Exfiltration Stormwater Treatment Systems – Versatile WSUD Devices

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ABSTRACT

Exfiltration stormwater treatment systems (STSs) offer the stormwater industry a versatile and effective method of combined stormwater treatment, detention and retention. They are in themselves self-contained treatment trains with the following components and functions:

- GPT or pit baskets – for pre-filtering.
- Inlet sump – for maintenance and eduction.
- HydroCon permeable pipes – promotes sediment retention within the pipe, chemical precipitation as water exfiltrates through the pipe wall and mainly is a maintainable method to deliver water into the filter media.
- Filtering media matrix – promotes filtering, adsorption and microbial digestion and transformation of pollutants.
- Surface surcharge (where required) – for detention.

As the systems rely on simple materials such as pipes, pits and filter media, they can be designed into any shape or size. In the Kiama CBD, Grasmere and Ashgrove residential subdivisions in Western Sydney, Exfiltration STSs are designed as basins with surcharge. In the Elambra residential estate in Gerringong, the sand filter is a linear device that lies adjacent to a perimeter road within the road easement. This flexibility in shape and size confers excellent versatility.

Research conducted by the University of Technology Sydney (UTS) as part of an Australian Research Council Linkage Project has shown that Exfiltration STSs with pre-filtering devices, provide exceptional water quality treatment with log reductions in pathogens and substantial reductions of other pollutants including sediment and nutrients. The resultant water is of a quality that is suitable for subsurface irrigation without further treatment, or surface irrigation when combined with disinfection.

At the Ashgrove subdivision, treated stormwater is harvested in a centralised 800 kL tank and distributed to each residence for toilet flushing and irrigation. At Kiama the water is used for surface irrigation.

With the exception of trees and deep rooting shrubs, Exfiltration STSs can be landscaped to match with surrounding areas. In this respect, they can be designed as rain gardens or biofiltration systems. In the Ashgrove residential subdivision, the basin filters are combined with public open space such that the community is encouraged to utilise the surcharge area of the basin for passive recreation in scenically landscaped surrounds. In this respect they are true multi-objective systems.

With intelligent design and no moving parts, exfiltration STSs can be easy to maintain. Sumps and the Hydrocon pipes are simply backflushed and educted while pre-filtering devices need to be routinely cleaned.

The adoption of Exfiltration STSs as a combined treatment and detention measure has made development in two severely constrained sites feasible, providing an example of WSUD driving true ESD.

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. The concept of Water Sensitive Urban Design (WSUD) has been adopted in Australia to meet this challenge. WSUD is no longer a new approach but is has been defined as one that aims to sustainably integrate the management of the total urban water cycle into urban development (Lloyd et al., 2001).

There has been a rapid expansion in the availability of proprietary products that assist with the development of WSUD. These originate from both Australia and overseas. For example, products have been developed in Germany where discharge water quality criteria are more stringent in comparison with Australia due to the need to protect drinking water aquifers. These products tend to be used for traditional metal clad roofs and larger transport depots or car parks, where heavy metals, which can be toxic to both macroinvertebrates and humans, are of primary concern. In the past there were limited options that would ensure that water quality targets are achieved.

The new products that are available provide an effective method for pre-filtering runoff to such an extent that land areas required for delivery of "equivalent" water quality have been significantly reduced. Such systems often incorporate enhanced filtration through filter media (Kandasamy et al, 2008). This effectively creates more usable space on a development. The reduction in area required is attributable to the use of pre-filtering products that can be easily maintained and which prevent clogging of the filter media.

The introduction of the HydroCon porous concrete pipes in Australia has provided an opportunity for industry innovators. Further details about these pipes are provided in the next section. Hornsby Shire Council pioneered this technology by constructing a trial Exfiltration treatment system that drained the Asquith Tennis Club car park. At around the same time, STORM_CONSULTING, who were engaged by Kiama Council, proposed two separate Exfiltration STSs. The first located at the lower end of the central business district (CBD) catchment and the second located in the Elambra Estate residential subdivision in Gerringong.

