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Practical Applications of Pollutant Retention and Biodegradation Devices for Stormwater Infiltration Systems Serving Impervious Surfaces and Sites under Construction

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ABSTRACT

A problem associated with pervious surfaces of all types is the reluctance by some developers to make use of them. Another important issue, in a retrofit situation, is the need to improve the sustainable aspect of existing drainage may well not be sufficient to justify ripping up and re-laying large areas of pavement (Stovin and Swan, 2003). Indeed pervious pavements are amongst the least economic options for SUDS retrofit (Stovin, 2004). These factors defined the need to create a system which could be used in conjunction with new or existing impermeable surfaces and with the flexibility to allow either infiltration or attenuation/further treatment under a new paved surface or to facilitate off-line infiltration for retrofit purposes. It is necessary that the system retains much of the hydrocarbon and suspended solid removal capabilities of a pervious pavement. The system proposed is a potentially attractive pre-cleaning device prior to a sand filter or filter trench or swale. Where space allows, such systems could be constructed either as a continuous trench or at intervals along the boundary of a paved area such as a car park, allowing water to be infiltrated directly into the ground. This can be achieved with minimal disruption to an existing paved surface; allowing conversion to be carried out relatively cheaply. Alternatively, in new build applications, the water can be directed back under the surface into a water-storing sub-base or synthetic sub-base replacement system for either infiltration or attenuation. Utilising this technology in combination with the Permaceptor close-coupled oil interceptor, equipped with the floating mat oil sorbing/biodegradation system, can produce a surface water treatment train with three phases of treatment. The device, which was developed, was based on a kerb drain where, instead of the water being conveyed linearly along the drain, the water would be transmitted perpendicular to the drain into a downstream infiltration or attenuation device via a proprietary oil/water separation system. All installations to date have been achieved using either the close-coupled oil interceptor, formed using membranes within shallow structural modules, or by incorporating standard kerb drains and channel drains modified for the process. However, this device has gone through a series of development stages and the testing reported upon is from an earlier form of the system before the development of the current system, which is much more amenable to mass production. Several practical applications of this device will be reported, as will the latest results on the mass produced model. Further important developments relate to the protection of sites from hydrocarbon pollution during the construction phase. This issue is also addressed.

1 INTRODUCTION

The current research and technical guidance for SUDS and in particular pervious pavements is perceived and applied almost exclusively to new developments rather than via implementation into existing schemes. The retrofit of SUDS elements or schemes is a rather novel approach fronted by Swan & Stovin in 2001; focusing on the economic point of view. Consequently, fewer solutions have been developed that conveniently achieve retrofit installations. The solutions put forward in this publication are appropriate for either application: new developments and retro-fit.

The performance and effectiveness of pervious pavement (PP) systems, regarding the retention and biodegradation of hydrocarbons, is unquestionably good and well understood. This has been previously demonstrated both in laboratory studies aimed at hydrocarbons (Newman *et al.*, 2002(a) & 2002(b), Coupe *et al.*, 2003) and field studies (Pagotto *et al.* 2000, Brattebo and Booth, 2003). Pratt *et al.*, 1999, which have shown that the oil retention properties of some block paved PP systems, are capable of adsorbing the volume of oil arising from the regular daily drips from vehicles in a car park. Despite this performance, it has also been shown that higher oil loadings exceed the oil retaining capacity of these systems, causing them to fail under certain circumstances as described by Puehmeier *et al.*, 2004.

These problems can be overcome by a closely coupled pavement/oil separating system, which allows post-infiltration/separation of oil from polluted infiltrated stormwater. The effectiveness of this development was described by Wilson *et al.* (2003) and Newman *et al.* (2004). This separating arrangement demonstrated greater performance when constructed in conjunction with proprietary polypropylene load bearing/storage elements used in attenuation, rather than an infiltration format. This system has shown, in shock loading conditions, to have a much better oil retaining performance compared to systems constructed without the oil/separator configuration as shown by Puehmeier *et al.*, 2004.

Based upon the system described by Wilson *et al.* (2003) the Permakerb/channel has also been developed, as has a temporary refuelling bund for use by plant on construction sites (see case study 3 below).

