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WSUD INFRASTRUCTURE: AN ASSET TO BE MANAGED

BIOFILTRATION DESIGN – A CASE STUDY OF BIOFILTRATION SYSTEMS IN RESIDENTIAL AREAS USING DIFFERENT FILTER MEDIA

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Abstract

In 2004, Ku-ring-gai Council commenced an environmental capital works program to deliver a range of Water Sensitive Urban Design (WSUD) projects. As waterways from the council area drain into three national parks, a focus of the program was to quantify the performance of various treatment systems to evaluate their impact on improving water quality and also to improve future design and operation. This case study investigates the design and function of two biofiltration systems using different filter media. The results suggest that sand may be a preferred filter media when targeting nutrients and metals, while sandy loam performed better in terms of removal of faecal coliforms. In relation to the capture and treatment of metals the research indicates there is an export of some of these contaminants from both filter media possibly due to the source of the media. However, the data set was small and more testing is required to further explore these preliminary finding. The results highlight the need to consider the type of filter media when designing stormwater treatment biofilters along with other design parameters such as hydraulic conductivity and surface area.

1 INTRODUCTION

The Ku-ring-gai local government area (LGA) is located approximately 15 kilometres north of the Sydney CBD in New South Wales (NSW), Australia and covers an area of 85.4 km2 (ABS 2006). It is characterised by low density residential housing set on individual lots. Formalised drainage systems are present in most developed areas and the connected impervious percentage is approximately 29.3% (Davies et al, 2010).

In 2004 Ku-ring-gai Council introduced a seven year environmental levy program of which one of the funding areas was the implementation of Water Sensitive Urban Design (WSUD) projects. This responded to the degraded state of many of the urban waterways, the high importance the local community placed on these natural assets and the need for water conservation and reuse that responded to the drought affecting Sydney at the time.

Some of the major challenges of the WSUD program were the difficulties in retrofitting devices into catchments with limited space and the emerging body of research informing the design and function of systems. While the developed areas of the catchment are dominated by low density development, services such as electricity, water, gas and telecommunications present ongoing design and site constrains. This is particularly so for biofiltration systems (also called raingardens or bioretention systems), where it can be difficult if not impossible to secure the surface area required to comply with existing design guidelines. In many cases this results in a smaller sized unit with lower treatment capacity therefore reducing the effectiveness of the system and in turn may compromise the project's objectives.

The Australian guideline informing the design of biofiltration systems recognises the relationship between ponding depth, size and hydraulic conductivity of a filter media to its overall ability to capture and retain pollutants (FAWB 2009). However, much of the research focuses on the efficiency of the filtration media in removing target pollutants and has been largely based on laboratory studies. Limited research has been undertaken to validate laboratory results with that experienced in the field. Reflecting on these limitations, one of the elements of Council's WSUD program is to measure the performance of the various devices installed to improve future design and operation, and contribute to the applied research in this field.

This paper presents a case study of the design and performance of two biofiltration systems using different filter media. Water quality test results and hydraulic conductivity tests are used to compare against assumptions made during design.

2 BACKGROUND

In 2006 and 2007 Council completed a number of small biofiltration systems. These were designed in accordance with then current design guidelines (Ecological Engineering et al 2006). However, once in operation they encountered problems with the hydraulic conductivity being considerably lower than what was designed and indicated as part of the soil specification. Water quality testing conducted in 2008 also returned results that were not consistent with results reported in other studies. The test results have been discussed in a previous paper (Findley et al 2008). This data coupled with observations that large amounts of fine sediments were exported from the systems during establishment led council to investigate alternative design approaches for biofiltration systems. The objectives were to identify design solutions to enable the construction of smaller systems and to reduce export of sediments from the system itself without compromising the overall performance of the system.

Many organisations in Australia are using the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) as developed by the Australian Cooperative Research Centre for Catchment Hydrology (CRCCH) when designing and evaluating the performance of biofiltration systems used to treat urban runoff. As part of this process, hydraulic conductivity of the filter media is a key input into the modelling and the use of realistic values is essential for both design and during evaluation.

The specification of a soil media intended for biofiltration applications often include a value for saturated hydraulic conductivity as tested by the supplier. However, time and financial constraints often limits the ability to test filter media as supplied to site and therefore verify that the media complies with the specifications. If the supplier has provided a value for the saturated hydraulic conductivity, this is often relied upon when making design decisions and evaluating the performance and benefits of a biofiltration system.

