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Identifying representative stormwater quality events for pollution load prediction in planning and modelling contexts

Identifier les événements représentatifs de la qualité des eaux pluviales pour la prévision des flux de pollution dans des contextes de planification et de modélisation

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RÉSUMÉ

Les solutions actuellement appliquées pour une meilleure gestion des eaux pluviales doivent cibler des aspects liés à la quantité et à la qualité des eaux. Bien qu'il existe déjà des cadres pour estimer la performance en termes de quantité (à travers de *e.g.* les périodes de retour d'excédante comme paramètre de décision), il y a encore un désaccord sur la meilleure approche d'évaluation en termes de la qualité de l'eau. En ayant l'objectif de répondre au besoin de pluies de projets en termes de qualité d'eau, cette étude explore la possibilité d'identifier une sélection d'évènements caractéristiques (CRE) avec des courbes correspondantes masse-volume (MV) de flux de Matière en Suspension (MES), à travers d'une approche de *clusters*. Ces évènements représentatifs basés sur des caractéristiques pluviales peuvent aider à connecter les différents acteurs dans une planification multi-objective, interdisciplinaire, ainsi que fournir une aide à la modélisation et à la prise de décisions.

ABSTRACT

Currently, applied solutions for better stormwater management systems often target both water quantity and quality related issues. However, while frameworks for assessing quantity performance have been developed and applied (using e.g. exceedance return period as decision parameter), there is still a lack of consensus on the best evaluation approach for water quality performance.

This study aims at simplifying the evaluation of pollution removal performance of stormwater control solutions in the planning phase by exploring the possibility of identifying a selection of Characteristic Rain Events (CRE). Each CRE will be associated with a corresponding mass-volume (MV) curve for Total Suspended Solids (TSS) loads. This relationship is identified by using a clustering approach.

The use of CRE can simplify the planning process with respect to water quantity and quality aspects, provide an additional aid in modelling for decision making, and it can thus speed up collaboration between stakeholders in multi-objective, interdisciplinary planning situations.

KEYWORDS

Characteristic rain events (CRE), cluster analysis, event load distribution, MV curves, stormwater quality.

1 INTRODUCTION

Management of stormwater quantity and quality are interlinked issues, which require integrated planning strategies (Pahl-Wostl, 2007), and which push for multifunctional solutions that address the needs of a range of different actors (Fratini et al., 2012). This leads to projects with multiple short- and long-term goals (Bach et al., 2014), which complicate the comparison of different solution scenarios.

The type of solutions that are applied to prevent flooding, ensure water supply safety and protect receiving water bodies increasingly include decentralised, above-ground, and nature-based stormwater control measures (SCMs). Additional benefits of these SCMs are provided by their potential for controlling stormwater runoff while retaining pollutants and increasing liveability (Liu and Jensen, 2017; Eriksson et al., 2007).

Despite the multifunctional nature of SCMs, the main driver for their implementation is often flood mitigation. Therefore, most of the frameworks for decision support only rely on water quantity-related indicators, e.g. the exceedance return period for flood causing events (Dhakal and Chevalier, 2016). An example of such a framework is the three points approach (3PA) (Fratini et al., 2012), which defines three planning domains for event return periods: the everyday domain, the design domain and the extreme domain (Madsen et al., 2018; Fratini et al., 2012). The 3PA has proven itself effective for achieving interdisciplinary terminology consensus in planning projects (Sørup et al., 2016), where it is desired to evaluate the performance of different solution types for different event magnitudes

When it comes to evaluating water quality aspects, however, there is still disagreement and uncertainty about the best approach (Ellis et al., 2012; Bach et al., 2014). Prudencio and Null (2018) recently carried out a literature review of 170 articles on stormwater management and ecosystem services, concluding that there is a need for standardizing terminology and inventing metrics to help quantify the ecosystem services from green stormwater infrastructures.

Classically, the pollutant loads from urban stormwater discharges are evaluated on two temporal scales: (i) the short term (acute) effects and (ii) the long term (chronic) effects. The first requires examination of the concentrations during specific event situations (with a time scale of minutes or hours), while the second is assessed by looking at expected total load over a representative time period (yearly time scale).

Stormwater event loads show high variability, which might be linked to the characteristics of the catchment, the drainage network, and the rainfall/runoff. The latter is often used as a common denominator between quantity and quality assessments. Given the inherent variability of event loads, long-term simulations, covering several events and providing statistics on the SCMs performance, are necessary. However, the computational requirements make the use of dynamic simulation models difficult to employ in a planning process that involves several stakeholders, where different solutions need to be tested on the fly.

This study aims at simplifying and accelerating the evaluation of SCMs compliance with water quality criteria at a planning level by defining a selection of representative events that can be used to test the SCM under different pollution scenarios (see Figure 1). These events are selected based on rainfall characteristics to represent a range of different patterns in pollution (e.g. first flush, concentrations correlated to flow, etc.). The proposed methodology will create the base for the definition of pollution-based design events, which can be combined with existing flow/volume-related design events, supporting multifunctional planning processes for distinct design domains.

