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# Sectional analysis of the pollutant wash-off process based on runoff hydrograph

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A B S T R A C T

The validity of using rainfall characteristics as lumped parameters for investigating the pollutant wash-off process such as first flush occurrence is questionable. This research study introduces an innovative concept of using sector parameters to investigate the relationship between the pollutant wash-off process and different sectors of the runoff hydrograph and rainfall hyetograph. The research outcomes indicated that rainfall depth and rainfall intensity are two key rainfall characteristics which influence the wash-off process compared to the antecedent dry period. Additionally, the rainfall pattern also plays a critical role in the wash-off process and is independent of the catchment characteristics. The knowledge created through this research study provides the ability to select appropriate rainfall events for stormwater quality treatment design based on the required treatment outcomes such as the need to target different sectors of the runoff hydrograph or pollutant species. The study outcomes can also contribute to enhancing stormwater quality modelling and prediction in view of the fact that conventional approaches to stormwater quality estimation is primarily based on rainfall intensity rather than considering other rainfall parameters or solely based on stochastic approaches irrespective of the characteristics of the rainfall event.



## 1. Introduction

Research literature has noted the significant influence exerted by rainfall characteristics on pollutant wash-off and the essential need for an in-depth understanding of the relationship between pollutant wash-off processes and rainfall characteristics for effective stormwater treatment design (Liu et al., 2012a; Carroll et al., 2013). Past research studies commonly consider rainfall characteristics as lumped parameters for investigating the role of rainfall characteristics on pollutant wash-off (for example Egodawatta et al., 2007; Kim et al., 2007; Liu et al., 2012a). However, other research studies have questioned the validity of the adoption of rainfall characteristics as lumped parameters for investigating the pollutant wash-off process (such as Willems, 2001; Andreassian et al., 2001). For example, first flush refers to the initial sector of the runoff hydrograph which can transport a relatively higher fraction of pollutants (Li et al., 2007), while the later part of the hydrograph would transport a decreased pollutant load due to the reduction in easily-detachable pollutants on the surface. Therefore, this gives rise to two important research questions: (1) how does pollutant wash-off in different sectors of the runoff hydrograph vary with rainfall characteristics? (2) What are the key influential rainfall characteristics in terms of the wash-off process in different sectors of the runoff hydrograph?

To provide answers to these two questions, this paper discusses a research study which investigated the influence of rainfall characteristics on the pollutant wash-off process in different sectors of the runoff hydrograph. The knowledge created will contribute to the enhancement of stormwater treatment design, particularly first flush capturing devices. Additionally, the knowledge created can also contribute to improving stormwater quality modelling approaches where commonly, the pollutant wash-off process is replicated based on rainfall intensity rather than considering other rainfall event parameters (SWMM, 2004; MIKE URBAN, 2008) or solely based on a stochastic approach irrespective of the characteristics of the rainfall event (MUSIC, 2011).

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## 2. Materials and methods

### 2.1. Study sites

The study sites consisted of three small urban residential catchments located at Gold Coast, Queensland State, Australia. These catchments are provided with a range of Water Sensitive Urban Design (WSUD) measures in order to protect the receiving water environment from stormwater pollution. Fig. 1 shows the three study catchments (A, B and C), the location of the monitoring stations, stormwater flow direction and baseline catchment characteristics.

### 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. Flow measurements were undertaken using calibrated V-notch weirs and samples were collected by stage triggered, peristaltic pumping. Discrete stormwater runoff samples were collected during rainfall events to investigate the variation in water quality during a runoff event. The total number of sampling episodes selected for analysis was 23 rainfall events from the three catchments. The relevant information regarding the selected rainfall events is given in Table S1 and S2 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; Liu et al., 2012b). Sample testing was undertaken according to test methods specified in Standard Methods for the Examination of Water and Wastewater (APHA, 2005), which are listed in Table S3 in the Supplementary Information. Sample collection, transport and storage complied with Australia New Zealand Standards, AS/NZS 5667.1:1998 (AS/NZS, 1998).

