WATER CONSERVATION

Applications of Permeable Pavements

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A potent solution to the issue of water conservation has been the collection of rainwater. This water management strategy has been implemented through harvesting methods such as the digging of ponds and canals, as well as the installation of rain water catchment ducts and storage systems in homes. A novel rainwater harvesting concept, which is presented as the main proposal of this paper, has the potential to bridge the intermediate gap between domestic rainwater collection efforts and metropolitan level water harvesting measures. The aforementioned method is permeable paving. The utilization of porous yet durable materials in the construction of surfaces for pedestrian and vehicular routes in urban areas vastly expands the total surface area available for the catchment of rainwater. Paired with an efficient subterranean water harvesting system, porous paving shows promise in solving various issues relating to water conservation through; (1) enhancing water management by providing an additional source of harvested water, (2) reducing overland flow of excess storm water, (3) inherent filtration of pollutants from collected rainwater and (4) circumventing reduction of water quality of natural reservoirs through the removal of pollutants from drained storm water.

Keywords:
Filtration, harvesting, paving, permeable, rainwater.

1.0 Introduction

Permeable paving refers to the practice of utilizing porous materials or specific arrangements of non-porous materials in the construction of urban surfaces with the goal of allowing enhanced infiltration of water into a medium underneath (Mullaney, 2014). This could be done with the aim of increasing water absorption by soil in urban areas or the collection of rainwater for later use. The solution reviewed in this paper has two fundamental objectives:

1. Providing an alternative renewable source of water, contributing to improved water management in urban centers.
2. Preserving the quality of natural freshwater sources through the reduction of contaminated urban runoff.

A requisite of sustainable water management is the reduction of water consumption from non-renewable water resources. Therefore, self-supply through rainwater harvesting provides a potent solution to curtail the depletion of non-renewable water resources. A common strategy implemented for rainwater collection at the domestic level is rooftop rainwater harvesting, where the roof a home intercepts the flow of rainwater in combination with gutters and down pipes to supply water for household use. Urban runoff refers to the flow of excess storm water over the Earth's surface. This is a result of land development and urbanization which has enfolded surface soil with impervious materials, leading to inadequate percolation of rainwater through the ground. Unfortunately, urban runoff has become a major source of water pollution as contaminants are carried from urban communities into natural sources of water such as streams and rivers.

In light of this, permeable paving is an elegant solution which is capable of solving both of the aforementioned issues through implementation of a single system. It is hypothesized that widespread application of permeable paving in urban environments for the purpose of rainwater collection could potentially provide a singular system capable of collecting large amounts of rainwater, surpassing conventional rooftop rainwater harvesting efforts (Beecham, 2018). Permeable paving may also diminish urban runoff at the source by infiltration of storm water through permeable surfaces as well as filtration of water which inexorably ends up in streams, lakes and rivers, preserving the water quality of natural sources (Wang, 2010). In the interests of confirming these speculations, some questions need to be answered. Could permeable paving efficiently percolate water such that surface runoff is substantially reduced? Is permeable paving suitable for water collection? Could permeable paving, with limited depth of material, effectively filter storm water?

In this paper, the aim is to test and demonstrate the fundamental principles behind the application of permeable paving, namely high water infiltration rates, resulting in a reduction of surface runoff, as well as the capability to filter out major suspended contaminants from storm water such that it could be safely introduced to natural water sources. To this end, a permeable system arrangement has been and devised and experiments conducted to determine its characteristics and suitability as a method of water harvesting.

2.0 Methodology

2.1 Materials

Materials used in the **creation** of the permeable system are as follows: Bunsen burner; scissors; nail; needle; test tubes; activated carbon; zeolite; coarse silica (2.4-4.8mm diameter granules), rough silica (1.2-2.4mm diameter granules), fine silica (0.6-1.2mm diameter granules); 4 x egg cartons.

Materials used in **testing** the permeable system are as follows: 4 x 1 liter measuring beakers; 4 x 100 milliliter measuring cylinders; tripod stand; stopwatch; pH indicator papers; 8 liter plastic basin; distilled water; collected drain water.

2.2 Chemicals

Chemicals used in the experiment are as follows: activated carbon (C); zeolite ($Ca_2Al_2\,Si_3O_{10}.\,2H_2O$); silica ($SiO_2$). These materials were selected due to their suitability in the filtration of water.

