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WATER STORED WITHIN PERMEABLE PAVING AND THE EFFECT OF GROUND SOURCE HEAT PUMP APPLICATIONS ON WATER QUALITY

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Note: The following is the notation used in this paper: (.) for decimals and (   ) for thousands.

Summary

Collaborative research into the effect of ground source heat pump coils on water quality has been pursued during the last four years. The use of permeable pavement systems with integrated ground source heat pumps for the treatment and recycling of urban runoff is novel and timely due to increase interest in sustainability.

This study assesses the efficiency of the combined technology in controlled indoor and uncontrolled outdoor experimental rigs comprising six simulated pavement systems of which some receive diluted gully pot liquor spiked with dog droppings. The heating and cooling modes of a ground source heat pump when regulating a building's temperature have a profound effect on the water temperature within the sub-base region of Aquaflow permeable paving. The research described here has shown that despite an increase in pavement water temperature of up to 25°C, when the paving is used as a heat sink to cool a building, the differences between most water quality variables in heating and cooling modes are relatively small.

The importance of the geotextile layer in regulating water quality and the 'polishing' of stored water whilst retained in the sub-base was assessed. Mean removal rates of 99% for biochemical oxygen demand, 95% for ammonia-nitrogen and 96% for orthophosphate-phosphates were recorded. The microbiological water quality is also good despite an expected increase in the growth of potentially pathogenic bacteria due to warmer water. The presence of *Legionella* bacteria was rare and correlated more closely with organic contaminants than with changes in stored water temperature. No long-term survival of *Salmonella* spp., *Escherichia coli*, faecal Streptococci and *Legionella* was noted. It is hoped that this work will remove some of the concerns about the quality of water stored within permeable paving systems and show that innovative heating solutions do not necessarily lead to a decrease in water quality within permeable pavements.

1. INTRODUCTION

Over the past decade there has been growing concern over the presence of contaminants in urban runoff. Significant advancements in Sustainable Drainage (SUDS) technology such as permeable pavements, enables engineers, scientists and researchers to identify a range of contaminants in the environment and to detect these at lower levels than before. The management of runoff in urban areas has taken a 'green' approach due to the emergence of SUDS, which collect, store, treat, redistribute and/or recycle water. Permeable pavement systems (PPS) are suitable for a wide variety of residential, commercial and industrial applications (e.g., see Figure 1) and are designed for light duty and infrequent usage, even though the capabilities of these systems allow for a much wider range of uses [Grabowiecki *et al.*, 2006]. Where there is any concern about the possible migration of pollutants into the groundwater, PPS should be constructed with an impermeable membrane to surround the excavated area, and the treated storm water should subsequently be discharged into a suitable drainage system [Wilson *et al*. 2003].

Sustainable drainage systems such as PPS have evolved as a result of growing recognition that traditional storm water management systems have limitations where growing rates and volumes of storm water runoff are observed, mainly caused by increased urbanization and changing weather patterns [Dierkes *et al*. 2002; Schlüter and Jefferies 2004]. Permeable pavement systems have not only been established as a SUDS solution, but also as a technology for pollutant control concerning surface runoff from areas used as roads or parking spaces, where contaminated water may infiltrate into the soil. Harmful pollutants such as hydrocarbons and heavy metals in surface runoff have the potential to endanger soil and groundwater resources when they are not sufficiently biodegraded and/or removed during infiltration [Dierkes *et al.*, 2002; Brattebo and Booth, 2003; Coupe, *et al.*, 2008].

Figure 1. Bristol Business Park, Stoke Gifford putting into practice Permeable paving, swales, and wetland ponds (Varying SUDS Techniques). Cabe 2009 accessed online - (www.cabe.org.uk/.../bristol-business-park.).

Ground source heat pumps (GSHP) and PPS are both commercially available applications, but never used as a combined system in research [Coupe, *et al.*, 2009]. This sustainable hybrid system has the potential to capture, detain, and treat runoff and to take simultaneously energy from the water or from the soil, to provide cooling, heating and hot water for buildings nearby [Tota-Maharaj, K. *et al.*, 2009]. The GSHP consists of a few simple components: a compressor, a source of heat, a condenser and a pressure reducer. The refrigerant circulating in the closed circuit uses free heat from the ground which is distributed by the condenser to the heating and hot water system at a high temperature [Scholz and Grabowiecki 2009; Grabowiecki *et al.,* 2008; Tota-Maharaj, K. *et al.,* 2009].