In 2007 Council undertook a modelling exercise using MUSIC version 3.01 to investigate the sensitivity of hydraulic conductivity as part of the design and performance of biofiltration systems. This found that small systems that used filter media with a high hydraulic conductivity would lead to an improved treatment of stormwater runoff compared to using a filter media with a lower hydraulic conductivity (Jonasson et al 2010). A hypothesis was developed that by utilising a sand filter media rather than sandy loam the overall performance of the system could be improved. This approach could support the use of systems with a smaller footprint than the traditional approach using a sandy loam media.

In order to assess the hypothesis, a sand filter biofiltration system was constructed in 2008 at Kooloona Crescent, West Pymble (Latitude -33.7667, Longitude 151.1322). Coarse washed river sand was used and was amended with water absorbing polymers in an attempt to provide some longer term water availability for the plants. During construction the filter was unfortunately covered with decomposed granite containing fines that may have impacted on the overall hydraulic conductivity of the system (reflecting the inherent challenges faced by devices in the field). The garden was planted with a mix of *Juncus usitatus, Dianella caerulea* and *Dichelachne micrantha*.

The sand filter biofiltration system at Kooloona Crescent was compared with one of three biofiltration raingardens constructed at Karuah Road adjacent to Turramurra Memorial Park, Turramurra (Latitude -33.7264, Longitude 151.1303), called Karuah Road 3. The Karuah Road raingarden used for comparison were constructed in 2007 using sandy loam filter media and has been described in previous papers (Findlay et al

2008, Jonasson et al 2007). All gardens included a subsoil drainage system, collecting filtered water and returning it back to the drainage system.

3 METHODOLOGY

3.1 Hydraulic conductivity measurement

Hydraulic conductivity of soil in laboratory was assessed using two different methods:

1. Australian Standard AS4419-2003 for permeability testing
2. United States Golf Association (USGA) (ASTM F1815 (2006)).

The field method recommended for use in Australia by the Facility for Advancing Water Biofiltration (FAWB) (FAWB 2009) and used in this study is the single ring, constant head infiltration test method (shallow test), as described by Le Coustumer et al. (2007). The test utilises a single ring infiltrometer inserted 50mm into the filter media and applies a constant head. The saturated hydraulic conductivity is calculated using flow rates from two different constant heads, 50mm and 150mm.

As a comparison, field tests were also carried out using the method described in Bouwer (1986) by an external consultant. This method uses a single ring infiltrometer similar to the shallow test described by Le Coustumer et al (2007) but this is inserted approximately 100mm into the soil media. Saturated hydraulic conductivity is calculated using flow rates from a constant head of approximately 150mm. Bouwer (1986) applies Darcy's Law when calculating the saturated hydraulic conductivity as opposed to the shallow test method described by Le Coustumer et al (2007) that assumes a Gardner's behaviour of the soil (Le Coustumer et al. (2007)).

3.2 Water quality testing

Semi-controlled sampling was conducted to determine the removal of various pollutants from Kooloona Crescent biofiltration system and Karuah Road 3 rain garden. The analysis included electrical conductivity, suspended solids, total nitrogen, total phosphorus, hydrocarbons, faecal coliforms and dissolved and total metals (Hg; Ca; As; Cu; Cr; Ni; Pb & Zn). This sought to provide an understanding of water quality function of the respective biofiltration systems against the design of the filter media.

The concentration of pollutant in stormwater runoff can vary significantly (Duncan 1999), and will also change during a storm event. Synthetic stormwater was created for the experiment in an attempt to create water that contained a representative level of pollutants. This involved mixing dry weather flow water from a local creek (that drains a residential catchment) with decanted water from a street sweeper. By sampling water of a known concentration at the inflow to the filter and at the outflow, change in concentration through the filter can be demonstrated. The method used to apply and sample the water was the same for each occasion, using a 1,000L water tank to store and mix the water before application.

One sample was taken from the untreated inflow from each garden and two samples were taken from the designed sampling well or outflow. The first outflow sample was collected as soon as water had passed through the media into the sampling well. To address concern that some of the water in this first outlet sample may be influenced by water of a previous storm event stored within the filter media, a second sample was taken after all water ponding on the surface had filtered into the biofiltration system.

At Kooloona Crescent, a grab sample was also collected during a storm event with one sample collected from water entering the filter from the road and one sample collected from the outflow pipe of the filter.

4 RESULTS

4.1 Hydraulic conductivity

The top layer of a bioretention system is most susceptible to clogging from fine sediments getting washed into the system and therefore limiting the overall hydraulic performance. Tests were therefore only performed on the top layer of the filters.

