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HIGH RATE TREATMENT SYSTEM IN STORMWATER HARVESTING AND REUSE IN URBAN AREAS

S. Vigneswaran and J. Kandasamy
Faculty of Engineering and IT, University of Technology, Sydney, P.O. BOX 123, Broadway, NSW 2010, Australia
s.vigneswaran@uts.edu.au

Abstract
Expanding the beneficial reuse of stormwater runoff lowers the demand placed on municipal water supplies and reduces water pollution. This study analysed the water quality of stormwater collected at Carlton, in Kogarah, Sydney. Water quality measurements in terms of physical, chemical, biological and organic characteristics were taken and compared against Australian average values and against drinking water standards. Suitable technology to treat this stormwater for potable and non-potable reuse was evaluated. Stormwater for harvesting and reuse purposes should be assessed primarily for nutrients, physical properties (suspended solids, turbidity), bacteriological properties (total and faecal coliform), heavy metals (such as iron, manganese and lead), and organic matter since it is more unlikely to meet these water parameters. Stormwater discharge is relatively high and therefore needs to be treated at a high rate. High rate treatment systems have relatively high removal rates of nutrients (total nitrogen and total phosphorus), suspended solids or turbidity, heavy metals such as iron, manganese and lead, and dissolved organic matter. These systems are compact and do not require a significant land footprint as there is no need to store water before pretreatment. This makes these systems suitable for treatment for stormwater harvesting and reuse. The alternative is to store the stormwater before treatment in a manner similar to current stormwater management treatment systems. These systems are viable where there is less space constraints.

Keywords: Stormwater, Characterisation, Harvesting, Reuse.

1. Introduction

Stormwater runoff is the main source of polluting lakes and waterways. The chemical characteristics of stormwater are dependent on the nature of surfaces runoff passes on such as roads, roofs etc. (Eriksson et. al 2007). Best management practices (BMPs) or sustainable urban drainage systems (SUDs) such as filter strips and swales; infiltration systems (soakaways, infiltration trenches and infiltration basins); and storage facilities (detention basins, retention ponds, lagoons) are widely used as treatment of stormwater to reduce the amount of stormwater based pollutants entering the receiving water as well as the urban runoff peak flows (Eriksson et. al 2007). Studies have shown that a large number of pollutants, both organic and inorganic, may be present in stormwater (Eriksson et. al 2007), both in their dissolved and colloidal forms and associated with particles. Such discharges of urban stormwater may cause numerous adverse impacts including the export of heavy metals, organic compounds and pathogens to the receiving waters.

The high potential for continued proliferation of organic and inorganic contaminants pose substantial challenges to the recycle and reuse of stormwater. As Australia enters an era of recycling of stormwater and wastewater, it is essential to identify the emerging contaminants of concern in urban stormwater.

This study analysed the water quality of stormwater collected at Carlton, in Kogarah, Sydney. Water quality measurements in terms of physical, chemical, biological and organic characteristics were taken and compared against Australian average values and against drinking water standards. Suitable technology to treat this stormwater for potable and non-potable reuse was evaluated.

2. Results and Discussion

The stormwater was collected from a stormwater channel at Carlton, in Kogarah, Sydney, on six occasions between September 2008 and March 2009. Detailed laboratory analyses were carried out on the stormwater to determine individual pollutants that exist in the stormwater. The pollutants analysed were heavy metals (aluminium, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver and zinc), mineral salts (calcium, magnesium, chloride, potassium, sodium and sulphate), nutrients (nitrate and nitrite, ammonia, total nitrogen, total phosphorous, orthophosphate), physical and chemical parameters (pH, conductivity, hardness, turbidity, total suspended solids, total dissolved salts and bicarbonate) and biological (faecal coliform and total coliform).

2.1 Comparison of Raw Stormwater with Water Quality Standards

A comparison of the concentration of pollutants from the stormwater samples collected from a stormwater channel at Carlton, in Kogarah, Sydney, Australia is presented in Table 1 in the form of range values, mean and standard deviations. A comparison is provided against the range of pollutant concentration in Australian stormwater and against Australian water quality standards.

