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THE STORAGE AND PROTECTION OF RAINFALL RESOURCES STORED IN PERMEABLE PAVING

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

Summary

Stored rainwater for recycling has been recognised as a valuable resource that can contribute to increased sustainability in housing and commercial schemes. Output from the United Kingdom (UK) Code for Sustainable Homes (CSH) covering the environmental impact of new housing has shown that recycled rainwater provided by the 1 000 litres of stored rainwater per 10 m^2 of Aquaflow paving contributes strongly to internal and external water use and gives a high score in CSH.

Pioneering research at the University of Cantabria, Santander, Spain, in collaboration with a UK permeable paving manufacturer based on a functioning car park (Parque de las Llamas, Santander) has examined the water budgets in the storage tanks over eighteen months. The research has demonstrated that during dry periods a specifically engineered geotextile can assist in the prevention of evaporation from the storage reservoir but that where rainfall exceeds evaporation, the water in the parking bays is sufficient to supply large water volumes for reuse. Analysis of the water budget has been achieved by monitoring the water depths with a level meter after calibration of the storage capacity using a hose pipe. Meteorological measurement including rainfall depths, wind speed, humidity and temperature have assisted in monitoring the rates of water loss and the relative impact of these environmental variables on rainwater recycling.

By implementing a ‘real life’ car parking situation with rainwater storage it is hoped that a long term information can be established that will provide much needed data on the capacity of permeable paving to contribute to the sustainability of buildings.

1. INTRODUCTION

An experimental pervious pavement car park area has been designed and constructed in a new park located in Santander, in the north of Spain. The parking area presents 45 pervious pavement parking bays of different types. Ten of these structures follow the design shown below. The surface layer is composed of concrete blocks with small gaps in the short ends which allow rainwater to infiltrate into the pavement. Under the surface layer there are two aggregate layers called regulating course and sub-base, formed of clean limestone. Generally there is a geotextile between the regulating course layer and sub-base, in order to avoid the 5 mm bedding layer migrating into the spaces between the larger aggregates. The sub-base layer is the reservoir where infiltrated water is stored and available to be used for non potable demands as surface or car washing and irrigation [Gomez-Ullate et al., 2008] (See Figure 0).

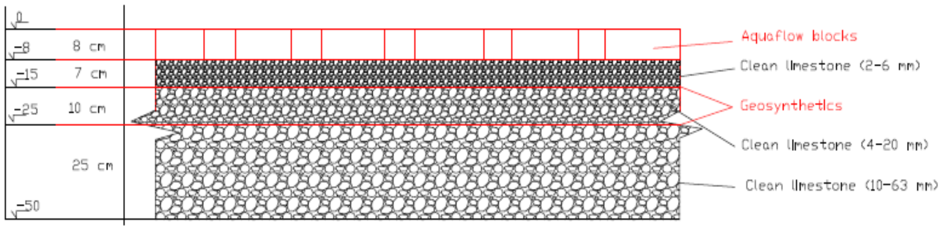

Figure 0. Components of a pervious pavement in Santander, Spain.

Pervious pavements are one of the tools in a group of techniques for the improvement of urban drainage in a sustainable way, which are known as SUDS in UK (Sustainable Urban Drainage Systems) and in Spain (Sistemas Urbanos de Drenaje Sostenible) or Stormwater BMP in USA (Best management Practice). Pervious pavements are source control SUDS which mean that these structures allow the infiltration of rainwater, avoiding the superficial runoff formation and consequently reduce the risk of floods. Rainwater infiltrated into the pavement can infiltrate into the ground recharging aquifers or can be stored within the sub-base layer [Castro- Fresno *et al*., 2005; Coupe *et al*., 2006].

