Alternative Urban Drainage Strategy Utilising the Single Pipe System

Stratégie alternative de gestion des eaux pluviales utilisant le système «single pipe»

R.Y.G. Andoh*, R.P.M. Smisson**

* Hydro Research & Development Ltd., Shearwater House, Clevedon, Avon BS21 7RD, U.K.

** Smisson Foundation, Shearwater House, Clevedon, Avon, BS21 7RD, U.K.

RÉSUMÉ

L'urbanisation rapide, et par conséquent, l'augmentation des surfaces imperméables et la modification résultante de l'usage des sols, ont généralement provoqués des problèmes d'inondations et de forte pollution des rivières urbaines et autres eaux réceptrices. Ces problèmes ont souvent été associés à une réduction des nappes phréatiques et à une menace sur les ressources en eau. L'article présente une philosophie et une stratégie alternative pour le drainage, qui copie le cycle naturel de l'eau en ralentissant les ruissellements urbains. Cette approche permet la mise en place de systèmes de drainage économiques, réalistes et conformes à l'idée du développement durable. Cette stratégie alternative peut être décrite *comme préventive plutôt que comme corrective*. Elle consiste à mettre en place des contrôles plus proches de la source que l'approche traditionnelle qui transfére les problèmes en aval, aggravant ainsi le problème et provoquant un cumul et un besoin de contrôle à grande échelle.

SUMMARY

Rapid urbanisation and its consequent increase in impermeable surfaces and changes in land use has generally resulted in problems of flooding and heavy pollution of urban streams and other receiving waters. This has often been coupled with ground water depletion and a threatening of water resources. The paper presents an alternative drainage philosophy and strategy which mimic's nature's way by slowing down (attenuating) the movement of urban runoff. This approach results in cost-effective, affordable and sustainable drainage schemes. The alternative strategy can be described as one of *prevention rather than cure* by effecting controls closer to sources rather than the traditional approach which results in the transfer of problems downstream, compounding the problem, resulting in its cumulation and, the need for large scale centralised control.

1.0 INTRODUCTION

The current world population of more than five billion people is estimated to increase to over six billion by the end of the millennium. Of the estimated 90 million people currently added to the global population, each year, 94 percent are in developing countries. The poor of the developing countries are moving into urban areas and as a results the urban centres are the fastest growing areas of these countries.

The problems of urbanisation manifest and currently being dealt with in both developed and developing countries such as hydrologic/hydraulic control and environmental impact reduction, will no doubt grow worse in the developing countries. If the cost estimates of £107 billion (1992 price base) attached to the meeting of the European Council (EC) urban wastewater treatment Directive by the EC member countries (Wright, 1992) is anything to go by, then it is clear that the provision of urban drainage infrastructure along the conventional approach is going to be unaffordable for the urban centres where the majority of the world population will reside.

This paper presents an alternative drainage philosophy and strategy which represents a paradigm shift from the traditional approach. The alternative strategy, based on the philosophy of the single pipe system (Smisson, 1980), aims to mimic nature's way by slowing the movement of storm water from urban areas, encouraging the infiltration of relatively uncontaminated rainfall runoff to help maintain base flows in rivers and the beneficial re-use of rainwater through distributed storage close to source. A number of case studies are presented which demonstrate the significant cost savings that can be realised by adopting the alternative approach.

In order to appreciate the potential benefits of the alternative strategy, it is necessary to review the evolution of current urban drainage practice and highlight how the alternative strategy represents a shift from the conventional approach.

2.0 URBAN WASTEWATER DRAINAGE

2.1 General

Wastewater flows in urban drainage systems are derived from two main sources: *«Base Flows»* and *«Storm Water Runoff».* Urban wastewater conveyance systems have been described as «foul»,»surface», «combined», «partially combined/separate» or «separate» depending on the relative contributions of base flows and storm water runoff. Conventional drainage practice recommends the use of foul systems for draining base flows to a central wastewater treatment plant and the use of surface water systems, only, for draining storm water runoff. This results in a number of sewer networks draining developed areas.

