

SOURCE CONTROL AND DISTRIBUTED STORAGE – A COST EFFECTIVE APPROACH TO URBAN DRAINAGE FOR THE NEW MILLENNIUM?

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ABSTRACT

The paper describes the results of a study investigating the cost and operational benefits of source control and distributed storage. Hypothetical catchments based on the aggregation of (20Ha) sub-modules derived from analysis of combined sewer networks in the UK were used as the basis for assessment. Source Control, distributed storage and conventional techniques of sewerage rehabilitation were assessed in a staged approach regarding levels of service provision. The study also reviewed impacts resulting from a general increase in catchment impermeability from 30 to 40% for flat and steeply sloping catchments.

The results show a general trend of decreasing costs for alleviating flooding, the further upstream the rehabilitation measure is effected within the drainage system. Cost savings in the region of 25 to 80% compared to conventional solutions, are realised depending on the type of rehabilitation scheme adopted. The paper advocates a shift in focus from end-of-pipe solutions to upstream controls as an effective alternative urban drainage strategy, especially to resolve the challenges of urban drainage infrastructure provision for the new millennium.

KEYWORDS

Source control; distributed storage; stormwater management; developing countries

INTRODUCTION

A review of urban drainage practice shows that the traditional (conventional) approach has evolved from the philosophy of conveying municipal wastewater and storm run-off away from the urban areas as quickly as possible. As a result, sewers are designed on the basis of providing hydraulic capacity to convey the peak flows for a given return period storm associated with the desired level of service provision (e.g. no surcharge for the 1 in 2yr 'critical storm'). The 'critical storm' here refers to the duration producing the maximum runoff rate – typically the time of concentration for the catchment.

Conventional piped systems have developed over many centuries in response to a changing problem. Originally open channels were used to transport rainfall runoff (water) away as quickly as possible and prevent local flooding. However, over time, these open channels became contaminated and caused objectionable odour problems. This led to the use of closed sewers (combined systems) and as more and more paved areas were built, these sewers in turn became overloaded. Overflows (acting as pressure relief valves) were then provided to prevent flooding from the overloaded sewers.

In time, these overflows have caused pollution of local receiving watercourses resulting in the current focus on improvements to combined sewer overflow (CSO) structures. The urban drainage infrastructure resulting from

the necessary improvements associated with increasing urbanisation and industrialisation, coupled with developments in flood plains, has resulted in downstream flooding and heavy pollution of receiving waters.

The current focus and emphasis on resolving problems associated with CSOs is a natural progression in the “traditional” water control policy which has been to cure problems when they arise (i.e. a reactive-curative) rather than the more holistic approach (proactive-preventative) in tune with nature’s way. The traditional curative approach has tended towards “end-of-pipe” solutions for resolving problems associated with our urban drainage systems. These include the provision of costly large interceptor / relief sewers, massive storage tanks (or basins) in downstream locations to alleviate flooding, and centralised wastewater treatment facilities to reduce the pollution of receiving waters.

Flooding from combined sewers in most urban centres is caused by increase in runoff rates and volumes resulting from expansion and growth beyond the core area. The search for conventional solutions of larger relief sewers or detention basins in the areas where the problems are manifest (i.e. the urban centre), are fraught with problems of lack of space and congestion of services and inevitably leads to very costly schemes.

It has been estimated that by the year 2,000 half of the world population (of over six billion) will be living in urban areas and of the estimated 90 million people currently added to the global population, each year, 94% are in developing countries. A large proportion of the urban population in these countries has no access to sewage disposal systems and urban drainage infrastructure. Most of the existing collecting systems discharge directly to the receiving waters without any treatment. The problem of urbanisation is growing worse on a global scale with the rural poor in the developing countries moving into urban areas. As a result, these urban centres (the fastest growing areas of these countries) will suffer unprecedented demands on the already inadequate urban drainage infrastructure and will be subjected to immense growing strains, both in its physical and socio-economic dimensions.

Sadly, the resolution of problems associated with urban drainage infrastructure provision in the developing countries currently most invariably follows along the traditions of the developed countries even though these schemes are known to be inappropriate and often unaffordable (Sonuga, 1993). The need for more cost-effective, affordable and sustainable urban drainage in the new millennium is clear. This poses severe challenges for all.

