Expected performances and lifespan of the enviss™ stormwater treatment technologies: results of a breakthrough analysis

C. Schang*[1], D. T. McCarthy[1], K. Bratieres[1],and A. Deletić[1]

[1] *Centre for Water Sensitive Cities, Department of Civil Engineering, Monash University, Clayton, VIC3800, Australia*

**Corresponding author, e-mail christelle.schang@monash.edu*

ABSTRACT
An intensive experimental study has been undertaken by enviss™ and Monash University (Australia) to develop a new range of modular stormwater treatment systems. These systems, which can be implemented in highly urbanized areas, will be used to treat stormwater for (a) discharge to downstream ecosystems or (b) stormwater harvesting. The main objective was to quantify their treatment performances for a wide range of pollutants typically found in urban stormwater over an extended period of operation. The laboratory study was based on an intensive breakthrough experiment, to provide information on the lifespan of three different enviss™ stormwater treatment systems. All of the systems showed efficient removal of all the pollutant tested for a lifespan ranging from two to five years depending on the systems considered. The enviss™ system is one of only a few available technologies which can treat stormwater to a level that is acceptable for harvesting purposes and require easy and low maintenance. It is also the only known system that has undergone independent testing for this purpose in Australia.

KEYWORDS
Engineered filter media, stormwater treatment, stormwater harvesting, WSUD, lifespan.

INTRODUCTION
Urbanisation leads to significant changes in the volume and 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 pollutant carried by stormwater runoff, such as nutrient and heavy metals.Meanwhile, the increased runoff volumes generated by urbanisation remains an abundant and untapped resource, often exceeding the total water demand of a city. Such volumes could be harvested if treated to an adequate level. As such, stormwater harvesting has been emerging, and brings with it multiple benefits (Fletcher *et al.*, 2008).

A range of passive stormwater treatment systems exist, including wetlands, biofilters and sand filters. As it stands, however, these technologies require significant space and are not always able to deliver a consistently high standard effluent discharge (Al-Anbari *et al.*, 2008). Also, there are only a few technologies available to treat stormwater to a level acceptable for harvesting purposes; thus, advanced treatment systems are required to underpin safe and reliable stormwater discharge in receiving water bodies and for stormwater harvesting.

An intensive experimental study has been undertaken to develop the enviss™ stormwater treatment and harvesting technologies. These technologies are modular filtration systems which can be implemented in highly urbanised areas. Their respective hydraulic conductivity allows them to be seven times smaller than typically-used biofilters. To date, three enviss™ systems have been developed for specific uses; two systems (WSUD LF and WSUD HF) 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 (REUSE) is suitable specifically for harvesting applications.

This paper reports on the results of an intensive breakthrough testing regime, which quantified the treatment performance for the three enviss™ systems (outflow concentrations and their reductions) for typical stormwater pollutants.

METHODS

Experimental set-up

The laboratory study was based on an intensive breakthrough testing. The main aim of the experiment was to provide information on the lifespan of three different enviss™ stormwater treatment systems (Table 1): REUSE, WSUD-LF and WSUD-HF. Each configuration was designed for three likely use scenarios: (1) for safe non-potable reuse – REUSE, (2) for smaller catchment outlets, or at source treatment, with improved treatment capacity – WSUD-LF, or (3) as a large end-of-pipe treatment with a very high flow rate – WSUD-HF. Three replicates of each system were used to allow basic statistical comparisons (9 columns in total). The WSUD-LF system presented in this paper slightly differs from the one presented in Schang *et al.* (2010) and Bratières *et al.* (2011) as its sediment trap design has been improved by reducing the particle size of the media.

Table 1: Column configuration tested for enviss™

Column Type	Design Flow rate	Depth of media	Disinfectant (Cl)	End-use scenario
REUSE	low (2000mm/hr)	shallow (270mm)	YES	Treatment and reuse
WSUD-LF	low (2000mm/hr)	deep (400mm)	NO	Stormwater treatment
WSUD-HF	high (8000mm/hr)	deep (800mm)	NO	Stormwater treatment End-of-pipe

