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USE OF PERMEABLE, RESERVOIR PAVEMENT CONSTRUCTIONS FOR STORMWATER TREATMENT AND STORAGE FOR RE-USE

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ABSTRACT

Permeable surfaces for roads and footpaths have been used as a means of disposal of stormwater in developed urban areas. Such surfaces provide an alternative to impermeable concrete or tarmacadam surfaces which would otherwise produce rapid stormwater runoff, leading to possible flooding and degeneration of receiving water quality through the uncontrolled discharge of polluted urban waters. A further advantage may be obtained from such constructions by undersealing them so as to retain stormwater for re-use for non-potable uses. The potential for general introduction of this type of storage and re-use system in residential areas is discussed and possible alternative designs for the drainage infrastructure proposed. To have widespread impact such a strategy must deliver cost savings as well as reduce the impact on the water environment of anticipated water usage demands. The source of such cost savings and the general environmental benefits of such systems will be presented. The materials used in such a sealed construction and the beneficial changes to the stored water quality are outlined. Recent work has also shown that where the pavement is used for car parking any oils dropped on the surface and washed into the structure by the stormwater may also be degraded. Details will be given of a site in the UK where the above construction is to be used to provide stormwater storage for re-use in flushing toilets at a Youth Hostel.

KEYWORDS

Permeable surfaces; stormwater; water re-use; reservoir pavement; water storage; sub-base.

INTRODUCTION

The last twenty years have seen many important developments in urban drainage in the UK, in terms of the technologies; methods of analysis and design; and the institutional organisations of the water industry. There has been a significant shift from interest solely in water quantity issues, such as flood defence and water supply, towards a more balanced concern for both quantity and quality aspects within the water environment. This change has highlighted the intimate and inseparable link which must exist between water supply, use and disposal, together with the environmental impacts of such actions. The supply of water, which results in the periodic disappearance of local streams and rivers because of over-abstraction of groundwater; or the disposal of wastewaters and surface waters, which leaves the householder free from health hazards and from flooding only to pollute and adversely modify receiving watercourses, should no longer be tolerated.

There are many complex, inter-related issues in the water environment in the UK and the problems are made no easier to solve by the involvement of many and varied organisations in the field. Some of the present concerns include that:

a) the demand for water is rising, outstripping available resources in some parts of the UK;
b) the available resources are not located in the areas of major demand or of expected growth in population and usage;
c) over-abstraction has resulted in unacceptably low flow regimes in several rivers;
d) despite increased capital investment in water reclamation works, there have been only moderate improvements in receiving water quality;
e) continuing urban and highway developments have increased surface water runoff volumes and discharge rates, which have resulted in adverse changes to stream geomorphology, aquatic habitat and water quality; and
f) traditional approaches to flood alleviation and channel protection, such as straightening channels and lining them with concrete and steel, have themselves created additional problems through speeding the downstream progress of floods and the downgrading of the river corridor for wildlife and human recreation.

Householders in some parts of the UK have seen their price for water services double in the last five years. The private water utilities have made these price increases to allow for the required capital investments in new water reclamation works. To many householders little seems to have changed: sea and river water quality have not markedly improved and the environment of the rivers seems little changed. The result has been public disquiet at the increased costs for water supply and wastewater treatment. For some people, the disquiet has led them to investigate ways to reduce their water charges through more efficient use of water. In view of the relatively high water usage per person in the UK, this move is being more widely encouraged by the Environment Agency, through its consideration of the various approaches to demand management, to assist in solving some of the concerns previously listed.

