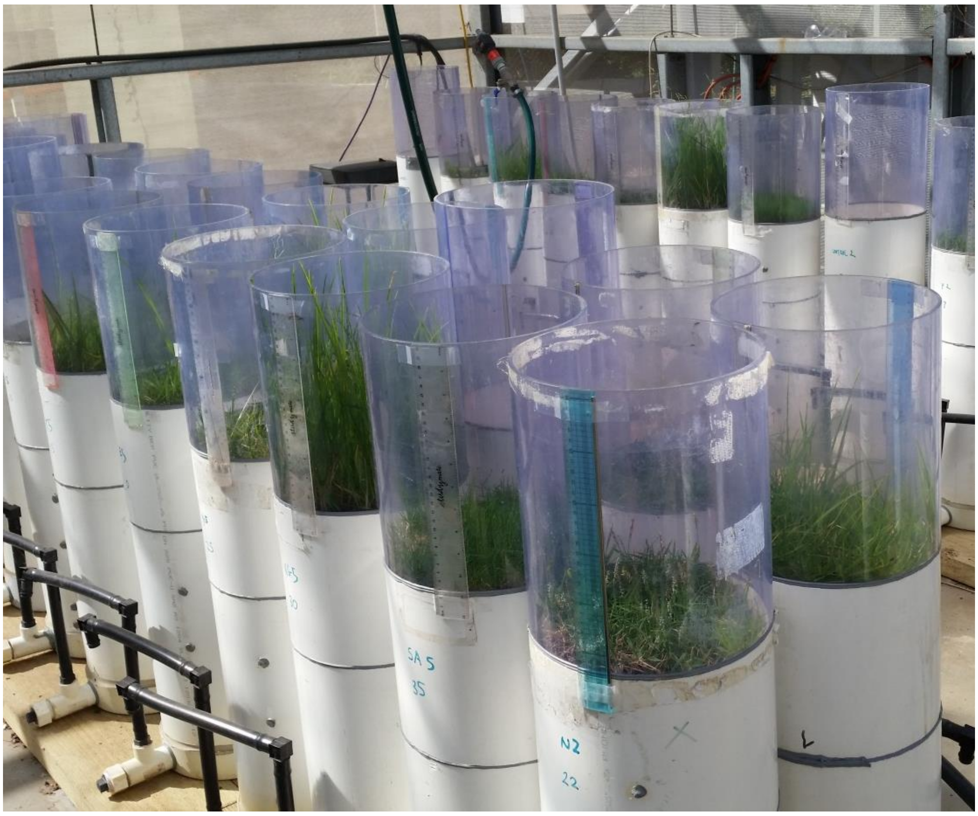
The performance of turf grass species in ZAM-WSUD stormwater biofilters



Final report

April 2018

Manningham City Council

Monash University

Prepared by

Harsha Fowdar, Ana Deletic, Emily Payne & Simon Brink

MONASH University
Engineering

MANNINGHAM

Acknowledgements

This project was funded by the Living Rivers funding grant awarded by Melbourne Water (50%) and Manningham City Council (50%). Dr Belinda Hatt and Dr Emily Payne (Monash University) are acknowledged for their help during the development of the project proposal. Masters student, Feiran Huang is also acknowledged for her contribution in the laboratory work.

Executive summary

Manningham City Council, in partnership with Melbourne Water and the CRC for Water Sensitive Cities, has been testing novel stormwater biofiltration systems that aim to require no more than typical council maintenance works (i.e. 'Zero Additional Maintenance' WSUD systems). Planting with lawn grasses comprise one such design modification of these ZAM-WSUD systems. A trial of five different lawn grass species, tested for their survival and growth in the field, found that different site conditions require different lawn grass species to best suit the environment. While the field trial only assessed grass survivability, the nutrient removal abilities of various lawn grasses remain unknown. The aim of this project was to quantify the nutrient removal performance of a range of lawn species and elucidate on their capacity to meet regulatory requirements and best practice standards.

A 6-month laboratory column trial was set-up in an open-air greenhouse at Monash University where six different lawn grasses were dosed with semi-synthetic stormwater at different intervals, hence simulating wet and dry weather conditions. A total of four water quality sampling campaigns were conducted during which time inflow and outflow water samples were collected for analysis of their nitrogen and phosphorus concentrations (two sampling events). Infiltration rate measurements were also periodically conducted to assess whether any species were associated with fast- or slow-drainage. In response to the results of this initial laboratory trial, the experiment was extended for another five months to incorporate an additional set of testing under wet and dry weather respectively.

The results found that the grass species (including Kenda Kikuyu, Village Green Kikuyu, Santa Ana Couch, Empire Zoysia and Palmetto Soft Leaf Buffalo) are likely able to meet best practice stormwater management standards in terms of pollutant reduction. Nitrogen removal performance was relatively poorer for some species during winter, during which time the grasses went into a period of dormancy, indicating a seasonal variation in removal performance. After establishment, all species performed comparatively well under both wet and dry weather conditions.

In summary, the results of this trial indicate that various lawn grasses can be effective for nitrogen removal as long as they grow well and are healthy. The key message is, essentially, that for a particular site, choose the lawn species that is more likely to thrive under that particular site condition and this will most likely translate into effective nitrogen treatment performance (slower growing plants will have lower percentage reductions). In this study, Kenda and Village Green Kikuyu were the best performers, followed by Santa Ana Couch, Empire Zoysia, Palmetto Soft leaf Buffalo and Nara Native Zoysia) at start-up (winter and spring). During summer when the species were relatively mature, all species were identical in their nitrogen removal performance.