An important issue associated with the device reported by Wilson *et al.* (2003) is the eventual formation of flocculated bodies of oily matter, which might either by-pass the system or clog the geotextile filters at the outlet. This has been recently addressed by the development of a floating mat device (Puehmeier *et al.*, 2005), which interacts with the free product oil, allowing the formation of a biofilm on a solid surface and provides the opportunity for nutrient recycling, which can promote active biofilm development in the absence of regular nutrient inputs. The system is intended to provide an environment which is ideal for the encouragement of oil degrading micro-organisms where moisture, oil and oxygen from the atmosphere are all available in a situation supplied with a large surface area for oil adsorption and biofilm attachment. This development is presented in more detail (Puehmeier *et al.*, 2005), particularly with respect to biofilm development, but it is mentioned here because it allows greater choice in treatment train options and, in particular, the Floating Mat device could replace oil removing devices such as sand filters.

2 DESIGN AND CONSTRUCTION CONSIDERATIONS

The design and installation of various traditional methods of achieving a sustainable drainage system e.g. ponds, swales, end of line oil separators etc. often prove to be unsuitable due to numerous problems, predominantly related to commercial (e.g. cost of land-take), feasibility (e.g. level restrictions) or environmental (e.g. underlying aquifer) issues. In addition, the impact of the CDM Regulations (HSE 2001), with its emphasis on health & safety risk assessment to achieve safe construction methods, has led designers and contractors to seek SUDS components that avoid the need for deep excavation or man-entry maintenance. All of these problems are exacerbated by the presence of abnormal construction hazards such as a high water table or contaminated ground, and these 'abnormal' conditions are more frequently encountered due to the increasing re-development of 'Brownfield' sites and the continued increase in groundwater levels throughout many areas of the UK. However, the recent introduction of high-strength modular plastic sub-base replacement attenuation, together with the close-coupled oil-interception systems described above, has presented alternative methods of effectively achieving the control of run-off volume and the treatment of effluent at source. These systems are typically installed with a construction formation less than 500mm deep and are designed to receive and control run-off locally to each sub-catchment. In this way, silt, effluent and run-off volumes are prevented from amassing within the site. This approach has numerous benefits to each aspect of the SUDS design:

Effluent treatment - The potentially contaminated run-off is intercepted and oils separated at source, preventing any large scale spillage from passing through the system, and preventing the development of large scale point-loading of hydrocarbons at the end of the drainage system. With this approach, the prolonged oil loading is able to be degraded aerobically within the interceptor channels or withheld within the floating mat and by designing the channels as stilling mechanisms rather than hydraulic conduits (they are laid to zero gradient) the development of high flow velocities is prevented, thus minimising emulsification of any oil content. The close-coupled, shallow nature of the system (may be as shallow as 250mm at outgoing invert level) facilitates the incorporation of multiple treatment phases within close proximity and usually offers a wider choice of SUDS components for

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incorporation within the treatment train e.g. the connection to shallow swales or infiltration trenches after the primary treatment by the channels, mats or Permaceptor (may incorporate all four phases).

Silt Control – As run-off is immediately stilled within the channel element, silt is deposited on a localised basis at the head of the system. This prevents silt being passed through the whole system and amassing at particular points within the system. The silt is collected from the channels during routine maintenance. The silt loading design for a typical installation is usually factored to allow for years of non-maintenance, before the effectiveness of the oil separation and flow control mechanisms are significantly impaired (see case study 1).

Volume control – Run-off is controlled at source via the channels and close-coupled oil interceptors. Attenuation or infiltration attributable to the local catchment is invariably located adjacent to the channels; either within the pavement construction or within narrow, shallow infiltration trenches that may incorporate sand filters. This approach facilitates the attenuation of run-off at very shallow depths (typically 300mm to invert), enabling flow control to be achieved using simple orifice plates, as the hydraulic head developed within the system is minimal, avoiding the need for sophisticated velocity control mechanisms. In these systems, storm events exceeding the designed values result in localised control of excess run-off volume at the surface, adjacent to the channels.

In applications where there is a reluctance to use pervious surfaces, the properties of SUDS treatment trains can be enhanced by the introduction of an oil separating kerb or channel drain device which acts as a protective pre-filter for further downstream elements. The initial testing and practical application of such a device is the main focus of this paper.

The experiment briefly described here represents a sub-section of the field installation. In this particular version of the model, the kerb drainage elements were intended to be linked such that the entire length of the drainage system is used as a stilling chamber, to spread out the oil. The experimental design was such that it represents a situation in which a major hydrocarbon spillage occurs simultaneously in every single car parking bay on the car park and that all spillages occur one meter from the kerb edge, through which the water enters the combined channel/sand filter system. Figure 1 shows a cross-section through an improved version of the Permachannel, which is currently under development, and will provide practical advantages for installation. A closed-coupled oil interceptor is formed between adjacent channel ends.

