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Zero additional maintenance stormwater biofilters: from laboratory testing to field implementation

Des biofiltres pour eaux pluviales sans entretien supplémentaire : depuis les essais en laboratoire jusqu'à l'application sur le terrain

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RÉSUMÉ

Les biofiltres pour eaux de ruissellement sont l'une des solutions naturelles les plus utilisées pour la gestion des eaux urbaines. Au cours des 20 dernières années, leur capacité à éliminer les polluants a été largement étudiée. Cependant, leur application sur le terrain est limitée par le niveau élevé de maintenance qu'ils exigent. Dans la présente communication, nous avançons l'idée de biofiltres sans entretien supplémentaire. Un programme de recherche en trois étapes a été réalisé pour i) examiner les configurations de matériaux filtrants pouvant éviter l'encrassement de surface, ii) tester la qualité d'élimination des polluants de différentes herbes à gazon, iii) valider les résultats obtenus en laboratoire par un suivi sur le terrain. Les résultats ont montré qu'une couche protectrice de matériau filtrant retardait l'apparition de l'encrassement. Cinq herbes à gazon se sont révélées capables de réduire efficacement les concentrations d'azote et de répondre à d'autres critères locaux de réduction des polluants. Le suivi de trois biofiltres sans entretien supplémentaire en essai grandeur nature a confirmé leur haut degré d'élimination des nutriments et des métaux lourds. Globalement, les résultats de ces trois études confirment le potentiel de ces biofiltres conçus pour répondre aux critères de gestion des eaux de ruissellement, sans exiger d'entretien supplémentaire par rapport aux travaux habituels en matière d'aménagement paysager urbain.

ABSTRACT

Stormwater biofilters are one of the most widely used nature-based solutions for urban water management. In the last 20 years, biofilters have been extensively studied for their pollutant removal performance, however, their application in the field is limited by high maintenance requirements. In this work, we propose the concept of Zero Additional Maintenance (ZAM) biofilters. A three-stage research program was conducted to i) examine filter media configurations that could protect against surface clogging, ii) test the pollutant removal performance of a variety of lawn grasses, iii) validate the laboratory findings through field monitoring. The results showed that a protective filter media layer delayed the onset of clogging. Five lawn grasses were found to effectively reduce nitrogen concentrations and meet other local pollution reduction requirements. Monitoring of three field-scale ZAM biofilters confirmed their high nutrient and heavy metal removal performance. Overall, the findings of these three studies confirm the potential for well-designed ZAM biofilters to achieve stormwater management requirements with no additional maintenance compared to standard street landscaping.

KEYWORDS

heavy metals, nature-based solution, nutrients, rain gardens, water sensitive urban design

1 INTRODUCTION

Biofilters (also known as raingardens and bioretention systems) are one of the most widely used nature-based solutions for urban stormwater management, especially across Europe and Australia, due to their flexible sizing and efficacy in managing water quantity and quality (Zinger et al., 2021). In the last 20 years, biofilters have been extensively studied for their pollutant removal performance with respect to nutrients, heavy metals, microorganisms, and, more recently, organic pollutants (Feng et al., 2022). Optimisation of their operational conditions has also been studied (Zinger et al., 2021), as has their ability to treat other urban water sources, such as greywater and groundwater (Zhang et al., 2021). However, studies that examine longevity and performance of stormwater biofilters in field conditions are still somewhat limited, and it's even rarer to see data on failures at the field scale and maintenance needs and challenges. Zhang et al. (2021) recently studied the pollutant removal performance of two field-based biofilters, but did not consider long-term performance or maintenance requirements. Al-Ameri et al. (2018) showed that a large number of biofilters constructed in major Australian cities are still showing high efficiency for heavy metal uptake, even after more than 16 years of operation, suggesting that well-designed biofilters in residential catchments might never exceed quality guidelines for heavy metal accumulation. However, this study still highlights high-performing field biofilters and focuses on a group of pollutants (i.e. metals) that are relatively easy to remove from stormwater, and it is likely that there are a large number of biofilters that have failed due to design or maintenance issues. For example, an audit of 83 biofilters in Melbourne, Australia, found that 50% were underperforming and 25% were failing due to a variety of design and maintenance issues (Alluvium, 2017). Beryani et al. (2021) showed that at least 40% of tested field biofilters in Sweden need significant maintenance. Maintenance of biofilters still remains a major challenge and obstacle for widespread biofilter implementation, and is generally considered unsatisfactory (Hawken et al., 2021). Poor maintenance is usually attributed to asset owners and managers (mostly local governments) lacking the necessary financial and human resources to conduct rigorous assessments and repairs. Biofilters that are not maintained are more prone to failure by clogging or vegetation damage (die-off, weed ingress), both of which result in reduced pollutant removal performance (Beryani et al., 2021).

