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URBAN STORMWATER REDUCTION AND QUALITY IMPROVEMENT THROUGH THE USE OF PERMEABLE PAVEMENTS

C. J. Pratt, J. D. G. Mantle and P. A. Schofield

Department of Civil and Structural Engineering, Trent Polytechnic, Nottingham, NG1 4BU, U.K.

ABSTRACT

Construction details are given of an experimental permeable pavement, comprising four separate sub-base sections containing different stone or crushed rock. Sub-base drain effluents have been monitored for discharge volume, flow rate and water quality parameters on the four sections. Preliminary results are presented which indicate that useful volume and flow rate reductions may be obtained via permeable pavements, and that water quality may be enhanced by sedimentation and other treatment processes occurring within the pavement. Effluent quality may be improved as compared with that discharged from the usual impermeable highway surfaces in similar residential areas.

KEYWORDS

Stormwater; permeable pavement; sub-base; flow reduction; peak flow attenuation; sedimentation; highway pollutants; effluent quality.

INTRODUCTION

Natural, permeable ground surfaces exist in various proportions within developed urban areas. Generally, these surfaces are not equipped with any drainage and only occasionally supply stormwater flows, overland to a highway drainage system. Stormwater infiltrates the surfaces, passing to groundwater or percolating to a nearby watercourse through the upper soil horizons; or the water evaporates, directly from puddles or the soil, or via plant transpiration. Therefore, the rainfall on these natural, permeable surfaces contributes little to the problem of hydraulic over-loading of urban drainage systems.

Several studies have shown that natural surfaces and the vegetation upon them may be effective at retaining pollutants as urban stormwater passes over them and hence at reducing their discharge to receiving waters (Yousef et al., 1984). The processes of sedimentation and adsorption by soil particles and plants provide a form of primary treatment which may be enhanced over a period of time by natural chemical and biological degradation of the pollutants.

Man-made, engineered, permeable pavements have the potential to reproduce the above advantages, of flow reduction and water quality improvement, but in addition may also provide urban surfaces which are designed to be load-bearing for vehicle usage in all weathers. Presently, permeable pavements are only used in car parking or storage areas, but in such situations the stormwater and

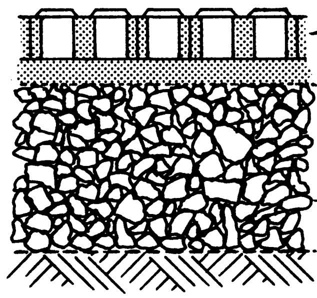

Fig. 1. Typical cross-section of permeable pavement

pollutants may be directly intercepted at source, prior to entry to any public sewer, or discharge to a watercourse.

Typically, these man-made surfaces comprise a porous macadam or open-textured concrete block wearing course, overlying a free-draining road base/sub-base (Fig.1). The sub-base may be of various types of stone or crushed rock, and the road base is either a similar material of smaller size or gravel, according to whether the wearing course is porous macadam or concrete block paving, respectively. In either case, the road base serves the dual purpose of providing a levelling course, between the sub-base and the wearing course, and a working surface for the movement of plant for the laying of materials. The sub-base provides the reservoir for temporary storage of water.

Stormwater entering the construction may percolate through the sub-base to groundwater, or be collected by sub-base drains for discharge off-site to a nearby sewer or receiving watercourse. Where the permeable pavement is constructed on a freely draining sub-grade, stormwater may be totally directed to groundwater, subject to considerations of groundwater pollution. If the sub-grade is weak and/or poorly draining, it may be necessary to seal the formation with an impermeable membrane and collect all stormwater via a sub-base drain system for discharge from the construction.

With to-day's practice of separate sewerage, sub-base drain effluent will be discharged eventually to a watercourse, where water quality considerations will be important. Hence, whether the permeable pavement discharges to groundwater or to a watercourse, the quality of the effluent must be considered. Few studies have been made to date on this aspect of permeable pavement performance, or of the impact of directing urban stormwater from roofs and highway surfaces to groundwater generally (Hogland et al., 1987; Malmquist and Hard, 1982). This paper reports the preliminary results of a study of effluent quality and runoff volume/peak discharge reduction on four trial areas of permeable pavement, being undertaken as part of a wider study into the general reduction and quality enhancement of urban stormwater.