Most assessments of stormwater quality have been predominantly targeted for the impacts on receiving water and not for reuse purposes. Table 1 gives a comparison with water quality standards for drinking water and for non-potable such as irrigation. These standards include the Australian Drinking Water Quality (ADWG, 2004) and the Australian Guidelines for Water Recycling-Stormwater Harvesting and Reuse (AGWR, 2009). It also gives the traditional comparison for impacts on receiving water. It can be immediately noted that in many instances the water quality standards for discharge into receiving water is much more stringent. These are based on the Australian and New Zealand Environment Conservation Council (ANZECC, 2004) water quality trigger values whose objective is to maintain and enhance the ecological integrity of freshwater and marine ecosystems, including biological diversity, relative abundance and ecological processes. The trigger values are those applicable to estuaries since that are the classification of the receiving water to which most stormwater discharges to.

The physical and chemical properties of the raw stormwater meet the water quality standards except for turbidity. The pH analysis demonstrated that the stormwater complied with the ADWG guidelines of between pH 6.5 and 8.5. The ADWG (2004) state that there are no health guideline values for total hardness, but an aesthetic value is suggested at 200 mg/L $CaCO_3$ (which is reasonably hard water). Very hard water is likely to cause scale (insoluble calcium and magnesium compounds) to form on the inside of pipes and boilers. Water hardness values were in the range of 70-110 mg/L $CaCO_3$ equivalent, and were within the ADWG standard. The ADWG (2004) has a recommended limit of turbidity of 5 NTU. The turbidity in the stormwater was sometimes more than 10 times compared to the average of 5 NTU indicated in ADWG (2004). Similarly it does not meet the AGWR (2009) standard for turbidity.

In general the raw stormwater collected at Carlton meets most of the chemical parameters of the ADWF (2004) and AGWR (2009) water quality standards. In terms of nutrients, with regards to nitrate, nitrite and ammonia, the raw stormwater meets the ADWG (2004) standard. The samples however do not meet the standards for irrigation (AGWR, 2009) in terms of total nitrogen and total phosphorus. High nutrient levels can cause operational problems and hence a tougher standard. Orthophosphate is being used around the world as a corrosion inhibitor in some potable water supplies, especially where it has been observed that high concentrations of copper exist from the potable water pipelines. Water supplies with concentrations of orthophosphate of up to 1 mg/L are dosed to generally decrease copper released in the water distribution pipes, (Edwards et al. (2002). All stormwater samples contained concentrations of orthophosphate of less than 1 mg/L.

The bacteriological properties of raw stormwater, as expected, fail to meet both the ADWG (2004) and AGWR (2009) water quality standards.

Mineral salts are a part of most of daily dietary intake. The concentration of heavy metals in raw stormwater collected at Carlton, Kogarah are mostly within the relevant water quality standards with the exception of iron, manganese and lead. Iron, nickel and lead values were found in some tests up to nine, five and two times the limit of ADWG (2004) 0.3, 0.02 and 0.01 mg/L respectively. Aluminium, arsenic, cadmium, chromium, copper, manganese, mercury, selenium, silver and zinc concentrations were all under the ADWG (2004) limits. The specific metals that do not comply may be related to the specific catchment conditions as a comparison with the Australian average would suggest.

3. High Rate Treatment Systems for Stormwater Harvesting and Reuse in Inner City Areas.

Stormwater discharge is relatively high and therefore needs to be treated at a high rate. Physio-chemical treatment systems such as fibre filters and deep bed filters can achieve a relatively high pollutant removal at a high rate, Table 2. These high rate systems are targeted to enhance water quality suitable for at least non-potable irrigation. The details of these systems are briefly described. Further details can be found elsewhere (Fibre filter, Lee et al., 2006, 2007, Johir et al, 2009a; Deep bed filter, Johir et al, 2009b; Membrane hybrid systems, Johir et al, 2009b).

Table 1 General Characteristics of Stormwater during the study.