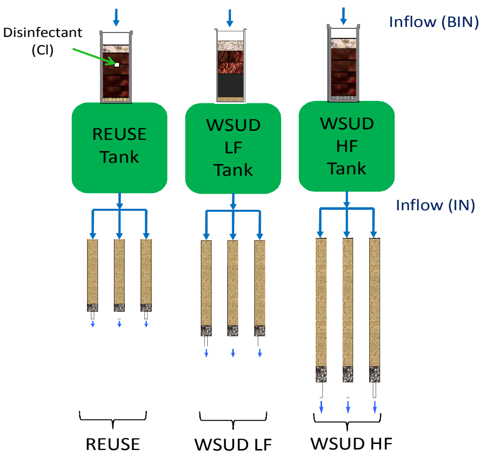

Figure 1: Laboratory testing rig. (the arrows indicate where samples were taken from)

A small laboratory rig (Figure 1) was used for the breakthrough testing. enviss™ systems typically comprise the following components (see Schang *et al.*, 2010; Bratières *et al.*, 2011): (1) a porous paver to remove gross pollutants and coarse sediment, (2) a sediment trap to protect the subsequent layers from excessive clogging; (3) the filter media to remove finer sediment and dissolved pollutant and (4) a drainage layer to prevent filter media migration and outlet clogging. The setup in these experiments was slightly different to what is normally seen in the field. The water filtered by each sediment trap, contained in 100mm PVC column, was first stored in a tank and then pumped into filter media packed within 28mm PVC tubes.

All enviss^{TM} sediment traps are 255mm deep and are made of layered filtration media to ensure clogging is minimized. The components of the sediment traps differ between systems and therefore 3 sediment traps and three tanks were used during the testing (Figure 1). This is especially the case for the REUSE system where a disinfectant (Cl) is part of the sediment trap.

Prior to testing, the sediment traps were washed rigorously to ensure that the filter media would not be clogged/polluted by other sources than the incoming water. The filter media was also washed prior to stormwater dosing.

Experimental procedure

Dosing/sampling regime with semi-synthetic stormwater

Semi-synthetic stormwater was applied to three sediment traps (Figure 1), with the effluent of each subsequently flowing into the three large tanks and then fed into each column using a peristaltic pump for 8 to 10 hours per day. The semi-synthetic stormwater target concentrations were based on large review conducted by Duncan (1999) and on data from both Taylor *et al.* (2005) and Makepeace *et al.* (1995). For more information about the method of producing semi synthetic stormwater please refer to Schang *et al.* (2010).

The testing was conducted considering Melbourne climate only. Using the envissDT software (software provided with the enviss^{TM} product range used to help size the filter systems) and 10 years of Melbourne rainfall data, the annual volume of stormwater which needed to be applied to each column configuration were determined (e.g. 92.4L for REUSE and WSUD-LF and 369.5L for WSUD-HF). Overall, the REUSE, WSUD-LF and WSUD-HF enviss^{TM} system were dosed with semi-synthetic stormwater corresponding to 4yrs, 5 yrs and 2yrs of simulated Melbourne rainfall, respectively.

Sampling procedures

Composite inflow samples were collected on a daily basis before (i.e. raw stormwater) and after being treated by the sediment trap. Outflows from the columns were only sampled at equivalent time periods: 0.5yr, 1 yr, 1.5 yr and so on until pollutants and/or hydraulic breakthrough was observed or 5 years of operation in a Melbourne climate was reached. Samples were then analyzed in NATA (National Association of Testing Australia) accredited laboratories for a large range of pollutants including sediment, nutrients (nitrogen and phosphorus for both particulate and dissolved forms), heavy metals (20 elements), disinfectant (chlorine) and disinfection by-product (TriHalomethanes -. THMs, etc.). It should be noted that: (1) only the total fraction of metals was analyzed, and (2) out of the array of heavy metals which were analyzed, only those which have a significant impact on human health and/or stream ecology were discussed in this paper: Al, Cd, Cr, Cu, Ni, Pb, Zn (Makepeace *et al.*, 1995). In addition, the hydraulic conductivity of the systems was monitored on a daily basis to understand the rate of clogging and to determine the interaction (if any) between treatment performance and hydraulic conductivity.

Data analysis

For each configuration, the overall pollutant treatment performances were assessed by calculating the median and the 95% confidence interval using the outflow concentration data from the three replicates and all sampling events. If the concentration of a pollutant was below the detection limit of the instrument, the value used to calculate the median and the

95% confidence interval was taken to equal half the detection limit for that pollutant (and the number of values above the detection limit was mentioned in superscript). In order to assess the treatment performance of each configuration over time, the removal rates and concentrations were also presented using box plots.

