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Real time control stormwater biofilters for removing organic chemicals

Contrôles en temps réel des biofiltres d'eaux pluviales pour l'élimination des produits chimiques organiques

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RÉSUMÉ

Les biofiltres sont des solutions naturelles courantes pour traiter les eaux pluviales en vue de leur collecte et de leur réutilisation, mais la variabilité de leurs performances en matière d'élimination des produits chimiques organiques empêche leur adoption à grande échelle. Les études antérieures ont principalement porté sur l'optimisation de la conception du système pour les polluants traditionnels, mais il a été démontré que les performances dépendent également des facteurs opérationnels. Nous avons mis au point trois stratégies de contrôle en temps réel (CTR) axées sur des règles pour améliorer l'élimination des produits chimiques organiques : (1) *le contrôle de l'humidité du sol* tente de simuler la frange capillaire pour un processus de biodégradation accéléré ; (2) *le contrôle du temps de rétention* vise à recueillir l'eau à réutiliser qui a passé une durée de rétention minimum requise dans la zone submergée ; et (3) *le contrôle du taux d'infiltration* vise à augmenter la durée de contact entre les eaux pluviales et le matériau filtrant. Toutes ces stratégies de CRT, ainsi que les biofiltres non-CRT, sont testées selon différents volumes de précipitations et longueurs de périodes sèches sur une période de 24 semaines. Cette étude contribuera au développement de la prochaine génération de biofiltres pour eaux de ruissellement, capables de produire des eaux pluviales traitées de haute qualité en vue de leur réutilisation.

ABSTRACT

Stormwater biofilters are common nature-based solutions to treat stormwater for harvesting and reuse, but their variable performance in removing organic chemicals is impeding their widespread uptake. Previous studies have mostly focused on system design optimisation for traditional pollutants, but evidence has shown that performance is also influenced by operational parameters. We developed three rule-based real time control (RTC) strategies to improve its performance in removing organic chemicals: (1) soil moisture control tries to simulate capillary fringe for an accelerated biodegradation process; (2) retention time control targets to harvest water for reuse that has stayed in the submerged zone for a minimum required retention time; and (3) infiltration rate control aims to increase the contact time between stormwater and filter media. All these RTC strategies, alongside non-RTC biofilters, are tested under different sizes of rainfall and length of dry periods over a period of 24 weeks. This study will further support the development of next generation stormwater biofilters that can produce treated stormwater of high quality for reuse.

KEYWORDS

(Bioretention, PMT Substances, Real time control, Stormwater Harvesting, Stormwater reuse)

1 INTRODUCTION

As the second driest continent in the world, Australia frequently experiences water shortage and widespread drought, thus, water recycling has been encouraged to supplement the drinking water supply, including the water that was traditionally seen as wastewater, sewage effluent and stormwater (NRMCC-EPHC-NHMRC, 2006). Stormwater, as an under-utilized resource for water reuse, has the potential to be harvested only if the associated risks are always under surveillance. Risks caused by hazardous contaminants in stormwater are needed to be addressed, especially for organic chemicals due to their recalcitrance, prevalence, and toxicity in urban stormwater (Flanagan et al., 2021).

Biofilter, a type of nature-based solutions (NBS), has been adopted as a technology for SWH. However, the human health risks assessment indicated the risks caused by organic chemicals are often overlooked in stormwater and NBS (Murphy et al., 2017). The main reasons are owing to the nature of biofilters for being passive systems, i.e., receiving stormwater inflow regardless of its characteristics and leading to an unpreferred condition for pollutant treatment under extreme events; and these reasons have caused the unreliable performance of biofilter systems (Payne et al., 2015).

Close correlations have been observed between operational conditions and biofilter system performance, however, the existing studies are predominantly focusing on improving the system performance with optimisation of design variables (e.g., media type) (e.g., (Lu and Chen, 2018)). To fulfill this gap, the concept of Real Time Control (RTC) from wastewater treatment and urban flood control could be borrowed. The RTC biofilters will upgrade passive water treatment systems to an adaptive system that can actively control the operational conditions, e.g., retention time, to cope with the unpredictable rainfall characteristics, as well as make decisions with pre-defined objectives (Shen et al., 2020). However, very limited studies were attempted to investigate the relationships between operational parameters and organic chemical removal. Consequently, there is a need to develop specific RTC strategies to enhance biofilter performance for removing organic chemicals, test the robustness of the developed RTC strategies and discover the change in underlying remove mechanisms.

2 METHODOLOGY

2.1 Laboratory set-up

All the RTC strategies were assessed using a columns study. 18 unvegetated columns were packed with washed sand, which is widely adopted as the filter media type (Payne et al., 2015). The size of all columns (diameter 32 mm) was designed following the design guideline (i.e., Payne et al. (2015)) (Figure 1): ponding zone depth = 210 mm; unsaturated zone depth = 400 mm; submerged zone depth = 400 mm. The pore volume of each column is 270 mL, and the pore volume of the submerged zone volume is 135 mL.