EXPERIMENTAL PERMEABLE PAVEMENT

The experimental pavements studied in the research reported herein were constructed on the Clifton Campus of Trent Polytechnic, where the underlying soil is poorly draining Keuper Marl (FSR Soil Class 4 (Anon., 1975)). Both the soil characteristics and the desire to monitor sub-base drain flows led to the installation of an impermeable membrane below the pavement (Fig.2). Overall, the site was 4.6m wide by 40m long, providing parking for 16 cars.

The site was excavated to depths of 300 and 400mm on the two long sides, which with a horizontal finished surface produced a sub-grade crossfall of some 2% to a perforated plastic drain pipe (Fig.3). Four separate sections, each some 10m long, were established within the pavement, so that any effects of using

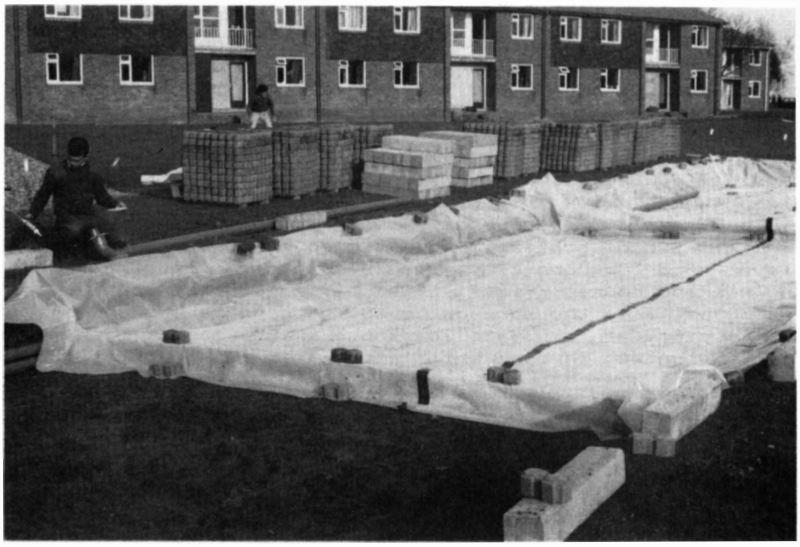

Fig. 2. Experimental permeable pavement construction showing impermeable membrane on formation

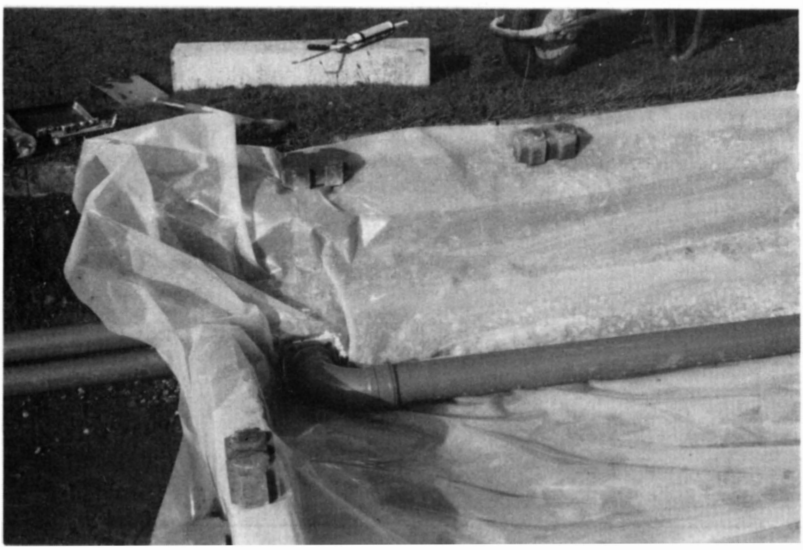

Fig. 3. Sub-base drain passing through membrane with water-tight flange

different sub-base stone could be monitored. Sub-base drainage from each of the four sections was separately installed and laid to discharge at an instrument pit, in which one-litre tipping bucket flow gauges measured discharged volume. Solid state data loggers recorded the time of tip of each of the four flow gauges and of a 0.1mm raingauge in the vicinity of the permeable pavement.

Four different sub-base stones were installed in the four sections: 10mm rounded gravel (DTp Clause 505, (Anon., 1986)); 40mm blast furnace slag (DTp Clause 505); 5-40mm granite (DTp Clause 803); and 5-40mm carboniferous limestone (DTp Clause 803),(see Figs. 4,5 & 6). Each stone was vibration compacted and a layer of geotextile positioned on top, prior to the spreading of a 50mm layer of 5-10mm gravel as road base and the bedding for a concrete block paving wearing course (Fig.7). The paving blocks were shaped to provide a pattern of holes, from the surface to the bedding layer, and a pattern of raised discs to carry vehicle tyre loadings, which would prevent compaction of the gravel in the holes, through which stormwater was to percolate (Fig.8).