Parameters	Unit	Kogarah SW Range	ADWG (2004)	ADWR (2009)
Nutrients				
Total Nitrogen	mg/L N	0.39-8.4		5
Nitrate	mg/L N	0.38-7.9	50	
Nitrite	mg/L N	0.069-0.97	3	
Ammonia	mg/L N	0.4-1.15	0.5	
Total Phosphorous	mg/L P	0.021-0.36		0.05
Traditional physical & chemical)				
pH	-	6.68-7.28	6.5 -8.5	
TOC	mg/L	3.48-9.52		
Turbidity	NTU	2.5-40	5	2
Total Suspended Solids	mg/L	0.5-28	500	50
True Colour	PtCo	28-270		
Total Dissolved Salts	mg/L	90-660		600
Bacteriological				
Total Coliforms	cfu/100 ml	10-28000	0	
Faecal Coliforms	cfu/100 ml	10-500	0	10
Dissolved Salts				
Potassium	mg/L	0.5-7.9		
Sodium	mg/L	6.4-126.0	300	
Calcium	mg/L	7.2-32.2		
Magnesium	mg/L	1.0-13.3	0.1	
Sodium Absorption Ratio	mg/L	1.0-4.7		
Chloride	Mg/L	17-176.4	400	A
Sulphate	mg/L SO_4^{2-}	3.6-86.2	400	
Chloride/ Sulphate Ratio		1.4-4.7		
Metals				
Aluminium	mg/L	0.04-0.16	0.2	5
Arsenic	mg/L	0.001	0.05	0.1
Cadmium	mg/L	0.001	0.002	0.01
Chromium	mg/L	0.002		0.1
Copper	mg/L	0.029-0.049	2	0.2
Iron	mg/L	0.53-2.55	0.3	0.2
Manganese	mg/L	0.28-0.375	0.1	0.2
Nickel	mg/L	0.002-0.10		0.2
Lead	mg/L	0.019-0.022	0.01	2
Zinc	mg/L	0.026-0.123	3	2

3.1 Fibre Filter.

High rate fibre filters were successfully used in tertiary treatment of wastewater. In fibre filter, in place of the sand, fibre media consisting of bundles of U-shaped fine polyamide fibres are used. Compared with the conventional rapid sand filter, the filtration velocity of a fibre filter is more than 5 times and the specific surface is more than twice (Lee et al., 2006, 2007). The fibre packing combines the two advantages of a large specific surface area and very large porosity (more than 90%) which results in high removal efficiency and low pressure drop despite the high filtration velocity (Lee et al., 2007). In-line additions of flocculants enhance the pollutant removal capacity for both dissolved organics and trace metals.

3.2 Membrane filtration and Membrane Hybrid systems

Advances in low pressure driven membrane technologies such as microfiltration (MF) and ultrafiltration (UF) have permitted their use in stormwater due to their high efficiency, ease of operation and small footprint, (Qin et al., 2006). Membrane filtration is usually coupled with a pre-treatment of fibre filter or deep-bed filter and such systems are called membrane hybrid systems. This significantly improved the removal efficiency of the system yielding high quality reuse water.

These systems can from part of a stormwater filtration system (Figure 1). Stormwater from the site (Figure 2) is directed and collected in a stormwater pit and is extracted through a gross pollutant screen to exclude rubbish and coarse sediment. The high rate system will treat stormwater to a water quality level equivalent of at least non-potable level.

Following a pre-treatment with high rate fibre filter the effluent is stored in a storage tank. Water in this tank may be augmented by roof rainwater which has a quality commensurate with the treated stormwater effluent and the storage tank will also serve as a rainwater tank (Figure 1).

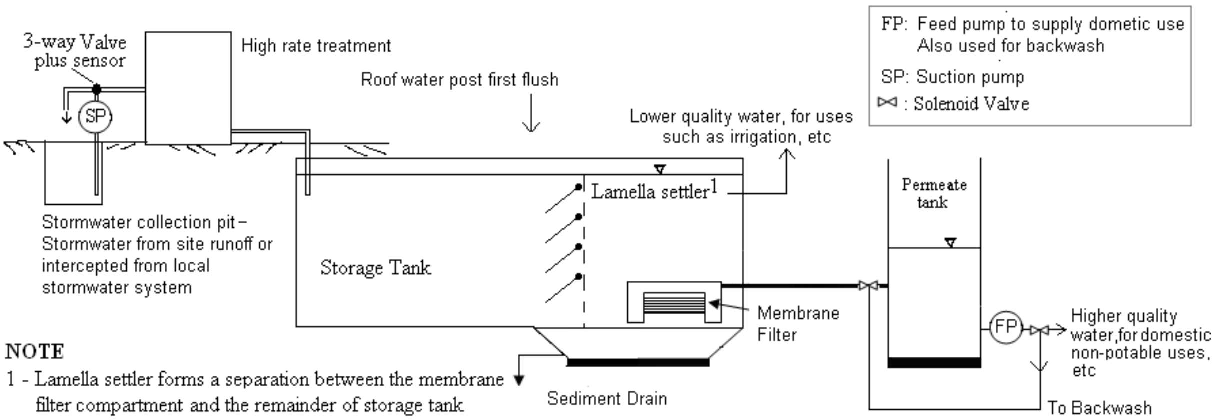

Figure 1 Scheme of the stormwater harvesting treatment system (not to scale).

