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Design and Construction of an Experimental Pervious Paved Parking Area to Harvest Reusable Rainwater

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ABSTRACT

Pervious pavements are sustainable urban drainage systems already known as rainwater infiltration techniques which reduce runoff formation and diffuse pollution in cities. The present research is focused on the design and construction of an experimental parking area, composed of forty-five pervious pavement parking bays. Every pervious pavement was experimentally designed to store rainwater and measure the levels of the stored water and its quality over time. Six different pervious surfaces are combined with four different geotextiles in order to test which materials respond better to the good quality of rainwater storage over time and under the specific weather conditions in Northern Spain. The aim of this research was to obtain a good performance of pervious pavements that offered simultaneously a positive urban service and helped to harvest rainwater with a good quality to be used for non potable demands.

KEYWORDS

Rainwater management, SUDS, pervious pavement; storm-water harvesting

1 INTRODUCTION

One of the main problems of the rapid urbanization processes occurred during the last decades is the increasing construction of the impervious surfaces which negatively alter the urban water cycle. Impervious surfaces impede rainwater infiltration into the ground, thus the runoff formation increases, originating numerous urban water problems associated with quantity, quality and urban service (Acioli, 2005; Gilbert, 2006).

The increased runoff resulting from the higher imperviousness may lead to the saturation of conventional drainage systems, to the formation of superficial water courses or floods, which are part of the quantity-related urban water problems. On the other hand, quality problems mainly respond to the fact that the runoff accumulates the pollution found along the urban surfaces. This contamination, known as diffuse pollution, does not have a single located source, but it accumulates the pollution found over the surfaces. This fact makes more difficult its treatment due to the high concentration and diversity of pollutants (Brattebo, 2003, Gilbert, 2006). Finally, urban service problems are derived from the risk of flooding that drag materials, makes walking horrible to pedestrians or traffic.

Urban water management needs to be improved in order to do urbanization more sustainable and it involves both the management of wastewater and the groundwater and rainwater. Recovering rainwater by collecting runoff is a water management strategy which is increasingly used in many countries.

In Brazil, the use of rainwater tanks for potential potable water savings has already been studied (Ghisi, 2007), and in Australia there are already storm-water treatment and recycling practices. Among those, there are some techniques based on recycling runoff from all urban surfaces for non potable demands (Hatt *et al*., 2005). This also occurs in Germany where rainwater harvest has been widespread since the 1980s, even the techniques for recycling runoff from every urban surface have been developed (Nodle, 2007).

Within this framework emerge the new techniques for rainwater harvest which make urban drainage more sustainable: the Sustainable Urban Drainage Systems (SUDS). These techniques can be grouped by their main function differentiating firstly source control techniques which reduce runoff in origin, helping rainwater infiltrate into the soil and avoiding runoff formation; secondly, SUDS whose main function is transporting the runoff (e.g. swales) and thirdly, SUDS with a passive treatment function (e.g. retention ponds) as a final treatment train. Finally, there is a type of SUDS called pervious pavements which treats water from the infiltration of rainfall to the passive treatment of stored water (Castro Fresno, 2005).

In different countries, such as The USA, The UK (Brattebo, 2003; Gilbert, 2006) or Brazil (Acioli, 2005), SUDS techniques are already employed to store and treat rainwater, which follow guidelines and standards established for these techniques. In Spain, even these techniques are being increasingly established; urban water harvesting is only regulated by laws for treated wastewater and not for rainwater.

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Pervious pavements are especially relevant for Sustainable Urban Drainage Systems because these surfaces are commonly used in parking areas which involve large areas in cities and therefore large volumes of runoff can be reduced. For many years, these pervious surfaces have been mainly used for light traffic, especially in car parking areas in countries such as The USA, England or Scotland; but pervious pavements are also well known all over the world: France, Germany, Austria, Brazil, Chile or Japan; even for heavier traffic areas.

These surfaces are composed of several increasingly permeable layers from the top surface layer to the lowest; therefore, runoff is filtrated through the pavement and later it can be infiltrated into the ground, either for groundwater recharge or stored within the pavement for use for non-potable demands, such as car washing, toilet flushing or garden watering. Therefore, these techniques help in urban storm-water management by solving problems related to rainwater quantity and quality and offering an aesthetic and environmentally friendly solution.