2.3 Method

The first phase of the activity was entirely focused on the construction of the actual permeable system on which further tests could be run. Egg cartons were designated very early on as the matrix to hold the layers of the permeable system due to their durability, suitable container-like characteristics and structure reminiscent of interlocking pavers associated with certain permeable paving concepts. After some deliberation it was decided that industrial materials such as permeable concrete or asphalt were far beyond this team's available resources. After a stage of preliminary testing, activated carbon, zeolite and silica, mediums commonly used in water filtration, were selected to form the layers of the permeable system.

Plastic egg cartons (4 units) were separated into their two halves with a pair of scissors. Of the resultant 8 halves, 7 were used in the system. These halves formed the basis of the permeable layers as 26 holes of approximately 4mm in diameter and 42 holes of approximately 0.5mm in diameter were perforated through the bottom of each half using a nail and needle respectively heated over a lit Bunsen burner. The aforementioned materials were then tightly packed into the halves according to the following fixed ratio from the highest layer to the lowest: 1 layer of coarse silica, 1 layer of medium-sized silica, 2 layers of fine silica, 1 layer of zeolite, 2 layers of activated carbon (see Figure 1). This ratio was devised based on ratios commonly used in conventional water filtration. Cloth was applied as a base to the lowest layer of activated carbon to prevent outflow of carbon granules through the holes at the base of the layer. The layers were then arranged on top of each other in accordance with the previously stated parameters.

Figure 1: *Assembly of the permeable system. From left to right: samples of the permeable materials used. Note that the order of the layers were inverted as conventional filtration systems pump upwards; layers of silica and zeolite arranged as upper and midsections of the system; activated carbon packed into the egg carton half forming the second last layer of the system.*

Once the system was assembled, the task left was to test its characteristics and suitability as a water harvesting strategy. The first stage of tests were conducted to study the system's permeability through the analysis of two factors, which were the ability of 1 litre of water to fully infiltrate the system and the rate at which water could infiltrate the system. This was done by holding the permeable system aloft in a large plastic basin using a tripod stand. A litre of distilled water was then measured and poured onto the surface of the system with a 1 litre measuring beaker. Immediately upon introduction of the distilled water to the system, a stopwatch was started with the aim of measuring the elapsed time between the introduction of the water and the point at which water ceases to infiltrate through the system. Once water had stopped exiting the lowest layer of the system, the stopwatch was stopped. The effluent from the system was collected in the plastic basin and later measured using a 1 litre measuring beaker and a 100 millilitre measuring cylinder to obtain precise readings. This experiment was repeated three times and the results averaged for accuracy. The data acquired (time elapsed between introduction and exit of water and volume of effluent) was used to determine the percentage and rate of infiltration of the permeable system.

Figure 2: *Testing infiltration of water. From left to right: Assembly of the general apparatus and system; infiltration of water through the permeable system subsequent to introduction; measuring the volume of effluent.*

The second round of testing was focused on the permeable system's efficacy as a water filtration system. For this test, 1 litre of contaminated storm water was collected from a drain in close proximity to the laboratory area. The contaminated water was introduced to the permeable system. The resulting effluent was collected and poured into a 1 litre measuring beaker. The quality of the initially collected storm water and the filtered storm water was compared visually and through odour and pH indicators. Unfortunately, the results obtained from the pH indicators were deemed inconclusive, and will not be reviewed in the results and discussion.

3.0 Results and Discussion

Table 1: *Results of the water infiltration tests. The results from the three rounds were averaged for the discussion below.*

Rounds of testing (repetitions)	Volume of effluent (ml)	Percentage of infiltration (%)	Time taken for complete infiltration (s)	Rate of infiltration (ml/s)
Round 1	952	95.2	208	4.577
Round 2	994	99.4	205	4.849
Round 3	985	98.5	199	4.950

From the results obtained (see Table 1), it was determined that the permeable system on average successfully permitted 97.7% of introduced water to fully infiltrate its layers. It could thus be reasonably concluded that 97.7% of rainwater that falls on the surface of the system could be collected by an underdrain for later use. The calculated rate of infiltration was on average 4.792 millilitres per second. The most striking results, however, were obtained from the filtration test. Compared to the initially collected storm water, the filtered storm water was free of visible suspended solids and lacked the distinct odour present in the initially collected samples.

