WATER QUALITY IMPROVEMENTS PROVIDED BY CONCRETE BLOCK PERMEABLE PAVING

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SUMMARY

Changes to the UK Building Regulations since 2000 have aimed to discourage the installation of new paved areas without the simultaneous provision of associated measures to prevent runoff being directed to drainage systems. Options given for achieving this objective are for paved areas to be free draining to grassland or similar non-paved areas, or for permeable paving to be used. If neither of these options is practicable for the case under consideration then surface water can still be directed to the drainage system.

The increased awareness of sustainability as a local as well as a global issue is about to strengthen these regulatory requirements and to direct developers more positively towards the use of permeable paving as a new Code for Sustainable Homes requires that runoff from a development should be no greater than it was for the site prior to development. No mention is made of the opportunities for water quality improvements by any solution adopted to meet these requirements but this is clearly an important sustainability issue too.

Despite the lack of past regulatory inducements to limit runoff from new developments there has been a steady growth in the use of permeable block paving over the last 15 years. During this time the potential additional benefit of a permeable pavement's ability to improve water quality was recognised and some work has been done to measure such improvements. The results of studies to date are very encouraging with significant enhancements to water quality being achieved compared to runoff from adjacent impermeably paved areas. It was also found that peak flows and the total volume of outflow were both reduced significantly. More work is being planned in this area covering a wider range of pavement constructions than has been studied to date. UK evidence currently in the public domain is reviewed in this paper.

1. INTRODUCTION

Growth of the UK block permeable paving market has been steady but slow since concrete block permeable paving was first introduced in the 1990's.

Building Regulations have recently (2000) been amended and now encourage, but not make mandatory, the use of Sustainable Urban Drainage Systems (SUDS) or permeable paving and industry has been promoting concrete block permeable paving through marketing initiatives. Industry Guidance in the form of the Interpave permeable paving design guide' (Interpave, 2005) and an updated British Standard[2] (British Standards Institution 2005) extended to cover the installation of block permeable paving as well as impermeable paving have been developed. Commercially available software for the hydrological design of SUDS including permeable paving is also well established. These actions have collectively contributed to a continuing growth in the UK market for permeable paving. In anticipation

of a significant market growth, most major UK producers now offer at least one block designed expressly for permeable paving.

Pavement designers have been influenced positively by a number of factors when considering permeable paving for the first time but mainly by a desire to avoid directing runoff to drainage systems. Many designers have been dissuaded from trying a permeable paving option by the lack of comprehensive and coherent guidance for both hydrological and structural design as well as the lack of supporting British Standards.

SUDS in their various guises have been widely advocated for about the same length of time as permeable paving but have not been widely used. Such SUDS systems as have been installed have generally been based on impermeable paving incorporating features such as swales and wetlands which require the assignment of significant areas of expensive land to a project and also undertakings to keep the key functional features adequately maintained. The cost and responsibility of and for maintenance issues have proved to be a disincentive for many prospective SUDS opportunities.

Encouragement through the regulatory system, the removal of technical barriers and marketing are all important aspects in developing a market. Compulsion is in quite a different league however and in the UK we are now in a situation where a new Code for Sustainable Homes (CSH), initially applicable in England only, will require that the runoff from a new development should be no greater than it was from the site prior to development. At this stage the Code is supposedly only mandatory for publicly funded housing but advisory for the private sector. However, even for the private sector it will be quasi-regulatory as Government is encouraging the adoption of the CSH through the planning system for all new-build schemes. It could thus be a condition of obtaining planning approval for permeable paving to be included in the scheme. These changes are clearly going to see a significant growth in interest in permeable paving as a sustainable way of meeting the requirements of the code by preventing runoff being directed to the drainage system.

The draft code makes no mention of the ability of a permeable pavement to bring about significant improvements to the quality of water passing through it. Some work has been done to quantify the improvements in water quality possible and although the studies are few in number, cover only modest permeable paving designs and were carried out relatively early in terms of the life of a permeable pavement the results are very encouraging. This potential for water quality improvement is a major sustainability issue and it will be for industry to promote as a key benefit of permeable paving. This paper summarizes test evidence currently in the public domain in the form of two case studies published in CIRIA report 582[3] (Pratt C, Wilson S, Cooper P, 2002).