The main driving force resulting in storm water runoff in urban drainage systems is rainfall. Urbanisation and its consequent land use changes have resulted in surface levelling, reductions in surface detention and a consequent reduction in the pre-development natural flow attenuation capacity of the land. Pollution of storm water runoff results from the contamination of rainwater through contact with various substances from the time of its origin in the atmosphere until the moment of its discharge into a receiving body of water.

2.2 Evolution of conventional urban drainage systems

The urbanisation process has involved the growth of communities with people living closer and the conversion of open ground, that absorbed rainwater, to impermeable pavements and buildings. Associated with this has been the accompanying reduction in areas where the resulting stormwater, following rainfall, could be absorbed into the soil. This resulted in flooding in the vicinity of households. Open channels were therefore constructed to convey run-off from roads and roofs, away from properties to prevent flooding. The increasing population concentrations associated with the urbanisation process also resulted in increases in waste generation. Household wastewater were connected (disposed off in the nearest open channel) and this in turn created problems of smell. As a result, the open channels constructed to alleviate flooding were covered creating combined sewer systems.

Sewage treatment (initially via sewage farms) evolved from the need to alleviate the problem of pollution resulting from discharges from combined sewers into receiving waters close to the centres of population. For example, the Thames River through London in the UK, was becoming foul smelling between 1862 and 1864. Sewers were therefore built down to the estuary below London to take London's wastewater and discharge it straight into the estuary. A number of years later, however, problems were again becoming apparent so sewage treatment started in the late 1800s.

A review of the pattern of development of urban drainage described, shows that the response has characteristically been one of finding a cure to an observed problem. «Mankind» has traditionally operated and still to an extent operates under a feedback law. A control action is sought and implemented only when an undesirable state of affairs is observed.

2.3 Institutional issues

In most countries, the institutional arrangements pertaining to responsibilities and control of the various stages (facets) of the water cycle have typically been fragmented with, for example, one institution responsible for municipal wastewater sewerage and treatment, another responsible for land drainage and urban runoff drainage systems and yet another for the drainage of highways and urban roads. This fragmentation is not conducive to the implementation of an integrated watershed or catchment approach to urban drainage owing to the imposition of artificial boundaries and potential conflicting interests.

Cross-connections, wrong connections and combined sewer overflows mean in effect that the traditional descriptions of foul, combined or surface water sewerage systems of urban drainage, which have typically formed the basis for the divisions in institutional responsibilities, are not strictly correct. In the urban environment, the interactions between the various wastewater networks (e.g. combined sewers, highway drainage and land and surface water drainage systems) means in effect that wastewater derived from sources under the jurisprudence of one institution could in effect ultimately be disposed off into a receiving water through a network in the jurisprudence of another institution.

In this regard, the preferred description for urban drainage systems is one of; *«several complex networks of sewers with varying proportions of contributions of base flows and surface water run-off».*

If the overall interests with regards to mankind's interactions with the water cycle in the urban environment is stated as one of; *«the provision of adequate quantities of safe (potable) drinking water supplies, the safe disposal of all urban wastewater, the maintenance of water resources and the prevention of adverse aquatic environment impacts»,* then it is suggested that the division of institutional responsibilities be along the lines of «service provider» and «regulator». Boundaries for such institutions would not be along the lines of administrative regions but rather on receiving water catchment or natural watershed basis.

2.4 The alternative approach

Current developments in technology mean there is a spectrum of control measures (Andoh, 1994) that the l990s drainage engineer can implement to resolve urban drainage problems. These range from structurally intensive traditional solutions of sewer separation and the construction of enlarged relief sewers through source and in-system control methodologies, to non-structural measures such as street cleaning, litter control and public education programs. Each of the available control measures has an associated reliability and risk of failure which needs to be taken into account in the evolution of control measures. Generally, it would appear however that, the further upstream a control measure (ie. far removed from end of pipe) the closer it is to source and hence nature's way of a spatially distributed control system.

Prior to urbanisation, nature utilised the vegetation in the habitat (the leaves of trees etc.) to attenuate the run-off, encouraged evapotranspiration and slowly recharged ground water aquifers via percolation. This was in essence a spatially distributed flow attenuation system where small volumes of «system» storage was mobilised to slow down the rate of run-off following rainfall.