Field testing of the hydraulic conductivity of the Kooloona Crescent system was performed in 2009. Testing was carried out using both the single ring (shallow test) infiltrometer as described by Le Coustumer et al (2007) and the method described by Bouwer (1986). The results from hydraulic conductivity tests from Kooloona Crescent have previously been presented elsewhere (Jonasson et al 2010) and summarised in Table 1. The single ring infiltration test (shallow test) as described by Le Coustumer et al. (2007) indicated a lower hydraulic conductivity than other methods where the difference in flow rate is small between the two heads used as part of this method.

The method described by Bouwer (1986) applies Darcy's Law and appears to overestimate the hydraulic conductivity. Where the hydraulic conductivity is high, that is for the sand media, using the method described by Bouwer (1986) would appear to provide a more reliable result.

***Table 1 Results from Hydraulic conductivity testing for Kooloona Crescent**.*

	Hydraulic conductivity Kfs (mm/h), Single ring infiltration test (shallow test) as described by Le Coustumer et al. (2007)	Hydraulic conductivity Kfs (mm/h), Single ring infiltration test as described by Bouwer (1986).	Laboratory testing performed (by SESL) on actual sand (called +425) delivered for use in biofiltration systems, using USGA
A (washed sand)	34	1009	740
B (washed sand)	45	1077	740
C (washed sand)	N/A	1127	740
D (washed sand)	N/A	758	740
Average (washed sand):	*39.5*	*993*	*740*

(Jonasson et al 2010)

The Karuah Road 3 raingarden used for comparison was tested for hydraulic conductivity in 2008 using the infiltration test as described by Le Coustumer et al. (2007) and the method described by Bouwer (1986) in 2009. As the different tests were carried out at different times it is noted that the results may not be directly comparable. A summary of the hydraulic conductivity is presented in Table 2.

***Table 2. Saturated Hydraulic conductivity for Karuah Road Number 3*.**

	Hydraulic conductivity Kfs (mm/h), Single ring infiltration test (shallow test) as described by Le Coustumer et al. (2007)	Hydraulic conductivity Kfs (mm/h), Single ring infiltration test as described by Bouwer (1986).	Laboratory testing performed (by SESL) for the soil supplier, using AS 4419
A (sandy loam)	21	46	203
B (sandy loam)	77	87	203
C (sandy loam)	37	118	203
Average (sandy loam):	*45.0*	*83.7*	*203*

4.1.1 Field observations

The rain garden at Karuah Road 3 has a rectangular shape with vertical walls, and allows calculating the hydraulic performance during a storm event with reasonable accuracy. During water quality tests, the rate of which the water level dropped in Karuah Road 3 was recorded after inflow to the biofiltration bed had ceased. The water level was recorded as dropping by 155mm over a period of 108 minutes (from 155 to 0). Adopting Darcy's Law (though not taking into account the falling head) this would be equivalent to a saturated hydraulic conductivity of approximately 57mm/hr. For the Karuah Road 3 biofiltration system both methods returned results comparable to field observations.

During storm events at the Kooloona Crescent biofiltration system it was observed that water did pond on top of the filter during high inflows. Though no detailed recording was carried out of water levels and the rate of which the level dropped, it was observed that the water subsided rapidly in a matter of minutes once flow into the garden decreased.

4.2 Water quality

The pollutant concentrations from untreated water (inflow, A) for sampling of Kooloona (K) and Karuah Road 3 (3) compared with stormwater contaminant characteristics for roads and urban runoff as described by Duncan (1999) (dark grey shading) are presented in Figures 1-3. The figures also include inflow concentration for grab sample at Kooloona biofiltration system (K1)

As illustrated in Figures 1-3, with the exception of Mercury (Hg), nutrients and bacteria, none of the inflow mixtures provided stormwater with concentrations of pollutants within the "typical" range of stormwater runoff from roads and urban areas. However as water was tested at both the inflow and outflow the results allowed comparison of the pollutant removal performance for the two filters tested. It should be noted that for some pollutants such as Suspended Solids and Total Nitrogen, the inflow concentration was similar to the background concentration expected in a biofiltration system (CRC for Catchment Hydrology 2005).

The outflow data was used to compare the function of the different filter media used in each rain garden. There were some discrepancies in the sampling regime and not all tests included the same parameters. The results of the water quality analysis are provided in Table 3. The analysis of the results below recognises that further sampling is required to provide statistical confidence.

