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A model library for dynamic transport and fate of micropollutants in integrated urban wastewater and stormwater systems

Luca Vezzaro [a,*], Lorenzo Benedetti [b,c], Veerle Gevaert [b], Webbey De Keyser [b], Frederik Verdonck [b], Bernard De Baets [d], Ingmar Nopens [b], Frédéric Cloutier [e], Peter A. Vanrolleghem [a,e], Peter Steen Mikkelsen [a]

[a] DTU Environment, Technical University of Denmark, Department of Environmental Engineering, Miljøvej, Building 113, 2800 Kgs. Lyngby, Denmark
[b] BIOMATH, Department of Mathematical Modelling, Statistics and Bioinformatics, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium
[c] WATERWAYS srl, Via del Ferrone 88, 50023 Impruneta, FI, Italy
[d] KERMIT, Department of Mathematical Modelling, Statistics and Bioinformatics, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium
[e] modelEAU, Département de génie civil et de génie des eaux, Université Laval, 1065 av. de la Médecine, Québec, QC G1V 0A6, Canada

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A B S T R A C T

The increasing efforts in reducing the emission of micropollutants (MP) into the natural aquatic environment require the development of modelling tools to support the decision making process. This article presents a library of dynamic modelling tools for estimating MP fluxes within Integrated Urban Wastewater and Stormwater system (IUWS – including drainage network, stormwater treatment units, wastewater treatment plants, sludge treatment, and the receiving water body). The models are developed by considering the high temporal variability of the processes taking place in the IUWS, providing a basis for the elaboration of pollution control strategies (including both source control and treatment options) at the small spatial scale of urban areas. Existing and well-established water quality models for the different parts of the IUWS (e.g. ASM models) are extended by adding MP fate processes. These are modelled by using substance inherent properties, following an approach commonly used in large-scale MP multimedia fate and transport models. The chosen level of complexity ensures a low data requirement and minimizes the need for field measurements. Next to a synthesis of model applications, a didactic example is presented to illustrate the potential of the use of the developed model library for developing, evaluating and comparing strategies for reduction of MP emissions from urban areas.

Software availability

Name of the software: IUWS_MP model library
Software requirements: WEST 3.7.6 (or higher)
Program Language: Model Specification Language (MSL)
Program Size: approximately 25 MB
Availability: The source code for the IUWS_MP model library can be obtained for free; please contact Prof. Peter Steen Mikkelsen, Technical University of Denmark, Department of Environmental Engineering, Miljøvej, Building 113, 2800 Kgs. Lyngby, Denmark – e-mail: psmi@env.dtu.dk.

1. Introduction

The reduction of emission of micropollutants (MP) from urban areas is an essential step towards the improvement of the environmental status of natural waters, as required by legislation such as the European Water Framework Directive (WFD – European Commission (2000)). This can be achieved through the implementation of emission control strategies dealing with the entire Integrated Urban Wastewater and Stormwater system (IUWS). These emission control strategies include a wide variety of control options (source control, treatment, etc.) whose efficiency needs to be assessed and compared before a final decision on implementation is taken. Urban water managers can thus benefit from the application of mathematical models (see for example Benedetti et al., 2013) to evaluate the effects of the various MP pollution control strategies and to identify the option (or combination thereof) which ensures the most cost-effective solution. Also, models can be used for training and education purposes, enabling

* Corresponding author. Tel.: +45 45251579; fax: +45 45932850.
E-mail address: luve@env.dtu.dk (L. Vezzaro).

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the understanding of the complex interactions and processes which affect MP fluxes across the urban water systems.

Various modelling tools are available for estimating MP concentrations at the river basin scale (e.g. Feijtel et al., 1997; Keller et al., 2007; Koormann et al., 2006; Schowanek et al., 2001; Williams et al., 2009), but they often assume steady state conditions and focus on wastewater treatment plants (WWTP) and river stretches, neglecting or excessively simplifying the sewer network. Given (i) the complexity of the urban water system, (ii) the highly dynamic processes taking place in it, (iii) the number of possible control options and (iv) the wide variety in characteristics of the considered substances, it is important to apply an approach which includes the entire IUWS. Recent studies (e.g. Gasperi et al., 2012; Launay et al., 2013) highlighted how Combined Sewer Overflows (CSO) can represent an important MP source which can affect the overall quality of the receiving water body. Therefore, limiting the model to river and WWTP strongly reduces the ability to simulate the effect of MP control strategies specifically acting at the relatively small scale of urban areas (e.g. local handling of storm- and wastewater, CSO treatment, WWTP tertiary treatment).

Furthermore, the major driver of the system, rainfall, is characterized by a highly dynamic behaviour. Therefore, steady state or equilibrium multimedia fate models, commonly applied in chemical risk assessment (e.g. Feijtel et al., 1997; Koormann et al., 2006; Struijs, 1996), might not be appropriate to fully describe the highly dynamic processes and the effect of specific pollution control strategies (e.g. CSO treatment). This was already recognized in this discipline because Boeije et al. (1997), for example, presented a stochastic approach to take into account spatial and temporal variability in chemical risk assessment, while employing steady-state models to describe the fate of chemicals.

