Confined Water Sensitive Urban Design (WSUD) Stormwater Filtration/Infiltration Systems for Australian Conditions

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ABSTRACT
This paper describes a project that investigates confined stormwater infiltration/filtration systems and their ability to reduce and retain pollutants present within stormwater runoff. These highly innovative Water Sensitive Urban Design (WSUD) systems are located in three locations to the north and south of Sydney, Australia. They are positioned at different geographic locations and face different subsoil conditions, pollutant loadings and other constraints.

The systems contain specially designed porous concrete pipes. Stormwater exfiltrates through the permeable walls of the pipe into the surrounding substrate media material. This provides primary, secondary and tertiary treatment of the stormwater. The systems are positioned underground and are designed to ensure that the integrity of surrounding soil, vegetation, groundwater and receiving water is not negatively impacted.

The focus of this paper is the results obtained from the analysis of stormwater samples collected from the inlet and outlet of the systems. The results indicate significant reductions in the concentration of pollutants present in the stormwater that passes through the system. Some of the findings include: approximately 45% reduction in nutrient concentrations, while zinc concentrations have been lowered by approximately 90% and Faecal Coliform levels have been reduced by approximately 95%. The monitoring work is ongoing and further sample collections are required to further validate the findings.

KEYWORDS
groundwater contamination; infiltration; porous pipes; pollution; water reuse; WSUD

INTRODUCTION
In today's urban centres, water quality issues, a diminishing water supply and downstream flooding concerns 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 concept that aims to integrate sustainable water management with urban development. WSUD is analogous to the Sustainable Drainage Systems (SuDS) being used in the United Kingdom (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 project funded by the Australian Research Council, which is being conducted through the University of Technology, Sydney (UTS), with five industry partners. These partners are HydroCon Australasia Pty. Ltd., Kiama Municipal Council, Hornsby Shire Council, Residual Pty. Ltd. and Storm Consulting Pty. Ltd. These represent local government authorities, consulting engineering firms and product manufacturers.

The aim of the project is to study the performance of both confined and unconfined WSUD stormwater systems and to develop a predictive model that describes the treatment effectiveness of confined WSUD systems. In a confined system, primary, secondary and tertiary stormwater treatment takes place wholly within the system prior to the release of the stormwater into the surrounding soil matrix and to groundwater. Hence, the system effectively functions in isolation to that of the surrounding soil and vegetative landscapes.

All three systems being studied contain HydroCon porous concrete pipes and one of the systems contains a HydroCon cyclone pollution control pit. The systems have been installed at Hindmarsh Park, Kiama, Mills Park Tennis Centre, Asquith and the Weathertex Industrial Site, Heatherbrae. Significantly, these three sites represent different land uses. The Kiama site drains a major residential, commercial and park area. The Asquith site consists entirely of a heavily used car park area, while the Heatherbrae site is industrial.

While new in Australia, the HydroCon technology has been studied extensively in Germany, where investigations have generated positive results (Dierkes et al., 2002). Australia and Germany are very different in terms of rainfall intensities, soil types and consequently average residence times. Many Australian clay-based soil areas also suffer salinity problems. The results from this research will allow for the adaptation of porous pipe technologies to confined systems that can be safely used in sensitive soil and groundwater conditions in Australia. The project is of wide interest since it demonstrates how to adapt WSUD systems to very difficult site conditions.

The primary purpose of this paper is to focus on the water quality treatment and reuse aspects of the system. Comparisons will be made between the quality of the flow entering the systems and that exiting the systems. A further aim is to present the initial findings at one of the sites that was selected to test the effects of bacterial seeding of the filter media.

POROUS PIPE STORMWATER TREATMENT SYSTEM

There are numerous aspects to the HydroCon porous pipe stormwater treatment system. These are summarised in the flowchart in Figure 1.

