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Do Pervious Pavements Really Need Pervious Surfaces? The Concept of the Macro-pervious Pavement as a SuDS Device

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Abstract

Pervious pavements, as part of sustainable drainage systems, have a long history but there is some resistance to their use based on worries over pavement life and difficulties associated with clogging. Whilst stormwater run-off rates and volume controls that arise from a pervious pavement certainly do not require a pervious surface (*i.e.*, the storage and infiltration of water could be equally well achieved no matter how the water is directed underground), it is the water quality issues dependent on the filtration through the pervious surface which are receiving more attention. The purpose of this study is to illustrate that this is not the case and that a pavement with a sub-surface storage and treatment zone can operate effectively when water is directed underground by suitably designed, discrete, infiltration points. These infiltration points serve to trap the majority of pollutants in the upstream part of the treatment train where they can be dealt with via a simple maintenance schedule. In particular this study reports up to date results from an on-going study on a macro-pervious pavement in Scotland and on studies on systems which utilise oil separators installed either to take stormwater from individual gulley pots, or within channel drains, serving a pervious sub-base.

Keywords; Sustainable drainage systems, pervious pavements, hydrocarbons

1. INTRODUCTION

Pervious pavement systems are well established devices which can form part of a sustainable drainage system (SuDS) and their use is particularly well established in Scotland. Forming a subset of pervious pavement systems (PPSs), a newer approach is an alternative device, which has been described as a "macro-pervious pavement" system (MPPS) and which directs stormwater underground through a system of widely distributed, but distinct, infiltration points [1].This allows the use of traditional impervious surfacing. The design of a MPPS should provide a treatment process that removes stormwater pollutants and should detain the bulk of these pollutants in a position where they can be easily removed. A good example of the advantage that could be provided by such a system is illustrated by the results reported previously [2], relating to the performance of traditional pervious pavements, which showed that when stressed with a major oil loss equivalent to a total sump failure or a significant fuel leak the PPS will release unacceptable concentrations of hydrocarbons, including free phase hydrocarbons. Even if the PPS is equipped with an oil sorptive geotextile between the laying course and the storage layer the extra protection provided by that element will eventually be overcome. Once the pollutant has moved underground there is little to be done to prevent the continuing, ongoing losses of hydrocarbons in the effluent other than excavating the contaminated material which by that time may have spread to cover a significant area below the pervious surface. The question arises then as to whether there is another means of directing water below ground which allows the retention of day to day inputs of automobile derived pollutants, at least as well as can be achieved in a pervious pavement, whilst providing a barrier to a large spillage of free phase oil providing an opportunity to recover it, before entering the storage layer where it would be difficult to recover. Two alternative methods to achieve this are considered here. The first is a combination of a traditional gully pot and a miniaturised gravity separator constructed below the wearing course. Figure 1 provides a schematic diagram.

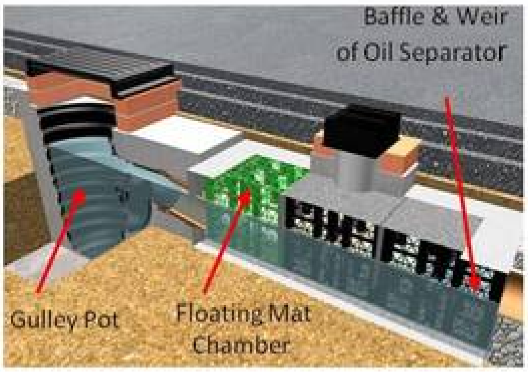

Figure 1: Schematic Section Through Typical Gully Pot and Miniaturised Gravity Separator System

The second option is the channel drain separator developed as part of a Knowledge Transfer Partnership between Coventry University and SEL Environmental Ltd. of Bury, Lancashire [4].

Figure 2 illustrates a schematic of one form of this type of installation and Figure 3 provides an indication of how the gravity separation system operates. Both of the systems studied here usually also include a chamber containing a floating polyolefin geotextile to provide a sorptive barrier to any floating oil sheen and a surface upon which biodegradation can take place [3].