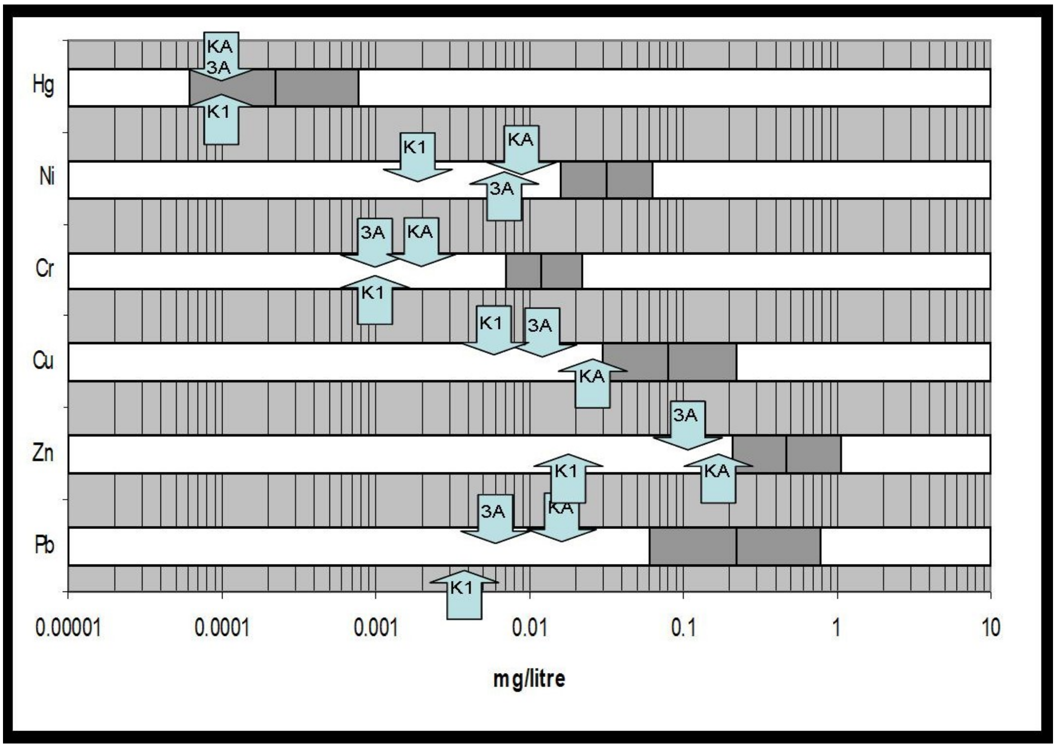

Figure 1. Concentrations of total metals in untreated water for Kooloona (K) and Karuah Road 3 (3) compared with stormwater contaminant characteristics for roads and urban runoff as described by Duncan (1999) (dark grey shading).

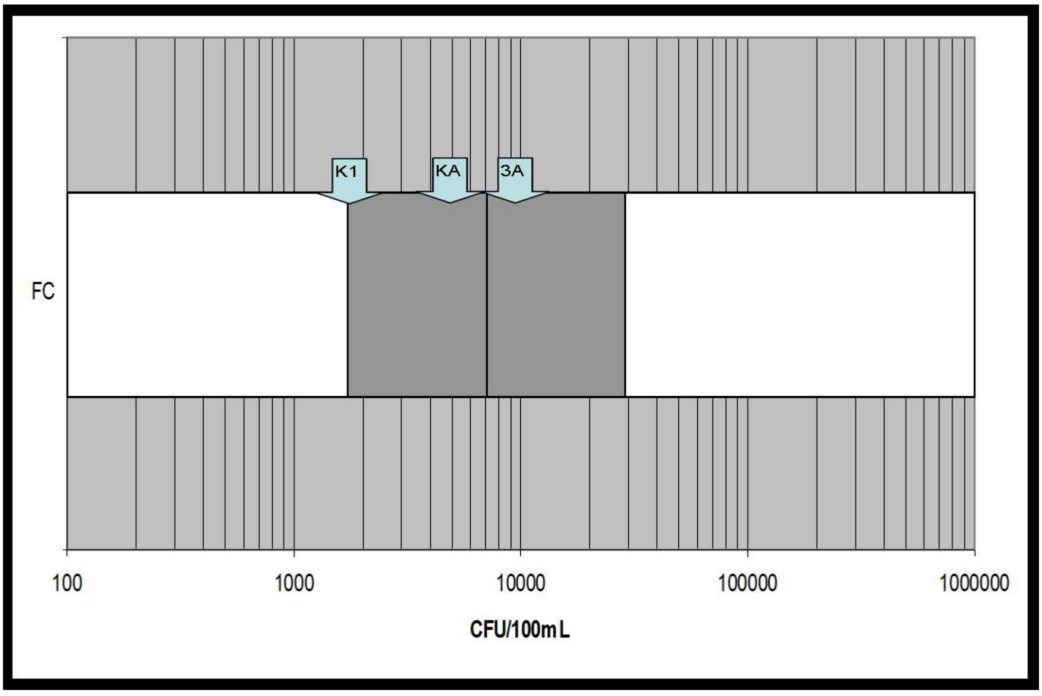

Figure 2. Faecal Coliforms in untreated water for Kooloona (K) and Karuah Road 3 (3) compared with stormwater contaminant characteristics for roads and urban runoff as described by Duncan (1999) (dark grey shading).