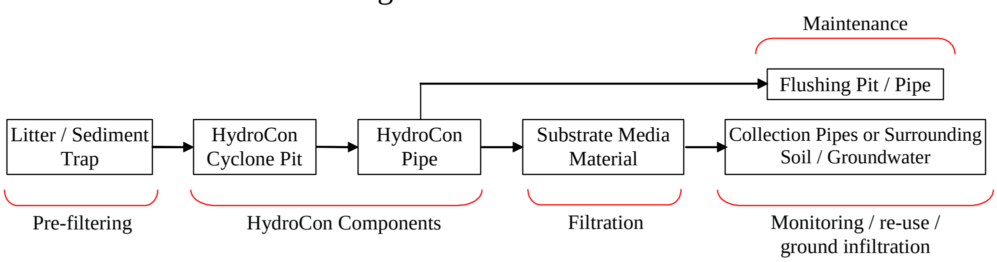

Figure 1. The HydroCon Stormwater Treatment Process

A diagram of the HydroCon system is presented in Figure 2. The HydroCon porous concrete pipes are designed to exfiltrate stormwater through the permeable walls of the pipe into the surrounding substrate filtration media material. Examples of the media material include granular activated carbon (GAC), sand and gravel. Iron oxides may also be injected into the pipe walls at the time of manufacture to further enhance the treatment ability of the HydroCon pipe, through chemical precipitation processes.

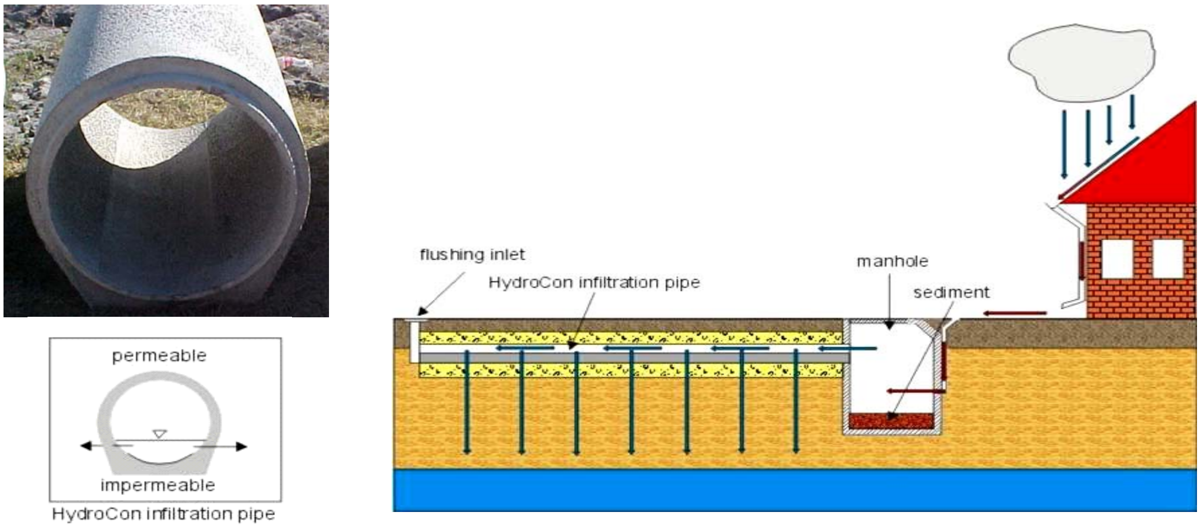

Figure 2. The HydroCon Pipe and System Layout

FIELD INVESTIGATION SITES

A tabular summary of the characteristics of the HydroCon systems being investigated are presented in Table 1. Details of the water sampling set-up are also presented.

Table 1. Site Summary

Site Location	Mills Park Tennis Centre, Asquith	Weathertex Industrial Site, Heatherbrae	Hindmarsh Park, Kiama
Land Use/s	car park	industrial	commercial, residential & parkland
Catchment Area (m^2)	1600	2185	65000
Filtration Media	Gravel / Sand	Gravel / Sand / Sand & GAC	Sand
HydroCon Pipe Diameter (mm)	400	600	400
Length of HydroCon Pipe (m)	100	18	32
Infiltration/Filtration System	Infiltration	Infiltration	Filtration
Iron Oxide Injection of HydroCon Pipe	Yes	No	No
Water Sampling Set-up	Inlet: Sigma 900 MAX automatic sampler Outlet: Half-pipe collection pipes	Inlet: Sigma 900 automatic sampler Outlet: Half-pipe collection pipes	Inlet: Sigma 900 MAX automatic sampler Outlet: Sigma 900 MAX automatic sampler
Pre-filtering	Ecosol pit trap and Rocla CPO precast sump pits	Ecosol pit traps and a HydroCon cyclone pit	Enviropods and maximesh screen
Receiving Location of Treated Stormwater	Ku-ring-gai Chase National Park	Tomago Sandbeds	Black Beach / Irrigation

SAMPLING

Sampling Protocol

Prior to collecting any samples, it is important to adopt a suitable sampling protocol. The main reasons for this are quality assurance and improved results reliability. The following briefly summarises the methods that have been undertaken.

