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Research article

Decision support for water quality management of contaminants of emerging concern

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A B S T R A C T

Water authorities and drinking water companies are challenged with the question if, where and how to abate contaminants of emerging concern in the urban water cycle. The most effective strategy under given conditions is often unclear to these stakeholders as it requires insight into several aspects of the contaminants such as sources, properties, and mitigation options. Furthermore the various parties in the urban water cycle are not always aware of each other's requirements and priorities. Processes to set priorities and come to agreements are lacking, hampering the articulation and implementation of possible solutions.

To support decision makers with this task, a decision support system was developed to serve as a point of departure for getting the relevant stakeholders together and finding common ground. The decision support system was iteratively developed in stages. Stakeholders were interviewed and a decision support system prototype developed. Subsequently, this prototype was evaluated by the stakeholders and adjusted accordingly. The iterative process lead to a final system focused on the management of contaminants of emerging concern within the urban water cycle, from wastewater, surface water and groundwater to drinking water, that suggests mitigation methods beyond technical solutions. Possible wastewater and drinking water treatment techniques in combination with decentralised and non-technical methods were taken into account in an integrated way. The system contains background information on contaminants of emerging concern such as physical/chemical characteristics, toxicity and legislative frameworks, water cycle entrance pathways and a database with associated possible mitigation methods. Monitoring data can be uploaded to assess environmental and human health risks in a specific water system. The developed system was received with great interest by potential users, and implemented in an international water cycle network.

1. Introduction

Chemicals are continuously produced for various beneficial purposes, such as protecting crops, conserving food or treatment of diseases. Over 347.000 chemicals are registered and regulated via national and international authorities (CHEMLIST), new chemicals enter the market continuously and the global volume of production of chemicals is growing (CEFIC, 2016). Many of these chemicals and their transformation products enter the aqueous environment during their life cycle (Schwarzenbach et al., 2006).

Preliminary risk assessments consistently show that these environmental concentrations are lower than required for adverse human health effects, hence for individual compounds risks are not expected (Bruce et al., 2010; de Jongh et al., 2012; Debroux et al., 2012; Houtman et al., 2014; Schriks et al., 2010). However the toxicological risk of summed concentrations in complex environmental mixtures is heavily debated, especially related to potential endocrine disruption (Bergman et al., 2013; Dietrich et al., 2013;

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Nohynek et al., 2013; Vandenberg et al., 2012). This causes increasing concern for the public, regulators and users of surface water (Diamond et al., 2015; Schwarzenbach et al., 2006).

There are many definitions of these contaminants of emerging concern (CECs), but in this article the following definition is used: “manufactured or manmade chemicals or materials which have now been discovered or are suspected to be present in various environmental compartments and whose toxicity or persistence are likely to significantly alter the metabolism of a living being” (Sauvé and Desrosiers, 2014). CECs include, but are not limited to, drugs of abuse, artificial sweeteners, pesticides and biocides, musks and fragrances, perfluorinated compounds, industrial substances, nanoparticles, plasticisers, pharmaceuticals and transformation products of these chemicals (Richardson, 2012; Richardson and Ternes, 2011).

Information on CECs multiplies with rapid speed. Several legal frameworks, e.g. the Water Framework Directive (WFD) and the EU chemicals regulation (REACH), are dealing with the issue both from a water quality and authorisation perspective (EU, 2000, 2006). However water quality legislation, both on a national and international level, are not meant to cover all individual substances authorised on the market (Houtman, 2010). Furthermore there is often a time lag from the time a compound with adverse effect is observed in the environment, to the time that the necessary legislation or policy is implemented (Christensen et al., 2011; Halden, 2015). The time lag is due to complex decision structures and the need for compromises (Halden, 2015; Houtman, 2010). This leaves water authorities and drinking water companies with the question if, where and how to abate these substances in the urban water cycle.

