

## **THE PERFORMANCE AND EFFECTIVENESS OF GEOTEXTILES WITHIN PERMEABLE PAVEMENTS FOR TREATING CONCENTRATED STORMWATER**

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### **ABSTRACT**

One of the guiding principles of sustainable urban drainage systems (SuDS) is centred on mitigating adverse effects of urban stormwater runoff such as increased urban flooding and deteriorating receiving water quality. SuDS such as permeable pavements are commonly perceived as an effective source control measure to reduce stormwater flows and pollution loads. However, there are limited studies aimed specifically at quantifying the effectiveness of utilising permeable pavements with geotextiles as a pollutant source control measure. This research examines the effectiveness of permeable pavements in treating concentrated urban runoff for water reuse and recycling, assessing the presence of geotextile membranes within the permeable pavement structures in terms of its efficiencies for removing water pollutants. The main aim of this research assesses and quantifies the performance of permeable pavements in reducing stormwater pollution loads for UK conditions. Environmental monitoring of flow and water quality were conducted within the sampling regime from an experimental setup of pavement systems with design variations including (i) no geotextile membrane, (ii) one upper geotextile and (iii) a upper and lower geotextile membrane. The inflow and outflow water quality were measured from the three experimental pavement rigs on a weekly basis. The water quality analysis include nutrients, biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids and other relevant water parameters on a weekly basis for influent (concentrated urban runoff) and effluent. The experimental surveys of the permeable pavement setup shows that contaminants are captured throughout the layers of the pavement structure and produced higher removal efficiencies for nutrients, phosphates and

organic matter in the presence of geotextile membranes. Water quality analysis indicates that the infiltration and absorption capabilities of the geotextile membrane provide higher removal efficiency for typical contaminants in urban runoff when compared to permeable pavements without the geosynthetic layer.

