the long-term progressive reduction of contaminant discharges to the aquatic environment in urban wastewater (UWW). Sewage sludge is also a product of wastewater treatment and the Urban Waste Water Treatment Directive (91/271/EEC) aims to encourage the use of sludge whenever appropriate. Potentially toxic elements and hydrophobic organic contaminants largely transfer to the sewage sludge during waste water treatment with potential implications for the use of sludge although some may be emitted with the effluent water.

Inputs of metals and organic contaminants to the urban wastewater system (WWTS) occur from three generic sources: domestic, commercial and urban runoff. A review of available literature has quantified the extent and importance of these various sources and the inputs from different sectors. In general, urban runoff is not a major contributor of potentially toxic elements to UWW. Inputs from paved surfaces due to vehicle road abrasion and tyre and brake-lining wear have been identified and losses from Pb painted surfaces and Pb and Zn from roofing materials represent localised sources of these elements.

Platinum and Pd are components of vehicle catalytic converters and emissions occur as the autocatalyst deteriorates. Catalytic converters are the main source of these metals emitted to the environment and releases have increased with the expansion in use of autocatalysts. Platinum group metals (PGMs) potentially enter UWW in runoff and transfer to sewage sludge in a similar way to other potentially toxic elements. The Pt content in sludge is typically in the range 0.1 – 0.3 mg kg^{-1} (ds) and the background value for soil is 1 µg kg^{-1}. PGMs are inactive and immobile in soil.

In contrast to potentially toxic elements, inputs of the main persistent organic pollutants of concern, including: PAHs, PCBs and PCDD/Fs, to UWW are principally from atmospheric deposition onto paved surfaces and runoff. Combustion from traffic and commercial sources accounts for the major PAH release to the environment, although inputs from food preparation sources also represent an important and often under-estimated contribution of certain PAH congeners. PCDD/Fs are released during waste incineration and also by coal combustion. Soil acts as a long-term repository for these contaminant types and remobilisation by volatilisation from soil is an important mechanism responsible for recycling and redistributing them in the environment. For example, the industrial use of PCBs was phased out in Europe during the 1980s-1990s, but 90 % of the contemporary emissions of PCBs are volatilised from soil. Since emission controls are already in place for the main point sources and PAHs, PCDD/Fs or PCBs enter UWW principally from diffuse atmospheric deposition and environmental cycling, there is probably little scope, from source control, to further reduce inputs and concentrations of these persistent organic substances in UWW or sewage sludge.

Being strongly hydrophobic these organic pollutants are efficiently removed during urban wastewater treatment (WWTS) and bind to the sludge solids. However, the increasing body of scientific evidence has not identified a potential harmful impact of these substances on the environment in the context of the urban wastewater system. Therefore, on balance, the importance of these contaminants in UWW and sewage sludge has significantly diminished and there may be little practical or environmental benefit gained from adopting limits or controls for PAHs, PCBs or PCDD/Fs in UWW or sewage sludge. This is emphasised further by the high cost and specialist analytical requirements of quantifying these compounds in sludge and effluent.

Potentially toxic element contamination of urban wastewater and sewage sludge is usually attributed to discharges from major commercial premises. However, significant progress has occurred in eliminating these sources and this is reflected in the significant reductions in potentially toxic element concentration in sewage sludge and surface waters reported in all European countries where temporal data on sludge and water quality have been collected. However, potentially toxic element concentrations remain higher in sludge from large urban wastewater treatment plant (WWTP) compared with small WWTP and they are also greater in sludges from industrial catchments compared with rural locations. These patterns in sludge metal content suggest that commercial sources may still contribute significantly to the total metal load entering UWW. Indeed, recent regional surveys of metal emissions from commercial premises confirm that further reductions in most elements could be achieved from this sector. The primary targets for source control include health establishments, small manufacturing industries (particularly metal and vehicle related activities) and hotel/catering enterprises, as 30 % of medical centres and 20 % of the other types of activity could be discharging significant amounts of potentially toxic elements in UWW. Mercury is a specific case where compulsory use of dental amalgam separators, and substituting Hg with alternative thermoreactive materials in thermometers, may be effective in reducing discharges of this element to the WWTS wastewater treatment system .