- 'National Association of Testing Authorities' (NATA) accredited laboratories were used for the sample testing.
- Pre-prepared sample containers were provided by the laboratories.
- Preservatives were used in the containers where necessary, to prolong the life of the sample prior to testing.
- Sample containers and collection equipment were appropriately rinsed prior to use.
- A stainless steel container was used for sample collection and mixing.
- Sample containers were appropriately labelled.
- Samples were transported to the laboratory in an ice-cooled storage container.
- Samples were transported to the laboratory in such time that they are collected and analysed within a 24 hour period.
- Field notes were recorded.
- A chain of custody form was used to record possession details of the samples. This form also included details of the tests required for the samples.
- Safety equipment was utililised. The equipment included latex and needle-proof gloves, safety vests, boots and lifting apparatus.

For further details refer to Dunphy et al. (2005).

Sampling Methods

Water samples were collected in two ways, either with an automatic sampler or by grab sampling using a half pipe collection system.

Automatic Samplers. Automatic sampling units have been used to collect time-integrated composite stormwater samples.

Half-Pipe Collection System. This sampling approach utilises a half-pipe with longitudinal slits cut along its invert. The half-pipe sits on a three-quarter pipe. The half-pipe acts as the collection area, while the three-quarter pipe transports the water to the collection point. The entire pipe system is wrapped in geofabric. This system is shown in Figure 3.

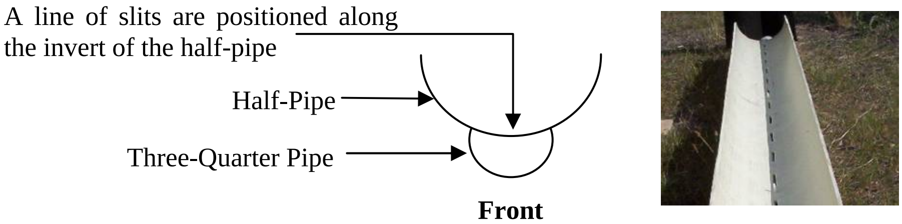

Figure 3. Front View and Photograph of the Half-Pipe Collection System

This system was developed following difficulties encountered when using the traditional collection approach of a full pipe with longitudinal slits cut along its top. The main problem encountered was the lack of water collected. The half-pipe collection system that was developed greatly enlarges the area in which water can be collected.

Tested Analytes

The collected samples are being tested for a range of analytes. These include Total Kjeldahl Nitrogen (TKN), Total Nitrogen (TN), Total Phosphorus (TP), Orthophosphates (PO_4-P), pH, Total Organic Carbon (TOC), Dissolved Organic Carbon (DOC), Biochemical Oxygen Demand (BOD_5), Total Suspended Solids (SS), Total Dissolved Solids (TDS), Faecal Coliforms (F. Coli), Total Petroleum Hydrocarbons (TPH), Copper (Cu), Zinc (Zn), Lead (Pb), Cadmium (Cd) and Iron (Fe). Some of the results that have been obtained to date are presented in this paper. The intention is to refine this list based on the results obtained.

RESULTS AND DISCUSSION

Hindmarsh Park, Kiama

A diagram of the system and sample collection points at Kiama is presented in Figure 4.