**Keywords:** Pervious Pavement, Permeable Pavement, SuDS, Geotextile, Herbicide, Glyphosate, Stormwater Reuse.

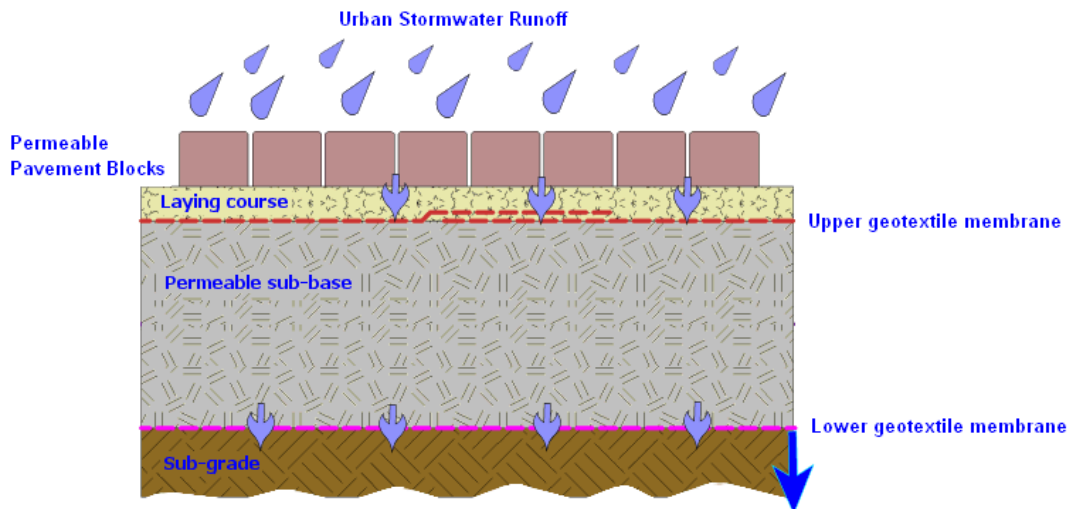
## 1. INTRODUCTION

The effectiveness of stormwater drainage in prolonging the service life of permeable pavement systems (PPS) has been the subject of discussions for several years in the UK and across the globe for designing, construction, and maintenance. Provisions for good pavement designs and drainage include surface drainage, groundwater lowering and internal drainage (Tota-Maharaj, 2010). The focus of the paper is on the use of geotextiles in pavement drainage. There are limitations in knowledge of water pollutants such as herbicides and pesticides entry mechanisms into drainage systems such as permeable pavements, and information of their transportation and fate is still incomplete. There has been an ongoing debate with regards to the application of geotextiles within permeable pavements. In some designs of PPS, there us an upper and lower geotextile membrane as shown in Figure 1. The design of PPS with a geotextile installed immediately below the laying course supporting concrete block pavers is one of the most accepted types in the UK [1]. The role of the geotextile membrane supports the growth of microorganisms which has the potential to biodegrade hydrocarbon pollutants filtering through pavement systems. [2-4]. Pratt *et al.* [3] and Bayon *et al.*[4] stated that geotextile membranes are effective in retaining oil and related hydrocarbons. The use of geotextiles within sustainable urban drainage systems (SUDS) such as PPS involves [2, 3]:

- Erosion protection
- Filtration and sediment trapping
- Separation layer
- Deflection resistance
- Void forming
- Bio-remediation and pollutant removal

Geotextiles are pervious between the laying course and the permeable sub-base. They are informally referred to as filter fabrics. The size of the openings or pores within geotextiles can vary from 0.02 to 0.002 inches, with the portion of the area in open pores varying up to about one third of the surface. In some permeable pavements, a geotextile layer under the base course can contribute to distributing the traffic load over soft subgrade. As the subgrade attempts to deform under a load the geosynthetic layer is placed in tension and its tensile strength properties add support for the load. Polymeric materials may be used in two locations within PPS, an optional upper geotextile at the laying course/coarse graded aggregate interface and a lower geotextile. However, the presence of geotextiles does not allow a reduction in the required base thickness of pervious pavements. Furthermore, the geotextile functions as a bio-filter, which physically intercepts and digests organic matter present in urban runoff by biochemical reactions [5]. The use of geotextiles to encourage biofilms and provide optimum conditions for urban runoff treatment has been well researched by [4] Pratt *et al.* [4] and [6] Legret *et al.* [6]. Geotextiles applications include layer or strata separation, reinforcement, filtration and drainage [7]. Geotextiles have been identified as one of the most important components within PPS [8]. However, there can be susceptibility to clogging by biological growth or chemical precipitation within geotextiles layers.

The aim of this paper is to assess the potential of PPS for degrading and removing stormwater pollutants the relation of geotextiles and its role in water pollutant removal efficiencies. The key objectives are to report preliminary experimental outcomes on the geotextile membranes and its potential as a pollutant trapping mechanism for the removal of phosphate-based herbicide glyphosate.



**Figure 1: Cross section of permeable pavement systems (PPS) with upper and lower geotextile membranes (adapted from Hanson Formpave Aquaflo Permeable Paving, [9])**

## 2. EXPERIMENTAL METHODOLOGY

### 2.1 Materials and permeable pavement structure

Each pavement system (Figure 2) was constructed within a 40 cm (width) x 60 cm (length) x 40 cm (height) tanked system. The top layer consisted of commercially available concrete permeable pavement blocks of dimensions (15 cm x 25 cm x 8 cm) from Hanson Formpave. This was followed by a sub-base layer of fine pea gravel (2-6 mm), and finally a layer of gravel (20 mm in diameter) as a base layer. The geosynthetic layer was located in between the base and the sub-base for the second experimental rig (II), whilst an additional geotextile membrane was placed 30 cm beneath the sub-base layer and 6 cm from the bottom of the pavement structure for experimental rig (III). Each experimental rig was filled with varying layers of standard pavement aggregated in accordance with British Standards (BS British Standards, (BS 882:1992). Geosynthetic layers for permeable pavement constructions were installed in according to British standards BS EN 13252:2001 and BS EN 13249:2001. Water sample pipes were placed at the bottom of all pavement structures for outflow collection (See Figure 2).