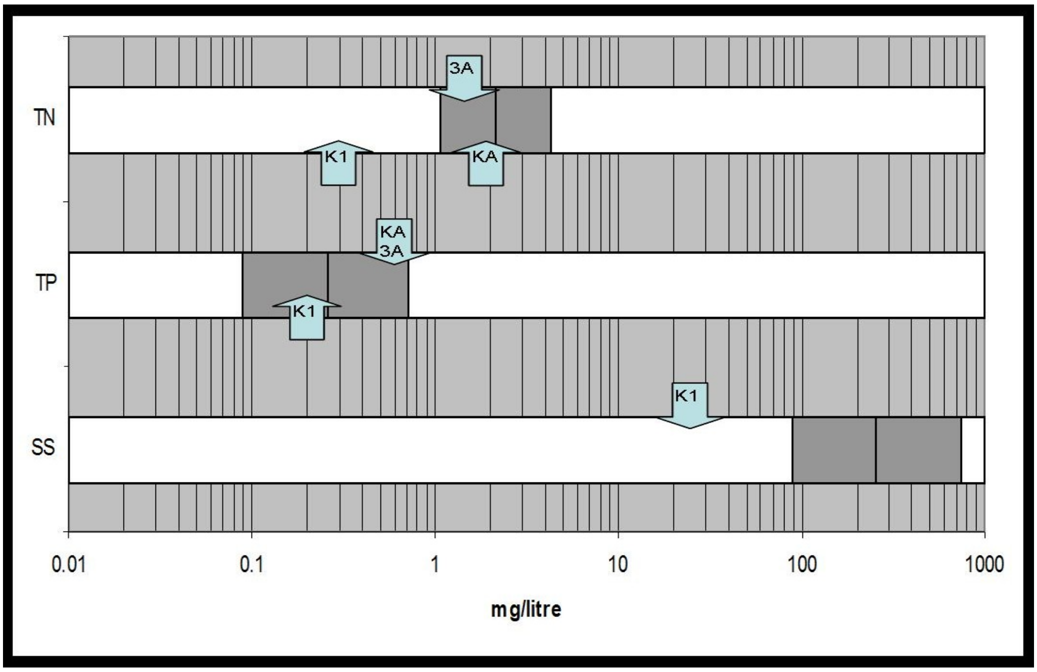

Figure 3. TN, TP and TSS concentrations in untreated water for Kooloona (K) and Karuah Road 3 (3) compared with stormwater contaminant characteristics for roads and urban runoff as described by Duncan (1999) (dark grey shading).

The notable results from the in-situ water quality analysis are as follows:

E-coli:

- The sandy loam filter reduced *E-coli* concentration with a maximum of 86% (outflow 1).
- During the 'controlled' test water filtered through the sand filter had a maximum reduction of 24% (outflow 2), with no reduction in outflow 1
- Results from the event based grab sample showed a reduction of 72%

Total Nitrogen (TN) and total phosphorus (TP):

- Both the sandy loam and the sand export TN. The sandy loam had a minimum increase of 235% (outflow 2) while the sand had a minimum increase of 6% (outflow 2).
- Sandy loam reduced TP with a maximum of 88% (outflow 2) compared to sand which had a maximum of 90% reduction (outflow 1).

Total Petroleum Hydrocarbons(TPH):

- TPH was exported from the sand filter during the controlled sampling; the largest increase (outflow 2) was 42%. No TPH were detected in either the inflow or outflow for the event based sample. The sandy loam filter demonstrated a maximum of 62% reduction (outflow 1).

Turbidity and total dissolved solids (TDS):

- Turbidity initially increased for both systems before returning to values that closely resemble the inflow. Only the outflow from the grab sample from Kooloona Cr and outflow 2 from the sand complies with current guidelines for reuse (NRMMC et al, 2009)

- TDS significantly increased (over 1100%) in the grab sample from Kooloona biofiltration system. As TDS and TSS were not analysed in the controlled sample events no thorough comparison is possible.

