Water management in cities of the future using emission control strategies for priority hazardous substances

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ABSTRACT

Cities of the future face challenges with respect to the quantity and quality of water esources, and multiple managerial options need to be considered in order to safeguard urban surface water quality. In a recently completed project on ‘Source control options for reducing emissions of Priority Pollutants’ (ScorePP), seven emission control strategies (ECSs) were developed and tested within a semi-hypothetical case city (SHCC) to evaluate their potential to reduce the emission of selected European priority hazardous substances (PHSs) to surface waters. The ECSs included (1) business-as-usual, (2) full implementation of relevant European (EU) directives, (3) ECS2 in combination with voluntary options for household, municipalities and industry, (4) ECS2 combined with industrial treatment and best available technologies (BAT), (5) ECS2 in combination with stormwater and combined sewer overflow treatment, (6) ECS2 in combination with advanced wastewater treatment, and (7) combinations of ECS3-6. The SHCC approach was chosen to facilitate transparency, to allow compensating for data gaps and to decrease the level of uncertainty in the results. The selected PHSs: cadmium (Cd), hexachlorobenzene (HCB), nonylphenol (NP) and pentabromodiphenyl ether (PBDE) differ in their uses and environmental fate and therefore accumulate in surface waters to differing extents in response to the application of alternative ECS. To achieve the required reduction in PHS levels in urban waters the full implementation of existing EU regulation is prioritised and feasible combinations of managerial and technological options (source control and treatment) can be highly relevant for mitigating releases.

Key words : best available technologies, best management practices, combined sewer overflows, source control, wastewater treatment, water management

INTRODUCTION

Central among the objectives of the European Water Framework Directive (EU WFD; Directive 2000/60/EC) is the aim to protect and improve the aquatic environment by ultimately eliminating emissions of priority hazardous substances (PHSs). The EU WFD also states that receiving waters should be protected through the introduction of specific measures aimed at managing pollutant discharges, emissions and losses. This is a driver for cities and municipalities to manage pollution across different scales within an urban context, applying for instance, source control options and/or end-of-pipe treatment. The term emission control strategy (ECS) was originally introduced to describe actions taken to mitigate the release of air pollutants, such as CO_2, NO_X, volatile organic compounds and greenhouse gases (e.g. Schöpp *et al*. 1998). In this paper, ECSs are considered as combinations of measures to manage releases, emissions and discharges of PHSs, on a city scale by addressing the emissions at various scales from their point of release (i.e. the commodity or activity) to the urban receiving environmental and technical compartments. Whilst potential receiving compartments include air, soil, surfaces, groundwater, sewage sludge and industrial waste, this paper focuses on releases leading to emissions to surface waters. A key research objective of the EU FP 6 Source control options for reducing emissions of Priority Pollutants (ScorePP) project was to develop and test comprehensive and feasible ECSs which authorities, cities, water utilities and industry can employ to reduce releases and emissions of PHS from urban areas into the receiving water environment. This research involved constructing scenarios for the defined ECS for the semi-hypothetical case city (SHCC) 'Nordic European Coastal' (NC), for four PHS; cadmium (Cd), hexachlorobenzene (HCB), nonylphenol (NP) and pentabromodiphenyl ether (PBDE). As described fully in Eriksson *et al*. (2009) the concept of SHCC involves the use of field data from the case city together with literature data (where field data is not available) as a way to address data gaps and hence reducing the level of uncertainty in subsequent assessments.

THE CATCHMENT AND ITS MANAGERIAL AND TREATMENT OPTIONS

Initially, the urban catchment (a Northern European Coastal town; Eriksson *et al*. 2009) was analysed to identify sources of PHS release and which managerial options were suitable at different levels. The efficiency of each option was quantified using available literature data (Seriki *et al*. 2008) and ranges of values used if substantial differences were reported by different references (see Tables 2–5). Where no efficacy data could be obtained from the literature, one of 3 tiers of reduction efficiency (i.e. 25, 50 and 75%) were used as generic scenarios of potentially achievable levels of reduction to enable ECS evaluation to be undertaken. In order to incorporate the multiple stakeholder interests' characteristic of an urban catchment, project partners (which included representations from universities, research organisations, municipalities and water utilities as well as industrial representatives) were involved in the development and testing of ECSs.