Faeces contribute 60 – 70 % of the load of Cd, Zn, Cu and Ni in domestic wastewater and >20 % of the input of these elements in mixed wastewater from domestic and industrial premises. Faecal matter typically contains 250 mg Zn kg^{-1}, 70 mg Cu kg^{-1}, 5 mg Ni kg^{-1}, 2 mg Cd kg^{-1} and 10 mg Pb kg^{-1} (ds). The other principal sources of metals in domestic wastewater are body care products, pharmaceuticals, cleaning products and liquid wastes. Plumbing is the main source of Cu in hard water areas, contributing >50 % of the Cu load and Pb inputs equivalent to 25 % of the total load of this element have been reported in districts with extensive networks of Pb pipework for water conveyance. Adjusting water hardness in order to reduce metal solubilisation from plumbing is technically feasible, but is likely to be impractical at the regional scale necessary to significantly reduce metal concentrations in UWW and sludge and may be unpopular with consumers in hard water areas. The gradual replacement of Pb water pipes can be achieved during building renewal and renovation programmes.

Reductions in domestic discharges of metals may be possible through increased public awareness of appropriate liquid waste disposal practices and the provision of accessible liquid waste disposal facilities. It may be impractical to eliminate the use of metals in body care products when they are an important active ingredient, but advice and labelling could be improved to minimise excessive use. Cadmium may be a contaminant present in phosphatic minerals and removing phosphate from detergent formulations can reduce associated potential discharges of Cd from domestic sources.

Detergent residues (e.g.nonyl phenol, NP), surfactants (e.g. linear alkyl benzene sulphonates, LAS), plasticising agents (e.g. di-(2-ethylhexyl)phthalate, DEHP) and polyacrylamide compounds, added to sludge to aid dewatering, are quantitatively amongst the most abundant organic contaminants present in UWW and/or sewage sludge. Dewatering agents based on polyacrylamide may contain traces of the potentially toxic acrylamide monomer, but this is rapidly degraded and polyacrylamide itself is biologically inactive. Detergent residues and DEHP are primarily of domestic origin and they are effectively degraded during aerobic wastewater treatment and are not considered to represent a potential environmental problem from the discharge of treated effluents to surface waters. Anaerobic digestion is the principal method employed for stabilising sewage sludge, but NP accumulates during anaerobic digestion, DEHP is not removed by this conventional process and, although a significant amount of LAS is biodegraded, residues of this substance remain because of the large concentrations initially present in raw sludge. The inability to degrade detergent residues anaerobically and the large concentrations present in sludge and UWW have prompted ecolabelling initiatives in a number of European countries to influence consumer choice away from detergents containing these surfactants to alternative products. This has been successful when supported by extensive public awareness campaigning. For example, the market share for ecolabelled detergents in Sweden increased to 95 % and the consumption of LAS has decreased to a similar extent. Surfactant residues and plasticisers degrade quickly when added to aerobic soils. The oestrogenic activity of NP is however, a principal concern and measures are proposed to eliminate the discharge of this substance to UWW.

Natural and synthetic oestrogens are degraded in WWT, but trace amounts remain and represent the main source of oestrogenic activity in treated effluents. Further work is necessary to link these substances to oestrogenic responses in aquatic life, but it may be necessary in future to consider the requirement for tertiary treatment processes (e.g. ozonation) to eliminate these substances from treated effluents.

A number of other groups of organic compound are identified as being potentially resistant to wastewater and sewage sludge treatment and the most significant of these are brominated diphenyl ethers (PBDEs) and chlorinated paraffins. Further research is warranted, in particular to assess the persistence and potential environmental significance of these compounds. Synthetic nitro musks are used in perfumed products and traces may be present in UWW and sludge. Little is known about the environmental fate of these compounds, but effects on human health from this route seem unlikely given that the main exposure route is through direct contact.

The degree of removal and biodegradation of pharmaceutical compounds during WWT varies considerably, although many common analgesic drugs rapidly biodegrade. They are soluble and transfer to sludge is only of minor concern. Significant amounts of prescribed drugs are excreted from the body and controlling these inputs from the general population would be impractical. However, the disposal of unused drugs into UWW should be reviewed and alternative methods of disposal should be encouraged. The potential significance of pharmaceuticals in the environment should be assessed in context of the major inputs and presence arising from widespread veterinary administration of drugs to livestock and farm waste disposal to land.

A general recommendation to protect the water and soil environment is that a hazard, biodegradability and fate assessment should be required for all new synthetic chemicals, irrespective of their purpose or end-use, to determine the potential from them to transfer to UWW or sewage sludge and the subsequent implications for the environment. Specified criteria regarding toxicity and biodegradation could be set for compounds that exhibit a propensity to enter the WWTS and restrictions could be enforced regarding production and use if these were not met. These decisions would need to balanced against the potential benefits to health derived from the administration of pharmaceutical drugs.