Table of Contents

1. Introduction

Manningham City Council, in partnership with Melbourne Water and the CRC for Water Sensitive Cities, has been testing novel stormwater biofiltration systems that aim to require no more than typical council maintenance works (i.e. 'Zero Additional Maintenance' WSUD systems). This was driven by an increasing need for WSUD across the urban environment, but the limited capacity to fund maintenance of a growing asset base into the future. The program has successfully installed, trialled and refined various ZAM-WSUD designs at multiple sites and has led to the generation of a freely available ZAM-WSUD handbook to facilitate widespread adoption of these low maintenance systems (the ZAM-WSUD handbook is available through the Clearwater website at https://www.clearwatervic.com.au/resource-library/publications-and-reports/zero-additional-maintenance-water-sensitive-urban-design-zam-wsud-handbook.php). Following to the success of the research project, Manningham Council is considering opportunities to integrate ZAM-WSUD into Council's Capital Works Program, as a regular component of projects.

Initial field trials were largely planted with Palmetto Soft Leaf Buffalo, as the performance of this lawn species for nutrient removal from stormwater was tested by Monash University in biofilter column tests (Payne et al., 2014a). In this laboratory-scale study (using small columns of 150 mm diameter) buffalo grass was associated with good removal of both nitrogen and phosphorus. However at some field sites with high sun exposure the Palmetto Soft Leaf Buffalo was not surviving well, particularly during establishment and this led to testing of a wider range of lawn grass species.

A field trial of five different lawn grass species were tested for their survival and growth at a site with high pedestrian traffic (adjacent to a car park) and high sun exposure. The results showed that different site conditions will require different lawn grass species to best suit the environment, including degree of sun/shade exposure, pedestrian traffic and proximity to environments sensitive to invasion. For instance, after four months of growth (across autumn and winter) Kenda Kikuyu and Empire Zoysia grew particularly well. Palmetto Buffalo was doing relatively well, followed by Nara Native Zoysia with fair to good survival.

The field trial only assessed grass survivability, and the nutrient removal capabilities of these various lawn species remains unknown. The potential for species to differ significantly in their nutrient removal capabilities, most critically for nitrogen, has been demonstrated in multiple studies (Read et al., 2008, Bratières et al., 2008, Payne et al., 2014a). Multiple councils are interested in the use of grassed biofiltration systems but without understanding how different turf varieties differ in their performance. There is uncertainty surrounding their capacity to meet regulatory requirements and best practice standards.

This document reports on a six-month laboratory study undertaken by Monash University in collaboration with Manningham City Council. The objective of this study was to test a range of lawn grasses for their nitrogen and phosphorus removal ability. Performance during dry periods has also been tested. As clogging has been problematic for some lawn grasses previously tested (particularly Velvetene (Pham et al., 2012)), infiltration rates were also measured during the lab study. This document, ultimately, attempts to make recommendations regarding the most effective lawn grass species for installation in ZAM-WSUD systems.

2. Methodology

2.1 Lawn grass species tested

Palmetto soft leaf buffalo, Kenda Kikuyu, Empire Zoysia, and Nara Native Zoysia have been trialled in the field. Field trials of the Palmetto SS100 cultivars showed that they can be grown in biofilter sands, for "full sun" sites with dry soils. The trials indicated that for south eastern Australian climatic conditions, sterile male Kikuyu species Kenda and Village Green) are most suitable for sites with minimal shade (<20%). Empire Zoysia was found to be more suitable for low to medium pesdestrian traffic sites with part shade (20-40%). Santa Ana Couch may also be generally suitable, but has not yet been trialled in field installations. The following six lawn species (Figure 1) were, thus, tested for their nutrient removal ability to assess their suitability for use in ZAM-WSUD applications.

Figure 1 Lawn grasses tested in the laboratory trial

2.2 Experimental set-up

35 columns were set-up (including five replicates of each lawn species and five non-vegetated controls) in an open-air greenhouse with a clear impermeable roof. The columns were constructed from 240 mm diameter PVC pipe, with a transparent Perspex top section allowing for plant growth and ponding of water (Figure 2). The insides of the columns were sand-blasted to reduce preferential flow along the column edges. Columns were filled with different layers of media as shown in Figure 2. Freshly sourced lawn grasses were laid into a total of 30 columns. The remaining 5 columns were left un-vegetated, thereby acting as controls and to inform on the performance of bare sites with poor grass survival. Depth of the saturated zone was 300 mm (by raising the outlet pipe); this comprised the gravel and transition layer.

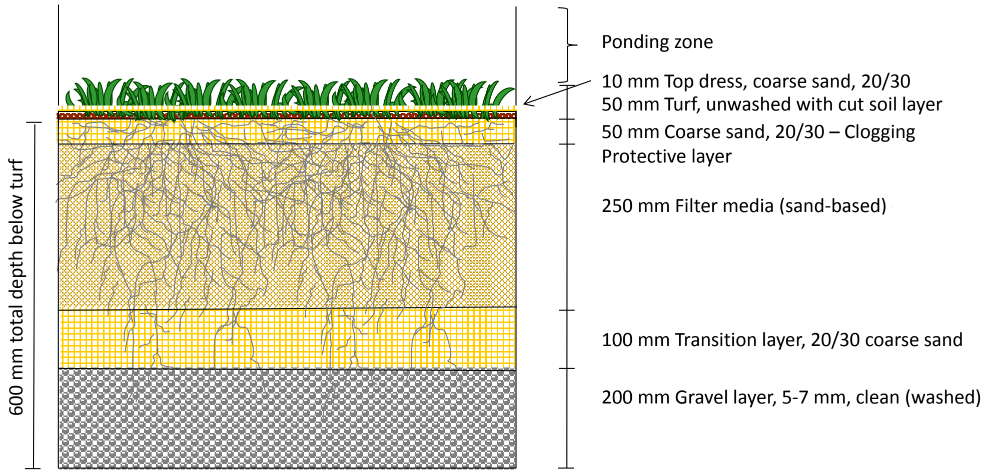


Figure 2 Schematic of biofilter cross-sectional profile

2.3 Experimental procedure

2.3.1 Plant establishment

A liquid fertiliser (Multicrop Plant Starter Liquid Fertiliser) was added after planting (~2L after dilution with tap water). Plant establishment period lasted for six weeks during which time the grasses were watered with approximately 2 L of tap water three times per week for the first two weeks to ensure survivability. The watering frequency was then reduced to twice per week. Lawn grasses were mowed as necessary during the trial period.

