Use of Concrete Additives to Improve the Quality of Stormwater Runoff from a Car Park

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ABSTRACT
This paper describes a three-year study of two innovative stormwater infiltration/filtration systems and their ability to reduce and retain pollutants present within stormwater runoff. The systems contain specially designed porous concrete pipes. Stormwater exfiltrates through the permeable walls of the pipes into the surrounding substrate media material.

Iron oxides are recognised for their ability to remove heavy metals from stormwater, due to the process of chemical precipitation. The porous concrete pipes used within the system located within the Mills Park Tennis Centre, Asquith, were injected with iron oxides during the manufacturing process. The porous pipes within the second study system located within Hindmarsh Park, Kiama, did not have iron oxide additives. The influence of these iron oxides forms the focus of this paper.

Overall, it was found that the Asquith system had the ability to remove substantial amounts of dissolved copper and zinc from the car park runoff. Significantly lower outlet concentrations were achieved by the Asquith system. The dissolved iron concentration was found to increase after passing through the Asquith system, indicating that the iron oxide injected pipes were leaching iron. Comparisons with water quality guidelines indicate that the resulting iron concentrations are still below the recommended guideline levels.

KEYWORDS
heavy metals; infiltration; iron oxides; porous pipe; stormwater; water sensitive urban design (WSUD)

INTRODUCTION
Within today's urbanised catchments, water quality concerns, a diminishing water supply and greater risk of flooding due to an increasing number of impervious surfaces, have led to the consideration of alternative ways for conserving and re-using stormwater runoff.

Water Sensitive Urban Design (WSUD) is a relatively new approach that aims to sustainably integrate the management of the total urban water cycle into urban development (Lloyd et al., 2001). WSUD is analogous to the Sustainable Drainage Systems (SuDS) being used in the United Kingdom, and the Low Impact Development (LID) and Best Management Practices (BMPs) of the United States (Beecham, 2003). It is important to note that Australian stormwater drainage systems are separate from sewerage systems. In contrast, in many parts of Europe and Eastern USA, combined stormwater and sewerage systems are often encountered.

This paper describes a three-year study of two underground WSUD systems. The first system is located at Mills Park Tennis Centre, Asquith, which is a suburb of Sydney, Australia. This WSUD system services a high-use car park. The second system is located at Hindmarsh Park, Kiama, 110 km south of Sydney. The Kiama system services commercial areas, residential areas and a small recreational park.

The underground systems were designed to minimise the impacts of stormwater runoff on the surrounding soils, vegetation and groundwater systems. The systems had the capacity to undertake primary, secondary and tertiary treatment of stormwater. A key component of both of the systems was a porous concrete pipe. The systems were designed such that stormwater exfiltrated through the permeable walls of the pipe into the surrounding substrate media material (Dunphy et al., 2007).

The receiving location of the stormwater from the study system located at Asquith was the Ku-ring-gai Chase National Park. This park was classified as an environmentally sensitive area and this highlighted the importance of ensuring the treated stormwater was of an acceptable quality prior to its release. It was recognised that heavy metals and hydrocarbons were the primary pollutants of interest generated from the car park catchment draining to the Asquith study system.

Investigations undertaken by Sansalone (1999) found that the capacity of silica sand for zinc, cadmium, copper and lead removal was significantly improved when the sand was coated with iron oxide due to the process of chemical precipitation. In addition, it was identified by Davis et al. (2006) that aluminium or iron oxide materials can enhance the phosphorus uptake of a system. The porous concrete pipes used within the Asquith system were injected with iron oxides during the manufacturing process to enhance metals removal. The Kiama system did not have iron oxide additives. The influence of these oxides forms the focus of this paper.

POROUS PIPE STORMWATER TREATMENT SYSTEM

The focus of the investigation was a porous pipe stormwater treatment system. The components of this system are summarised in Figures 1 and 2. The steps shown in Figure 1 correspond to the boxed numbers in Figure 2.

The systems were designed such that stormwater exfiltrated through the permeable walls of the concrete pipe into the surrounding substrate media material (Dunphy et al., 2007). The porous pipes used within the system located at Asquith were injected with iron oxides at the time of their manufacture. This was done to allow for the treatment performance of iron oxide injected pipes to be investigated. It was anticipated that chemical precipitation would occur as a result.

