Development of the enviss™ filtration media

Développement du système d'infiltration enviss™

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RÉSUMÉ

Une étude a été réalisée afin de déterminer les performances d'une nouvelle gamme de systèmes développés par enviss™ et Monash University (Melbourne, Australie). Ces systèmes seront utilisés pour l'assainissement des rejets urbains de temps de pluie afin de permettre soit (a) leur rejet en milieu naturel ou (b) leur récupération et leur réutilisation. Le but principal de cette étude était d'évaluer leur potentiel de traitement pour une large gamme de polluants, tels que : les matières en suspension, les nutriments, les métaux lourds, les hydrocarbures, les pathogènes et les dérivés de produits de désinfection. Après une sollicitation équivalente à 4 mois de pluie moyenne annuelle pour Melbourne, tous les systèmes testés se sont révélés efficace pour le traitement de chacun des polluants testés. Cependant, la simulation de fortes pluies ou de périodes de sécheresse a révélé influencer le taux d'épuration de la majorité des polluants. En particulier, le système de réutilisation a démontré une excellente capacité à contenir les espèces pathogéniques. En effet les espèces *E. coli* et F-RNA phages n'étaient présentes dans aucun des effluents. De plus, le nombre de *C. perfringens*, considérablement plus résistants à la désinfection que les deux espèces précédentes, a été réduit de 98%. Les *C. perfringens* aurait pu être totalement absents des effluents si, par erreur, la concentration initiale n'avait pas été égale à dix fois la concentration moyenne observée pour les rejets urbains de temps de pluie. Des recherches supplémentaires seront réalisées pour élargir notre compréhension de l'efficacité des systèmes lorsqu'ils sont soumis à une année entière d'événements pluviaux pour Melbourne.

ABSTRACT

A study was conducted to assess the performance of a new range of modular stormwater systems developed by enviss™ and Monash University (Melbourne, Australia). These systems will be used to treat stormwater for (a) discharge to downstream systems or (b) stormwater harvesting systems. The main objective was to quantify their treatment performance for a wide range of pollutants commonly found in urban stormwater, such as: suspended solids, nutrients, heavy metals, hydrocarbons, pathogenic indicators and disinfection by-products. After an equivalent of approximately four months of Melbourne's annual rainfall, all the systems showed efficient removal of all the pollutants tested. However, both wet and dry weather periods influenced the removal rates of most of the key stormwater pollutants. The stormwater harvesting system performed extremely well, with *E. coli* and F-RNA phages being completely removed from the influent. Moreover, *C. perfringens*, which are considerably more robust against disinfection, were still reduced by >98% and could have been completely removed if the influent concentrations were not mistakenly ten times that seen in typical stormwater flows. Further work will be conducted to fully understand the performance of the systems after a full year of Melbourne's rainfall.

KEY WORDS

Filter media, stormwater, nutrients, heavy metals, hydrocarbons, pathogenic indicators, water harvesting

1 INTRODUCTION

Urbanisation leads to significant changes in the volume and the quality of stormwater runoff (Walsh *et al*., 2004). Whilst the increase of urban stormwater generates changes in hydraulic regimes which affect stream ecology, it also causes a significant degradation of water quality because of the pollutants carried by stormwater runoff, such as heavy metals, nutrients and microorganisms.

However, the increase in runoff volumes also makes it an abundant and untapped resource close to the point of use that could be reused if treated to an adequate level. As such, stormwater harvesting has been emerging, and brings with it multiple benefits. Not only does stormwater reuse reduce stresses on potable water demands, but it actually improves the health of urban creeks, rivers and bays (Fletcher *et al.*, 2008) by reducing pollutant loads to these systems and by restoring the flow regime closer to its pre-developed level.

As a response to the above, stormwater treatment technologies, known as Water Sensitive Urban Design (WSUD) systems, are being developed to treat stormwater either to a level which is acceptable for discharge to downstream systems or for stormwater harvesting. To date, of all WSUD systems, bio-retention systems have been the most widely adopted in Australia, mainly due to their good nutrient and heavy metal removal performance. However, their inability to remove pathogenic indicators to the levels required does not make them a viable standalone option for stormwater reuse (Bratières *et al.,* 2008). Additionally, due to their space requirements, the need of an establishment phase and their low infiltration rates, biofilters are not suited for confined urban environments. Also, biofilters require water to maintain plant health, which can be an issue during extensive dry periods (unless carefully designed). New systems that could fit into highly urbanised areas could be beneficial for both discharge applications and possibly reuse scenarios, especially if their treatment performance could exceed current technologies.