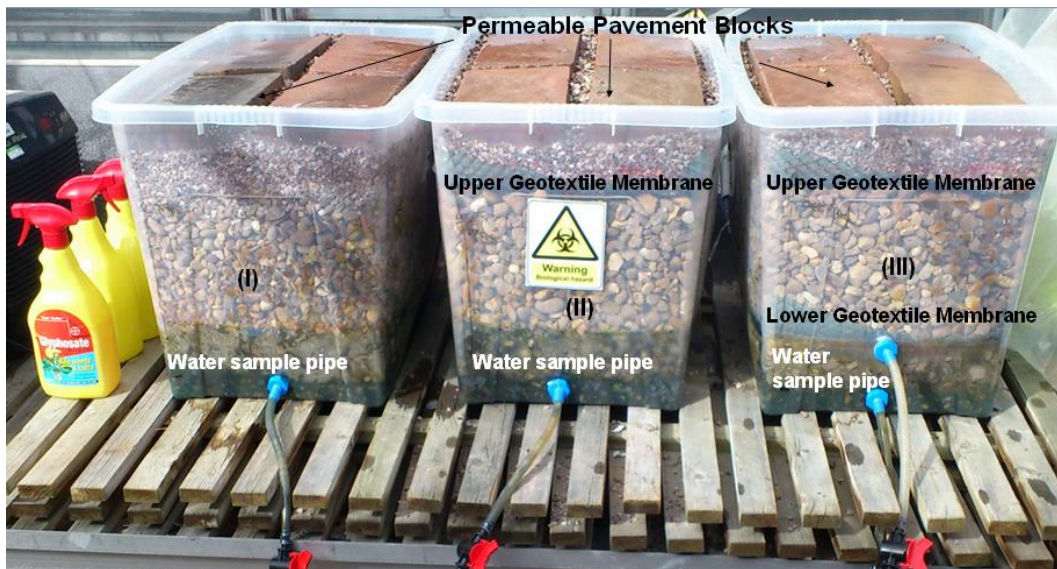


Figure 2: Photograph of experimental setup, showing (I) PPS with no geotextile membrane, (II) PPS with upper geotextile membrane and (III) PPS with both upper and lower geotextile membrane.

### 2.2 Concentrated Urban Stormwater

The concentrated urban stormwater influent consisted of 4 litres of municipal wastewater collected from the inlets at the Davyhulme Wastewater Treatment Works, Greater Manchester. This wastewater was mixed with 1 litre of de-

chlorinated tap water and approximately 60-80 ml of glyphosphate herbicide weekly and spiked via a sprinkling can, onto the top surfaces of the pavement block for each experimental rig. The retention time of the water within the saturated water zone at the base level of the pavement structure ranged from 3 to 4 days.

The addition of the glyphosate herbicide was intended to simulate the inputs of phosphorous and phosphates from external sources which will naturally occur in a real PPS scenario. Glyphosate is the mostly used herbicide in European countries today [10]. Considering pavements on industrial sites, airports, rail-roads, the application of glyphosate is even higher. Drinking water threshold is 0.1 microgram/litre for all herbicides and pesticides and 0.5 microgram/litre [11]. Previous literature has found that the eco-toxilogical threshold for glyphosate is 77 micrograms/litre. The final product of decomposition from glyphosate is normally the phosphate ion  $\text{PO}_4^{-3}$ , as well as organic phosphorous by-products that do not depend on the mechanism of decomposition [12]. Several sites surveyed within the Greater Manchester area, typical concentrations of glyphosate applied as a weed control within paved surfaces ranged from 40 to 360  $\text{ml/m}^2$  depending on the maintenance regime for the pavement surfaces and percentages of unwanted weeds and shrubs.

