Urban Drainage and Wastewater Treatment for the 21st Century

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Abstract

The paper reviews urban drainage and wastewater treatment practice highlighting the role of conventional sewerage and wastewater treatment in promoting public health in the 20th century. It advocates the need for a shift from the reactive-curative framework or philosophy that has been the central theme governing the evolution of the traditional (conventional) approach, to a proactive-preventative approach centring more on sustainability principles and involving the social dimension to a greater degree than has been the practice in the past. It argues that this is especially required if the challenges faced by the rapidly urbanizing mega-cities in countries with fragile economies are to be met in the current millennium.

Introduction

The need for conservation of natural resources, the abatement of pollution and consideration of environmental factors in development and planning has become an important issue. It is more now than ever before in the history of the human race, becoming evident that our ecological systems cannot cope with many of our activities resulting from urbanisation and industrialisation.

Unfortunately, the human race has traditionally operated and still to an extent, operates under a feedback law with a control action sought and implemented only when an undesirable effect or state of affairs is observed (Andoh, 1994).

Urban drainage and wastewater treatment practice and control philosophies have been no different; solving problems either by transferring excessive flows in drainage systems downstream by upgrading sewer pipes or, relieving flooding by constructing storm overflows or providing stepwise improvements in wastewater treatment in response to identified acute pollution impacts.

Observations of downstream flooding and pollution and the interdependence and interaction of the effects of control measures adopted within drainage networks and at wastewater treatment works sites, have focused attention, in more recent times, on the need for an integrated systems approach (Butler and Davis, 2000).

The paper reviews urban drainage and wastewater treatment practice showing that the traditional (conventional) approach has evolved from a curative framework or philosophy with feedback loops as the main control options adopted. It advocates the need for a major shift in paradigm and approach from the conventional "reactive-curative" to a "proactive-preventative" one with both feedback and "feed-forward" control loops. It suggests that the coupling of this new approach with increased stakeholder participation is what will ultimately lead to more sustainable urban drainage and wastewater treatment systems in the 21st century.

Background

As we begin a new millennium, the major challenges faced by public health / environmental engineers and professionals, is the provision of sustainable urban water infrastructure in the rapidly urbanising mega-cities mostly in developing countries and emerging economies. These countries generally have a deficit of trained manpower and personnel to implement appropriate urban water systems and are heavily reliant on developed economies for both development aid and technical assistance.

Unfortunately, most public health engineers and environmental professionals engaged in activities relating to technical assistance for urban water infrastructure provision are trained along the lines of conventional urban infrastructure provision which in turn creates a cycle that sustains and fuels the conventional approach. Conventional urban infrastructure provision is costly (GAO, 1979) and may not be the most appropriate for this new millennium.

Towards the end of the 20th century, a number of practitioners in the general field of urban water sounded the call for a change in approach to a new paradigm more in tune with nature's way (Smisson, 1979; Andoh, 1994; Beck *et al.*, 1994; Harremones, 1997; Andoh and Declerck, 1999; Butler and Davis, 2000; CIRIA, 2000; McKissock *et al.*, 2001; Iwugo *et al.*, 2002). This general approach has been described in a number of ways / acronyms including Source Control, Best Management Practices (BMPs) and more recently, Sustainable Drainage Systems (SuDS). The approach recognises the multi-dimensional aspects of urban water infrastructure provision especially the role and inputs of stakeholders, the social dimension and the need for adequate education / training elements. The call now is for a more holistic approach to urban water infrastructure provision integrating various facets of the urban water environment.

Despite increased awareness of alternative approaches, the current practice in relation to urban water infrastructure provision in the main still follows along the lines of conventional approaches (Andoh and Iwugo, 2002) and the reasons for this include the fact that the vast wealth of knowledge and available technical guides (including software tools and other knowledge based materials) are centered on conventional systems. Design and operational practices and norms have evolved around conventional systems and being creatures of habit, humans generally resist change and prefer to operate from known "comfort zones".

The paper reviews the evolution of both conventional and emerging drainage and wastewater treatment systems through the 20th century and presents a case study highlighting benefits that accrue from adopting systems and approaches centered more on a proactive-preventative principle / framework. It discusses the need for actions taken now to include "feed forward" loops in the form of 'future casting' of the potential impacts of current global trends such as climate change and consideration of sustainability issues and other long ranging impacts or evolutionary pathways. This contrasts with the current philosophy and approaches that focus on the resolution of the immediate acute problems of concern.