To address maintenance challenges and increase confidence in biofilters as stormwater management assets, this work proposes a new concept called Zero Additional Maintenance (ZAM) biofilters. The concept of ZAM biofilters was initially developed by Manningham Council, a local government area in Melbourne and aims to ensure that maintenance implications for asset owners are comparable to maintenance of standard nature strips i.e., the area of public land situated between a private property boundary and the road kerb, also known as a road verge. This would reduce the need for specialised maintenance and better align ZAM biofilter maintenance with regular streetscape maintenance activities compared to traditional biofilter designs (Beryani et al., 2021), thus adding benefits of stormwater management to the urban streetscape without increasing the overall maintenance cost.

2 MATERIALS AND METHODS

This work validates the ZAM biofilter concept by investigating performance across three studies.

Study 1 used vegetated biofilter columns, constructed from 100mm PVC pipe, with a total filter depth of 400mm and a 200mm ponding zone. The filter profile was comprised of a 300mm treatment zone which overlaid a 50mm sand transition layer and a 50mm gravel drainage layer. Within the top 100mm of treatment zone, five alternative filter media configurations were tested for their potential to protect against surface clogging. All columns were planted with lawn grass (*Soft Leaf Buffalo*). The aim of the stormwater dosing regime was to load the biofilter columns with the equivalent of 18 months of inflow over 15 days. To achieve this, the biofilter columns needed to be dosed with 16L of stormwater per day. To assess the development of clogging, outflow rates were manually measured three times a day.

Study 2 assess the nutrient removal ability and hydraulic performance of six lawn grass species in a laboratory-scale column study. The rationale for using lawn grass as the biofilter vegetation was that it could be mowed at the same time as the surrounding nature strip. A total of 35 columns (240mm diameter) were constructed, with five replicates of each lawn grass species and five non-vegetated controls (Figure 1). Over the 10-month study period (12 months from planting, including an initial establishment period), both wet and dry weather conditions were simulated, with eight months of wet conditions (where the columns were dosed with 9.4L of semi-synthetic stormwater twice weekly), and two months of dry conditions, when columns were dosed once per fortnight. During each sampling run, inflow and outflow water samples were collected and analysed for concentrations of total suspended

solids (TSS) as well as total and dissolved nitrogen and phosphorus.

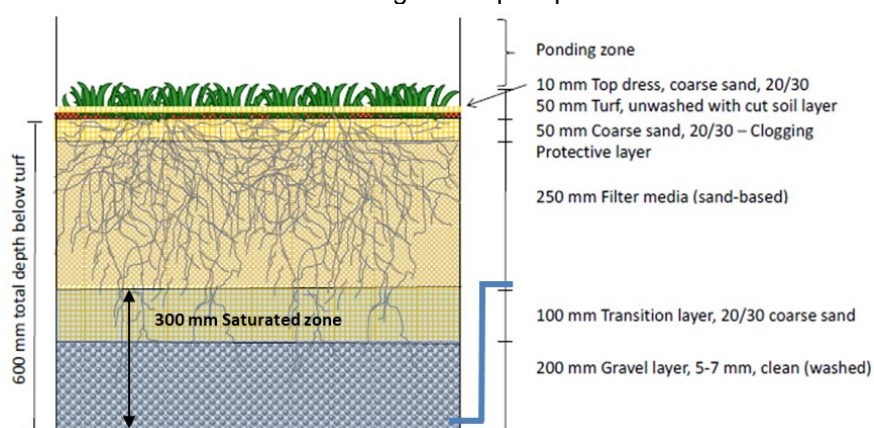


Figure 1. Schematic drawing of biofilter cross-sectional profile for Study 2 and Study 3

In Study 3, three constructed ZAM biofiltration systems located within the Manningham Council boundary were monitored. The total areal footprint of each biofilter was around 6.75m² while the treatment surface area was 2m², equivalent to 1-2% of the impervious catchment area. The filter media configuration and layering were the same as for Study 2 (Figure 1) for two biofilters (HW1 and HW2), while the third (ER) did not have a saturated zone. Five inflow events were simulated at each site over a period of eight months. Influent and effluent samples were analysed for concentrations of copper (Cu), zinc (Zn), TSS, total nitrogen (TN), and total phosphorus (TP).

3 RESULTS AND DISCUSSION

3.1 Performance of alternative surface filter media configurations in clogging prevention

There was a rapid initial decline in outflow rate from all six media configurations over the first 50L, from >700mm/h to 300-400mm/h, followed by a slower decline up to the end of the dosing period. Generally, all five designs containing a protective layer delayed the onset of clogging compared to the control (standard biofilter media profile with no protective top layer). The extent to which clogging was delayed appeared to be partially determined by particle size distribution; designs whose protective layers were comprised of a smaller mean particle size had higher outflow rates, perhaps because they were better able to trap and distribute incoming sediment across the full depth of the protective layer. Selection of the protective layer configuration needs to consider complexity of construction, cost, and capacity to support healthy plant growth as well as ability to delay the onset of clogging.