There are multiple studies about the construction of pervious pavement parking areas. In 2003, Brattebo studied the long-term effectiveness of different systems of pervious pavement parking areas, focusing on their durability, infiltration capacity and rainwater storage quality. Pervious pavements reduced runoff and infiltrated water showed less pollution. In addition, Gilbert et al., 2006 studied infiltrated storm-water quality and quantity in different driveways in a residential area located in Waterford (US). They obtained higher storm-water reduction for the pervious pavement driveway.

However, runoff pollutants have been demonstrated to be reduced in the water infiltrated through the pervious pavements; it is important to know the behaviour of these pollutants. Dierkes *et al*., 2002, studied the main problems present in pervious pavement parking areas, such as behaviour of runoff pollutants, clogging problem effects and the result for infiltration capacity. They concluded that pervious pavements were suitable provided that the construction and maintenance were correctly carried out. For this reason, this article, which describes the requirements and difficulties in achieving good performance and improving rainwater urban management during the design and construction of these techniques, is relevant. In addition, the present experimental site includes all the qualifications for water quantity and quality and service aspects.

The typical section of a pervious pavement is the shown in Figure 1. The pervious surface helps water to be infiltrated into the pavement. Under the surface, base and sub-base, generally composed of clean limestone are separated by a geotextile layer.

The geotextile layer has an important role as the main filter; avoiding the materials to be mixed in order to conserve the infiltration capacity of the systems; being the support for the biological film responsible of the biodegradation of hydrocarbons and reduces evaporation of the stored water. The sub-base is the reservoir layer where water is stored

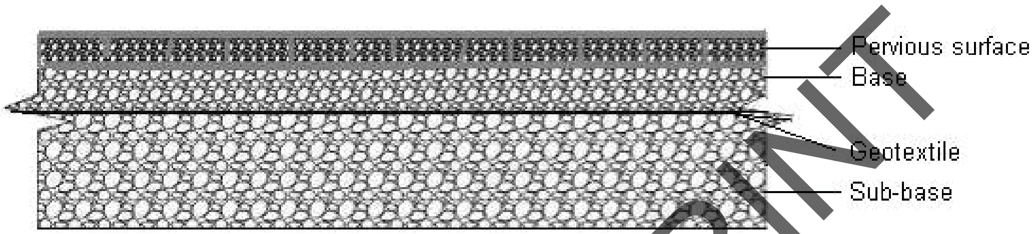

Figure 1: Typical section of a pervious pavement

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2 METHODOLOGY

The methodology of this research started with the design of the experimental pervious pavements in order to achieve the storage capacity of these devices and allow the scientific activity monitoring the stored water within the pervious pavements and the quality of this stored water. In addition, the methodology used to construct these structures was an important point in order to conserve the structural functions of the pavements. Finally, the scientific methodology was focused on the study of water storage and water quality within each pervious pavement type.

2.1 Experimental design of the pervious pavement parking bays.

Every pervious pavement parking bay was experimentally designed to store water and monitor the level and the quality of the stored water over time. Each parking bay was an individual concrete drawer of 0.5m height x 2.4m wide x 4.2m long., inner sealed with a bituminous geomembrane (Figure 2). Within these watertight drawers the corresponding pavement materials were placed.

In addition, as it is shown in Figure 2, each individual parking bay was connected to a control manhole where the water samples were taken and the levels of stored water were monitored. The connection parking bay-control manhole is through two pipes: a bottom pipe (2 in Figure 2), that is only open to take water samples and an emergency pipe (4 in Figure 2), which is permanently open to drain the excess of water when the pavements are filled with water. Due to the sub-base is the reservoir, when this layer is full of water the excess is drained out through the emergency pipe which is just under the geotextile. In this manner flooding problems were avoided. But, even so, the base layer is an emergency security reservoir layer, in case that water inputs were higher than the water drained out through this pipe.

There is a third connection pipe, called “gas pipe”, which helps to measure the inner atmosphere of the pervious pavements just on top of the geotextile layer. This allows the estimation of the biological activity involved in biodegradation processes, which is one of the main depuration mechanisms of pervious pavements.