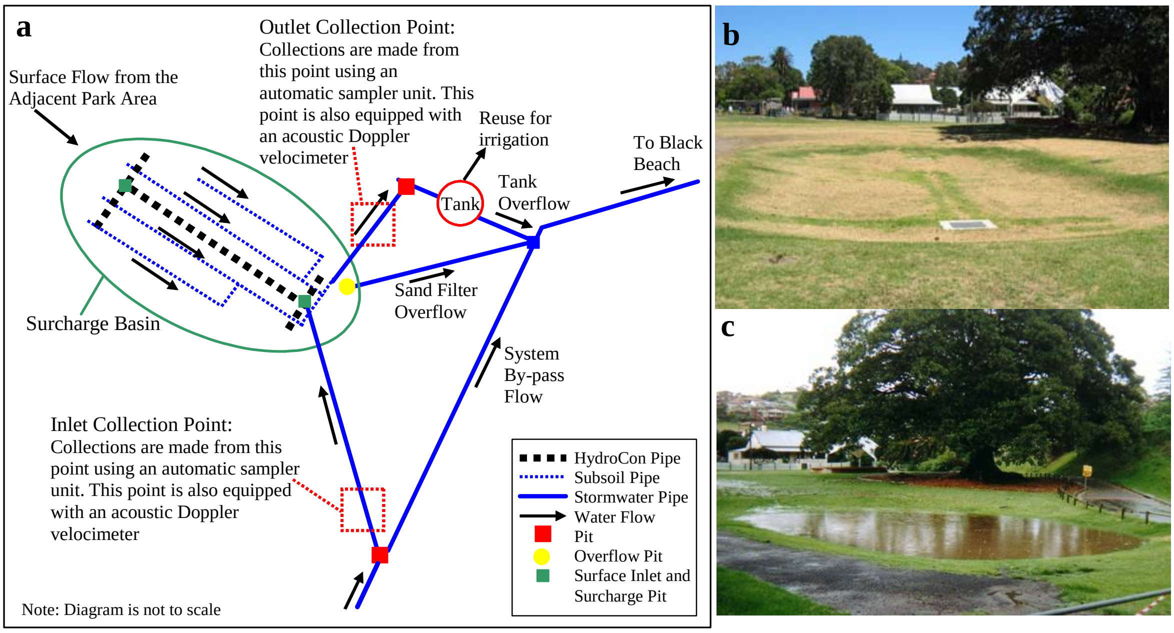

Figure 4. Hindmarsh Park, Kiama – (a) Plan View of System Layout and Sampling Set-Up, (b) Sand Filter During Dry Weather and (c) Sand Filter Following Surcharge

The results obtained from the collection of water samples from the inlet and outlet of the system at Kiama are presented in Figure 5. For each analyte an average inlet and outlet value is presented. These averages are based on 11 sample collections. To simplify the presentation of the results, these values have been normalised to the highest concentration, which is therefore represented as 1. A reading of 0.4 therefore represents 40% of the highest concentration.

Overall a reduction in pollutant concentration is evident for the majority of analytes. The concentration of nutrients, represented by total nitrogen (TN) and total phosphorus (TP), reduces by approximately 45%. Organic carbon (TOC and DOC) concentrations are lowered by approximately 60%. The concentration of suspended solids (SS) is reduced by approximately 75% as the stormwater passes through the system. The total dissolved solid (TDS) load has increased and this may be due to leaching from either the pipe or more likely the surrounding media material. Heavy metal concentrations have reduced: there has been a significant reduction (approximately 90%) in the zinc (Zn) concentration. Faecal coliform levels have reduced by approximately 95%.

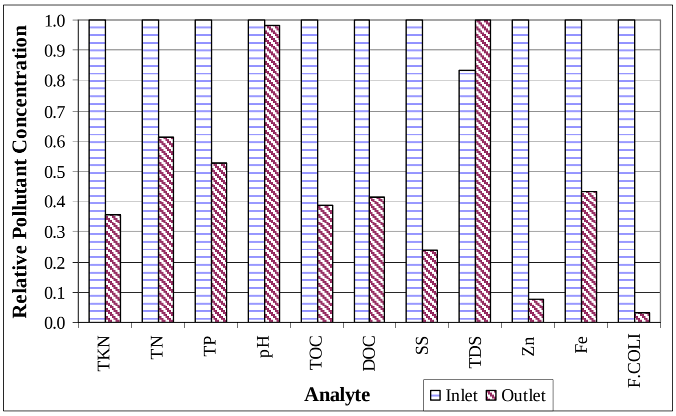

Figure 5. Hindmarsh Park, Kiama – Water Quality Results

A tank is to be installed at Kiama to collect and store the stormwater that has travelled through the HydroCon system. The collected water will be used to irrigate the neighbouring foreshore parkland.