In many respects the future of the UK's water environment is not in the hands of the various organisations who presently manage and regulate it, but in those of the water consumers. On the one hand, the consumer expects a secure, clean supply of water combined with efficient protection from, and disposal of, 'waste' water; and on the other hand, looks for these services to be priced reasonably and not undertaken to the detriment of the environment in general. The key agent for change must be the water consumer, the householder, the ordinary person, who must modify his/her demand for water services, or assist with the implementation of new techniques to limit 'waste'. Some reduction in demand may be possible and the introduction of water efficient household appliances and fitments may help, but one aspect, with potential to significantly reduce the demand for new water resources and limit the discharge of poor quality, untreated water to rivers and streams, is the reduction of 'waste' water. A significant component of this 'waste' is presently stormwater runoff, which in future might be seen more appropriately as a resource for re-use.

PRESENT UK WATER USAGE

It is estimated that each person in the UK draws 140 litres per day from the treated water supplies for use at home. About 5 litres of this is used for external purposes, such as watering gardens; in sewered areas across the country, the remainder is eventually passed to the water reclamation works for cleansing prior to discharge to rivers or the sea. (DoE, 1992).

In the middle of England, away from high ground, a typical average annual rainfall-runoff from roof surfaces would be 580mm. The volume of runoff depends upon roof area, which in turn varies with the style of housing, number of occupants, density of housing, etc. Table 1 shows estimates of the 'waste' water produced from a range of typical households in the UK

Table 1. An estimate of the average daily 'waste' water per household

Houses per hectare		8	15	25	35
Persons per household		6-5	5-4	4-3	4-3
Roof area,	m^2	169	110	74	37
Stormwater runoff,	litres	269	175	118	59
Daily domestic wastewater*	litres	810-675	675-540	540- 05	540-405
Total 'waste' water,	litres	1079-944	850-715	658-523	599-464

(* Number of persons x 135 l/day, usage in the house)

Present concerns about the standard of treatment provided at some water reclamation works and about the rapid runoff of untreated stormwater into streams and rivers could be addressed if the 'waste' water was better controlled. This could be achieved by locally storing the stormwater from roofs and re-using it, thus reducing the amount of water drawn from the treated supply, which in turn would reduce the volumes of 'waste' released. In the UK stormwater is either discharged directly to a nearby watercourse from a separate storm sewer, in which case local damage may be caused to the water environment; or it is conveyed in a combined sewer with foul waters to the water reclamation works, which may become overloaded by the sudden increases in flow and release poorly treated effluent directly, or via storm overflows within the sewerage system.

FUTURE WATER STORAGE AND RE-USE

Some part of the water drawn from the water supply may be re-used. It is estimated that some 53 litres per day (some 38% total daily usage) is used by each person for personal and clothes washing, which could be re-used given suitable treatment for certain purposes, such as toilet flushing, for which about 43 litres per day per person are used (some 31% total daily usage). Table 2 illustrates the effect on water supply volumes of local storage and re-use.

Other wastewater must pass immediately to the water reclamation plant as at present and in due course the stored water would pass to treatment after use in toilet flushing. Combined with external uses for the re-use water, the total re-use volumes could amount to some 34% saving on demand for water from the treated supply.

From Table 3 it is clear that stormwater from roofs alone might be inadequate in the Midlands of England to provide all the necessary re-use water and that either additional stormwater must be collected from other surfaces, or grey water from washing used instead, or the combination of washing and stormwater are needed to meet the re-use demand. At this time in the UK there is no cheap, compact and readily available grey water treatment system for residential properties, although at least one is near to being marketed (Delves, 1996) and other more extensive systems are on trials (Withers, 1996). Therefore at the moment, it is necessary to restrict the implementation for 'waste' water re-use to the use of stormwater, accepting that the stored water will provide a partial substitute for treated water supplies, but with the advantage that it limits considerably the possibility of stormwater discharges and hence questions the need for a separate stormwater sewer.