Metals:

- The sand filter appears to export trace amounts of As and Cr, both Total and Dissolved.
- Dissolved Cu was exported from both gardens (Sand controlled 100% increase; Sand grab 150% increase; sandy loam 150% increase). Sandy loam also exported Total Cu (514% increase), while the sand reduced Total Cu on the controlled sample occasion (24% decrease). There was no change in Total Cu for the grab sample.
- The removal of Pb through the sand was 80% (outflow 1 and 2) while the sandy loam initially was exporting Total Pb before returning to a removal of 16%. No dissolved Pb was detected in any of the samples.
- Sand had the highest removal of Total Zn at 96% (outflow 2). Maximum removal of Zn for the sandy loam was 89% (outflow 2). Both media showed high removals of dissolved Zn.

Table 3: Results of the water quality analysis

		Kooloona (sand)	**Kooloona (sand) grab sample during storm**	**Karuah (sandy loam)**
E.coli	Inflow (A)	4900	1800	9700
(org/100ml)	Outflow 1 (B)	4900	500	1300
	Outflow 2 (C)	3700	-	1800
TN	Inflow (A)	1.8	0.3	1.4
(mg/L)	Outflow 1 (B)	4	0.2	6.8
	Outflow 2 (C)	1.9	-	4.7
TP	Inflow (A)	0.63	0.2	0.56
(mg/L)	Outflow 1 (B)	0.06	0.26	0.25
	Outflow 2 (C)	0.1	-	0.07
TPH	Inflow (A)	0.69	Not detected	0.65
(mg/L)	Outflow 1 (B)	0.79	Not detected	0.25
	Outflow 2 (C)	0.98	-	0.3
Turbidity	Inflow (A)	38.2	26.3	30.1
NTU	Outflow 1 (B)	109	19.7	99
	Outflow 2 (C)	42.1	-	18.6
TDS	Inflow (A)	-	13	-
(mg/L)	Outflow 1 (B)	-	162	-
	Outflow 2 (C)	-	-	-
TSS	Inflow (A)	-	24	-
(mg/L)	Outflow 1 (B)	-	2	-
	Outflow 2 (C)	-	-	-
Total metals				
Hg	Inflow (A)	<0.0001	<0.0001	<0.0001
(mg/L)	Outflow 1 (B)	<0.0001	<0.0001	<0.0001
	Outflow 2 (C)	<0.0001	-	<0.0001
As	Inflow (A)	<0.001	<0.001	<0.001
(mg/L)	Outflow 1 (B)	0.006	0.007	<0.001
	Outflow 2 (C)	0.006	-	<0.001

Cr	Inflow (A)	0.002	<0.001	<0.001
(mg/L)	Outflow 1 (B)	0.013	0.002	0.002
	Outflow 2 (C)	0.01	-	<0.001
Cu	Inflow (A)	0.025	0.006	0.014
(mg/L)	Outflow 1 (B)	0.019	0.006	0.086
	Outflow 2 (C)	0.02	-	0.034
Pb	Inflow (A)	0.015	0.004	0.006
(mg/L)	Outflow 1 (B)	0.003	0.001	0.031
	Outflow 2 (C)	0.003	-	0.005
Ni	Inflow (A)	0.009	0.002	0.007
(mg/L)	Outflow 1 (B)	0.003	<0.001	0.003
	Outflow 2 (C)	0.003	-	0.001
Zn	Inflow (A)	0.183	0.017	0.11
(mg/L)	Outflow 1 (B)	0.008	0.007	0.053
	Outflow 2 (C)	0.007	-	0.012
Dissolved metals				
Hg	Inflow (A)	<0.0001	<0.0001	<0.0001
(mg/L)	Outflow 1 (B)	<0.0001	<0.0001	<0.0001
	Outflow 2 (C)	<0.0001	-	<0.0001
As	Inflow (A)	<0.001	<0.001	<0.001
(mg/L)	Outflow 1 (B)	0.005	0.008	<0.001
	Outflow 2 (C)	0.006	-	<0.001
Cr	Inflow (A)	<0.001	<0.001	<0.001
(mg/L)	Outflow 1 (B)	0.007	0.002	<0.001
	Outflow 2 (C)	0.009	-	<0.001
Cu	Inflow (A)	0.009	0.002	0.01
(mg/L)	Outflow 1 (B)	0.016	0.005	0.02
	Outflow 2 (C)	0.018	-	0.025
Pb	Inflow (A)	<0.001	<0.001	<0.001
(mg/L)	Outflow 1 (B)	<0.001	<0.001	0.001
	Outflow 2 (C)	<0.001	-	<0.001
Ni	Inflow (A)	0.005	<0.001	0.006
(mg/L)	Outflow 1 (B)	0.002	<0.001	<0.001
	Outflow 2 (C)	0.002	-	0.001
Zn	Inflow (A)	0.083	<0.005	0.086
(mg/L)	Outflow 1 (B)	<0.005	0.005	0.014
	Outflow 2 (C)	<0.005	-	0.009