The University of Technology Sydney (UTS) through Professor Simon Beecham together with STORM_CONSULTING saw merit in researching the performance of these systems. Professor Beecham secured an Australian Research Council (ARC) grant for this purpose. This research was undertaken by Alison Dunphy, a PhD candidate at UTS. The research involved assessing the performance of three field systems that were located at Asquith, Kiama and Heatherbrae. There was a number of industry partners involved with the project who provided project funding and in-kind contributions. The partners were HydroCon Australasia (porous concrete pipe supplier), UTS, Hornsby Shire Council, Kiama Municipal Council, CABP (Weathertex industrial site and the proponents of the Kinross subdivision) and STORM_CONSULTING (consultants to Kiama Council and CABP).

THE EXFILTRATION STORMWATER TREATMENT SYSTEM

The components of the exfiltration stormwater treatment system are summarised in Figures 1 and 2. The steps shown in Figure 1 correspond to the boxed numbers in Figure 2.

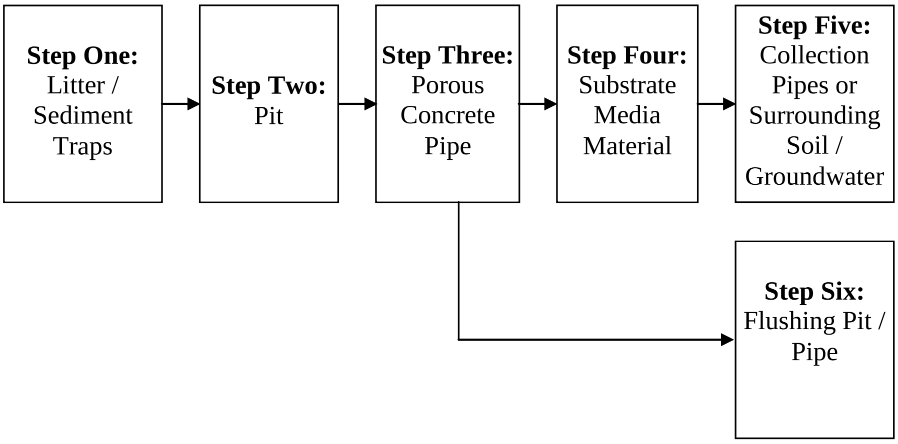

Figure 1. The Exfiltration Stormwater Treatment Process

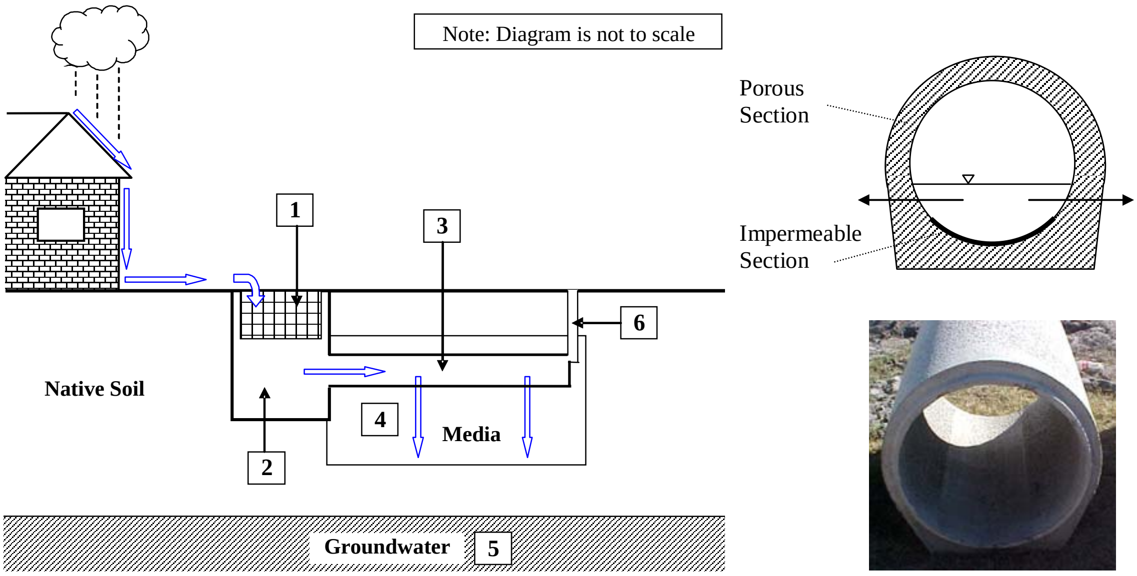

Figure 2. The Exfiltration Stormwater Treatment System and Porous Pipe

A series of pre-filtering devices are located at the upstream end of the system (Step 1). Examples of these devices include litter baskets and screens.