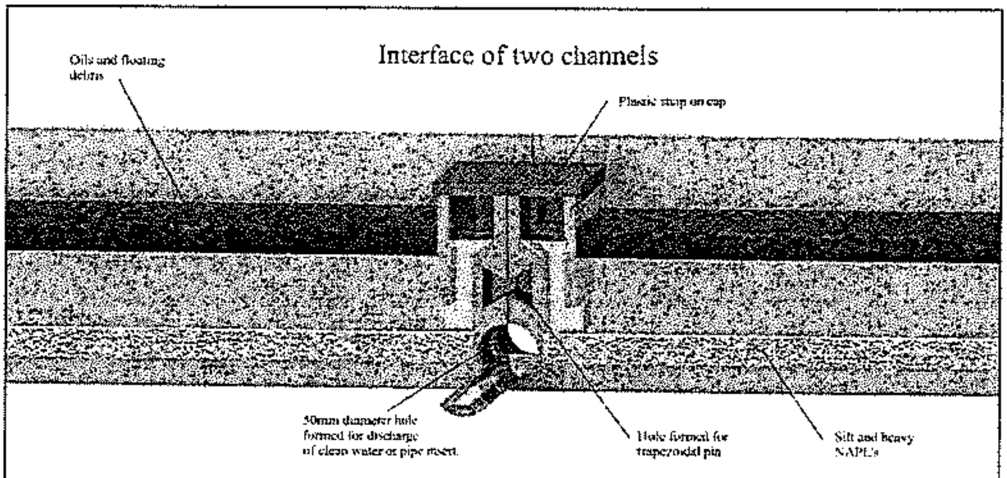

Figure 1: Permachannel – MK II

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3 TEST APPARATUS

The test apparatus comprised three main parts - a section of the Permakerb/channel, a sand filter and a section of paving, onto which, pollution and rainfall could fall and then flow into the treatment device. Thus, the test apparatus replicates a small part of a typical car park installation. The poured concrete pavement section of the model had a width of 0.7 m and length of 1.5m with a 1 in 80 fall. The pavement conveyed the surface water from the experiment through the treatment element. The effluent from the Permakerb/channel was discharged into the sandfilter by a geotextile-lined slotted pipe encapsulated in filter geotextile. The sand filter cross section (0.6 m^2 plan area, with a depth of 0.7 m) was constructed within a geomembrane-lined rectangular cavity, which was reinforced with a metal frame and fitted with an acrylic front panel to allow observations of the water movement. The photograph below Figure 2 shows the test rig in mid cross-section and was taken before the sampling pipes were fitted.

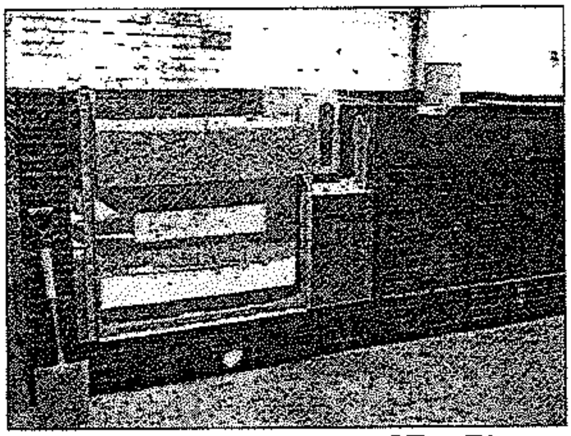

Figure 2: Cross Section of Test Rig

Sampling points were fitted between the Permakerb and the sand filter and at the bottom of the sand filter section, to facilitate sampling from the individual parts of the model system.

The system was provided with an artificial rain device, which was pressure-fed and capable of delivering water to the cross-section of parking surface. This was used to provide realistic raindrops directly interacting with the "oil spill". The artificial rain was supplied as tap water. The pressure fed rainfall simulation device, previously described (Pratt et al., 1999), was installed such that the raindrops fell 1m before directly contacting the oiled surface. Additionally, at the up-gradient extreme of the pavement cross section, there was provision for the application of additional water to represent the sheet flow over the surface of the parking bay. The water flow was controlled by gravity through a constant head device. This would not be contaminated by oil but would contribute to the potential for the surface water flow to lift the oil from the pavement and carry it into the Permakerb/channel. The ratio of the flow applied as rain directly to the polluted surface versus flow applied as sheet flow was 1:4.

