

# **Development of a Confined Water Sensitive Urban Design (WSUD) System Using Engineered Soils**

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## **ABSTRACT**

Innovative Water Sensitive Urban Design (WSUD) systems are being investigated at three locations to the north and south of Sydney, Australia. These systems contain porous concrete pipes that are designed so that stormwater exfiltrates through the permeable walls of the pipes into the surrounding substrate media material. The porous pipes and media material treat the passing stormwater. The primary aim of the overall project is to develop a model to describe the treatment effectiveness of confined WSUD systems.

This paper focuses on the system located at the Weathertex Industrial Site, Heatherbrae. Due to wood processing operations that occur at this site, it is recognised that the surface runoff will carry a heavy organics loading. Granulated Activated Carbon (GAC) is recognised for its ability to reduce the concentration of dissolved organics present in both wastewater and stormwater. GAC was therefore chosen as a filtration media to be investigated at this site.

To maximise the effectiveness of the GAC, extensive laboratory batch studies were undertaken prior to the field system being constructed to determine the optimum GAC/sand ratio. The purpose of the experimental work was to assess the dissolved organic removal potential through sorption of various concentrations of GAC. The aim of this paper is to describe these laboratory experiments and discuss how they related to the field system. Through these experiments it was determined that a sand/GAC ratio of 25:1 was ideal for the media material at the Heatherbrae site.

## **KEYWORDS**

granulated activated carbon (GAC), infiltration, porous pipes, stormwater pollution, stormwater reuse, water sensitive urban design (WSUD)

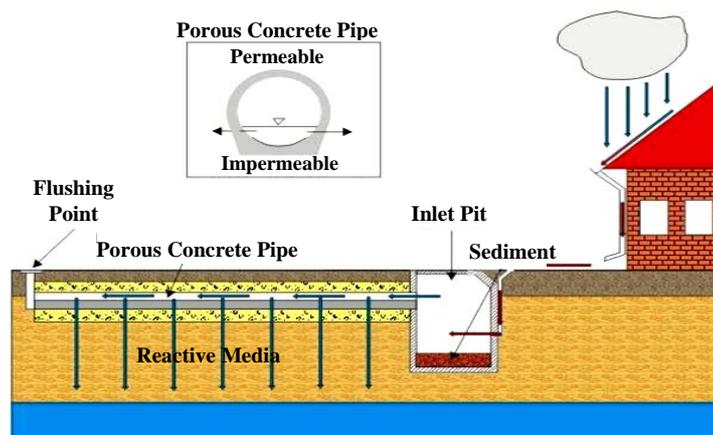
## INTRODUCTION

In Australia, it is widely recognised that water is a scarce resource. Therefore the conservation and re-use of stormwater runoff is important to supplement the municipal water supply. The quality of the runoff is also important to ensure that it can be re-used, or discharged to a location where it will not have negative impacts.

In this study, three innovative Water Sensitive Urban Design (WSUD) systems are investigated. The systems are located at Mills Park Tennis Centre, Asquith, which services a high-use car park, Hindmarsh Park, Kiama, which services commercial, residential areas and a small recreational park, and the Weathertex Industrial Site, Heatherbrae, which services an industrial area.

These systems are confined stormwater filtration/infiltration systems that are positioned underground and are designed to minimise the impacts of stormwater runoff on the surrounding soils, vegetation and groundwater systems. The term confined refers to the retention of all pollutants within the media surrounding the system. This is achieved either by lining the system with an impermeable membrane or by using reactive (or engineered) soils containing amelioratives such as granulated activated carbon (GAC), perlite or zeolite (Beecham et al., 2004).

A diagram of the treatment system is presented in Figure 1. The porous concrete pipes, supplied by HydroCon Australasia, are designed such that stormwater exfiltrates through the permeable walls of the pipe and filters through the surrounding substrate media material.



**Figure 1.** Diagram of the Porous Pipe Treatment System

One of the systems being investigated is located approximately two hundred kilometres north of the city of Sydney, at the Weathertex Industrial Site, Heatherbrae. Wood processing is the primary activity that occurs at this site and therefore it is recognised that the surface runoff will carry a heavy organics loading. GAC is recognised for its ability to reduce the concentration of dissolved organics present in both wastewater and stormwater (Chaudhary et al., 2003). Therefore one of the filtration media being investigated at this site is native sand, mixed with a proportion of GAC.