The alternative drainage concept being advocated utilises the single pipe system philosophy. This approach differs from the conventional combined drainage concept in that no overflows are permitted from the single pipe system. A single sewer network system conveys the highly polluting urban wastewater sources to a treatment facility prior to its discharge as treated wastewater into a receiving water course. Flows in excess of downstream sewer capacities during rainfall are retained adjacent to the intakes to the sewer system, in local transient storage.

Wastewater that has entered the sewer system is 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. Details of the basis for design of the single pipe system are described elsewhere (Smisson, 1980). The single pipe system design philosophy recommends the use of *minor* and *major* drainage systems. The minor system consists of a piped drainage network constructed to serve the area with sufficient capacity to convey base flows and the «more frequent» storm runoff from roads, highways and other paved areas likely to be sources of relatively polluted runoff.

The major system consists of the natural drainage routes and patterns evolved by nature prior to mankind's interference through development. This is defined by the topography and geomorphology of the area. Overland flow routes for the major system may incorporate roadways, existing streams and their flood plains and, suitably graded lawns, park lands and green belts. Overland routes can be engineered such that large parks and gardens etc. are utilised as flow attenuation or retention/detention basins which encourage evapo-transpiration and percolation.

Sadly, the lack of adequate planning policies and controls coupled with a lack of awareness of the importance of the natural drainage routes has resulted in developments that alter or obstruct the natural drainage paths. There is a need therefore for an increased awareness of the impacts of uncontrolled urban developments and a clear demarcation and inclusion of natural drainage paths in urban development plans. Plans for land use changes should incorporate features to increase the surface storage and reduce the velocity of overland flows. The hydrogeological characteristics of the area should be taken into account such that the maximum potential for percolation into the underlying soil is realised.

A review of the hydrological cycle would suggest that one of the key objectives in environmental water quality protection should be that of preventing the contamination of relatively unpolluted water sources. Rain water tends to be the least contaminated of sources. Collection and storage of rainwater water runoff from roofs, for example, could serve the dual purpose of significant reductions in the volume of runoff into sewer networks and the provision of water which could be used for general purposes such as watering of lawns and gardens.

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 basin 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. Adopting the alternative philosophy of prevention rather than cure would mean solutions investigated look at ways in which flows into and through the urban centres can be reduced or attenuated before they arrive at the problem areas.

The single-pipe system drainage concept advocated as an alternative to the conventional approach, represents a shift from a curative approach to a preventative approach. This inevitably results in the conservation of resources and leads to cost beneficial schemes for either the provision of new urban drainage infrastructure or the resolution of problems with existing infrastructure caused by the urbanisation process. The potential benefits resulting from adopting such an approach are demonstrated by the case studies presented

3.0 CASE STUDIES.

3.1 York, Ontario - Toronto, Canada

The borough of York, a suburb of Toronto, Canada, has a combined sewer system and in the past had suffered from severe sewer backup along with combined sewer overflows polluting the Humber and Don Rivers. Following a consultant's recommendation, York embarked on a $50 million program along the traditional structural-intensive solution of sewer separation and storm sewer enlargement, in 1968. Between 1968 and 1976, York spent an average of $646,000 per annum (22 percent of its annual budget), on this project (GAO, 1979).

By 1976, the borough council had become quite concerned about the tremendous cost of the project and engaged an engineering firm to find an alternative solution. This firm determined that the conventional approach of relief sewers was far too costly and suggested using flow regulators in catch basins, constructing limited-storage underground tanks, and either disconnecting down spouts from roofs, or installing restrictors in the down spouts as alternatives to the traditional construction for four chronically flooded areas:

Under this approach, when sewer system capacity is exceeded, stormwater would be temporarily stored in underground tanks or on the surface for slow release into the system. York opted for a 10-year storm protection and accepted a final cost of $987,633. The alternative approach was completed in 1978, with the exception of installation of restrictors in the down spouts, and has worked satisfactorily with no reported flooding in the four areas.