5 DISCUSSION

5.1 Hydraulic conductivity

The biofiltration systems were tested at multiple points (between two and four locations) using two different methods (refer to Table 1 and 2).

The hydraulic conductivity as measured using the single ring infiltration test (shallow test), as described by Le Coustumer et al. (2007) reported a low hydraulic conductivity for the sand, inconsistent with field observations. The results did not compare favourably with the results obtained using the field method described by Bower (1986). The average hydraulic conductivity of the sandy loam was 45mm/hr. This was similar to both field observations and results obtained using the field method described by Bower (1986).

The single ring infiltration test (shallow test) as described by Le Coustumer et al. (2007) and recommended by current Australian guidelines (FAWB 2009), calculates the saturated hydraulic conductivity using a different equation than the field method described by Bower (1986), and utilises the difference in flow rate from 50mm and 150mm of head. For the sand, many tests carried out as part of this study showed only minor differences in flow between 50mm and 150mm head. The resulting hydraulic conductivity was calculated as low in these cases irrespective of the actual flow rate. The significant impact on the results where the difference in flow between the 50mm and 150mm heads is low is identified as a limitation of this method. This could potentially impact on the calculated effectiveness of the system during evaluation.

The method described by Bouwer (1986) appears to overestimate the hydraulic conductivity for the sand media. For Karuah 3 the results were largely consistent with field observations. There are some questions whether the testing was carried out for a sufficient duration of time to achieve saturated conditions and this may have impacted on the test results. If a higher hydraulic conductivity is assumed as part of the design or evaluation process this may overestimate the performance of the treatment system.

Le Coustumer et al (2007) and later in Le Coustumer et al (2008) reported variability in the hydraulic conductivity using shallow and deep tests on the same sites, noting that the deep test applied Darcy's Law. This is consistent to the results reported in this study. Whilst some of the differences can be attributed to variability within the individual systems this presents difficulties for stormwater managers to evaluate the performance of their systems. The results obtained by using methods applying Darcy's Law appear to be more consistent. This method shows a clear difference in hydraulic conductivity between sand and sandy loam. This is not the case for results obtained using the (shallow test) method described by Le Coustumer et al. (2007). Uncertainty will be further compounded over the life of the system as the hydraulic conductivity will change due to a range of variables including settlement of soil layers, compaction and establishment of vegetation (FAWB 2009).

Given the spatial and temporal variability of any system, it is appropriate to recommend multiple testing within each individual system and that testing is performed using different heads. Importantly, the results should be read as indicative rather than definitive.

5.2 Water quality testing

Semi-synthetic runoff was used in this study, noting that repeatability and representativeness of inflow sample varied significantly. Although the semi-synthetic stormwater did not provide concentrations within the "typical" range of stormwater runoff for some pollutants, testing the water at both the inflow and outflow allowed comparison of the pollutant removal performance for these systems. The use of a spiked creek sample from contaminated street sweeper water was therefore considered a viable alternative and was able to demonstrate the performance of the two types of biofiltration systems.

The heavy metals Cr and Cu did not show the changes as found in column experiments as reported by Hatt *et al.* (2007) who found mean reductions in excess of 92% across a range of analytes. However, the inflow concentrations in this field study were considerably lower than "typical" stormwater runoff (Duncan 1999). Notable was that the sand and the sandy loam both reported a reduction in total Zn by around 90%.

There was a net export of Cu and As in both media and for Cr in the sand media. This may be due to the source of the media. This may also explain the apparent net export of TPH from the sand media, however this may also be due to earlier hydrocarbons being washed into the system. The sand may be less effective in absorbing and retaining hydrocarbons within the media and it is possible this is being slowly released back over time. The data in Table 3 suggest that sand may be a preferred filter media when targeting metals, while sandy loam performed better in terms of removing faecal coliforms. Even though both filter media was found to export TN, sand exported considerably less and showed a reduction for the grab sample. This, coupled with a higher removal rate of TP may suggest that sand is the preferred filter media when targeting nutrients. However, as the data set was small more testing is required to further investigate this preliminary finding.