The urban catchment scale and associated pollution control options

Barriers to pollution release can be effective at different levels in the urban catchment and it is therefore important for cities, in the future, to address pollution control on this basis, such as:

- pre-application (source control options such as chemical substitution, international and national legislation, and voluntary initiatives);

- pre-release (treatment of urban wastewater before emissions to the receiving compartment, e.g. wastewater treatment plants (WWTP) and combined sewer overflow (CSO) treatment); and

- post-release (attenuation of pollution after release into the urban environment such as structural and non-structural stormwater best management practices (BMPs), e.g. stormwater ponds and street sweeping; and dredging of contaminated sediments).

Emission control strategies

The seven ECS identified in Table 1 cover both the managerial and technical options as well as source control and end-of-pipe treatment in order to address all three catchment release levels described above. Given the predicted implications of climate change such as flooding and particularly the need to mitigate CSOs, the use of stormwater BMPs have been included. ECS1 is a ‘business-as-usual strategy’, i.e. not involving any deliberate changes compared with the current situation, whereas ECS2 assumes that all applicable existing EU directives will be fully implemented for each PHS (see Tables 2–5). ECSs 3–6 build on the measures described for ECS2 and include the addition of voluntary options (ECS3), industrial onsite treatment using best available technologies (BAT) (ECS4), stormwater and CSO management (ECS5) and advanced wastewater treatment (ECS6). For example, ECS3 involves introduction of voluntary initiatives aimed at ceasing (or substituting) the use of products containing a certain PHS. Such initiatives can promote the use of eco-labelled articles to industries, municipalities and households (Bleda & Valente 2009). Implementation of ECS4 involves the treatment of all industrial effluents using BAT (Samarakoon & Gudmestad 2011). ESC5 introduces stormwater BMPs which can be used at the household level, at industrial sites, or within public open spaces (Revitt *et al*. 2011; Vymazal 2011). Hence different ECS developed have the potential to address PHS emissions from a range of sources and scales including households, municipalities, industries and governments. An additional strategy (ECS7) represents the combination of the different managerial and technical strategies from ECS3-6 and is included at the request of representatives from a number of municipalities (Table 1).

Table 1. Details of the seven defined ECSs

ECS	Description
ECS1	Business-as-usual
ECS2	Full implementation of relevant EU directives
ECS3	ECS2 combined with the use of voluntary options by households, municipalities, industry/other organisations
ECS4	ECS2 combined with industrial treatment using BAT
ECS5	ECS2 combined with stormwater BMPs (for some PHS also CSO volume reduction and treatment)
ECS6	ECS2 combined with the use of advanced WWTP technologies
ECS7	ECS2 combined with treatment technology options (combination of ECS4, 5 and 6)

Table 2. Details of the ECS scenarios for Cd (figures in brackets indicate level of Cd reduction by identified process/management option/technology compared to ECS1)

ECS no.	Description
ECS1	10% of wastewater collected in CSS discharged as CSOs; WWTPs apply secondary treatment, 20% of the stormwater retained and treated in ponds. 80% of the stormwater discharge directly to the recipient. Cd removal by sludge adsorption (60%)
ECS2	Directive 2000/53/EC restricts Cd content in vehicle materials (25%) Directive 76/116/EEC restricts Cd content in fertilisers (25%) Directive 86/278/EEC restricts Cd content in agricultural applications of sewage sludge (25%) Directive 91/157/EEC regulates the collection and disposal of batteries containing >0.25% Cd (25%) Directive 91/338/EEC prohibits Cd use in paints: (50%) Regulation 466/2001/EC sets maximum levels for Cd in foodstuffs: (25%) 100% of the wastewater generated arrives at the WWTP (no discharge of wastewater by CSOs)
ECS3	ECS2 combined with collection and treatment of waste (40%); waste incineration (20%), energy production (10%), paint in households and battery recycling (25%)
ECS4	ECS2 combined with treatment by BAT of 100% of industrial wastewaters from waste incineration, production of electricity, Cd producing plants, Cd processing plants, manufacture of other inorganic basic chemicals, manufacture of NiCd batteries, and manufacture of other non-metallic mineral products. Manufacture of basic iron and steel and of ferro-alloys etc and recycling; e.g. of NiCd batteries Adsorption to industrial sludge (80%)
ECS5	ECS2 combined with 80% of stormwater generated treated in BMPs (63%)
ECS6	ECS2 combined with adsorption to sludge (82.5%)
ECS7	Combination of ECS2, 4, 5 and 6

