3.3. Dispersion of hazardous substances

Main findings

Europe is one of the largest chemical-producing regions in the world, supplying 38% of global turnover. Since 1993 the chemical intensity of EU GDP has been rising, both for all chemicals and for hazardous chemicals production. There are 20 to 70 thousand substances, or groups of substances, on the European market, many being derived from chlorine-based organic chemistry. Little is known about the toxicities, eco-toxicities or risks from most of these substances.

Figures on the quantities of substances produced or marketed are in general of little use for predicting dispersion and potential exposures which are yet difficult to estimate due to increasing non-point sources of emissions and recycling processes, despite improvements in multi-media modelling.

The European coverage of monitoring data for halogenated organics in general and persistent organic pollutants (POP) in particular is rather patchy. Information on degradations, transformations, by-products and exposures to mixtures is also poor. Most monitoring programs focus on mobile media (air, water), but often neglect soil, sediments and consumer products.

Combustion of fossil and other organic fuels is thought to account for over 90% of the environmental load of the 280 types of carcinogenic polycyclic aromatic hydrocarbons (PAHs).

Emissions of dioxins, such as polychlorinated dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF), which are mainly from air emissions and waste, are significant, but falling in most countries.

During pesticide application, because of losses from volatilisation or washing-out, less than 5% of the pesticide applied can reach its intended target, depending on weather conditions.

Indoor exposures to chemicals such as paradichlorbenzene from mothballs and domestic deodorants, tetrachloroethene from freshly dry-cleaned clothes, or to pesticide residues and dye-stuffs from textiles, can be significant. Exposures to dioxins have been decreasing, but remain significant. Heavy metal exposure has been reduced through improved water treatment and the phasing out of leaded petrol which more than halved emissions of lead in the EU between 1990 and 1996. Little is known about the effects of mixtures at the low concentrations to which most people are exposed. Children may have greater exposure per unit of body weight than adults.

If current trends and policies continue, there could be a growth of 30% to 50% in chemicals output for most of the EU countries by 2010 as a result of increasing economic activity, including road transport and agricultural production. Emissions of certain substances that are not included in the baseline scenario used in this report, such as platinum (used in catalytic converters) and brominated flame-retardants (electronics), are expected to increase.

Cadmium and mercury emissions are expected to increase by 26% and 30% respectively between 1990 and 2010; some countries plan to phase out these substances. Emissions from pesticides and POPs - such as dioxins/furans and PCB will continue to decrease, but PAH, HexaChloroBenzene (HCB), and xylene emissions are likely to increase.

However, the impact of some emerging trends in the management of chemicals such as: eco-efficiency improvements; a shift from products to services; the internalisation of external environmental costs into prices, via taxes etc.; increased information to the public; increased evidence on low-dose effects; greater use of the precautionary principle; and implementation of the OSPAR/Sintra agreement, the Integrated Pollution Prevention and Control Directive, and other international policies could lead to marked reductions in the chemical intensity of European GDP, particularly of those substances of concern.

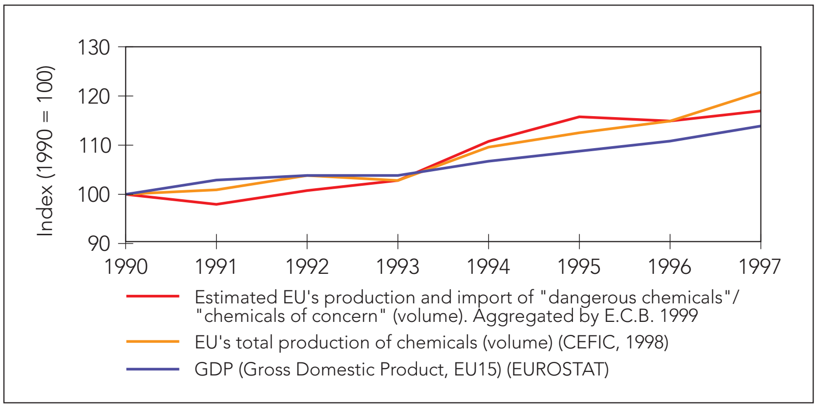
There is an urgent need to fill the considerable gaps in information about chemicals dispersion, fate, concentration and associated exposures to wildlife, eco-systems and humans, particularly for sensitive groups such as infants, children and the elderly.

1. Chemicals in society

1.1. Considerable benefits but environmental data and reaction pathways are scarcely known.

Humans and ecosystems are constantly exposed to a mixture of natural and manufactured chemicals, not all of which are necessarily harmful. The ‘chemicals intensity’ (EEA/UNEP, 1998) and ‘dangerous chemicals intensity’ of the EU economy (production plus imports per unit of GDP; Lindholt, 1999) have been increasing since 1993 (Figure 3.3.1). Supplying 38% of global turnover, with western Europe being responsible for 33%, Europe is one of the largest chemicals-producing region in the world, and the industry is expected to continue its vigorous growth. In line with the decline in their GDP between 1989 and 1995, chemical production in the Accession Countries fell, but has seen a recovery in more recent years. The higher value-added brands of the sector are expected to flourish benefiting from increases both in domestic demand and in exports.

Figure 3.3.1 **EU production and import of ‘dangerous chemicals’/‘chemicals of concern’ and total chemical production**



These chemicals consist of 802 selected High Production Volume Chemicals (HPVC - petrochemicals are not included). The ‘dangerous chemicals’ are all classified by the EU and placed on Annex 1 to the Directive 67/548. The ‘chemicals of concern’, here estimated, are HPVC considered as problematical by some Member States. These indicators can be seen as a first attempt towards developing indicators on ‘dangerous chemicals’/‘chemicals of concern’.

Source: Lindholt, 1999; European Chemicals Bureau

The social and environmental costs of harmful environmental and health impacts are difficult to quantify (Holland *et al.*, 1996) and rarely borne by those responsible for these impacts (see chapter 4.1).

An assessment of dispersion processes is helpful in understanding potential environmental impacts (Box 3.3.1). This chapter specifically addresses dispersion of heavy metals (HMs) and peristent organic pollutants (POPs), while other chemicals of concern, such as volatile organic compounds, are discussed in Chapter 3.4. Exposure scenarios and dispersion routes in the environment, which are heavily dependent on the formulation and use of a chemical, include:

- dispersion during combustion processes, such as fuel conversion or waste incineration: chemicals released include HMs, polycyclic aromatic hydrocarbons (PAHs) and dioxins/furans;
- unintentional release following accidents or by slow leakage: for example, the release of polychlorinated biphenyls (PCBs) from electrical installations;
- intentional dispersion: for example in the case of pesticides and agro-chemicals.

Many other chemicals have rather low emission values during their intended use, but are dispersed once they enter the waste stream; examples are cadmium and chlorinated paraffins used as additives in polyvinylchloride (PVC) consumer products.

Human and ecosystem exposure depends upon the dispersion pattern of chemicals, which is determined by their physico-chemical properties, the respective release mode, the environmental medium into which they are first released (Mackay *et al.*, 1996), their reactivity and degradability, and the kinetics of these physical and chemical processes. Certain chemicals, most notably the chemical elements, never degrade, while organic substances may have half-lives and environmental residence times ranging from a few days up to geological timescales.

Assessment of dispersion and exposure is exceedingly difficult: while processes can be studied in a laboratory, their impact in varied environmental conditions is very uncertain. Data on environmental impacts can only be gathered through extensive and continuing monitoring of both the environmental concentrations of selected substances, and also attributable impacts on environmental compartments. A recent workshop on environmental monitoring (OECD, 1998) has emphasised the importance of long time series in order to be able to detect changes with time, but has also highlighted the need to re-evaluate older data with improved scientific insight. Data on the bio-toxicity and toxicity of chemicals is very limited (Figure 3.3.2). For 75% of large volume chemicals (marketed in excess of 1 000 tonnes a year) there is insufficient publicly available data even for minimal risk assessment under the OECD guidelines (EEA/UNEP, 1998).

As environmental regulation has developed, the focus has shifted away from emission reduction through 'end-of-pipe' treatment at point sources, geared to particular impacts of a substance on a single environmental medium. There is now an increasing emphasis on integrated approaches, which take account of the movement of chemicals through the environment over time. Because of the difficulty and cost of assessing the environmental impact of the large number of potentially hazardous chemicals, some current control strategies now are rather aimed at reducing the 'load' of chemicals in the environment through the elimination or reduction of their use (OSPARCOM; Århus Declaration, 1998; UNECE 1998a,b). Better understanding of the fate of chemicals in the environment is needed to aid the development of targeted exposure reduction measures and to aid the assessment of long-term exposure from chemicals dispersed in the environment.

Box 3.1.1. Some definitions

Dispersion: here the term encompasses all phenomena which give rise to the proliferation of substances through the man-made and natural environment.

Hazardous Substances '...are defined as substances, or groups of substances, that are toxic, persistent and ('or') liable to bioaccumulate. In this definition toxicity should be taken to include chronic effects such as carcinogenicity, mutagenicity and teratogenicity and adverse effects on the function of the endocrine system.' (Esbjerg Declaration, 1995). The OSPAR/Sintra agreement also added to this definition 'substances which give rise to an equivalent level of concern, especially those that act as endocrine disruptors.' (OSPAR, 1998).

Persistent organic pollutants 'are chemical substances that persist in the environment, bioaccumulate through the food web, and pose a risk of causing adverse effects to human health and the environment' (UNEP 1998; UNECE 1998a)

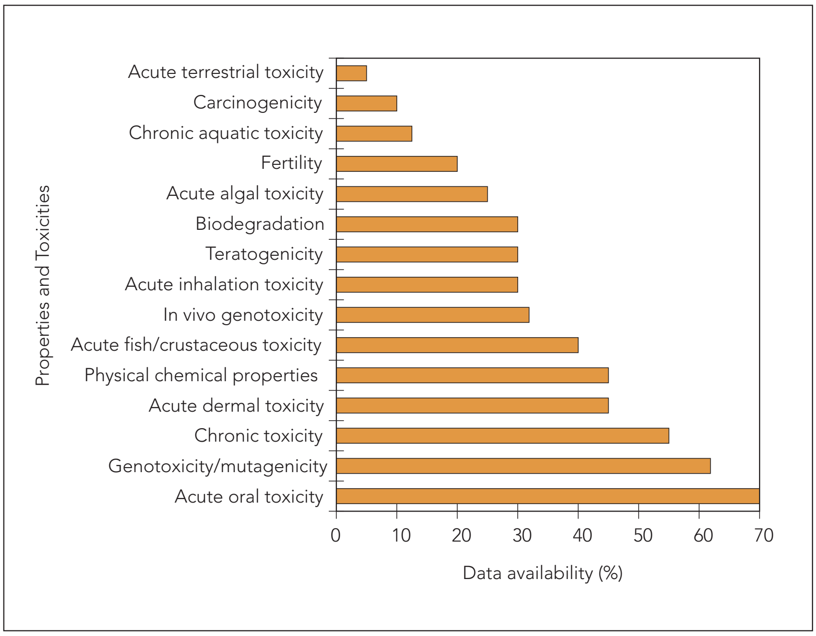
Heavy metals: metals or metalloids which are stable and which have a density greater than 4.5 g cm-3, namely lead, copper, nickel, cadmium, platinum, zinc, mercury and arsenic.