RESULTS AND DISCUSSIONS

General overview

The overall median inflow and outflow pollutant concentrations, together with the median removal efficiencies of the three enviss^{TM} systems are summarised in Table 2. All three configurations were able to reduce TSS concentrations by over 96% during their respective lifespans. The analysis of the cumulative load reduction showed that all three systems met the TSS load reduction target stipulated by the Victorian Government (Clause 56.07-4 – DSE, 2006) (results not shown).

Table 2 Overall median [2.5%ile, 97.5%ile] concentrations of pollutant during the sampling regime. Unless indicated, 24 values for Reuse-LF, 36 values for WUSD-LF2 and 12 values for WSUD-HF were used on the calculations to represents 4, 5 and 2 years of typical operation respectively.

	d.l	*Inflow concentrations [mg/L, mm/hr]*	*Outflow concentration [mg/L] [mm/hr]*			*Removal rate [%]*		
			REUSE	WSUD-LF	WSUD-HF	REUSE	WSUD-LF	WSUD-HF
TSS	<0.5	110 [82.1, 150]	1.15 [0.4, 4.7]	0.75 [0.3, 1.5]	1.15 [0.8, 2.7]	99 [96.4, 99.7]	$>99.4^{30/36}$ [98.5, 99.8]	>99.1 [97.8, 99.2]
TP	<0.01	0.37 [0.33, 0.42]	0.19 [0.17, 0.25]	0.1 [0.07, 0.15]	0.15 [0.12, 0.17]	48.7 [35.2, 53.8]	75.6 [58.3, 81.6]	59 [56.4, 63.2]
TN	<0.02	2.4 [2.17, 2.7]	1.4 [1, 1.6]	0.99 [0.6, 1.4]	1.3 [0.99, 1.47]	40.8 [32.1, 57.9]	59 [41.7, 73.9]	44.3 [34.1, 58.6]
Al	<0.01	0.73 [0.34, 1.4]	0.35 [0.28, 0.77]	0.12 [0.08, 0.2]	0.13 [0.09, 0.15]	69.3 [10.5, 82.1]	80.3 [56, 88.5]	80.9 [79.4, 87.4]
Cd	<0.0002	0.0038 [0.003, 0.005]	0.00095 [0.0007, 0.0014]	0.0011 [0.0007, 0.0018]	0.0008 [0.0006, 0.001]	77.5 [71.5, 82.9]	66.7 [51.4, 81.4]	80.4 [65.5, 82.6]
Cr	<0.001	0.014 [0.005, 0.018]	0.002 [0.001, 0.003]	0.002 [0.001, 0.002]	0.0013 [0.001, 0.002]	84.5 [77.2, 90.4]	85.7 [80, 92.3]	91.3 [84, 96.8]
Cu	<0.001	0.21 [0.077, 0.52]	0.065 [0.039, 0.13]	0.074 [0.056, 0.093]	0.038 [0.026, 0.046]	68.3 [18.2, 79.3]	80.8 [24, 84.4]	80.3 [79.2, 81.5]
Ni	<0.001	0.024 [0.02, 0.028]	0.011 [0.008, 0.013]	0.011 [0.009, 0.016]	0.009 [0.008, 0.012]	54.7 [45, 65.3]	54.2 [33.3, 60.5]	63.8 [44.6, 64.5]
Pb	<0.001	0.11 [0.025, 0.13]	0.007 [0.003, 0.013]	0.005 [0.003, 0.008]	0.007 [0.005, 0.009]	94.2 [83.4, 97.7]	93.7 [85, 97.5]	93 [92.5, 94.1]
Zn	<0.001	0.26 [0.2, 0.33]	0.1 [0.08, 0.13]	0.09 0.07, 0.15]	0.082 [0.053, 0.099]	64.1 [52.2, 75.2]	63.1 [34.8, 72.7]	70.7 [53, 75.8]
Chlorine[a]	<0.2	-	0.9 [0.3, 3.1]	-	-	-	-	-
THMs[b]	<0.001	-	0.037 [0.017, 0.053]	-	-	-	-	-
k_{20}			750 [501, 1816]	1305.8 [720.1, 1727.1]	3855.7 [3641.5, 5741.4]			