Table 3. Details of the ECS scenarios for HCB. All percentages are compared to ECS1

ECS no.	Description
ECS1	As Table 2
ECS2	Whilst the use of HCB is banned in the EU, the ban on HCB does not address its presence as an impurity in the pesticides dichloran and hexachlorocyclohexane; fireworks, and in pentachlorophenol (used for the preservation of wood and impregnation of textiles)
EC3	ECS2 combined with voluntary measures. This ECS will have no effect in many areas as HCB use is banned as a pesticide and the ban is considered implemented in ECS2. However, historic HCB contamination of harbour sediments is assumed in this SHCC and a voluntary initiative exists (partnership between polluting industry, municipality, harbour commission, country board) to dredge and treat 130,000 m3 of sediment (97% efficiency; Eggens & Bakker 2001)
ECS4, 5 and 6	Implementation of ECS2 together with ECS 4, 5 or 6 – will have no effect as use of HCB is banned
ECS7	Combination of ECS2, 4, 5 and 6

Table 4 | Details of the ECS scenarios for NP (figures in brackets indicate level of NP reduction by identified process/management option/technology compared to ECS1)

ECS no.	Description
ECS1	As Table 2
ECS2	Directive 2003/53/EC limits use of NP in domestic cleaning, industrial cleaning, leather production, manufacture of some chemical products, paper manufacturing, pulp manufacturing and textile processing, and suggests limiting the concentration of NP in sewage sludge applied to land (25–50% for different applications) No CSOs occurring and BAT applied to wastewater derived from heavily polluting industries
ECS3	ECS2 combined with voluntary industrial and household initiatives (50%)
ECS4	ECS2 combined with BAT with adsorption to sludge applied to all industrial wastewaters (90%)
ECS5	ECS2 combined with treatment of stormwater using BMPs (72%)
ECS6	ECS2 combined with adsorption of NPs to sludge (87.5%)
ECS7	Combination of ECS2, 4, 5 and 6

Table 5 | Details of the ECS scenarios for PBDE (figures in brackets indicate level of PBDE reduction by identified process/management option/technology compared to ECS1)

ECS no.	Description
ECS1	As Table 2
ECS2	Directive 2002/95/EC restricts the use of hazardous substances (50%); Directive 2002/96/EC impacts on the management of waste electrical and electronic equipment (50%); 2003/11/EC and the BREF on Waste Treatments Industries mitigate the use of PBDE in manufacturing beyond the restriction and the waste management (50%)
ECS3	ECS2 combined with household and municipality voluntary measures: an amnesty for old cars and the collection of upholstery (25%) and industrial goods management of waste beyond BAT (25%)
ECS4	ECS2 combined with industrial treatment by BAT (50%)
ECS5	ECS2 combined with CSO mitigation by 50% e.g. by increasing stormwater infiltration, use of retention ponds, etc. and the remainder of the CSO volumes is treated. 75% of the stormwater is treated in BMPs (1% degradation; 90% adsorption)
ECS6	ECS2 combined with enhanced coagulation/flocculation yield an adsorption of 93% (Seriki *et al*. 2008) and anaerobic degradation of sludge yield a dechlorination by 22% (Shin *et al*. 2010)
ECS7	Combination of ECS2, 4, 5 and 6

The seven ECSs described in Table 1 were developed and evaluated with respect to their effect on the emissions of four different PHS. To accommodate the differences between the selected PHSs in terms of their uses, sources, pertinent legislation, and pollutant-specific treatment efficiencies, it was necessary to construct specific ECS scenarios (see further below) scenario for each PHS under valuation and these are detailed in Tables 2–5. Furthermore, the applicability of education and information campaigns differs for individual products and goods that contain particular PHS, making the release of each PP not only pollutant, but also urban context specific.