After passing through these devices stormwater enters a pit where sedimentation is promoted (Step 2). A regular stormwater pit or a more sophisticated HydroCon filter pit may be used. If a HydroCon filter pit is used, the conical base of the filter pit induces a vortex action on stormwater which enhances sedimentation.

The stormwater then enters into the porous concrete pipe (Step 3). The pipes are porous, except for along their invert where they are impermeable. The terminal nature of the permeable pipe reduces the water velocity and enables sediment to settle out of the water and build-up on the impermeable pipe invert. The pipes may be injected with iron oxides during their manufacture to enhance pollutant removal, due to the process of chemical precipitation.

The stormwater then exfiltrates through the walls of the porous concrete pipe and this exfiltration allows for mechanical filtration processes to take place. The concrete pipe will also have a neutralising effect on the typically acidic stormwater.

The stormwater then passes through the surrounding substrate media (Step 4). Some examples of readily available media may include sand, gravel, perlite, zeolite and granulated activated carbon (GAC). Alternatively, other types of media including those regularly used by the wastewater industry may be appropriate for use. Pollutants may adsorb to or may be filtered by the media material. Biofilms may develop within the media substrate and they may assist with the retention and biodegradation of pollutants, particularly dissolved organic carbon and oils (hydrocarbons). Some media types are able to remove particular pollutant types and these materials should be used when a particular pollutant is recognised as being of significant concern.

If the system is lined with an impermeable membrane it is classified as a filtration system and stormwater can not move directly to the surrounding native soil and groundwater. The stormwater is collected and transported from the system (Step 5). Alternatively, if the system is not lined with an impermeable membrane it is an infiltration system. Therefore stormwater can move directly to the surrounding native soil and toward groundwater (Step 5).

The system may be designed with a pit at each end of the length of porous concrete pipe, or it may be designed with a pit at one end and a flushing pipe at the other (as indicated in Figure 2).

The sediments and pollutants that accumulate within the pits and on the pipe invert are removed by back flushing the system and extracting the material from an upstream pit (Step 6).

KEY CHARACTERISTICS OF INSTALLED EXFILTRATION STORMWATER TREATMENT SYSTEMS

Table 1 shows the location and key features of a range of Exfiltration STSs.

Table 1. System Characteristics

System Location	Implementation Timeline →					
	Mills Park Tennis Centre, Asquith*	**Kiama CBD***	**Elambra Estate Subdivision, Gerringong**	**Kinross Business Park, Heatherbrae***	**Grasmere Subdivision, W. Camden**	**Ashgrove Subdivision, Regents Park**
Land Use	Car Park	Commercial, & Residential	Residential	Industrial	Residential	Residential
Catchment Area (m^2)	1,600	65,000	10,000	2,185	70,000	80,000
Filtration Media	Gravel / Sand	Sand	Sand	Gravel / Sand / GAC and Sand	Sand	Gravel / Sand
Infiltration or Filtration System	Infiltration	Filtration	Filtration	Infiltration	Filtration	Filtration
Iron Oxide Injection of Porous Concrete Pipe	Yes	No	No	No	No	No
Water Sampling Arrangement	Inlet: Automatic sampler Outlet: Half-pipe collection system	Inlet: Automatic sampler Outlet: Automatic sampler		Inlet: Automatic sampler Outlet: Half-pipe collection system		
Pre-Filtering	Litter basket and precast sump pits	Litter baskets, screen and sump (surcharge) pits	Litter baskets	Litter baskets and a filter pit	Litter baskets	CDS units
Receiving Location of Treated Stormwater	Discharge to Ku-ring-gai Chase National Park	Stormwater re-use for park irrigation Kiama Harbour	Union Creek	Tomago Sand Beds (drinking water aquifer)	Local creek	Duck River

*subject of research by the ARC Linkage project

USE OF EXFILTRATION STSs

When compared with other WSUD systems, for example wetlands, Exfiltration STS take much less land space. This releases more land and can provide a greater yield for the developer.

