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Short communication

Time as the critical factor in the investigation of the relationship between pollutant wash-off and rainfall characteristics

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ABSTRACT

The approach adopted for investigating the relationship between rainfall characteristics and pollutant wash-off process is commonly based on the use of parameters which represent the entire rainfall event. This does not permit the investigation of the influence of rainfall characteristics on different sectors of the wash-off process such as first flush where there is a high pollutant wash-off load at the initial stage of the runoff event. This research study analysed the influence of rainfall characteristics on the pollutant wash-off process using two sets of innovative parameters by partitioning wash-off and rainfall characteristics. It was found that the initial 10% of the wash-off process is closely linked to runoff volume related rainfall parameters including rainfall depth and rainfall duration while the remaining part of the wash-off process is primarily influenced by kinetic energy related rainfall parameters, namely, rainfall intensity. These outcomes prove that different sectors of the wash-off process are influenced by different segments of a rainfall event.

1. Introduction

It is commonly known that pollutant wash-off is strongly influenced by rainfall characteristics (Kleinman et al., 2006; Greenstein et al., 2004; Egodawatta et al., 2007; Lindblom et al., 2011; Freni et al., 2008). Consequently, there has been significant research effort on investigating the relationships between the pollutant wash-off and rainfall characteristics in order to enhance the effectiveness of stormwater treatment system design such as Water Sensitive Urban Design (WSUD) (For example Miguntanna et al., 2013; Liu et al., 2012; Wium-Andersen et al., 2013). These research studies have used stormwater quality data such as event mean concentrations (EMC) and common rainfall parameters such as average rainfall intensity (Shigaki et al., 2007; Liu et al., 2012; Berndtsson et al., 2009). Unfortunately, this approach represents a significant limitation as parameters such as these represent the entire rainfall event (lumped parameters) and does not permit the investigation of the influence of rainfall characteristics on different sectors of the wash-off process.

It is hypothesised that different sectors of the wash-off process are influenced by different segments of a rainfall event. This hypothesis needs to be viewed in the context of the occurrence of the first flush phenomenon, which refers to the wash-off of a relatively higher pollutant load at the initial part of a runoff event (Lee et al., 2002; Li et al., 2007). Accordingly, it can be argued that the common approach of using lumped rainfall parameters could overshadow the critical relationships between pollutant wash-off and rainfall characteristics and hence cannot provide an in-depth understanding of the wash-off process. For investigating the different sectors of the wash-off process, the research study discussed in this paper adopted an innovative approach by partitioning the wash-off process and rainfall characteristics in order to create new knowledge to enhance the effectiveness of stormwater treatment system design.

2. Materials and methods

2.1. Study sites

Data required for the study was generated by monitoring residential catchments located at Coomera Waters, Gold Coast, Australia. Coomera Waters is a residential estate developed around a 17 ha lake and natural wetlands based on Water Sensitive

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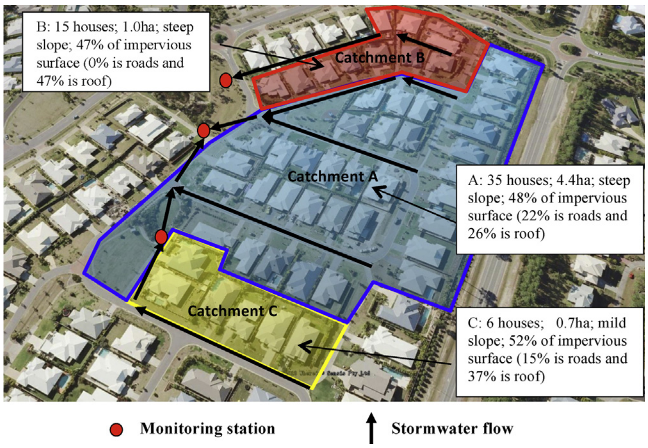

Fig. 1. Study catchments and their characteristics.

Urban Design (WSUD) principles in order to protect the natural waterways from being polluted by the stormwater runoff. Three small catchments in Coomera Waters were selected as the study catchments and named as Catchment A, B and C. Details of the catchment characteristics are given in Fig. 1.