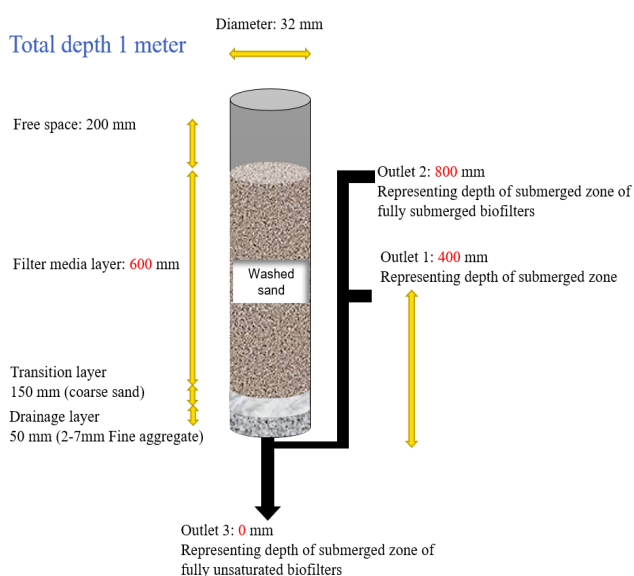


Figure 1 left: Biofilter column design; right: Real constructed biofilter columns in glasshouse

Three rule-based RTC strategies, targeting the improvement of key organic chemical removal processes were proposed and tested in this study, including (i) RTC strategy 1 (soil moisture control) – to enhance biodegradation by simulating redox gradient, (ii) RTC strategy 2 (retention time control) – to enhance biodegradation by only harvesting water that is treated with the minimum required time, and (iii) RTC strategy 3 (infiltration rate control) - to increase adsorption by providing more contact time. Each RTC strategy was tested using columns in triplicate.

These columns were firstly inoculated daily with 270ml (i.e., one pore volume of biofilters) of stormwater from constructed wetlands for two weeks and then dosed with 270 ml of synthetic stormwater (including organic chemicals, nutrients and sediments) once per three days for three weeks to allow growth of microbial community in the columns (Figure 2).

Five different types of rainfall events with different number of dry days and amount of inflow volumes were developed to fully assess the robustness and performance of proposed RTC strategies with a total of 12 sampling events over 24 weeks (Figure 2). At the completion of the experiment, the columns were divided into three groups; one group was deconstructed to analyse the chemical accumulations in the filter media by using the media extraction procedure described in Pritchard et al. (2018). Thereafter, media from one of the other undistributed groups of columns was extracted, autoclaved to eliminate the microbes, and then re-packed into the columns. Finally, the autoclaved columns and the last group of undisturbed columns were spiked with synthetic stormwater and media was extracted on day 1, 3, 7, 14, and 21 to analyse the effectiveness of biodegradation (Figure 2).

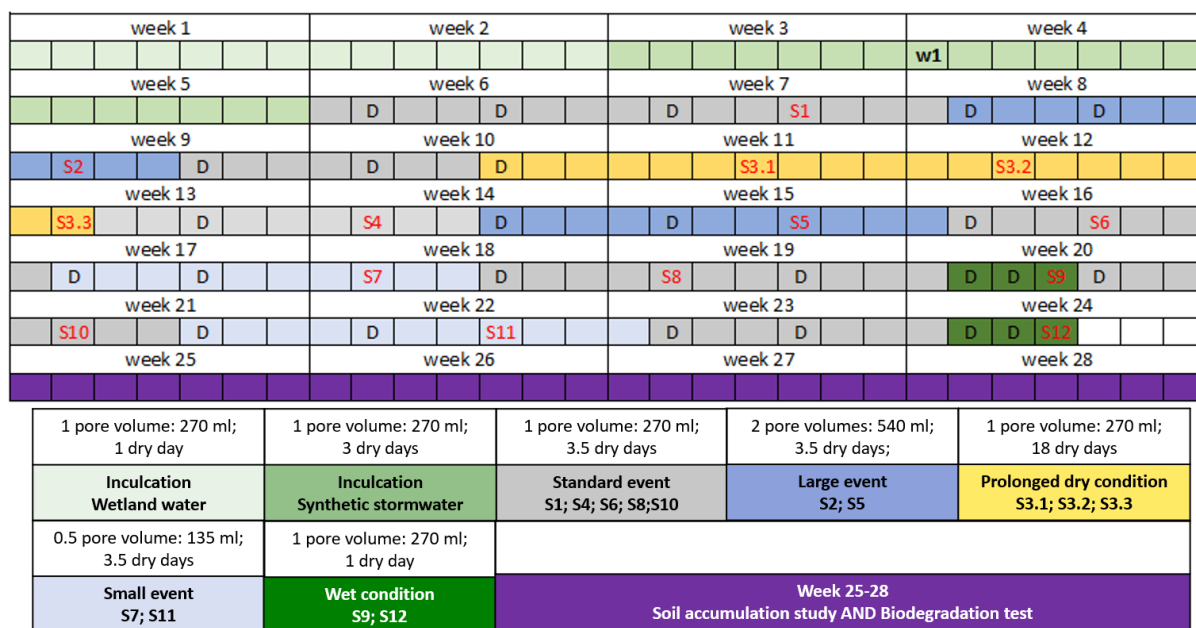


Figure 2 Experimental timeline for 28 weeks, showing synthetic stormwater dosing regime and distribution of water quality sampling events; in addition, the five weeks of column inoculation in the beginning and four weeks of remove mechanism studies at last