2.3.2 Semi-synthetic stormwater dosing and water quality sampling

In early June 2017, dosing of the columns with 9.4 L of semi-synthetic stormwater twice weekly commenced. This dosing regime was based on an annual average effective rainfall of 540 mm/year for Melbourne and using a biofilter sized to 2.5% of its contributing catchment. Use of semi-synthetic stormwater allowed us to minimise variations in inflow concentration whilst maintaining realistic composition. It contained sediment from a local stormwater retention wetland, sieved to 1 mm and mixed with dechlorinated tap water to achieve the target TSS concentration. Laboratory chemicals (potassium nitrate, ammonium chloride, nicotinic acid, potassium sulphate and sodium thiosulphate) were added to match any deficit in targeted pollutant concentrations as detailed in Bratieres et al., 2008. Target nutrient concentrations were shown below.

Pollutant	Target concentration (mg/L)
Total nitrogen, TN	2.10
Total phosphorus, TP	0.35
Total dissolved nitrogen, TDN	1.60
Ammonia, NH_3	0.27
Oxidised nitrogen – sum of nitrate and nitrite, NO_x	0.75
Particulate organic nitrogen, PON	0.50
Dissolved organic nitrogen, DON	0.59

Over the 6-months study period, both wet and dry weather conditions were simulated; 5-months of wet period (twice weekly dosing) and 1 month of dry period (dosing once per fortnight) were simulated (Figure 3).

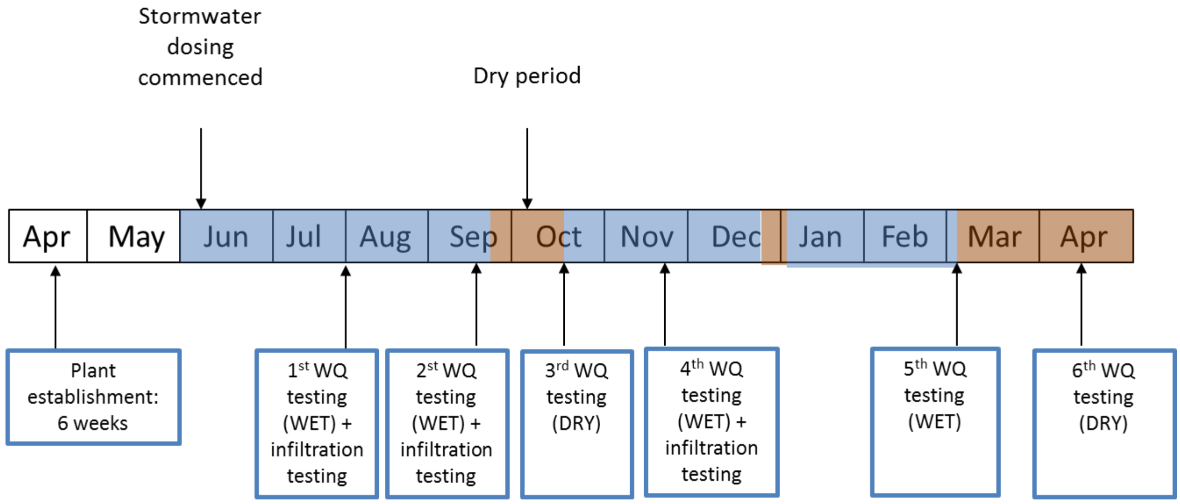


Figure 3 Dosing and sampling schedule (April 2017 to April 2018)

A total of four sampling runs were conducted over a period of 6 months. During each sampling run, inflow and outflow water samples were collected. A composite outflow sample was taken after the column finished draining. This was sub-sampled into a 1 L bottle. All samples were analysed in a NATA (National Association of Testing Authorities, Australia) accredited laboratory according to standard methods (Hosomi & Sudo, 1986; APHA/AWWA/WPCF, 1998). All sampling runs were analysed for TN, TDN, NH_3, NO_x while the last 2 sampling runs were also analysed for TP, TDP and FRP (filterable reactive phosphorus, a measure of orthophosphate, PO_4^{3-}). DON was calculated as the difference between TDN and NH_3 + NO_x. The difference between TP and TDP is a measure of particulate phosphorus.

Trial extension for monitoring nitrogen removal

Initial results found species-specific difference in the grasses growth rate which, in turn, influenced their nitrogen removal rate (see further Figure 6). To get a better idea of the removal performance over the long term as grasses become established, the trial was extended for a period of five months during which time, an additional two sampling runs were undertaken (Figure 3).

2.3.3 Infiltration rate measurements

In order to ensure that the grass species had an adequate drainage rate over time and were not subject to clogging, infiltration rate measurements were conducted at regular intervals (Figure 3). During a dosing event, the drop in ponding water level was measured every 60 s for at least 15 minutes depending on the rate of drainage of the column. The infiltration rate was calculated as the average decrease in water level over measurement time.

3. Results and discussion

3.1 Infiltration rate

Three infiltration rate measurements were conducted over the 6-month study period to determine any clogging behaviour and identify any species associated with slow or fast drainage. After 15 weeks since planting (August, after about 8 weeks of stormwater dosing), the average infiltration rate amounted to 456 mm/h and there was no significant difference across grass type. Rates slightly increased in September 2017 (i.e. after about 14 weeks of stormwater dosing) and significantly increased from September 2017 to November 2017 for all grass species (Figure 4). This increase could be due to weather conditions (that is lower rates during winter vs spring) as well as the development of grass roots in the soil over time. In contrast, a decrease in infiltration rate was observed for the non-vegetated columns over time. This could stem from an accumulation of sediments on the surface of the filter media over time. The above results confirm the positive effect that vegetation has in WSUD systems in alleviating issues associated with clogging.