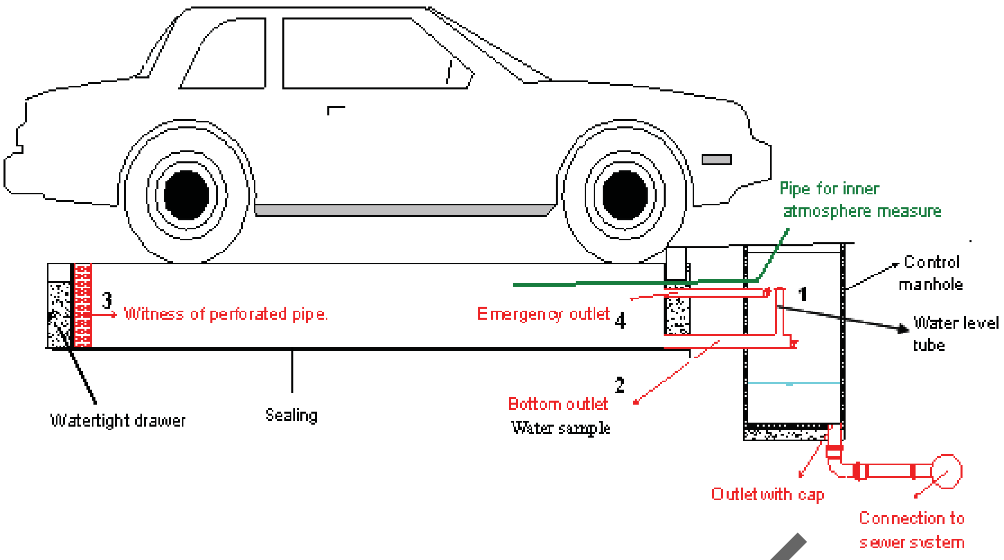

Figure 2 : Experimental parking bay section: 2. (1) graduated level control tube; 2. (2) Bottom outlets; 2 (3) vertical perforated pipe; 2. (4) Emergency outlets.

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Every parking bay communicated with a corresponding control manhole for sampling and experimental monitoring. Each of these manholes was a polypropylene drawer reinforced with concrete of 1m height, and with an area of 400 x 400mm. All of them were also communicated with the general collector system.

Within the control manholes, there is a vertical, transparent and graduated plastic pipe, coming from the bottom pipe, which was utilized to measure the water level within the parking bay by communicating vessels.

2.2 Construction process of the pervious pavement parking bays

The experimental parking area is composed of forty five pervious pavement parking bays. There were a total of six types of pervious surfaces combined with four different geotextile layers. The base and the sub-base were similar for the entire area.

The construction processes started with the excavation of each watertight drawer, the inner sealing and the installation of the connection pipes. This was the first critical step due to the importance of a good performance to keep the imperviousness of the structures. For this reason, the sealing was protected with a non woven geotextile before setting the rest of the pavement materials (Figure 3a).

At the same time, the plastic control manholes for sampling and water analyses were placed into the concrete drawer and all pipes were installed (Figure 3b). Next, the roadbed material was placed. It was very important to conserve the materials clean, without fines, conserving the drainage capacity of the pavements. Finally, all the structures were filled with water in order to prove the storage capacity and thus, the good performance of the sealing (Figure 3c).

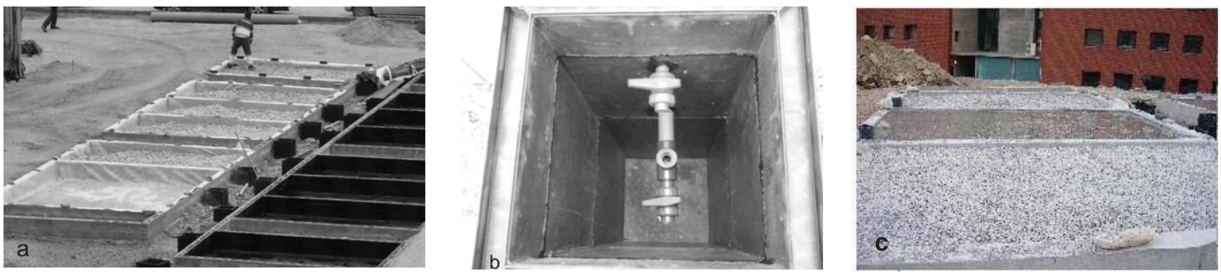

Figure 3: First steps of construction (a) watertight drawers with the sealing, (b) control manhole and (c) roadbed materials and sealing test.