### 2.3 Water Quality Analysis

Water pollutant removal efficiencies were studied within the 3 different models of permeable pavements. The concentrations of ammonia, nitrite, nitrate, orthophosphate, chemical oxygen demand, and suspended solids, were determined using Hach Lange DR 2800 spectrophotometer according to United States Environment Protections Agency [13] approved standards for wastewater analysis (Hach Manual, [14])

**Temperature and pH:** The water sample temperature and pH were measured immediately after collecting the samples (influent and effluent) with model WTW Var meter handheld pH/mV/Temperature meter manufactured by Wissenschaftlich-Technische Werkstätten GmbH, Weilheim Germany.

**BOD:** The biochemical oxygen demand (BOD<sub>5</sub>) (Nitrification inhibitor N-Allylthiourea) was determined using the OxiTOP IS 12-6 system supplied by WTW, (Wissenschaftlich-Technische-Werkstätten GmbH, Weilheim, Germany). The system uses a piezo-resistive measure of pressure differences, from a respirometric method based on carbon dioxide produced within the bottle. A nutrient inhibitor was added to suppress the oxidation of ammonia to nitrates/nitrites. The pressure changes when sodium hydroxide transforms into sodium carbonate. Carbon Dioxide is then removed by sodium hydroxide tablets.

The pressure changes are recorded by an electronic data logger and measured over a five-day period at a constant temperature of 20 °C. The amount of water samples used was approximately 0.5 litres for the influent and effluents respectively. After 30 minutes of aeration with air pumps, a nutrient inhibitor was added to the samples, and bottles were incubated at a constant temperature of 20°C for five days. This method provided a simple operation, improved controllability and non-toxicity, with a measuring ranges of up to 4000 mg/l BOD. As the measured pressure is automatically converted, the values can be directly read as mg/l BOD.

*Chemical Oxygen Demand:* Hach's USEPA-approved dichromate COD Method [13, 14] is one of the most widely used chemical oxygen demand methods in the world for reporting and for easy process monitoring of water and wastewater samples. The Hach Lange DRB200 Reactor (Heating block) is preheated to 150 °C. 100 ml of inflow and outflow water samples are mixed for 30 seconds. Thereafter 2.0ml are pipetted into a vial. The vial is inverted gently several times and placed into the DRB200 reactor and is heated for approximately two hours. Next, the sample is cooled for 20 minutes to approximately 120 °C or less. The outside of the vial is cleaned with tissue and ethanol, an inserted into the spectrophotometer whereby the instrument reads the barcode and results are coded as mg/l of COD.

*Phosphorus, Reactive (Orthophosphate) ( $PO_4^{3-}$ ) and Total Phosphorous ( $PO_4-P$ ):* The Phosphorus content of the stormwater samples was determined using the DR 2800 Spectrophotometer (HACH) with PhosVer 3 (Ascorbic Acid) Method as described in the HACH manual [12,13]. The DRB200 Reactor is heated to 100 °C. Subsequently, 2.0 ml of inflow and outflow water samples are pipetted into the vial. From this point, the vial is mixed and shaken to dissolve the reagent in the cap. The vial is inserted into the DRB200 Reactor and heated for 1 hour at 100 °C. After, the vial is allowed to cool at room temperature of (15- 25 °C). 0.2 ml (200 µl) of the given reagent B (Hack Lange) is pipetted into the cooled vial. The capped vial is inverted and shaken 2 to 3 times to dissolve the reagent. Then, it is inserted into the spectrophotometer and the results are given in mg/l of  $PO_4^{3-}$  and  $PO_4-P$

*Suspended Solids:* Total suspended solids were determined using the spectrophotometer according to USEPA approved methods of analysis [13, 14]. 500 ml of water samples from the inflow and outflow are mixed rigorously for 2 to 3 minutes. The mixed water sample in then poured into a 600 ml beaker, the sample is stirred and immediately poured into a 10 ml sample cell. A second sample cell of 10ml is filled with deionized water for a blank preparation. The outside of the sample cells are cleaned and wiped with tissue and ethanol. Thereafter, the spectrophotometer is zeroed displaying 0 mg/l TSS. Subsequently,

the water samples are swirled to remove any gas, bubbles and uniformly suspend any residue and placed into the spectrophotometer for readings.