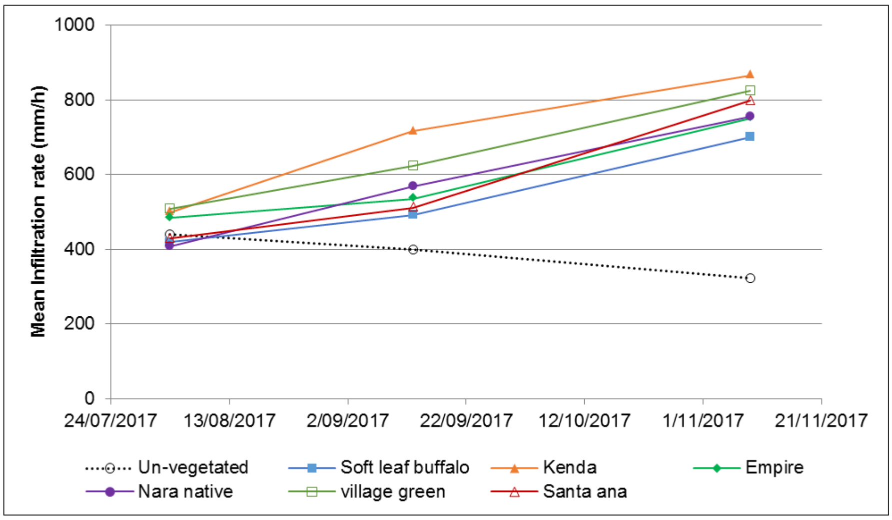


Figure 4 Evolution of mean infiltration rate over time for the different grass species

It should be noted the high infiltration rate measured in this trial (Figure 4) may not be reflective of field conditions (i.e. it is expected that infiltration rate would be lower in the field as a result of compaction due to vehicular and/or human traffic, litter accumulation, etc). Yet, these results give a clear comparison of the behaviour of different lawn grasses in the field.

Average infiltration rates were statistically similar across grass species ($p>0.05$) after 15, 21 and 28 weeks of planting respectively. Interestingly, particularly in November, planted columns had significantly higher infiltration rates than unplanted columns (Figure 5). Vegetation indeed loosens up the inside of the filter media with roots. Santa Ana Couch and Kenda Kikuyu had the least variation in infiltration rates across replicates whilst Empire Zoysia the greatest (Figure 5).

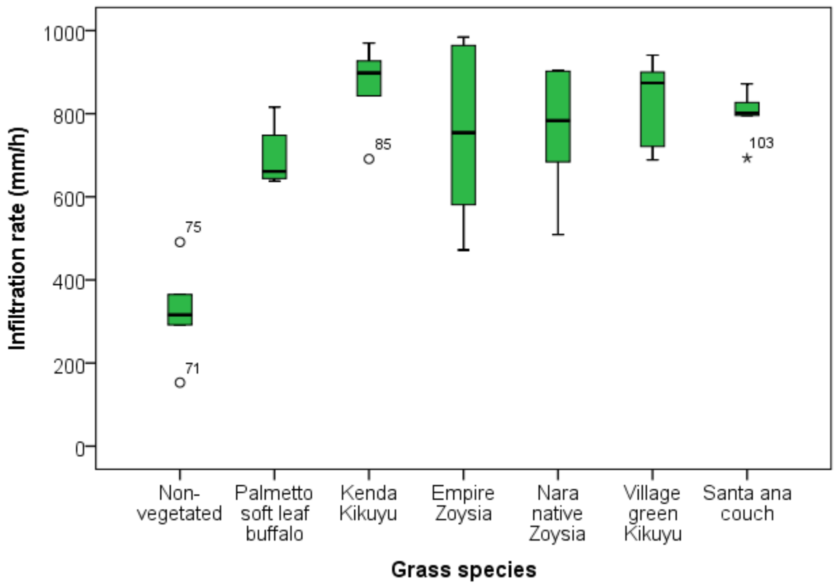


Figure 5 Variation of infiltration rate across grass species after 6 months of stormwater inflow (November 2017)

3.2 Water quality

3.2.1 Nitrogen

The TN removal efficiency (calculated as a percentage of the difference in inflow and outflow concentration) and the variation of outflow NO_x, NH_3 and DON concentrations over time are shown in Figure 6 and 7 respectively. We can see a net removal of total nitrogen for all grass species in every sampling event, except for the non-vegetated and Nara native columns in the 3rd sampling (at week 26 where outflow concentrations were greater than inflow concentrations). Week 26 sampling occurred after 4 weeks of dry period (i.e. columns received stormwater only twice over a 30 day period). Reduced performance is typical after dry weather spells due to some root die-off and leaching from filter media and reduction in microbial activity as a result of desiccation. It is highly likely that Nara Native Zoysia had not well established at that time (it essentially went into a state of dormancy during winter) which resulted in a decrease in its performance. Indeed, as the lawn grasses matured and under summer conditions, all species experienced an increase in nitrogen removal. Interestingly, two weeks dry period had no significant effect on nitrogen removal during this period (see results at week 45 and 51, Figure 6).In general, columns planted with the grass species performed better than the bare columns. This is more apparent at week 45 and 51 which represent more mature conditions.

Removal was low in the initial sampling rounds because as mentioned previously the grasses were still establishing and the winter season caused some species to enter dormancy (particularly, Nara Native, Santa Ana, Palmetto Buffalo, Empire Zoysia). But at the end of spring (week 30), an increase in removal for most grass species was accompanied by an increase in grass growth to peak to approximately 80% removal at week 45 and 51. See also Figure 8 for visual images of the grasses in September vs November.