Table 2. An estimate of the average daily recoversable 'waste' water per household

Houses per hectare		8	15	25	35
Washing water for re-use (WWR-U),	litres	318-265	265-212	212-159	212-159
Stormwater from roof (RSW),	litres	269	175	118	59
Total potential recoverable water (TPRW),	litres	587-534	440-387	440-387	271-218

Table 3. Summary of demand and potential savings per household per day

House per hectare		8	15	25	35
Present total demand,*	litres	840-700	700-560	540-420	540-420
Potential re-use demand (PR-UD),**	litres	288-240	240-192	192-144	192-144
(PR-UD)/(WWR-U),	%	91	91	91	91
(PR-UD)/(RSW),	%	107-89	137-110	163-122	325-244
(PR-UD)/(TPRW),	%	49-45	55-50	44-37	71-66

(* Number of persons per household x 140 l/day, typical total daily demand)
(** Number of persons per household x 48 l/day, typical usage for toilet flushing plus external uses)

STORAGE OF RE-USE WATER WITHIN A RESERVOIR PAVEMENT

In the UK in the 1800s and early 1900s it was not uncommon for houses in urban and rural locations to have a 'soft' water cistern - a rainwater tank frequently used to supply water for clothes washing. The construction of these cisterns below the back yard or under part of the kitchen floor ceased as more properties were connected to a reliable, piped water supply. Today, these cisterns are rarely used even when they still exist in old properties.

The provision of storage for re-use water has not been seriously considered in the UK in recent times and the costs are viewed as a major obstacle by house builders, anxious not to deter prospective purchasers. With the major increase in water costs, the public is showing a growing interest in re-use techniques and the capital costs are seen as less discouraging. (Schneider, 1996). The question which then must be addressed is where to construct the storage on new or existing property. Storage tanks are an obvious answer but they may be rather large and inconvenient to position inside the property; they may require deep excavation to install below the ground, or be unattractive and difficult to hide if above ground; and they may require sheltering from the worst of the weather, particularly freezing conditions.

One answer is to reconstruct the footpaths and driveways in such a way that they contain the storage. Again, the storage could be a tank, but if a suitable sub-base to the pavement is enclosed within an impermeable membrane and an appropriate surface laid over the top, a storage system may be established which is easy to construct, does not need deep excavation and uses space which is presently available and remains open for the existing purpose.

The typical section through the construction envisaged would comprise a surfacing material which could be of a traditional paving type, however it could also be permeable thus allowing stormwater from the surface to be collected to augment the roof waters. A permeable or porous surfacing would be laid on 50mm gravel over a geotextile fabric, separating the surface layers from a clean, crushed stone sub-base layer. If the pavement is used by motor vehicles the construction may need to be some 300-400mm thick to support the applied loading, which could provide about 100mm effective depth of water storage, assuming a 30% void space in the sub-base i.e. 100 litres/m^2 pavement. There are plastic, honeycomb materials which could be used for the sub-base which have 95% free volume, providing much higher effective storage per unit area, but their expense sometimes limits their choice, although the reduced availability and rising cost of crushed stone is making their use more attractive. The whole construction would be enclosed within an impermeable membrane to provide a watertight storage volume.

It is unlikely that there will not be adequate areas of paths and driveways to provide the requisite storage volume. In the survey which provided the values of typical roof areas for given housing densities (Table 1), it was also found that the plot areas within which houses are constructed in the UK are typically 5-8 times the roof area of the house for the housing densities investigated here, the higher range occurring at the lower housing density.

Table 4. An estimate of the land usage on typical housing plots

House per hectare		8	15	25	35
Housing plot area,	m^2	1250	665	400	125
Roof area per housing plot	%	13.5	16.5	18.5	30
Reservoir pavement area,*	m^2	41	34	27	27
Pavement area per plot,	%	3	5	7	22

(* Based on storage volume being equivalent to 14 day's potential re-use demand (from Table 3)

There are various possible methods for establishing required design storage volume, but if simply it is assumed that potentially 14-days' re-use water supply is desirable as an available volume in storage then the required reservoir pavement areas are as shown in Table 4. Typically, the area of one car parking space is 12.5m^2, hence the space required to meet this storage specification would lie between the standing space for some 2-4 cars. At the highest housing density shown in the Tables, it is unlikely that adequate space exists for this form of storage on individual plots, but it is not uncommon to find communal parking areas in these cases, which would be ideal locations for a single, communal storage pavement.