1.2. Sources of chemicals

The European Inventory of Existing Chemical Substances (EINECS, Council Decision 81/437) lists over 100 000 compounds that were on the market in 1981. The estimates of the actual number currently produced and marketed in any amount varies from 20 000 to 70 000 (Figure 3.3.3; Teknologi-Rådet, 1997). A significant number of these substances do not occur naturally, but are manufactured, in some cases, in large quantities (High Production Volume Chemicals – HPVC) with a resulting high statistical probability of human exposure. Many of the HPVCs are used in a vast range of manufac-

Availability of data on 2472 high-production volume chemicals submitted to the European Chemicals Bureau

Figure 3.3.2.



Following Council Decision 81/437 an inventory is being drawn up and the European Chemicals Bureau administers this data bank (IUCLID). A range of substances which are produced in large quantities are earmarked as priority substances for further data collation. The figure indicates the availability or rather scarcity of data of ecological relevance for those substances.

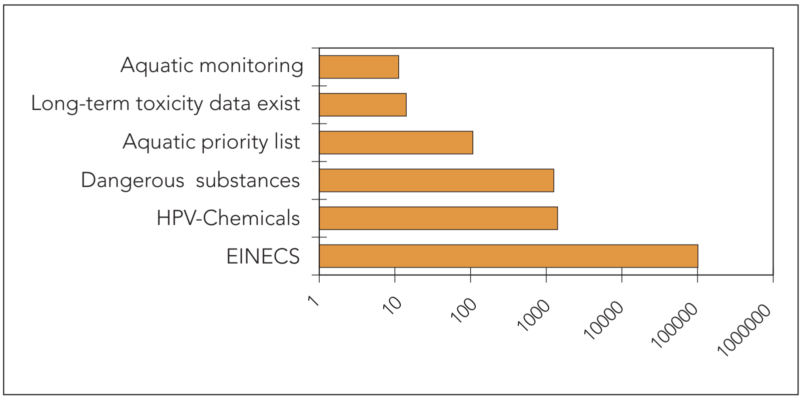
Source: adapted from Van Leeuwen *et al.*, 1996.

tured goods and other products considered essential in modern life, including detergents and other 'down-the-drain' chemicals. Several hundred new substances are marketed each year and are recorded on the European lists of notified chemical substances (ELINCS), which has over 2000 substances listed.

The International Uniform Chemical Information Database (IUCLID), compiled by the European Chemicals Bureau (Hansen and Verburgh, 1997; ECB, 1994), in addition to providing data on HPVC properties, categorises them according to functional use and industrial use areas.

The Draft Protocols to the Convention on Long-Range Transboundary Air Pollution by persistent organic pollutants (UNECE, 1998a) and heavy metals (UNECE, 1998b) have identified respective categories of stationary sources (Table 3.3.1).

Figure 3.3.3 **The chemical universe in contrast with some current monitoring and classification activities.**



The EINECS lists over 100000 substances which are supposed to have been on the market in 1981. However, only 10 000 are produced in volumes greater than 10 tonnes/year. There is very little data on dispersion or fate or effects of most substances.

EU aquatic monitoring: various CEC Directives.

Aquatic priority: Directive CEC 76/464 List I

HPVC: see explanation in text.

EINECS: see explanation in text.

Source: Technologi-Rådet, 1997

Table 3.3.1. **Stationary sources as examples for air emissions of heavy metals and POPs.**

Heavy Metals

Combustion installations with a net rated thermal input exceeding 50 MW.

Metal ore (including sulphide ore) or concentrate roasting or sintering installations for ferrous, copper, lead, zinc, or any gold and mercury ore treatment.

Installations for the production of pig-iron or steel including continuous casting.

Ferrous metal foundries.

Installations for the production of copper, lead and zinc from ore, concentrates or secondary raw materials by metallurgical processes, or for any primary production of mercury.

Installations for the smelting (refining, foundry casting, etc.), including the alloying, of copper, lead and zinc, including recovered products.

Installations for the production of cement clinker.

Installations for the manufacture of glass using lead in the process.

Installations for chlor-alkali production by electrolysis using the mercury cell process.

Installations for the (co-)incineration of hazardous or medical waste.

Installations for the (co-)incineration of municipal waste.

Persistent Organic Pollutants

(Co-)incineration of municipal, hazardous or medical waste, or of sewage sludge.

Sinter plants.

Primary and secondary production of copper.

Production of steel.

Smelting plants in the secondary aluminium industry.

Combustion of fossil fuels in utility and industrial boilers with a thermal capacity above 50 MW_{th}.

Residential combustion.

Firing installations for wood with a thermal capacity below 50 MW. Th

Coke production.

Anode production.

Aluminium production using the Soederberg process.

Wood preservation installations.

Source: UNECE, 1998a,b

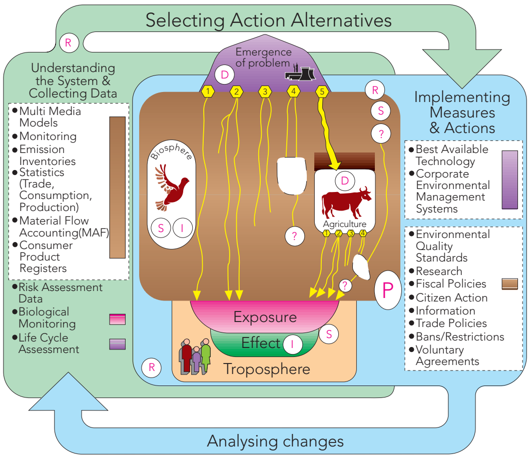
2. The fate of chemicals in the environment

2.1. Environmental Cycle: few known point sources with the majority of chemicals released from diffuse sources

Whether a chemical is hazardous to humans or ecosystems depends on its properties, form, the environmental medium in which the chemical is found, respective concentrations and the potential exposure pathways. Tracking the fate of certain hazardous chemicals in the environment is frequently complicated by the fact that the same chemicals occur naturally. Once released from the anthroposphere, chemicals will become involved in the complex natural atmospheric, geochemical, and biological cycles (Figures 3.3.4 and 3.3.5).

Environmental concentrations are the result of multiple processes affecting the mass of a chemical released from a multitude of sources. Process parameter values can be deduced – with limitations – from repeated measurements of the same variable at the same location, for instance as part of monitoring programmes. The range of variables to be considered can be narrowed, for instance, by emission inventories describing the chemicals' source terms.

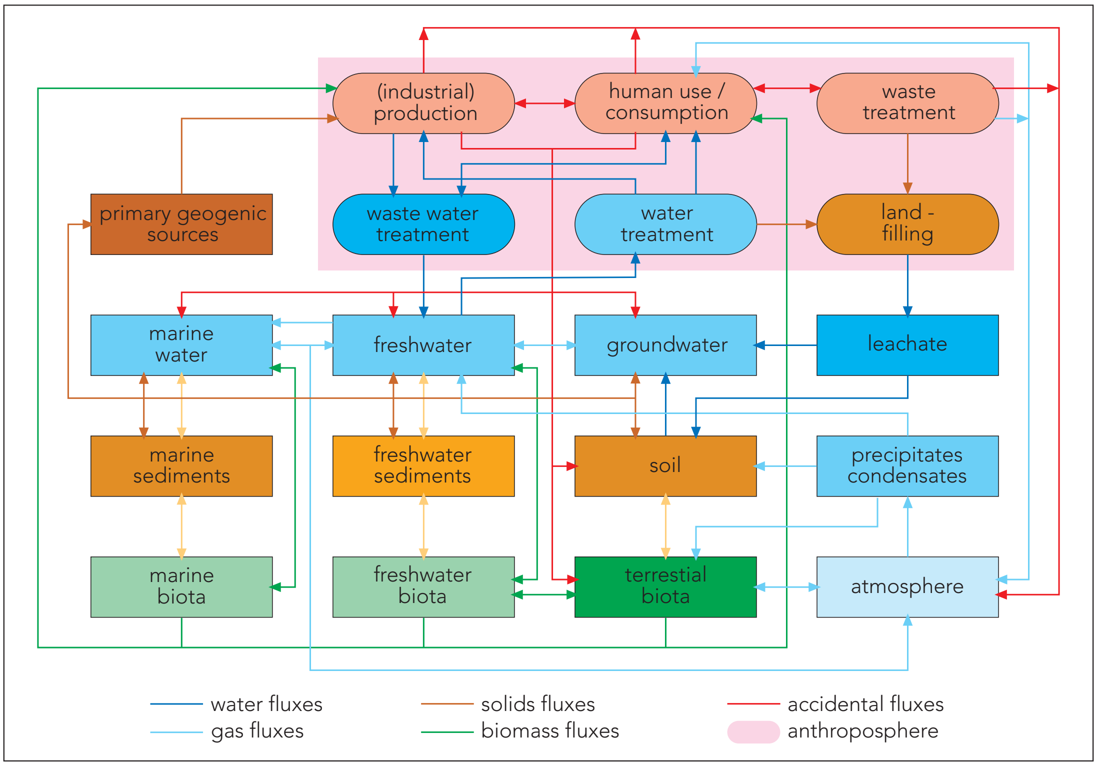
Chemical dispersion pathways Figure 3.3.4



This is a representation of five pathways. The brown area is where the chapter focuses: pathways, resulting fate and concentration of chemicals in the environment. The main driving force (D) assumed here is a pesticide factory. Other extractive and manufacturing industries that supply raw materials may also be involved, but are not represented. Emissions (1 to 4) are point sources at the manufacturing site. In (1) the chemical is persistent and does not change in the envi- ronment. Human exposure is caused by the same molecule as released by the factory. In pathway (2) the chemical breaks down in three parts, one harmless and the other two potentially toxic. Pathway (3) is a safe chemical that degrades completely. In (4) the chemical decomposes in a natural substance (e.g. H_2O, CO_2, CH_4) and another that reacts or recombines with manufactured or natural background chemicals resulting in a new or unknown chemical. In (5) an herbicide is transported to a farm (driving force again (D)) and applied to the soil, giving rise to non-point sources where all pathways (1 to 4) are repeated. Environmental pressure (P) from chemicals is widespread. Before or concomitant to human exposure the biosphere is subject to impact (I) and stress (S). To limit environmental exposure and reduce stress, it is necessary to understand the system through data collection. Policy makers formulate response hypothesis (R) and select those that are most suitable. The darker brown area indicates where the effort for understanding the system and applying response measures are most effective. A key factor are the driving force itself which could be targeted in order to avoid or limit emissions by applying environmental management methods and techniques.