The water flow from the rain device was adjusted to represent a rainfall intensity of 13mm/hour and the sheet flow volume was adjusted to a volumetric flow rate of 4 times the flow from the rain device. The system was set up and the flow rates for both sources of water were set (direct rainfall and sheet flow). The system was allowed to prime for half an hour. The catastrophic spillage was simulated by applying 2.9 litre of new lubricating oil (Shell Rimula Super SAE 15W-40) directly onto the pavement whilst continuing to apply the rain. One litre Samples were taken continuously after the oil application for approximately 1125 minutes. Samples from the Permakerb/channel were extracted from a bypass pipe,

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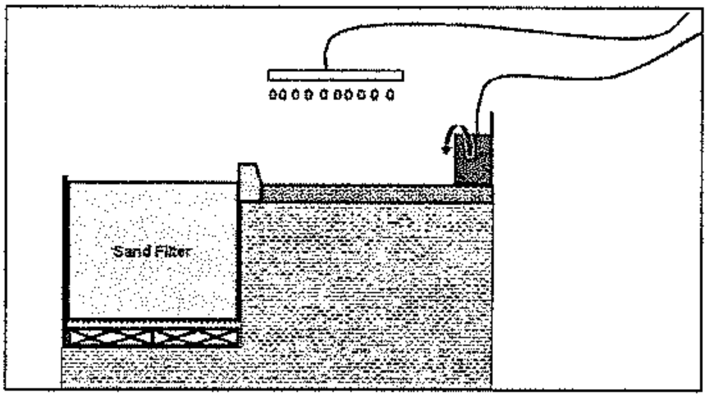

Figure 3 Experimental setup with rain simulator

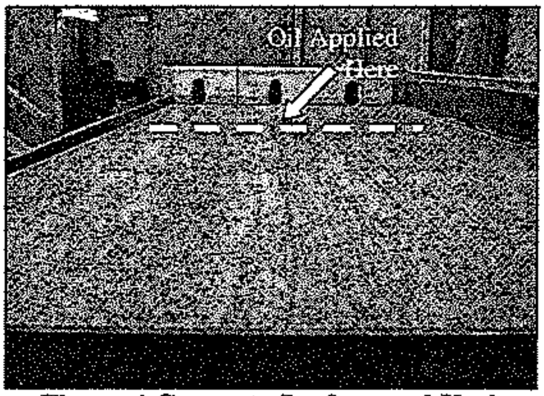

Figure 4 Concrete Surface and Kerb Drain Inlets

The amount of oil used equates to an equivalent of 10 litres of oil on a single car parking bay. One litre samples were taken continuously after the oil application for approximately 1125 minutes. Samples from the Permakerb/channel were extracted from a bypass pipe, which intercepted the effluent directly from the oil separator, before entering the sand filter with an interval of 0, 13, 30, 45, 60 120 and 158 minutes from the oil application. The sand filter samples (representing the overall performance of the system) were collected from the lower drain, below the sand filter, as soon as it started to discharge, at 127 minutes from the oil application and at 143 and 189 minutes. A control sample was also collected. The samples were subject to direct analysis, providing an immediate indication of the concentrations during the experiment and later by independent analysis by a United Kingdom Accreditation Service (UKAS) accredited commercial laboratory (Severn Trent Laboratories, STL) utilising their standard laboratory methods. The analysis during the experiment was undertaken with a portable, non-dispersive infrared analyser (OCMA 310, Horiba UK). A sample was also collected 1125 minutes from the start of the test, but this sample was subjected to analysis on the portable analyser only.

4 RESULTS AND DISCUSSION

The applied oil was washed from the pavement in approximately 15 minutes after the start of the rainfall simulation and was collected in the Permakerb/channel. This is obviously a good representation of a worst-case scenario, demonstrating the ease with which the oil was lifted from the surface and transferred into the Permakerb/channel. This behaviour was probably a result of the pavement being completely saturated with water prior to the oil application. In practice, application to dry concrete would result in a much greater degree of surface retention of the oil due to it being soaked into the concrete. Asphalt surfaces would retain a greater proportion of a very large spillage of oil than concrete but this would lead to softening of the surface. The layer thickness of free-product oil, which could be seen in the cross section of channel drain, was approximately 40mm and the surface water was seen to pass through this layer without disturbing the surface, due to the low flow velocities within the system. The 40mm thickness was anticipated, based on the volume of oil added and the surface area of channel.

Figure 5 below shows graphically the analytical results obtained for both the pre-treatment system and for the infiltrating sandfilter. To put this into context, it is plotted on a scale of 0-5mg/l with 5mg/l being the limit specified for a Class 1 interceptor in British Standard BS EN 858-1: 2002.