An experimental study has been undertaken to develop the enviss™ stormwater treatment and harvesting technologies. For similar space requirements, these systems have a capacity seven times that of a traditional biofilter, meaning enviss™ systems can be sized seven times smaller than biofilters for a given impervious catchment area. This system is one of just few available technologies which can treat stormwater to a level which is acceptable for reuse, and the only known system which has undergone independent testing for this purpose in Australia.

To date, three enviss™ systems have been developed for specific uses; two systems are suitable for treatment of stormwater to meet current regulations for discharge to downstream waterways (e.g. (Victorian Government’s Clause 56.07-4 – DSE, 2006) and one system is suitable for reuse applications. This paper reports on the results of an intensive testing regime for the three enviss™ systems. It quantified the treatment performance (outflow concentrations and concentration reductions) for typical stormwater pollutants.

2 METHOD

2.1 Experimental set-up

100mm diameter PVC columns were constructed in a covered greenhouse and used for testing of the developed filtration media. Each column consisted of four layers (see Figure 1): (1) a porous paver top to remove gross pollutants and coarse sediment, (2) a sediment trap to protect subsequent layers from particles, (3) the filter media to remove finer sediment and dissolved pollutants and (4) a drainage layer to prevent filter media migration and outlet clogging. Each column and sediment trap was washed to ensure the media was clean prior to testing. To provide information about the rate of flow through the media, infiltration rates were measured continuously during the study.

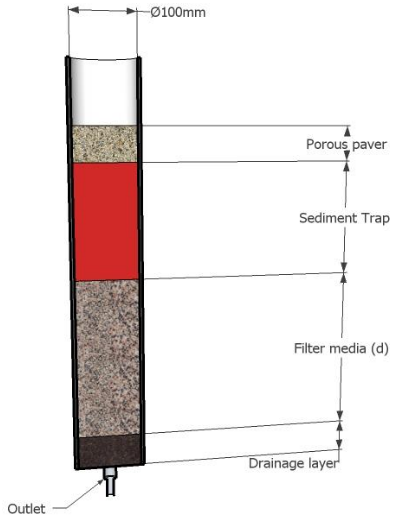

Figure 1: General design of the column (schematic drawing)

2.2 Column configurations

Three configurations were developed by Monash University and enviss™ (Table 1). These configurations are now being used in the field, each designed for three likely scenarios: (1) as a large end-of-the pipe treatment filter with a very high flow rate WSUD-HF-Deep, (2) for smaller catchment outlets, or at source treatment, with improved treatment capacity - WSUD-LF-Deep or (3) for safe non-potable reuse (Reuse-LF-shallow). To allow for statistical comparisons, five replicates for each column configuration were used (15 in total).

Table 1: Column configurations tested for enviss™.

Column Type	Flow rate	Depth of media (d)	Disinfectant	Use purpose
WSUD-HF-Deep	high (8000mm/hr)	deep (800mm)	NO	Stormwater Treatment
WSUD-LF, Deep	low (2000mm/hr)	deep (400mm)	NO	Stormwater Treatment
Reuse-LF-Shallow	low (2000mm/hr)	shallow (270mm)	YES	Treatment and Reuse

Results of the envissDT software (a software provided with the enviss™ product range used to help size the filter systems) show that, for a Melbourne climate, the low flow filters should be sized to 0.3% of their impervious catchment area to treat 90% of the annual runoff, whilst high flow filters should be sized to 0.075% of their impervious catchment area.

2.3 Dosing and sampling regime

The columns were manually dosed with semi-synthetic stormwater according to the timetable presented in Table 2. Due to time and cost constraints, a full year of rainfall was simulated using a compressed time-scale of just four months. To ensure that the dosing was close to what the media would receive in reality different drying and wetting regimes were investigated.