Source: EEA-P. G. Meozzi

Selection of some of the more important pathways for the transfer of chemical substances between different compartment of the natural and man-made environment (anthroposphere) Figure 3.3.5



The cycles of chemicals in the environment are complex and manifold interwoven. The shaded area indicates the anthroposphere and its interface with the natural environment

Source: W.E. Falck

Persistent chemicals (HMs, POPs) have the potential to become dispersed over a wide area, even on a global scale, and to accumulate in certain environmental compartments, for instance in biota, where they may become metabolised. Dispersion increases the probability of exposure, while bio-accumulation can result in body burdens that increase up the food chain and which may eventually reach toxic levels.

While some chemicals of concern are released at a few known point sources, the majority of them are emitted from countless, diffuse sources. An European Integrated Emissions Inventory (EIEI) has been proposed in connection with the IPPC. Emission inventories, based on actual measurements or typical emission factors, are used to assess releases from point sources. This makes it virtually impossible to describe discrete dispersion pathways from source to exposure target in a quantitative way. Assessment of the state of the environment resulting from chemicals of concern, therefore, requires additional information from regional or even global mass balances of substances, derived from Substance Flow Analyses (SFAs; EUROSTAT, 1997). SFAs help to identify significant emissions or losses and whether a chemical's use is driven by its origins as by-product or waste from another process (Udo de Haes and van der Voet, 1997). They also help to pin-point those uses or processes that could be targeted most effectively for overall environmental impact reduction. SFAs consists of a stocktaking exercise on all fluxes of a substance to and from a region, such as a country or a river basin (Neal *et al.*, 1998). Diffuse emissions can be estimated by combining inventories and monitoring data. Evaluating mass balances on a regional or even global scale requires a combination of monitoring data and modelling.

SFAs have been prepared for a range of substances in a number of EU Member States, including Austria (Gerhold, 1997), the Netherlands, Finland (Nordisk Ministerråd, 1997) and Sweden (Statistics Sweden, 1997). Hellsten (1997) discusses the difficulty of identifying substances in the anthroposphere based on data available from national sources, such as statistical offices or custom and excise registers, as in Sweden. Movements between compartments of the natural and man-made environment also need assessing. Very detailed SFAs have been compiled for The Netherlands (Gorter, 1997).

The PIC (Prior Informed Consent) procedure, developed between by the United Nations' Environmental Programme (UNEP) and Food and Agriculture Organisation (FAO) allows control of technosphere (e.g. trade) cross-border fluxes of certain chemicals.

2.2. Dispersion through the environmental compartments

2.2.1. Air: particles are important carriers for contaminants

Emissions of many chemicals of concern occur into the air initially, from where they are dispersed into other media. Air is one of the main carriers of chemical carcinogens to humans (Corvalán and Kjellström, 1996).

Many chemicals emitted into the air, for instance from combustion processes, tend to become associated with particulates (see also Chapter 3.10). Removal from the air occurs through a range of complex processes involving photo-degradation, and particle sedimentation and/or precipitation, (known respectively as dry and wet deposition). Volatile and semi-volatile substances may undergo several cycles of evaporation and precipitation. Such cycling can make chemicals more accessible to photochemical or bio-degradation.

The usual mode of application for plant protection products is spraying, which results in high atmospheric emissions, drift and potential exposure of non-target species (Kleijn *et al.*, 1997). Depending on weather conditions during application, losses due to volatilisation or washing-out (Lennartz *et al.*, 1997) may be high, such that sometimes less than 5% of the substance applied reaches its intended target (Bullek *et al.*, 1991).

Substances which are not easily degraded and are semi-volatile can follow the atmospheric circulation patterns on a global scale (Wania and Mackay, 1996a). This is evidenced by the occurrence of halogenated hydrocarbons (e.g. certain pesticides, PCBs) in polar regions, far from their industrial or agricultural sources (Wania and Mackay, 1996b). The concern for the effects of long-range air-transport has led to international action (UNECE, 1998a,b).

Air pollution control measures (such as the Integrated Pollution Prevention and Control Directive and its predecessors), although not necessarily targeted primarily at hazardous chemicals, also effect reductions of chemicals air emission.

2.2.2. Water: improved means available to understand fluxes in river catchment basins

For many industrial discharges and household 'down-the-drain' chemicals, such as detergents, surface waters are the initial receiving medium. Although many countries prohibit discharge into aquifers, contaminating fluids will nevertheless reach groundwaters, for instance by the way of natural recharge, seepage from leaky municipal and industrial sewerage systems, landfills, storage tanks or accidental spills.

The migration behaviour of a chemical along the water path is largely determined by its chemical and physico-chemical properties. Re-distribution of contaminants between the aqueous and solid phase is controlled by the prevailing water chemistry and resulting surface properties. Zones of high acidity or alkalinity (measured by low/high pH) and/or *redox* potential or of high sorption capacity (for example clays) can act as geochemical barriers. Indeed, these properties are utilised in engineered landfills to prevent leakage.

Groundwater and river loads are a complex function of such phenomena and the hydrological characteristics of catchments which are linked to atmospheric and marine processes and fluxes. This is illustrated by drinking water analyses for pesticide pollution in France (Figure 3.3.6). The proposed EU Water Framework Directive (see chapter 3.5) puts much emphasis on qualitative and quantitative resources management at catchment level. The necessary information support is illustrated by the LOIS project (1999; Neal *et al.*, 1998; Leeks and Jarvie, 1998), which estimated pollutant loads for selected European rivers (Jarvie *et al.*, 1997).

2.2.3. Soils and sediments - the number of contaminated sites, including landfills, is in the order of hundreds of thousands

Soils are recipients for chemicals from combustion processes, pesticide applications, landfilling and other waste disposal methods, and leakage from petrol stations, industrial sites, etc. The estimates for numbers of contaminated sites, including landfills, are in the order of hundreds of thousands for the whole of Europe, but no definite number can be given (see Chapter 3.6). Agricultural disposal of sludges from biological wastewater treatment (BWWT) processes increasingly raises concern (Directive EEC/86/278), since HMs and certain persistent organics accumulate in these sludges and biofilms.

Soils and sediments act as a reservoir for many chemicals of toxicological relevance (HMs as well as lipophilic organics) owing to their affinity to solid surfaces in general and the organic fraction in particular. Slow and delayed release will occur, controlled thereafter by prevailing bio-geochemical conditions, thus extending potential environmental exposure times well beyond the initial emission event. This geochemical behaviour is an important factor to be considered in long-term exposure assessments and the design of monitoring programmes.

Eroded soil fines might act as secondary sources, from where chemicals, both inorganic and organic, are released into the air, surface and groundwaters, and ultimately the sea (Neal *et al.*, 1998).

2.2.4. Biota - concerns on the increase of persistent organic and inorganic pollutants along the trophic or reproductive chain, i.e. biomagnification.

Toxicology and risk assessment are mainly concerned with the effect chemicals have on biota. Meanwhile the biota themselves may act as a vector of dispersion.

Some tissues have an inherent affinity for certain chemicals, for instance, halogenated organic compounds are taken up into body lipids, such as in mammal milk. Other tissues remove excess chemicals from body fluids or detoxify them, as do the kidneys and the liver. The capacity to metabolise xenobiotic chemicals is species and compound depend-

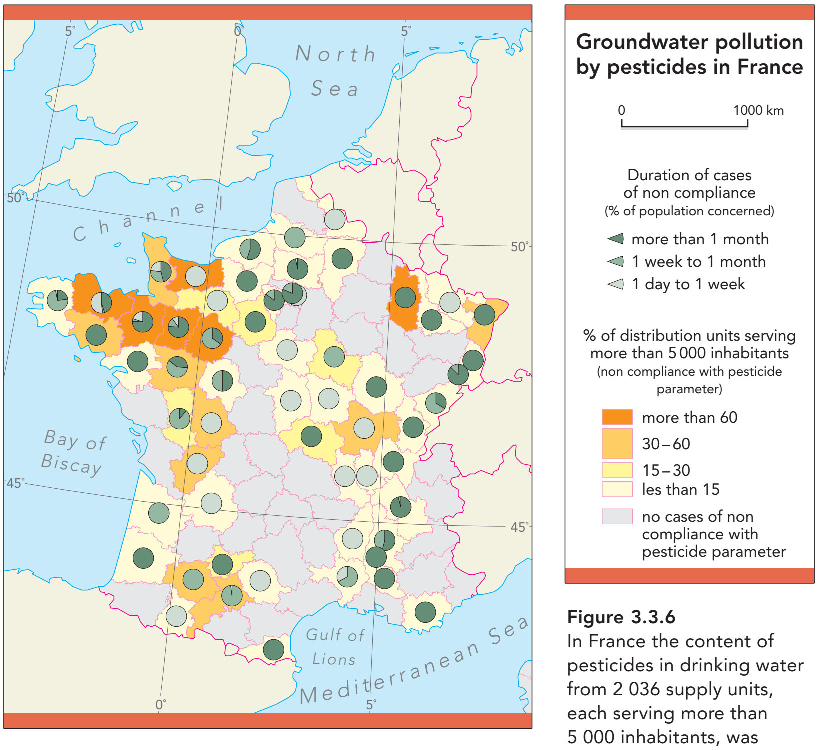


Figure 3.3.6
In France the content of pesticides in drinking water from 2 036 supply units, each serving more than 5 000 inhabitants, was analysed during the period 1993-1995.