FLOW REDUCTION

With a pavement construction which incorporated an impermeable membrane, enclosing the sub-base reservoir, the potential for runoff volume reduction might seem limited, as the only sources of loss were surface wetting (and limited absorption) of the constuction materials in the short term, and evaporation from the surface in the longer term, between storm events. Figure 9 shows rainfall-runoff plots for the section of the trial pavement with blast furnace slag sub-base, during a period in September 1987.

It may be seen that marked reductions in runoff volume with respect to rainfall volume in 0.1 Julian day increments have been monitored; some rainfall events up to 5mm have produced no runoff from the sub-base drain; and generally, storm runoff volume for any event on the permeable pavement is significantly lower than the total event rainfall. Table 1 shows the observations for all four sections of the trial pavement and illustrates the effect of using the different sub-base stones. Blast furnace slag produced the least runoff volume, presumably because its honeycomb surface offered many storage sites for stormwater. Granite had the highest runoff, which is assumed to result from its lower surface area for wetting, relative to the gravel, and to its limited absorption potential, relative to the limestone.

TABLE 1 Total Rainfall-Runoff Data for Experimental Permeable Pavement

Julian Day	Total Rainfall mm	Total Runoff, mm			
		Sub-base Stone			
		Gravel	B.F.S.	Granite	Limestone
225-234	34.8	24.5	20.2	26.5	25
235-244	26.2	17.0	15.5	21.7	15.8
245-254	19.5	8.9	8.6	11.9	8.7
Total	80.5	50.4	44.3	60.1	49.5
Percentage runoff		63%	55%	75%	61%

The performance of permeable pavements in comparison to traditional, impermeable urban surfaces with positive drainage systems was most marked when individual storms were examined in detail. It may be seen that peak effluent discharge rate from the permeable pavement was only 30% of peak rainfall intensity and the attenuation of the peak was some 5 to 10 minutes, in comparison with impermeable surface times of concentration of 2 to 3 minutes at similar rainfall intensity. Typically, impermeable surfaces would discharge almost all runoff by the end of the rainfall, but the permeable pavements displayed

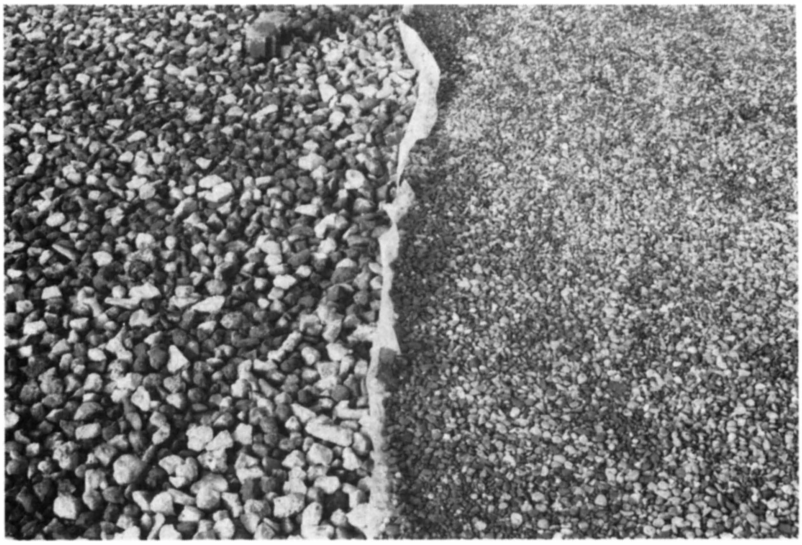

Fig. 4. Experimental sub-base stone: blast furnace slag (left); gravel (right)

