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Evaluation of stormwater micropollutant source control and end-of-pipe control strategies using an uncertainty-calibrated integrated dynamic simulation model

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ABSTRACT

The estimation of micropollutant (MP) fluxes in stormwater systems is a fundamental prerequisite when preparing strategies to reduce stormwater MP discharges to natural waters. Dynamic integrated models can be important tools in this step, as they can be used to integrate the limited data provided by monitoring campaigns and to evaluate the performance of different strategies based on model simulation results. This study presents an example where six different control strategies, including both source-control and end-of-pipe treatment, were compared. The comparison focused on fluxes of heavy metals (copper, zinc) and organic compounds (fluoranthene). MP fluxes were estimated by using an integrated dynamic model, in combination with stormwater quality measurements. MP sources were identified by using GIS land usage data, runoff quality was simulated by using a conceptual accumulation/washoff model, and a stormwater retention pond was simulated by using a dynamic treatment model based on MP inherent properties. Uncertainty in the results was estimated with a pseudo-Bayesian method. Despite the great uncertainty in the MP fluxes estimated by the runoff quality model, it was possible to compare the six scenarios in terms of discharged MP fluxes, compliance with water quality criteria, and sediment accumulation. Source-control strategies obtained better results in terms of reduction of MP emissions, but all the simulated strategies failed in fulfilling the criteria based on emission limit values. The results presented in this study shows how the efficiency of MP pollution control strategies can be quantified by combining advanced modeling tools (integrated stormwater quality model, uncertainty calibration).

1. Introduction

The move towards a holistic approach in urban water management has increased the focus on stormwater quality management. The growing awareness of the potential non-wanted biological effects of stormwater discharges due to micropollutants (MP), including heavy metals and organic compounds (e.g. Eriksson et al., 2007; Kayhanian et al., 2008; Wium-Andersen et al., 2011; Zgheib et al., 2012; Zhang et al., 2011) and the legal requirements for reducing the discharge of these substances (e.g. the Water Framework Directive (WFD – EC, 2000)) require extended monitoring campaigns, as well as development and implementation of strategies to control stormwater pollution. The collection of monitoring data to support these strategies is however affected by significant financial and technical limitations (see for example Ledin et al., 2013), as representative samples during stormwater discharges are costly and difficult to collect. Furthermore, MP are commonly found in low concentrations (in the range of ng/l-μg/l), which are difficult to measure. Conversely, information on different MP sources can be retrieved using cartographic information (stored in GIS databases) that is commonly available at the municipality level. For each land usage it is possible to find MP release data in the existing literature, or using database systems supporting pollutant source mapping (e.g. Lützhøft et al., 2012; Revitt et al., 2013). Therefore integrated models which combine source characterization with measured data are essential tools to understand and analyze the behavior of complex stormwater systems and to evaluate different strategies to achieve desired water quality standards, as discussed for combined systems by Rauch et al. (2005).

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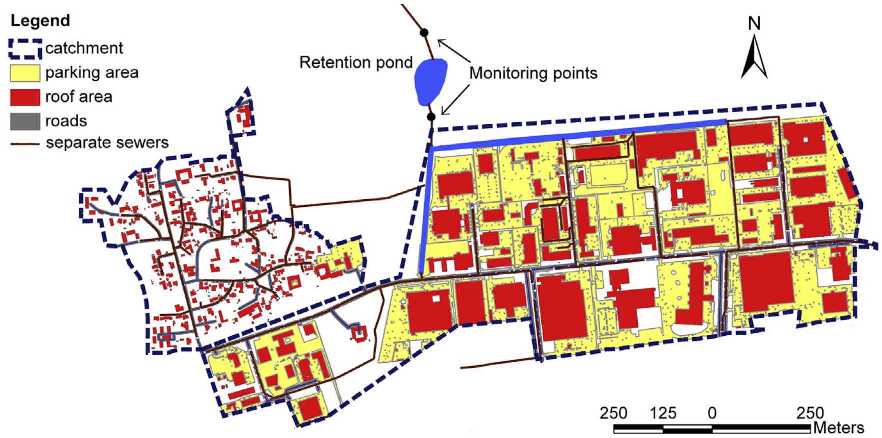

Fig. 1. Characterization of the study area according to land usage (Vezzaro et al., 2012).