About 43 million people were served with drinking water from these plants, of which 5.4 million (13%) received water with pesticide concentrations above the limit values (0.1 ug/l for a single pesticide or 0.5 ug/l for total pesticides as specified in the Drinking Water Directive for a mixture of pesticides). These exceedences were recorded for a certain part of the year ranging from one day to several months. As in other countries the substance most often found to exceed the limit value was atrazine.

The presence of pesticide in drinking water is well in accordance with the fact that 49% of sampling points in rivers and 35% of groundwater points are moderately contaminated by pesticide. In about half of the river sites pesticides are the main reason of pollution while for the groundwater sites it is one-fifth. In surface waters, c.a. 80 pesticide substances are involved, whereas 25 substances contribute only to groundwater contamination.

Source: Ifen, 1998

ent (Borrel *et al.*, 1995, 1996; Bernhoft *et al.*, 1997); if it is insufficient bio-accumulation ensues. Of particular concern is the concentration increase of persistent organic and inorganic pollutants along the trophic or reproductive chain, i.e. bio-magnification. Transfer of the chemical to the offspring thus can result in exposure at a time when they are most susceptible to adverse effects (Fear *et al.*, 1998).

The time lag until complete breakdown of a chemical may cause sufficient exposure and result in adverse effects. Observable effects may be considerably delayed. Metabolites, in fact, may be even more toxic than the original substance.

3. Chemicals of concern

3.1. Heavy Metals: losses during production, use and waste management

Human activity generally leads to the dispersion of metals (Renberg *et al.*, 1994) and other elements that had been concentrated by geological processes and over geological time scales. The use of, and hence human exposure to, metals has significantly increased since the onset of the industrial revolution and continues to do so on a global scale (Bergbäck and Lohm, 1997). Arsenic, cadmium, copper, lead and nickel have been identified as being of greatest concern (Denzer *et al.*, 1998).

3.1.1. Production and use

The production and use of heavy metals is driven by a wide variety of industrial, agricultural and domestic uses such as metallurgy, catalysts, pigments for paints, batteries, electronics components, fertilisers, solid fossil fuels, or plastics and fuel additives. The major diffuse anthropogenic mercury source, in Germany for instance (LAI, 1995), is burning of fossil fuels. EU average contributions from agriculture to cadmium emissions are around 1% (Vissedijk *et al.*, 1998). Cadmium in phosphate fertilisers is of some concern (OECD, 1996) and is dealt with by national legislation in Finland, Sweden and Austria.

3.1.2. In water pathways

Direct human exposure to elevated HM concentrations via the water pathway has been of limited importance in many western European areas, but has regained importance as a result of declining control over the quality of (groundwater) resources and the distribution system (see also Chapter 3.10). This may, for example, increase human lead exposure from drinking water, countering lead solubility control measures for water piping. Exposure to surface water-derived HMs might occur indirectly via bio-accumulation in freshwater or estuarine or marine fish consumed by humans. The latter, for instance, accounts for half of the mercury intake in Germany (LAI, 1995).

The increasing abundance of biological wastewater treatment (BWWT) plants throughout Europe leads to a shift of environmental dispersion pathways of HM from effluents to sludges. Sludges are either used as fertiliser (if contaminant concentrations are within legal limits), or are incinerated. River loads have decreased considerably as a result of waste-water treatment (see for example UBA, 1997; Chapter 3.5).

The LOIS studies (*Land Ocean Interaction Study*, 1999) have confirmed that elevated concentrations of HMs in river waters are linked to the presence of high suspended particle loads and natural or anthropogenic complexants. HMs re-mobilised from stream sediments are of some concern where drinking water resources are augmented by bankfiltration. Ultimate recipients for HMs in surface waters are the large marine basins of the Baltic, the North Sea, the Black Sea and the Mediterranean. The European countries have, through the North Sea Conference, the Oslo-Paris Commission for the Protection of the Marine Environment of the North-East Atlantic (OSPARCOM) and the Helsinki Commission on Baltic Marine Environment Protection Commission (HELCOM), agreed to reduce overall inputs of HMs.

3.1.3. In the atmosphere

Combustion processes as part of fuel conversion, metal production and processing, or waste treatment constitute important airborne sources of HMs on a European scale. Until the introduction of lead-free petrol, air dispersion was the most important pathway for human exposure to lead (cf. Århus Declaration, 1998, p. 18).

HMs emitted to air are often chemically bound in, or physico-chemically attached to, particles, and follow their global dispersion patterns (see Chapter 3.4). True gaseous transport is an important mechanism for mercury and results in an even higher potential for long-range transport and extensive atmospheric cycling (LAI, 1995). Air transport of HMs can be in the order of thousands of kilometres, as is indicated by their occurrence far from their sources (Renberg *et al.*, 1994). Wet or dry deposition will eventually transfer airborne HMs to water, soils or onto plant surfaces (Dmuchowski and Bytnerowicz, 1995; Herpin, 1995).

3.1.4. In soil

Higher HM concentrations in soils tend to be more localised, either from high natural background levels (mineral deposits), or from mining, ore processing, and other industrial activities.

3.1.5. In food

The major pathway for human uptake, after inhalation, is ingestion of plant and animal derived foodstuffs. The chemical processes associated with bio-accumulation, both in humans and animals, lead to preferential accumulation in certain tissues. Wahlström *et al.* (1996) concluded that the consumption of fish or game in general in Finland can be considered safe, but their liver and kidneys should be avoided. Human exposure to HMs may not only result from the dietary uptake, but also from smoking.

3.2. Persistent Organic Pollutants (POPs)

The number of chemicals to be considered as Persistent Organic Pollutants (POPs) is unknown, but certainly exceeds those that are listed as being of concern (UNEP, 1998; UNECE, 1998a) or are included in current monitoring programmes.

3.2.1. Polycyclic Aromatic Hydrocarbons (PAHs) - combustion still a major sources for the environmental concentrations

PAHs comprise a suite of around 280 substance from which 16 have been selected by EU and US EPA as priority substances (Howsam and Jones, 1998; Keith and Telliard, 1979). PAHs are ubiquitous and many have environmental half-lives in excess of weeks or months. They are subject to various chemical and photochemical processes in the environment; some of which result in degradation to less toxic products, while others lead to more hazardous compounds, such as nitrosubstituted PAHs (Harvey and Jones, 1998).

The major source of PAHs are fossil and other organic fuels such as wood. Combustion is thought to account for over 90 % of the environmental concentrations. Non-combustion processes such as the production and use of creosote and coal-tar, though poorly quantified, are potentially very significant primary and secondary sources (Howsam and Jones, 1998). Combustion processes have the highest dispersion potential over wide areas, but may decrease in relative significance as emissions are reduced by integrated pollution prevention and control (IPPC) measures (see also Chapter 3.4), although total emissions are liable to increase with economic activity (see Chapter 2.2).

Human exposure occurs mainly through inhalation of smoke particles to which the PAHs readily attach. Indeed, certain voluntary practices such as smoking and the use of household chemicals such as air fresheners result in significant indoor PAH concentrations and human exposures (Wallace, 1993).

3.2.2. Organochlorines dispersal in soil, groundwater and some global scale problem

Chlorine-based organic chemistry has become one of the most important branches of the chemical industry (Nolte and Jonas, 1992), accounting for some 55 % of the production (EuroChlor, no dated). The main products are pesticides and biocides, and components for a wide range of industrial and household goods.

A class of chlorinated hydrocarbons released into the natural environment on purpose are those which are intended as *plant protection products* (insecticides, fungicides, herbicides) and *biocides*. Active ingredients may be not only chlorinated hydrocarbons, but also other organic, metal-organic or metal compounds. Application generally results in diffuse source emissions (for example from agriculture, or organo-tin anti-fouling paints on ships), but for specific applications linear (e.g. weed control on railways), or point sources (wood protection, sheep dips, accidental spills) may be relevant.

Emission factors in industrial applications and household goods vary considerably, but are generally quite low during normal use; there are small losses from the technosphere by way of abrasion, wear, or leakages, notably PCBs from electrical installations. PVC-based plastics have been of some concern, mainly due to emissions of additives, such as stabilisers or plasticicers (e.g. phthalates, chlorinated paraffins), in the waste stream (Wolff *et al.*, 1994) and from consumer goods intended for children's use. Recycling of many PVC-based goods and better process control in incineration has reduced the impact from dioxin formation in thermal waste treatment.

Most lipophilic organochlorines (those that are absorbed by fats) will be found on the soil solids (the organic or clay fraction), from where they can migrate into deeper strata. A number of European countries have reported pesticides in groundwater, although there is little reliable information for POPs in general (Denzer *et al.*, 1998). The pollutants eventually reach the sea via surface waters and, *inter alia,* by colloid or particle-mediated transport (Craig and Guth, 1996).

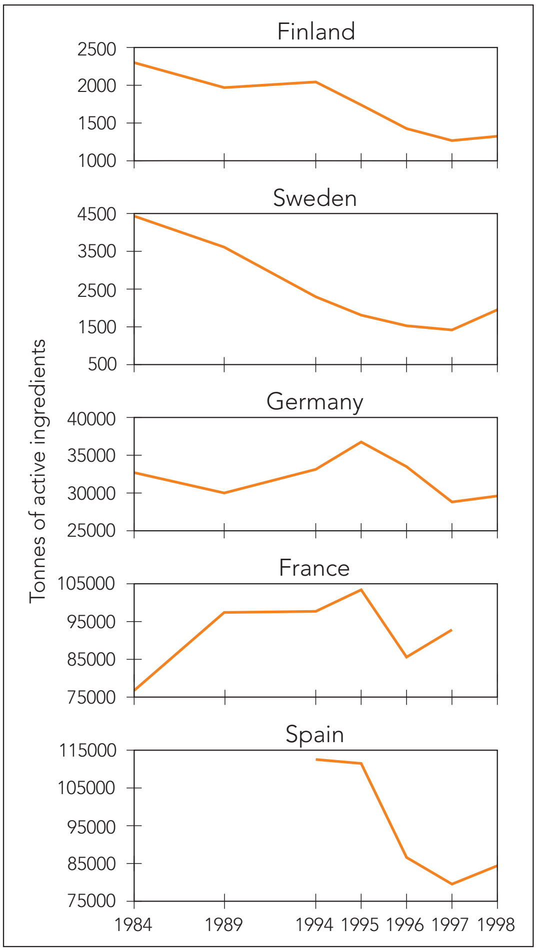
Primary emission into the air or evaporation during application furthers global dispersion of pesticide-derived POPs, following atmospheric circulation patterns (Pacyna and Lindgren, 1997). Both transport behaviour and possible breakdown of air-borne POPs are linked to the presence of particles and oxidants. Under tropical conditions, biocide formulation derived POPs are broken down relatively fast when they reach the ground, but air-borne, revolatized and particle-bound POPs spread northward towards the Arctic in the train of the global movement of air masses (Wania and Mackay. 1996a). (Re-)volatilisation and deposition complicate the assessment of emissions and depositions.