'-'– Non tested, [a] REUSE – chlorine was always undetected in the inflow [b]Trihalomethanes (THMs) include bromodichloromethane, bromoform, chloroform and dibromochloromethane - REUSE – Inflow was not analysed for THMs

The results show that nutrient concentration reductions varied between the media types (Table 2) and over time (Figure 2). Detention time plays an important role in pollutant removal for stormwater treatment (Hatt *et al.*, 2007). This holds true for the enviss^{TM} system, where the WSUD-LF, which has the longest detention time (≈17mins), largely outperformed the other two systems especially for TP and TN. Interestingly, the REUSE system performances were lower than the WSUD-HF, even though its contact time was higher (≈13mins against ≈9mins). Bratières *et al.* (2011) and this study revealed that the disinfectant used in the

REUSE was limiting the reduction of the dissolved fraction of phosphorus (results not shown). However, given the suggested end-uses for REUSE filters, this side effect was of no great concern.

For some pollutants, it appeared that no matter the design configuration, the system's performance reached the same outflow concentration after a certain amount of time; this was especially true for TN (around 1.5mg/L; Figure 2) and heavy metals (Table 2 - Pb around 0.006mg/L, Ni around 0.01mg/L). This trend has been observed in other systems such as biofilters which can reduce nutrient concentrations to a consistent 'background concentration' which depends on the properties of the soil media (Fletcher *et al.*, 2007).

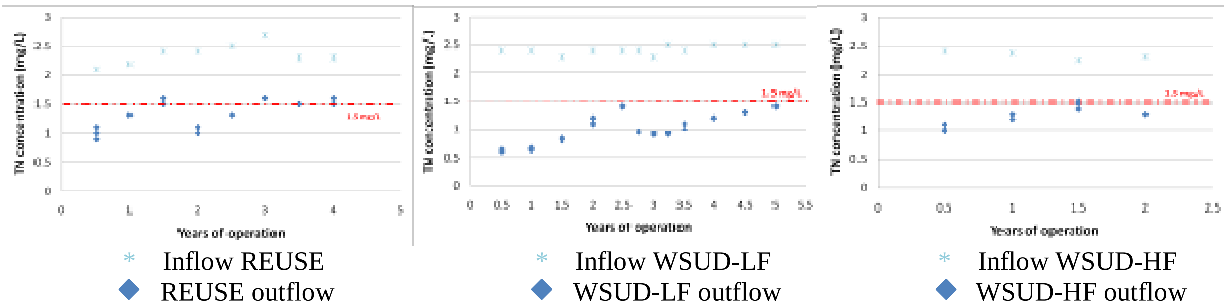

Figure 2 TN inflow and outflow concentrations over the respective testing period for the REUSE (left), WSUD-LF (middle) and WSUD-HF (right) system. The red dashed line represents the 1.5mg/L TN concentration.

The heavy metal concentrations and removal rates varied greatly between metals. However, in general, all systems showed efficient removal of heavy metals with a removal rate higher than 50%, and up to more than 93% for Pb.

Design improvement and compliance with guidelines

REUSE

All samples from the laboratory system met the 'operational risk' targets stormwater harvesting for a system with a design lifespan of up to 20 years (NMMRC, 2009) (i.e. TP < 0.5mg/L. Fe < 10mg/L, TSS < 50mg/L).

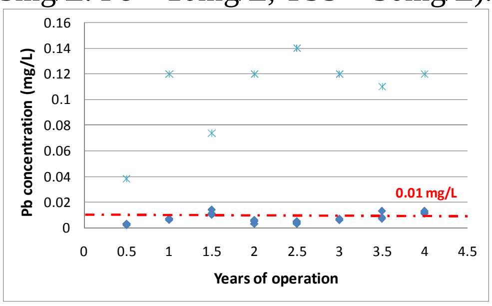

Figure 3. Pb inflow and outflow concentrations over the testing period for the REUSE. The red dashed line represents the 0.01mg/L threshold of the ADWG.

All but a few samples met the Australian Drinking Water guideline (ADWG) values for human health protection (NHRMC & NRMMC, 2004). The analysis shows that the REUSE media complied with those guidelines during at least 1.5 years of operation. Figure 3 actually shows that after 1.5yrs of operation, Pb concentrations occasionally exceeded the guideline values, but usually only by a few percent). Considering that those guidelines are a lot more stringent than really required for stormwater harvesting (i.e. irrigation, toilet flushing, etc), the system performed extremely well.