Priority hazardous substances

The PHSs selected for testing the performance of the 7 ECSs identified were selected as representative of a range of uses, sources and distributions within the urban receiving compartments Holten Lützhøft *et al*. (2008) and their key uses are described below, where CASRN refers to the Chemical Abstracts Service registry number (ACS 2008):

- *Cadmium (Cd; CASRN: multiple)*. Used as a pigment, corrosion inhibitor, in batteries, as a constituent of various alloys and in vehicular brake pads making it ubiquitous in the urban environment. It was previously used as a stabiliser in PVC production.

- *Hexachlorobenzene (HCB; CASRN: 118-74-1*). Previously used as a fungicide and raw material for synthesis of other organic substances or resins. Also a chemical intermediate.

- *Nonylphenol (NP; CASRN: 25154-52-3*). A precursor to NP ethoxylates which are used as surfactants in detergents, emulsions and pesticides. Also a stabiliser, emulsifier and bactericide as well as a degradation product of NP ethoxylates.

- *Pentabromodiphenyl ether (PBDE; CASRN: 32534-81-9*). An additive flame retardant in mainly foam, electronics, rubber and paint.

Identification of urban sources of PHS (e.g. commodities and activities) and specific information on their dynamics and releases were obtained from the ScorePP database (Holten Lützhøft *et al*. 2009), which includes data on a wide selection of WFD-listed pollutants. Data on specific pollutants can be extracted from the ScorePP database in various ways, e.g. possible pollution sources, dynamics and releases for a given pollutant (as undertaken in this work) or to short-list possible pollutants of concern in a specific location based on knowledge of the activities undertaken in a given catchment. Each pollution source is referred to as a release string (RS) due to the way in which the information is sorted and stored. The database contains mainly generic data from the literature incorporating the results of field and laboratory data. It is therefore possible that identified pollutant releases, emissions and discharges may not be relevant for all case cities and that, whilst every attempt has been made to include key sources of pollutants, there may be additional PP sources for some cities that are not yet listed within the database. An example is Cd emissions from heating systems (e.g. Engelhard *et al*. 2007), which was not considered here.

Emission control strategy scenarios

As different substances have different inherent properties and source/release patterns, the most feasible and appropriate source control measures and treatment processes may vary for different pollutants. In recognition of this, specific ECS scenarios have been developed for each PHS being evaluated, defining which source control and treatment options have been included as well as the associated performance data used (e.g. reduction efficiencies) (see Tables 2–5).

Releases (loads) from each identified PHS source were extracted from the RS database (Holten Lützhøft *et al*. 2009) and the total load was found by extrapolating the RS release documented to the characteristics of the SHCC of ‘Northern European Coastal town’ (NC). For example, releases reported as ‘per person’ were multiplied by the number of inhabitants in NC, releases reported per vehicle where multiplied by the traffic density figures reported for NC etc. This approach was used to calculate the loads associated with ECS1, with the reduction figures reported in Tables 2–5 used to calculate the reduction in total load to a range of urban receiving compartments (for more details see Eriksson et al. 2011).

RESULTS AND DISCUSSION

The results shown in Figure 1 illustrate the major fluxes of the four selected PHSs in the urban environment. Data is presented though the use of relative pollution mitigation efficacies whereby ECS1 (the business-as-usual scenario) is allocated a value of 100% and the change in release per compartment for ECSs 2–7 is shown relative to this. Results indicate how the effect of alternative ECSs vary on a PHS-by-PHS basis and the relative impact of each ECS on both the overall load released and the distribution of loads released to individual receiving compartments. For example, ECS2 has a comparatively much greater impact on total releases of NP in comparison to the total releases of Cd, with releases of NP to surface waters also showing a greater relative reduction in comparison to Cd. This is associated with the fact that the majority of uses of NP are currently covered by existing legislation which specifically refers to its use in applications with the potential to release NP to surface waters. This is in contrast to the current legislative situation for Cd, where existing regulations neither address all products which use Cd nor comprehensively address potential emission pathways.