The paper also suggests that the relatively recent developments in information technology and communications should provide a framework for rapid dissemination of information and that fostering and adoption of appropriate knowledge tools and methodologies will ultimately facilitate the assessment and implementation of more sustainable urban water infrastructure for this new millennium.

Conventional Urban Drainage and Wastewater Treatment Systems:

Conventional sewerage and wastewater treatment systems evolved over many centuries in response to changing problems. Originally open channels (sewer system) were used to transport rainfall runoff (stormwater) away as quickly as possible from the city's populated centre and prevent local flooding. As indoor plumbing became popular, the sewer system was used to carry wastewater as well. However, over time, these open channels became contaminated and caused objectionable odour problems. This led to the use of closed sewers (combined sewer systems) discharging to the nearest watercourse.

With increasing urbanization and its associated increase in anthropogenic inputs, the local watercourses became heavily polluted. Because of concern for water quality and public health, cities initially built interceptor sewers to transport the combined sewage further downstream away from the developed area. As the main rivers in turn became polluted, sewage treatment started initially in the form of sewage farms. Additional treatment stages (i.e. Primary, Secondary and Tertiary) evolved to address the need for increased pollutant removals to restore the "ecological health" of the rivers.

Urban water-related environmental efforts in the second half of the twentieth century focused on the control of point-source effluent discharges such as wastewater treatment works effluents. The use of separate surface water sewers (especially for new developments) evolved to address the issue of increasing stormwater flows into combined sewer systems. The thinking was that stormwater is relatively "clean" and as such can be discharged to the nearest watercourse without treatment. As controls to reduce water pollution from traditional point sources were implemented, it became evident that diffuse sources of pollutants, including discharges from separate storm drainage systems and combined sewer systems are major causes of water quality problems (CIWEM/IWA, 2000; Ellis, 1991).

Runoff from parking areas, highways and other impervious surfaces in urban areas, drained by separate surface water sewers (see Figure 1), have been found to contain high concentrations of pollutants. These include oil and other hydrocarbons, microbial organisms, heavy metals and other toxic micro-pollutants, many of which have been found attached to suspended solids and sediments. In recent years, there is a heightened awareness of the adverse water quantity and quality impacts of stormwater leading to increasing legislative focus and tighter environmental standards (e.g. Phase 1 and Phase II Stormwater Rules in the USA).

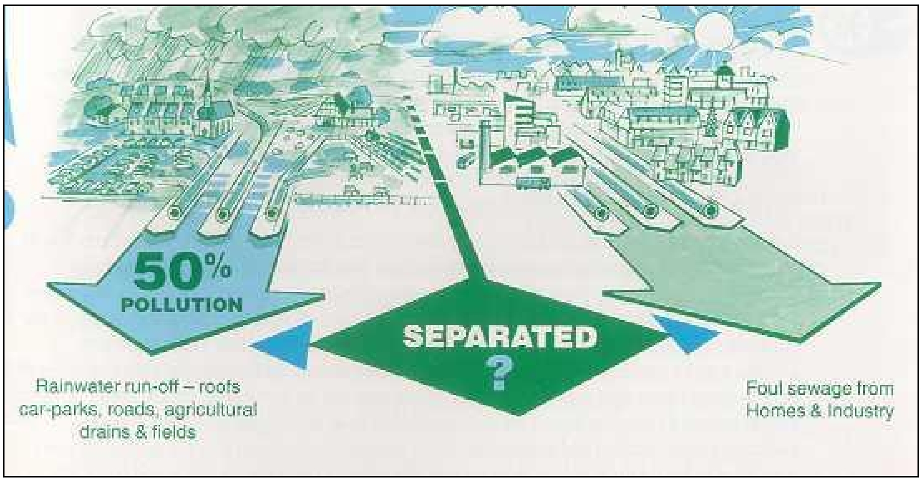

Figure 1: Diffuse Sources may account for greater than 50% of the Pollution Load

A review of urban drainage and wastewater treatment practice shows that the traditional (conventional) approach has evolved from a reactive-curative approach governed by feedback controls with remedial actions sought and implemented focussing only on the undesirable effect or state of affairs observed. The central philosophy being that of "**getting rid of water as quickly as possible**" and "**transporting and handling pollutants as far away as possible**".