3.2 Wadley road - Waltham Forest, London

The Wadley Road Storm Sewer System serves a steeply sloping catchment area of approximately 20 Ha. Overflows from storm water sewers had inundated Wadley Road every year for as long as residents can remember creating flooding up to about 1 metre deep. The main cause of the flooding was found to be due to the fact that Wadley Road represents the low spot for the catchment area upstream and the three collector sewers which converge just upstream of Wadley Road had times of concentration within a minute of each other. Also, the combined hydraulic capacity upstream of Wadley Road was 455 l/s compared with a downstream capacity of 250 l/s. The only solution which seemed possible (adopting the traditional approach) was the construction of a bypass sewer system at an estimated cost of £90,000 to £100,000. Though this solution would cure the flooding problems at Wadley Road, it run the risk of flooding another street further downstream.

A review of the problem showed that a viable, and by far more cost effective alternative, solution would be to use Hydro-Brake™ flow controls to mobilise available system storage throughout the catchment area upstream of Wadley Road. Nine Hydro-Brake™ flow controls of various suitable sizes were installed at a cost of £24,000 resulting in a reliable economical solution well below the cost of an unsatisfactory traditional alternative.

3.3 City of Evanston, Illinois - USA

Evanston, a community with a population of approximately 75,000 is served by a combined sewer system. Sewer overloading leading to frequent basement backups, occurring up to six times a year, was a major problem facing the city. In 1987, an engineering consultant was engaged to evaluate the problem and develop a cost effective alleviation program for the City's combined sewer problems (Barber et. al., 1994).

The traditional solution of relief sewers/sewer replacement, which would have provided a 1 in 5 year level of protection was estimated to cost $290 million. In addition, the traditional solution would cause major disruption because up to 90% of the City's streets were affected. The high cost of the traditional solution coupled with the potential disruption to local residents caused the city to seek a more affordable solution.

Following a review of alternatives, the plan adopted involved partial sewer separation with above ground storage and overland flow. Inlet restrictors to limit the inflow to the hydraulic capacity of the existing system were installed in catch basins. Excess storm flow is temporarily retained on the street surface and overland flow routes have been established to convey flow to new high capacity inlets at the head of new stormwater relief sewers. This alternative is estimated to cost $143 million, approximately 50% of the conventional sewer relief scheme. Furthermore, the level of protection against basement flooding has been increased from the 1 in 10 year level, with the conventional solution, to the l in 100 year level for the adopted alternative.

Following completion of the first phase of the project, Evanston has been subjected to several storm events which would have created basement backup in the past. A survey of the area's residents revealed that no backups were experienced.

4.0 CONCLUDING REMARKS

The main factors preventing the wholesale adoption of the alternative approach are *«Tradition»* and *«Institutional issues».* Engineers have been trained to think along the lines of the traditional concepts and the Institutional arrangements in most countries are not conducive to the implementation of the alternative approach. Provision of urban drainage infrastructure along traditional lines is too costly. The alternative approach described provides a framework which should enable staged implementation of effective urban drainage infrastructure. Changes in institutional structures to reflect integrated environmental service provision and control and an increased awareness through educational programs and public awareness campaigns should help in the evolution of appropriate urban wastewater control systems.

REFERENCES

ANDOH, R.Y.G. (1994) *Urban Runoff: Nature Characteristics and Control*. J. IWEM, 4, August, pp 107-199.

BARBER, D., PERSAUD, R., STONEBACK, D., and VELON, J. (1994) *Evanston's Unique Solutions to Large Combined Sewer Problems*. IWEA, March 31.

SMISSON, R.P.M. (1980) *The Single Pipe System for Stormwater Management*. Prog. Wat. Tech., 13, 203-214.

US GENERAL ACCOUNTING OFFICE. (1979) *Large Construction Projects To Correct Combined Sewer Overflows Are Too Costly*. Report by the Comptroller General of the United States, CED-80-40, December.

WRIGHT, P. (1992). *The Impact of the EC Urban Waste Water Treatment Directive*. J. IWEM, 6, December, pp 675-681.