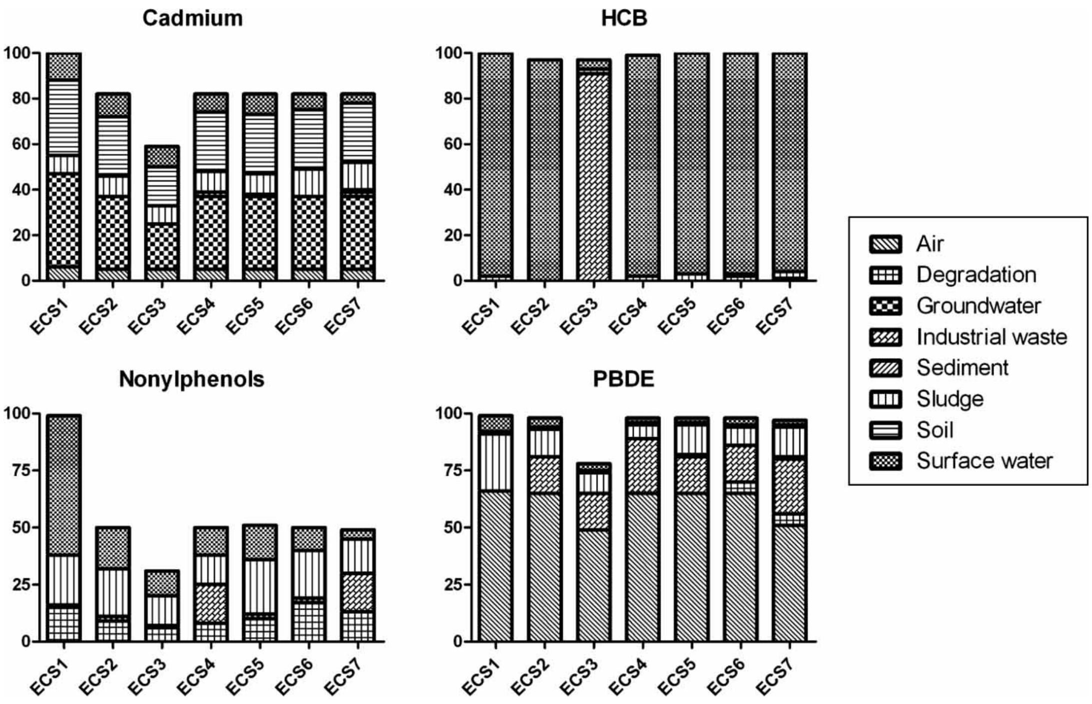

Figure 1. Emissions (%) in each of the defined ECSs relative to the total emission in ECS1 (where 'business-as-usual' is allocated a value of 100% (Note: surface water refers to all combined discharges to surface waters).

The impact of ECS2 is less prominent for HCB and PBDE. The use of both PHSs has been banned in the EU but pollutants can still be found in many urban environments to their presence in which are present in materials accumulated in the city (e.g. PBDE in sofas). Also of particular note is the finding that even the combination of all of the developed ECSs (i.e. ECS7) will not fully eliminate emissions to the environment of any of the PHSs (as required by the EU WFD) raising serious questions about the achievability of this central component of the EU WFD within current technological and managerial contexts.

Figure 2 presents data on ECS implementations on a 'compartment by compartment' basis. Results indicate that Cd is primarily released to soil and groundwater (Figure 2) and the emission is decreased compared to the business-as-usual scenario (ECS1) by the implementation of existing EU legislation (ECS2) and further by the use of voluntary measures (ECS3) targeting the improved collection and treatment of Cd-containing waste such as the recycling of batteries (Figure 1). As Cd is mainly associated with nonpoint sources the impact of ECS4 (increased on-site treatment of effluents by industry) did not yield a substantial reduction of Cd emissions to surface waters. It is noted that the implementation of ECS4, ECS5, ECS6 and ECS7 changes the compartment where the Cd is stored (e.g. see emissions to surface water in Figure 2) rather than mitigate the total pollutant release (see Figure 1).