Finally, the surface layers were placed: Aquaflow concrete block (8cm of thickness), Montserrat pervious concrete block (10cm), porous asphalt (8cm), porous concrete (8cm) and grass surfaces reinforced with concrete (9cm) and plastic cells. Each surface was combined with two types of geotextile and with no geotextile (control bays). The bays with the Aquaflow concrete blocks were combined with an Inbitex geotextile and a One-Way geotextile. Two of these bays have no geotextile. The other types of pervious surfaces were combined with Polyfelt TS30 and Danofelt PY150 geotextile and control bays without geotextile layers.

The materials used in the construction of the experimental parking bays were chosen partly based on the previous studies of this research group (Bayon, 2008; Rodriguez, 2008). The clean limestone sub-base has been demonstrated to be more appropriate for the infiltration and treatment of water through the pervious pavements. Finally, a non-woven geotextile is recommended, and Bayon (2008) found that Inbitex was the best adapted geotextile to different scenarios although Polyfelt TS30 showed the most extreme results.

3 SCIENTIFIC ACTIVITY

The scientific activity is planned to be along two years, even in this research only preliminary results were presented in order to demonstrate the good performance of the experimental pervious pavement area.

3.1.1 WATER QUANTITY

The methodology used to analyze the stored water quantity was based on monitoring the levels of water stored within each experimental bay and on analyzing the stored water evaporative losses within each pervious pavement type.

Water level measurements were performed weekly through the water level pipe which was graduated. Differences in the stored water levels among two consecutive measurements within the same parking bay are called "weekly level differences" and these will be used to compare the different pervious pavement types.

Water evaporative losses were calculated with the stored water levels and the water inputs that were measured with a meteorological station placed at the experimental area.

The inner temperature and humidity of the pavements were measured in some parking bays in order to correlate external and internal factors with the volume of stored water.

3.1.2 WATER QUALITY

The main objective of the water quality analyses is to verify if the quality of the water stored within the pavements was good enough to be used for non-potable demands.

All samples were taken from each bottom pipe, and an integrated sample of the replicates (same pervious pavement types) was used as the laboratory sample.

Water quality parameters were selected according to three different aspects. Firstly, some parameters were measured in order to prove that the stored water quality was suitable according to the Spanish legislation. Although in Spain there is no legislation regulating harvested rainwater, some parameters were measured following drinking water and re-use depurated wastewater laws. Temperature (ºC), conductivity (µs/cm), dissolved oxygen (mg/l) and the pH of the stored water were measured using multi-parametric probes. In addition, suspended solids (mg/l) were calculated using the membrane filtration method in the laboratory. Moreover, the turbidity (NTU) of the water is analyzed by the nephelometric method using a nephelometer and total nitrogen (mg/l of $_{Total}N$), total phosphorus (mg/l of $_{Total}P$) and the chemical oxygen demand (mg/l of COD) were measured by spectrophotometry. The method for total nitrogen was the LCK 138 (Hach), for total phosphorous was the LCK349 method and for COD was the LCK414 (Hach) method.

Secondly, some water quality analyses were related to the main pollutants found in parking areas: hydrocarbons and heavy metals: lead (Pb), Zinc (Zn) and Iron (Fe), were measured by using an atomic absorption spectrophotometer. Hydrocarbons were measured using a total hydrocarbon analyzer, which measures the total hydrocarbon content in water by extraction with the dissolvent S-316 and analyzing by infrared spectrophotometer.

Finally, the third aspect related to the water quality analyses is focused on biodegradation processes, which is one of the main depuration mechanisms of pervious pavements. These are natural processes in which specific microorganisms degrade hydrocarbons filtered into the pavements with the water.

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Different techniques are performed simultaneously in order to estimate these processes within the pavements. A quantitative analysis of the total hydrocarbons in water is developed using the Horiba OCMA 310 analyzer. Although these analyses did not study specifically biodegradation processes, the quantity of hydrocarbons within the stored water over time, applied together with the other techniques, is valid to study them. Thus; specific hydrocarbon degrading microbes are estimated in the laboratory using the Most Probable Technique (MPN), to count the number of microorganisms that are present in the stored water as a representation of the microbes present within the pervious pavements.