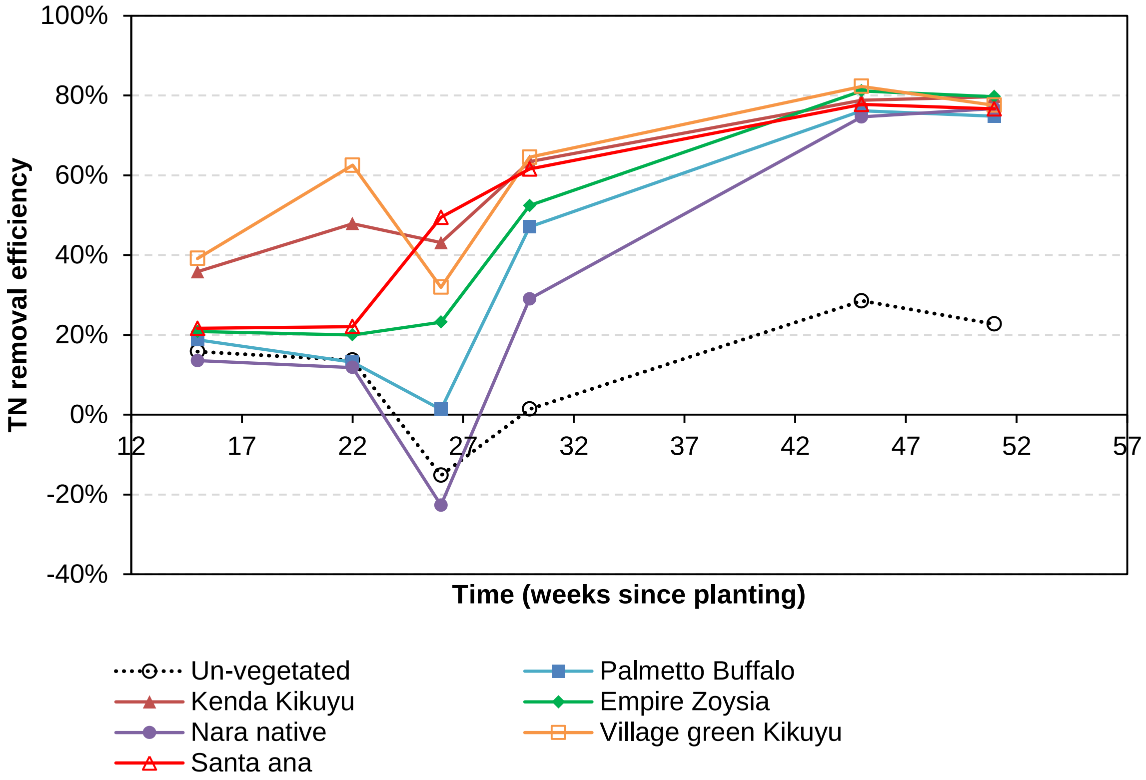


Figure 6 Average total nitrogen (TN) removal efficiencies over time for different lawn grasses

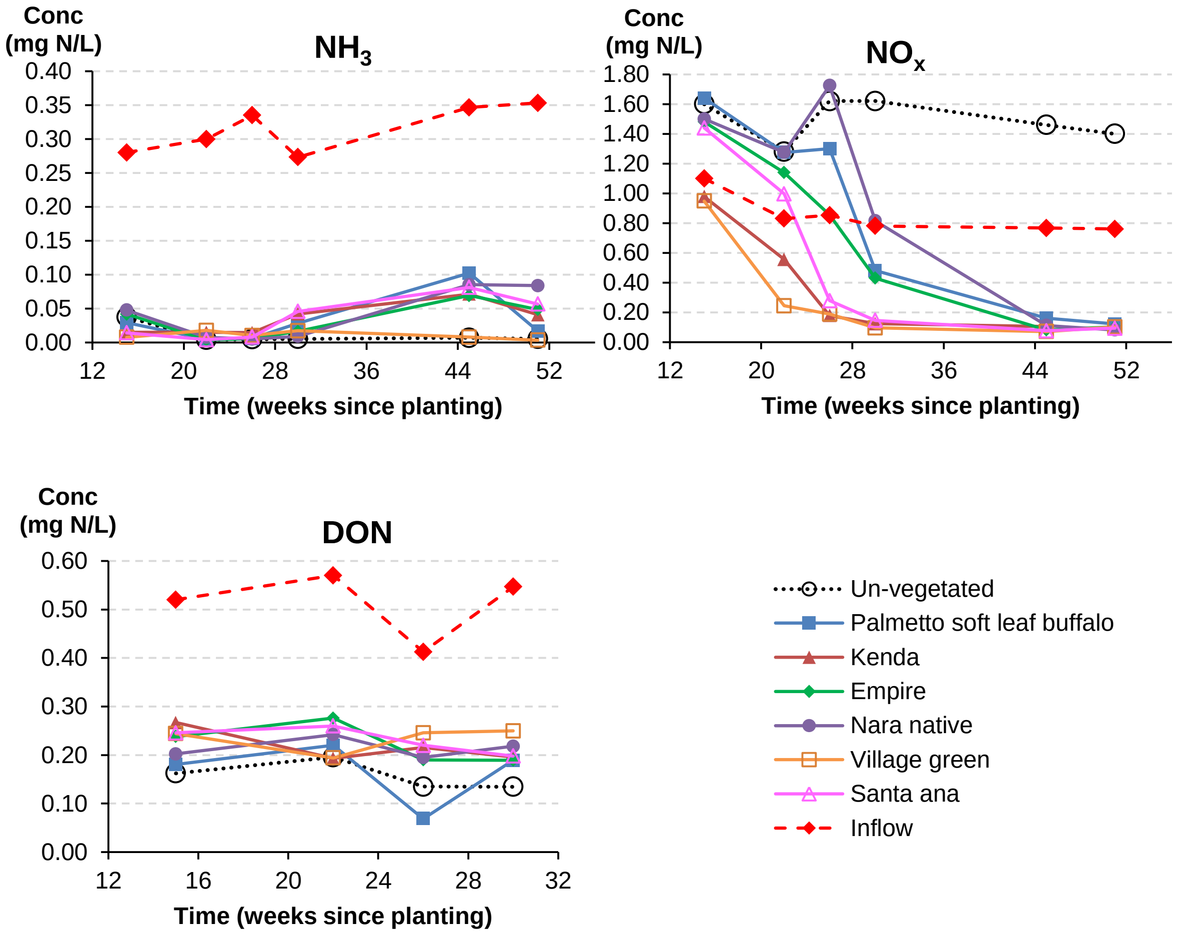


Figure 7 Effluent concentrations in column outflow of dissolved nitrogen species (ammonia, NH_3; oxidised nitrogen, NO_x and dissolved organic nitrogen, DON) across lawn grasses