Mills Park Tennis Centre, Asquith

A diagram of the system and sample collection points at Asquith is presented in Figure 6.

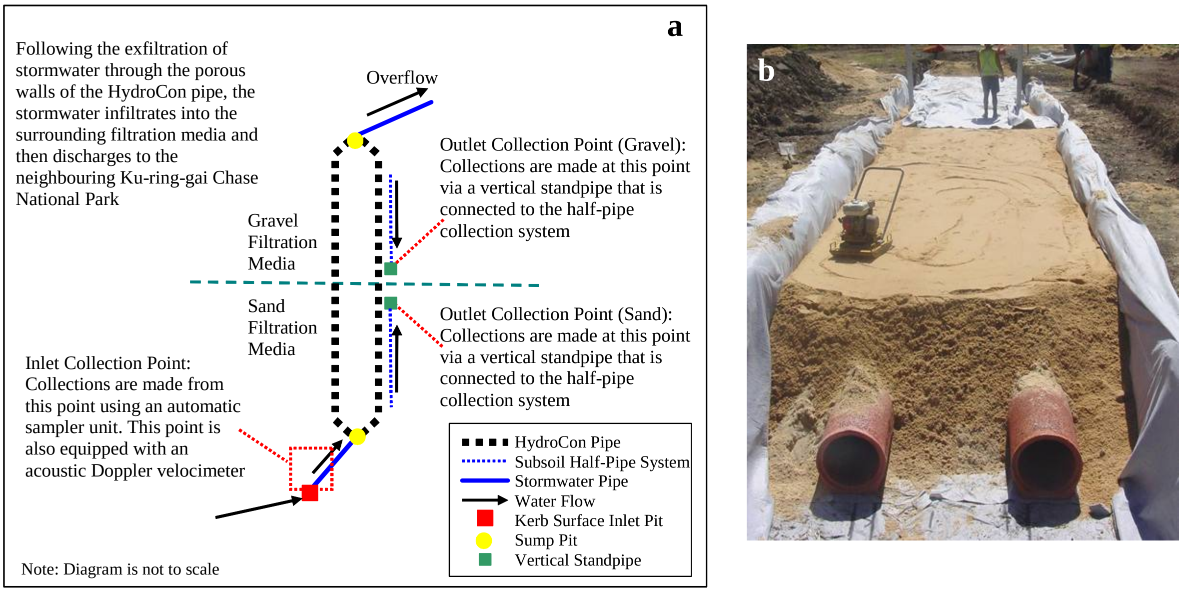

Figure 6. Mills Park Tennis Centre, Asquith – (a) Plan View of System Layout and Sampling Set-Up and (b) System During Construction

The Mills Park system was the first constructed in Australia. This site was selected for seeding of the filter media with nutrients, organic matter and microbial populations. Bacterial seeding in particular was of interest to see if the pollutant removal efficiency of the surrounding media could be increased if bacterial populations could be sustained during inter-event periods. The system was seeded by flushing with 15kL of tertiary treated effluent.

It was recognised that in the short-term this effluent flushing would increase the pollutant concentrations exfiltrating from the system, but in the long-term it would aid in the pollutant treatment process. In particular, the micro-organisms would assist with the assimilation of pollutants entering the system through tertiary treatment processes.

The results obtained to date indicate the short-term expectations of increased nutrient, organic and suspended solid loads as the stormwater passes through the system laden with residual effluent.

Initially, the exfiltration of the treated stormwater was so successful that difficulties were experienced with obtaining adequate outlet samples. This was due to the use of a conventional slotted collection pipe at the outlet. As a result, a new design for a half-pipe collection system was developed. This was described earlier (see Figure 3). Since installation, this new system appears to be operating satisfactorily.

Weathertex Industrial Site, Heatherbrae
A diagram of the system and sample collection points at Weathertex is presented in Figure 7.