2.2. Data collection and testing

The three catchments have been continuously monitored for stormwater quality and quantity and rainfall since 2007 using automatic monitoring stations established at the outlets to collect flow measurements and stormwater runoff samples and pluviograph stations for rainfall data collection. The data collection procedures are outlined in the Supplementary Information. The samples collected were tested for total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS) which are the primary stormwater pollutants (Goonetilleke et al., 2005; Qin et al., 2010; Collins et al., 2010; Francey et al., 2010; Dierberg and DeBusk, 2008). Sample testing was undertaken according to test methods specified in Standard Methods for the Examination of Water and Wastewater (APHA, 2005). Field blanks and laboratory blanks were used as part of the QA–QC procedure. Sample collection, transport and storage complied with Australia New Zealand Standards, AS/NZS 5667.1:1998 (AS/NZS, 1998).

2.3. Determination of innovative parameters

Two sets of innovative parameters were derived as detailed in the Supplementary Information to meet the needs of the envisaged investigation. These parameters which represented the pollutant load percentages washed-off by different sectors of runoff volume are described below.

2.3.1. Interval parameters

The interval wash-off parameter (termed as LV) is the cumulative pollutant load percentage for every 10% of runoff volume interval until 90% of runoff volume. The LV parameter was selected in order to compare rainfall events, based on temporal variations. For example, LV20 is the cumulative pollutant load percentage washed-off from the beginning until 20% of the runoff volume. The same approach was used to calculate interval rainfall parameters for every 10% of the rainfall hyetograph up to 90%. As examples, RDep20 and RD20 are the rainfall depth and rainfall duration from the commencement of rain until 20% of effective rainfall, respectively, while the AI20 gives the average intensity from the commencement of rainfall to 20% of effective rainfall. RDep is rainfall depth; RD is rainfall duration and AI is the average intensity. Accordingly, the interval wash-off and rainfall parameters determined are LV10-LV90, RDep10-RDep90, RD10-RD90 and AI10-AI90.

2.3.2. Section parameters

The section wash-off parameter (termed as P) is the increment in pollutant load percentage washed-off at 10% of runoff volume interval while the section rainfall parameters represented the rainfall characteristics at 10% of effective rainfall interval. P parameter was selected in order to investigate the variations in the wash-off process within a rainfall event. For example, P2030 represents the percentage of pollutant load washed-off between 20% and 30% of runoff volume; RDep2030 and RD2030 give the rainfall depth and rainfall duration between 20% and 30% of effective rainfall, respectively; AI2030 represents the average rainfall intensity which occurred between 20% and 30% of the effective rainfall depth. Accordingly, the section wash-off and rainfall parameters are P0010-P8090, RDep0010-RDep8090, RD0010-RD8090 and AI0010-AI8090.

3. Results and discussion

3.1. Univariate data analysis

Table 1 gives the mean and relative standard deviation (RSD) values for LV and P for TSS, TP and TN for the 23 rainfall events that were investigated in the study. In terms of mean values of LV, most pollutant loads are washed-off by the first 40% of runoff volume regardless of the pollutant type (LV40 is 61.22%, 60.74% and 52.43% for TSS, TP and TN respectively). From the perspective of first flush, this observation means that the occurrence and characteristics of first flush could be determined by assessing the pollutant loads in the first 40% of the runoff volume.

For RSD, it can be noted that the corresponding values generally decrease from LV10 to LV90 for all three pollutants, where the RSD values are larger than 10% for up to LV60 (except for LV50 of TN). Since a data set with RSD greater than 10% is considered as having a high variability (Hamburg, 1994), this means that there is high variation in the wash-off process with rainfall characteristics, particularly the pollutant loads carried by the first 60% of runoff volume.

In terms of P parameters, the mean values reduce from P0010 to P8090 for TSS, TP and TN, which indicates that relatively higher percentage of pollutant loads are washed-off by the initial portion of the runoff volume (first flush phenomenon). It is also noteworthy that the RSD values are relatively higher for the initial P parameters (P0010) and the later ones (from P5060 to P8090), while the RSD values for the middle P parameters (from P1020 to P4050) are relatively lower.

These observations derived from the LV and P data suggest that different sectors of the wash-off process behave differently and their variations with rainfall characteristics are also different. It is important to understand the reasons for differences in wash-off for rainfall events with different characteristics and for different segments in a rainfall event. This underlines the inadequacy of investigating pollutant wash-off using lumped rainfall parameters and the importance of further investigating the relationship between different sectors of the wash-off process and different segments of a rainfall event.

3.2. Multivariate data analysis

In order to undertake a comprehensive investigation of the relationship between rainfall characteristics and the wash-off process,