The use of HCB has been mitigated through EU legislation already implemented in the SHCC of NC studied here. However, part of the scenario for this SHCC is that the city contains a substantial sink of HCB contaminated sediments. Based on its organic carbon to water phase distribution (Holten Lützhøft *et al*. 2008), it is predicted that a constant release of HCB to the surrounding water will occur. In this situation, only voluntary initiatives to dredge and treat the contaminated sediment will have an obvious effect with regard to the overall released load (Figures 1 and 2).

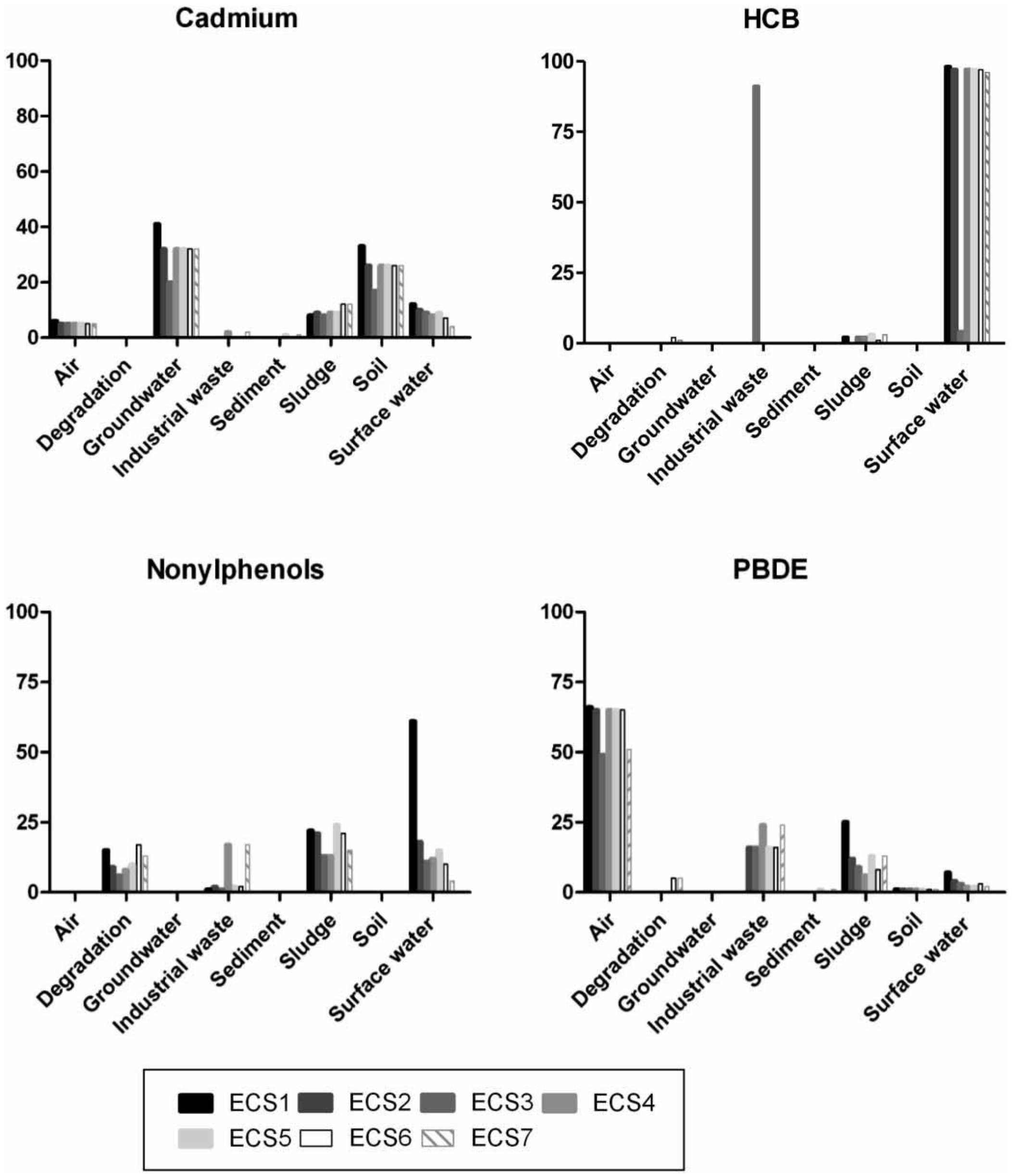

Figure 2. Distribution of PHSs in urban compartments for the different ECSs as percentage of the total load (Note: surface water refers to all discharges to surface waters).