There two reasons why the Exfiltration systems take up less space:

1. They provide advanced pre-filtration of sediment which enables clogging factors to be reduced, which in turn enables the size of the device to be reduced.
2. If contact time and exposure to a pollutant reducing bacteria (such as *Nitrosomonas* for example, which is known to transform Nitrogen) drives good water quality outcomes, then filtration through a fine media will maximise the contact surface area available. Generally the finer the media the greater the contact surface. In contrast, for a constructed wetland the contact surface area is only in the water column and may only occur on the stems of reeds. Yet a delicate balance needs to be achieved between maximising contact time (which reduces the treatable flow rate) and maximising the treatable flow rate (which reduces the contact time). In essence, a good design is one which will maximise the amount of pollutant retention achieved by the filter. This process can be more easily controlled in an Exfiltration STS than within a constructed wetland. The vertical flow process that occurs in an Exfiltration system is one which is analogous to a "plug flow" model (often used as the basis of wetland design) and it is suggested that this aids in achieving better design control and smaller, more effective designs.

Exfiltration STSs are largely (but not entirely) subsurface, however, the land above can keep its amenity value and be utilised for other purposes, such as provision of parklands. The system can be easily combined and blended with the urban fabric.

Other WSUD components such as bioretention systems utilise vegetation as part of the treatment process and are influenced by the permeability of the surface of the system. It is therefore important that the surface landscape and surface permeability are maintained accordingly. For vegetated Exfiltration STSs (such as the Kiama system), similar maintenance regimes may be required. Such systems function both as an exfiltration device and also as a bioretention device.

On detailed examination of the Kiama sand filter after two years of operation, the rooting depth of the grass was found to be close to 1 metre. A feature of the Kiama filter media was that it used river sand from the Shoalhaven River. Despite its alluvial origin it was likely to be relatively nutrient poor (typical of coarse sand) and this encouraged the grass above to root deeply into the media in search of both water and nutrients. Bioretention media is often specified to be a loamy organic material which will easily support plant life. On the other hand, it is suggested that stressing the vegetation by depriving it of water and nutrients (between storm events) will maximise rooting depth. This in turn maximises the penetration of flow pathways down into the media, which in turn helps keep open the infiltration pathways through the filter media.

Not all Exfiltration STSs have surface storage. However, the ones that do will obviously function with two distinct regimes – one below the surface which is described as exfiltration and one above the surface with vertical flow down through the filter media. Described as bioretention this operates once the exfiltration capacity of the pipe has been exceeded.

Even exfiltration systems with surface storage will rarely surcharge because the majority of flow is delivered into the media via underground pipe systems. This causes the surface vegetation to have a greater rooting depth as the vegetation searches for water below the ground.

The Exfiltration system does have limits to its application. It is not suited to areas where the groundwater is high and where subsurface storage is therefore limited. It is recommended that at least 1m separation to the groundwater table needs to be present for infiltration to be effective and also to enable wetting and drying of the filter media to occur – this in turn permits both anaerobic and aerobic conditions to develop which can assist with nitrogen removal.

Exfiltration STSs do require a hydraulic gradient to drive the flow and there is a head loss across the system. Because of this requirement, wetlands may be preferable in very flat landscapes.

Pre-filtration is absolutely critical to the success of Exfiltration STSs. Lessons learnt here include the need for more sophisticated gross pollutant traps. The litter baskets used in this study were generally inadequate. This statement does not imply that litter baskets are not effective. However, where exceptionally good pre-filtering is required to prevent clogging, the performance of more sophisticated devices such as cyclonic or vortex separating units is preferred. The reason being they offer a fail-safe mechanism that prevents flow from reaching the device if the unit is blocked. The performance of litter baskets is very much contingent on being able to capture sediment and debris from every pit in the catchment. Generally litter baskets are better suited to installations where protection of a sensitive downstream stormwater treatment device is not required.