Due to the experimental set-up constraints, the lifespan of the filter was not tested in respect to microorganism treatment. This information can be found in Bratières *et al.*, (2011). This current study did reveal, however, that the filter was still able to reduce the disinfectant concentrations (Cl) to a level which could meet all the applicable guideline values for human health protection (Cl < 5mg/L; NHRMC & NRMMC, 2004) without producing any harmful by-products at the same time (THMs<0.25mg/L; NHRMC & NRMMC, 2004).

The laboratory studies have shown that the hydraulic conductivity of this system was initially above 2000mm/hr, and steadily decreases as the total load of sediment applied to the system increases. When performing regular maintenance (i.e. replacing the sediment traps and top 30mm of filter media), this hydraulic conductivity can be maintained around 1000mm/hr for the recommended 2 to 3 years lifespan of the media.

WSUD-LF

Figure 4 (right axes) shows the cumulative load reduction for TSS, TN and TP for a Melbourne climate and the 5 year simulated period and the corresponding annual concentrations (left axis). The cumulative sediment load reduction remained consistently high, while the cumulative load reduction for the nutrients decreased over the five years. However, it is noted that for a total of three years, the WSUD-LF system removed over 70% of the total phosphorus load and 60% of the total nitrogen load entering the system. Therefore this system achieved the load reduction requirement set by the ARQ (Wong, 2006) for the 5 years simulated period, indicating that the filter media could last 5 years without replacement in a Melbourne climate. It is noted that this analysis assumes there is no overflow from the system, where as in reality overflows could be up to as much as 10% of the total influent volume.

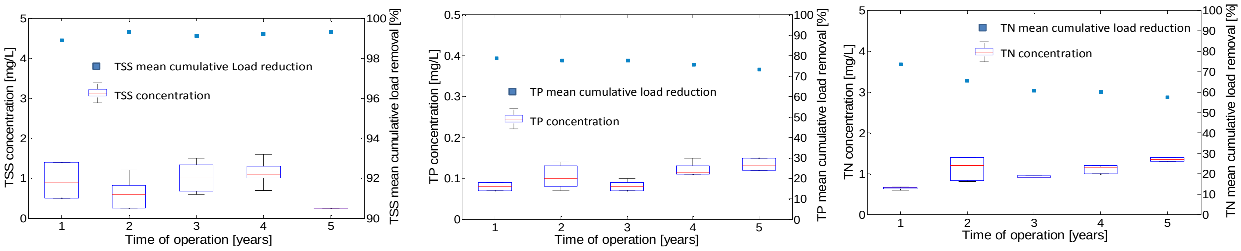

Figure 4 Annual outflow concentrations of the WSUD-LF system (left axis) and mean annual cumulative load reduction (right axis) for TSS (left), TP (middle) and TN (right).

After 5 years of operation in a Melbourne climate, the WSUD LF system complied with the Stormwater Harvesting Guidelines for a system of a design lifespan of 20 years (i.e. TP < 0.5mg/L. Fe < 10mg/L, TSS < 50mg/L; NMMRC, 2009).It also consistently met the majority of the ANZECC & ARMCANZ (2000) thresholds for recreational purposes. NH_3 and Mn were the only pollutants not meeting these guidelines for recreational purposes (respectively exceeding the guideline threshold by 25% and 8% of the time during the 5 year period and with maximum concentration 19 times and 1.1 times the trigger values of 0.01mg/L and 0.1mg/L, respectively). On the other hand, the system rarely complied with the same guideline threshold for aquatic ecosystem protection. All pollutant except As, Bo, Mn and Se exceed the guideline values It is noted that although many of the pollutants from the enviss™ systems do not meet these freshwater quality guidelines, these guidelines are for water quality in the actual creeks, streams and rivers, and, as such, it is difficult to directly compare these with the outflow concentrations from the enviss™ systems. Indeed, the treated stormwater will often be significantly diluted when entering these systems and depending on the scenario, these guideline values may still be met using the enviss™ system for stormwater treatment.

Even if the hydraulic conductivity of the WSUD-LF system consistently decreased over time (Figure 5) due to the load of sediment accumulated, it was maintained to a satisfactory flow rate of over half its design capacity (i.e. 1000mm/hr, as per enviss™ design) .