Figure 3.3.7

Pesticide consumption [tonnes of active ingredient] as a function of time for selected European countries.

Pesticide consumption in the various EU countries does not follow a uniform trend, being a function of agricultural activity and legislation on certain substances. Absolute levels reflect the size of the country as well as the respective importance of the agricultural sector. Consumption in terms of mass, however, does not necessarily reflect environmental impact, as more active and more specific substances are being developed.

Source: New Chronos/ EUROSTAT)



Acute poisoning of humans by chlorinated hydrocarbons is rare in the European region and usually associated with accidental releases during manufacturing, storage or application. Bio-accumulation (Blomkvist *et al.*, 1992) and persistence in many environmental media can lead to long-term low-level exposure of non-target species. Health effects on humans and animals from continuous or intermittent long-term exposure to low levels are varied and frequently difficult to attribute. Certain pathological observations, including eggshell thinning in various bird species, skeleton malformation in seals and otters, hormonal (endocrine) or reproductive disturbances in various species, were found to coincide with pesticides in the animal tissue (Swedish EPA, 1996).

The continuing use of some active ingredients of concern, for instance DDT in developing countries, results in dispersive input to European regions, even though the respective ingredients have been phased out in Western Europe (UNECE, 1998a). Lower acute human toxicity and easier handling for less well-educated farmers might be valid reasons for continuing their use in developing countries (Koss, 1997). The ever-increasing global trade in plant material (foodstuffs, textiles) provides another, anthropogenic, pathway for transboundary dispersion and possible human exposure in Europe.

Overall pesticide use – measured by mass of active ingredient – appears to have been decreasing in most EU countries over the past two decades (Thyssen, 1999; Figures 3.3.7 and 3.3.8); but even though the production and use of DDT and Lindane have been reduced or prohibited for decades, it will take considerable time for the reservoirs in various environmental compartments to become depleted and for stock-piles to become run down.

3.2.3. Dioxins and furans: reasonable data on air emissions but not for other pathways

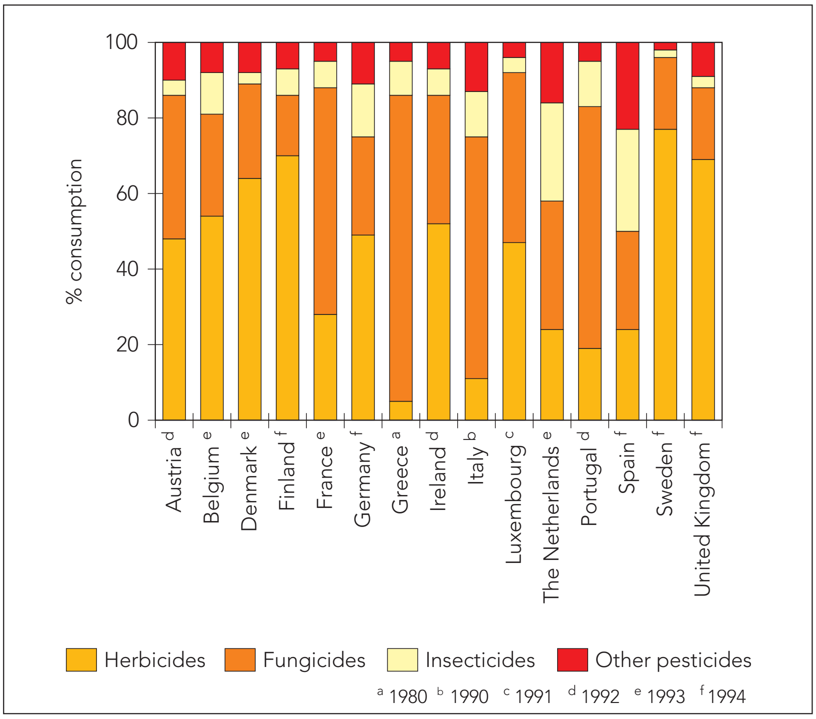
Dioxins are a category of POP which became notorious following the 1977 accident at Seveso, Italy, involving the most toxic dioxin, congener 2,3,7,8-TCDD, an impurity in certain herbicides, which is at present the only congener recommended for classification as being carcinogenic to humans (Becher *et al.*, 1998).

Polychlorinated dibenzo-*p*-dioxins (PCDD) and dibenzofurans (PCDF) and their congeners are present in traces naturally, but are formed on a larger scale as by-products of sub-optimal combustion processes of organic matter in the presence of chlorine (ICC, 1996).

Dioxins have atmospheric half-lives of the order of days, which is sufficient for their global dispersion (Renner, 1996). Their half-lives in soil and biota, where they accumulate in fatty tissues of top-predators, are of the order of years (Becher *et al.*, 1998) (Figure 3.3.9). Food is the main pathway to humans.

The Fifth Environmental Action Programme (1993) set out to reduce dioxin emissions until the year 2005 by 90% as compared to the reference year 1985. Residential burning of wood and possibly co-burning of domestic refuse is a significant source of dioxins in some Member States (Figure 3.3.10). Such sources are difficult to monitor and control, and are likely to constitute an unavoidable anthropogenic background level. Industrial and transportation sources are more accessible to assessment. The latter are linked to the use of leaded fuel and, therefore, should soon vanish completely. There are regulations controlling dioxin emissions from hazardous waste incineration (see Chapter 3.7), but not from industrial installations.

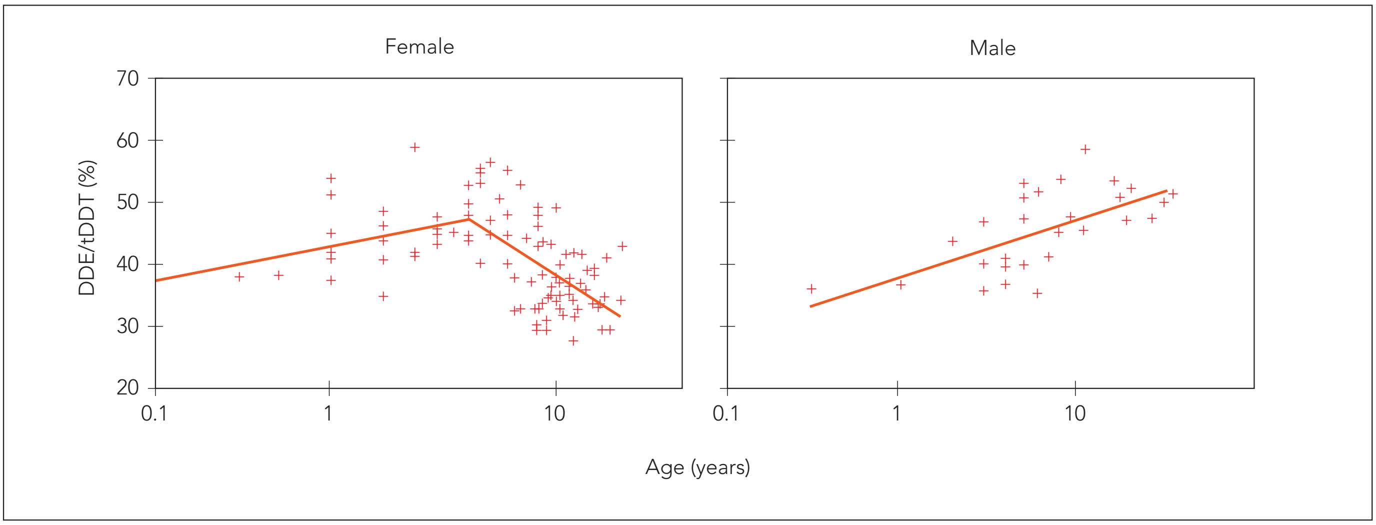
Percentage consumption of pesticides according to type of pesticide Figure 3.3.8



Pesticides are not only used in agriculture, although this is the main user in many countries. The type of pesticide required reflects the specific problems in each geographical area: humid countries such as the Mid-European and the Scandinavian countries mainly face weed control problems, while Mediterranean countries are consuming pesticides mainly in agricultural fungus control.

Source: New Chronos/EUROSTAT

Comparison of DDE/total DDT ratios in arctic mammals, males and females, of different age Figure 3.3.9



Low DDE/tDDT ratios at higher age indicate loss of DDE by reproductive transfer.

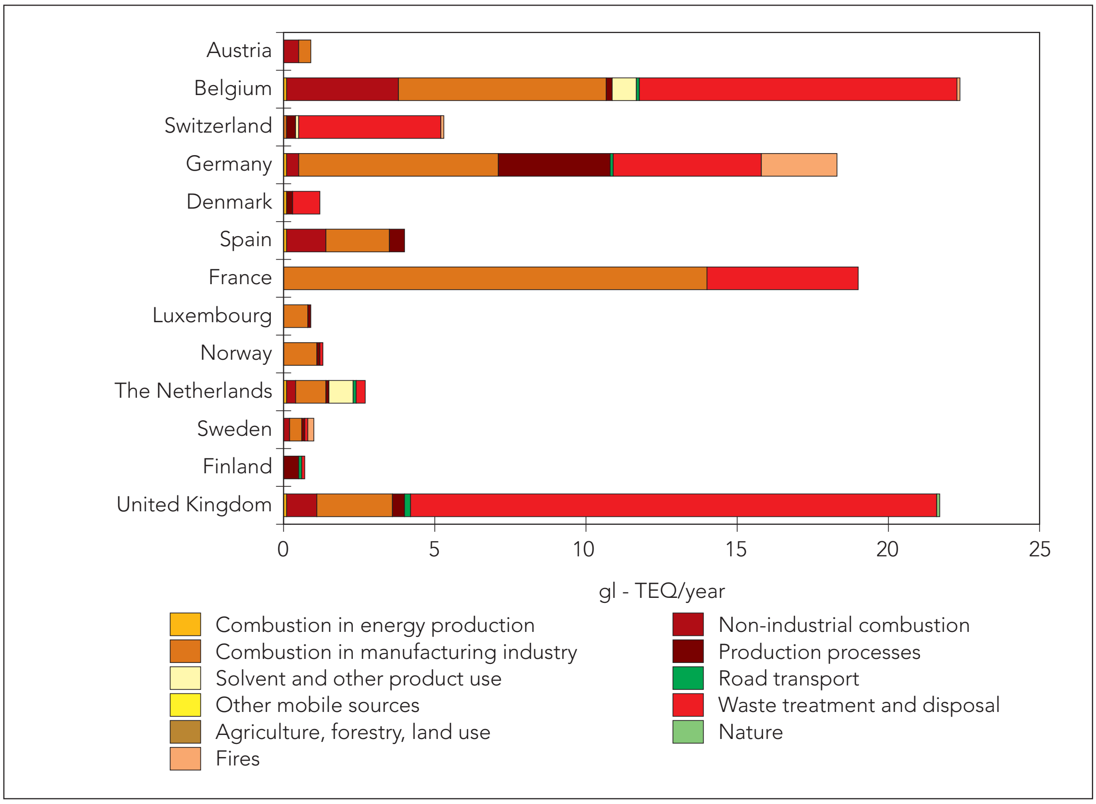
Source: Borell *et al*, 1995

Figure 3.3.10

PCDD/PCDF air emissions for selected countries and for those CORINAIR categories in which significant contributions have been observed.