2. AIMS AND OBJECTIVES

This study aims to undertake a comprehensive investigation of the performance of a combined sustainable urban drainage system containing a Renewable Energy Device (GSHP). The corresponding objectives were to assess the water's physical, chemical and biological processes, and the overall treatment performance. The research main objectives are:

- Providing permeable paving and ground-source heat pumps (GSHP) design and construction for academic research purposes, allowing for reliable simulation of both systems.
- To assess the combined pavement and GSHP systems' performance and potential influence on each other.
- To describe relationships between water quality parameters e.g. between pH, TDS and conductivity providing information on processes and connections between individual parameters; their influence on each other and overall water quality.

3. METHODOLOGY

Experimental rigs were designed and set up in two locations. A set of indoor PPS consisted of six bins, placed in a temperature-controlled room with a mean ambient temperature of 15.5°C, whilst the outdoor rigs were submerged within the ground and located outside the local laboratory building in the King's Building Campus, University of Edinburgh, where atmospheric temperature conditions prevailed. The two rigs are operated under controlled and uncontrolled conditions (i.e. internal and external rigs). A simulated Ground source heating and cooling system was installed to achieve temperatures in a heating cycle and In-line coolers were set up to apply a decrease in temperatures within coils. The bins mimicked impermeable tanked systems and provided suitable conditions for water collection.

Gully pot liquor was used to introduce all possible pollutants available in urban runoff [Scholz and Graboweicki; 2007]. A gully pot is a biochemical reactor where pollutants are released after acidic dissolution and sediment maturation. Also various microbial degradation processes take place in the gully pot chamber [Morrison et al., 1995]. Gully pot liquor was mixed with de-chlorinated tap water and animal faeces to mimic urban runoff. Animal faeces can be used for simulating pathogenic organisms in urban runoff [Grabowiecki and Scholz, 2007]. Such mixtures provide the most extreme conditions which may occur in field conditions [Grabowiecki et al., 2008]. Because of their nature, animal faeces (e.g. dog droppings) can cause serious health concerns associated with PPS water (particularly if contaminated with faecal matter), which could potentially be distributed within buildings for toilet flushing and other applications as discussed previously [Grabowiecki and Scholz, 2007; Scholz and Grabowiecki, 2008].

Gully pot liquor (0.2 l) was mixed with de-chlorinated tap water (2.0 l). Approximately 3.1 g of dog faeces are subsequently added and mixed properly to obtain a homogenous mixture. Approximately 2.2 l of sample water was slowly collected approximately 100 mm from the bottom of each bin by a hand lever pump. The temperatures of the water samples were immediately recorded at this stage. Samples were then stored at a constant temperature (16°C) for no longer than 0.5 h before. The apparatus and methods of the present simulation enabled efficient and appropriate treatment of urban water runoff, so that the treated urban water runoff could be can be introduced into public waterways without contaminating such systems.

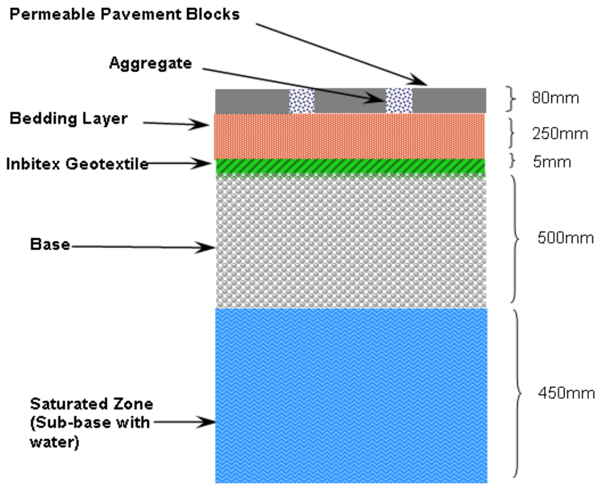

Figure 2. Indoor Experimental rigs and schematic layout of permeable (pervious) pavement systems with integrated ground-source heating and cooling elements.