### 2.3. Determination of sector parameters

A parameter ‘P’ defined as “sector indicator” was determined for the pollutant concentrations and corresponding runoff volumes. It represents the increment in percentage pollutant load washed-off for the respective 10% increment in runoff hydrograph. For example, P2030 represents the percentage of pollutant load washed-off between 20% and 30% of the runoff hydrograph. The corresponding rainfall characteristics were also determined based on 10% increments in effective rainfall. To determine sector rainfall intensity, the effective rainfall intensity corresponding to each pollutant sector indicator was determined. For example, AI2030 represents the average rainfall intensity which occurred between 20% and 30% of effective rainfall depth.

Accordingly, nine ‘P’ sector parameters (P0010, P1020, P2030, P3040, P4050, P5060, P6070, P7080 and P8090) were determined for each pollutant species per rainfall event. The rainfall characteristics are also determined accordingly (average intensity: AI0010, AI1020, AI2030, AI3040, AI4050, AI5060, AI6070, AI7080 and AI8090; rainfall depth: RD0010, RD1020, RD2030, RD3040, RD4050, RD5060, RD6070, RD7080 and RD8090).

## 3. Results and discussions

### 3.1. Univariate data analysis

‘P’ parameters of TSS, TN and TP were initially investigated using boxplots as shown in Fig. 2. It is evident that all three pollutant species show similar behaviour. In terms of mean value, P0010 shows the highest load percentage washed-off by the first 10% of the runoff hydrograph (20.78% for TSS; 15.13% for TN; 22.26% for TP) while the corresponding values decrease from P1020 to P8090. This confirms first flush occurrence for TSS, TN and TP.

Additionally, it can be observed in Fig. 2 that each P parameter indicates a data range and the range is different for different sectors of the runoff hydrograph. P0010 has the widest range for all three pollutant species, followed by a narrowing trend in the middle

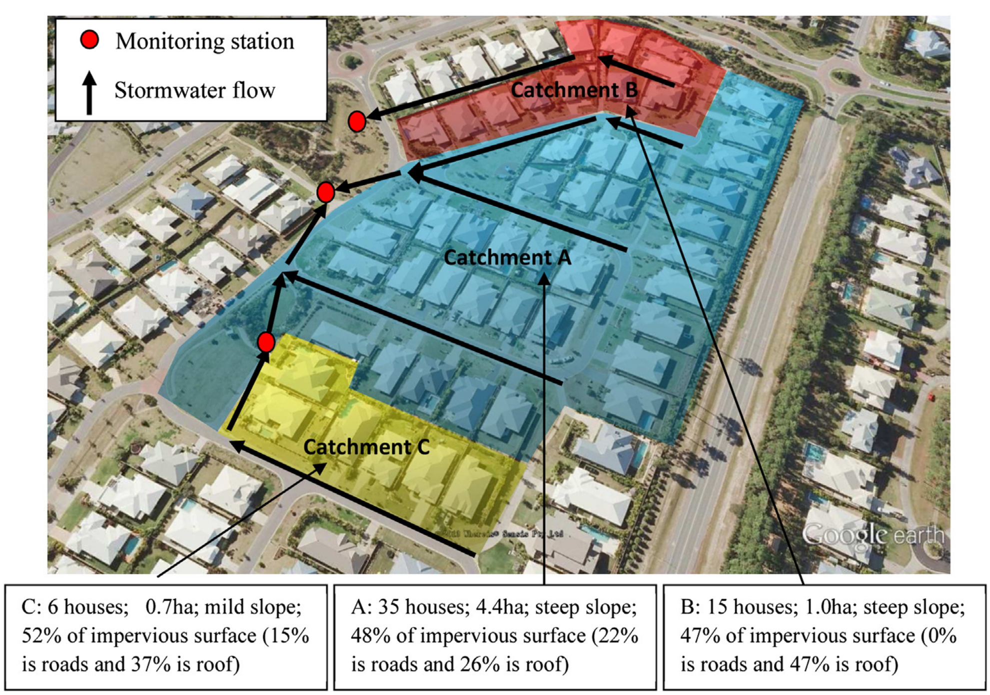


**Fig. 1.** Study catchments.