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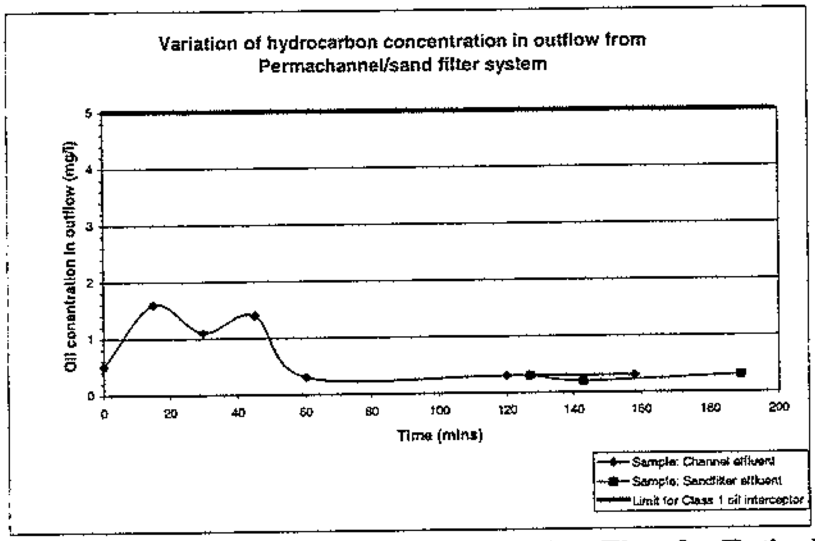

Figure 5: Graph of Oil and Grease Concentration Against Time for Entire Experiment.

Clearly the system is operating very effectively and there is no indication that the system is at risk of exceeding 5mg/l even under these very onerous test conditions.
Since the concentrations measured in the output from the pre-treatment system were well below 5mg/l the output concentration in the sand filter effluent is not particularly important. However, the results do indicate that under the conditions of test there is additional treatment taking place as the effluent passes through the sand filter. This is unlikely to be particularly effective under these test conditions since the free product is retained in the pre-treatment system and we are only dealing with dissolved phase pollutant. However, if free product oil did enter the filter, it would be trapped within the sand filter and biodegradation would occur. The results obtained by the two different analysis methods (Horiba, STL) have proven to be very comparable.

5 CASE STUDIES

The Permakerb/channel and Permaceptor (within structural plastic sub-base replacement storage) described above, have already been incorporated within numerous field installations. The following case studies demonstrate the effectiveness of these pre-treatment devices in more detail, relating to their performance in the field rather laboratory test models.

Case Study 1. Springfields Shopping Centre, Spalding - Stormwater Management Design
Key Aspects:

- Retail Development with extensive car parking
- SUDS Design
- Run-off volume control at source
- Pollutant control at source
- Best Value Engineering

Project Aims:

To develop a cost-effective alternative stormwater drainage system to serve a new retail development. Utilising shallow SUDS techniques to avoid problems with high water table, cohesive silty soils (running sands) and to reduce health and safety risks.

The Springfields Outlet Shopping and Garden Festival development is located in Spalding, Lincolnshire. The entire site covers nearly 12 ha with 5.2 ha comprising buildings and hard paved areas (30000 sq.m) that are drained directly into the SUDS system. Flood protection against a 1 in 100 year return period storm was required. A conceptual SUDS design was developed as an alternative to a conventional stormwater drainage and storage scheme.