The media within the Asquith system is present within two compartmentalized sections. The first compartment consists of sand and the second contains gravel. Stormwater that exfiltrates through the porous concrete pipe enters either the sand or gravel compartment. Sand is the only media present within the Kiama system.

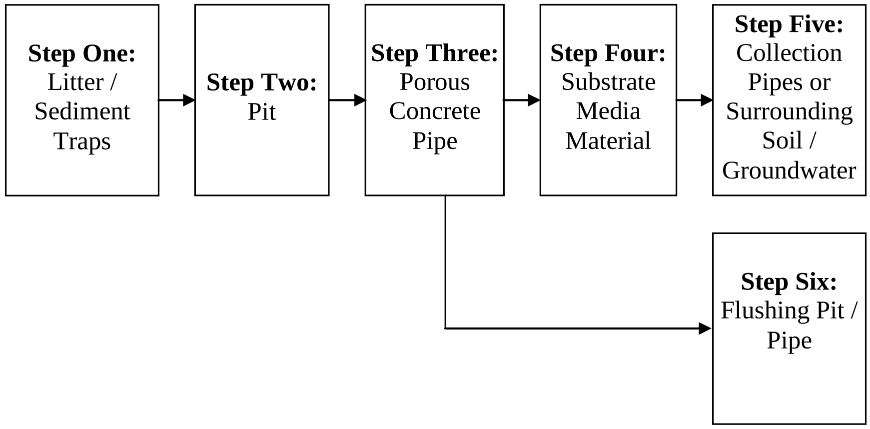

Figure 1. The Porous Pipe Stormwater Treatment Process

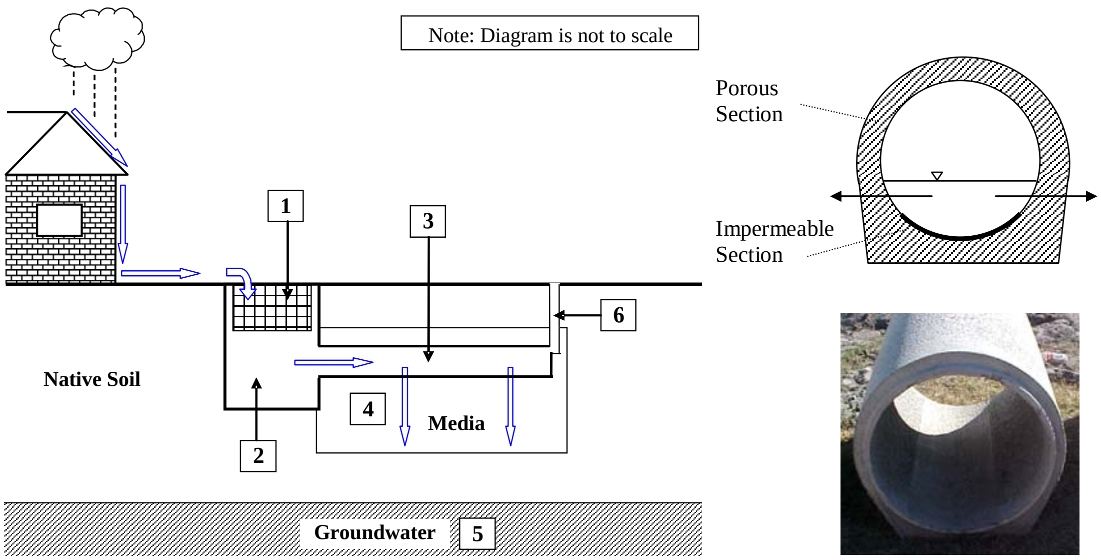

Figure 2. The Porous Pipe Stormwater Treatment System and Porous Pipe

METHODS

A rigorous stormwater sampling and testing program was implemented at the two study sites. Stormwater samples were collected from the inlet and outlet of each system over a three year period. More specific details of the sampling program, including the sampling protocol, are presented in Dunphy et al. (2005a; 2005b).

RESULTS AND DISCUSSION

Zinc

The box plots in Figure 3 present the inlet and outlet zinc concentrations from the field system investigations. Note: I = system inlet; O-S = system outlet (sand media); O-G = system outlet (gravel media).