The water from the storage tank passes through a submerged membrane filter (SMF) placed inside the storage tank. The quality of permeate from the SMF is aimed at least equivalent to potable level. The gravity driving head, or the difference in water levels between the storage tank and the permeate tank will be used to drive treated stormwater through the membrane filter, and eliminate the need for pumping. The permeate tank need not be a separate tank as shown in Figure 1 but may be a compartment within the storage water tank so long as there is no mixing of water between compartments. The driving head will decrease as water filters thorough the SMF into the permeate tank and raises the water level there. This reduces the flow through the SMF until it stops. The flow resumes when water level in the permeate tank drops as water is pumped for domestic use, or if there is more inflow to the storage tank. The innovative feature of the system is that it naturally adapts its treatment capacity to the demand for treated water.

3.3 Performance of High Rate Systems

The high rate treatment systems can be used to create a sustainable urban development with a low demand on town water, low stormwater pollution export and reduced stormwater discharges. Residues of the treatment process (concentrated pollutants and sludge) can be discharged to the sewer alleviating sludge disposal problems and is attractive in creating a low maintenance system. The use of these treatment systems for water reuse can significantly reduce the stormwater pollution export from a site that is transported downstream into the receiving water.

Tables 2 and 3 show how high rate treatment systems are suitable for treatment for stormwater harvesting and reuse. They have relatively high removal rates of nutrients (total nitrogen and total phosphorus), physical (suspended solids or turbidity), heavy metals such as iron, manganese and lead, and organic matter. These systems are compact and do not require a significant land footprint as there is no need to store water before pretreatment.

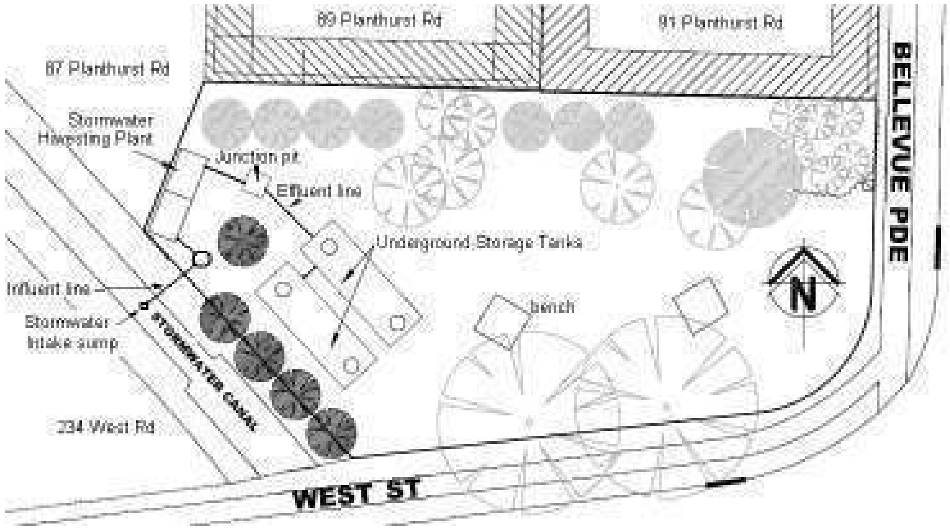

Figure 2: Carlton Stormwater Harvesting Plant, Kogarah, Sydney

Table 2 Indicative percent of pollution retained in the treatment system and indicative levels of pollutants in the outflow for a range of high rate treatment measures

Treatment system	Fibre filter[1]	Deep-bed filter[1]	Submerged Membrane hybrid systems (Figure 1)	Biofilter
Suspended Solids	98%	99%	99%	-
Heavy Metals	90%	40-54%	-[2]	90%
Total Phosphorus	90%	50%	-[2]	74%
Total Nitrogen	90%	38%	-[2]	34%
Turbidity[3]	95%	95%	98%	75%
TOC	40%	30-45%	40%	100%
E. coli[3]	93%	80%	99.9% (Log 5 reduction)	-
Reference	Johir et al, 2009a	Johir et al, 2009b	Johir et al, 2009b	Thamer 2011