This philosophy of rapid conveyance of municipal wastewater and stormwater run-off away from the urban areas coupled with remote handling and processing, has promoted the current (conventional) "out-of-sight-out-of-mind" infrastructure and associated control and rehabilitation options that focus on downstream- "end-of-pipe" solutions (see Figure 2).

Figure 2 "Out of Sight Out of Mind" Nature of Conventional Urban Water Infrastructure

It can be surmised that the progress of civilization has been directly proportional to the distance mankind has placed between itself and its waste and that the community at large has had very little knowledge and interaction with its own wastes and effluents. An ever increasingly crowded world now however has to live closer and closer to its own wastes and effluents and this calls for a change in paradigm from the "out-of-sight-out-of-mind" attitude, which has led to the "end-of-pipe" approach.

Though the conventional systems have served the countries with developed economies quiet well and have contributed significantly to the major strides in public health achieved during the 20th century through the simple expediency of breaking the cycle of direct contact between humans and contaminated wastewater sources, their "out-of-sight-out-of-mind" nature coupled with general societal practices of using them as dumps for practically all waste products other than solid wastes, has resulted in significant material exports and major reductions in the scope for reuse and recycling of potential resources (e.g. rainwater harvesting and local recovery and reuse of nutrients). Questions are currently being asked about the general sustainability of conventional systems (Everard and Street, 2001).

Emerging Systems:

Source control and distributed systems present an alternative preventative approach to urban drainage and wastewater management infrastructure provision, more in tune with "Nature's Way" and sustainable development principles. These concepts are described in detail elsewhere (Smisson, 1980; Urbonas and Stahre, 1993; Andoh and Smisson, 1995; Andoh and Declerck, 1999) and involve solutions that aim at counterbalancing and compensating the adverse effects of the increase in impermeability (resulting from the urbanization process). They also involve intercepting and treating wastewater at an early stage in the cycle of collection, transport, treatment and disposal (CTTD) and are effected through:

- Intercepting and reusing rainfall runoff,
- Better control of flows in the upper parts of the catchments, close to their inflow sources,
- The use of high rate passive solids-liquid separating devices in upstream locations and
- Utilizing ecological based wastewater treatment systems (e.g. reed beds, constructed wetlands and waste stabilization ponds).

Though these systems are increasing being adopted in the main stream, there is still significant barriers to their widespread adoption (Andoh and Iwugo, 2002) despite the growing number of case studies describing their application and demonstrating the scope for major cost savings (of the order of 25% to 80%) over traditional schemes (Boner, *et. al.*, 1992; Barber, *et. al.*, 1996; Andoh *et. al.*, 2000; Coombes and Kuczera, 2001).

Recognition of the need for flow attenuation and post development runoff control (on the water quantity dimension) is currently widespread and as such this section of the paper will focus mainly on the water quality dimension.

The Water Quality Dimension**:** Sewage is typically composed of less than 1% solids with over 99% being water. Extensive sewerage systems draining to a central wastewater treatment facility therefore involve the carting of “primarily” water over rather long distances.

Within extensive sewerage networks conveying foul sewage for example, the large organic solids typically discharged at the top end of the system, in water closets (WCs), are degraded into smaller sized particles with age and transport through the sewerage network. This is especially the case where ancillary components such as pumping stations create hydrodynamic regimes with high turbulence and shear. It stands to reason therefore that wastewater discharged at the end of an extensive sewerage network will have a higher proportion of smaller sized (less readily settleable) solids compared with wastewater at the top end of the system.

Given that one of the main objectives of sewerage and wastewater treatment is to prevent direct human contact and to separate the contaminants or pollutants from the wastewater, the above suggests that separation of contaminants or pollutants from wastewater should be undertaken at the earliest opportune time in the cycle of Collection, Transport, Treatment and Disposal- CTTD (Andoh, 1995). This predicates the use of satellite (i.e. distributed) treatment as opposed to the centralized conventional approach. The distributed approach would appear to have other benefits including possible reductions in the extent of the associated conveyance system (sewer network) and hence costs.

It is surmised that the interception and treatment of wastewater at an early stage in the CTTD cycle also enables much more effective utilization of the assimilative capacity of the receiving waters (environment). With conventional schemes where treatment plants tend to be “out-of-sight”, there generally is very little community / local involvement and an “out-of-sight-out-of-mind” type mentality develops with no community sense of “duty of care”. Localized schemes on the other hand provide scope for community involvement, an awareness of the need for schemes to be sustainable and increased scope for beneficial reuse and recycling.