It is important during the construction of an Exfiltration STSs that appropriate sediment controls are implemented until the system is completely stable. A better approach yet may be to construct the STSs device sometime after the development construction is substantially complete and with vegetation established and soils stable. Alternatively one may accept that the device will be inundated with high sediment loads during construction and to factor in the need for maintenance sooner than would otherwise be required. These are factors that need to be considered when installing WSUD systems in general.

SYSTEM PERFORMANCE

A rigorous stormwater sampling and testing program was implemented at the three study STSs (Kiama, Asquith and Heatherbrae) investigated as part of the ARC Linkage Project. Stormwater samples were collected from the inlet and outlet of each system over a three year period. More specific details about the sampling program, including the sampling protocol, are presented in Dunphy et al. (2005a; 2005b).

The results obtained from the collection of stormwater samples from the inlet and outlet of the system at Kiama are presented in Figure 3. 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.

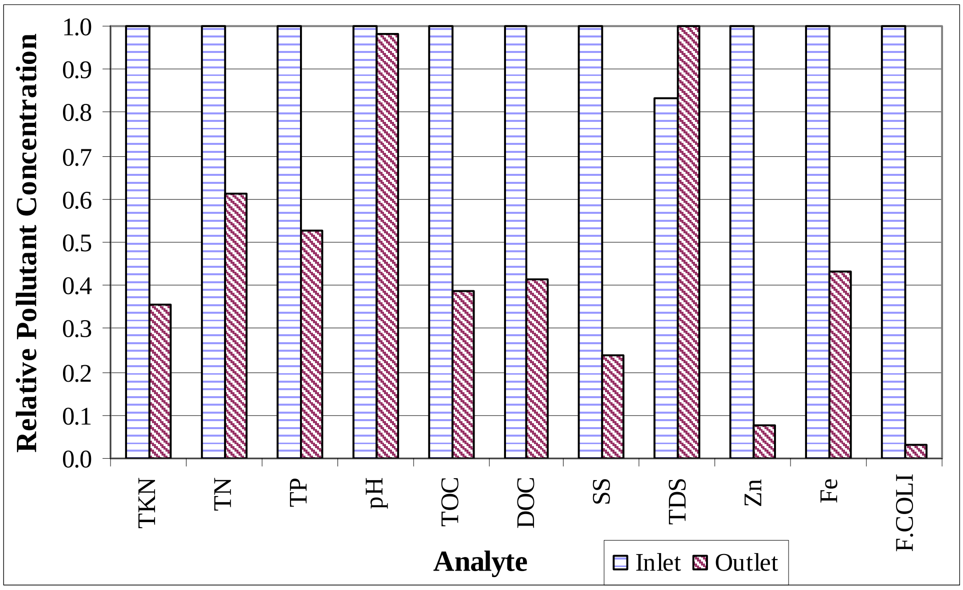

Figure 3. Hindmarsh Park, Kiama – Water Quality Results (Dunphy, 2005b)

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

Overall the three study systems (Kiama, Asquith and Weathertex) are performing well. These systems, however, could be modified to optimise performance. Some of the key findings of the research include:

- Associated with a filtration system is a longer stormwater residence time, and therefore there is greater opportunity for pollutant removal because of the increased contact time.
- The concrete (of the porous concrete pipe) neutralises stormwater acidity.
- Iron oxides are recognised for their ability to remove heavy metals from stormwater, due to the process of chemical precipitation. It was found that there was a significantly greater reduction in the average zinc and copper concentrations, and significantly smaller average outlet zinc and copper concentrations, associated with the Asquith system where iron oxides were present in the porous pipe.
- It was discovered that there was an increase in the average iron concentration and this was identified as being potentially due to the leaching of iron from the iron oxide injected pipes. Comparisons with water quality guidelines indicate that even though there is an increase, the resulting values are still within the recommended guidelines.