To sum up, biodegradation processes are mainly aerobic and the gases involved in this process: oxygen (O_2) and carbon dioxide (CO_2), confirm the microbial respiration and thus, the microbial activity. The main biodegradation processes within the pervious pavements take place at the geotextile layer, which is the main layer where the pollutants are retained and where the bio-film is fixed and developed. A portable probe is with an electrochemical sensor for the O_2, and an infrared sensor for the CO_2 is used through the gas pipe mentioned previously.

4 PRELIMINARY RESULTS AND DISCUSSION

The results presented in this article are referred to the water storage and its quality after the first year of the monitoring. After this period, pervious surfaces were demonstrated to be more influential than the geotextiles on water storage under the weather conditions occurred at the experimental site. Therefore, results for water storage and water quality are given for the pervious pavements grouped only by their superficial layers.

Firstly, it should be pointed out that due to the abundant rainfalls taken place over the experimental period, all pervious pavement types were at their maximum storage capacity, which was marked by the emergency pipe height. Figure 5 shows the levels of stored water within the experimental parking bays and the registered rainfalls. As it is appreciated water levels were around 30cm over the entire period regardless of the rainfalls. A methodological error of 2cm was assumed.

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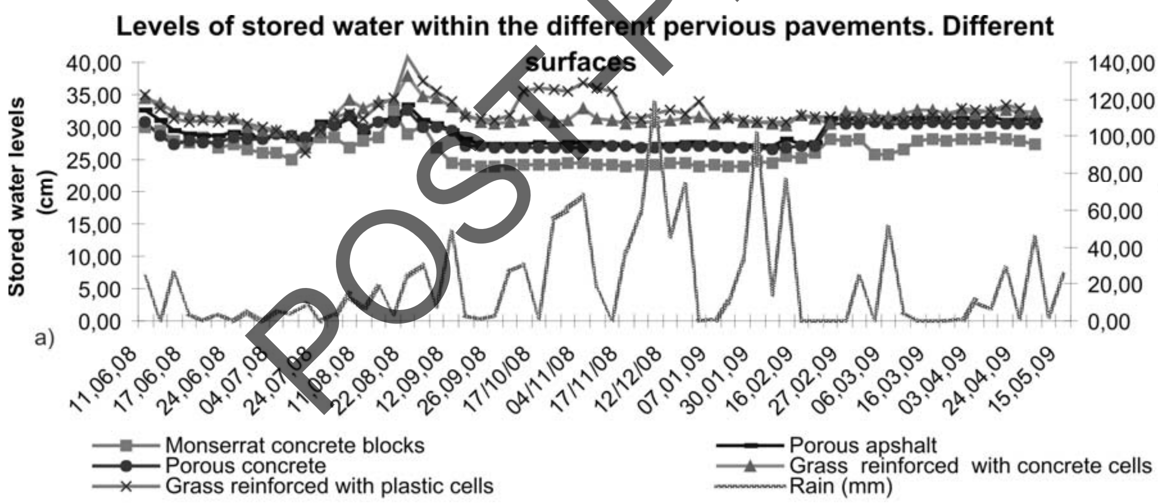

Figure 4: Level of water stored within the pervious pavements.

Looking at the graph, higher variability was observed at the beginning of the experiment. The reason was that the structures started full of water and the emergency pipes did not drain out all the excess of water properly. Therefore, at the end of September, these outlets were perforated in order to improve the drainage. Since then, water levels were more stable at their maximum capacities. However, some variability is still observed in some pavements. Grass reinforced surfaces, mainly reinforced with plastic cells, overpassed their maximum capacity even after perforating the emergency pipes. This fact was due to the natural soil of the surfaces, which was dragged into the pavement with the infiltrated rainfalls and clogged, partially, the emergency outlet.

On the other hand, it is appreciated porous asphalt and porous concrete behaved similarly and the concrete block surfaces separately. The distinction of these three groups appreciated in the graph was corroborated by clustering analyses, which grouped pervious pavements, by their similarities in the stored water levels over the experimental period. Next, the three groups differentiated are shown:

- Porous asphalt (PA) and porous concrete (PC), were the group of continuous surfaces
- Concrete blocks (CB), was the group of open surfaces
- Grass reinforced plastic (GPC) and concrete (GCC) cells were the group of grass surfaces