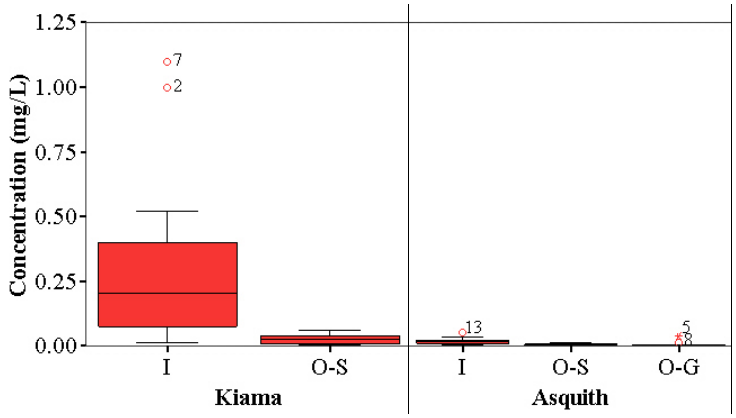

Figure 3. Treatment Performance of Field Systems – Zinc Box Plots

It is evident from the box plots that the inlet concentrations of the Asquith system are small when compared with the inlet concentrations of the Kiama system. This is potentially due to the larger traffic load associated with the Kiama catchment, which includes the town's central business district. The outlet average concentrations are also smallest for the Asquith system (approximately 0.005 mg/L for both the sand and gravel media).

The greatest overall reduction in the average zinc concentration is achieved by the Kiama system (approximately 90%). The percentage reduction in the average zinc concentration by the Asquith system is smaller and is comparable through both the sand and gravel media sections (approximately 70%).

There is an impermeable membrane that lines the base of the Kiama system making it physically confined, whereas there is no such membrane at the base of the Asquith system. Therefore the larger reduction in zinc concentration achieved by the Kiama system is likely to be influenced by the comparatively larger inlet zinc concentrations and the longer residence time associated with the physically confined Kiama system. Mechanical filtration and the adsorption of zinc on to suspended solids and colloidal particles is the likely cause of the reduction in the average zinc concentration in both the Kiama and Asquith systems.

Chemical precipitation due to the presence of iron oxides in the porous concrete pipe of the Asquith system is the potential cause of the significantly smaller average outlet zinc concentration achieved by the Asquith system.

Presented in Table 1 are the ANZECC and ARMCANZ (2000) water quality guidelines and the NHMRC and NRMMC (2004) drinking water guidelines for zinc. These are the national guidelines for water quality used in Australia.

The average outlet zinc concentration from the Kiama system is approximately 0.0256 mg/L. Through the sand section of the Asquith system the average concentration is approximately 0.0055 mg/L and through the gravel section of the Asquith system it is approximately 0.0053 mg/L.

Table 1. Water Quality Guidelines for Zinc

Guideline Classification		Guideline Value (mg/L)	Source
Aquatic Ecosystem - Freshwater	99 % Protection	0.0024	ANZECC and ARMCANZ (2000) - Table 3.4.1
	80 % Protection	0.031	
Aquatic Ecosystem - Marine	99 % Protection	0.007	
	80 % Protection	0.043	
Irrigation	Short Term	5	ANZECC and ARMCANZ (2000) - Table 4.2.10
	Long Term	2	
Recreational Waters		5	ANZECC and ARMCANZ (2000) - Table 5.2.3
Drinking Water Quality	Health	ID	NHMRC and NRMMC (2004) - Table 10.10
	Aesthetic	3	

ID: insufficient data

The freshwater aquatic ecosystem (80% level of protection), marine aquatic ecosystem (80% level of protection), irrigation (short and long term), recreational water and drinking water guidelines are met by both systems for zinc. Both the sand and gravel media sections of the Asquith system meet the marine aquatic ecosystem (99% level of protection) guideline value.

The potential dilution of the stormwater once it reaches the receiving water body should be considered when assessing the performance of the systems in relation to the guidelines for aquatic ecosystems. The potential treatment of the stormwater while it is travelling to the receiving location should also be considered.