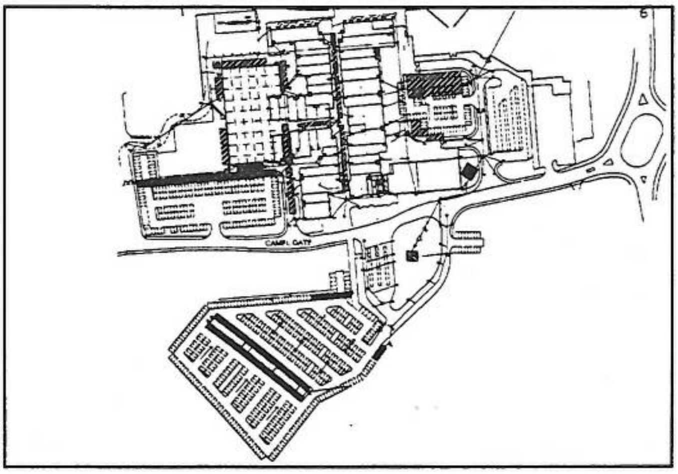

Figure 6: Spalding - Site overview

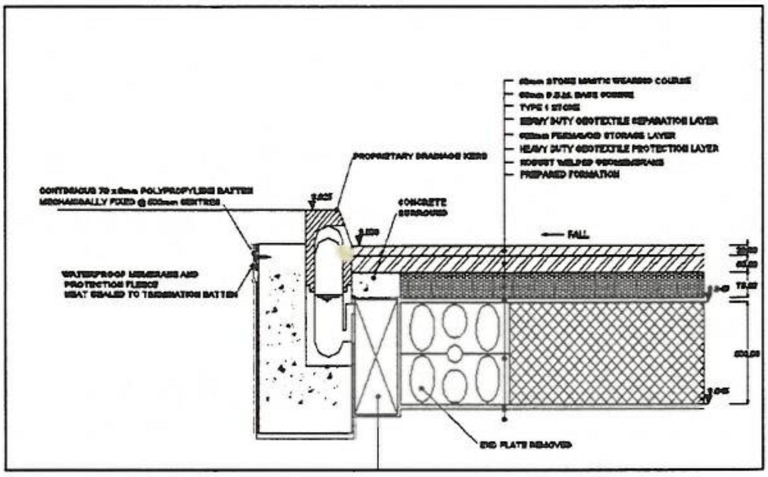

Figure 7: Permakerb detail

Elevated groundwater levels precluded the use of infiltration drainage systems. The use of 523 linear meters of Permakerb/Permachannels, incorporating close-coupled oil interception, in conjunction with adjacent shallow attenuation storage achieved using 32,000 plastic sub-base replacement storage units with passive flow controls, were best suited to resolving the site-specific issues. The surface water system outfalls directly to a shallow ditch system.

The Permakerbs/Permachannels are designed to receive sub-catchment run-off from the impervious pavements to car parks (asphalt) and service yards (concrete). The Permakerb/channel performs several key functions including stilling the sheet flow to encourage controlled deposition of silt and effluent interception & separation at source. At the first annual maintenance inspection, the drainage system was reported to be operating effectively, with silt and effluent controlled within the channels and the development manager reported no problems with the system, which is routinely monitored and maintained.

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Case Study 2. City College, Manchester

Key Aspects:

Sustainable Drainage Detailed Design.
Multi-phased Oil Interception and Treatment.

Project Aims:

Development of a cost effective alternative stormwater drainage system. Protection of the site's underlying zone 2 aquifer from road derived pollutants.

The campus of the City College in Manchester was reconstructed in 2003/04. The solution to achieving the management of surface water, whilst protecting the site's underlying zone-2 aquifer, in accordance with The Environment Agency's imposed conditions, was a key challenge to the project. The first drainage concept for this development was designed as end of line attenuation. This concept was found not to be viable with increasing site restrictions.

The eventual solution was achieved by direct infiltration of the surface runoff into the ground. In order to stop pollutants entering the aquifer, a multi-layered treatment train was implemented. This 'train' comprised three-stage treatment.