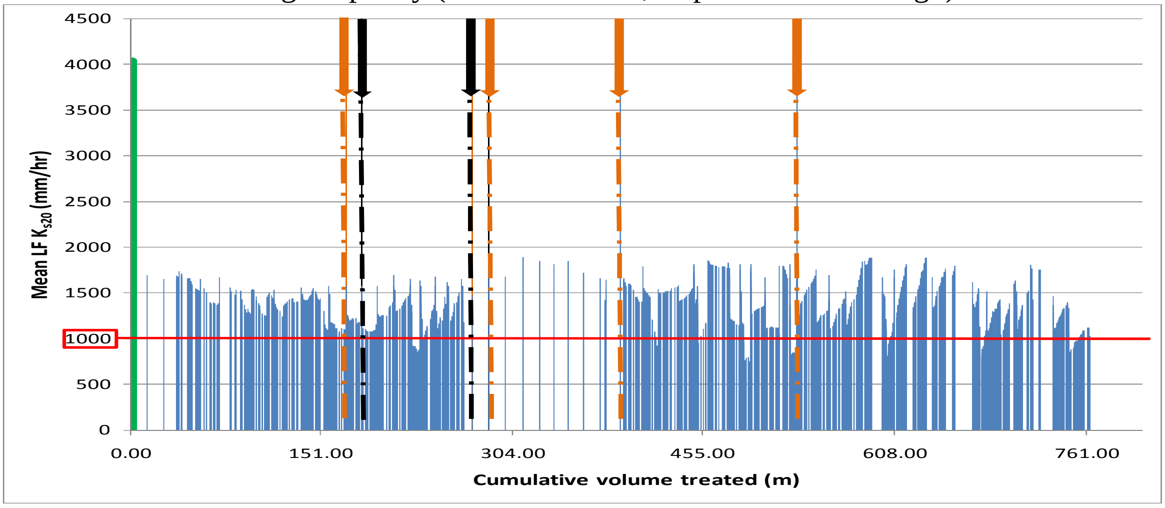

Figure 5. Evolution of the mean hydraulic conductivity for the WSUD-LF systems over the testing period. Orange arrows and dot lines represent changes of sediment trap, whilst black arrows and dot lines represent replacement of the top of 30mm of media within the columns. The initial hydraulic conductivity is indicated by a green bar on the left hand side of the graph.

WSUD HF

The WSUD-HF filters complied with the TSS and TP load reduction targets of the ARQ guidelines (Wong, 2006) for the entire 2 simulated year period and would, in fact, continue meeting this guideline into the future. On the other hand, the system seemed to reach its capacity to comply with the 45% TN load reduction removal within 2 years (Figure 6).

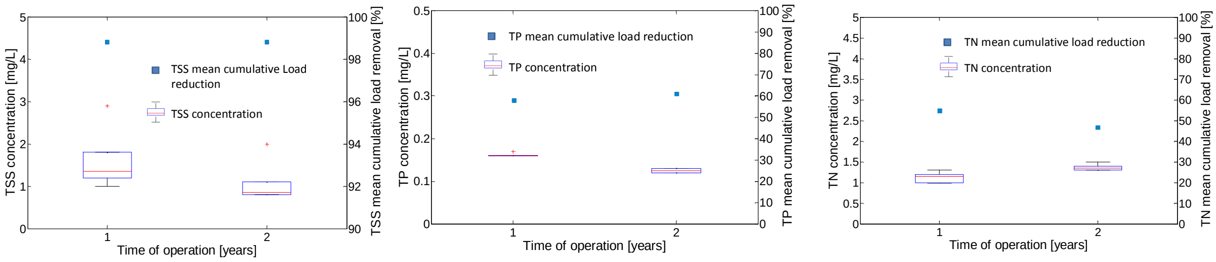

Figure 6 Annual outflow concentrations of the WSUD-HF system (left axis) and mean annual cumulative load reduction (right axis) for TSS (left), TP (middle) and TN (right).

The system was able to reduce most of the inflow concentrations to a level acceptable for recreational purposes (ANZECC & ARMCANZ, 2000). Other than NH3 and Al, all other pollutants met the recreational water quality targets. Similarly with WSUD-LF, aquatic ecosystem protection and freshwater guidelines were not met for a range of pollutants, probably because these targets are difficult to meet considering that these are ‘in-stream’ targets and dilution effects are not considered.