During each dosing day, the low flow and high flow columns would receive 50L and 200L of stormwater, respectively. These volumes are equivalent to a 20 mm rainfall event when sized using envissDT. Inflow samples were taken each time the columns were dosed, whilst the outflows from the columns were only sampled on six occasions (see Table 2). Currently, the systems are still being tested and only the first three sampling results are presented: one after a normal period of rainfall (W2), one after a short dry period (W4) and the last one after a wet period (W6). During the testing regime, sediment traps were replaced on columns which fell below 50% of their initial infiltration rates (see Table 2), which simulates the maintenance of the filtration system. The performance of the sediment trap was not assessed in this report, and is part of future work by the authors.

Table 2: Timetable used to dose and sample the columns.

Week starting	Monday	Tuesday	Wednesday	Thursday	Friday
W1					Dosed
W2	Dosed		Dosed and Sampled		
W3			**2 week drought**		
W4			Dosed and Sampled		Dosed
W5	Dosed				
W6	Dosed	Dosed	Dosed and Sampled		
W7					Dosed
W8	Dosed		Dosed and Sampled		
W9 to W12			**5 week drought**		
W13			Dosed and Sampled		Dosed
W14	Dosed				
W15	Dosed		Dosed		Dosed
W16					Dosed
W17	Dosed		Dosed and Sampled		

2.3.1 Dosing with semi-synthetic stormwater

Semi-synthetic stormwater was made by adding typical stormwater pollutants to dechlorinated tap water. The target concentrations for these pollutants are outlined in Table 2 and are based on a large review conducted by Duncan *et al*. (1999) and data from both Taylor *et al*. (2005) and Makepeace *et al*. (1995). For more information about the method of producing this stormwater please refer to Hatt *et al.* (2007). On sampling days only, *Escherichia coli, Clostridium perfringens* and F-RNA coliphages were added to the stormwater to help understand the effectiveness of the media at removing pathogenic indicators.

Table 3: 'Typical' stormwater pollutant concentrations based on worldwide (Duncan, 1999, Makepeace *et al.,* 1995) and Melbourne (Taylor et al., 2005) data.

Sediment, nutrients, hydrocarbons		**Concentration (mg/L)**	**Heavy Metals**		**Concentration (mg/L)**
Total Suspended Solids	TSS	100	Aluminium	Al	1.5
Total Nitrogen	TN	2.18	Cadmium	Cd	0.0045
Total Phosphorus	TP	0.35	Chromium	Cr	0.025
Total and Polyaromatic Hydrocarbons	TPH PAH	2.5 0.005	Copper	Cu	0.05
Escherichia coli[a]		20,000	Iron	Fe	3.00
Clostridium perfringens[a]		3000	Lead	Pb	0.14
F-RNA coliphages[a]		3000	Zinc	Zn	0.25

[a] Pathogenic indicators were only added to the stormwater mixture on sampling day (**Error! Reference source not found.**), the concentration are given in orgs/100mL

2.3.2 Sampling procedures

During sampling days, five sub-samples were taken from each column outlet in order to create an event mean concentration for that column's outflow. Inlet samples were also taken using five subsamples. All samples were analysed in a NATA (National Association of Testing Authorities, Australia) accredited laboratory and analysed for many pollutants, including: sediment, nutrients (nitrogen and phosphorous), heavy metals (20 elements), hydrocarbons (Total and Polycyclic Aromatic Hydrocarbons), microorganisms (*E. coli*, *C. perfringens* and F-RNA phages) and disinfection by-products (Total TriHalomethanes - THMs, chloral hydrate, chloroacetics, dichloromethane, etc). It should be noted that only heavy metals which have a significant impact on stream ecology and/or health safety were analysed in this paper: Al, Cd, Cr, Cu, Fe, Pb and Zn (Makepeace *et al*., 1995).

2.3.3 Data analysis

For each pollutant, the mean and the coefficient of variation (CV) were calculated using the outflow concentrations for each media type. Each mean and CV were calculated using the data from the five replicates and the three sampling days. This was also repeated for removal efficiencies. If the concentration of a pollutant was below the detection limit of the instrument, the value was removed from the data analysis and the number of values used for the calculation of the mean and CV was noted. In order to compare the change in filter media performance across each sampling run, the removal rates were presented using box plots.

3 RESULTS AND DISCUSSION

3.1 Overall performance

The mean inflow and outflow pollutant concentrations, together with the mean removal efficiencies, of the three enviss™ systems are summarised in

Table 4: The overall mean and coefficient of variation (presented in square brackets) of pollutants during the sampling regime. Unless indicated, 15 values (five replicates, three sampling runs) were used for mean and coefficient of variation calculations.

