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Performance assessment of a commonly used "accumulation and wash-off" model from long-term continuous road runoff turbidity measurements

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ABSTRACT

The suitability of a commonly used accumulation and wash-off model for continuous modelling of urban runoff contamination was evaluated based on 11-month turbidity and flow-rate records from an urban street. Calibration and uncertainty analysis were performed using a Markov Chain Monte-Carlo sampling method for both suspended solids loads (discharge rates) and concentration modelling. Selected models failed at replicating suspended solids concentration over the complete monitoring period. The studied dataset indeed suggests that the accumulation process is rather unpredictable and cannot be satisfactorily represented with usual accumulation models unless short periods are considered. Regarding suspended solid loads modelling, noticeably better performance was achieved, but similar results could as well be obtained with much simpler constant concentration models. Unless providing very accurate estimates of concentrations in runoff, accounting for their temporal variability during rain events may therefore not always be necessary for pollutant loads modelling, as loads are in fact mostly explained by runoff volumes.

1. Introduction

Since the early eighties, several research programs have identified urban runoff as a major source of diffuse contamination and evidenced the need for better stormwater pollution control (Saget, 1994; US-EPA, 1983). Today, many local communities have already undertaken mitigation efforts to minimize the adverse impacts of stormwater discharge on the environment. More specifically, Low Impact Development (LID), advocating for on-site runoff and pollution control, has become increasingly popular (Ahiablame et al., 2012; Dietz, 2007). In this context, simulation of temporal variations of pollutant concentrations in runoff originating from urban surfaces such as streets during rainfall (and from a storm to another) is of great interest to both researcher and practitioners for various applications related to the development of relevant stormwater management strategies for diffuse pollution control.

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Various models have therefore been proposed in the past, among which, "accumulation and wash-off" models, implemented in most software solutions (Aryal et al., 2009; Obropta and Kardos, 2007) are often relied on to replicate time series of concentrations. While such models have been shown to perform relatively well (Crobeddu and Bennis, 2011; Piro and Carbone, 2010; Wang et al., 2011), investigation of the temporal variability of concentrations in runoff has, however, for a long time been restricted by experimental constraints related to sampling methods and thus relied on relatively scarce observations, with limited number of rain-events and very partial information on pollutant wash-off dynamics (Métadier and Bertrand-Krajewski, 2012). As a consequence, these models have generally not been verified against long-term continuous water quality measurements and several recent findings suggest that their ability to simulate temporal variability of pollutant concentrations in runoff might have been overestimated (Dotto et al., 2011; Freni et al., 2009; Kanso et al., 2005; Shaw et al., 2010).

The use of long-term continuous water quality measurements, which have only recently been made available, provides significant opportunities for in depth investigation of the processes associated with stormwater contamination (Deletic, 1998; Hannouche et al., 2014; Joannis et al., 2014; Métadier and Bertrand-Krajewski, 2012). The main purpose of this study is therefore to discuss and clarify the capacity of conventional water quality models to simulate sediment wash-off dynamics based on continuous monitoring of flow-rate and turbidity from an urban street over an 11-month period. While models' ability to replicate both suspended solids loads (e.g. discharge rates) and concentrations will be investigated, application of a "Markov Chain Monte-Carlo" (MCMC) method for calibration will furthermore enable quantification of uncertainties associated with parameters values so as to better identify potential limitations of usual accumulation and wash-off formulations.

2. Material and methods

2.1. Experimental settings

The experimental site is located in "Sucy-en-Brie" municipality, a residential district within Paris conurbation. The studied catchment consists in an 800 m^2 portion (½ roadway width + sidewalk) of an urban road carrying moderate traffic loads (~8000 vehicles per day), with a runoff length of 160 m and an average slope of 0.8%. Runoff was collected by a storm drain where the monitoring equipment was installed. 11-litres tipping buckets were used for flow-rate measurement corresponding to a 0.014 mm resolution in runoff height over drainage area.

Runoff quality was monitored with a YSI 6820VZ multi-parameter probe. In order to save storage capacity and reduce power consumption, the probe was driven by the flow-metre and measurements were performed at 1-min time step during runoff periods only (from the first bucket tipping of a rain event up to 30 min after the last tipping). Turbidity measurements were here considered as a surrogate for runoff contamination. In order to facilitate the interpretation of results and comparison with other studies, turbidity data was however converted into Total Suspended Solids concentrations (TSS) from a linear TSS-turbidity relationship adjusted from event mean runoff samples performed for 7 rain events ($R^2 = 0.96$). Implication of the accuracy of this relation on the TSS values calculated or modelled will not be discussed here (further details on TSS-turbidity relationship may be found in Bertrand-Krajewski, 2004; Hannouche et al., 2011; the impact of input data uncertainty is discussed in Kleidorfer et al., 2009). A rain gage located nearby (500 m from studied site), additionally provided rainfall measurements over the entire monitoring period.

Data were collected from September 2012 to December 2013. Technical maintenance was performed every two weeks to remove litter from the storm drain and to verify the measurement system (turbidity probe cleaning and tipping bucket system control). Despite regular inspection of the experimental system, several mechanical problems were encountered with the tipping bucket system during the monitoring period, resulting in absence of record over several weeks. Snow periods were as well excluded from the dataset (as selected water quality models do not apply for snowmelt). Overall, 175 rain events from January 2013 to November 2013 (considering a 30 min minimum inter-event time for their identification) were fully monitored.

As indicated in Fig. 1, a sudden increase in turbidity values, followed by a slower return to previous turbidity levels, was observed at the beginning of the monitoring period (after mid-January). This trend presumably does not result from a failure of the multi-parameter probe, for which calibration was verified three times during the experiment (from standard formazin solutions) and which never showed any drift in the measurements.

2.2. Exponential accumulation and wash-off models

The models selected for this study are based on SWMM "exponential" accumulation and wash-off formulations (Huber and Dickinson, 1988). Although widely adopted, these models have often been reported to fail to replicate the variability of concentrations in runoff (Bai and Li, 2013; Shaw et al., 2010) and several studies cast doubt on their relevance for loads and concentrations modelling as compared to simpler formulations (Freni et al., 2009; Joannis et al., 2014; Kanso et al., 2006; Vezzaro, 2008). Simpler modelling approaches were thus also considered in this study so as to evaluate the benefits of accumulation and wash-off equations.

"Event mean concentration" (or EMC) models assume that concentrations in runoff remain invariant during a rain event. While such approaches do not allow for simulation of wash-off dynamics, recent studies on combined sewers suggest that it could be relevant for loads estimation (Joannis et al., 2014). Two "Event Mean Concentration" models were thus adopted for loads modelling, with, on the one hand, a constant concentration over the whole simulation period (referred to as constant EMC hypothesis, Eq. (1)), and considering, on the other hand, an exponential EMC decrease from January to November in accordance with turbidity measurements (referred to as decreasing EMC hypothesis, Eq. (2)). In both cases, concentrations are hence assumed to