4. WATER QUALITY ANALYSES

Composite water samples were collected from the systems as the infiltrated water passing through each of the pervious pavement systems. The analyses were generally carried out according to standard methods as described below. The five-day biological oxygen demand (BOD) was determined at 20ºC (N-Allylthiourea nitrification inhibitor) was determined. The amount of sample water used was usually 0.432 l for the outflows, and between 0.192 l and 0.250 l for the inflows. After 0.5 h of aeration with air pumps, a nutrient inhibitor was added to the sample, and bottles were incubated at a constant temperature of 20ºC for 5 days. After this time, relevant values were displayed electronically and recorded. Nutrients were determined by chemical methods outlined in [Clesceri et al., 1998]. Nitrate was reduced to nitrite by hydrazine in alkaline solution and determined at 550 nm by a colorimetric method using an AA3 flow injection analyzer [Bran and Luebbe, 1999] following ISO standard methods [Clesceri et al., 1998] Ortho-phosphate-phosphorus was determined using ammonium molybdate, ascorbic acid and sulfuric acid. Ammonium molybdate and 0.5 mol bicarbonate of soda were also used in the analyses performed by automated colorimetry with an AA3 colorimeter [Clesceri et al., 1998]. Ammonia coloured blue compounds were measured at the same using a autoanalyser [Bran and Luebbe, 1999]. American standard methods [Clesceri et al., 1998] were used for the examination of suspended solids, pH, conductivity and total dissolved solids. A Hanna HI 991 300 meter was applied for this examination. Dissolved oxygen was measured with a WTW Oxi 315i meter and the Redox 201 meter.

5. MICROBIOLOGICAL DETERMINATION

Nutrient Agar, which is a non-selective growth medium that allows for the growth of a wide variety of oxygen-tolerant genera and was used to culture and enumerate bacteria such as *Escherechia Coli*, one of the key water quality indicators. MacConkey Agar allows for the detection and isolation of *Salmonellae* and *Shigellae* species occurring frequently, for example, in pathological and food specimens. The Slanetz and Bartley Agar was designed to favour the growth of faecal *Enterococci* including *E. faecalis*, *E. faecium*, *E. avium*, *E. casseliflavus*, *E. cecorum*, *E. durans*, *E. gallinarum*, *E. hirae* and *E. malodoratus* [Tejedor, 2001]. *Legionella* GVPC agar is specially developed for the isolation of most *Legionella* species, notably those responsible for infections: *Legionella pneumo-*

phila, which is the species most frequently involved (Pontiac fever). This selective medium also enables the enumeration of *Legionella* in water according to standards T90-431 and International Standard, ISO 11731:1998(E) Water Quality - Detection & Enumeration of *Legionella*. [Leoni and Legnani 2001]. Petri plates and filter papers (MF 200 with diameter of 125 mm) and primers were also used. Total heterotrophic bacteria were determined by spread plate method (Cappuccino and Sherman, 1996). Nutrient Agar plates were incubated at 36°C ± 1°C for 2 d. *Enterococci* plates were kept at 45ºC for 5 d and The Legionella GVPC agar plates were incubated and inoculated in a moist chamber and incubated at 36°C ± 1°C for 10 days and examined at intervals between 1 or 2 days during the incubation period (Leoni and Legnani 2001).

6. RESULTS AND DISCUSSION

The BOD inflow concentrations strongly depended on the gully pot liquor characteristics. 82 mg/l and 106 mg/l were recorded for the inflow and the inflow spiked with dog excrements, respectively. The BOD reductions due to water treatment within the sub-base of the pavement were relatively high; i.e. between 60% and 90%, and between 75% and 100% for both the indoor and outdoor rig, respectively (see Figure 3). The presence of suspended solids contributes to turbid waters, which may be objectionable for aesthetic reasons. Moreover, suspended particles may interfere with disinfection processes. Solids provide shelter for microorganisms, thus inhibiting the ability of a disinfectant to destroy potentially pathogenic organisms. The mean SS removal rates were 70-100% and 70-90% for indoor and outdoor rigs respectively (see Figure 3), indicating how effective permeable pavements are in turbidity and suspended solids removal and efficacy.

The growth of heterotrophic bacteria was evaluated based by the determination of colony forming units on nutrient and specific media agar plates. Results showed that the heterotrophic bacterial count was higher in raw urban water samples when compared with treated water as shown in Figure 3. There was no recovery of Legionella spp, observed from the GVPC-agar. The samples were analysed for five months from October to February for Legionella. No growth of faecal Streptococci and very small numbers of E. coli were observed in samples collected for all twelve bins indicating that they do not survive or are completely removed via the permeable pavements and geotextile combination.