These techniques have numerous advantages. Firstly, SUDS and specifically, pervious pavements help to conserve the natural hydrologic cycle in cities. The rapid urban growth has increase the number of impervious surfaces in cities which impede the infiltration of water altering the natural water cycle. In addition, pervious pavements save rainwater which is very important, mainly in areas with water shortage. Moreover the infiltration capacity of these systems decrease the risk of floods and other water quantity problems associated with cities [Bayon R.J., 2008; Rodriguez-Hernandez J., 2008]. In many countries including the UK, SUDS are being already used to improve the management of urban water, helping to reduce urban flooding [Pratt, 1999; Coupe *et al*., 2005].

Pervious pavements (PPS) are particularly important in cities due to their capacity to reduce superficial runoff. These structures are commonly used in car parks which include an elevated percentage of urban surfaces and, consequently, and use of PPS provides a potential reduction of runoff. Experimental research developed by Brattebo *et al*. [2003] evaluated the effectiveness of pervious pavements as a stormwater management strategy, studying the quantity and quality of the effluent of four pervious pavements and demonstrated that motor oil, lead nor diesel were found in any of the effluents. In another experience, the Institute for Hydraulic Research of the Federal University of Rio Grande do Sul, in Brazil, observed a reduction of runoff when pervious pavements were tested under defined traffic conditions and demonstrated the maximum storage volume in the gravel reservoirs of 260 mm thickness [Acioli *et al*., 2005].

The aim of the present research is to study the storage capacity of pervious pavement parking bays and to compare the influence of different geotextile materials in the water evaporative losses from the pervious pavements. In this sense, it is important to consider the environmental factors in order to estimate water inputs into the pavements and study the influence of the temperature, humidity or wind speed on the stored water. Different geotextile materials could be more suitable to retaining stored water depending on the weather conditions for the purpose of the structure which in this context is water harvesting.

2. OBJECTIVES

The main objectives of this experimental research are:

- Determination of the overall storage volume of the parking bays.
- Determination of the rate of water increase or decrease in the bays depending on the type of geotextile used.
- Analysis of the effect of the prevailing weather condition on the storage volume – temperature effect, humidity, rainfall, wind speed and direction.
- Analysis of the faecal contamination of the stored water to demonstrate its good quality to be used for non potable demands.

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3. METHODOLOGY

3.1 Materials

In the Llamas Car Park, there are ten experimental parking bays constructed with standard geotextile based products, varying only in the geotextile layer. The surface layer is composed of Aquaflow blocks provided by the manufacturing company, and which have a small gap in the short ends to allow water to infiltrate (see Figure 1).

Figure 1. Pervious pavement surface of Aquaflow blocks.

Under the surface, the pavements are composed by two granular layers composed of clean lime stone: a 50 mm depth base layer with limestone of 4 mm to 8 mm size; and below a 350 mm depth sub-base layer composed of 20 mm to 80 mm limestone.

Therefore four of the experimental parking bays are constructed with a geotextile layer, another four with a "One way" layer and two without any geotextile layer. The geotextile is a Polypropylene- polyethylene geotextile with a pore size of 145 μm and mass of 125 g/m^2, and it is the geotextile commonly used in pervious pavements in UK. The "one way" is a geocomposite formed by an outer layer of geotextile and an inner layer of another impermeable geotextile which has been designed to reduce water evaporative losses within the pavements (See Figure 2).