Strategies aimed at controlling pollutant discharges can only focus on those sources that can be identified and quantified. Published mass balance calculations indicate there is a high degree of uncertainty regarding inputs of potentially toxic elements entering the WWTS. Indeed, unidentified sources may contribute as much as 30 - 60 % of the total metal load entering the WWTS, although more than 80 % of the Cd discharged is from identified inputs. This apparent discrepancy could be related to difficulties in measuring the highly variable inputs of metals in urban runoff and the underestimation of discharges from commercial premises that have not been subjected to trade effluent control.

The European Commission has proposed a list of 32 priority and 11 hazardous substances (COM/2001/17) with the aim of progressively reducing emissions and discharges of these chemicals to the environment. Current developments also suggest that Zn, Cu and LAS may be the most limiting constituents in sludge if the proposed maximum permissible concentrations for these substances in soil (Zn and Cu) and sludge (LAS) are carried through in the revised of Directive 86/278/EEC, but they are not listed as priority substances. Consideration should be given to designating Zn, Cu and LAS as priority substances to minimise their to UWW as far as is practicable and to ensure there is a consistent link and approach to defining the environmental quality standards for sludge with those for sustainable water use and contaminant discharge reduction.

The main identified priorities for future research relating to contaminant sources, fate and behaviour in the WWTS are:

- To reduce the uncertainty in quantifying contaminant discharges to UWW by identifying and surveying specific sources to determine the potential for controlling inputs particularly from small commercial sources and medical establishments;

- To establish the extent and variability of contaminant entry into UWW by catchment investigations in relation to precipitation frequency and changes in sludge quality;

- To critically and independently review the fate, behaviour, degradability, toxicity and environmental consequences of alternative surfactant and plasticing compounds, in collaboration with the related chemical manufacturing industries, to inform decisions of the benefits and disadvantages of product substitution in detergent formulations and plastics manufacture;

- To determine the extent of volatilisation-deposition cycling of persistent organic pollutants in the environment, identifying the processes controlling the extent and magnitude of diffuse inputs of these substances to UWW and to provide long-term predictions of changes in release patterns and the consequences for UWW and sludge;

- To develop a consistent statistical and reporting protocol for national chemical composition data presented in surveys of sewage sludge quality.

1. INTRODUCTION

The primary objective of this study is to determine the sources of pollution in urban wastewater (UWW) treated in wastewater treatment systems (WWTS). This includes the pollutants introduced into the UWW collecting system with run-off rainwater, from domestic and small commercial sources. The pollutant contents in urban wastewater and sewage sludge has been evaluated by review of the existing literature, in order that measures may be proposed to reduce pollution at source.

1.1 Introduction to pollutants in urban wastewater

The pollutants of interest can be divided into two main groups;

- **potentially toxic elements (PTEs)** including cadmium (Cd), chromium (Cr III and Cr VI), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn),

- **organic pollutants** including PAHs, PCBs, DEHP, LAS, NPE, dioxins (PCDD) and furans (PCDF). Over 6,000 organic compounds have been detected in raw water sources most of which are due to human activities. While some of these are highly persistent, others are easily biodegradable in WWTS.

Other pollutants of interest are the metalloids, arsenic and selenium and the metal silver. Platinum group metals (PGMs), and pharmaceuticals are covered in detail in case studies.

The sources of metal pollution in the wastewater system can be classified into three main categories:

- Domestic,
- Light industrial (connected to the WWTS) and commercial,
- Urban runoff (which also encompass lithospheric and atmospheric sources).