2. THE CASE STUDIES

Both case studies (case A & case B) were carried out at the end of the 1990s at sites in Scotland where the concept of SUDS in all its aspects was embraced and applied earlier than it was in other parts of the UK. Both case studies relate to car parks and are believed to have used an empirical design known to be suitable for light vehicular loadings only. Both were case studies relating to extensions to existing impermeable car parks and so it was possible to compare some aspects of the performance of impermeable and permeable pavements on the same sites where appropriate comparative measurements were made.

The two permeable pavements studied were of a similar design. Both used 80mm pavers laid on a 50mm thick bedding course of 5mm single-sized aggregate placed on a geotextile. Beneath the geotextile was a 350mm sub-base. The sub-bases were constructed with coarse natural aggregates and the gradings of these differed. The sub-base aggregate gradings for the two case studies are shown in Table 1. In case study B an impermeable geomembrane was installed beneath and around the installed pavement. In case study A infiltration into the subgrade was expected to be negligible as the soil permeability was low. No geomembrane was therefore incorporated. Perforated pipes located in the sub-bases of both pavements acted as overflows.

Simple diagrammatic representations of the case study pavements are given in Figures 1 and 2. The case study car park details are summarized in Table 2.

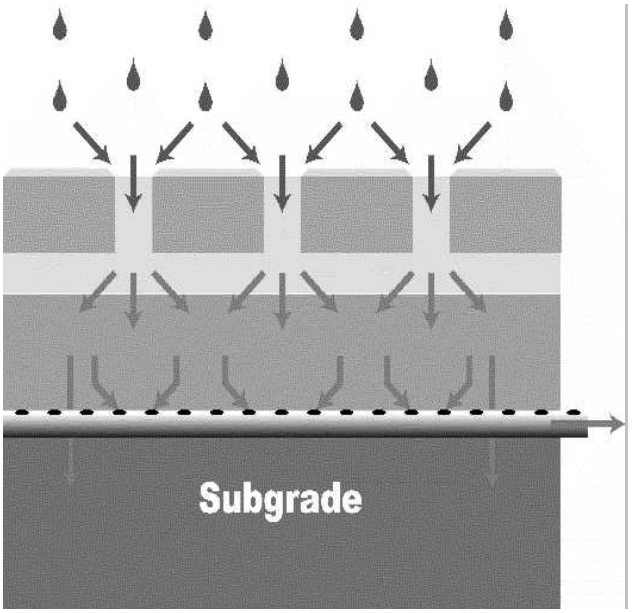


Figure 1

Partial infiltration into subgrade. Perforated pipes in sub-base (Case study A)

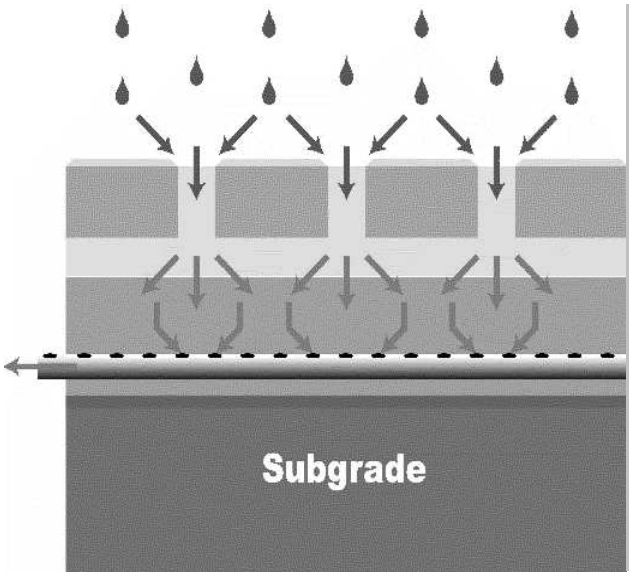


Figure 2

Impermeable geomembrane beneath sub-base. Perforated pipes in sub-base (Case study B)

Table 1. Aggregate gradings

CASE STUDY A		CASE STUDY B	
Sieve size	**Percentage by mass passing**	**Sieve size**	**Percentage by mass passing**
63mm	100	100mm	100
37.5mm	85-100	80mm	80-100
20mm	0-25	60mm	60-80
10mm	0-5	40mm	30-50
		20mm	0-20
		10mm	0-5

Table 2. Permeable car park details

	CASE STUDY A	CASE STUDY B
Location	Edinburgh	Edinburgh
Area	1400m^2	6200m^2
Age at time of monitoring	Approx 4 years	Approx 20 months

2.1 Flow monitoring

For case study A flows were monitored over a total period of approximately 16 months split into two tranches. The first monitoring period was over 10 months with a second 6 months monitoring period taking place after a break of a year. A total of over 150 rainfall events were recorded over the two monitoring periods. For case study B monitoring took place over one 6-month period and the detailed evidence of flows was less comprehensive than for case study A.