To determine the amount of GAC that should be used in the field system and to maximise the effectiveness of the GAC, extensive laboratory studies were undertaken. The primary aim of the laboratory work was to determine an optimum GAC/sand ratio that should be used in the system. The dissolved organic carbon removal potential through sorption of various concentrations of GAC were investigated and assessed during the experimental work. The goal of this paper is to describe these laboratory experiments and discuss how they relate to the field system.

It is expected that this paper will be a useful information source for consultant engineers and council officers 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. It will also be helpful to researchers who are investigating pollutant retention in modified soil systems.

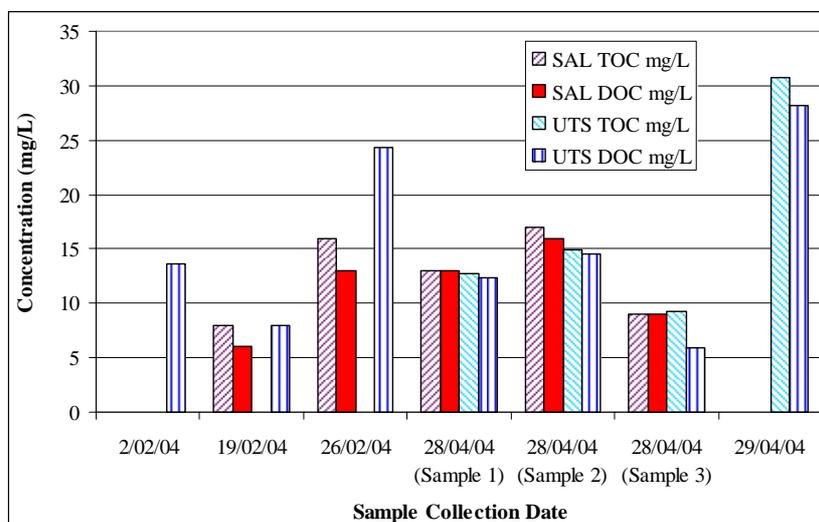
## METHODS

Laboratory batch studies were carried out to gain an appreciation of the percentage dissolved organic carbon (DOC) reduction that could be expected using different quantities of GAC.

### Synthetic Stormwater

Synthetic stormwater was utilised during all stages of the experimental work in accordance with the work of Davis et al. (2003). Particulate pollutants were not considered during the laboratory studies, the focus was on dissolved pollutants. This is not a major concern, as in a real life system the majority of the particulates present in the runoff will be removed by prefiltration and sedimentation processes prior to the stormwater coming in contact with the filtration media. These processes occur in inlet pits and in the porous concrete pipe.

The concentration of DOC found in actual stormwater that was collected from the Weathertext site was used to assist with the development of a synthetic stormwater solution. Numerous samples were collected and sent for analysis at Sydney Analytical Laboratories (SAL) and the University of Technology Sydney (UTS) Public Health Laboratory. The samples were analysed for Total Organic Carbon (TOC) and DOC. The results from this analysis are presented in Figure 2.



**Figure 2.** Weathertext Industrial Site - TOC and DOC Concentrations

The results indicate that the organics present within the stormwater at the site are primarily dissolved. The concentration of DOC ranges from approximately 5mg/L to 30mg/L, with an average value of approximately 15mg/L. This is the concentration used for the DOC in the synthetic solution. For DOC, humic acid was used in the synthetic stormwater solution.

The values for the other constituents are based on a synthetic stormwater developed by Davis et al. (2003). The composition of the synthetic stormwater used for the laboratory work is presented in Table 1.

**Table 1.** Synthetic Stormwater Composition

Synthetic Stormwater Constituents	Concentration or Value	Chemical
Total Phosphorus (TP)	0.6 mg/L	Dibasic Sodium Phosphate (Na <sub>2</sub> HPO <sub>4</sub> )
Organic Nitrogen (Org-N)	4 mg/L	Glycine (NH <sub>2</sub> CH <sub>2</sub> COOH)
Nitrate	2 mg/L	Sodium Nitrate (NaNO <sub>3</sub> )
Copper (Cu)	0.08 mg/L	Cupric Sulfate (CuSO <sub>4</sub> )
Lead (Pb)	0.08 mg/L	Lead Chloride (PbCl <sub>2</sub> )
Zinc (Zn)	0.6 mg/L	Zinc Chloride (ZnCl <sub>2</sub> )
Dissolved Organic Carbon (DOC)	15 mg/L	Humic Acid
pH	7	Sodium Hydroxide (NaOH)

### Filtration Media

Granulated Activated Carbon (GAC) sourced from James Cummings & Sons Pty Ltd was used during the laboratory studies. The main characteristics of the GAC are presented in Table 2. Prior to the use of GAC in the laboratory work, it was washed three times with distilled water and then oven dried at 103.5 degrees Celsius for 24 hours. It was then kept in a desiccator before being used in the experiment.