SOURCE CONTROL AND DISTRIBUTED STORAGE

Source control and distributed storage present an alternative preventative approach to urban drainage, more in tune with “Nature’s Way” and sustainable development principles. The concepts of source control and distributed storage are described in detail elsewhere (Smisson, 1980). Case studies describing the application of these alternative approaches to real catchments demonstrating the scope for cost savings of the order of 50% over traditional interceptor schemes are described by Andoh and Lamb (1996) and Barber et. al. (1994).

In this paper, the term Source Control is used to describe mitigating measures implemented when the rain first impacts upon the catchment surface, typically upstream of piped drainage and sewerage networks. These include storage on flat roofs, in water butts or below ground, in temporary reservoirs formed by impermeable membranes beneath permeable surfaces. Storm flows may also be routed back to the natural environment by enlisting the aid of natural processes such as infiltration and percolation. These techniques have been called Best Management Practices (BMP’s) or compensating techniques (Urbonas and Stahre, 1993).

Distributed storage on the other hand refers to storage facilities implemented in the upstream parts of storm water or wastewater collection and conveyance systems where each storage unit is relatively small and is located closer to inflow sources. The target of this approach is to provide a preventive solution to flooding and associated pollution through distributed attenuation and treatment facilities in the upstream parts of the

catchment. Thus by controlling the flows at their source so that they match the downstream system capacity, best use is made of the existing drainage infrastructure.

These solutions aim at counterbalancing and compensating the adverse effects of the increase in impermeability (resulting from the urbanisation process). This is effected through better control of flows in the upper parts of the catchments, close to their inflow sources. The application of upstream controls to mitigate downstream problems in urban drainage systems is illustrated simply by Figures 1 and 2.