*Nitrite:* The Nitrite content of wastewater samples was determined by using the DR 2800 Spectrophotometer (HACH) with Diazotization Method LR, a method used for monitoring water, wastewater and seawater, USEPA approved for wastewater analysis under federal register ,44(85), 25505 (May 1, 1979), as described in the HACH manual [12,13]. 2.0 ml of influent and effluent samples are placed into the nitrite vial. The vial is closed and shaken 2-3 times dissolving the nitrite reagent within the vial. The vial is placed at room temperature for 10 minutes to ensure that the entire reagent has been dissolved. After, the outside of the vial is cleaned with tissue and ethanol and placed into the spectrophotometer for the barcode programme giving concentrations of  $\text{NO}_2\text{-N}$  in mg/l.

*Nitrate:* In order to determine the Nitrate content of the wastewater samples the DR 2800 Spectrophotometer (HACH) manufactured by Hach company was used with the cadmium reduction method (MR), a method used for monitoring water, wastewater and seawater described in the HACH manual. 0.2 ml of water samples from the inflow and outflow are pipetted into the nitrate reagent vial. 1.0 ml of the given Hach Range solution is placed into the vial, sealed, inverted and mixed thoroughly 2-3 times. The vial is then placed in a tray at room temperature for 15 minutes. Finally it's placed into the spectrophotometer and reads the barcode producing results of nitrate as  $\text{NO}_3\text{-N}$  mg/l.

### 3. RESULTS & DISCUSSION

Table 1 demonstrates throughout the experimentation, there was a wide range of water contaminants with respect to biochemical oxygen demand (BOD) and chemical oxygen demand (COD) levels ranging from 80 to 308 (mg/l) and 118 to 626 (mg/l) respectively. Water and wastewater samples with high organic content typically consist of high suspended solids which had a mean of 73.13 mg/l. Their in-situ decomposition of organic content can deplete levels of dissolved oxygen leading to undesirable conditions of water reuse from a pavement system. There was little variation of the water's pH level for the influent stormwater ranging from 7.73 to 8.08. Phosphorus appears in wastewater as orthophosphate, polyphosphate and organically bound phosphorus. The addition of glyphosate increased the orthophosphate phosphorous and phosphate ion concentrations by approximately 25 to 30 % when compared to the organic and inorganic phosphorous concentrations which were present from the inlets of the wastewater treatment plant. A relatively stable pattern can be seen to prevail, with the high concentrations of nitrogen-based compounds. The mixture of municipal industrial wastewater loads shows the characteristics of nitrogen as it appears in the inflow as ammonia, nitrite, and