**Table 2.** GAC Specifications

Specification	Value
Nominal size	12 x 40 Mesh
Finer than 40 Mesh (0.42mm)	4% max
Coarser than 12 Mesh (1.7mm)	5% max
Iodine number (mg/g min)	1000
Hardness (%)	80-85
Moisture content (%)	2% max
Bulk density (kg/m <sup>3</sup> )	280-320
Type	Coal based

### Experimental Procedure

All samples were filtered using 0.45µm nylon filters prior to testing. Preservatives were added to the samples and all samples were refrigerated to increase the allowable storage time prior to analysis of the samples. The UTS Public Health Laboratory UV Persulfate TOC Analyser was used for sample testing. It is important to note that sample blanks were used to test the stability of the synthetic stormwater and testing was undertaken in duplicate for quality control. Three sets of batch tests were undertaken.

*Batch Test One.* 200mL of synthetic stormwater solution was combined with different amounts of GAC in conical flasks. These quantities were 0.1g/L, 0.5g/L, 1g/L, 2g/L and 5g/L. The flasks were placed on a shaker table for a period of 24 hours. Following the 24 hours of shaking, the concentration of DOC in each flask was measured.

*Batch Test Two.* Two GAC quantities were then selected for further experimentation. These quantities were 0.5g/L and 2g/L. The synthetic stormwater solution was combined with the GAC in conical flasks. The flasks were again placed on the shaker table. During this batch test the concentration of DOC was measured at different times during the total 24 hour period.

*Batch Test Three.* A batch experiment was also undertaken using an initial DOC concentration of approximately half that of the average concentration. This was undertaken to ensure that different initial DOC concentrations were accounted for. Two GAC quantities were also investigated during this experiment. These were 0.5g/L and 2g/L. The shaker table was again used and the flasks were placed on the table for 8 hours.

## RESULTS AND DISCUSSION

### Batch Test One

The results from the first batch test are presented in Figure 3. The amount of GAC investigated is shown on the x-axis and the DOC concentration following the 24 hours of shaking is presented on the y-axis. The initial DOC concentration was 15.75mg/L. The results indicate that a larger quantity of GAC results in a greater reduction in DOC concentration, as expected.

### Batch Test Two

The results from the second batch test are presented in Figure 4. The amount of GAC sorbed per gram of GAC with respect to time is presented. The initial DOC concentration was 25mg/L. As expected the higher quantity of GAC results in a greater reduction in the DOC concentration. The results also indicate that with increasing time the concentration of DOC reduces. From Figure 4, it is possible that the 24 hour data point for 0.5g GAC/L is spurious and this has been taken into account in the analysis.

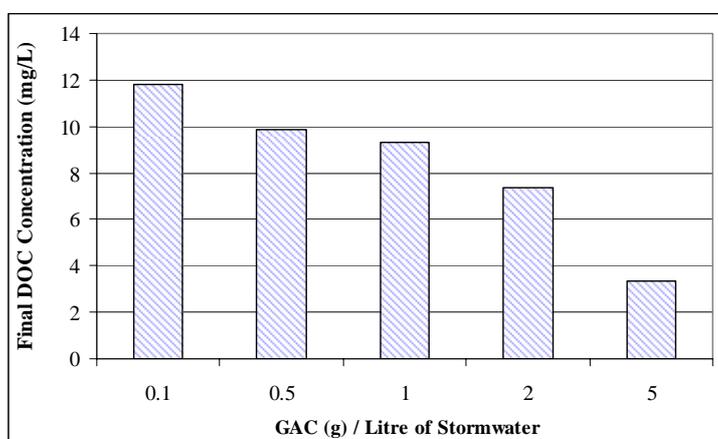


Figure 3. Batch Test One – DOC Concentration after 24 Hours (at time  $t = 0$ , DOC = 15.75 mg/L)