Dioxin and furan air emissions in four countries for which reasonable data coverage existed. In Belgium, Germany and the UK the predominant source is waste treatment, while in France it is combustion in the manufacturing industry. Absolute figures indicate not necessarily poor pollution control but the relative importance of industry and waste management techniques (incineration).

Source: Quass and Fermann, 1997



4. Exposure estimation

4.1. Dispersion, exposure pathways and the difficulties of linking health effects to exposure

Various factors have to be taken into account when estimating exposures from environmental monitoring data and linking these to observed health effects (Corvalán and Kjellström, 1996). Variables controlling the dose received include: the duration of exposure; the time of exposure in relation to the total life-span of an organism (children may have greater exposure per unit of body weight than adults -EEA/UNEP, 1998); the capacity to bio-accumulate; and absolute concentrations, or concentrations above certain threshold values. Typical exposure pathways are ingestion, inhalation and dermal uptake, and for humans the total environment, lifestyle and diet, including breast milk, must be taken into account (Figure 3.3.11).

Exposure to a particular chemical does not necessarily follow from its mere presence in a environmental medium (Feijtel *et al.*, 1997b), and the uncertainties in predicting exposures are considerable (Box 3.3.2).

For heavy metals, physico-chemical characteristics alone are not sufficient to assess bio-availability and ecotoxicity (van Brummelen *et al.*, 1998), because in many instances the bio-availability is enhanced by organic complexation and the formation of metal-organic compounds. Not only the concentration-related total dose received by a recipient might be of relevance, but also the dose received by particular tissues over time. The specific problem of bio-accumulation and magnification in secondary and tertiary compartments requires special attention in exposure assessment (Feijtel *et al.*, 1997). Similarly, transformation of chemicals *in vivo* and in other environmental media, and the exposure to resulting transformation products needs to be considered. It appears therefore that impact assessments based on PEC (predicted environmental concentration) to PNEC (predicted no-effect concentrations) ratios may not be sufficient in the case of some bio-accumulating chemicals.

Exposure-based threat assessments can be used to identify priorities for exposure reductions. EEA/UNEP, 1998, states:

> *'An exposure-based assessment that uses the persistence and spatial range of the chemical as an indicator of environmental threat requires less data and can usually be performed faster, than a toxic effects-based risk assessment (Scheringer and Berg, 1994). It can also help to identify any gap between those who benefit from chemicals and those who bear the environmental or health damage, as chemicals with a high persistence and spatial range can distribute costs over a much wider area than that which receives the benefits, as, for example, with CFCs and ozone layer damage. It has been suggested that exposure-based threat assessment can be used for the initial screening of chemicals, complemented by toxic effects risk assessment, where this is likely to be cost effective and where data is available (Scheringer, 1997).'*

Some of the complexities of exposure assessment and its relation to risk estimates can be illustrated with dioxins (Box 3.3.3).

4.2. Mixtures and unidentified chemicals are issues of concern

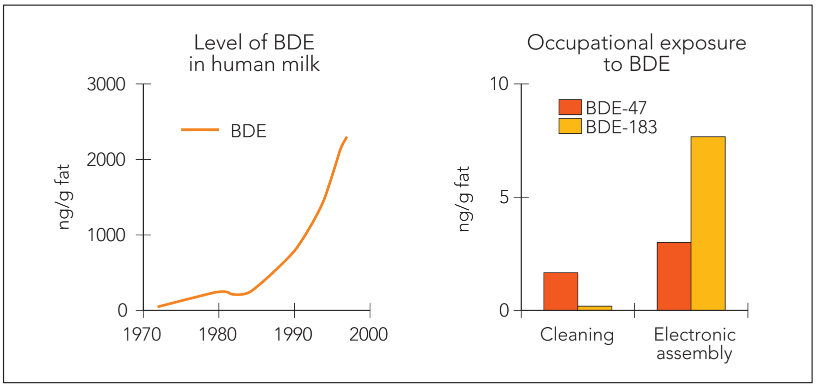
The significance of personal activities contributing to exposure has been emphasised by Wallace (1993). Household dust stirred-up by domestic activities leads to higher exposure to particles and particle-bound chemicals. Indoor personal exposure to chemicals such as paradichlorbenzene from mothballs and domestic deodorants, to tetrachloroethene from freshly dry-cleaned clothes, or to pesticide residues and dyestuffs from textiles can be significant. Bulk

Box 3.3.2. Uncertainty in exposure predictions

Uncertainty in exposure predictions is an important aspect in the regulatory context and arises from the fact that we inherently cannot know all system properties at any point in space and time. Conceptually there are five sources of uncertainty (Cowan *et al.*, 1995):

- deterministic variance (e.g. experimental error);
- stochastic variance (e.g. variations in nature) resulting from environmental properties changing in time and space and which cannot be controlled;
- variance in reaction rates which are both deterministic and stochastic;
- lifestyle variances such as age, ingestion rates, and food preferences;
- errors in model implementation by the developer and improper problem conceptualisation by the user.

Exposure from polybrominated diphenyl (PBDE) Figure 3.3.11



Eight individual PDBE were analysed in Swedish mothers milk as pooled samples which were collected from the years 1972, -76, -80, -84/85, -90, -94, 96 and -97. The mothers were between 27 and 31 years of age. The total PBDE concentrations (ng per gram extracted lipids (l.w.) are given as the sum of the eight PBDE congeners analysed. The major PBDE congener in the mothers milk was 2,2',4,4'-tetrabromodiphenyl ether making up approximately 60% of the total PBDE levels in the milk. The level of the PBDE should be compared to total PCB concentrations of approx. 1100 ng/g l.w in 1972 and 320 ng/g l.w. in 1997. The PBDE concentrations are increasing in milk from women in Sweden at the same time as other environmental contaminants are decreasing, e.g. PCB. The difference is today 80 times and a doubling of the PBDE concentration in the milk can be expected in five years unless the trend is changed.

Source: Left: Norén, K. and Meironyté, D., Organohalogen Compounds 38 (1998) 1-4;. Right: Meironyté, D., Bergman, Å. and Norén, K., Organohalogen Compounds 35 (1998) 387-390

Box 3.3.3. Dioxins: Current public exposures, lowest adverse effect levels, and recommended daily intake

	Daily intake of dioxins and dioxin-like compounds[1] (TEQ TCDD pg/kg/gw/day)[2]
Current adult dose (industrialised countries)	2-6
Lowest adverse effect level, adults (estimated from animal studies)	14-37
Recommended tolerable dailyintake (WHO: lowest effect level divided by 10 as the composite uncertainty factor for differences in susceptibility between animals and humans; between humans, such as foetuses and adults; and differences in half-lives of the chemicals in the TEQ mixtures)	1-4

[1] 29 dibenzo-p-dioxins, dibenzofurans and PCBs have been allocated toxic equivalency factors (TEFs) based on the most hazardous dioxin, TCDD, and these, in combination with their concentrations in the mixtures, can be summed to a toxic equivalent concentration (TEQ), based on the assumption that their effects are additive.

[2] Toxic equivalent concentration to TCDD dioxin, in picograms per kilogram of body weight per day.

Source: EEA, derived from WHO (in press) concentrations in ambient media, such as air or water, and respective consumption rates may, in consequence, lead to an underestimation of actual exposure.

Humans and the ecosystems are constantly exposed to a mixture of natural and manufactured chemicals, yet only a few are monitored or have been even identified. The toxic effects of exposure to some chemicals via certain pathways, such as oral ingestion or inhalation, is well understood and lethal or acceptable doses have been established. Very little is known, however, about the effects of mixtures of chemicals at low concentrations (van Leeuwen *et al.*, 1996) in particular, if the effects of single substances do not manifest themselves immediately. The poor understanding of the interrelation between an individual‘s historic record of exposure to the chemical environment and any observed effects hampers the deduction of clear causalities in most cases (Nurminnen *et al.*, 1996). Even within a human population the susceptibility of certain sub-groups, such as children, may depart considerably from the average.

Groups of substances of increasing concern, for which only limited insight in their environmental impact is available, include brominated flame retardants (Box 3.3.4) and substances affecting the endocrine system (Weybridge, 1996).

Box 3.3.4. Brominated flame retardants

Flame retardants are a diverse group of organic and inorganic compounds used to improve the fire resistance of polymers and other materials. IPCS (1997) lists 175 known compounds, most of which are brominated organics. Main areas of application are plastic housings of electrical and electronic equipment, such as TV-sets, computers and household appliances, circuit boards, cables, and textiles.

The respective compounds such as polybrominated biphenyls (PBBs; IPCS, 1994a) and diphenyl ethers (PBDEs; IPCS, 1994b) are precursors for the brominated analogues PBDD/F to PCDD/F (IPCS,1998) and may form under similar circumstances. Elevated concentrations of PBDD/F have been found in house and office fires, where fabrics, insulating material and office equipment are the source.

Health and environmental properties of PBDEs and similar compounds are poorly known, but they are persistent in the environment. Bioaccumulation decreases with increasing degree of bromination, but dehalogenation cannot be ruled out (Kemi, 1996).

Rising environmental concentrations are of concern. Drawing on the lessons learnt from PCB, it is evident that there is a risk of complex and harmful effects on a longer time-scale. Measures to prevent further dispersion from the technosphere should therefore be undertaken (Kemi, 1996).