This paper shows that both the channel drain and the gravity separator/gulley pot combination can provide, on their own accounts, a very high proportion of oil separation and retention when applied in large quantities and when stressed with significant storm events.

Figure 2: Schematic Section Through Channel based MPPS

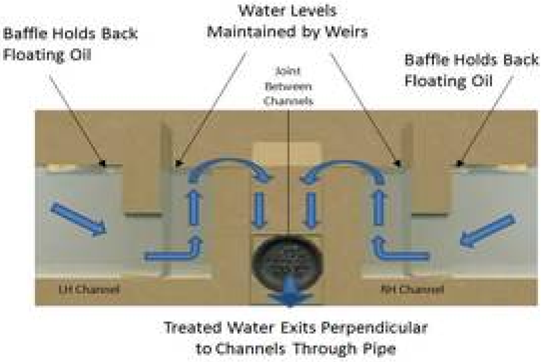

Figure 3: Schematic Representation of Active Part of Channel Separator

However these devices would not normally be expected to be used as sole collectors. Rather relatively numerous installations (so as to limit the individual catchment areas and flow velocity at each individual infiltration point) would be used to provide upstream protection to other SuDS devices and, notably, both are well capable of being incorporated into a sub-surface storage layer to form a "macro-pervious pavement". They have also been applied to protect sand filters.

This paper reports three separate studies. The first two are previously unpublished experiments, available only in internal reports, demonstrating the efficacy, with respect to hydrocarbon retention, of the channel drain based and gulley pot based initial pollutant collectors (in isolation). The experiment using the channel drain device simulates the loss of a full sump of oil on the equivalent area of a single car parking space (11.5 m^2) onto a wet surface, followed by a rainstorm after the oil had time to run into the initial collector. The second experiment illustrates the gulley pot device tested to simulate the more challenging situation when the oil is lost during the rain event and arrives at the collector already intimately mixed with water. The final study reported here is an extension, by four years, of an investigation previously reported [1], into the quality of water from a channel drain based macro-pervious pavement.

2. MATERIALS AND METHODS

2.1. Performance of the Channel Drain Based Device

Apart from a shorter run time the method used in this study was identical to the method previously reported for the investigation of the performance of a similar device based on a concrete kerb drain [3]. Although this device was found to perform well with respect to oil retention, problems in maintaining the integrity of the water seal lead to the development of the device tested here [4]. In summary, 2.9 litres of unused engine oil (Castrol GTX) were applied to a wet concrete surface and allowed to run into the device.

A simulated rain event of 13 mm per hour was applied over 3 hours to the concrete surface, with grab samples collected from the device outlet at intervals. Analysis of petroleum hydrocarbons was carried out using a Horiba model OMCA-310 oil analyser using the manufacturer's specified method. The simulated rain event was applied as a combination of sheet flow and direct rain from a rainfall simulator.

2.2. Performance of the Gulley Pot/Miniature Separator

The experimental protocol was designed to simulate worse credible pollution and rainfall events. The apparatus constructed for this trial comprised a full size miniature interceptor unit (1062 mm × 708 mm × 300 mm, currently available under the trade name Gulleyceptor) which was installed in the laboratory simulating the conditions as installed in the field. The system tested did not include the floating mat inserts so as to represent the performance of the device itself. The system under test was receiving a stormwater/oil mixture from a separate mixing chamber (725 mm × 360 mm × 450 mm) discharging directly into the standard road gully of the unit. The experimental set up is shown schematically in Figure 4.

During the experiment the system fed by pump with a constant water flow of 3.0 l/s. The flow was set and monitored using a flow meter (Danfoss MAG 3000, Denham Bucks), which was installed in the feeder pipe work. The entire oil retention performance test was conducted over a period of 20 minutes. The test oil used was Castrol GTX, added at a rate of 5 ml per litre of feed water. The simulated stormwater was then transferred to the separation unit and then discharged over a weir to the outlet.