Effluent NH_3 concentrations were low in all cases (Figure 7). NH_3 is mainly removed through adsorption and microbial processing via nitrification which occurred effectively. There was a net reduction in DON concentrations which occurred up to a background concentration. On the other hand, effluent NO_x concentrations varied during the study period, with some net production from nitrification (the microbial conversion of NH_3 to NO_x) and insufficient plant uptake in certain instances. A general decrease in effluent NO_x concentration was, nevertheless, observed with time. In fact, TN removal was dictated by the extent of NO_x removal and/or production.

Variation across grass species

There was a significant difference in TN removal and effluent NO_x concentrations across grass type ($p<0.001$) in the initial 4 sampling runs, with some species performing better than others (Figure 6). This difference could be attributed to the growth pattern of the different lawn grasses. For instance, some species were dormant during winter while others experienced active growth (particularly, the Kikuyu species), leading to higher removal performance. Previous studies have found that plant uptake likely plays a key role in nitrogen removal (Payne et al., 2014b). In the same vein, growth rate of the lawn grasses is likely another factor influencing nitrogen removal. Nara native Zoysia is known to be slow growing which explains its lower performance. Nara Native Zoysia also goes dormant during drought, which explains the poor performance during week 26.

Interestingly, after establishment and under more mature state, the difference in performance across lawn grasses became insignificant.

The results indicate that the lawn grasses are able to achieve a high removal efficiency which could meet best practice guidelines for stormwater management recommending at least 45% reduction in the field. Further field tests need to be conducted to confirm this.

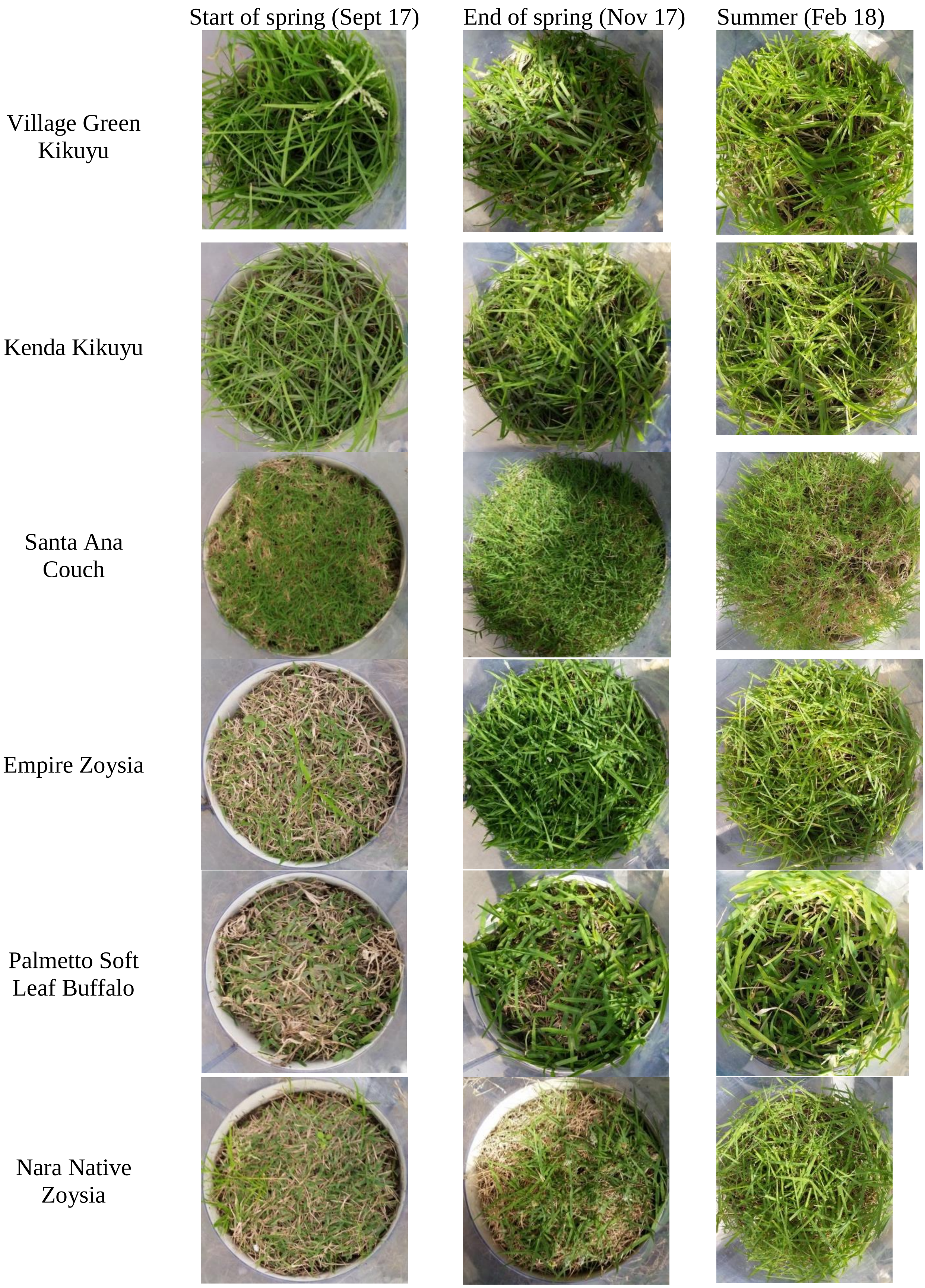


Figure 8 Comparison of the physical appearance of lawn grasses in August (Melbourne winter) and November (Melbourne spring end). Almost all lawn species showed good growth and greening in November.