The usual concern regarding distributed / satellite wastewater treatment schemes relates to potential increases in maintenance and operational costs and commitments with the proliferation of treatment sites and possible lack of adequate control to prevent cross-contamination and direct human contact with contaminated sources. In fact this may be the case where factors such as poorly constructed septic tanks, cesspits, latrines etc. are sited in close proximity to ground water aquifers used as primary sources of potable water, or: cemeteries, solid waste disposal sites etc are located on higher ground such that there is scope for wastewater flows to contaminate potable water sources. It may also be the case for equipment and devices that require external sources of power, sophisticated control, regular inspection, high levels of maintenance and offer inadequate control pathways.

The adoption of a holistic integrated approach to potable water and wastewater systems (taking into account the hydro-geology of the region) and the use of appropriate treatment and control systems provide scope for effective distributed systems. Appropriate systems are ideally those that require no external sources of power, are simple with no sophisticated control, are robust and reliable; require virtually no maintenance, and provide effective control at relatively minimal costs.

Passive robust devices with no moving parts such as vortex flow controls, hydrodynamic vortex separators, filter systems and ecological based wastewater treatment systems are examples of appropriate treatment and control systems which provide scope for the implementation of effective distributed flow control systems with satellite treatment. The development and use of innovative 'hard structures' in the upstream parts of highly urbanized catchments to provide alternative cost-effective stormwater management systems for the control of both water quantity (alleviating flooding) and water quality (preventing pollution) is described elsewhere (Andoh ***et. al***., 2001). These innovative systems have been found to be more efficient, more compact and offer more effective "controls" compared with conventional systems thereby providing significant cost savings in addition to improved efficacy.

Implementation Strategy: The alternative approach advocated involves managing and controlling rainfall runoff at a very early stage in its cycle enabling beneficial reuse. Heavily polluted water such as foul sewage from domestic sources and the polluted first flushes from roads, highways and other paved surfaces, likely to be sources of relatively polluted runoff, are conveyed via sewer networks to satellite treatment sites. If interception of solids is undertaken close to their sources, then the concept of the single-pipe sewerage system (Smisson, 1980 and Mara, 1999) can be made as shallow as possible with relatively smaller bores compared to conventional combined sewerage systems as these sewerage systems will not have to be designed for solids transport.

At the satellite treatment site, the treatment processes advocated incorporate a mix of high rate sedimentation including physico-chemical treatment where appropriate, in compact devices such as hydrodynamic vortex separators for preliminary, primary and enhanced primary treatment. These may then be followed by filter systems or ecologically based wastewater treatment systems such as constructed wetlands, waste stabilization ponds and other aqua-cultural systems for secondary and tertiary treatment as appropriate. In regions where favorable hydro-geological conditions exist, a simple soak-away system could serve as an alternative secondary / tertiary treatment stage.

Constructed wetlands and other aqua-cultural wastewater treatment systems are susceptible to fouling when the waste stream contains high sediment and suspended solids loads and therefore pre-treatment (preliminary and primary) of some form is required. Reed Beds and other ecologically based systems have been applied extensively (Mara, 1999; and Khanna and Kaul, 1996) and generally achieve high levels of carbonaceous and nitrogenous pollutant removals with maturation waste stabilization ponds for example providing very effective disinfection.

Relatively recent developments in water and wastewater treatment technologies have resulted in the intensification of unit processes and the evolution treatment devices that combine a number of unit processes in a single vessel (e.g. *Screening, Sedimentation and Disinfection* – Andoh ***et. al***., 2002). The efficacy of these relatively new technologies and the ecologically based systems advocated is well documented and there is no doubt that they provide appropriate levels of preliminary / primary, secondary and tertiary treatment.

System Configurations: In terms of system configuration, the ideal would be for individual households to have on-site treatment. This would involve effective solids removal upstream of an appropriate on-site ecologically based wastewater treatment system. It is recognized however that for high-density urban developments land and other constraints may make it inappropriate to use ecologically based systems at the individual household or lot level. The strategy here would be to combine flows from households and effect solids separation at the earliest opportunity. Effluents can then be subjected to further treatment using some of the proven emerging technologies as appropriate. Where feasible, the further treatment could also be in the form of ecologically based systems, constructed at appropriate "green sites" taking into account hydro-geological factors etc.