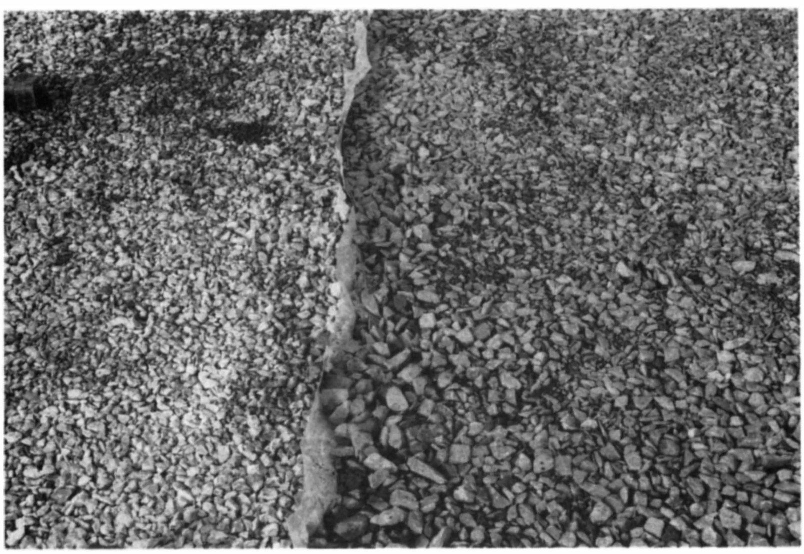

Fig. 5. Experimental sub-base stone: limestone (left); granite (right)

Fig. 6. Prepared sub-base surface, awaiting geotextile layer, road base (gravel) and permeable block paving

Fig. 7. Laying block paving surface

Fig. 8. Surface detail on experimental permeable pavement

important storage characteristics e.g. on Figure 9, for the storm on Julian day 225 with total rainfall 22 mm, only 37% was discharged from the blast furnace slag within the rainfall duration; only 51% discharged after one hour from the end of rainfall; and only 66% rainfall ever discharged.

The stormwater discharge characteristics illustrated could be further enhanced on larger constructions, since part of the flow attenuation is derived from the time of travel to, and within, the sub-base drains. The maximum distance within the construction of the drain from any point on the formation was only some four metres in this case, which could be conveniently doubled on a bigger site, and benefits of drainage cost economies also result.

WATER QUALITY IMPROVEMENT

Traditional highway drainage in urban areas comprises gratings and gully pots, prior to discharge into the public sewer. Gully pots provide some sedimentation, but not to a satisfactory standard for material less than 100 microns, or material of an organic nature which is easily transported with stormwater. Permeable pavements may be effective sedimentation devices, however, the deposited material may eventually lead to a deterioration in the water infiltration efficiency. The deposited material is collected either, within the voids in porous macadam, from which it must be flushed periodically, or in the gravel bedding layer and holes though the concrete block paving, whichever forms the wearing course . In the latter case it is not possible to flush the material into the sub-base, and so eventually the blocks and bedding must be lifted, clean gravel placed and the blocks be re-laid. Such an operation could be quickly undertaken and little material need be wasted. The question of how long do permeable pavements continue to perform satisfactorily without material blockage is difficult to answer; experiences differ widely, as do the individual site conditions e.g. availability of mobile materials alongside the site, use of the site by construction traffic, etc. greatly influence the answer.