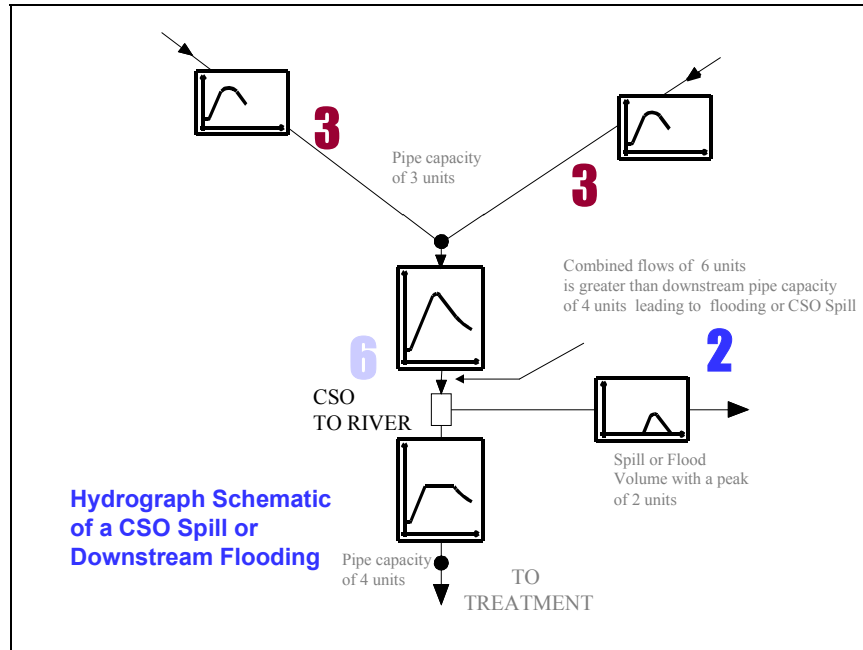


Figure 1

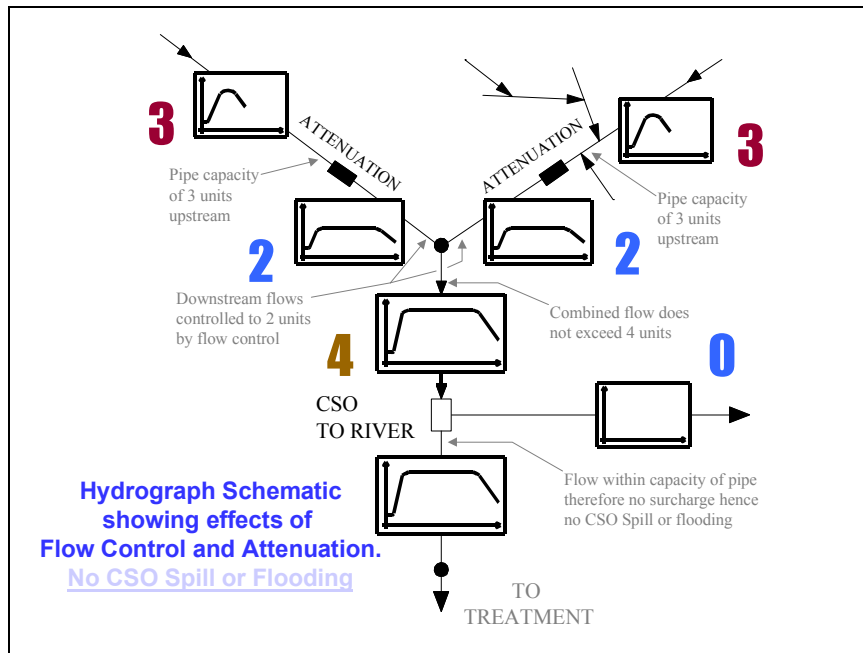


Figure 2

Figure 1 shows the combined flows from two sub-catchments on a network exceeding the capacity of a downstream sewer resulting in flooding or a CSO spill. The conventional solution to this problem would typically involve providing storage at the downstream location where the flood or spill occurred or transferring the problem further downstream by upgrading the capacity of the downstream sewer to cope with the combined flows from upstream.

In Figure 2, the combined flows from upstream are prevented from overflowing or flooding a downstream location because the rate of release of water from upstream parts of the catchment is limited, by the use of flow control devices, to the capacity of the downstream sewer. This results in a distributed storage system with inherent system storage in upstream sewers mobilised. Where the mobilised system storage volumes are inadequate, supplementary storage in the form of on or off-line storage tanks or over-sized sewers may be provided as appropriate.

Source control and distributed storage systems generally result in a multiplicity of control elements and structures within the catchment, the further upstream the control measure is implemented. Fears and worries about maintenance and issues relating to responsibilities has been one of the mitigating factors preventing the wide-spread adoption of these approaches in the UK (McKissock, et. al., 1999). In general however, a distributed system with passive robust control elements *is inherently more reliable and less susceptible to failure than a centralised system*. Failure of one component of a distributed system may not necessarily be critical whereas failure of a centralised system can lead to catastrophic effects.

The key to the effective implementation of distributed storage systems within the context of urban drainage systems lies in the availability of passive robust flow control devices such as vortex flow controls (Andoh, 1994). These devices require no external power source to operate but rather harness the inherent energy within the flow to effect the required control. In addition, they have virtually no maintenance requirements and are less susceptible to blockage compared with other flow control devices such as orifice plates.

METHODS

Catchment Characteristics and Modelling Tools

The catchment models used for the analysis were based on the aggregation of sub-module catchments with characteristics derived from an assessment of information from a number of Drainage Area Studies conducted for Water Service Companies in the UK. This resulted in the derivation of a 20Ha sub-module with the following features:

- Total length of sewers: 11 000m
- Total number of manholes: 210 (one manhole every 50m on average)
- Pipes roughness: 1.5mm
- Slope: 1% for flat catchments and 4% for steep catchments.
- Average depths: from 2 to 4 metres.
- Pipe diameter: from 225mm to 900mm

The catchments were assumed to be evenly developed with an impermeability of 30% (medium density residential area – 19% for roofs and 11% for the paved surfaces). Further catchment development via the urbanisation process was represented by an increase in impermeability to 40% derived from (19% roofs, 21% paved).

The Hydroworks simulation package was used as the network-modelling tool in this study. For each of the identified rehabilitation options, a range of storm durations were simulated for each of the desired levels of service (return periods). This was to ensure that the design storms investigated included that for maximum rate

of flow (for which the critical duration is approximately equal to the time of concentration) and that providing the maximum storage (for which the critical duration may be significantly longer than the time of concentration).

Conventional Approach

The Sewerage Rehabilitation Manual (WRc, 1983) was used as a guide for the evolution of the conventional solutions. The approach adopted involved identifying flooding caused by inadequate hydraulic capacity. Design was then carried out from the most upstream deficient areas to the downstream end of the overall catchment. The methodology can be summarised as follows:

1. Determination of the contributing sub-catchment related to the problematic node.
2. Evaluation of the peak flow to be handled by the system at this location for the design return period (i.e. obtain peak flow for the critical storm duration).
3. Selection of the pipe (sewer sizes) capable of conveying his peak flow.
4. Assessing storage requirements to contain flows in excess of the permissible outlet flow.