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	Inflow concentration [mg/L]	Outflow concentration [mg/L]			Removal rate [%]		
		WSUD-HF-Deep	WSUD-LF-Deep	Reuse–LF-Shallow	WSUD-HF-Deep	WSUD-LF-Deep	Reuse -LF-Shallow
TSS	105 [15%]	7.4 [51%]	4.5 [41%]	4.47 [25%]	93% [3%]	96% [1%]	96% [1%]
TP	0.33 [5%]	0.12 [16%]	0.11 [14%]	0.15 [13%]	64% [7%]	67% [5%]	55% [9%]
TN	2.44 [6%]	0.54 [36%]	0.51 [20%]	0.95 [19%]	78% [11%]	79% [6%]	61% [13%]
Al	1.26 [13%]	0.33 [19%]	0.28 [8%]	0.38 [13%]	74% [7%]	77% [3%]	70% [9%]
Cd	0.01 [15%]	0.0006 [64%]	<0.0004 [12%] [a]	0.0008 [69%]	93% [5%]	>95% [1%] [a]	90% [7%]
Cr	0.021 [11%]	0.003 [28%]	0.003 [26%]	0.004 [26%]	86% [4%]	87% [4%]	80% [6%]
Cu	0.07 [17%]	0.01 [29%]	0.01 [18%]	0.01 [23%]	84% [4%]	88% [2%]	83% [2%]
Fe	1.72 [44%]	0.35 [35%]	0.24 [7%]	0.3 [10%]	80% [4%]	85% [4%]	81% [6%]
Pb	0.22 [7%]	0.07 [22%]	0.04 [36%]	0.07 [26%]	69% [12%]	81% [9%]	67% [15%]
Zn	0.37 [11%]	0.05 [52%]	0.02 [68%]	0.06 [62%]	85% [10%]	94% [4%]	83% [13%]
TPAHs	0.006 [42%]	ND	ND	ND	ND	ND	ND
TRH	2.5 [37%]	0.39 [41%]	<0.25 [10%][b]	0.36 [27%]	81% [18%]	>89% [5%][b]	83% [12%]
THM[c]	<0.022 [5%][d]	-	-	<0.016 [8%][e]	-	-	-
E. coli	21000 [38%]	-	-	ND	-	-	>99.995% [0%]
C .perfringens	31000 [50%]	-	-	750 [102%]	-	-	98.004% [1%]
F-RNA *Phages*	580 [81%]	-	-	ND	-	-	>99.858% [0%]

'-' - Non Tested, 'ND' - All the values were below the detection limit for every outflow samples in W2, W4 and W6, [a] Cd was undetected in the 5 outflow samples in W2 and W4 and was only present in 4 of the 5 outflow samples in W6, [b] all the values were below the detection limit for every outflow samples in W2 and W6 and only two concentration were equal to the detection limit of the instrument during W4, [c]Trihalomethanes (THM) include bromodichloromethane, bromoform, chloroform and dibromochloromethane, [d]the inflow concentration was only tested during W2. As bromoform and dibromochloromethane were below the detection limit, the mean value for the inflow concentration is based on bromodichloromethane and chloroform inflow concentration for W2 (6 values), [e]all the outflow values were below the detection limit except for chloroform for W2,W4 and W6, the values in the table are therefore representing chloroform only.

The TSS concentrations were reduced by over 90% for all three sampling runs and hence are sufficient to meet the TSS load reduction target stipulated by the Victorian Government (Clause 56.07-4 – DSE, 2006). The low flow designs (both WSUD and Reuse) performed slightly better than the high flow design, which is because the lower infiltration rate (or pore space volume) of the low flow media provides improved filtration. In fact, the mean outflow TSS concentrations of the high flow media are almost double that of the low flow media, which corresponds to the high flow media having twice the infiltration rate of the low flow media. However, when comparing removal rates, the two media types only differ by less than 3%, mainly because of the high relative TSS inflow concentrations.