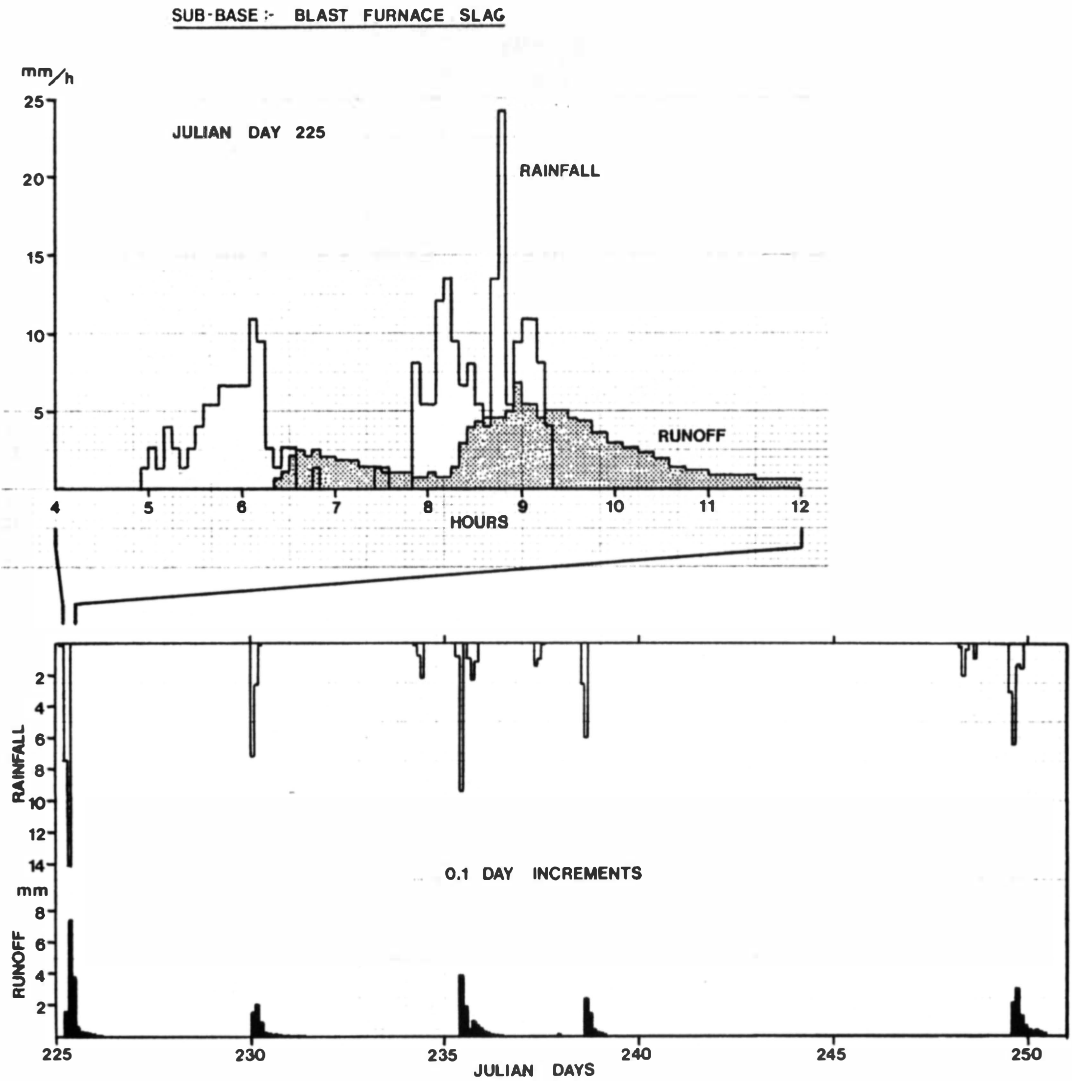

Fig. 9. Rainfall - runoff plots for experimental permeable pavement

The results from the present trials do illustrate clearly that very effective sedimentation is achieved. Effluent suspended solids concentration was generally around 20mg/l and less than 50 mg/l, which may be compared with typical gully pot discharges ranging upwards from 50 to 300mg/l (Pratt et al., 1986).

Suspended solids provide important transport sites for heavy metals and other pollutants. The mobilisation of heavy metals is affected by pH, hardness and alkalinity. Figure 10 shows how these parameters may be modified by the choice of construction materials within the permeable pavement. Under the conditions established in the trials, the total lead concentrations, highest in effluent from the blast furnace slag sub-base, were still some one order of magnitude lower than typically occurs in gully pot discharges in residential areas. Clearly, improvements in effluent quality are possible by the appropriate sub-base stone selection.