Water quality assessment was performed before the spiking of water into rigs and after the sample collection from each rig. The temperature of each sample from outside and inside rigs was noted immediately after collection. Results showed that the average temperature of samples varied from 13.7-14.9 ^{o}C in outside rigs and 16.4-17.2 ^{o}C in the inside rigs, while the average temperature of input samples (In+1 and In+Feces) varied between 17.3-17.6 ^{o}C, as shown in Figure 2. The temperature of the samples collected from inside was higher than the samples collected from outside rigs. Indoor bins were installed under a controlled temperature of 16 ^{o}C.

Outdoor bins were installed outside the lab and functioned at uncontrolled environmental conditions and external temperature. Temperature varied in samples collected from outdoor bins.

Similarly the pH of treated indoor water samples also varied from 7.15 to 7.33, while the pH of treated outdoor samples was 7.14 to 7.28. In the raw urban water samples, (In and In+Faeces) the average pH varied from 6.56 to 6.59. As a result the urban runoff water samples were slightly acidic and treated water samples were neutral.

Temperature and pH variations in each rig are given in Figure 1. The data showed that both the indoor and outdoor rigs improved the pH of water sample from acidic to neutral. The permeable pavements can buffer acidic rainfall, which may be a result of calcium carbonate and magnesium carbonate in the pavement and aggregate materials. This provides a significant buffering capacity as shown in Figure 2 with high input loads of urban runoff.

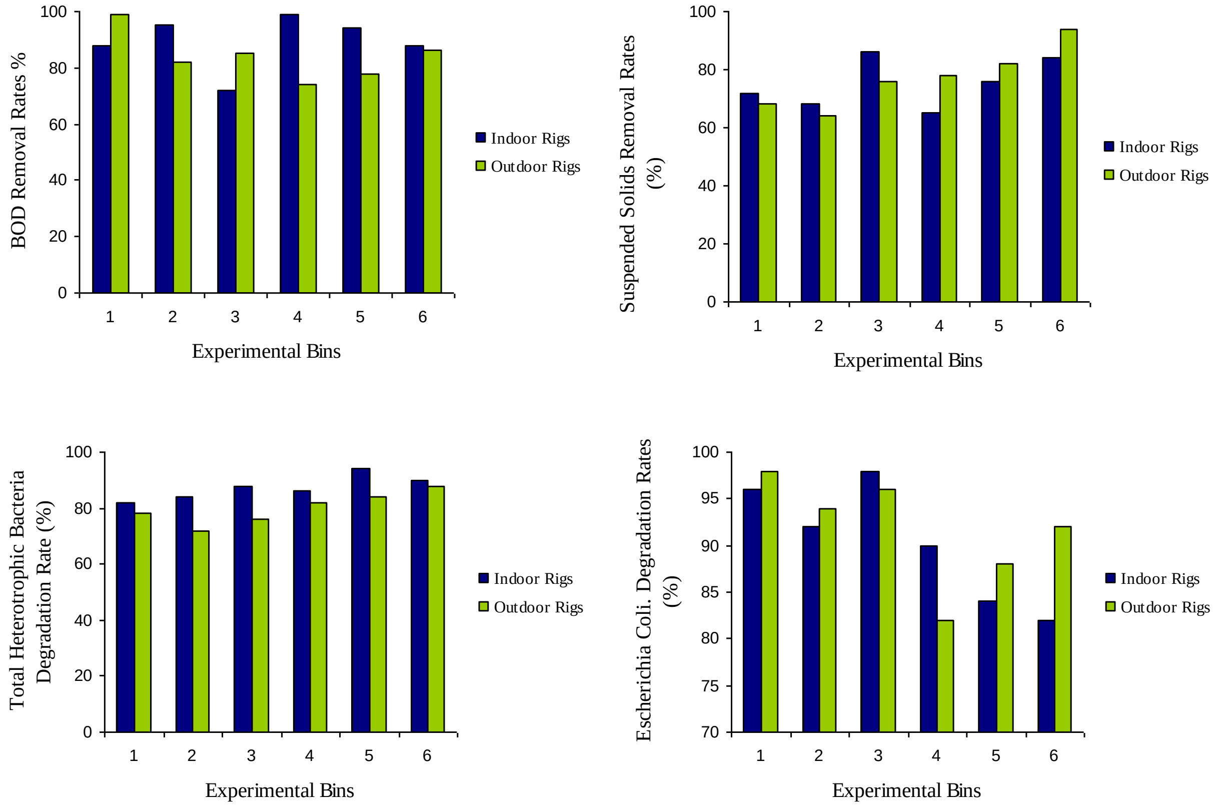

Figure 3. Mean Removal rates for BOD5, Suspended Solids, Total Heterotrophic Bacteria and E.Coli from June 2006 to March 2009.