Re-assessing the total stored stormwater for re-use when collected from both roof and driveway surfaces, it may be seen from Table 5 that, on average, there could be adequate for residential developments at housing densities up to about 25 units per hectare, where the potential re-use demand is less than average daily total stormwater entering storage at the lower levels of occupancy per household. Such a conclusion is based solely on average daily rainfall/ demand and is heavily influenced in practice by the actual rainfall distribution throughout the year. In the UK where rainfalls are generally heavier and more frequent from November to April, it could be expected that the storage volumes would fill adequately to meet demand. From May to October a deficit in stored water might persist, but the available free volume would accept the short, intense storm runoff which might occur during thunderstorms in this period and be beneficial in minimising flashflows in drainage systems. Hence, whilst the stormwater re-use system on residential housing has some limitations in its ability to replace completely water from the treated supply, it may provide an important supplement and reduce the growth in demand for new water sources.

Clearly, the effectiveness of such a system depends upon the size of the collecting areas relative to demand. The opportunity to increase the collecting surface area may be more readily available at individual public buildings. Such a system is being installed on a new Youth Hostel at Edwinstowe, Nottinghamshire, UK.

Table 5. An estimate of the adequacy of stormwater to meet re-use demand

Houses per hectare		8	15	25	35
Roof plus pavement collecting area,	m^2	210	144	101	64
Stormwater collecting area per plot,	%	17	22	25	51
Average daily total stormwater (TSW),	litres	334	228	160	102
(PR-UD)/(TSW),	%	86-72	105-84	120-90	118-141

A CASE STUDY OF STORMWATER RE-USE

The new Edwinstowe Youth Hostel comprises a building with a 400m^2 roof plan area with an adjacent car park for 14 cars of some 325m^2 (Perkins, 1997, Fig. 1). Stormwater from both these surfaces will be stored within the car park sub-base. The car park is surfaced with permeable blocks allowing direct inflow of stormwater to the sub-base. Roof runoff is collected to a sump and pumped into storage because of ground level differences. Any excess stormwater will overflow from the sub-base into an infiltration trench.

Stored water in the sub-base is connected to a supply sump alongside the Youth Hostel from which waters are pumped to feed the toilet cisterns: the supply pump is activated by a drop of pressure in the supply line. Strainers at the supply pump and in the supply pipe will ensure that re-used waters are free from particular matter which might affect the operation of the toilets. The storage volume within the pavement construction is approximately equal to the average monthly rainfall i.e. $34m^3$ landing on the roof and car park surfaces. This volume will be adequate to provide totally for toilet flushing each month for up to 33 people in the Hostel.