The results of the flow monitoring are given in Table 3.

Table 3. Flows measured during monitoring phase

	CASE STUDY A		CASE STUDY B	
	Permeable pavement	**Impermeable pavement**	**Permeable pavement**	**Impermeable pavement**
Outflow to drainage system (range)	0-66%	21-73%	n/m	n/m
Outflow to drainage system (mean)	22%	48%	n/m	n/m
Lag time (Centroid of total rainfall to peak flow) (range)	29-600 minutes	(158)*-123 minutes	42-143 minutes	n/m
Lag time (mean)	180 minutes	9 minutes	n/m	5 minutes
Rainfall before runoff (range)	2.6-17.2mm	0-26mm	n/m	n/m
Rainfall before runoff (mean)	7.3mm	0.8mm	n/m	n/m

Key: * peak flow occurred before centroid of rainfall event n/m not measured

2.2 Structural integrity of case study pavements

Design guidance in the Interpave permeable paving manual[1] indicates that for structural vehicle loading purposes for a car park a gross vehicle weight of 2000kg (1000kg/axle) should be assumed and for this weight of vehicle a minimum sub-base thickness of 475mm would be required. The Interpave manual represents current best practice industry design advice. In both case studies the sub-base thickness was stated to be 350mm. Whilst no measurements were made of the structural performance in either case study from visual evidence no sign of failure was noted at either site.

2.3 Water quality determinations

2.3.1 Case study A

Water for quality checks was taken from the overflow manhole over two periods. These were the same two periods as used for flow measurements.

The first of these periods was approximately 2-3 years after the pavement was constructed. Measurements were made both at rainfall events and as spot samples and the measurement results were not differentiated. The measured general results for water quality for both the permeable and impermeable paving are given in Table 4 and those for metals and hydrocarbons for the permeable paving are given in Table 5.

Table 4. General water quality results (permeable & impermeable pavements) Case Study A

	pH	Conductivity (µS/cm)	TSS (mg/l	BOD (mg/l)	TON (mg/l)	Ortho phosphates (mg/l)	Chloride (mg/l)	Ammoniacal nitrogen (mg/l)
Range (permeable)	7.7-8.2	210-416	15-24	1.5-2.2	0.36-1.36	0.05-0.65	3-57.6	0.03-1.13
Mean (permeable)	8	316.5	19.1	1.74	0.9	0.21	23.9	0.32
Range (impermeable)	6.4-6.9	41-62	15.8-51	2.8-5.8	0.15-1.42	0.02-0.04	6.5-10.9	0.03-0.48
Mean (impermeable)	6.7	49.3	30.0	4.8	0.7	0.03	8.3	0.2

Table 5. Metals & hydrocarbons results (permeable pavement) Case Study A

	Cadmium (µg/l)	Lead (µg/l)	Copper (µg/l)	Chromium (µg/l)	Nickel (µg/l)	Zinc (µg/l)	Hydrocarbons (mg/l)
Range	0.12-5.33	0.93-24.03	3.76-23.1	3.85-8.73	0.95-8.69	17-67	0.12-1.21
Mean	1.91	9.8	10.9	5.73	3.78	42	0.4

2.3.2 Case study B

Data were gathered for 4 flow events over a 3 month period commencing approximately 20 months after the pavement was constructed. Spot sampling for analysis was also made regardless of flow and the results from these spot samples are recorded separately.

The general results for water quality during rainfall events are given in Table 6 and spot results are given in Table 7. The results from rainfall events for hydrocarbons are given in Table 8 and spot results for hydrocarbons are given in Table 9.