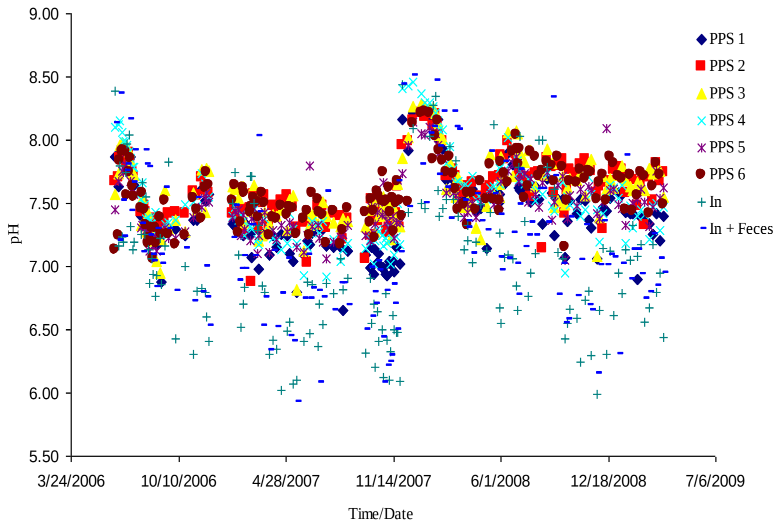

Figure 2A. Temperature and pH values from Inflows and pavement systems 1-6 for Indoor experimental setup June 2006 to March 2009.

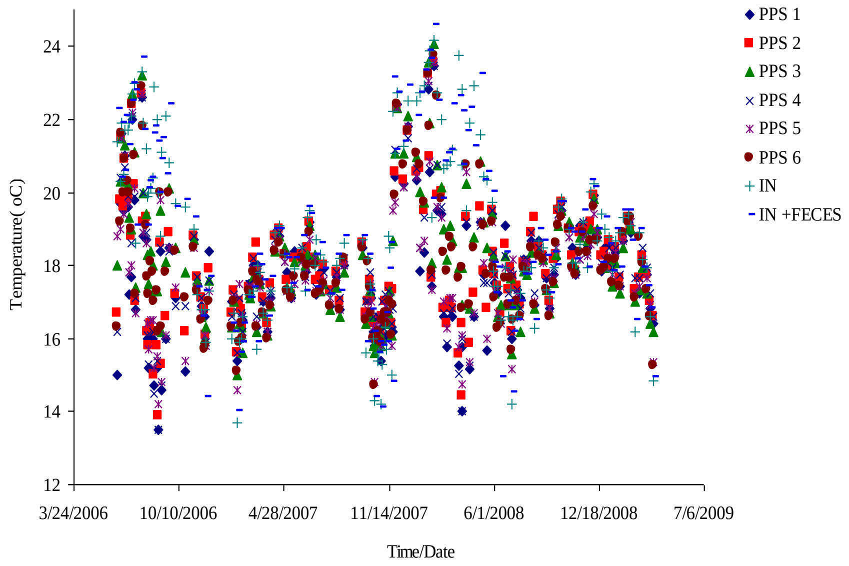

Figure 2B. Temperature and pH values from Inflows and pavement systems 1-6 for Indoor experimental setup June 2006 to March 2009.