3.2 The performance of lawn grass species in ZAM biofilters

3.2.1 Hydraulic performance

15 weeks after planting, the average infiltration rate was 456 mm/h and there were no significant differences between grass types. Rates slightly increased after about 14 weeks of stormwater dosing and significantly increased in subsequent three months for all grass species. This increase is likely due to the development of grass roots in the filter media over time, especially during spring, when plants are in their active growth phase. These results confirm the positive effect of biofilter vegetation on maintaining hydraulic capacity.

3.2.2 Pollutant removal performance

There was a significant difference in TN removal rates and effluent NO_x concentrations across grass types ($p < 0.001$) in the initial four sampling runs, with some species performing better than others (Figure 2). This difference could be attributed to the varying growth rates between lawn grasses. The final results indicate that all tested lawn grasses were able to achieve a TN removal efficiency of up to 70-80%, exceeding the 45% reduction recommended by Australian best practice guidelines for stormwater management. There was no significant difference in TP removal across grass species ($p > 0.05$). TP removal by the vegetated columns was poor compared to non-vegetated columns, suggesting that leaching of plant matter may have occurred. Clogging was not found to be an issue, hence the choice of any of the tested lawn species would be suitable for ZAM biofilter design in that respect.

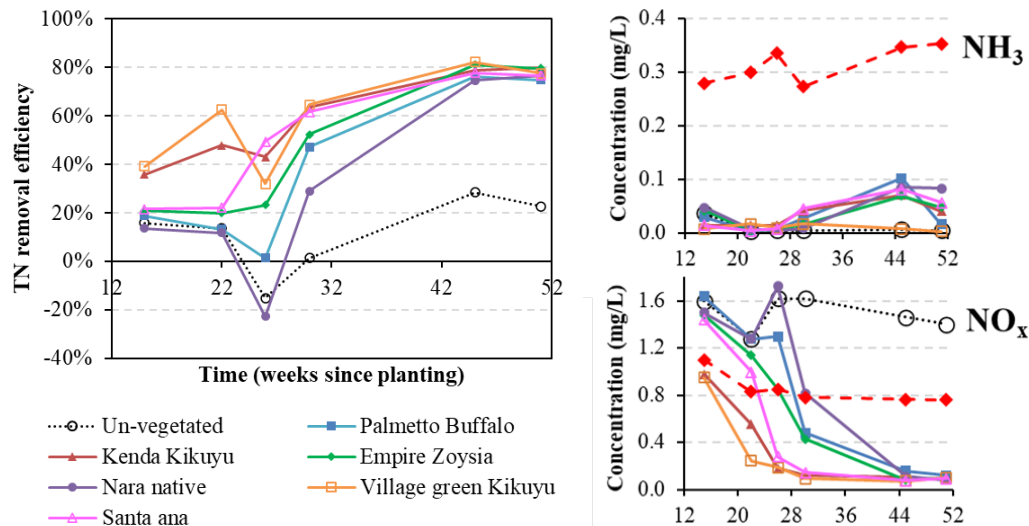


Figure 2. Average TN removal, and NH_3 and NO_x concentrations over time for different lawn grasses

3.3 Performance of of field-scale ZAM biofilters

The lawn grass grew well in all three ZAM biofilters and was green, healthy, and completely covered the treatment area. Outflow concentrations of TSS, TP, Cu, and Zn were significantly lower than inflow concentrations ($p < 0.05$) at all three sites. TP removal increased in comparison to the column trials in Study 2, and this performance is consistent with the literature. In contrast, removal of TN was highly variable, in the range of 28-64%. The median stormwater runoff volume reduction in HW1, HW2, and ER biofilters were 60, 53, and 78%, respectively. This, combined with the general decrease in pollutant concentrations, meant that these systems complied with the local stormwater treatment targets of 80%, 45%, and 45% reduction in loads of TSS, TN, and TP, respectively. Heavy metal concentrations were effectively reduced and the removed metals accumulated close to the surface. There was no surface clogging observed over the 8-month monitoring, proving the effectiveness of ZAM biofilter design.

4 CONCLUSIONS

The results showed that the use of a protective media layer delayed the onset of clogging compared to the design with no protective layer. The choice of easy-to-maintain lawn grasses for ZAM biofilter revealed that biofilters planted with lawn grass species, including Kenda Kikuyu, Empire Zoysia, Santa Ana Couch, Village Green Kikuyu and Palmetto Soft Leaf Buffalo, could be effective for reducing nitrogen concentrations from stormwater. The field study of three ZAM biofilters confirmed their high nutrient and heavy metal removal. All designs achieved substantially higher pollutant load reductions than required by guidelines for stormwater treatment targets. Overall, the findings confirm the potential for ZAM biofilters to achieve stormwater management requirements with no additional maintenance.

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