3.2.2 Phosphorus

Phosphorus from stormwater is usually well-removed in biofilters since it is mostly associated with sediments and thus removed through physical processes. To verify the performance of TP in systems planted with lawn grasses, TP was analysed for only two sampling events: during October (dry period) and November (wet period). The results are presented in Figure 9. During the dry period (week 26), TP reduction ranged from -13% (Nara Native) to 26% (bare column). FRP removal ranged from 54% (Nara Native) to 91% (Kenda). Since FRP was mostly well-removed and most of the TDP was in the form of FRP, this signifies that the poor TP performance was due to leaching in the form of particulate phosphorus (see also Figure 10), released from the filter media and mostly from plant matter as a result of dessication as explained previously. During the wet period (week 30), a major improvement in phosphorus reduction was recorded with TP ranging from 14% (Nara Native) to 53% (bare column) while FRP ranged from 40% to 82%. Since most of the P in the effluent is bound to particles, that is, are potentially in a non-reactive/less bioavailable form, this minimises the environmental risk. In the future, a deeper transition layer comprising coarse sand can be implemented to screen fine particles migrating from the upper filter media. There was no significant difference in TP removal across grass species ($p>0.05$). Poorer removal of vegetated columns compared to non-vegetated columns could be leaching from plant matter.

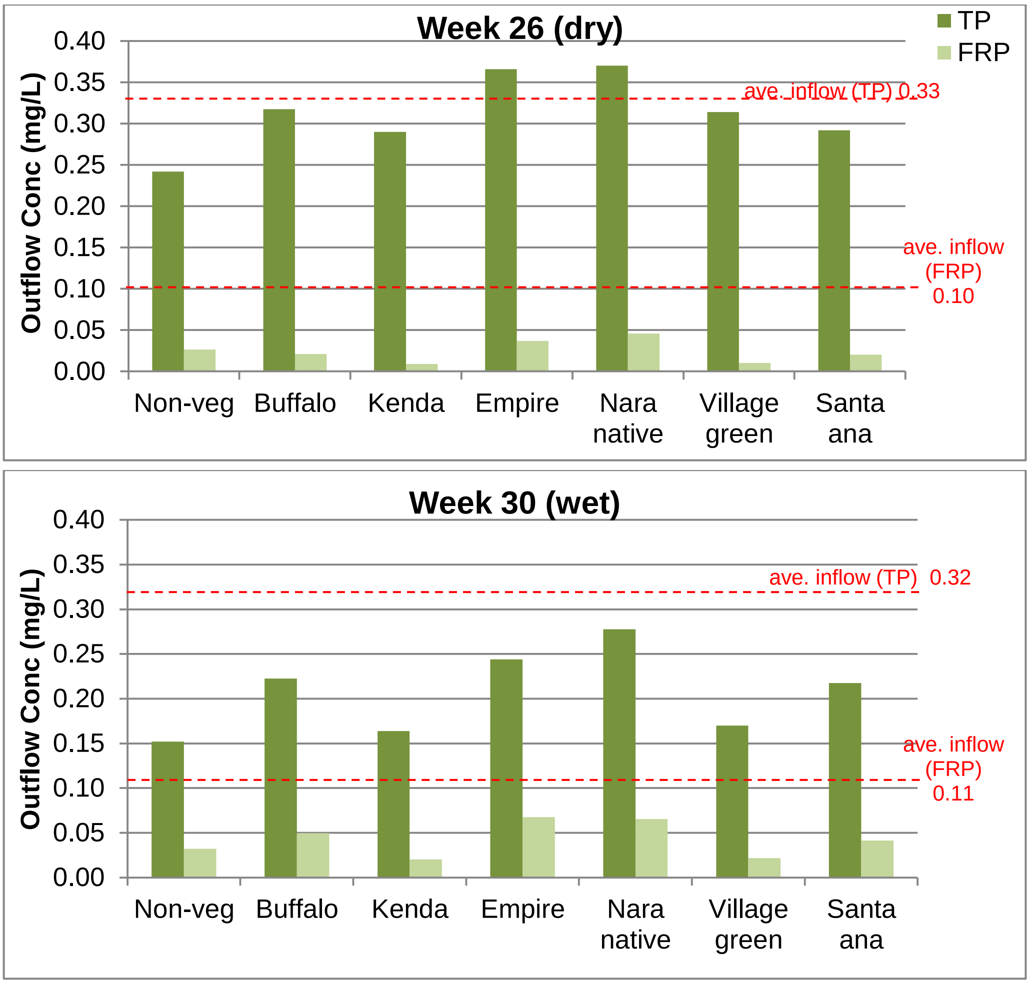


Figure 9 Comparison of average outflow total phosphorus (TP) and filterable reactive phosphorus (FRP, a measure of orthophosphate) concentrations across lawn grasses during dry and wet weather conditions

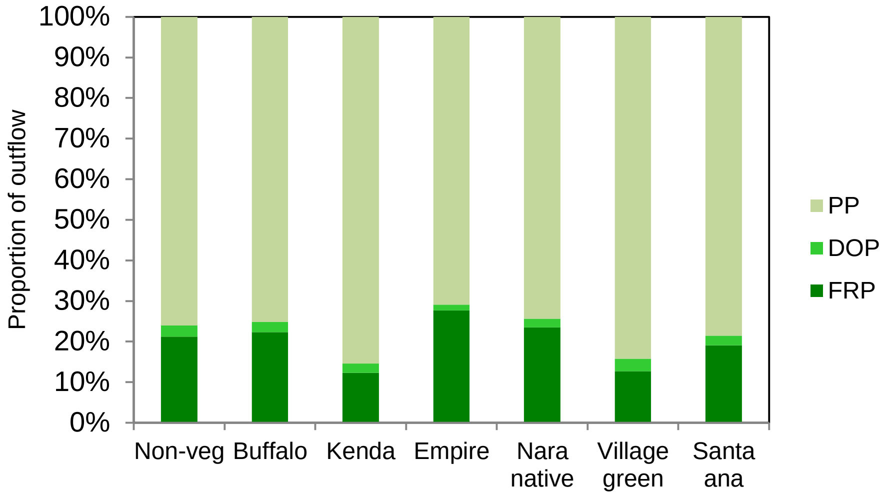


Figure 10 Proportion of outflow TP concentration as FRP, dissolved non-reactive P (DOP) and particulate P (PP)