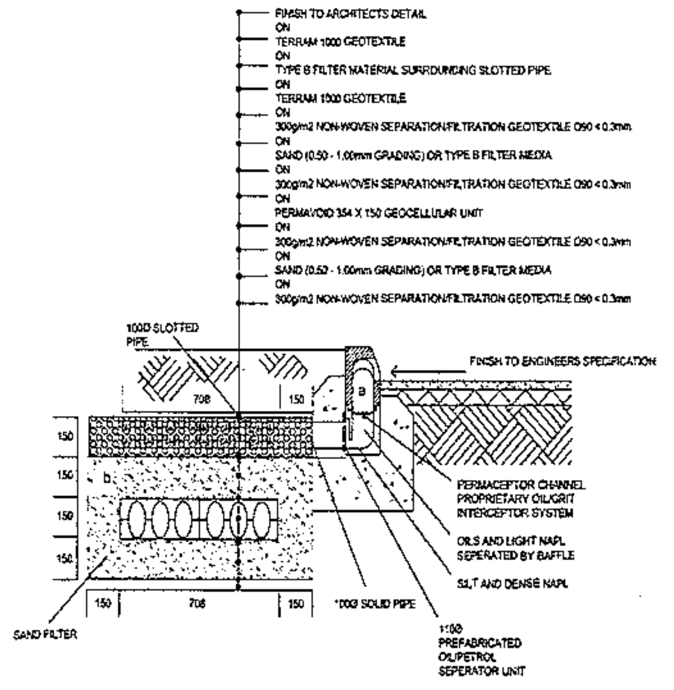

Figure 8: Permakerb & Infiltrating sandfilter

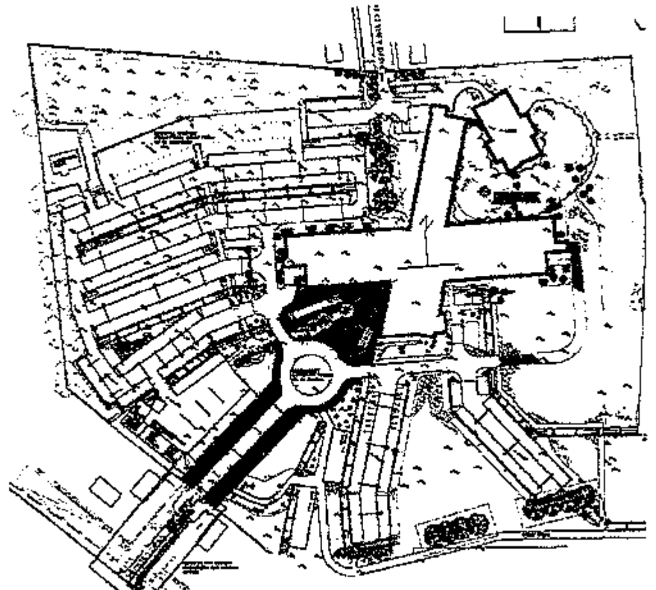

Figure 9: City College - Site overview

The primary treatment step is provided by a Permakerb/channel oil-separating device (Figure7), which discharges via perforated drains, encapsulated in filter geotextile (the secondary treatment), into the third treatment element, a slow sandfilter (Figure 8).

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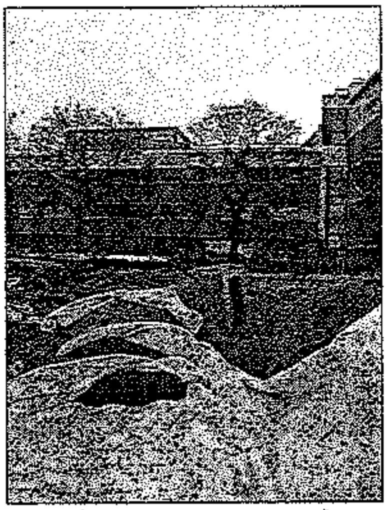

Figure 10: Part-constructed system

Key Benefits:
This solution provided unique benefits for the client. The overall excavation volumes and depth were reduced. Shoring requirements were minimized and the overall construction time was reduced. The whole scheme could be constructed without costly flow control mechanisms and petrol interceptors and the drainage system commissioned in a phased manner.

Case Study 3. Temporary Oil Interception System beneath refuelling areas
Key Aspects:
To be incorporated into 600 UK sites by major house-builder. Key element in client's environmental management plan

Project Aims:
To provide the client with a standardised, modular oil interception, separation and recovery system as an alternative to conventional bunds for refuelling areas on 600 construction sites throughout the UK. System required to be capable of installation by competent site operatives, flexible in range of effluent management capability and able to withstand heavy plant wheel-loading.
Following extensive physical trials, two types of interceptor were developed based on effluent loading requirements. Each system is based on the incorporation of close-coupled oil-interception, achieved using impermeable membranes to create a baffle & weir arrangement within high strength, interlocking plastic sub-base replacement storage components (Permavoid). Figure shows a 'Standard Permaceptor', which incorporates a robust impermeable geomembrane that is unfolded at site and infilled with granular material. Figure shows an 'Enhanced Permaceptor', which is constructed as a preformed unit, fabricated entirely from high strength, interlocking plastic sub-base replacement storage components encapsulated to the sides and base in robust impermeable membrane. Both types of interceptor are provided with an oil recovery component that is installed at site.

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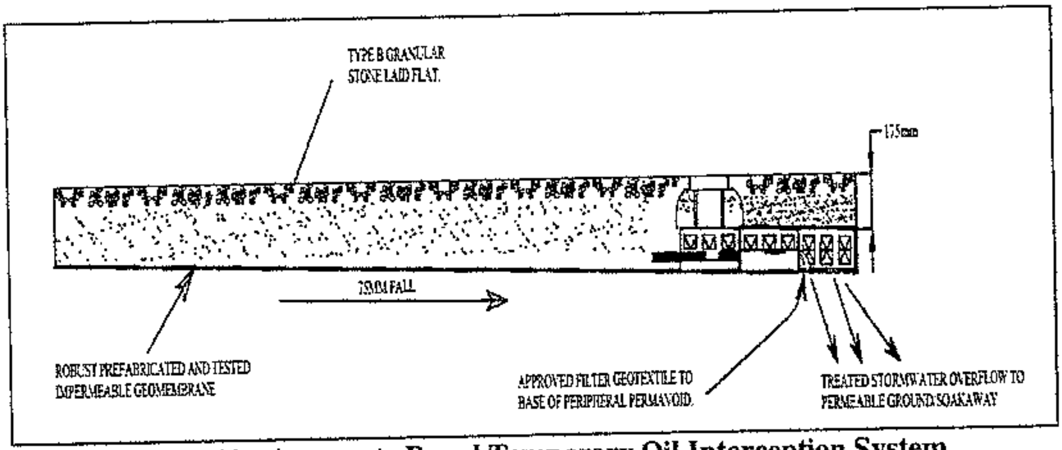