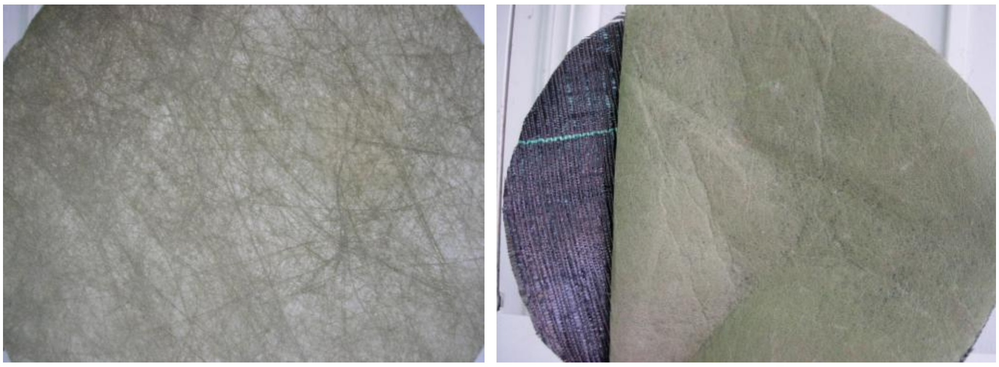

Figure 2. Geotextile materials: a) Infiltration and b) One Way.

In order to achieve the storage of water within the pervious pavements, every bay was sealed using a bituminous geomembrane which makes each structure a waterproof drawer. The sealing was protected with non woven geotextile in order to avoid damages when the rest of the road bed materials were put in place.

3.2 Method

The experimental pervious pavement parking bays are designed in order to measure the water level within the pavements over time. Each parking bay is an individual waterproof drawer of 0.5 m depth, and with an area of 2.4 m x 4.2 m., apart from one bay, designed for disabled access and consequently with bigger dimensions. Each structure is individually connected to a control manhole which is equipped with the required tools for water quantity measurements and quality analysis sampling. The connexion between every experimental parking bay and its control manhole is made through two pipes: a bottom pipe coming from the base of the parking bay and an emergency outlet located above the geotextile layer. Inside the control manholes there is a vertical transparent plastic tube emerging from the bottom pipe, which is graduated in order to measure the level of water stored within the pavement thanks to the principle of communicating vessels. Water samples can be collected by the bottom pipe. The emergency outlet is permanently open in order to drain the excess of water when intense rainfall occurs, avoiding overflow problems (see Figure 3).

Figure 3: Control manhole with the pipe connexions and the water level tube.

During nine months of analysis, between April 2008 and January 2009, water levels within the pavements were measured weekly using a digital water level meter specifically designed for this investigation. This probe is introduced into the vertical graduated tube located in the control manhole and measures the level of water after stabilization.

The environmental factors are measured by a meteorological station (MK III) located in a lamp post of the car park (see Figure 4). The station has a rain gauge, thermometer, hydrometer and anemometer. Data are discharged with the Weather View Standard version and processed using Excel spread sheet.

Figure 4. Meteorological station placed on a stoplight of the experimental parking area.

3.3 Results and discussion

Water harvesting results are represented by the water level within each type of geotextile (giving a mean of the replicates) of pervious pavements over the time. The structures were almost always full of water during most of the period due to the severe and frequent rain events over the experimental period. The dry periods between rainfall events were not long enough to produce significant differences between pavement types. In previous laboratory experiments [Gomez-Ullate et al., 2008], it was demonstrated that after an initial simulated rain event of 1.5 l, experimental models of the pervious pavement types represented in this study, required a dry period of 4 weeks to obtain statistically significant water evaporative losses. The longest dry period between two rain events during the present study was 11 days (27/02/09 - 09/03/09) thus, significant differences on the water levels of the different types of pervious pavements over this time were not found (considering $\alpha < 0.05$ in the Kruskal Wallis' test), under the especially hard environmental conditions during the study period in Santander.

Error! Reference source not found. shows the stored water within the three types of pervious pavements and the rain events at the location over time. The levels of stored water remain approximately constant regardless of the rain events, as at most times the bays were full and any excess drained from the emergency overflow. No statistically significant differences were demonstrated among the water levels of different pervious pavement types over the study period, although small water level increases and decreases were observed within the pervious pavements (see **Error! Reference source not found.**). However, these differences could result from the different overflow rates of the emergency pipes, once the bays were full. Below the emergency overflow pipes, the small water level decreases were clearly related to evaporation, as there was no other way to lose water within the pavements.