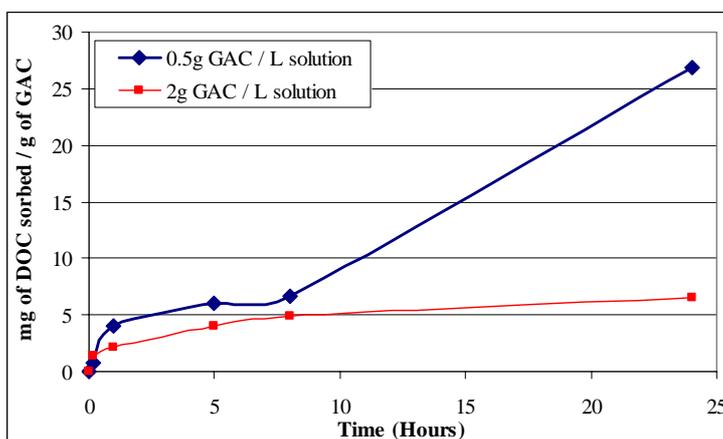
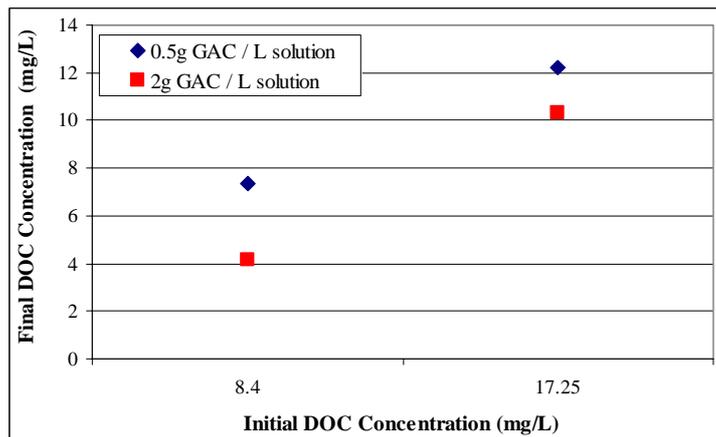


Figure 4. Batch Test Two – Amount of DOC Adsorbed per Unit Mass of GAC

### Batch Test Three

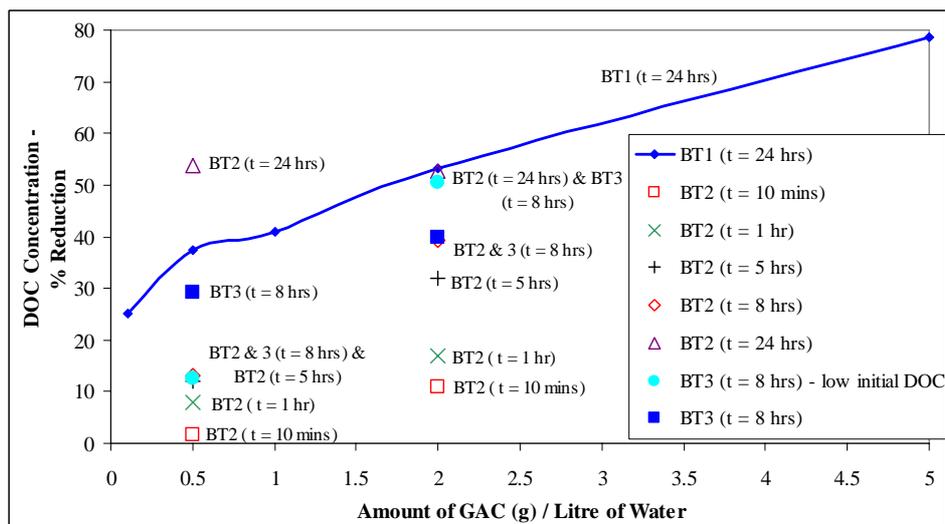
The results from the third batch test are presented in Figure 5. The x-axis indicates the initial DOC concentration of the stormwater solution and the y-axis indicates the final concentration following eight hours of shaking. The 17.25mg/L initial DOC concentration is approximately the average DOC concentration at the site. A concentration of 8.4mg/L was also investigated and this represents the concentration that is approximately half of the average. The results indicate that a higher quantity of GAC results in a greater DOC reduction.