Copper

The box plots in Figure 4 present the inlet and outlet copper concentrations from the field system investigations. Note: I = system inlet; O-S = system outlet (sand media); O-G = system outlet (gravel media).

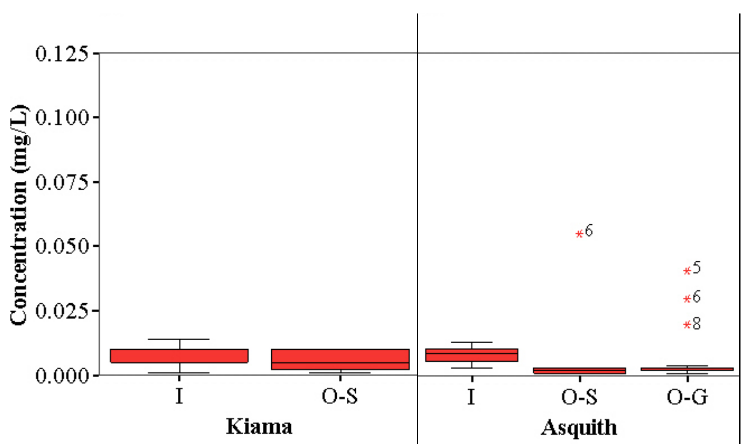

Figure 4. Treatment Performance of Field Systems – Copper Box Plots

It is evident from the box plots that the inlet concentrations at the two sites are comparable.

A clear reduction of approximately 75% and 40% in the average copper concentration is achieved by the Asquith system through the sand and gravel sections respectively.

There is approximately a 20% reduction in the average copper concentration as stormwater passes through the Kiama system. This is potentially due to the small inlet concentration and as a result the system was not able to significantly modify the concentration. The slight change in the average concentration, either an increase or decrease, is potentially due to natural variations during testing, some treatment by the system or the leaching of copper from the media or sediment within the system.

The presence of iron oxides in the porous concrete pipe of the Asquith system and the precipitation of metals that is likely to occur as a result, is a potential reason for the significantly smaller average outlet copper concentration achieved by the Asquith system. The greater reduction achieved by the sand section is likely to be due to the stormwater being in contact with the concrete pipes for longer when it passes through the sand section and as a result there is more residence time available for the removal or precipitation of copper when compared with the gravel section.

The adsorption of copper to suspended particles or the filter media may also have assisted with the removal of copper from the stormwater as it passes through both systems.

Presented in Table 2 are the ANZECC and ARMCANZ (2000) water quality guidelines and the NHMRC and NRMMC (2004) drinking water guidelines for copper.

The average outlet copper concentration from the Kiama system is approximately 0.0059 mg/L. Through the sand section of the Asquith system the average outlet copper concentration is approximately 0.0019 mg/L and through the gravel section of the Asquith system it is approximately 0.0050 mg/L.

Table 2. Water Quality Guidelines for Copper

Guideline Classification		Guideline Value (mg/L)	Source
Aquatic Ecosystem - Freshwater	99 % Protection	0.001	ANZECC and ARMCANZ (2000) - Table 3.4.1
	80 % Protection	0.0025	
Aquatic Ecosystem - Marine	99 % Protection	0.0003	
	80 % Protection	0.008	
Irrigation	Short Term	5	ANZECC and ARMCANZ (2000) - Table 4.2.10
	Long Term	0.2	
Recreational Waters		1	ANZECC and ARMCANZ (2000) - Table 5.2.3
Drinking Water Quality	Health	2	NHMRC and NRMMC (2004) - Table 10.10
	Aesthetic	1	

The marine aquatic ecosystem (80% level of protection), irrigation (short and long term), recreational water and drinking water guidelines are met by both systems for copper. The sand media section of the Asquith system meets the freshwater aquatic ecosystem (80% level of protection) guideline value.

As identified for zinc, the potential dilution of the stormwater once it reaches the receiving water location should be considered when assessing the performance of the systems in relation to the aquatic ecosystem guidelines. In addition, the potential treatment of the stormwater while it is travelling to the receiving location should also be considered.

Iron

The box plots in Figure 5 present the inlet and outlet iron concentrations from the field system investigations. Note: I = system inlet; O-S = system outlet (sand media); O-G = system outlet (gravel media).