The hydraulic conductivity results showed that the system needed frequent maintenance to maintain appropriate drainage rates through the column. This showed the importance of the pre-treatment method placed before the WSUD HF system to avoid premature clogging.

CONCLUSIONS

The final design of the three enviss^{TM} systems have been tested for a wide range of stormwater pollutants. Overall, all configuration performed really well regarding their specific end-uses purposes. Combined with results from other studies (Bratières *et al.,* 2011), the REUSE enviss^{TM} system appeared to be unique and results indicate that it will be able to treat water to a level acceptable for non-potable reuse whilst maintaining an appropriate hydraulic conductivity for 2 to possibly 3 years with adequate maintenance. The WSUD-LF enviss^{TM} system showed the most promising results for safe effluent release downstream, with an extended lifespan of 5 years, whilst maintaining an appropriate flow rate through the system. Finally, whilst this laboratory study showed the importance of a pre-treatment method placed before the WSUD HF enviss^{TM} system to avoid premature clogging, it also showed that the system was performing appropriately for its end-use and for around 2 years of operation.

Overall the new enviss^{TM} filtration systems offer multiple benefits over current stormwater treatment systems, such as great treatment performances whist keeping a small footprint and are easy and cheap to maintain. It is also the only known system that has undergone independent testing for this purpose in Australia.

ACKNOWLEDGEMENT

Envirostream Solutions Pty Ltd (enviss^{TM}) for providing financial assistance for this research.

REFERENCES

Al-Anbari, R.H., Wootton, K.P., Durmanic, S., Deletic, A. and Fletcher, T. (2008) Evaluation of media for the adsorption of stormwater pollutants, Paper to be presented at the 11th Int. Conf. on Urban Drainage,Edinburgh, UK, 1-5 September 2008.

ANZECC (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council - Agriculture and Resource Management Council of Australia and New Zealand. Canberra, ACT, Australia.

Bratières K., McCarthy D.T., Schang C. and Deletić A. (2011) Performance of the envissTM filtration media: Laboratory trial. Proc. 12th Int. Conf. On Urban Drainage, Porto Alegre, Brasil, 11-16 September 2011.

Duncan H.P. (1999) Urban Stormwater Quality: A Statistical Overview, Report No. 99/3, Cooperative Research Centre for Catchment Hydrology, Melbourne, Australia.

Fletcher T.D, Deletić A., Mitchell V.G., and Hatt B.E. (2008) Reuse of urban runoff in Australia: A review of recent advances and remaining challenges. J. Environ. Qual. 37: 116-127.

Fletcher T.D, Zinger Y., Deletić A., Bratières K. (2007). Treatment efficiency of biofilters; results of a large-scale column study. Proc. 13th Int. Conf. on Rainwater Catchment System, Sydney, Australia, 2007.

Hatt B.E., Fletcher T.D., and Deletić A. (2007) *Treatment performance of gravell filter media: implication for design and application of stormwater infiltration systems.* Water Research, **41**(12): 2513-2534.

Makepiece D.K., Smith D.W. and Stanley S.J. (1995) *Urban Stomwater Quality: A Summary of Contaminant Data.* Critical Reviews in Environmental Science and Technology, **25**(2): 93-139.

NHMRC & NRMMC (2004). Australian Drinking Water Guidelines 6. Australian Government - National Health and Medical Research Council – Natural Resources Management Ministerial Council.

NMMRC (2009) *Australian Guidelines for Water Recycling: Stormwater Harvesting and Reuse.* Canberra, Australia. National Resource Management Ministerial Council, Environment Protection and Heritage Council, and National Health and Medical Research Council - National Water Quality Management Strategy, Document 23.

Schang, C., McCarthy, D. T., Deletić, A., Fletcher, T.D. (2010) Development of the enviss™ filtration media: preliminary results. Proc. 7th Novatech conference, Lyon, France, 27 June – 1st July 2010.

State of Victoria, Department of Sustainability and Environment –DSE (2006) Clause 56.07- Residential subdivision

Walsh, C.J., Leonard, A.W., Ladson, A.R., and Fletcher, T.D. (2004) Urban Stormwater and the Ecology of Streams, Cooperative Research Centre for Freshwater Ecology and Cooperative Research Centre for Catchment Hydrology, Canberra.

Wong, T. H. F., Ed. (2006) Australian Runoff Quality: A guide to Water Sensitive Urban Design, Sydney, Australia, Institution of Engineers Australia.