4. Conclusions and Recommendations

The results of this study showed 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. It was found that if installed under correct conditions, lawn grasses are able to meet regulatory requirements and best practice standards for nitrogen reduction (Victoria Stormwater Committee, 2006).

Because of their faster growth rate and probable growth during winter period, Kenda Kikuyu and Village Green Kikuyu were the best performing lawn species during the initial trial period.. At maturity, all species were universally effective at nitrogen removal.

Nitrogen removal may be poorer during the first few months as the grasses are establishing. It appears that lawn grasses may be more susceptible to seasonal variation in comparison with other species (e.g. native shrubs, sedge or ornamental plants) (Fowdar et al., 2017). For example, Nara Native Zoysia, Santa ana Couch and Empire Zoysia may go dormant during winter.

Clogging was not found to be an issue during the trial period.

While the effect of dry period could be more pronounced for some species during winter, all lawn species were able to maintain performance during summer in the present study.

The key message is that lawn species with poor survivability would result in poor nutrient removal. Lawn species that are healthy will provide the greatest benefit. Always choose lawn species that will grow well in the particular location (although slow growing species can be expected to render lower nutrient removal) for effective nutrient removal. For e.g., installing Kenda Kikuyu in a shady location (when it is not shade tolerant) will produce lower removal rates than Palmetto Soft Leaf Buffalo which is more shade tolerant.

From this study, while it can be speculated that nutrient removal of the lawn grasses is a function of grass health and growth rate, plant growth and vegetation mass changes were not monitored during this study. Further studies will validate this as well as whether nutrient removal is also based on other factors such as species type.

Table 1 Characteristics of lawn grasses and corresponding nitrogen removal performance

Lawn species	Characteristics	Nutrient removal performance (as per this study)
Village green Kikuyu	• High root volume for nutrient and water uptake. • Holds superior colour over the winter months compared to common Kikuyu • Maintains green colour and dense coverage for most of the year in Victoria • Drought tolerant • Winter active with an excellent recovery rate • Quick to establish a strong healthy root system	Effective
Kenda Kikuyu	• Fast establishment • Good drought tolerance • Good wear tolerance • Dense and deep root system • High winter activity	Effective
Santa Ana Couch	• Short dormancy period • Very deep root system • Recovers rapidly from damage • Goes dormant in winter	Effective (after establishment). Maintains performance during 15-weeks dry
Empire Zoysia	• Comparatively slower growth than Kikuyu or Couch • Drought tolerant • May be prone to brown off in winter • Slow to establish in winter • Winter dormancy	Effective after establishment
Nara native Zoysia	• Slower growing than Kikuyu and Buffalo • Faster growing than Empire Zoysia • Tends to produce a burst of seed head in early spring • Goes dormant in severe drought to survive • Some winter dormancy	Effective after establishment (not recommended in climates with frequent dry weather spells)
Palmetto Soft Leaf Buffalo	• Low maintenance (incl. watering) • Shade tolerant	Effective after establishment

References

APHA/AWWA/WPCF (Ed.) (1998) *Standard Methods for the Examination of Water and Wastewater,* Washington, USA, 20th American Public Health Association/American Water Works Association/Water Pollution Control Federation.

Bratieres, K., Fletcher, T.D., Deletic, A. and Zinger, Y.A.R.O.N., 2008. Nutrient and sediment removal by stormwater biofilters: A large-scale design optimisation study. *Water research*, *42*(14), pp.3930-3940.

Fowdar, H.S., Hatt, B.E., Breen, P., Cook, P.L. and Deletic, A., 2017. Designing living walls for greywater treatment. *Water research*, *110*, pp.218-232.

Hosomi, M. & Sudo, R. (1986) Simultaneous determination of total nitrogen and total phosphorus in freshwater samples using persulfate digestion. *International Journal of Environmental Studies,* 27 (3 & 4)**:** 267 - 275.

Payne, E.G., Pham, T., Cook, P.L., Fletcher, T.D., Hatt, B.E. and Deletic, A., 2014a. Biofilter design for effective nitrogen removal from stormwater–influence of plant species, inflow hydrology and use of a saturated zone. *Water Science and Technology*, *69*(6), pp.1312-1319.

Payne, E.G., Fletcher, T.D., Russell, D.G., Grace, M.R., Cavagnaro, T.R., Evrard, V., Deletic, A., Hatt, B.E. and Cook, P.L., 2014b. Temporary storage or permanent removal? The division of nitrogen between biotic assimilation and denitrification in stormwater biofiltration systems. *PloS one*, *9*(3), p.e90890.

Read, J., Wevill, T., Fletcher, T. and Deletic, A., 2008. Variation among plant species in pollutant removal from stormwater in biofiltration systems. *Water research*, *42*(4), pp.893-902.

Pham, T., Payne, E.G., Fletcher, T.D., Cook, P.L., Deletic, A. and Hatt, B.E., 2012. The influence of vegetation in stormwater biofilters on infiltration and nitrogen removal: preliminary findings. In *WSUD 2012: Water sensitive urban design; Building the water sensitive community; 7th international conference on water sensitive urban design* (p. 145). Engineers Australia

Victoria. Stormwater Committee, 2006. *Urban stormwater best practice environmental management guidelines*, Melbourne: CSIRO Publishing.