It must be borne in mind that technology exists to convert wastewater into potable water and that it is all a question of costs. The implementation strategy and system configurations advocated applies equally well to highly urbanized catchments in developed countries where advanced technologies such as filtration, membrane bio-reactors and ultra violet disinfection may be applied in conjunction with hydrodynamic vortex separators to achieve appropriate satellite treatment. Selection of the appropriate technology mix for a given situation may be different but *the strategy boils down to preventing rainwater from entering the drains (sewers), adopting a satellite treatment approach and effecting water quality improvements as early as possible*.

A case study is presented demonstrating the potential cost savings that accrue when a satellite treatment as opposed to centralized treatment approach is adopted.

Case Example

The City of Columbus, Georgia in the USA is served by a combined sewerage system that in the past had approximately 16 overflow points (CSOs) into the local receiving watercourse – the Chattahoochee River (see Figure 3).

Figure 3

Columbus and other cities in the state of Georgia were requested to either separate their combined sewers or find ways of treating discharges to the Chattahoochee River to prevent water quality violations. Initial planning studies based on the conventional approach of a new interceptor sewer to pickup all the overflows points (shown in Figure 3) and convey the flows to a centralized wastewater treatment facility indicated that the city was facing a capital improvement program estimated between $135 and $250 million.

A review and assessment of alternative schemes involving a distributed approach showed that implementation of a full satellite system involving treatment at each of the CSO sites would result in a scheme costing in the region of $30 million thus providing the potential for savings of over 80%. Pilot studies were implemented due to the lack of knowledge and a perceived deficiency in technology available to solve the wet weather pollution problems (Boner *et al.*, 1992). The pilot study results demonstrated the effectiveness of passive hydrodynamic vortex separation systems and became the basis for design of the CSO control facilities for Columbus.

The adopted scheme constructed in 1995 involved a distributed approach incorporating satellite CSO treatment at two sites (see Figure 4). This scheme was implemented at a cost of ~ $85 million (with a savings of at least $50 ~ $160 million over previous estimates) and represents a **minimum** saving of ~ 40% compared with the conventional interceptor scheme approach initially proposed. Satellite treatment at each CSO site was not adopted because of the risks and maintenance issues associated with storage of sodium hypochlorite that would have been required for disinfection at each of the sites.

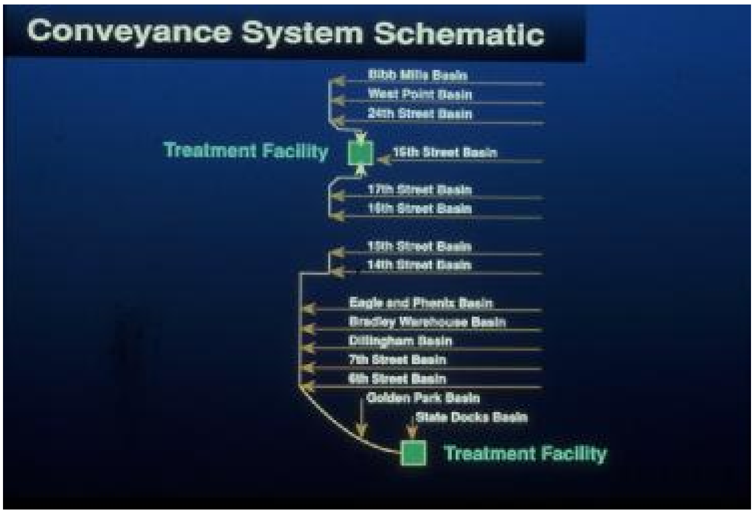

Figure 4

An assessment of the cost breakdown for the adopted scheme shows that the Conveyance Component (i.e. associated sewer networks), cost in the region of $55 million with the Treatment Component costing ~ $30 million. This highlights the fact that the major cost element in sewerage schemes lies in carting water around (i.e. the conveyance system). Any reductions in the extent of the conveyance system by adopting a satellite treatment approach, translates into major cost savings.

A review of the Capital and Maintenance and Operational costs following a five-year program of operations and performance testing of the full-scale facilities has shown that the system adopted at Columbus is equivalent or better than the conventional system and that it costs one-half and occupies one-tenth the footprint. Turner and Boner (1998) estimate that adopting the approach demonstrated at Columbus nationwide would result in potential savings of 50% in the estimated $44 billion required to resolve CSO related problems in the USA. Further details of the Columbus scheme can be found in Turner ***et al***., 2000 and Turner ***et al***., 2001.