The results show that, on average, TP concentrations were reduced by between 55 and 67% and TN concentrations were reduced between 60 and 79%, depending on the column configuration. The performance of the three systems met Clause 56.07-4 which requires a minimum of 45% reduction for both TP and TN. Detention time plays an important role in pollutant removal for stormwater treatment systems (Hatt *et al.*, 2007). This holds true for the enviss™ systems, where the configuration with the longest detention time (WSUD-LF-Deep ≈17mins) outperformed the other two systems. In fact, the WSUD-LF-Deep filter performed well for both TP and TN, with average removal efficiencies of greater than 67% and 79%, respectively. It is interesting to note that although the Reuse-LF-Shallow columns had longer contact times (≈13mins) than the WSUD-HF-Deep columns (≈9mins), the removal rates for both TP and TN in the Reuse-LF-Shallow systems were the lowest. This indicates that it is not just detention time which is playing an important role in removal of these pollutants. It is expected that the chlorine used in the Reuse-LF-Shallow columns is causing this reduced performance, since the chlorine is being preferentially absorbed to the filtration media instead of the pollutants. This is not a major problem for reuse scenarios, where excessive nitrogen and phosphorus is not going to cause a major inconvenience to non-potable uses.

In general, the systems showed efficient removal of heavy metals (often > 80%) and again the WSUD-LF Deep system was consistently performing better than the other two configurations. From a reuse perspective, the only elements discussed in this paper which are which are of *major* concern to human health are Cd, Cr, Cu and Pb. In fact, only Cd and Pb typically exist in raw stormwater at concentrations above that stipulated by the Australian Drinking Water Guidelines (ADWG, 2004) for safe potable use. While the filters are not intended for potable water consumption, this type of comparison can help understand the potential of the enviss™ systems for harvesting scenarios. Outflow concentrations of Cd were always well below the guideline value of 0.002mg/L, with concentrations always reduced by more than 90%. However, removal of Pb was lower, with only the WSUD-HF-Deep removing it by more than 80%. In fact, Pb outflow concentrations from the systems did not meet the guidelines for recreational water uses (0.05 mg/L - ANZECC & ARMCANZ, 2000) or for safe potable consumption (0.01mg/L - ADWG, 2004). However, the Pb concentrations in the stormwater used to dose the systems (Table 4) was almost 60% higher than that typically found in urban stormwater (Table 3), and as such it is possible that this was the cause for this poor removal. Poelsma *et al*. (2008) found that for very similar filtration systems as those described within this paper, Pb was removed by over 90% and met recreational use guideline values of 0.05mg/L when the inflow concentrations were approximately equal to that typically found in stormwater (0.12mg/L).

All filters were capable of removing PAHs, as they were not detected in any of the outflow samples. However, this might be caused by the very low concentration of PAHs in the influent, and the detection limit of the machine for the outflow samples. This is an important finding from a reuse perspective, since some PAHs are potentially harmful to humans (both during contact and ingestion – ADWG, 2004). The three configurations also showed efficient removal for TPHs (>80%). In both cases, the WSUD-LF-Deep configuration were again the best a treating these pollutants.

The Reuse-LF-Shallow system showed extremely efficient removal for all the pathogenic indicators tested. In fact, *E. coli* and F-RNA phages were never detected at the outlets of these systems. Even though *C. perfringens* spores are very resistant in an environment that has been stressed by a disinfectant (Bisson and Cabelli, 1980), the system was still capable of removing over 98% of *C. perfringens*. However, it was expected that this removal rate would have dramatically increased if the target concentrations (Table 3) were not exceeded by more than an order of magnitude (Table 4).

As a disinfectant was used in the Reuse-LF-Shallow systems, the outflow concentrations were also tested for disinfection by-products to ensure no harmful by-products were created during the disinfection process. The outflow concentrations of all by-products tested were always under the guideline limits stipulated by the ADWG (2004) for safe potable use.

3.2 Impact of time and wetting regime

Figure 2 presents boxplots for each sampling (W2, W4, and W6) for TN and TP removal rates. In general, TN treatment performance decreased between consecutive sampling runs for all three systems, possibly showing the decline in the adsorption capacity of the media with time or the impact of wetting and drying regimes on the removal capacity of the media. If the latter is the case, then the results indicate that TN removal is impacted more significantly by wet periods; this is especially the case with the WSUD-LF-Deep system which shows no impact on the removal rate after a dry period, whilst a significant decrease in the removal rate after a wet period. Future sampling runs should help determine the actual cause for the results shown.