Figure 11: Aggregate Based Temporary Oil Interception System

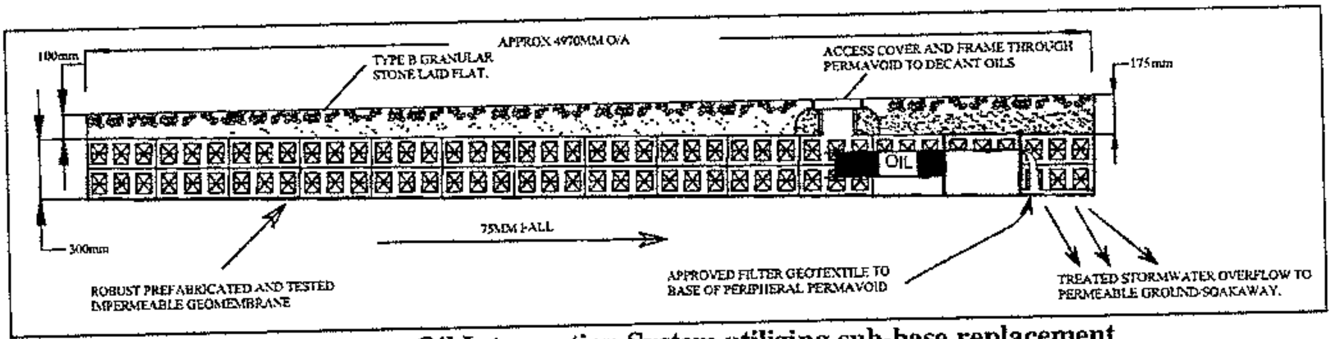

Figure 12: Temporary Oil Interception System utilizing sub-base replacement

To date, in excess of 400 Permaceptor fuel bund interceptors have been installed on sites throughout the UK, with no reported installation or function problems. The same arrangement can be incorporated into multi-phased treatment designs in conjunction with the close –coupled channel interceptors and the floating mat device.

6 CONCLUSIONS

It can clearly be demonstrated that the combined Permakerb/channel with infiltrating sand filter is capable of a significant reduction in the hydrocarbon concentrations even in the case of a catastrophic spillage of oil.

The kerb/channel drain systems can act as pre-cleaning devices to essentially replace the filtration effect of a pervious pavement and whilst it probably does not offer all of the advantages of direct infiltration through the paved surface (Wilson *et al.*, 2003) it can offer different benefits and be an attractive alternative when pervious paving is considered unsuitable.

The use of either the Permachannel or Permakerb will enable planners, designers and constructors to offer a solution that allows the interception and control of hydrocarbon pollution directly at source. Additionally this technology can be used either for impervious or pervious installations. In cases where pervious pavements are not an option, these products can satisfy the demands of water conveyance, pollution retention and land take. These systems deliver a quasi pervious system.

The experiments reported elsewhere (Puehmeier *et al.*, 2005) have shown that the Floating Mat is capable of trapping oil and creating a habitat for microbial life in a way that prevents the bacteria from flushing away by surface water flow. The floating mat device offers additional confidence that hydrocarbon spillages can be satisfactorily contained and biodegraded in stormwater attenuation and

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infiltration systems. The presence of an oil degrading biofilm on the floating mat has been demonstrated and the system has been shown to biodegrade used oil better than unused oil. The models using a floating mat do not exhibit oil/water emulsions thus preventing flocculation and the resultant sinking of oil. There is no need to add nutrients, although some of the laboratory experiments were carried out using the artificial addition of nutrients. The Floating Mat provides an additional layer of protection. For example, the Floating Mat device could replace the sandfilter as described in case study 2.

Collectively, the above systems manage effluent, silt and volume at source, avoiding the potential for a catastrophic failure of the site drainage system and allow for phased developments to manage the issues progressively, avoiding the need for initial investment in major infrastructure drainage components at outfalls from sites.

7 ACKNOWLEDGEMENTS

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The concept of integrating the oil interceptor into a pervious pavement, the geo-cellular units, the oil separating kerb/channel drain and the 'Floating Mat' described in the paper are subject to patent applications.

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