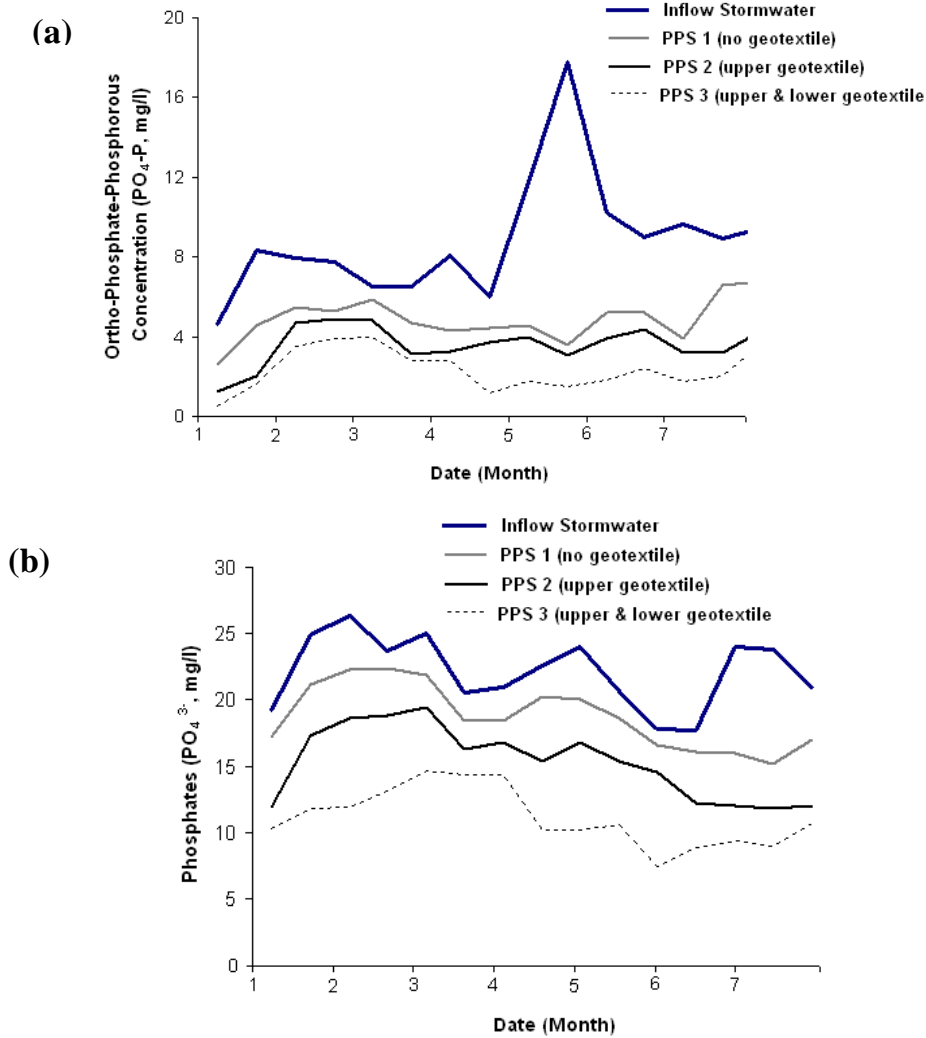
nitrate. Organic nitrogen is normally decomposed to ammonia and has a far greater content (12-43 mg/l) as compared to the inflow concentrations of nitrite-nitrogen and nitrate-nitrogen.

**Table 1: Overall inflow concentrations for urban stormwater (diluted wastewater mixed with glyphosate herbicide) from June 2011 to December 2011(sample number, n = 30)**

<b>Water Quality Parameters</b>	<b>Minimum</b>	<b>Maximum</b>	<b>Mean</b>	<b>Std. Error of Mean</b>	<b>Std. Deviation</b>
Water Sample Temp ( °C)	8.40	13.10	11.7	0.86	1.93
pH	7.73	8.08	7.91	0.07	0.15
Nitrite-Nitrogen (NO <sub>2</sub> -N, mg/l)	0.26	1.88	0.44	0.11	0.43
Nitrate-Nitrogen (NO <sub>3</sub> -N, mg/l)	0.01	0.06	0.03	0.01	0.02
Ortho-Phosphate-Phosphorous (PO <sub>4</sub> -P, mg/l)	1.05	17.80	8.14	0.96	3.73
Phosphate ion (PO <sub>4</sub> <sup>3-</sup> , mg/l)	3.21	28.20	20.62	1.65	6.39
Ammonium-Nitrogen (NH <sub>3</sub> -N, mg/l)	12.7	42.4	27.89	2.04	7.89
Chemical Oxygen Demand (COD, mg/l)	118.0	626.0	323.20	39.39	152.57
Biochemical Oxygen Demand (BOD, mg/l)	80.0	308.0	190.73	16.24	62.89
Suspended Solids (mg/l)	34.0	137.0	73.13	9.37	36.28