4.3. Monitoring and modelling in predicting the fate of chemicals; more data on environmental properties are needed

Monitoring and modelling are two elements of the same process aimed at understanding the fate of chemicals in the environment. Monitoring programmes tend to focus on the relatively mobile media air and water. Soils, sediments, and other solid substrates are often neglected (OECD, 1998 - see also chapter 3.6), although they can absorb pollutants, eventually becoming a long-term secondary source. Pollutant releases are triggered by changes in water chemistry or, in the case of river sediments, by storm-flow events and thus may escape monitoring programmes (Leeks and Jarvie, 1998). Monitoring chemical exposures from consumer products is also neglected. The Land-Ocean Interaction Study (Neal *et al.*, 1998) and a recent workshop, (OECD, 1998), have highlighted the importance of flexible environmental monitoring programmes and the importance of their proper design.

Models mainly serve two purposes:

a) to test hypotheses on the behaviour of natural systems, on the dispersion of chemical substances; and
b) to make predictions about the fate of chemicals using the tested hypotheses.

Besides mechanistic models, describing the migration behaviour of chemicals at a given site using site-specific data, multi-media models have gained importance (Figure 3.3.12).

A not yet fully explored application of MMMs is the coherence testing of environmental standards: permissible concentrations of contaminants in the various media are usually set without regard for each other and may not be achievable at the same time (Cowan *et al.*, 1995). MMMs will also help to set priorities for further research and to assess the value of proposed additional data generation. MMMs thus help to focus exposure assessment and monitoring programmes on that compartment or pathway with the highest predicted impact.

On a grander scale MMMs have been used to predict global dispersion of POPs using a chain of models arranged along a meridian (meridional model), simulating the ‘grasshopper effect’ (CCEC, 1997) and permitting estimation of the ‘recovery time’ of the environment following the phasing-out of a chemical (Mackay *et al.*, 1996).

5. The outlook to 2010

The use of certain chemicals is expected to decline over the next decade in the EU. However, a growth of 30% to 50% in chemicals output is expected for most of the EU countries by 2010 as a result of increasing economic activity, including road transport and agricultural production (European Commission, 1999; Table 3.3.2). This anticipated growth could accentuate concerns with respect to human and ecosystem health (see sections above). Considerable uncertainties exist over both the projections for emissions (and consequently concentrations and depositions levels) and the relationships between exposure and effects; emission uncertainties for dioxin, for example, range from 5 to 20.

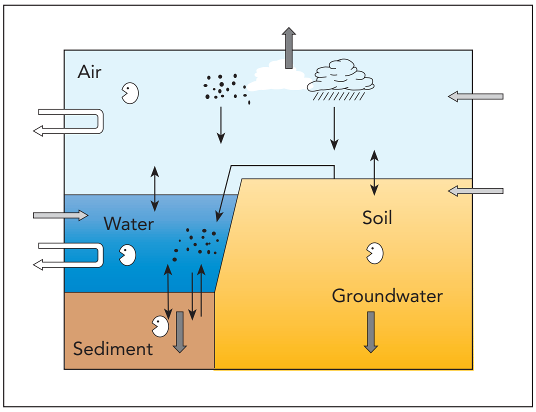
Nevertheless, it is important to consider the future trends for major groups of persistent chemicals because of the potential risk of significant impacts. Atmospheric emissions, concentrations and depositions have been modelled (European Commission, 1999) on a European scale for selected HMs, POPs, and for fine particulate matter (PM10). Emission estimates for 1990 have been prepared within the framework of the joint OSPARCOM-HELCOM-UNECE emission inventory (UBA-TNO '97) and are used to construct projections for the year 2010. More recent estimates from RIVM show slightly different emission levels for several substances. These are not used in this report because: a) the emission levels have not been evaluated in terms of state and impact indicators; and b) the documentation needs to be verified.

5.1. Emission trends of heavy metals

Phasing out leaded petrol (85/210/EEC) has, on average, more than halved lead emissions in the EU and the AC between 1990 and 1996, and further reductions are expected by 2010. The concurrent introduction of catalytic converters, however, will most likely result in increased platinum emissions, either through direct release or in the course of reprocessing.

Projections indicate that positive trends from abatement measures, such as improved efficiency and geographical coverage in recycling, are likely to be counteracted by a general increase in economic activity (European Commission, 1999). Thus the overall cadmium and mercury emissions are expected to increase in EEA countries by 26% and 30% respectively between 1990 and 2010 (Figure 3.3.13). Copper emissions (mainly from mining and smelting activities) increase by 8% and are unevenly distributed between countries. Policies in the pipeline lead to an appreciable decrease in emissions of lead, copper and mercury in the Accession Countries, although cadmium emissions are expected to increase by about 4% due to an increase in road transport and growth of the chemical industry.

Pictorial representation of a multi-media model Figure 3.3.12



Multi-Media Models (MMM) are based on the subdivision of a ‚unit-world' into representative fractions of relevant media, such as the air, surface and groundwaters, soil, and biota. Chemicals are distributed between the media according to certain physico-chemical properties.

Source: Cowan *et al.*, 1995

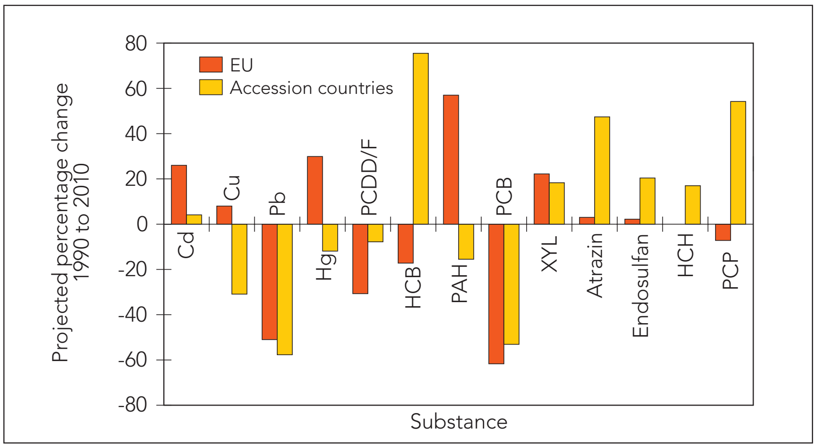
Examples of drivers for chemicals use and resulting exposure Table 3.3.2.

Main Drivers	Chemical	Source
Food production	Pesticides, Cd, Hg	crop treatment phosphate fertilisers seed treatment
Transport	Pb Pt, Pd, PAHs organics	petrol additive (in some countries); catalytic converters; incomplete combustion oil refining
Fuel conversion	PAHs, Cu, Cd, Hg, As	incomplete combustion fly ash
Mining, metals industry	Cu, Cd, Hg, As, Cd	ore processing zinc refining
Consumer goods and products (GDP growth)	Dioxins, furans	waste incineration

Source: EEA

A reduction in the sulphur content of fuels (following EU legislation COM(97)88), and a switch from solid to liquid fuels (UNECE, 1998b) heavy metal (HM) and arsenic emissions will also be reduced, as these are frequently associated with pyrite, the main sulphur source in coal and lignite. Improvements in waste-water treatment techniques and the degree of water-treatment connections, as well as tighter controls on industrial discharges, have led to reduced HM river

Figure 3.3.13 Projected percentage changes 1990 to 2010 in emissions of selected chemicals



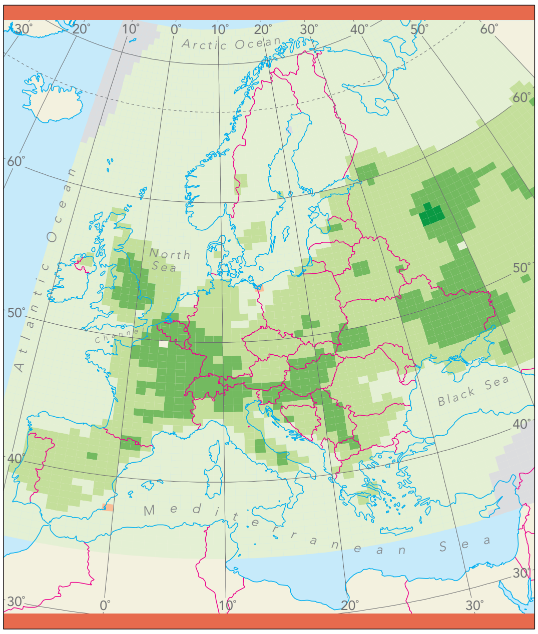
Source: European Commission, 1999

loads, but have exacerbated the problem of contaminated sludge disposal.

5.2. Emission trends of pesticides and persistent organic pollutants

Increases in general economic activity including agricultural production are projected to counteract positive trends from abatement measures (European Commission, 1999). Policy measures in the framework of the Integrated Pollution Prevention and Control (IPPC) Directive and its predecessors are expected to reduce emissions of dioxins/furans (from large-scale combustion plants) and of PCBs. Measures aimed at reducing energy consumption and/or improving conversion efficiency are also expected to have positive effects. In Western Europe anticipated growth in road transport is expected to increase PAH (for instance benzo[a]pyrene, Figure 3.3.13) and xylene emissions. In the Accession Countries this will be offset by the introduction of cleaner vehicles, although an expected increase in the annual volumes of incinerated waste will lead to increased emissions of HexaChloro-Benzene (HCB).

Changes in lead deposition, 1990–2010



Map 3.3.1

Source: European Commission, 1999

5.3. Concentrations and deposition

Among the heavy metals, while significant declines can be anticipated for the rate of lead (Map 3.3.1), a substantial increase is expected in cadmium in the environment (Map 3.3.2). Atmospheric concentrations in the EU are projected to increase over the period 1990 to 2010 by about 38% and 31%. Countries, such as Austria, Italy, the Netherlands and Belgium, which had high concentration levels in 1990, are likely to substantially increase concentration levels by 2010. Other countries, such as Germany and Greece, with high 1990 concentration levels, should experience only marginally increased levels in 2010. The UK, France, and Spain, with below EU average concentrations in 1990, will be above this average in 2010.

For the EU as a whole, deposition levels of cadmium are predicted to increase from 0.26 to 0.34g ha/year, or 31%, between 1990 and 2010. For specific countries, only Finland, Sweden and Germany are likely to maintain stable or relatively stable deposition rates over the 20 year timeframe. In comparison, both Spain and Portugal should experience an increase of over 65% in deposition rates. In 2010, the countries with the highest deposition levels are predicted to remain the Netherlands, Austria, Italy, Belgium and Germany.