The samples were taken directly from the effluent pipe through a proprietary sampling point. The samples were taken into amber glass bottles at one minute intervals during the last five minutes of the test. The sampling was started at exactly 15 minutes after the experiment started (minutes 16 to 20). The samples were transported to the laboratory on the following day and analysed for total petroleum hydrocarbons (TPH) by gas chromatography using a flame ionisation detector.

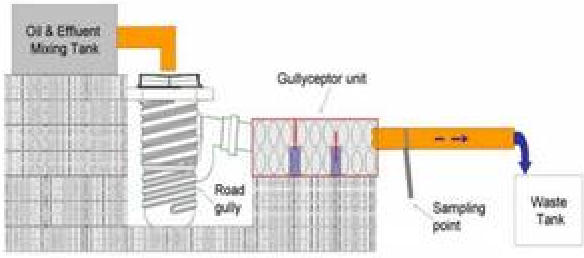

Figure 4: Section Through Gully Pot and Miniaturised Separator Test Apparatus.

2.3. Ongoing Investigation into the Performance of a Live Macro-Pervious Pavement.

This is an extension of the previously reported field study at Perth Prison in central Scotland and the details of the study site and sampling regime are described in detail elsewhere [1]. The following is a brief description to aid understanding of the data. The car park was constructed in 2008 and consisted of 3 sub-catchments (two of around 1,350 m^2 and one of 300 m^2). The extended study was applied only to the two larger sub-catchments.

The majority of the surface of the car park consists of impervious asphalt with surface water collected by linear shallow gravity separator units discharging into a secondary pollution attenuation system below the pavement. It then flows into the crushed limestone subbase which drains towards separate flow control chambers in each of the sub-catchments to allow flow control through an orifice plate at each outlet. These provide convenient sampling points. Twelve months after the car park was completed a sampling regime was instigated in which grab samples were collected from each of the flow control chambers. Samples were initially collected from April 2011 to September 2012 and then, following consideration of the data, sampling was recommenced in 2014 and continues.

Physical and Chemical Analysis

Characterisation of samples included: suspended solids (TSS), heavy metals (lead, zinc, chromium, nickel, cadmium and copper), organic pollutants, total petroleum hydrocarbons (TPH), benzene, toluene, ethyl benzene, xylenes (collectively BTEX), methyl tertiary butyl ether (MTBE) and nutrients (total oxidised nitrogen, ammonium and total phosphorus). For brevity each quality parameter is described in the results section by the maximum concentrations from either of the two sub-catchments over all sampling events for which data is available. The exception is for two parameters which gave an outlying maximum where the next highest value is also presented in brackets. Data is presented separately for sampling during 2011/12 and 2014/15 and, as abovementioned, sampling continues at this time. This paper presents data up to

April 2015 and considers the data from the point of view of discharge to the adjacent watercourse.

3. RESULTS AND DISCUSSION

3.1. Initial Collection Devices

Table 1 shows the results of the experiment performed on the channel drain device which was designed to illustrate its performance following a spillage to a wet surface followed by a subsequent storm event. It can be seen that under the experimental conditions used the channel collector provides good oil retention even if used in isolation.

Table 2 presents results for the gulley pot/miniature separator test and it is clear that this too provides very good performance. Since the oil was, in this case, intimately pre-mixed with water the performance would not be expected to be as good as the previous experiment but if this were to be used with the additional treatment capabilities discussed below it can be expected that the output from a pavement system equipped with this means of getting the water below ground would produce acceptable effluent quality with respect to hydrocarbons even in the event of a major spillage.

Table 1: Test Results Channel Drain Separator.

Sample Event	Time since oil application (mins)	Conc. of Hydrocarbon mg/l
1	0	0.0
2	15	1.8
3	30	2.0
4	45	3.2
5	60	2.4
6	75	2.6
7	90	1.9
8	105	1.5
9	120	1.8
10	135	2.1
11	150	1.6
12	165	1.9
13	180	1.7

Table 2: Test Results Gulley Pot System.