**Figure 5.** Batch Test Three – Initial DOC Variation – DOC Concentration after 8 Hours

### Analysis of Results

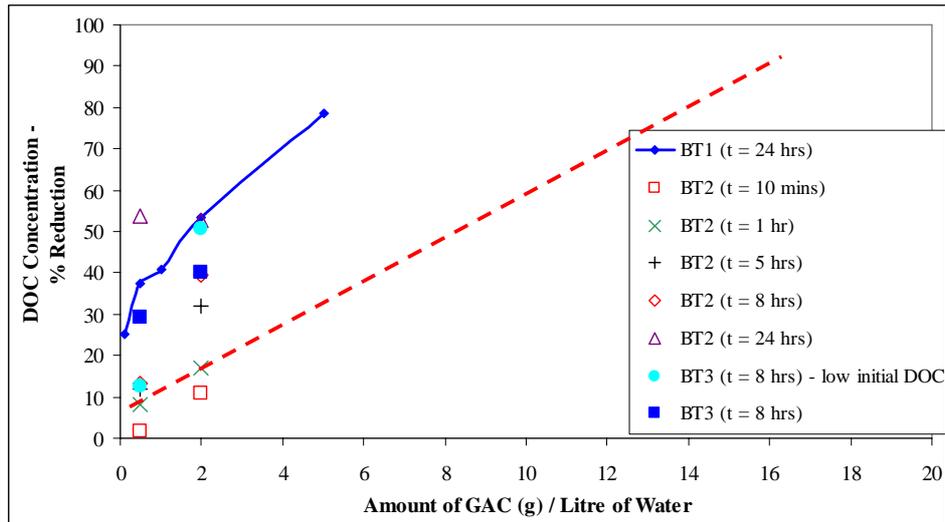
The results obtained from the three batch studies have been combined and summarised graphically in Figure 6. This figure indicates the influence of residence time on the percentage reduction of DOC. The results indicate that the greater the residence time, the greater the DOC percentage reduction. The results also show that with increasing amounts of GAC, i.e. Amount of GAC / Litre of water, there is also an increase in the amount of DOC that is removed.



**Figure 6.** DOC Concentration Reduction with Varying GAC Quantity (BT denotes Batch Test)

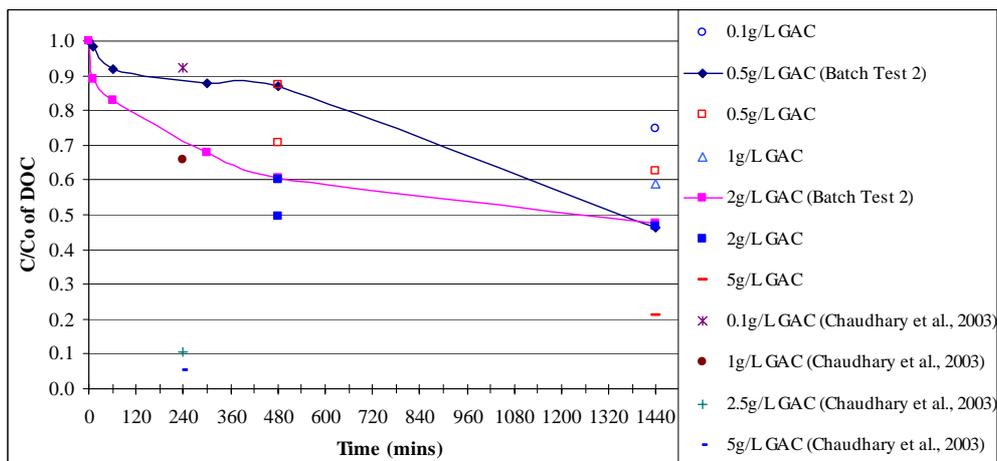
Based on investigations of the field systems at Asquith and Kiama, it has been identified that stormwater moves rapidly through these systems. This residence time has been observed as being typically less than one hour (Matuzic et al., 2001). If it is assumed that the relationship between the DOC percentage reduction and the amount of GAC / Litre of water is approximately linear, then the dashed line shown in Figure 7 would resemble the approximate relationship that exists if the residence time is one hour.

*Initial DOC Concentration Variations.* As indicated by the results, the initial synthetic solution DOC concentration for the three batch tests varied. It was intended that the concentration would be 15mg/L. This variation is due to difficulties with getting the humic acid to dissolve to the same DOC concentration each time.