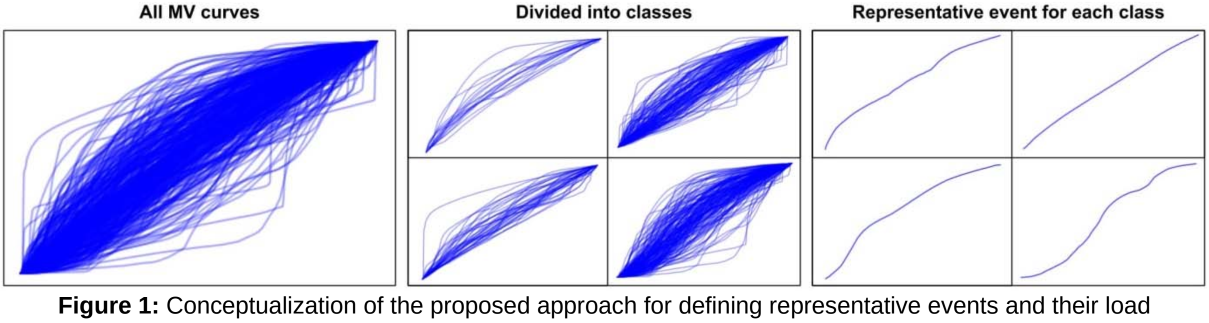

Figure 1: Conceptualization of the proposed approach for defining representative events and their load distribution curves based on classes of rain characteristics.

2 METHODS

The inter-event variability of pollutant loads can be described by using dimensionless mass-volume (MV) curves (e.g. Sun et al., 2015). The MV curves allow for visualization of the dynamic behaviour of pollutant fluxes as function of the flow, thereby supporting the identification of typical patterns, such as first flush, dilution, or linear correlations between volume and mass.

In this study, the data collected at the outlet of a separated sewer system of an urban catchment in Chassieu, France, were used (e.g. Sun et al., 2015). The data included high-time resolution measurements of rain (2 min time-steps), with flow and turbidity measurements that were collected between 2004 and 2011. The turbidity measurements have previously been converted to Total Suspended Solids (TSS) time series (Métadier and Bertrand-Krajewski, 2011), and a database of validated events has been constructed by (Sun et al., 2015).

The first step of the analysis focuses on the identification of rain characteristics (peak rainfall intensity and its timing, duration, total rainfall volume and antecedent dry days etc.) that may be used to divide the database into intuitive reasonable fractions (e.g. Figure 1). The combination of chosen rain characteristics will make up suggested event classes, and it is important that these classes are easily applicable in planning situations. Within each of these classes a representative event can be found by applying the Characteristic Rain Events (CRE) approach described in Andersen et al. (2017).

A clustering analysis is then carried out in order to ascertain whether the rain-characteristics-based classes succeed in sorting the database into load distribution clusters with comparable patterns. There are many available clustering methods, but as this study is based on predetermined classes (in order maintain control of the class definitions) it is chosen to work with the Principal Analysis by Conditional Expectation (PACE) k-centers functional clustering (kcfc) approach (Chiou and Li, 2007). The PACE kcfc is an analysis method for evaluating substructures in longitudinal data patterns (such as distribution curves) through specific meta characteristics, which allows for an a priori class determination, unlike e.g. hierarchal clustering algorithms (Gibert et al., 2018). In order to implement this approach, the event MV curve datasets are first modified, so that they all have the same dimensions by normalizing the event durations (e.g. Sandoval et al. (2018)). Then the PACE kcfc algorithm is applied to assess the a priori determined CRE classes, by evaluating whether the MV curves cluster according to the classes.

3 PRELIMINARY RESULTS AND EXPECTED FINDINGS

As an example of a preliminary result, it was chosen to divide 67 MV curves registered in 2007 into two classes based on whether the rain event duration was larger or smaller than 500 minutes. These classes were tested with the PACE kcfc algorithm, which resulted in the two clusters shown in Figure 2 of 47 and 20 events, respectively. As the figure shows, both clusters hold events from both classes (blue and red), indicating that this is not an appropriate class definition, wherefore it is not attempted to determine CRE for these classes.

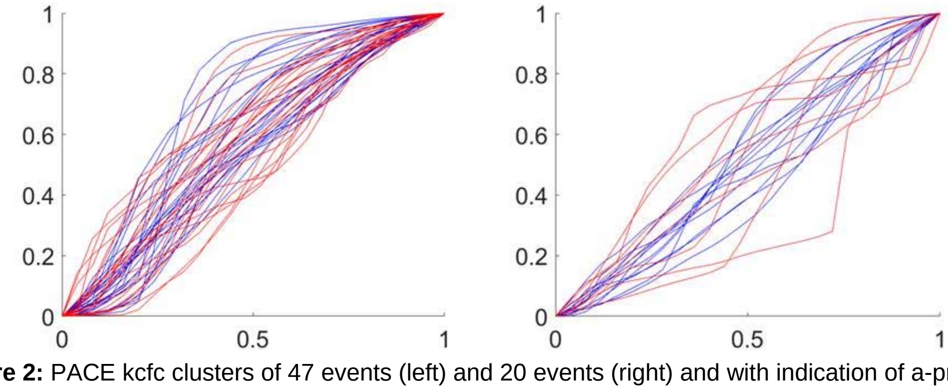

Figure 2: PACE kcfc clusters of 47 events (left) and 20 events (right) and with indication of a-priori determined classes. Blue color for duration < 500 min and red color for duration > 500 min.

A more comprehensive testing of different combinations of rain characteristics will allow for identifying the combination of classes that performs best, and determining whether representative events for these classes will be good enough to use in planning situations.

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