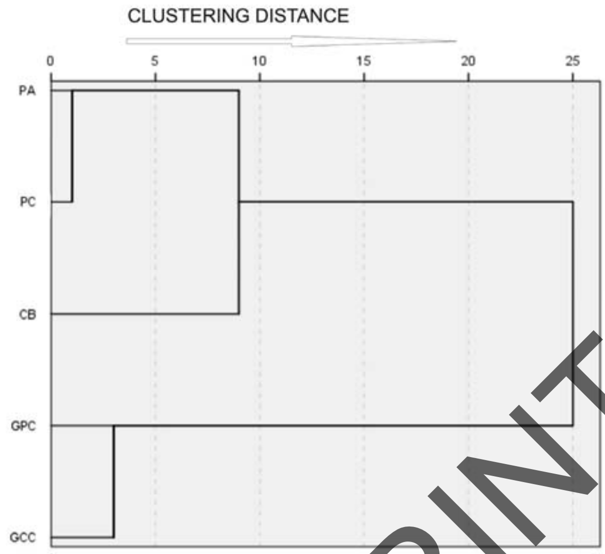

Figure 5 : Dendograme showing the three groups formed:1) porous asphalt (PA) and porous concrete (PC); 2) Concrete blocks (CB) and 3) grass reinforced with concrete (GCC) and plastic (GPC) cells.

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Due to the maximum storage capacity of each parking bay was not exactly the same because of the slight construction differences, the water stored within the different types of pervious pavements was compared using “weekly level differences”. Finally, in spite of the clustering results, the differences among these three groups were so small that these could not be demonstrated to be significant (Mann-Whitney, $p>0.05$).

Water quality results presented in this article are referred only to the parameters required by law to ensure the good quality of the water (Table 1). The objective was demonstrating that water could be used for irrigation after one year of storage.

Parameter	Value	Reference
pH	6.5-9.5	Agua Potable (RD 140/2003) (Drinking water, in Spain)
Conductivity(µS/cm)	2500	
Suspended solids(mg/l)	10-20	Agua Regenerada (RD 1620/2007) (Re-use regenerated wastewater, in Spain)
Total nitrogen (mg/l)	10	
Total phosphorous (mg/l)	2	

Table 1: Water quality parameter required by Spanish laws.

Figure 6 shows the results of the conductivity, dissolved oxygen (DO), Chemical Oxygen demand (COD), nutrients (phosphorous and nitrogen) and suspended solids (SST), over time. As it can be appreciated in the figure, water quality at the beginning of the experimental year was lower than during the rest of the time for all types of pavements. Conductivity, COT, and nutrients were high whereas the DO was low; lower even than the law requirements. In addition, it should be pointed out that porous concrete pervious pavements showed the worse water quality. The reason of the lower quality during the three first months of analyses was that first rainfalls after the construction of the parking washed the pavement materials, which decreased the quality of the water. Moreover, the porous concrete had an additive in its composition that made the water quality even worse. The pH results, although these were not shown because they were around the neutrality most of the time, confirmed this first materials wash, with higher results mainly for the porous concrete parking cells. Suspended solids were initially within the required limits but these increased during October and December of 2008 when rain events were higher and the drag of solids was high.