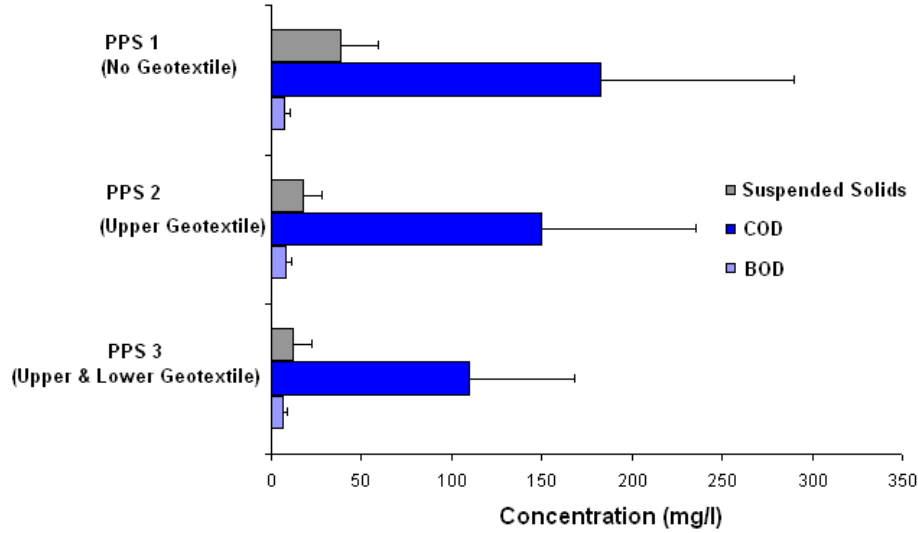
The permeable pavement systems act as a filtration device, with similar anaerobic conditions. Removal rates were quite high, suspended solids at a rate of 87 %, COD and BOD had values of 50-90 %, which can be considered to be quite satisfactory. Ammonia-nitrogen, nitrate-nitrogen and nitrite-nitrogen have almost been completely eliminated by the pavement systems. The fact, however shows how successful the operation and function of the geotextile membranes can be, and this performance index measured by COD, BOD, suspended solids, nutrients removals has been further supported by the well within the expected range, removal of ammonia and phosphorous.





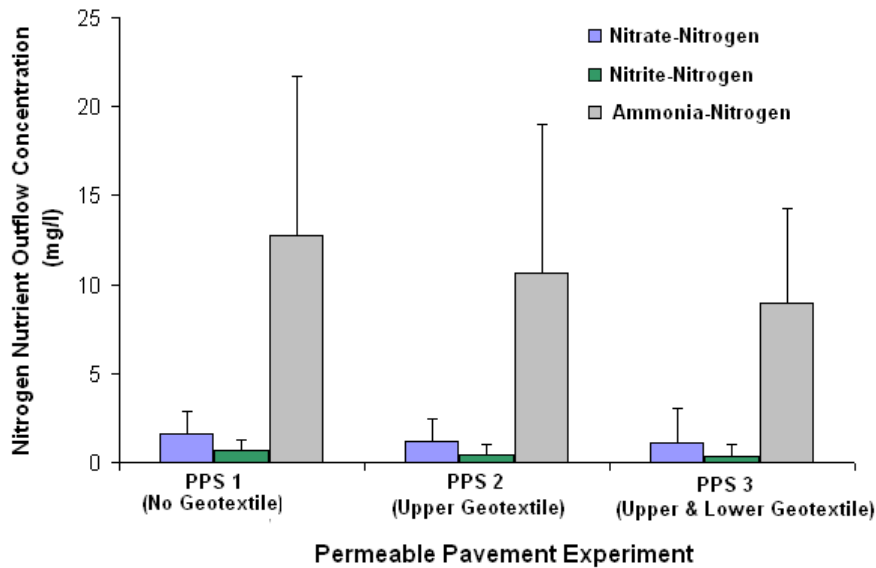
**Figure 3: (a) Mean monthly Inflow and outflow concentrations of ortho-phosphate-phosphorous (PO<sub>4</sub>-P mg/l); (b) Mean monthly inflow and outflow concentrations of total phosphates (PO<sub>4</sub><sup>3-</sup>, mg/l) from June to December 2011, Sample number n = 30.**

