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Validation of stormwater biofilters using *in-situ* columns

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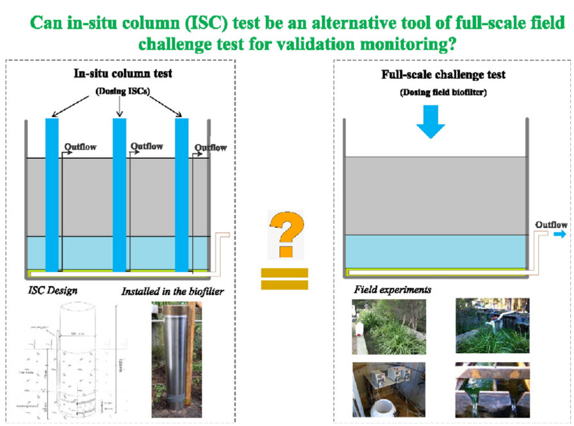
HIGHLIGHTS

- A novel *in-situ* column was proposed as an alternative validation monitoring tool.
- The tool can reproduce field results for fluorescein removal over different conditions.
- When using the tool for studying herbicide removal, some differences were observed.
- The *in-situ* column is a promising tool to study the field performance of biofilter.

GRAPHICAL ABSTRACT



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ABSTRACT

Stormwater harvesting biofilters need to be validated if the treatment is to be relied upon. Currently, full-scale challenge tests (FCTs), performed in the field, are required for their validation. This is impractical for stormwater biofilters because of their size and flow capacity. Hence, for these natural treatment systems, new tools are required as alternatives to FCT. This study describes a novel *in-situ* method that consists of a thin stainless steel column which can be inserted into constructed biofilters in a non-destructive manner. The *in-situ* columns (ISCs) were tested using a controlled field-scale biofilter where FCT is possible. Fluorescein was initially used for testing through a series of continuous applications. The results from the ISC were compared to FCT conducted under similar operational conditions. Excellent agreement was obtained for the series of continuous fluorescein experiments, demonstrating that the ISC was able to reproduce FCT results even after extended drying periods (Nash–Sutcliffe coefficient between the two data sets was 0.83–0.88), with similar plateaus, flush peaks, slopes and treatment capacities. The ISCs were then tested for three herbicides: atrazine, simazine and prometryn. While the ISC herbicide data and the FCT data typically matched well, some differences observed were linked to the different climatic conditions during the ISC (winter) and FCT tests (summer). The work showed that ISC is a promising tool to study the field performance of biofilters and could be a potential alternative to full scale challenge tests for validation of stormwater biofilters when taking into account the same inherent boundary conditions.

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1. Introduction

Many studies demonstrated that urban stormwater contributes to the deterioration of water quality in receiving bodies (Jeng et al., 2005; Brown and Peake, 2006) and cities are experiencing water stress (Fletcher et al., 2007). While stormwater harvesting is becoming more common and encouraged for non-potable uses (Hatt et al., 2006), potable uses currently have only limited uptake. There are scant examples of such systems, with the most notable being Singapore which has had indirect stormwater harvesting for potable end-uses since the 1960s (Philp et al., 2008).

Stormwater biofilters, which are established under Water Sensitive Urban Design (WSUD) principles, are used for stormwater harvesting, in particular for lower exposure end-uses such as irrigation and toilet flushing (Hatt et al., 2006). They have proven to be effective in dampening the high variability of stormwater quality (Zhang and Guo, 2014). Meanwhile, they are also effective in treating pollutants (sediments, nutrients, heavy metals, microorganisms and micropollutants (Bratieres et al., 2008; Chandrasena et al., 2012). Due to the natural components of these systems, the pollutants are removed through combined physical, chemical and biological processes. Moreover, stormwater biofilters experience both wetting (during rainfall events) and dry periods (when the systems are idle). The main removal processes are different in different periods. For example, micropollutants, the major removal processes in these systems involve adsorption (mainly during wet events) and biodegradation (mainly over the dry periods) (Zhang et al., 2015a). However, to date the treatment performance of stormwater biofilter is not recognized as reliable because it lacks a validation protocol for treatment validation (Zhang et al., 2015b).Validation protocols are common for other engineered systems, such as membrane filtration, and provide robust evidence as to their treatment performance (DHV, 2013).