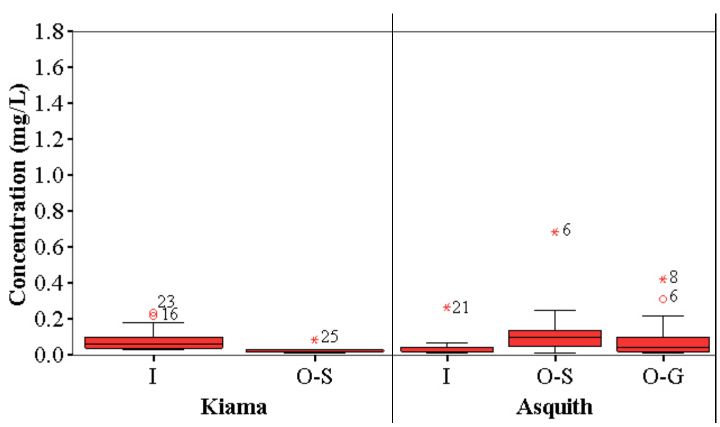

Figure 5. Treatment Performance of Field Systems – Iron Box Plots

There is a reduction of approximately 70% in the average iron concentration of the stormwater that passes through the Kiama system.

There is an increase of approximately 140% and 85% in the average iron concentration of the stormwater that passes through the sand and gravel sections of the Asquith system respectively.

The longer stormwater residence time associated with the physically confined Kiama system is the likely reason for the greater treatment provided by this system. Adsorption is the likely treatment process that caused the reduction in the average iron concentrations.

The increase in the average iron concentrations through the Asquith system may be due to the leaching of iron from the iron oxide injected concrete pipes. The greater increase through the sand section may be due to the longer residence time associated with the sand compared with the gravel. The stormwater is in contact with the concrete pipes for a longer period of time when it travels through the sand section and therefore there is a potential for greater release of iron into the stormwater.

Presented in Table 3 are the ANZECC and ARMCANZ (2000) water quality guidelines and the NHMRC and NRMMC (2004) drinking water guidelines for iron.

The average outlet iron concentration from the Kiama system is approximately 0.0269 mg/L. Through the sand section of the Asquith system it is approximately 0.0975 mg/L and through the gravel section of the Asquith system it is approximately 0.0750 mg/L.

Table 3 Water Quality Guidelines for Iron

Guideline Classification		Guideline Value (mg/L)	Source
Aquatic Ecosystem		0.3	ANZECC and ARMCANZ (2000) - Section 8.3.7.1
Irrigation	Short Term	10	ANZECC and ARMCANZ (2000) - Table 4.2.10
	Long Term	0.2	
Recreational Waters		0.3	ANZECC and ARMCANZ (2000) - Table 5.2.3
Drinking Water Quality	Health	ID	NHMRC and NRMMC (2004) - Table 10.10
	Aesthetic	0.3	

ID: insufficient data

Both systems meet the specified national guideline values. The comparisons indicate that even though there is an increase in the average iron concentration through the Asquith system, due to the potential leaching of iron from the iron oxide injected pipes, the resulting values are still within the recommended national guideline values.

As identified for the analytes discussed previously, when assessing the performance of the systems in relation to the national guidelines for aquatic ecosystems the potential dilution of the stormwater once it reaches the receiving water body should be considered. The potential treatment of the stormwater while it is travelling to the receiving location should also be considered.

CONCLUSIONS

It is expected that this paper will be a useful information source for both researchers and those who are considering implementing WSUD treatment systems in areas where there are particularly sensitive soil and/or groundwater conditions, or in systems requiring enhanced treatment prior to use.

The key findings from the paper are:

- The presence of iron oxides within the porous concrete pipes of the Asquith system resulted in the removal of substantial amounts of dissolved copper and zinc from the car park runoff.
- Significantly lower outlet concentrations were achieved by the Asquith system when compared with the concentrations achieved by the Kiama system where there were no additives within the porous concrete pipes.
- The dissolved iron concentration was found to increase after stormwater passed through the Asquith system. This was potentially due to the leaching of iron from the iron oxide injected pipes.

- Comparisons with water quality guidelines indicate that the increased concentrations are still below the recommended guideline levels.

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