- The filtration media should be chosen based on the pollutants of primary concern and therefore on the pollutant removal ability of the media. The residence time of stormwater within the system should also be considered when choosing the media (due to the amount of pore space) as typically the longer the residence time, the greater the level of treatment provided by the system.
- The system effectively removes sediment and colloidal matter from stormwater, due to the process of sedimentation within the pits and porous concrete pipe, and as a result of the process of mechanical filtration as stormwater exfiltrates through the walls of the pipe.

When designing an Exfiltration STS consideration of the abovementioned findings will help to optimise the performance of the system.

MAINTENANCE

To optimise the performance of the system and to prolong its life it is imperative that a series of pre-filtering devices be positioned at the most upstream end of the system and within the drainage catchment. These devices must be regularly maintained.

The sediment and pollutants that build up in the pits and on the invert of the porous concrete pipe are removed from the system by back flushing and extracting the material from an upstream pit (flush and educt). Photographs of the cleaning of the Heatherbrae system, and of the porous concrete pipe before and after cleaning are shown in Figures 4 and 5 respectively. The ARC Linkage study found that system cleaning is required on a yearly basis though cleaning of Kiama has taken place every two years without any apparent loss of performance. Clearly cleaning frequency will depend on the loading rate of the treatment system.

Figure 4. Cleaning of the Heatherbrae System

Figure 5. Porous Concrete Pipe – Before (Left) and After (Right) Cleaning

The majority of gross pollutants captured within the pre-filtering devices of the Kiama and Asquith systems were leaf matter. It is worth noting that at Kiama there were also litter baskets installed in almost every pit upstream and the leaf litter shown Figure 6 (right) has either bypassed the litter baskets or entered the system from a pit that does not have a litter basket. A selection of low leaf yield street trees would help to reduce the maintenance burden on treatment systems. However, such an approach may not be fully consistent with the principles of water sensitive urban design. The screen shown in the right of Figure 6 was placed as a final gross pollutant barrier and it is clearly required. As noted above, one of the key lessons learnt here would be to use a more sophisticated GPT device such as a cyclonic or vortex separating unit upstream of Exfiltration systems.

Figure 6. Leaf Accumulation in Pre-Filtering Devices (Left: Asquith; Right: Kiama)

CONCLUSIONS AND RECOMMENDATIONS

Exfiltration STSs may be designed in various shapes and sizes. The most economical shape is one that maximises surface storage and minimises the filter area. Linear devices are less economically efficient. Nevertheless, they are useful where space is at a premium - typically on new developments.

Exfiltration STSs can achieve excellent water quality performance. The performance of the Kiama CBD system shown in this paper is, however, not a representation of the full treatment train effectiveness in place at Kiama as it only measures performance of the sand filter itself and not the effect of the litter baskets. If the contribution of the upstream litter baskets was included in the assessment of pollutant reduction the actual performance would be higher. In particular the retention of suspended solids, attached heavy metals and total phosphorus is likely to be greater than that shown in Figure 3.

The exfiltration STSs can be readily adapted to most sites – designs are easy to replicate and construction is relatively straightforward. High groundwater tables and very flat sites may preclude the use of the Exfiltration STSs, yet clay soils and an inability to infiltrate water will not generally affect their application.

The ability of the Exfiltration STSs to be confined and to trap the treated stormwater makes them highly suitable for stormwater harvesting projects and at least two new major projects are now under construction or complete. Compliance with the NSW Department of Environment & Climate Change guidelines for water reuse requires that the treated stormwater is to have a turbidity of no greater than 2 NTU so that UV disinfection can be effective. It is highly unlikely that stormwater treated only with a pre-filtering device would achieve this criterion. However, a good pre-filtering system combined with the use of Exfiltration STSs is a reliable way of achieving compliance with the guideline. Exfiltration STSs alone will not provide reuse quality water (despite a log reduction in pathogens). Then again, once disinfected with a UV system, the resultant water should comply with Australian guidelines for the reuse of water for non-potable purposes.

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