The development of dynamic IUWS modelling tools was among the main objectives of the ScorePP project (Source Control Options for Reducing Emissions of Priority Pollutants – www.scorepp.eu), which focused on the 33 priority substances (PSs) and substance groups identified in the European legislation, i.e. the EU Environmental Quality Standard (EQS) directive (European Commission, 2008). This directive defines the Maximum Allowable Concentration (MAC-EQS) and Annual Average (AA-EQS) which should not be exceeded in the receiving water. Among these 33 substances, the ScorePP project specifically focused on those defined as priority hazardous substances, whose release into the environment should be eliminated within a short time frame (European Commission, 2000).

Within the ScorePP project, a model library that allows creating integrated dynamic models for the estimation of MP sources and fluxes at the urban scale was developed and it is presented in this contribution. The developed models are aimed to provide results that can be used to evaluate the performance of different MP control strategies, including compliance with legal requirements on the quality of receiving waters, e.g. the EU Environmental Quality Standards (European Commission, 2008). Specifically, these dynamic MP transport and fate models allow the quantification of the MP release from urban sources and their fate within different treatment systems (Plósz et al., 2013) and different environmental compartment (e.g. sediments, groundwater, atmosphere). The outputs of these models can subsequently be used to perform Substance Flow Analysis (SFA) for various MPs at the urban scale (e.g. Bjorklund et al., 2011), allowing for the comparison of different scenarios for MP emission control (e.g. Revitt et al., 2013). The models can be linked to river basin scale Multimedia Fate and Transport Models (MTFMs) commonly used in chemical risk assessment (De Keyser et al., 2010a). This allows the simulation of the interaction between the small-scale urban environment, where the assessment of e.g. short term toxic effects requires a detailed temporal resolution, and the surrounding environmental compartments, which are characterized by processes that can be represented in a less detailed manner (for example, long-range transport of MP and wet deposition, effect of stormwater control strategies on groundwater). An example is presented in De Keyser et al. (2010a).

This article presents the IUWS_MP model library by illustrating the main concepts that were adopted during the model development. The structure of the various units included in the model is subsequently introduced, and examples of application of the IUWS_MP model in the literature are then summarized. The results presented in this study describe a tool which can be used by urban water managers for control of MP releases at the urban scale.

2. Model library development

The development of the various sub-models included in the IUWS_MP system followed the procedure commonly adopted in model development (Carstensen et al., 1997; Dochain and Vanrolleghem, 2001; Jakeman et al., 2006; Refsgaard et al., 2007). These include (Fig. 1): (i) definition of model purpose (Section 2.1) and (ii) model context (Section 2.2); (iii) system conceptualization, including specification of available data, models and other prior knowledge (Section 2.3); and (iv) definition of model structure and

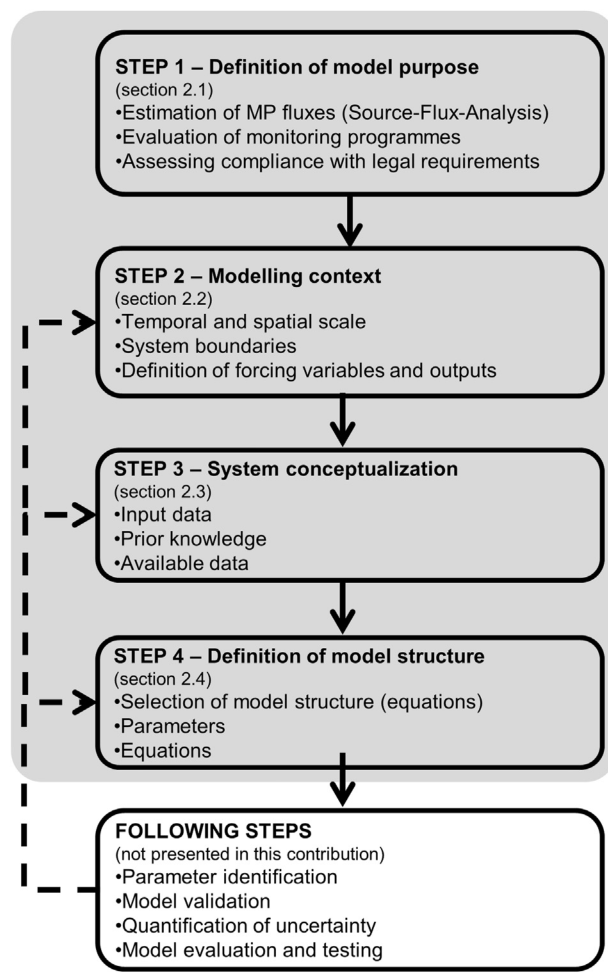

Fig. 1. Steps in the development of the IUWS_MP model that are presented in this article (in grey).
Adapted from Carstensen et al. (1997), Dochain and Vanrolleghem (2001), Jakeman et al. (2006), and Refsgaard et al. (2007).