Table 6. General water quality results from rainfall events
Case Study B

	pH	Conductivity (µS/cm)	TSS (mg/l)	BOD (mg/l)	TON (mg/l)	Ortho phosphates (mg/l)	Chloride (mg/l)	Ammoniacal nitrogen (mg/l)
Range	7.8-8.6	281-929	0-68	1.6-10	1.05-3.02	0.02-0.24	6.4-42.6	0.02-0.57
Mean	8.1	514	13.6	2.8	1.99	0.09	21.9	0.09

Table 7. General water quality results from spot measurements
Case Study B

	pH	Conductivity (µS/cm)	TSS (mg/l)	BOD (mg/l)	TON (mg/l)	Ortho phosphates (mg/l)	Chloride (mg/l)	Ammoniacal nitrogen (mg/l)
Range	7.4-8.2	358-730	1-16.1	0.7-3	1.15-2.15	0.01-0.04	8.5-34.9	0.02-0.04
Mean	8	544	8.2	2	1.53	0.03	24.8	0.03

Table 8. Metals and Hydrocarbon results from rainfall events
Case Study B

	Cadmium (µg/l)	Lead (µg/l)	Copper (µg/l)	Chromium (µg/l)	Nickel (µg/l)	Zinc (µg/l)	Hydrocarbons (mg/l)
Range	<0.066 -	0.9-2.6	1.7-9.5	<1.7-4.5	0.81-4	9-32	0.1-0.27
Mean	<0.66	1.8	5.2	2.2	1.7	22.2	0.1

Table 9. Hydrocarbon results from spot measurements
Case Study B

	Hydrocarbons (mg/l)
Range	0.1 – 0.375
Mean	0.98

3. DISCUSSION

3.1 General

Both pavements were fairly new at the time of monitoring so neither pavement would have had sufficient time for any significant build-up of detritus to occur in the paving surface which might have reduced the infiltration rate of rainfall into the pavement to any great extent. Infiltration rates of new concrete block permeable paving as installed are many times greater than they need be to cater for design storms so as to allow for natural infiltration reductions over their lifetime. Such lifetime reductions would affect not only infiltration rates but also the time before runoff commenced. The relative newness of both pavements would also have meant that there was insufficient time for the full establishment of beneficial microbial action in the sub-base.

Reduced outflows from the permeable paving may well have had an influence on the measurements as the outflows could contain higher concentrations of contaminants being 'flushed through' the pavement during rainfall events than those recorded for the higher runoff water flows from the impermeable paving. This effect is demonstrated to some extent by comparing the rainfall events result given in Table 6 with the spot measurements for permeable paving given in Table 7.

3.1.1 Water flows

As would be expected from a correctly installed and functioning permeable pavement not only were the outflows to the drainage system lower than for an impermeable pavement the lag time for the peak flow to occur was significantly increased. The mean rainfall before runoff started was found to be significantly higher for a permeable pavement than for an impermeable pavement.

For case study A an assessment of the initial run-off loss (IRL) was made for both the pavement types and found to be:

Permeable paving	5.6mm
Impermeable paving	0.9mm

No information was available on any antecedent rainfall events, which might have influenced the outflows, lag times or amounts of rainfall before runoff occurred.

3.1.2 Water quality

In case study A increased levels of conductivity, ammonium, total oxidised nitrogen (TON) and chloride were recorded for the permeable pavement. A decrease in the biochemical oxygen demand (BOD) was also recorded. The increase in TON and ammonium was attributed to the decay of organic matter within the pavement. The increase in conductivity was felt to be as a result of the

increased chloride contents. Both the results for the general water quality and for heavy metals and hydrocarbons were below the levels set for drinking water.

In case study B the levels of contaminants detected were below the levels set for drinking water also. As with case study A the water was found to be slightly alkaline. This may result from the cement in the blocks forming the surface of the relatively new pavement but no attempt was made to quantify this or any other potential source.

Values for the general water quality parameters were found to be very similar to those for case study A. However, for heavy metals and hydrocarbons the results were significantly lower than for case study A. The reason for this is probably that only spot measurements of these parameters were made in case study B and concentrations of contaminants would be lower in spot measurements than in flow conditions.

4. CONCLUSIONS

As expected there were many sustainability benefits deriving from the permeably paved areas studied.

- Outflows to drainage were reduced.
- Lag times of outflow (centroid of rainfall to peak flow) were increased.
- Rainfall before runoff was increased.

Despite the pavements not being sufficiently mature for microbial action within the sub-base to become fully established the quality of the water coming through both pavements met the requirements for drinking water. Increases in sub-base thickness to those currently recommended for concrete block permeable pavements and a microbially mature permeable pavement should see further significant improvements to water quality.

5. REFERENCES

1. Interpave. The Precast Concrete Paving & Kerb Association 2005. Guide to the design construction and maintenance of concrete block permeable pavements.

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3. Pratt C Wilson S Cooper P CIRIA report C582 2002. Source control using constructed pervious surfaces.

4. The water supply (Water Quality) (Scotland) Regulations 1991.