5.3 Implications of using a sand filter media compared to sandy loam

In laboratory studies sand based filter media has been found to be comparable to or in some cases better than sandy loam in capturing metals, TSS, TP and TN in a biofiltration application (Hatt et al 2007, Bratieres et al 2009).

Investigations into the use of sand based filter media instead of the sandy loam (Bratieres et al 2009) showed that compared to sandy loam, sand based filter media has quite poor treatment performance for the first six months. The difference is however less profound after one year. Bratieres et al (2009) also reported that a sand based filter media is less likely to leach nitrogen, while soil based biofiltration systems may be net producers of nitrogen (Hatt et al 2007). Results obtained as part of this study supports these findings, and provides further support for using sand based filter media. The poor performance during the first six months observed by Bratieres et al (2009) from the sand filter may be offset by the fact that a washed sand will contain less fines than a sandy loam and is thus less likely to export sediment during the initial period after installation. Such export has been observed from a number of biofiltration systems constructed using a sandy loam filter media across the Ku-ring-gai local government area. This observation is of some concern and is an area for more investigation. Anecdotal evidence from other councils in the Sydney region indicates that this is a common problem. There is little literature that reports on the amount and characteristic of exported sediment during the establishment phase of a biofiltration system and the potential impact this has on downstream ecosystem.

A filter media with a high hydraulic conductivity is however unlikely to support plant growth (FAWB 2009). As this is an important part of the effectiveness of a biofiltration system (Bratieres et al., 2009, 2010, Hatt et al., 2007a, Henderson et al.,2007) it may limit the use of sand as a filtration media, especially in areas regularly experiencing prolonged periods of drought. Measures such as incorporating water holding polymers or the use of a saturated zone can counteract some of these problems.

The long-term hydraulic performance of sand in a biofiltration application should also be considered. It is likely that fine sediment present in the stormwater runoff will be washed into the biofiltration system and reduces the hydraulic conductivity. This may transform the sand media to a sandy loam after prolonged exposure to urban runoff. Bratieres et al. (2010) also reported a significant decrease in the hydraulic conductivity for the sand based filter media after vegetation is fully established. This may however have been due to the extremely high plant density used in the test. No significant decrease in hydraulic conductivity for sand filter media was observed as part of this case study.

The overall capacity of the system to store captured pollutants should also be considered when designing systems that receive runoff from a large impervious catchment. A larger system will have more capacity to handle pollutant loads especially if maintenance is infrequent. Smaller biofiltration systems may not be advisable unless regular maintenance can be assured.

6 CONCLUSION

While different techniques used to measure hydraulic conductivity reported significantly different results when compared with field observations, the study shows that sand retains a significantly higher hydraulic conductivity compared to a sandy loam. Given the similar water quality improvement that can be expected from using sand compared to sandy loam in a biofiltration application (Hatt et al 2007), the findings from this study support the hypothesis that sand may be a preferable filtration media in small biofiltration systems. In retrofit situations where available land is limited this is an important finding, and verifies the importance of considering all aspects of a system (hydraulic conductivity, size and ponding depth) during the design of new systems.

As previously reported by Jonasson (2010) and further supported by this study the findings indicates that the method used to assess hydraulic conductivity may significantly influence the results. The single ring infiltration test (shallow test) as described by Le Coustumer et al. (2007) will report a lower hydraulic conductivity than other methods where the difference in flow rate is small between 50mm and 150mm head. The method described by Bouwer (1986) on the other hand appears to consistently overestimate the hydraulic conductivity. Where the hydraulic conductivity is high (sand media), using the method described by Bouwer (1986) (applying Darcy's Law), appear to provide a more reliable result.

Some questions are raised in relation to export of metals from both filter media tested. Water quality test results obtained as part of this study do however suggest that sand may be a preferred filter media when targeting metals, while sandy loam performed better in terms of removing faecal coliforms. In terms of nutrients sand had a higher removal rate of TP and while both filter media was found to export TN, sand exported considerably less and also showed a reduction for the grab sample. This would suggest that sand may be a preferred filter media when targeting nutrients. As the data set is small more testing is required to further investigate this preliminary finding.

When testing the performance of a biofiltration system to verify modelling and quantify the benefits of such WSUD treatments results need to be critically assessed. Hydraulic conductivity test results should ideally be verified by field measurements, including flow gauging at the outflow of the system, or by comparison with anecdotal evidence to ensure they are representative of the function of the filter. Importantly, all results should be considered as indicative not definitive.

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