Data presented in Figure 2 indicates that NP mainly distributes between surface waters and sewage sludge, as well as being collected as industrial waste or degraded (biological or chemical degradation on use of BAT, stormwater BMPs, CSO treatment and/or WWTPs technologies). Results of the application of the various ECSs indicate that implementation of ECS2 will result in a substantial decrease in emissions of NP to urban surface waters (Figure 2). This reduction may be further enhanced through application of ECS3 (combining ECS2 with voluntary options such as cessation of use of products containing NP via green procurement, information campaigns, etc). The introduction of BAT for industrial treatment (ECS4) yields increased amount of industrial waste/sludge whereas advanced wastewater treatment (ECS6 and ECS7) yielded the largest NP degradation (Figure 1) demonstrating that different ECS have differing implications for the long-term fate of pollutants following mitigation and hence impact evaluations of the sustainability of alternative mitigation options.

The flame-retardant PBDE is volatile and since many sources are located outdoors (e.g. paint), the primary receiving compartment is air (Figure 2). Full implementation of relevant EU directives will increase the amount of industrial waste generated with the use of ECS4 (BAT treatment), further increasing the load to this compartment. As with HCB, implementation of ECS6 and ECS7 results in the highest levels of degradation occurring. However, it is also noted that an identified limitation of the current study is that, whilst PBDE in the gaseous phase can precipitate or dissolve in rain and therefore be deposited on urban surfaces (including soil), this pathway has not yet been integrated within these findings.

For all four PHS evaluated, the least favourable strategy is ECS1, indicating that PHS loads to the environment can be reduced following the application of technologies and/or managerial options currently available. Hence, if implementation of the EU WFD does not lead to lower loads of the four PHS considered in this study to receiving waters, the wider socio-economic (and in particular institutional) aspects of implementing the identified feasible measures should form a key focus of research attention. Data presented in this study indicates that total loads to the environment are typically only reduced following implementation of ECS2, (underlining the importance of full implementation and subsequent enforcement/supervision of the relevant EU directives) and ECS3 (voluntary options) indicating that both industry, environmental regulators and the wider community can take an active role in contributing to EU WFD objectives. However, as noted earlier, despite the fact that that the developed ECS span a wide range of structural and non-structural mitigation options, none ensure compliance with the WFD requirement of cessation of emissions. Development of the PHS specific scenarios further illustrates the opportunities for managing PHSs before they become part of the urban water cycle (e.g. by implementing BAT (ECS4) as well as the need to address historic uses of substances e.g. managing ‘sinks of pollution’ such as sediments as identified in the HCB scenario. If distinct point sources are not present, the use of household and industrial voluntary initiatives, substitution of products, improved handling practices and management of PHSs in existing stock in society can be very beneficial (ECS3). However, if releases to wastewater do occur, tertiary treatment of wastewater, sludge treatment and mitigation and treatment of CSOs and stormwater will reduce the load to urban surface waters (ECSs 5–7). Hence, the ECS should be both PHS and city-specific, and hence likely to consist of a combination of source control and treatment options.

The results generated by application of all the ECSs are associated with varying types and levels of uncertainty. This is especially true for ECS3 as it was not possible to source robust data on the efficiencies of information campaigns. Whilst the aims and process through which such initiatives are implemented are documented, the effect of such campaigns on pollutant loads are rarely reported (Wickman *et al*. 2009). A consequence of this is that the ‘reduction efficiencies’ for the voluntary measures identified were allocated using expert judgement and a fuller evaluation of the efficiency of such measures is highlighted as a key research need. Another example of a source of uncertainty is in relation to ECS6, and the fact that reported advanced WWTP treatment efficiencies were found to vary by up to an order of magnitude depending on the PHS under evaluation. Addressing this issue again required the use of expert judgment in selecting a single value for use in calculations.