Minutes from Start of Test	Conc. of Hydrocarbon in Effluent (mg/l)
16	20.1
17	10.1
18	4.4
19	19.5
20	7.0
Feed Concentration	4265

3.2. Ongoing Performance of a Live Macro-Pervious Pavement Parking Lot

Table 3 reports the data obtained at this site from samples collected from the collector channels [1], and is reproduced here (open access source) to illustrate the fact that the system was subject to significant contamination from automotive sourced pollutants. Notable is the presence of BTEX compounds at high concentrations, presumably originating from gasoline. Table 4 presents the data for the two phases of study at the Perth Prison site. The BTEX compounds (data not shown) were always below the limits of detection which were themselves below or equal to the lowest of the available drinking water standards and thus were considered not to be a problem from the effluent discharge point of view.

Table 3: Pollutants Trapped in Macro Pervious Pavement; Samples of Retained Silt in Channels. n= 8 samples [1].

Pollutant	Units	Mean	Max
Pb	mg/kg	44	160
Zn	mg/kg	194	340
Cr	mg/kg	25	61
Ni	mg/kg	26	77
Cd	mg/kg	18	72
Cu	mg/kg	43	160
Benzene	µg/kg	<10	<10
Toluene	µg/kg	17	72
Ethyl Benzene	µg/kg	1510	4200
Total Xylenes	µg/kg	66	201
TPH	µg/kg	3500	13000
MTBE	µg/kg	<80	<80

Note: More detailed data available at reference [1].

Table 4: Maximum Recorded Concentrations in Effluent from Perth Prison Site.

		Maximum Recorded Concentration		
	Units	**2011-2012**	**2014-2015**	**Adopted Discharge Limits**
TSS	mg/l	18	8	25[a]
NH_4-N	mg/l	<0.2	0.4	0.42
Tot. Ox.-N	mg/l	1.3	29(1.1)	na
Tot. P	mg/l	13(<0.4)	<0.4	2.4
Pb	µg/l	2.1	<2	144
Zn	µg/l	280	72	1000
Cr	µg/l	5.7	0.9	68
Ni	µg/l	8.4	5.9	400
Cd	µg/l	0.3	<0.2	1.8
Cu	µg/l	56	26	200
TPH	mg/l	0.35	0.19	5[b]
MTBE	µg/l	<10	<10	13[c]

Note: For 8 sampling events 2011/12 and 7 events 2014/15. Figures in brackets are next highest values and are shown where single outlying events occured. See reference [1] for derivation of effluent limits except as follows: [a] Ref [5] ;[b] Limit for class 1 petrol interceptor (Ref [6]); [c] State of California drinking water standard., na-not available.

The effluent pH range throughout the study was between 7.9 and 11.1, with an overall median of 9.4. This reflects the passage of the exiting water through an extensive bed of limestone which probably plays a significant role in the precipitation of both phosphorus and metals. Clearly the effluent continues to be of very good quality and it certainly compares well with the data presented for traditional pervious surfaced car parks which is summarised in the earlier paper [1]. The question arises then as to where the pollutant attenuation is taking place. Significant retention in the channel drain collectors can be implied from the data presented in Table 3 but these collectors are not intended as barriers to dissolved or finely dispersed pollutants. Fortunately there are several other mechanisms available in the MPPS, indeed the same ones as are available as a PPS, filtration, adsorption, chemical precipitation, biodegradation and volatilisation. Not reported here but published previously [1] are the concentrations detected within the liquids in the channel drains during the 2011/12 survey. The values of total oxidised nitrogen were found to be much lower within the channels than was typically found in the effluents. This reflects the mineralisation of organic nitrogen within the system and indicates that aerobic conditions are maintained through to the outlet.

4. CONCLUSION

The answer to the question posed in the title to this paper is that there is clearly no absolute necessity to utilise a pervious surface to achieve the day to day pollution attenuation performance of a PPS. Furthermore a suitable means of directing the water underground can protect the sub-surface layers from large hydrocarbon spills in such a way that the separate phase can be recovered easily.

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