TP treatment performance decreased after both wet and dry weather periods, again indicating either a decline in the removal capacity of the media with time or that wet and dry weather periods have an impact on the treatment efficiency of the systems. Again, the WSUD-LF-Deep column performed differently than the other two configurations, showing no real impact of a wet period on TP removal, but still a small decrease in removal after a dry period.

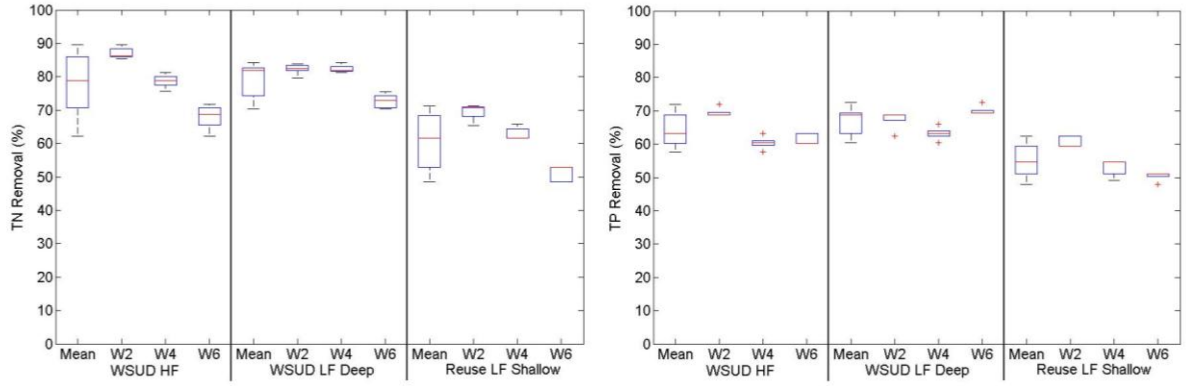
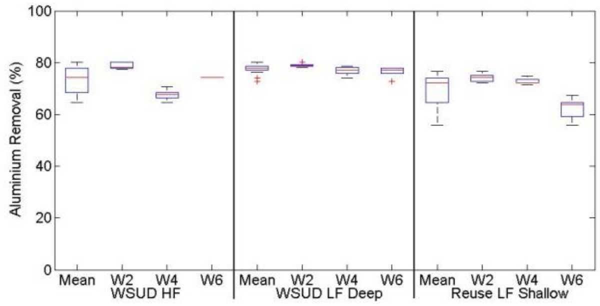
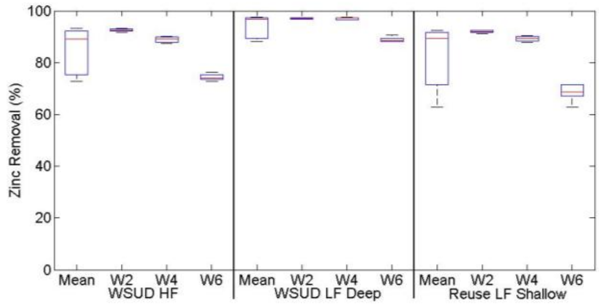


Figure 2: Mean removal rates for the three sampling runs for TN (left) and TP (right) for the three different systems

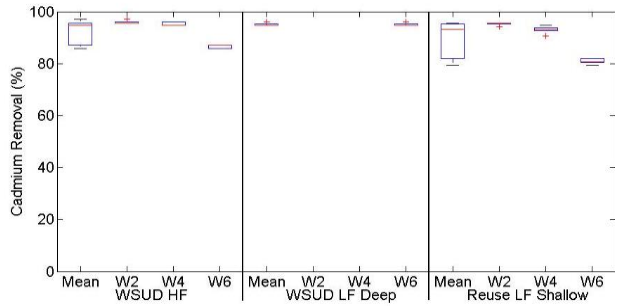
Wetting and drying regimes also had an influence on heavy metal removal efficiency (Figure 3). However, in general for the WSUD-LF-Deep system, the impact of these regimes was often minimal when these regimes caused a decrease in performance. Pb removal was a clear outlier in the results, with all enviss™ systems showing an increase in performance after dry, and especially wet, periods. Again, data from future sampling runs will help identify the key processes and factors which are influencing these removal rates.