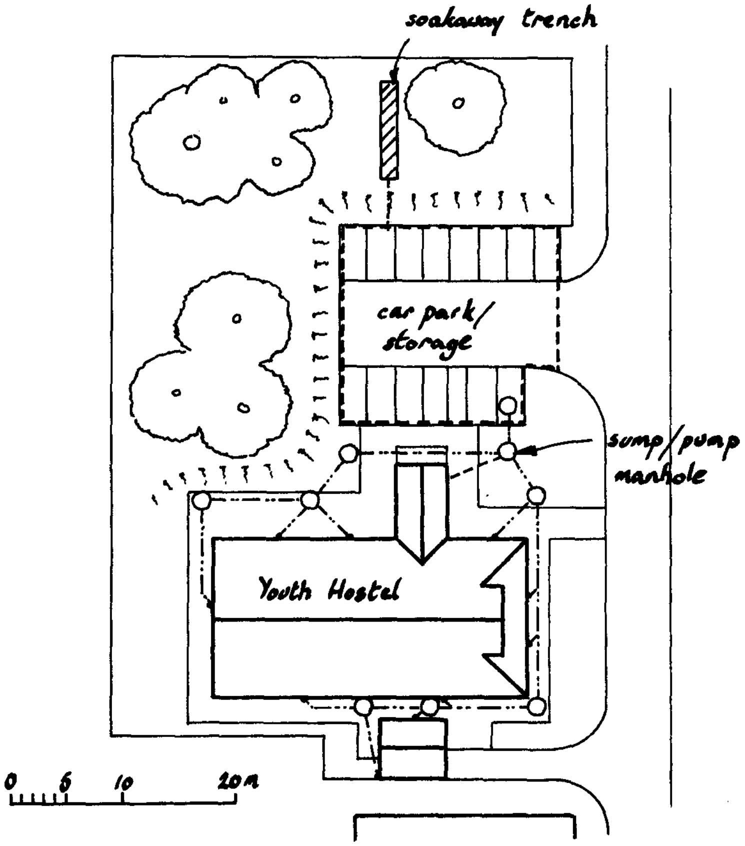

Figure 1. Details of the layout at the Edwinstowe Youth Hostel showing stormwater collection and storage system.

Field observations of the effluent from such reservoir pavements has indicated that suspended solids concentrations in the range 20-30 mg/l are to be expected (Pratt *et al.*, 1995). The conductivity, alkalinity and pH of the stored water depend upon the type of sub-base stone used in the construction: at the time of writing the stone-type has still to be decided. For the stone-types used in previous constructions, namely gravel, blast furnace slag, granite and limestone, typical ranges of these parameters are shown in Table 6 (Schofield, 1994).

Table 6. Chemistry of water in the sub-base associated with different sub-base stone types

Stone type	Conductivity µS/cm	Alkalinity mg/l	PH
Gravel	500	200	7.0
Blast furnace slag	2100	80	7.0
Granite	600	250	7.0
Limestone	550	275	8.0
Rainwater			6.5

Oil and grease dripping on the car park surface may be washed into the construction, but short-term observations (over 2-years) in the field (Schofield, 1994) and laboratory (Pratt *et al*, 1997) suggest that the contamination may be retained inside the construction and will degrade with time. Long-term monitoring at the Youth Hostel will seek to check that this is the case.

GENERAL CONSIDERATIONS OF STORMWATER RE-USE

This form of water storage has a number of advantages and disadvantages. Advantages include:

- inconspicuous;
- no loss of land use if already used or planned to be paved over for footpaths and vehicle standing;
- ease of construction, hence should be reasonably cheap;
- convenient access to pumping equipment which supplies water for re-use from the storage, as the construction is shallow and the pump may be reached easily from the ground surface;
- no danger of drowning for children and animals, as storage is totally enclosed; and
- in the UK climate no problems with freezing below ground.

Disadvantages may be:

- durability of membrane enclosing storage; and
- difficulties of cleansing if material is washed from roof surfaces into storage, therefore, filters will be needed to avoid this problem, but filters will be necessary whatever form of storage is used.

CONCLUSIONS

The UK faces a number of difficult problems in the water environment in terms of both quantity and quality impacts. A strategy of local water storage and re-use could assist in the solving of some of these problems. Storage costs money to install; this cost will not be met by householders alone in sufficient numbers to meet the need; however, if in new housing developments the sewerage undertakers revise their requirements for separate sewers to be constructed, developers may be able to provide the storage throughout the estate at no extra cost over that saved from the costs for a storm sewer. The debate on this approach is only just beginning, but the need for water economy is undeniable; the only question is how does the UK address that need. Presently, the emphasis is totally on the effect that rising prices for water services have in limiting water demand (plus a little encouragement to purchase more water efficient appliances) - this approach threatens public health and is socially divisive. An alternative has been presented here which it is hoped will be given serious consideration.

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