Treatment validation provides scientific evidence that the treatment process produces water of the required quality and that water quality objectives are continuously met (DHV, 2013). Treatment validation can be completed through three stages: (1) Pre-validation, which entails gathering necessary information for the following stages, including target pollutants, operational/challenging conditions, potential removal mechanisms and surrogates; (2) validation monitoring, which determines the system performance under challenging conditions; and (3) operational monitoring, which ensures the long term performance of the system during normal operation (Zhang et al., 2015b). This study focused on the validation monitoring stage. As per current validation procedures developed for engineered systems (USEPA, 2005; DHV, 2013), validation monitoring should be performed at full-scale, using challenge tests. Challenge tests are expected to confirm the maximum removal credit that a treatment system is eligible to receive. This is achieved by dosing challenging concentrations of target pollutants and measuring the removal under challenging hydraulic conditions (USEPA, 2005). However, this is difficult to apply to stormwater biofilters because they are usually very large and the operation of full-scale testing is difficult as large, uncontrolled volumes of urban stormwater will enter the system during short periods of time (*i.e.* <3 h).

In order to support the validation of stormwater treatment by biofilters, alternative validation monitoring methods are needed instead of the traditional challenge tests. Laboratory batch and column tests are widely used to assess the removal processes of pollutants in stormwater biofilters (Bratieres et al., 2008; Chandrasena et al., 2012) and similar soil-based systems, *e.g.* wetlands (Chevron Cottin and Merlin, 2007) and aquifers (Ying et al., 2008). However, although *ex-situ* types of studies can gain insights in the underlying removal mechanisms, they have also received criticism for not being able to represent the natural conditions of these systems. This has led to the development of *in-situ* based techniques, *e.g.* *in-situ* microcosms/columns, which could provide more-convincing evidence of the results with conditions closer to field tests (Nielsen et al., 1995; Mandelbaum et al., 1997). For example, Nielsen et al. (1995) reported that *in-situ* and laboratory studies on the fate of specific organic compounds in an anaerobic landfill leachate plume showed good concordance, but some transformations, for phenol particularly, were observed only in *in-situ* experiments. Similar *in-situ* style tools have been used with success to study the biodegradation of various chemical compounds in aquifer systems and wetlands (Geyer et al., 2005; Stelzer et al., 2006; Braeckevelt et al., 2007).

Currently there is no *in-situ* technique specifically designed for stormwater biofilters. The objective of the current study is to develop an *in-situ* tool to validate the treatment processes within stormwater biofilters. The specific aims include:

- Test the *in-situ* column (ISC) tool for fluorescein by comparing its performance with field challenge test (FCT) fluorescein results (both the ISC and FCT were conducted on a small field-scale biofiltration system under similar conditions); and,
- Test the ISC tool for three common herbicides (atrazine, simazine and prometryn) by comparing its performance with the results of the FCT tests performed on the same facility in the past work (Zhang et al., 2014; Zhang et al., 2015a). These herbicides were chosen because they are commonly detected in urban stormwater (Becouze et al., 2009; Zgheib et al., 2012) and can represent a human health risk if consumed over the long term (which would be the case for indirect potable uses) (NHMRC-NRMMC, 2011).

2. Materials and methods

2.1. Site description

The stormwater biofilter system selected in this study is located at Monash University, Melbourne, Australia. Full details regarding characteristics and configurations of the studied biofilter have been previously reported (Hatt et al., 2009; Zhang et al., 2014). The selected biofilter has a submerged zone and uses sand (sand 96.0%, silt 0.8%, clay 3.2% — by weight; soil organic matter 0.4%) as filter media, containing 0.35% soil organic matter, 30 mg/kg total phosphorus and 300 mg/kg total nitrogen content. The length and width of the biofilter are 9.6 and 1.4 m, respectively. The design maximum ponding depth, filter media depth and submerged zone depth are 410 mm, 500 mm and 200 mm, respectively. This biofilter is predominantly planted with *Melaleuca ericifolia*, which has been previously reported to be efficient in removing nutrients (Read et al., 2008).

This biofilter was used to perform both fluorescein and herbicides field challenge tests (FCTs).The results from FCTs were compared with those of the *in-situ* column (ISC) tests; this allowed the evaluation of the new proposed tool (*i.e.* the ISC) against the industry standard (*i.e.* the FCT). The following sections describe these tests.

2.2. Full scale experiment: field challenge tests (FCTs)

Two FCTs were conducted: (1) Fluorescein FCT, which was a short study undertaken to gain initial insights into the behavior of the biofilter using a fluorescein as a tracer; this is a cheap, commonly used model micropollutant which can degrade in sunlight, adsorb to soil and be degraded by microbes (Smart and Laidlaw, 1977; Sabatini, 2000), and (2) Herbicide FCT, which was a stand-alone study used to challenge the system for the removal of three herbicides (fully reported in Zhang et al., 2014).

The Fluorescein FCT (August 2013) was used to study breakthrough of fluorescein via spiking and flushing events; in-between the events, different lengths of dry periods were maintained (Fig. 1 left). Water was pumped from an adjacent stormwater pond, and if it was a spiking event, it was loaded with fluorescein to a concentration of 120 ± 5.0 μg/L. The inflow concentration of 120 μg/L was selected because it