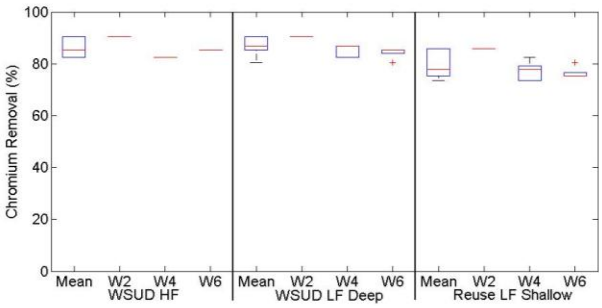
(a) Al



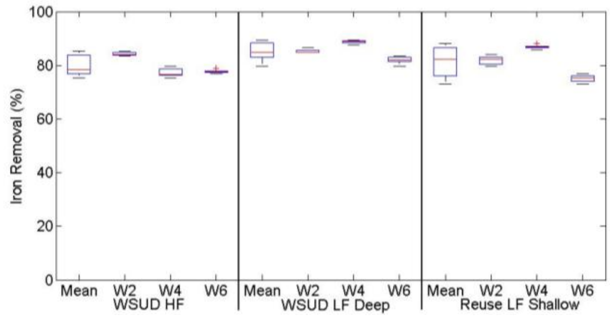
(b) Zn



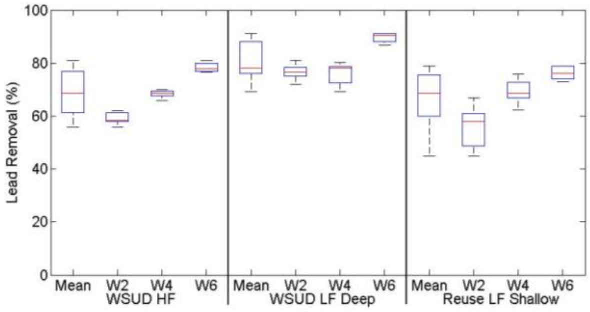
(c) Cd



(d) Cr



(e) Fe



(f) Pb

Figure 3: Mean removal rates for the three sampling runs for six heavy metals: (a) Al, (b) Cd, (c) Zn, (d) Cr, (e) Fe and (f) Pb for the three different systems.

4 CONCLUSIONS

The performances of three enviss™ systems have been tested for a wide range of stormwater pollutants. All the configurations showed great potential for the removal of Total Suspended Solid as they were removing over 90% of the influent TSS levels. The systems also show good removal for TN and TP, with all three configurations being able to exceed that stipulated by Victorian Government regulations (Clause 56.07-4; DSE, 2006). In particular, the WSUD-LF-Deep system achieved, on average, 79% reduction in TN concentrations and 67% reduction in TP concentrations.

All the systems performed well at removing heavy metals. However, Pb concentrations were only reduced in average by 65% at the start of the trial but all systems showed an improvement of nearly 20% over time. TPHs were removed on average by 80% and polycyclic aromatic hydrocarbons were below detection in the outflow for all configurations. However, because of the low PAHs inflow concentration and the detection limit of the instrument, these results should be used with caution.

The reuse system performed extremely well for pathogenic indicator removal, without producing harmful disinfectant by-products. The systems were even able to reduce the concentration of *C. perfringens* by >98%, which is considered reasonable since these microbes are more resistant than other typical indicators and the influent concentration was mistakenly made to ten times the level typically found in stormwater. This Reuse-LF-Shallow system is unique and the results indicate that it will be able to treat water to a level that is acceptable for non-potable reuse.

Overall, the new enviss™ filtration systems have multiple benefits over current stormwater treatment systems. Firstly, because of the high infiltration rates, the systems can be sized seven times smaller than traditional stormwater biofilters, for the same catchment impervious area. Their treatment efficiency is meeting all current stormwater regulations which exist within Victoria, and can treat to a significant enough level that the system can be used as a sole solution for stormwater harvesting applications. There are also minimal establishment periods. The system does require some maintenance, but the maintenance is only required between 1 and 2 times per year and because of the modular cartridge design this maintenance is very quick, easy and cheap.

At the stage of this paper, the experiment is still running, therefore only the results from the first three samplings have been presented. As shown in Table 2, a prolonged dry period will be simulated. The remaining sampling runs will allow us to fully understand the performance of the enviss™ systems, and which factors are impacting the treatment performance most significantly. Future work will also show how the different systems behave after a full year of water.

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