3 PRELIMINARY RESULTS

Preliminary results from week 6 (experiments without RTC strategies) showed that biofilters are able to provide effective removal for nonylphenol, triclosan, triclocarban and caffeine, with effluent concentrations $1.02 \pm 1.37 \mu\text{g/L}$, $2.16 \pm 0.48 \mu\text{g/L}$, $0.18 \pm 0.48 \mu\text{g/L}$, $0.33 \pm 0.38 \mu\text{g/L}$, respectively (Figure 3). On the other hand, some chemicals were poorly removed, e.g., the outflow concentrations of paracetamol and bisphenol A were $10.62 \pm 1.24 \mu\text{g/L}$ and $9.91 \pm 3.81 \mu\text{g/L}$, respectively. These results provide important basis for the general the performance of biofilters without RTC implementations, and it is expected that following the RTC, the treatment efficiency will be improved. Full results regarding the chemical removal performance of RTC systems will be presented at the conference.

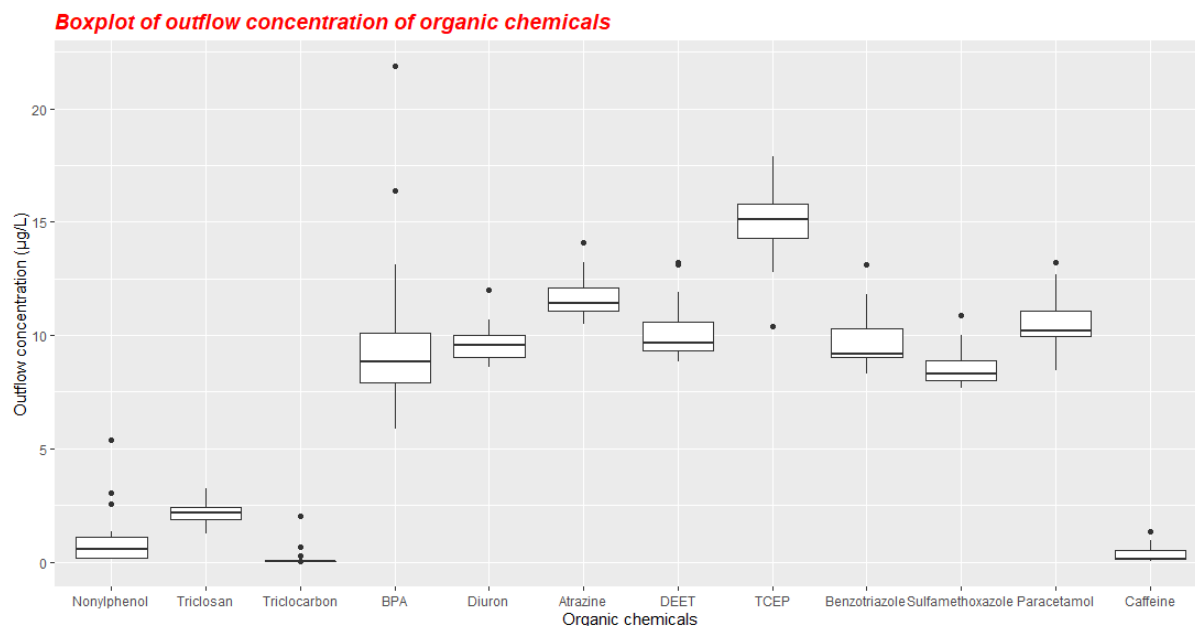


Figure 3 Boxplot of organic chemical outflow concentrations of 18 non-RTC biofilters from a single event. Inflow concentration: 10-20 µg/L.

4 PERSPECTIVE

We hypothesise that, by implementing proposed RTC strategies, the removal rates would be improved by having an enhanced adsorption process or accelerated biodegradation process, especially for those less hydrophobic organic chemicals. However, the enhancement in removal rate for different RTC strategies might be either reduced or further improved under various rainfall conditions. The operational conditions targeted by RTC strategies may be impacted by rainfall conditions, thus providing a great chance to assess the robustness of RTC strategies. Given the fact that the RTC strategies have targeted underlining removal mechanisms (i.e., biodegradation and adsorption), various types of accumulation patterns of organic chemicals in filter media could be found and analysed to understand the underlying mechanisms. Finally, based on the findings, individual or multiple RTC strategies would be selected as the best-performed strategies to further assist biofilters in removing organic chemicals and other pollutants adequately and consistently.

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