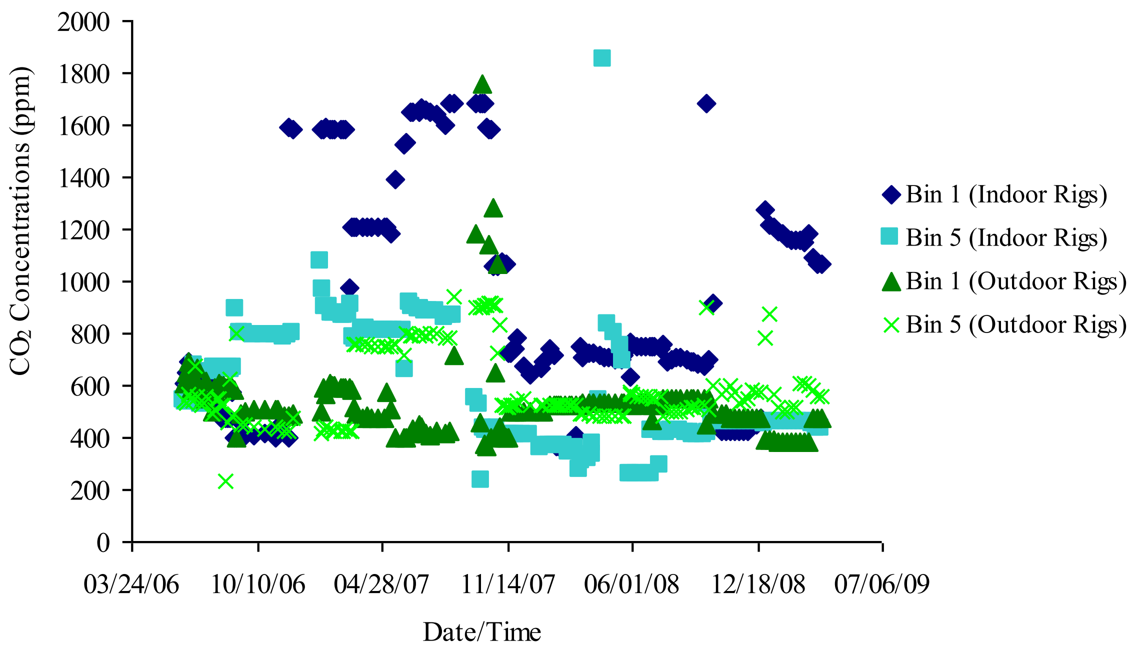

Figure 3. Average CO2 (ppm) measured for Bins 1 and 5, indoor and outdoor bins respectively, from June 2006 to March 2009.

In Figure 3, as a result of the high microbial activities in the bins, the systems as indicated by the CO_2 analysis shows the relation between high BOD removal efficacies within permeable pavements. In large scale PPS CO_2 levels mirrors the dissolved oxygen which is consumed by the microbes in the biodegradation process [Coupe 2004]. The bioactivity which is shown by CO_2 levels, with the maximum values of 2 000 ppm (air average approximately 400 ppm), which reflects the pollutant removal efficiency levels from 80% to 99% in PO4, NH4 which conquers the importance of geotextiles within the PPS.

Several studies have shown that under aerobic conditions, when the permeable pavement systems are drained this results in nitrification of ammonia-nitrogen (NH4-N) to nitrate-nitrogen (NO3-N). The graphs in Figure 3 appears that the ammonia-nitrogen and total phosphorus have been removed at high rates often attributed to adsorption from the gravel sub-base and trapped by the geotextile layer. This is an important finding, as it indicates that one type of pavement maybe preferable to other types with respect to the nutrient removal efficiencies.