Dioxin atmospheric concentrations and depositions both are likely to decrease in the EU15, over the period 1990 to 2010 with the implementation of policies in the pipeline. Dioxin depositions will decrease by 10% between 1990 and 2010. The highest levels are predicted for the Netherlands, Belgium, Germany, France, UK and Northern Italy, but depositions will decrease quite rapidly (typically 40%) from 1990 to 2010 in the majority of these countries. In contrast dioxin depositions in Spain and Portugal are forecast to increase sharply, by a factor of 3. Nevertheless, north-west Europe will continue to have the highest deposition levels.

PAH atmospheric concentrations are likely to rise to 2010 (Map 3.3.3), owing to the increasing number of combustion sources (mainly transport-related internal combustion engines) or their level of activity. Diffuse and domestic sources are difficult to control, but certain practices, such as stubble burning, are already banned in several EU15 countries.

Pesticide concentrations and re-distribution processes, such as leaching to the groundwater, depend on the substance and the environmental properties. Lindane concentrations (Map 3.3.4) are expected to fall, following its widespread ban, while those of other pesticides are likely to rise as a result of increasing agricultural activity.

Human indoor exposure to POPs is strongly linked to personal activities and the availability and use of consumer products (cleaning fluids, air fresheners), and thus closely linked to GDP growth.

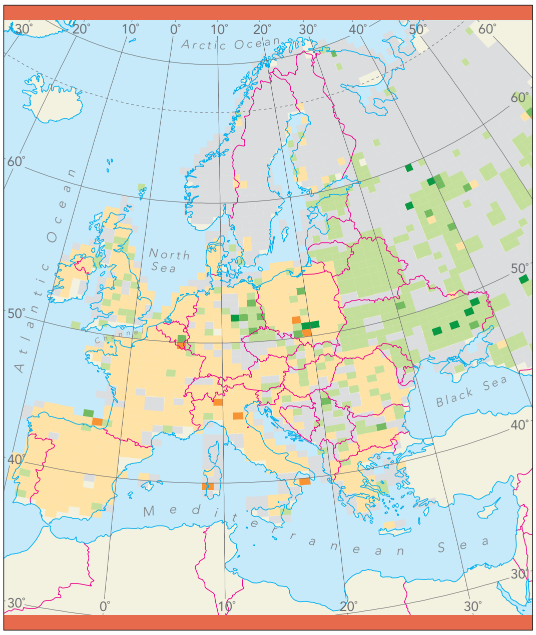
Bio-accumulation phenomena will continue as a result of redistribution processes for a long time after a substance has been banned from use.

5.4. Influence of main policies and distance to target

The ultimate objective of the 1988 Convention on Long Range Transboundary Air Pollution (regarding heavy metals and persistent organic pollutants) is the elimination of discharges, emissions and losses to the natural environment. In the first instance the amount of HM in applications with high emission factors during use should be reduced; a successful example is the replacement of lead or cadmium in pigments (UNECE, 1998b). A similar objective adopted by the parties to OSPAR of bringing discharges and emissions to near background levels for HMs and synthetic substances within one generation, however, is much more challenging.

The second Sulphur protocol, although not explicitly addressing HMs and arsenic, will to reduce their emissions from combustion sources. Improved controls of emissions to the air and water will reduce respective exposures, but generate potential secondary sources in the form of HM enriched wastes which have to be disposed of safely.

For many substances, including HMs and pesticides, target and/or action threshold groundwater concentration levels have been set at EU (for instance in the proposed Water Framework Directive) and at national



Changes in cadmium emissions, 1990–2010

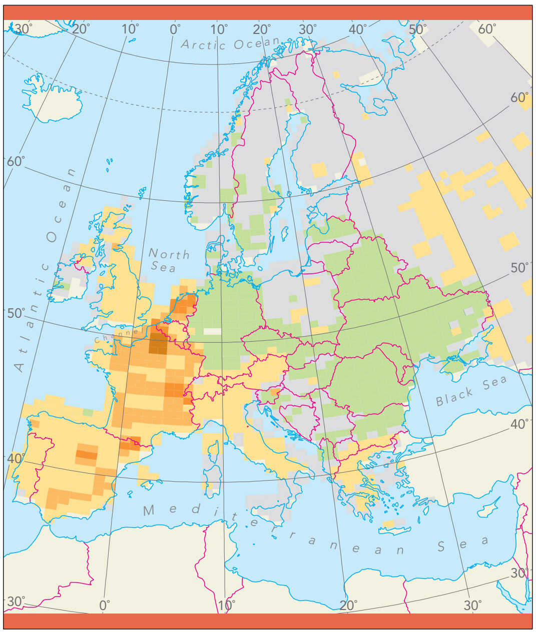
0 1000 km

Changes in kg/km²/year in cell 30' x 30'

- increase > 0.25
- 0.005 – 0.25
- no change
- -0.005 – -0.25
- -0.25 – -0.50
- decrease < -0.50

Map 3.3.2

Source: European Commission, 1999



Changes in benzo(a)pyrene emissions, 1990–2010

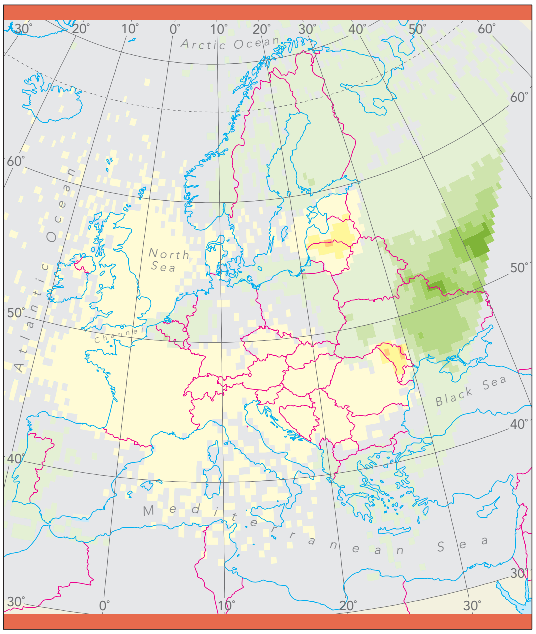
0 1000 km

Changes in kg/km²/year in cell 30' x 30'

- increase > 3.0
- 1.5 – 3.0
- 0.5 – 1.5
- 0.005 – 0.5
- no change
- -0.005 – -0.5
- decrease < -0.5

Map 3.3.3

Source: European Commission, 1999



Changes in lindane deposition, 1990–2010

0 1000 km

Changes in μg/m²/year in cell 30' x 30'

- increase > 50
- 25 – 50
- 0.005 – 25
- no change
- -0.005 – -25
- -25 – -50
- -50 – -75
- -75 – -100
- decrease < -100

Map 3.3.4

Source: European Commission, 1999

levels, but in some areas the specified standards may be difficult to achieve.

6. Emerging trends: minimisation of dispersion and substitution by less harmful substances

The currently rising chemicals intensity of EU GNP and the increases in some chemical emissions predicted in the “outlooks” section could well be reversed over the next decade if some recently agreed international and Member State policies on chemicals exposure reduction are implemented, such as the OSPAR/Sintra agreement and UNECE policies on POPS and Heavy Metals (EEA/UNEP, 1998).

Other emerging trends that could lead to reductions in the quantities of chemicals produced and used in the EU include:

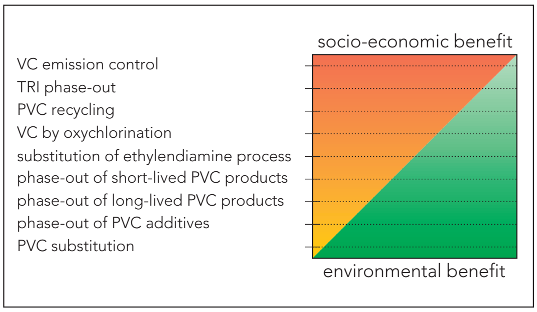
- the shift of low value bulk chemicals production to Asia and other areas, and an increasing EU focus on high value speciality chemicals;
- the green chemistry and other eco-efficiency developments described in Chapter 2.1;
- the replacement of chemical technology with biological technology;
- the internalisation of the environmental costs of chemicals into market prices, via taxes and other instruments (EEA/UNEP, 1998);
- the shift from products to services such as sales of degreasing services rather than solvents; and plant protection rather than pesticides (Seuring, 1994; Stahel, 1998);
- voluntary agreements such as in the Dutch chemical industry, and parts of the “Responsible Care” and “Sustainable Technology” programmes of CEFIC;
- EU investment in the production of less harmful products in the Accession and developing countries could remove environmental exposures in the EU from imported goods;
- increased information to the public and consumers, via toxic emissions inventories and product registers and labels;
- the development of toxic use reduction policies similar to those in the USA (Massachusetts and New Jersey) and Norway (REDUCE, 1998);
- increasing research and evidence on the harmful impacts to people, (particularly the foetus and children), wildlife, and ecosystems from multiple low-level exposures to chemicals and their break down products;
- increased use of the precautionary principle (Raffensperger, 1999; CECFSU, 1999).

In achieving reductions in exposures there must be a balance between the economic benefits of using hazardous substances and their impacts and risks to health and the environment. It is also important to carry out integrated environmental assessments of all measures banning or substituting substances: substitutes fulfilling the same function often are similar to, and give rise to the same problems as the original substance; or the cost of substitution may be disproportionate to the perceived benefit (Figure 3.3.14). Furthermore, a ban or substitution entails the problem of safe disposal or destruction of obsolete stockpiles. Alternative compounds may just shift the source of environmental pressure and may be more detrimental to the environment. Similarly, recycling does not always reduce overall human exposure and environmental impact because of higher emission factors during reprocessing.

Some of the emerging trends described above have been discussed during the current EU review of chemicals policies, and may be included in the proposed European Commission Communication on Chemicals, due in 1999.

Figure 3.3.14

Qualitative representation of the socio-economic and environmental cost of interventions in the PVC product stream



When considering the ban or replacement of substances in product streams the environmental and socio-economic consequences have to be analysed carefully. This has been done, for instance, in a study of the chlorine industry on behalf of the German Umweltbundesamt. A careful balance between expected benefits from measures and resulting costs is required.

Source: adapted from Wolff *et al.*, 1994; and Nolte and Jonas, 1992

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