Figure 3: *Filtration test results. From left to right: initially collected storm water; filtered storm water.*

In real world applications, permeable pavements are generally made of three principal materials; permeable interlocking pavers, permeable concrete and pervious asphalt (Selbig and Buer, 2018). Permeable interlocking pavers are essentially impermeable concrete units arrayed in such a way as to create open, permeable voids between units. This technique produces a surface capable of bearing moderate traffic. Permeable concrete consists of cement, water and exclusively large aggregate. The large aggregate size serves to increase the porosity of the concrete by opening minuscule channels allowing infiltration of water. Typically capable of bearing heavy traffic, the quality of permeable concrete is highly reliant on frequent inspection and installer skill due to the very low tolerances set on the ratio of water to cement required in fabricating and maintaining a strong and resilient surface.

Figure 4: *Examples of materials used in permeable paving (from left to right) permeable interlocking pavers, permeable concrete and pervious asphalt*

Pervious asphalt is similar to conventional asphalt, involving the same methods of application, with the omission of finer aggregate from the asphalt mixture, creating void spaces allowing the permeation of water. Subsurface reservoirs are usually built underneath pervious asphalt surfaces to allow gradual infiltration of water into the ground due to the high porosity of pervious asphalt.

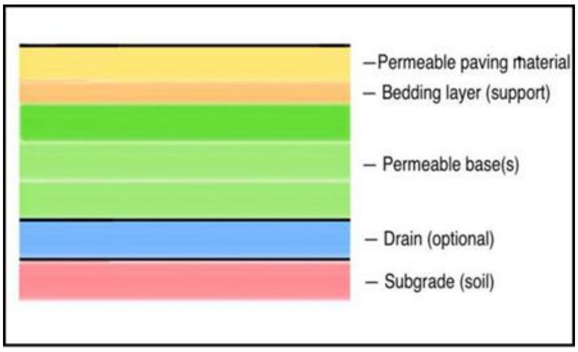

Figure 5: *Permeable paving is usually coupled with a combination of layers composed of large aggregate that together withstand loads, distributes stress and percolate water*

It should be stressed that these different materials have their own individual advantages and disadvantages and their successful application in permeable paving is highly dependent on environmental factors such as traffic intensity, volume of rainfall, presence or absence of polluting particulate, volume of suspended solids (leaves, pebbles, sediment) in the target area, availability of maintenance as well as aesthetic considerations. For example, due to its high porosity, pervious asphalt is ideal for areas which experience large volumes of surface runoff and a lack of regular maintenance as the large void spaces in pervious asphalt do not accumulate small particles. Permeable concrete is ideal for areas with heavy traffic and a presence of particulate pollutants due to the smaller void spaces' ability to filter out particulate matter, while permeable interlocking pavers are ideal for pedestrian walkways with the presence of regular maintenance due the surfaces' vulnerability to clogging. There is no 'one size fits all' material. Consequently, a combination of different materials tailored to different environmental conditions is necessary for effective application of permeable paving.

The predominant constant factor present in all materials utilized in permeable paving is reduced durability relative to non-permeable alternatives. Void spaces within the material to allow infiltration of water inevitably results in diminished strength. This limits the use of permeable paving to areas with low-volume and low-speed traffic such as pedestrian pathways, parking lots and residential streets. A possible solution to this issue is a semi-permeable paving technique which fabricates a surface with a permeable top layer with an impermeable base. This allows water to infiltrate the upper layers of the surface and drain away to the side into a storm drain or a fully permeable pavement. This preserves the overall strength of the material, rendering it suitable for use in high-intensity traffic routes. An example of such paving is open-graded friction courses (OFGC) which utilize pervious asphalt.

Conventionally, permeable paving is used to trap and gradually release precipitation by infiltration into the ground with the aim of reducing the volume of storm water which flows across urban surfaces, into storm drains and out to receiving natural water sources. Nevertheless, the results obtained from our experiment shed a positive light on the potential of permeable paving as a water harvesting strategy. Available data as to permeable paving's water infiltration qualities also paints a positive picture as to the benefits and other potential applications.

In a study conducted by the Ramsey-Washington Metro Watershed District, a test permeable pavement of $650m^2$ was found to produce no surface runoff when exposed to precipitation up to 51mm, as opposed to $15000m^3$ of runoff produced when a conventional non-permeable control pavement was exposed to 25mm of precipitation (Ramsey-Washington, 2006). The ability of permeable paving to curtail urban runoff is further displayed in a study by Gilbert and Clausen in which permeable interlocking pavers were found to reduce volume of runoff by 72% compared to a conventional non-permeable asphalt pavement, as well as Hou et al. which evaluated three different permeable paving materials and found them to have a surface runoff coefficient of 0 when exposed to precipitation of up to 59mm compared to conventional paving with a coefficient of 0.85 (Gilbert and Clausen, 2006; Hou, 2008). A study investigating the hydraulic characteristics of permeable paving in contrast to conventional paving in Italy on a stretch of highway found that permeable pavements take twice as much time to produce runoff after the beginning of rain than conventional paving (Pagotto, 2000).