Many strategies are available to mitigate emissions. During the design and production stage of the chemicals, legal regulations are in force. During the use stage, strategies such as drift reduction of pesticides can be used. Finally in the waste and removal stage, strategies such as take-back schemes for pharmaceuticals or treatment of wastewater and drinking water can be implemented (Schirmer and Schirmer, 2008). The most effective strategy under given conditions are often not clear to stakeholders. It requires insight into several aspects of the contaminants such as sources, properties, mitigation options, and their costs and benefits. Furthermore, multiple stakeholders (such as water boards, drinking water companies and municipalities) are often not aware of each other's requirements and priorities. Finally, processes to set priorities and come to agreements are lacking and this hampers the finding and implementation of possible solutions. The setup of river basin management plans required by the WFD address this issue (EU, 2000).

In 2013 the European Interreg programme funded the TAPES programme (Transnational Action Programme on Emerging Substances), with the aim to create a joint knowledge platform on CECs in the urban water cycle. As part of this knowledge platform a Decision Support System (DSS) was developed in strong cooperation with stakeholders within the whole water cycle. The objective of the DSS was to facilitate decision makers with the complex task of deciding on effective and efficient strategies to control CECs within their segment of the urban water cycle. To our best knowledge, no such DSS exists at this moment. In this paper the development process of this DSS is described, starting with the design criteria and finishing with the final DSS.

2. Design criteria

2.1. DSSs and complex issues

The definition of DSSs (Power and Sharda, 2009) is “an interactive computer-based system that helps people use data, documents, knowledge, and models to solve problems and make decisions”. DSSs are built to *support* people in making decisions, not to *make* the decision itself (Angehrn and Jelassi, 1994; Power and Sharda, 2009). DSSs are regularly used by decision makers all over the world (Delpla et al., 2014; Mysiak et al., 2005; Power and Sharda, 2009). There is no consensus on the classification of various types of DSSs (Holsapple, 2003; Power and Sharda, 2009). The categorisation by Power (2002) is the one that will be used here:

1. Communication-driven; DSS includes communication and collaboration supported by technologies such as e-mails, bulletin boards, chat systems and interactive videos.
2. Data-driven; DSS gives access to tools to manipulate large sets of data.
3. Document-driven; DSS can be used to retrieve and analyse documents, such as product specifications, minutes of meetings, policies and procedures.
4. Knowledge-driven; DSS suggests actions within a specific domain.
5. Model-driven; DSS gives access to a quantitative model.

Most DSSs are hybrids and consist of two or more of the above mentioned drivers (Power and Sharda, 2009).

DSSs shifted with time from solving semi-structured problems, to solving complex issues such as ‘wicked’ problems (Beynon et al., 2002; Courtney, 2001; McCown, 2002; Mysiak et al., 2005; Rauscher, 1999). The characteristics of a ‘wicked’ problem is that stakeholders cannot easily agree on the problem definition, and options for solutions are not clear beforehand (Rittel and Webber, 1973). To solve ‘wicked’ problems, a collectively accepted solution is required (Hocking et al., 2015). Therefore the main focus should be on the problem formulation, based on discussions with stakeholders, to incorporate their perspectives (Mitroff and Linstone, 1993; Shim et al., 2002) and to ensure that all relevant variables are included in the analysis (Shim et al., 2002; Wassen et al., 2011).

DSSs have several pitfalls that need to be accounted for in the design phase (McBride, 1997; Mysiak et al., 2005; Newman et al., 1999; Wassen et al., 2011). Common pitfalls are:

1. The process of decision making goes together with a learning process (Salewicz and Nakayama, 2004). It is difficult to know beforehand what information is needed to make decisions.
2. The acceptability of a DSS links to the stakeholders' possibilities to contribute and their abilities to communicate results, rather than the credibility of the underlying model (scientific soundness, high quality data etc.) (Wassen et al., 2011). Acceptability by the stakeholders is often known only at the last phase of the DSS development.
3. In order to meet new or more complex requirements of the decision makers, a DSS constantly needs to be kept up-to-date and further developed, otherwise it quickly becomes obsolete (Newman et al., 1999).

2.2. DSSs in the water sector

DSSs are widely used in the water sector, mostly related to river management (Salewicz and Nakayama, 2004; Xu et al., 2007). DSSs are developed to help implementing aspects of the EU Water Framework Directive (WFD), such as MULti-sectoral INtegrated and Operational decision support system (MULINO), SOurce COntrol of Priority Substances in Europe (SOCOPSE), and