**Figure 7.** DOC Concentration Reduction with Varying GAC Quantity

A comparison between the values obtained in this study and those obtained by Chaudhary et al. (2003) has been undertaken and is presented in Figure 8. The ratio between the DOC concentration and the initial DOC concentration is presented as a function of time. Only some of the values presented by Chaudhary et al. (2003) have been used. The comparison indicates that the results are of a similar nature. Note that for the values obtained in this study only the values obtained in Batch Test 2 have been labelled.



**Figure 8.** Ratio between DOC and Initial DOC Concentration (C/Co) with Respect to Time

The study by Chaudhary et al. (2003) involved the study of wastewater and GAC, to establish a relationship between DOC concentrations and GAC amounts required for wastewater treatment. Chaudhary et al. (2003) had an initial TOC value of 3.5mg/L. In this study the DOC concentrations ranged from 15mg/L to 25mg/L. The composition of the wastewater that was used is comparable with this study in terms of nutrient concentrations.

### Field System Design

The primary aim of the laboratory work was to determine the quantity of GAC to be used in the system at the Weathertex site. This was achieved by looking at the treatment efficiencies associated with different GAC to stormwater ratios for a one hour residence time, as found during the laboratory work and indicated in Figure 7, and correlating the findings with the field system.

The total volume of filtration media to be used in the field system was specified by the system designers. The question to be resolved was the proportion of GAC and sand that should comprise

this total volume. Different sand/GAC ratios were investigated ranging from 0% to 100%. It was assumed that the sand would provide negligible dissolved organics treatment of the stormwater. For each GAC/sand ratio the actual mass of GAC was determined together with the total quantity of stormwater that could fill the available pore space. A ratio was formulated between the parameters (kg of GAC / L of stormwater) and to each ratio a treatment efficiency was assigned based on the laboratory findings. The cost of the GAC required was also determined.

A cost benefit analysis of the different GAC proportions, led to a mix comprising 4% GAC and 96% sand to be chosen. The system has been installed at the Weathertex site with this GAC and sand mix. These materials were thoroughly mixed prior to their placement in the system. From the laboratory results, it is anticipated that the DOC concentration will be reduced by up to 91%. This is based on the assumption that the stormwater travels uniformly through the sand and GAC mixture.

It is important to remember that with time the system will begin to clog (or saturate) and as a result the treatment efficiency of the system will be reduced. It may be necessary to replace the GAC to ensure that the system is operating effectively. To quantify this degradation, further laboratory experiments are being undertaken and these are being supported by appropriate field investigations. The presence of biological activity will also increase with time and this will further aid with the treatment of the stormwater that enters the system.

## CONCLUSIONS

This paper has provided design information for WSUD treatment systems in areas where there are particularly sensitive soil and/or groundwater conditions. By using reactive soils it has been shown that dissolved organics can be readily removed from stormwater.

The laboratory results described in this paper were used for the design of the WSUD system at the Weathertex Industrial Site, where a 25:1 sand/GAC ratio was adopted. The results obtained from the initial experimental work, along with field findings and future experimental results, will be used to assess the WSUD systems under investigation. This will aid with the overall project aim of developing a model of a confined WSUD system.

## REFERENCES

American Society for Testing and Materials (ASTM), (2003), D 5285: Standard Test Method for 24-Hour Batch-Type Measurement of Volatile Organic Sorption by Soils and Sediments

Beecham, S., Hourigan, P., Wells, J. and Brisbin, S., (2004), *Estimating the Treatment Performance and OSD Characteristics of Both Proprietary and Non-Proprietary WSUD Systems at Castle Hill in Sydney*, 3rd International Conference on Water Sensitive Urban Design, Adelaide, South Australia

Chaudhary, D.S., Vigneswaran, S., Ngo, H.H., Kim, S.H. and Moon, H., (2003), *Comparison of Association Theory and Freundlich Isotherm for Describing Granular Activated Carbon Adsorption of Secondary Sewage Effluent*, Journal of Environmental Engineering and Science, Vol 2, Number 2, pp 111-118

Davis, A.P., Shokouhian, M., Sharma, H., Minami, C. and Winogradoff, D., (2003), *Water Quality Improvement through Bioretention: Lead, Copper and Zinc Removal*, Water Environment Research, ProQuest Science Journals, Vol 75, Number 1, pp 73-82

Matuzic, J., Blasi, A., O'Loughlin, G., Beecham, S., and Myl, S., (2001), *Stormwater Infiltration Experiments on a Sandy Area in Eastern Australia*, Novatech 2001, 4th International Conference on Innovative Technologies in Urban Storm Drainage, Lyon