Source Control and Distributed Storage

The analysis and design methodology adopted for this approach is opposite to the conventional one with analysis and calculations carried out from downstream to upstream. A stepwise scheme involving limiting the flows from upstream pipes to match downstream pipe capacities was employed. Successive restriction of flows resulted in flood volumes being displaced upstream of the control locations. Hydroworks enabled the quantification of these flood volumes and as a result, the amount of supplementary storage required at each location.

The procedure starts at the outlet of the overall catchment limiting the flow to the permissible outlet flow. The next stage involves moving further upstream in the catchment to the next main junction and restricting flows to match the full capacity of the downstream system. At these locations and further upstream, excess water may create floods. The further upstream we move up in the system, the smaller each individual flooding to deal with is and therefore the easier it is to mobilise latent (in-system) storage or provide supplementary storage as appropriate. One advantage of this methodology is that it systematically takes into account storage volumes, which may exist within the pipes and manholes, mobilised by the use of flow control devices.

Source control solutions involving the disconnection of roof downspouts were modelled in Hydroworks by reducing the contributing impermeable areas.

RESULTS AND DISCUSSION

The rehabilitation options investigated are described in outline below under the appropriate sub-headings.

- Option 1 – Conventional** : Upgrading hydraulic deficient pipes and providing underground storage at the outlet
- Option 2 – Source control** : Provision of flow controls, downspout disconnections and supplementary storage in oversized pipes and manholes.
- Option 3 – Source control** : Provision of flow controls, storage in oversized pipes and manholes and storage mobilised on paved surface.
- Option 4 – Distributed storage** : Provision of flow controls and distributed storage in contributing sub-catchments.
- Option 5 – Distributed storage** : Provision of flow controls and storage in oversized pipes and manholes.

Table 1: Costs for Conventional Solution – 10 to 35 years upgrading for steep catchment

Option No:	Description of components	Component Costs (£)	Total Costs (£)
1	200m of 600mm diam. Pipe	36000	480100
	500m of 750mm diam. Pipe	105000	
	100m of 975mm diam. Pipe	27000	
	5 No. precast manholes 1500mm, 3m deep	7500	
	Site clearance	5600	
	840m ³ reinforced concrete underground storage	294000	
	1 no flow control	5000	

Table 2: Costs for Source Control Solutions – 10 to 35 years upgrading for steep catchment

Option No:	Description of components	Component Costs (£)	Total Costs (£)
2	800 roof downspout disconnections + 800 concrete splash pads	80000	182000
	4 by 50m of 1050mm diam. Pipes	58000	
	8 No. precast manhole, 1700mm, 3 m deep	12000	
	4 No. vortex flow controls rated at 660 l/s (including chambers)	32000	
3	4 by 80m of 1050mm diam. Pipe	92000	148240
	12 No. precast concrete manholes, 1700mm, 2 m deep	18000	
	4 No Vortex Flow Controls rated at 400 l/s	28000	
	4 No Vortex Flow Controls rated at 10 l/s with up to 1cm depth detention on existing paved surfaces	8000	
	Site Clearance	2240	

Table 3: Costs for Distributed Storage Solutions – 10 to 35 years upgrading for steep catchment

Option No:	Description of components	Component Costs (£)	Total Costs (£)
4	4 No. 150m ³ reinforced concrete underground storage	210000	242000
	4 No. Vortex Flow Controls rated at 660 l/s (including chambers)	32000	
5	4 by 145m of 1050mm diam. Pipes	168000	230000
	20 No. precast concrete manholes, 1700mm, 2 m deep	30000	
	4 No. Vortex Flow Controls rated at 400 l/s	28000	
	Site Clearance	4000	

The results for rehabilitation schemes for improving the level of service from 10 years to 35 years against flooding for the steep catchment are summarised in Tables 1-3 for the five options outlined above. These show

a general trend of decreasing costs as control options are implemented away from “end-of-pipe” towards the upstream parts of the contributing catchment. Tables 2-3 show source control options being more cost-effective than distributed storage options with savings ranging from 30 – 50% compared with the conventional solution. Similar trends were observed for comparable rehabilitation schemes for the flat catchment.