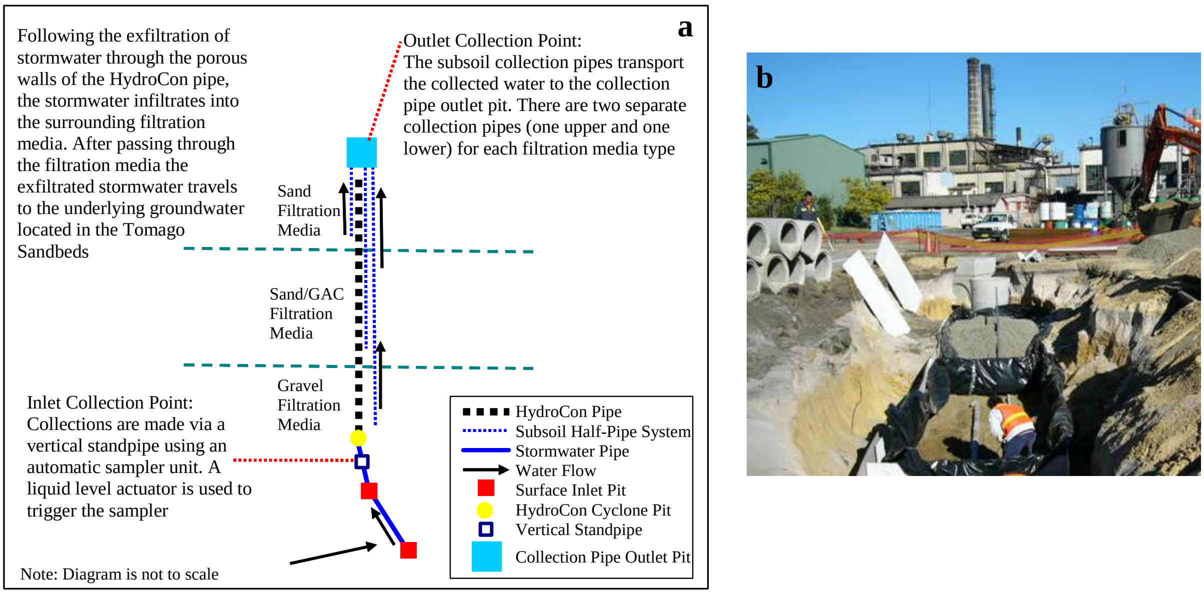

Figure 7. Weathertex Industrial Site, Heatherbrae – (a) Plan View of System Layout and Sampling Set-Up and (b) System During Construction

This site is of particular interest since it drains an industrial area where wood pulping operations take place and there is limited information available about stormwater sourced from such intensive industrial landuses.

Granular activated carbon (GAC) is one of the filtration media being investigated at this site. This material is used primarily to treat the high organics loads that results from the wood pulping operations. Preliminary laboratory tests were undertaken using GAC to investigate its organic removal capabilities. This experimental work is being reported in a separate publication which is currently in press.

The HydroCon system at Weathertex was the most recent to be constructed and was installed in late 2004. As a result a limited number of stormwater samples have been collected. Prior to conclusions being drawn about the capability of this system and the filtration media under investigation, further results are awaited.

CONCLUSIONS

The fieldwork component of this project is ongoing and therefore the collection of further data is currently underway to validate the results that have been obtained to date. The data will be used to develop a model that predicts the treatment performance of confined WSUD systems.

The main findings of this work include:

- The HydroCon stormwater treatment system has the ability to reduce the concentration of nutrients (total phosphorus and total nitrogen) by approximately 45%. TKN levels are reduced by over 60%.
- Organic carbon and particularly dissolved organic carbon levels are reduced by over 50%.
- Faecal coliform levels have been found to reduce by approximately 95%. This is likely to be due to mechanical filtration.
- The expected short-term effect of seeding a system with tertiary treated effluent has been realised with the associated increase in nutrient, organic and suspended solid loads. It is expected that in the long-term, this seeding will have positive impacts on the treatment performance of the system.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the Australian Research Council (ARC) for the funding of this project via the Linkage Project grant 0454374. We would also like to thank Mr. Rami Haddad and Mr. David Hooper of the Faculty of Engineering, UTS for their invaluable help with the field installations and laboratory work associated with this project.

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