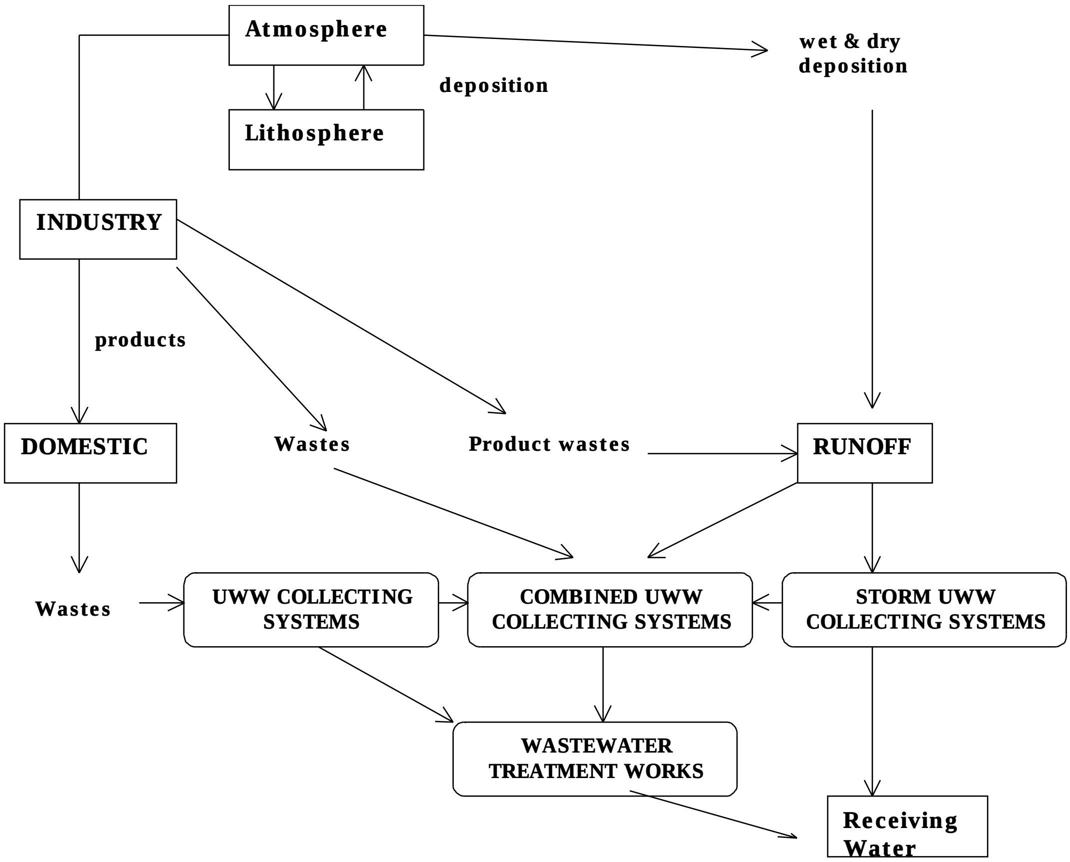

Figure 1.1: Sources of pollutants in wastewater [after Lester, 1987]

A summary of the various inputs, outputs and pathways followed by water and associated contaminants from both natural and anthropogenic sources encountered in urban environments is shown in Figure 1.1. It depicts the drainage area as an open system [Ellis, 1986]. A more detailed urban catchment figure is included in Appendix A.

Wastewater contains many constituents and impurities arising from diffuse and point sources. Large point sources are easily quantifiable and result from specific activities in the area that are connected to UWW collecting systems. The contribution from small point sources, such as households and small businesses, is much more difficult to identify and quantify, compared to point sources which are usually regulated. UWW is also vulnerable to illegal discharges of pollutants.

Diffuse sources, such as atmospheric deposition and road runoff have also been characterised and this study will attempt to present an overview of the available information in this area. Different methods have been used to estimate point sources and diffuse (non-point) sources contributions to the pollution load [Vink, 1999]. Inventories of point and diffuse sources, can link observed water quality trends to changes in socio-economic activities.

The type of pollutants and the magnitude of the outfall loadings are a complex function of:

- size and type of conurbation (commercial, residential, mixed)
- plumbing and heating infrastructure
- atmospheric quality, for example long range transport of pollutants
- factors affecting deposition of pollutants such as precipitation
- activity and intensity surface composition and condition
- urban land use
- traffic type and density
- urban street cleaning
- maintenance practices and stormwater controls
- specific characteristics of storm events
- accidental releases

A review of the sources and pathways of potentially toxic element pollutants in urban wastewater is presented in Section 2.1 and for organic pollutants in Section 3.1

1.2 Objectives and Goals

The main goals of the study were:

- To determine the sources of potentially toxic elements and organic pollutants in domestic, commercial, and urban run-off wastewater, which end up in the UWW collecting system.
- To make a qualitative and quantitative assessment of the pollutants in urban wastewater and runoff rainwater on the basis of the available data in the literature.
- To evaluate the percentage of inorganic and organic pollutants concentrated in sewage sludge and the percentage of pollutants released in the environment with the treated effluents.
- To review wastewater and sewage sludge treatment processes and possible measures to prevent pollution at source. The most important practices to treat wastewater and sewage sludge in Europe will be closely examined.
- Based on an overall assessment of the existing data from various sources, to identify further research directions in those areas with insufficient data.

This report presents a thorough literature review and is primarily based on the analysis and presentation of case studies from a wide variety of sources and test catchments across Europe, covering a time range from 1975 to date. Databases used during this project are listed in the reference section. As theoretical approaches, such as modelling of pollutant sources and predicted concentrations, are scarce the report attempts to summarise the monitoring, sampling and measurement of numerous studies, thus providing a concise overview of pollution source types and concentration ranges. The reader must keep in mind that there are significant differences between the experiments (in duration, location, measurement methods, measurement targets and initial conditions), and thus conclusions on mean or extreme values of pollutants will have to be drawn carefully.