Results of options for increasing the levels of service from 10 year to 50 years with a concomitant increase in catchment impermeability from 30 to 40% (to represent increased urbanisation) are summarised in a graphical form in Figure 3 for both steep and flat catchments.

Rehabilitation Options

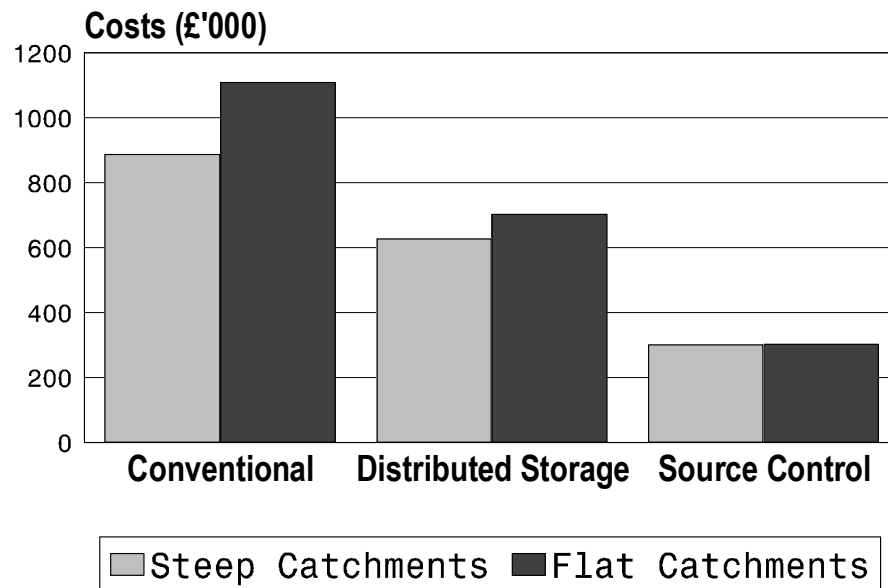


Figure 3

Figure 3 also depicts a general trend of decreasing costs as solutions move away from end-of-pipe towards inflow sources with overall cost savings ranging from 25 – 80%.

A general observation made was that the source control and distributed storage schemes required less storage per hectare of impermeable area compared with the conventional solutions. Storage requirements ranged from 24–27 m³/ha_imp.area for the source control and distributed storage schemes compared with 27–35 m³/ha_imp.area for the conventional schemes (Declerck, 1996). This is attributed to the better utilisation of the latent storage volumes available in the existing pipes and manholes.

CONCLUSIONS

The traditional paradigm for urban drainage involving the use of bigger and bigger capacity conduits downstream to get rid of the rainfall run-off as quickly as possible results in costly schemes. This approach is clearly unsuited to the developing countries where the major challenges for urban drainage in the new millennium are going to be. Urban run-off is typically highly polluted with pathogenic and organic substances that pose public health threats during flood events. In developing countries, this situation is exacerbated by the

rapid pace of urbanisation coupled with the inadequate facilities for the proper collection and disposal of domestic and industrial wastes. Most urban centres in the developing world have open drains that are receptacles for garbage from domestic and commercial activities. Solid wastes are often either dumped directly into water bodies or disposed on roadsides where they are later washed into ecologically sensitive urban streams and other receiving water bodies.

The provision of urban drainage infrastructure in such vulnerable environments requires special attention as the solution matrix is complex and requires a multidisciplinary approach taking into account the need to integrate differing facets of urban infrastructure needs. In order to promote a sustainable approach to urban drainage infrastructure provision, there is the need to go back to basics and copy nature's way. Nature has evolved balanced hydrological and hydro-geological cycles with relatively slow dynamics. Rainfall runoff response in nature is relatively slow on account of the natural flow brakes and distributed storage provided by the flora and habitats of fauna such as beavers (providing natural dams that prevent flash floods).

The results of the study presented in this paper suggest that a shift from a downstream focus to an upstream focus provides a potential new paradigm, more in tune with nature's way and that, this should ultimately lead to more cost-effective and sustainable urban drainage schemes. The scope for implementing source control schemes is greatly enhanced where "green field" sites are being developed (e.g. new developments in developed countries) or where urban drainage systems are relatively undeveloped such as in the developing countries. Where extensive systems already exist and institutional barriers mitigate against source control, a distributed storage approach provides alternative cost-effective solutions to the conventional approach.

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