[1] in conjunction with in-line flocculent ferric chloride addition
[2] at least equal to fibre filter, deep bed filter or biofilter depending on the system the membrane filter is coupled to. Usually membrane systems are coupled with in-line flocculent or adsorbent addition.
[3] influent and effluent pollutant concentrations in mg/L except for turbidity (NTU) and *E. coli* (cfu/100 mL)

Table 3. Removal of pollutants with sand filter followed by GAC filter and membrane filter (Figure 1)

Parameter	Raw	Treated	% Removal
TOC	4.538	0.067	>99%
Turbidity	29.07	0.27	99%
Aluminium	0.25	> 0.005	> 98%
Copper	0.025	0.002	92%
Iron	1.277	> 0.005	> 99%
Manganese	0.478	0.035	93%
Lead	0.003	> 0.001	> 67%
Zinc	0.058	0.001	98%

5. Conclusion

Stormwater for harvesting and reuse purposes should be assessed primarily for nutrients, physical properties (suspended solids, turbidity), bacteriological properties (total and faecal coliform), heavy metals (such as iron, manganese and lead), organic matter since it is more unlikely to meet these water parameters as the stormwater collected at Carlton, Kogarah as part of this study demonstrates. Stormwater discharge is relatively high and therefore needs to be treated at a high rate. The treatment provided by high rate treatment systems have relatively high removal rates of nutrients (total nitrogen and total phosphorus), suspended solids or turbidity, heavy metals such as iron, manganese and lead, and dissolved organic matter. These systems are compact and do not require a significant land footprint as there is no need to store water before pretreatment. This makes these systems better suited for treatment for stormwater harvesting and reuse in inner city areas.

Acknowledgement

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Reference

AGWR (2009) Australian Guidelines for Water Recycling: Stormwater Harvesting and Reuse National Water Quality Management Strategy, Document No 23, July 2009, A publication of the Natural Resource Management Ministerial Council, the Environment Protection and Heritage Council, and the National Health and Medical Research Council. ISBN 1 921173 45 9

ADWG (2004). Australian Drinking Water Guidelines, National Health and Medical Research Council, Australian Water Resources Council, Australian Government, 2004. p. 615.

ANZECC (2000). National Water Quality Management Strategy – Australian and New Zealand guidelines for fresh and marine water quality, ISBN 0 957 82450, 5 volumes, October 2000.

Eriksson, E., A. Baun, et al. (2007). Selected stormwater priority pollutants -- a European perspective. Science of The Total Environment 383(1-3): 41-51.

Edwards, M., L. Hidmi, and D. Gladwell, (2002). Phosphate inhibition of soluble copper corrosion by-product release. Corrosion Science 44 (2002) 1057–1071

Lee, J.J., Jeong, M.K., Im, J.H, BenAim, R., Lee, S.H., Oh, J.E., Woo, H.J, and Kim, C.W.(2006). Enhancing flexible fibre filter (3FM) performance using in-line coagulation Water Science & Technology 53(7) pp 59–66.

Lee, J.J., Im, J.H., BenAim, R., Kim, J.R., Kim, Y.J., Poo, K.M., Kim, C.W. (2007). Better understanding of the filtration characteristics in the flexible fibre filter module (3FM) Water Science & Technology Vol 55 No 1–2

Johir, M.A.H., Lee, J.J., Vigneswaran, S., Kandasamy, J., Shaw, K., (2009a). Treatment of Stormwater using Fibre Filter Media. Water, Air, & Soil Pollution: Focus, Volume 9, Issue 5 (2009), Page 439

Johir, M.A.H., Vigneswaran, S., Kandasamy, J, (2009b). Deep Bed Filter as Pre-treatment to Stormwater. Desalination and Water Treatment, 12(2009)313-323.

Mohammed, T., Vigneswaran, S., Kandasamy, J, (2011). Biofiltration as pre-treatment to water harvesting and recycling, Water Science and Technology, Vol 63 No 10 pp 2097–2105.

Qin, J.J., Oo, M.H., Kekre, K.A., Knops, F., and Miller, P. (2006). Reservoir water treatment using hybrid coagulation–ultrafiltration. Desalination, 193, 344–349.

Wilf, M. (2007). The guidebook to membrane desalination technology: reverse osmosis, nanofiltration and hybrid systems : process, design, applications, and economics.