Information about ‘relative reduction potentials’ is relevant for PHSs, where the ultimate goal is complete cessation of discharges. For other priority substances (PSs) listed in the EU WFD the goal is not complete cessation, but to bring down the emissions to the water environment to levels where defined annual average or maximum threshold concentrations (i.e. environmental quality standards) are respected. This requires consideration of the magnitude and dynamics of releases, emissions and discharges, which can, for example, be investigated by the use of models and though monitoring campaigns. Depending on the compartment which the PSs accumulate in, the associated financial burden will differ. For example, wider use of ECS4 and associated increased levels of pollutants in resulting sludges would have major economic implications for industry, with the greater use of ECS6 having similar implications for water companies emphasising the need for robust economic evaluation as part of the mitigation option-selection process.

CONCLUSIONS AND RECOMMENDATIONS

The developed ECSs are ‘standardised’ combinations of individual emission control options and may address pollutant release magnitude and dynamics across different parts of a catchment. The ECSs included (1) business-as-usual, (2) full implementation of relevant EU directives, (3) ECS2 in combination with voluntary options for household, municipalities and industry, (4) ECS2 combined with industrial treatment and BAT, (5) ECS2 in combination with stormwater and CSO treatment, (6) ECS2 in combination with advanced wastewater treatment, and (7) combinations of ECS3-6. The evaluated PHSs (cadmium (Cd), hexachlorobenzene (HCB), nonylphenol (NP) and pentabromodiphenyl ether (PBDE)) differ in relation to their sources and environmental behaviour and therefore in the receiving compartment with which they become associated. Despite these differences, this study indicates that total loads to the environment can be reduced through full implementation of existing legislation (ECS2) and the application of voluntary measures (ECS3). In contrast, whilst the application of the remaining ECSs 4, 5, 6 and 7 influences the relative amount of pollutants emitted to a particular receiving compartment, emitted loads are not reduced on an overall basis.

Generating a wider appreciation of this effect amongst pollution management practitioners is crucial from two key perspectives. Firstly, a lack of awareness of wider and interconnected impacts of manipulating the environmental behaviour of pollutants (i.e. the potential transference of pollution from one compartment to another as opposed to a reduction in total environmental emissions) is at odds with the EU WFD’s sustainability philosophy in that it is promoting an approach which ‘moves’ as opposed to manages environmental pollution. Secondly, and conversely, a fuller understanding of such impacts raises the potential for developing Programmes of Measures which aim to enhance the transfer of a pollutant from one compartment to another to facilitate its subsequent remediation (e.g. preferential accumulation of pollutants in industrial as opposed to municipal wastewater treatment sludges at concentrations which may be more easily addressed).

This study demonstrates the utility of a SHCC as a platform to support the theoretical evaluation of alternative pollutant mitigation options in the presence of identified data gaps (through the incorporation of data from other cities in combination with expert judgement). Having constructed this ‘generic base’ for evaluating the impact of alternative ECS, there is ample potential for this SHCC to be ‘customised’ to reflect the conditions within further urban locations on a city-specific basis, contributing to the need to support practitioners in implementing European/national policy at a local level. However, caution in the use of this approach is expressed in particular in relation to the current lack of any quantitative data on the efficiency of reducing emissions of many of the EU WFD pollutants by the technologies and voluntary options identified for many EU WFD pollutants. This aspect is highlighted as a key factor reducing the level of confidence which can be associated with the results generated. It is within this context that it is recommended that the developed approach be utilised in its current format as a decision-support (as opposed to decision-making) tool. For example, the approach presented here could form a focal point of discussion for stakeholders, facilitating the comparison of available technologies and voluntary measures within a city-specific context. Collation of available data (in combination with expert judgement where this is not available) and its subsequent evaluation over both the short-term (e.g. immediate impact with respect to pollutant loadings associated with a particular compartment) and longer-term (e.g. implications for subsequent waste management) facilitate stakeholders in viewing the ‘bigger picture’ and thus ultimately the relative sustainability of the pollutant management options selected.

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