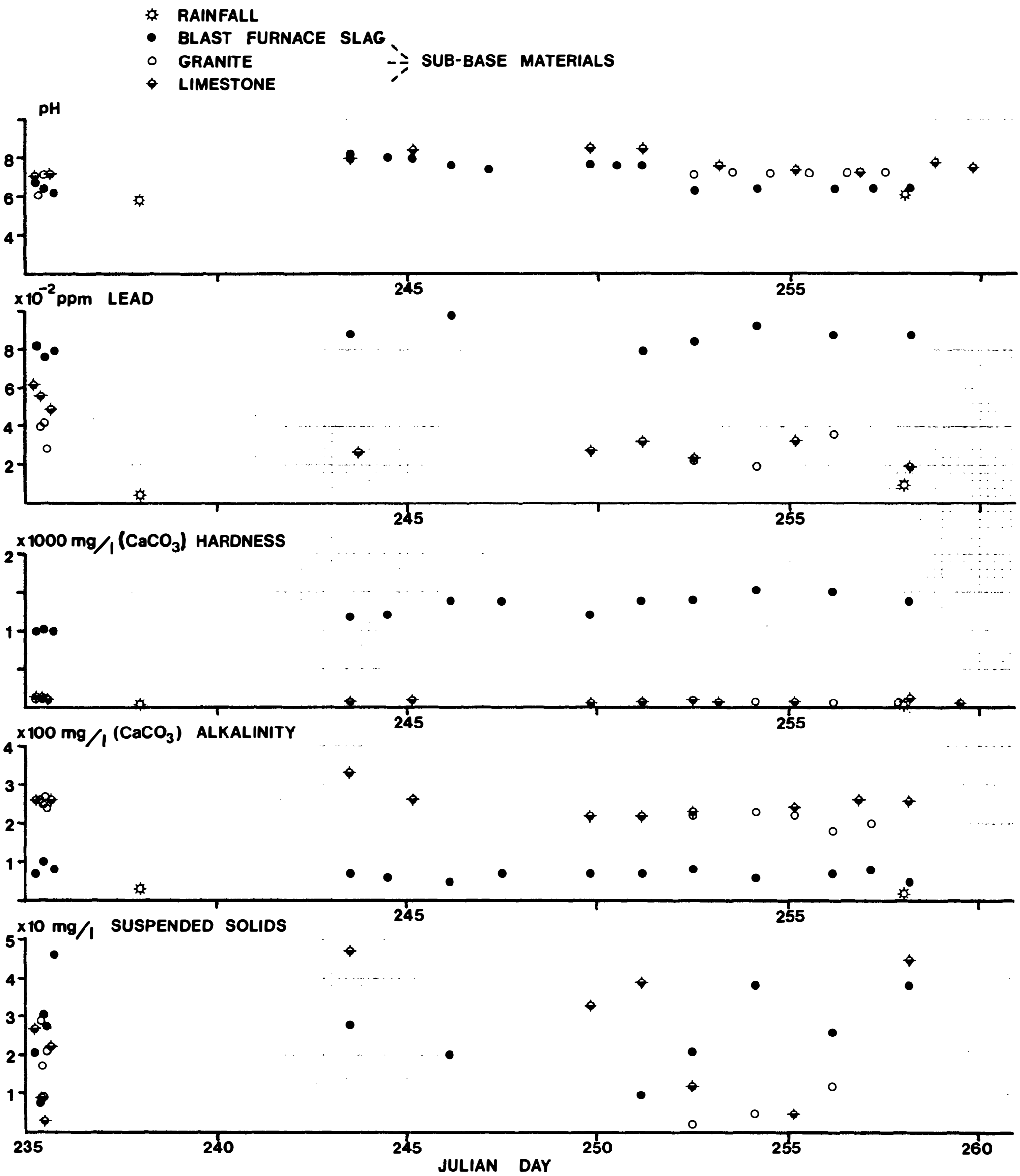

Fig. 10. Sub-base effluent and rainfall quality parameters monitored at experimental site

In the future, the present trial permeable pavements will be reconstructed with additional, possible effluent quality improvement features installed. It has been shown that a large proportion of the pollutants within a porous macadam construction in Lund, Sweden, were concentrated in a geotextile layer (Hogland et al., 1987). One modification to be studied is the effect on effluent quality of additional geotextile layers; presently there is one layer between the sub-base and the gravel bedding layer. Also of interest will be the effect of incorporating organic material e.g. peat or carbon granules, within the sub-base voids. Evidence exists that such material could increase the removal of organic pollutants from the effluent (Gjessing et al., 1984).

CONCLUSIONS

The preliminary results from a study of a permeable pavement, using various construction materials, show that both useful flow reduction and peak discharge attenuation can be achieved, even in circumstances where stormwater was collected via sub-base drains for discharge off-site.

Effluent quality has been found to be markedly better than typically monitored from urban, impermeable highway surfaces in similar residential areas, and there exists the opportunity for the design of construction and choice of materials to effect quality enhancement. The reduced effluent discharge, combined with lower pollutant concentrations, means much reduced pollutant loads are passed to receiving waters.

Permeable pavements have not been employed sufficiently for reliable estimates to be made of their effective working life and maintenance demands to be established. Therefore, these questions remain unanswered and are generally interpreted as disadvantages. The advantages of wider use of such pavements are beginning to be quantified, as here, but other advantages exist in the wider context of urban drainage basins, where problems are clearly evident: hydraulic over-loading of sewers leading to early structural deterioration; higher sewer flows causing frequent storm overflow operations; untreated discharge of urban stormwater, since the introduction of separate sewerage systems, producing continuing adverse effects on urban watercourses; etc. It is intended that the present research should provide information upon which wider consideration may be given to the opportunities presented by permeable pavements, as one component in the overall drainage strategy for urban areas, leading to the improvement of receiving water quality.

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