Apart from the rain, the influence of other environmental factors (temperature, humidity and wind) over the water storage volume within the pervious pavements was not strong enough to produce a significant difference between treatments taking into account the heavy rainfall. However, the correlation of the water levels within the pavements to temperature and wind combined was higher ($R^2 = 0.88$) than when the rain was combined with the temperature ($R^2 = 0.14$) or with the wind ($R^2 = 0.25$).

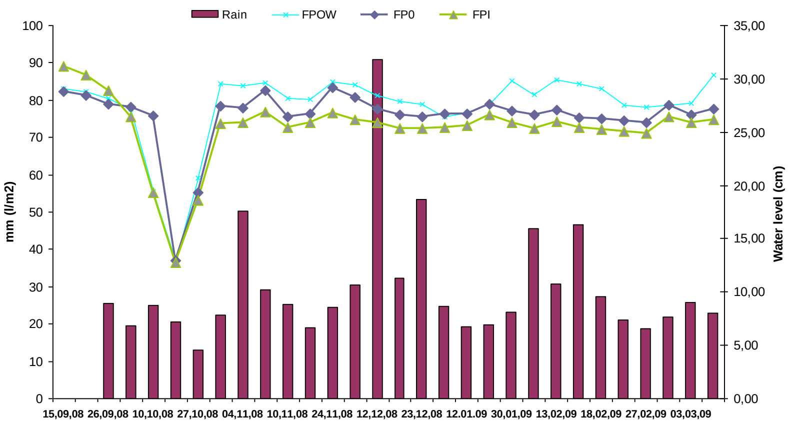

Figure 5. Water level within the different typologies of pervious pavements and rain events over the

time.

A rapid and pronounced decrease in the level of stored water level in all types of pavement during the experimental time period can be seen in **Error! Reference source not found.**. This resulted from an intended emptying of the bays in order to study the total storage volume and how quickly water reserved could be replaced by rainfall. In the previous experiment in the laboratory by Gomez-Ullate et al., [2008], it was observed that water evaporative losses within the pavements were different depending on the volume of water within the pavement and amount of water held close to the pavement surface. However, the bays were full of water before any difference could be seen and once again, the bays quickly showed an excess of water.

The real storage volume of the sub-bases had been previously calculated by adding water with a hose with a flow rate of 7.74 l/min. It took 3 hours to fill 350 mm (sub-base height), thus the volume of water added was 1 393 l. Considering that the volume of the sub-bases are 0.35 m height x 2.4 m x 4.8 m long this gives a total volume of 4 032 m^3 or 4 032 l. Finally, the real porosity was calculated to be: porosity (%) = (1 393.2 / 4 032) x100 = 35.56%. In consequence, relating back to the porosity, the real volume stored in the sub-bases is 1.4 m^3.

Even the preliminary results have not been shown yet, there is encouraging news from the quality study on bacteria, due to the absence of E.Coli as faecal contamination indicator has been demonstrated at first analyses. If the microbiological quality of the stored water can be demonstrated well enough during the following analyses, the volume of stored water within the experimental pervious pavement parking bays could supply water for non potable house holding demands as toilet flushes, washing machines, car washing, or public demands such as the irrigation of gardens. In particular, 14 000 litres of water can be utilized to irrigate the public park Vaguada de Las Llamas, when the ten experimental parking bays are full of water.

Despite there being no significant differences in stored water relative to the geosynthetic layer of the pervious pavement when tested under the weather conditions in Northern Spain, this is a good indication that long term storage of rainwater and water harvesting is feasible using permeable paving. Runoff has been completely removed and no overflow problems have been demonstrated during the test period.

It is expected that during longer dry periods in summer, the influence of the environmental factors will be demonstrated and differences in water evaporative losses will be found. Therefore, future analyses will be focused on the study of water evaporative losses during drier periods and comparing the full and empty bays. Required dry period between rain events to obtain water evaporative losses will be calculated under the local environmental conditions.

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