A great number of integrated models have been developed, tested and applied in the last decade with main focus on combined sewer systems, whereas diffuse pollution loads deriving from separate systems and stormwater treatment have received little attention from modelers, with some relevant exceptions (see for example the review in Elliott and Trowsdale, 2007). Also, as discussed by Bertrand-Krajewski (2007), stormwater quality modeling is affected by significant sources of uncertainty, which may limit the application of these tools in practice. For example, Vezzaro et al. (2012) introduced an integrated model – combining MP source characterization with dynamic modeling of runoff quality and stormwater treatment. Due to lack of data, only the hydraulic submodel was calibrated. The use of uncertainty analysis techniques is therefore essential to assess the prediction bounds of the models. In this context, the Generalized Likelihood Uncertainty Estimation technique (GLUE – Beven and Binley, 1992) has increasingly been applied in stormwater quality modeling due to the limited number of prior assumptions about the error structure involved (Freni et al., 2009). In this context, the term "uncertainty calibration" (Lindblom et al., 2011; McIntyre et al., 2002) has been coined for identifying "calibrated" (behavioral) parameter distributions that contain information about the model's predictive uncertainty, conditioned on the data used for calibration.

This study presents the uncertainty-calibration of the integrated model presented by Vezzaro et al. (2012) against water quality measurements, namely traditional quality parameters (Total Suspended Solids – TSS), heavy metals (copper – Cu – and Zinc – Zn), and organic substances (fluoranthene – CAS 206-44-0). The uncertainty-based calibration increases the robustness of model-based evaluation of pollution reduction strategies, as urban water managers can include result uncertainty (often neglected) in the comparison of different realistic scenarios. A case study is used to represent a common situation in the urban water field, where limited water quality data are available and pollution control options need to be implemented. The presented results thus illustrate the flexibility of the proposed approach as support to urban water managers.

2. Material and methods

2.1. The Albertslund case study

The Hersted Industripark catchment is a 95 ha mixed industrial-residential catchment located in the Albertslund municipality (Denmark). Runoff is collected by a separate drainage network consisting of open channels in the downstream end and is treated in a retention pond (Basin K) before discharge to a stream (Fig. 1). Several monitoring campaigns (Table 1) have been carried out in the catchment in order to assess the present stormwater quality. Stormwater composite samples were collected at the pond inlet (using a flow-proportional sampler) and at the outlet (using a time-proportional sampler). Samples were analyzed for TSS, heavy metals (Cu and Zn) and organic substances (fluoranthene – CAS 206-44-0). TSS was analyzed by filtering the sample through 1.5 mm Whatman™ 934-AH™ glass microfiber filters and drying the filtrate remained on the filter at 105 °C. Total and dissolved (0.45 m filter) Cu and Zn were analyzed using induced coupled plasma optical emission spectroscopy (ICP-OES). Fluoranthene was analyzed using the Gas Chromatography Mass Selective Detector (GC-MSD) by the commercial lab Højvang Miljølaboratorium A/S.

2.2. Pollution control strategies

Six different scenarios were identified in collaboration with Albertslund municipality, to exemplify potential strategies for reducing the MP loads discharged to the aquatic environment

Table 1
Description of the measurements used in the uncertainty calibration.

Data	Period	Resolution	No. of events		No. of samples	
Inflow, outflow	2009/09/22–2011/07/14[a]	2 min	216		–	
			Cu, Zn	MP[b]	Cu, Zn	MP[b]
Inlet quality	May 2010–May 2011	Flow-proportional	10	5	51[d]	13[c]
Outlet quality	September–October 2010	Time proportional	7	6	31	9[c]

[a] Due to interruptions in monitoring and snow melting processes, the available measurements cover approximately 293 days.
[b] Fluoranthene.
[c] Composite samples obtained by three different bottles.
[d] Some of the samples are composite samples.