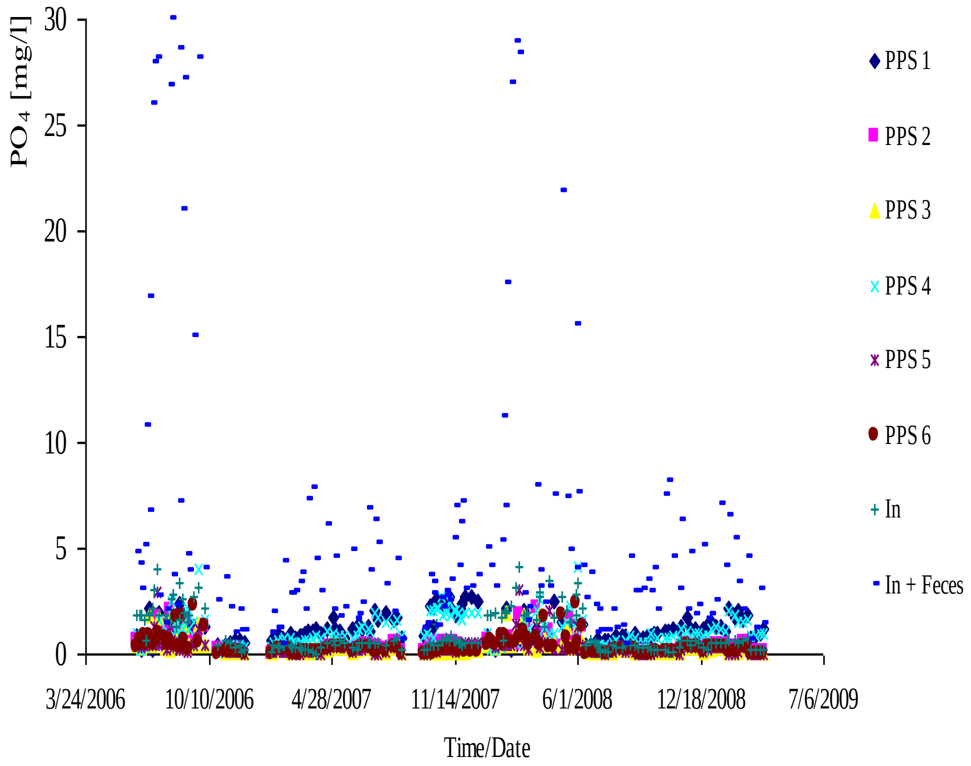

Figure 4A. Temperature and pH values from Inflows and pavement systems 1-6 for Indoor experimental setup June 2006-March 2009.

7. CONCLUSIONS

This analysis of permeable pavements has shown their use in removing nutrients and providing accurate and reliable data for industrial applications. Microorganism numbers were dependent on sediment occurrence and as this will be stopped from washout because of the PPS structure, pathogen presence at the overflow outflows will be very rare and random.

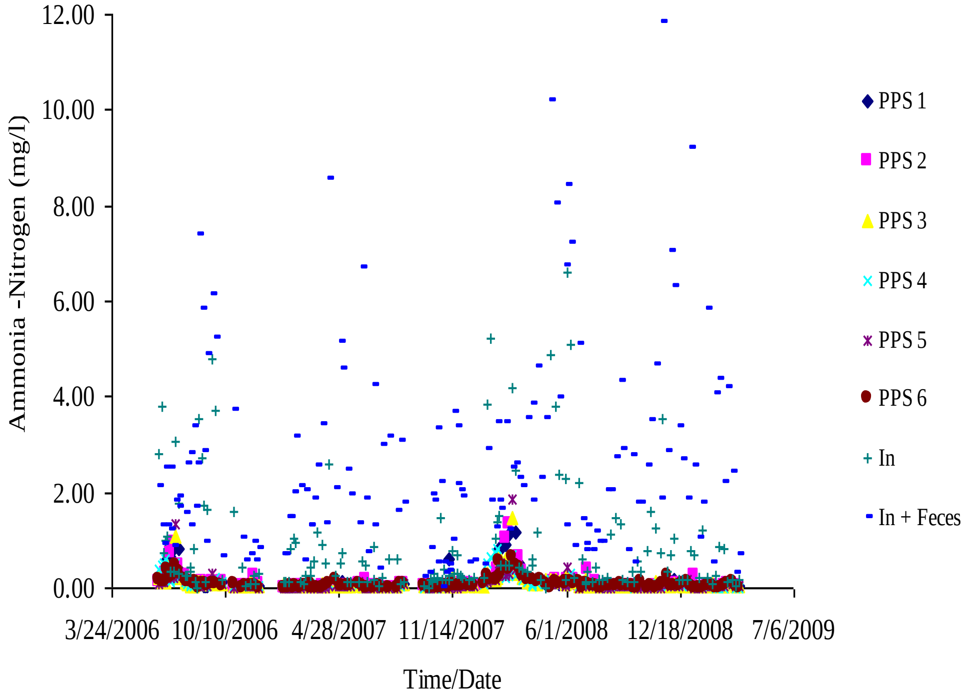

Figure 4B. Temperature and pH values from Inflows and pavement systems 1-6 for Indoor experimental setup June 2006-March 2009.

Despite the influence of temperature on the Total Heterotrophic Bacteria (THB) community, pathogenic organisms such as *Legionella* were not identified or detected following the heating/cooling cycle temperature patterns. Microbial reductions for *E.Coli* and THB were extremely high due to the large difference between influent and effluent levels. The permeable pavement systems did not allow for uncontrolled bacterial growth. Air temperatures had the strongest impact on microorganisms despite H/C installations in tanked systems. This effect was strong enough to determine the activity and numbers of organisms. The pollutant removal efficiency levels varied from 80% to 99% for BOD_5, PO_4, NH_4. These data confirm the importance of geotextile presence within permeable pavements. It can be assumed that potential pathogenic organisms would gather mainly around coils but other areas of PPS sub base would not create favourable environment conditions for their presence and growth.

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