The same study also found that the total suspended solids in storm water produced by the test permeable pavement had decreased be 81%. Other studies focusing on the filtration qualities of permeable paving include Legret and Colandini who found that permeable pavements retained 59-73% more pollutants than conventional pavements and Eck et al. which tested the filtering qualities of pervious asphalt and found a 96% reduction of total suspended solids in resultant storm water as well as reduction of total metallic pollutants upwards of 70% (Legret and Colandini, 1999; Eck, 2012). Permeable pavements could even be modified to retain and remove petroleum-derived pollutants from storm water as demonstrated by Pratt et al. through integration of a geo-textile membrane to a permeable concrete pavers based system, successfully retaining over 97% of the oil the pavement was subjected to (Pratt and Newman, 1999).

Of particular interest to the main thrust of this paper, studies have been conducted to evaluate the utilization of permeable paving as a water harvesting strategy. Antunes et al. assessed the possibility of using specially modified pervious asphalt in the city of Florianópolis, Brazil and found that the residential, public and commercial sectors could potentially save up to 18%, 57% and 69% on potable water respectively (Antunes, 2016). A case study involving a hostel in the UK with a combined roof and parking lot area of $725m^2$ estimated that, through application of permeable paving, the hostel pavements could store approximately $34m^3$ of water (Pratt, 1999). Thives et al. concluded that a permeable paving surface equal to $9058m^2$ connected to a $1000m^3$ storage tank could result in savings of up to 33% on total potable water savings for multifamily buildings in urban centers (Thives, 2018).

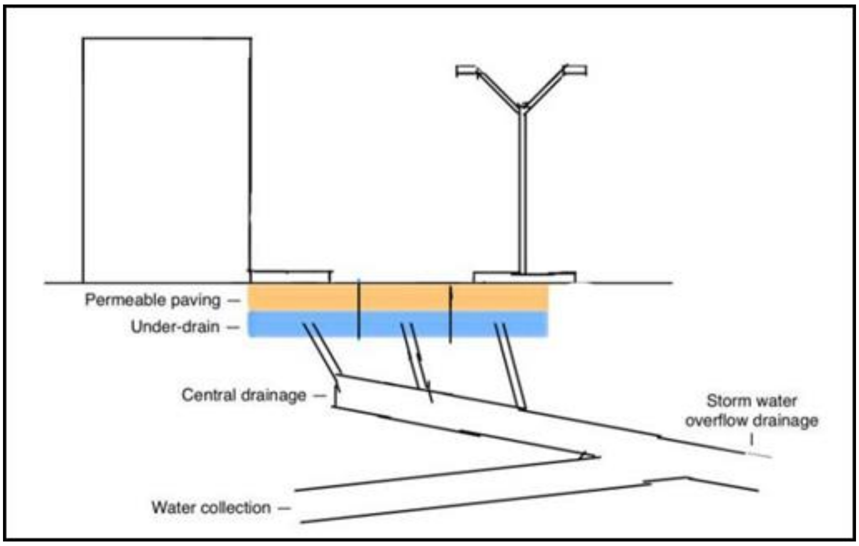

Figure 6: *Hypothetical layout of a permeable paving based water collection system.*

4.0 Conclusion

To conclude based upon the previously reviewed information, the merits of a permeable paving based water collection system have been adequately elucidated. A hypothetical system would involve a large surface area of permeable pavements consisting of various materials in accordance with environmental requirements, under-drains and downpipes leading to a central drainage channel, feeding into a water collection tank or into storm drains in the event of excessive water infiltration. Such a system would effectively reduce urban runoff, filter pollutants from storm water and furnish substantial savings in potable water and ensure the water quality of nearby sources.

Acknowledgements

We would like to take this opportunity to thank S.M. All Saints for providing experimental apparatus and laboratory facilities that has been essential to the rapid completion of our tests throughout the research period. We also thank Mrs. Susan Chin Syuk Man, our Chemistry teacher, for providing guidance and unrelenting cooperation during our research as well as writing assistance, proofreading and technical editing together with both team members. The permeable medium materials used in the experiment were privately sourced by the corresponding author from Platinum Marketing, Kolombong, Kota Kinabalu, Sabah as well as University Malaysia Sabah (UMS).

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