Influent phosphorus concentrations are removed via mechanical filtration and biological treatment. The infiltration of phosphorous based contaminants is shown in Figures 3(a, b). The total ortho-phosphate-phosphorous and phosphate ion concentrations were reduced significantly when there are two geotextile membranes and no geosynthetic layer present (PPS 1 versus PPS 3). Nevertheless, the single geotextile layer as seen in Figures 3(a, b) showed a higher retention and degradation of the phosphorous contaminants. This is expected with the increased filtration layer, phosphorous removal occurs via adsorption and bio-degradation within the pavement structure [15].



**Figure 4: Mean effluent concentrations and standard deviation (error bars) for Biochemical oxygen demand (BOD, mg/l), Chemical oxygen demand (COD,mg/l) and suspended solids (mg/l) for Permeable Pavement System (PPS) 1, 2 and 3, from June to December 2011, Sample number n = 30.**

The removal of suspended solids showed a strong statistical difference ( $p < 0.001$ ) when outflow concentrations were statistically compared using analysis of variance (ANOVA). However, there were no significant differences in the removal of BOD for PPS 2 (upper geotextile membrane) and PPS 3 (upper and lower geotextile membrane). Furthermore, the mean outflow concentrations were well filtered and treated using the geotextile layers as opposed to pavement structures consisting of a pea gravel and gravel sub-base only.



**Figure 5: Mean effluent concentrations and standard deviation (error bars) for Nitrate-Nitrogen ( $\text{NO}_3\text{-N}$  mg/l), Nitrite-Nitrogen ( $\text{NO}_2\text{-N}$ , mg/l) and Ammonia-Nitrogen ( $\text{NH}_3\text{-N}$  mg/l) for Permeable Pavement System (PPS) 1, 2 and 3, from June to December 2011, Sample number n = 30.**

As a result of nitrification and de-nitrification the two-way conversion of nitrate-nitrogen and nitrite-nitrogen leads to a very low removal efficiencies. Moreover, the influent concentrations of both nitrate-nitrogen and nitrite-nitrogen were very low and did not seem to be affected by the presence of the geotextile membranes in PPS 2 and PPS 3 respectively. As shown in figure 5 there is a uniformed stepped decrease in the mean removal of ammonia-nitrogen concentrations from PPS 1 to PPS 3 indicating the level of nutrient uptake, and degradation occurring anaerobically within the pavement structure. However, outflow ammonia-nitrogen concentrations did not show any statistical differences when assessed with anova ( $p > 0.05$ ).

#### **4. CONCLUSIONS**

Permeable pavements are a tried and tested solution for the attenuation of stormwater, improving the flood resilience of hard landscaped areas and increasing the quality of urban runoff discharge, particularly where geotextiles are deployed in the upper layers, trapping and treating pollutants. Water filtered and treatment within permeable pavements is a valuable resource; a prime objective to be achieved was the assessment of any herbicide contamination risk before the water can be recommended for secondary purposes. The research presented in this paper represents a leap in the understanding of the properties and viability of geotextiles and its assistance in water treatment as a sustainable urban drainage system. The ongoing experimental work on permeable pavements provides a greater understanding for the performance of geotextiles as a key component within permeable pavement structures. The overall conclusion of the experimental work carried out to date, is at this stage of the investigation the geotextile membranes showed exactly the behaviour it is designed for in retaining stormwater pollutants such as phosphates, nitrates and ammonia. This project can further increase the market for rain water harvesting with permeable pavements containing geotextiles and the water effluent being sufficient quality for reuse.

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