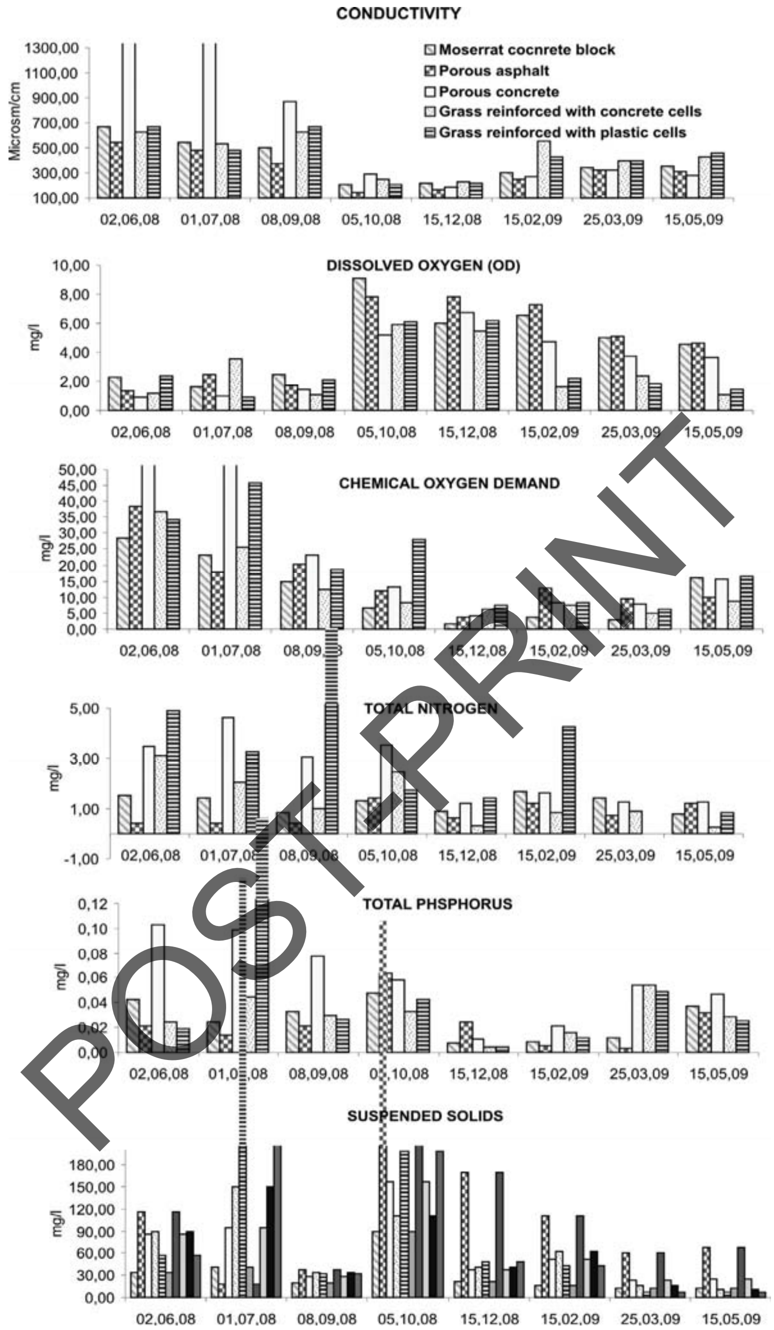

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Figure 6 : Quality of the water stored within the different pervious pavements over the experimental period.

Concluding, most of the water quality parameters were within the required limits after the three first months of the experimental period. However, dissolved oxygen recovered suitable values after three months but decreased again at the end of the experiment, staying around the inferior limit (4mg/l). The rest of the parameters were adequate. Moreover, suspended solids were higher than the limits imposed by law during all the experimental period.

CONCLUSIONS

The main conclusions, related to the stored water quantity and quality, after one year of monitoring the experimental pervious pavement parking area were:

- The water storage capacity was demonstrated because all the parking bays remained at their maximum storage capacity.
- The pervious surfaces were demonstrated to be more influential in water storage than the geotextile layers, at least, under the specific climatic conditions occurred during the experimental time.
- Regarding the water storage, three groups were differentiated with distinct behaviour: Group of continuous surfaces (PA and PC), group of open surfaces (CB) and group of grass surfaces (GCC and GPC). However, the rainfalls happened during the experimental period were so high that all pervious pavements stayed full of water and differences in their water storage were not high enough to be significant.
- Regarding water quality, it was demonstrated that there was an initial period in which rainfalls washed the pavement materials after the construction processes. It caused that the stored water quality was initially unsuitable to be used for irrigation. Porous concrete pervious pavements were worse than the other types, in this first stage, due to the presence of an additive in its composition that was toxic for water quality. After this first period most of the parameters become suitable for using it. However, suspended solids were above the limits required by the Spanish laws and special care should be taken with the dissolved oxygen as it was around the minor limits at the end of the experiments.
- With all the results, some recommendations were given in order to design and construct pervious pavements parking bays in which to store water for using it in secondary demands. Firstly, special care must be taken with the emergency outlets to ensure a proper drainage when rainfalls are abundant. In addition, it should be considered that first washes should be discarded due to the drag of the pavement materials decrease the stored water quality. Moreover, porous concrete contains additives that are damaging for water quality during the first washes. Finally, an intermediate tank may be recommended for water retention before using it in order to reduce the suspended solids and increase the aeration of water.
- Results obtained during the second year of the analyses will help to confirm these results and take final decisions.

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