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Performance characterisation of a stormwater treatment bioretention basin

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ABSTRACT

Treatment performance of bioretention basins closely depends on hydrologic and hydraulic factors such as rainfall characteristics and inflow and outflow discharges. An in-depth understanding of the influence of these factors on water quality treatment performance can provide important guidance for effective bioretention basin design. In this paper, hydraulic and hydrologic factors impacting pollutant removal by a bioretention basin were assessed under field conditions.

Outcomes of the study confirmed that the antecedent dry period plays an important role in influencing treatment performance. A relatively long antecedent dry period reduces nitrite and ammonium concentrations while increasing the nitrate concentration, which confirms that nitrification occurs within the bioretention basin. Additionally, pollutant leaching influences bioretention basin treatment performance, reducing the nutrients removal efficiency, which was lower for high rainfall events. These outcomes will contribute to a greater understanding of the treatment performance of bioretention basins, assisting in the design, operation and maintenance of these systems.

1. Introduction

Bioretention basins are among the most commonly used stormwater treatment measures using filtration as the primary mechanism for pollutant removal, supported by evapotranspiration, adsorption and biotransformation (Davis, 2007). Additionally, a bioretention basin attenuates runoff peak flow and reduces runoff volume through detention and retention. As noted by past researchers (Davis, 2008; Hunt et al., 2008), the water quality treatment performance of bioretention basins closely depends on hydrologic and hydraulic factors such as rainfall characteristics and inflow and outflow parameters. In this context, an in-depth understanding of the influence of hydrologic and hydraulic factors on treatment performance can provide important guidance for effective bioretention basin design.

Researchers using both, field and laboratory scale studies have assessed the performance of bioretention basins, highlighting the influence of hydrologic and hydraulic factors on pollutant removal processes (Dietz and Clausen, 2005; Heasom et al., 2006; Hsieh and Davis, 2005). In terms of field scale studies, past researchers have commonly evaluated the long term treatment performance rather than event-based performance (Hunt et al., 2006; Hatt et al., 2009a). This limits the detailed understanding of treatment performance, as only lumped characteristics of hydraulic and pollutant treatment processes are considered. Research studies focussing on developing an in-depth understanding of processes in bioretention basins have primarily been undertaken at the laboratory scale (Hatt et al., 2008). However, these studies can be far from reality in terms of replicating field conditions. This results in knowledge gaps relating to field performance, influential factors and event-based pollutant removal processes.

This research study was undertaken to create new knowledge relating to the influence of hydraulic and hydrologic factors on pollutant removal processes. The study was undertaken in a monitored bioretention basin in the field serving a small residential

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catchment. Detailed monitoring was conducted to characterise pollutant removal performance as a rainfall event progressed. A range of influential hydrologic and hydraulic parameters were investigated using a conceptual model which was calibrated using recorded rainfall event data. The study outcomes will contribute to a greater understanding of the treatment performance of bioretention basins and in turn enable improved design and operation and maintenance of these systems.

2. Materials and methods

2.1. Study sites

The bioretention basin selected for the study is located at 'Coomera Waters' residential estate, Gold Coast, South East Queensland, Australia. The bioretention basin receives stormwater from a catchment with a total area of 6530 m^2. About 52% of the area is impervious, consisting of roofs, road, and driveways, while the pervious areas mainly consist of lawns and yards (see Fig. 1). Design information on the bioretention basin is provided in the Supplementary Information.

2.2. Sample collection and laboratory testing

The inlet and outlet of the bioretention basin have been monitored since April 2008 using automatic monitoring stations to record rainfall and runoff data and to capture stormwater samples for water quality testing. Flow measurements were undertaken using calibrated V-notch weirs and samples were collected by stage triggered, peristaltic pumping. Discrete samples were collected during rainfall events to investigate the variation in water quality during a runoff event. The samples collected were tested for total nitrogen (TN), nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), total phosphorus (TP), phosphate (PO_4^{3-}) and total suspended solids (TSS), which are the primary stormwater pollutants (Goonetilleke et al., 2005; Liu et al., 2012). Total pollutant loads and event mean concentrations (EMCs) at the inlet and outlet were determined for each rainfall event. Sample testing was undertaken according to test methods specified in Standard Methods for the Examination of Water and Wastewater (APHA, 2005). Sample collection, transport and storage complied with Australia New Zealand Standards, AS/NZS 5667.1:1998 (AS/NZS, 1998).

2.3. Development of bioretention basin hydraulic conceptual model

A conceptual model, where the bioretention basin was divided into 10 equal zones (Fig. 2a) was developed to replicate the hydraulic behaviour of the system. The stormwater movement over the surface was replicated as flow from Zone 1 where the inlet structure is located, to Zone 10 where the outlet structure is located. Each zone was considered to be a soil column in which the water flows downward to replicate the infiltration process. The stormwater flow within the bioretention basin was modelled according to the processes described in the following steps, which were replicated by a range of mathematical equations as shown by the numbered labels given in Fig. 2b.

- Stormwater runoff inflow (1) into the bioretention basin infiltrates into the soil column (2). This is replicated using an infiltration model;
- When the inflow rate is higher than the soil column infiltration capacity, the excess runoff becomes surface flow to the next soil column (3);
- The infiltrated water percolates until it reaches the drainage layer where the stormwater is temporarily stored (4);
- Part of the stormwater stored in the drainage layer percolates to the original soil layer underneath (5).
- Through perforated pipes, stormwater in the drainage layer flows to the outlet structure where the flow is monitored (6).

Details of the conceptual model development, calibration and simulation can be found in Mangangka (2012).

2.4. Rainfall event selection and hydrologic/hydraulic parameters

Twelve monitored rainfall events were selected for the analysis. The selected rainfall events were less than 1 year average recurrence interval (ARI). This ARI range is used for most urban stormwater treatment system design (Dunstone and Graham, 2005) due

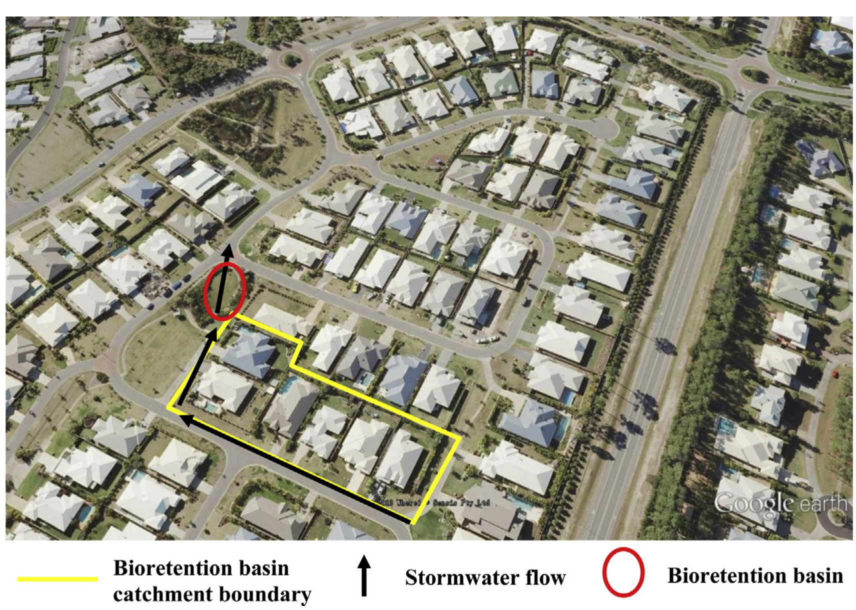

Fig. 1. Bioretention basin study site.