Challenges for the New Millennium:

In the early 1950s an estimated 30% of the world's population lived in urban centers. By the mid 1980s, this figure had risen to over 40%. In 1999, the world population reached six billion and has continued to rise at an annual rate of 1.4 percent, adding 200,000 people each day or the equivalent of the population of a large city each week. It has been estimated that within the next 25 years, over 60% of the world's population will live in urban centers with by far the greatest increase occurring in developing countries and emerging economies. Most of these countries have fragile economies and can hardly afford conventional urban water infrastructure especially in an environment where the provision of basic needs such as food, shelter and health services competes for meager resources.

It has been estimated that the costs of upgrading aging Urban Water Infrastructure and provision of associated technology along conventional lines to comply with various legislative requirements aimed at maintaining and improving public health and the environment (e.g. Clean Water Act) in the US over the next 25 years is in the region of $1 trillion (WIN, 2000 and WIN 2001). There is currently a call for Federal Government funding to assist in the meeting of these needs as the individual States lack adequate funds to undertake the required level of Capital and Operations and Maintenance investments without a near doubling of local rates and fees. This in turn would lead to issues of affordability with at least 22% of U.S. households facing hardships in paying their water and wastewater bills (WIN, 2001).

If there are issues of affordability of conventional urban drainage and wastewater treatment in one of the most prosperous if not the most prosperous developed country, what hope is there of providing urban drainage and wastewater treatment systems along conventional lines in the developing world? Urban water infrastructure is mostly non-existent or at best undeveloped in these countries. Urban run-off is typically highly polluted with pathogenic and organic substances that pose public health threats during flood events. This situation is exacerbated by the fact that most of these countries have inadequate facilities and systems for the proper collection and disposal of domestic and industrial solid wastes. Open drains therefore become 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.

There is clearly a need for alternative approaches that are more affordable and more sustainable if the urban drainage and wastewater treatment needs of the majority of under-privileged peoples of this world are to be met. This poses mammoth challenges for all and calls for innovative approaches to urban drainage infrastructure provision. Innovations are required in both "hardware" – (i.e. technologies, devices and components) and "knowledgeware" (i.e. software tools, system descriptors and other knowledge systems).

The question is how can engineers and environmental professionals solve these problems in a cost-effective sustainable manner without creating greater problems for future generations bearing in mind potential long ranging impacts of current global trends such as climate change, depletion of fresh water resources, increasing levels of recalcitrant chemicals, pesticides, endocrine disruptive substances etc in water sources? This is where alternatives such as the emerging systems described may have a role. ***Water should be treated immediately on passing it away as waste and not only when we need it again***.

There is a need for a change from the traditional "downstream reactive" control approach to an "upstream proactive" control approach. The effective adoption and implementation of these emerging systems and approach will however depend on institutional frameworks that facilitate this approach and the availability of appropriate system descriptors and knowledge tools coupled with their widespread dissemination.

***System Descriptors and Knowledge Tools*:** The advent of the personal computer coupled with developments in computing power and communications has facilitated rapid progress and developments in the field of information technology. Software tools have been developed to assist in the design and operation of urban water infrastructure. Initially a number of these tools were developed for modeling the individual sub-components (e.g. sewerage systems, wastewater treatment and receiving environment). With increasing awareness of the interconnectedness and the effects of localized control measures on the entire system, the current trend is now towards integrated modeling incorporating 'flow sources', 'in-sewer' components, 'end of pipe' systems and disposal media as part of integrated catchment systems. This enables systems evaluations and evolution of potential optimal solutions satisfying multi-objective criteria, which better reflect the interactions between the various subcomponents.

Figure 5 shows a schematic representation of the sub-components of urban drainage and wastewater treatment systems including the typical receiving environment. A review of the evolution of the majority of software tools currently available for modeling and designing these systems shows a similar stepwise pattern of increasing levels of sophistication primarily based on "feedback loops" (as with the evolution of the conventional drainage and wastewater treatment "hardware" systems).

Sewer network models for example were initially developed to enable the assessment of hydrological / hydraulic aspects of urban drainage with the main focus centering on urban flooding (- the water quantity dimension). The structure and framework of these initial models enabled rapid assessment of conventional solutions such as relief sewers or large end-of-pipe storage schemes but did not incorporate modules allowing the assessment of Source Control or Distributed Storage schemes. With sustainable drainage systems (SuDS) now receiving greater attention, in more recent times, software tools are beginning to incorporate Source Control and other BMP modules coupled with developments in Geographical Information Systems (GIS).

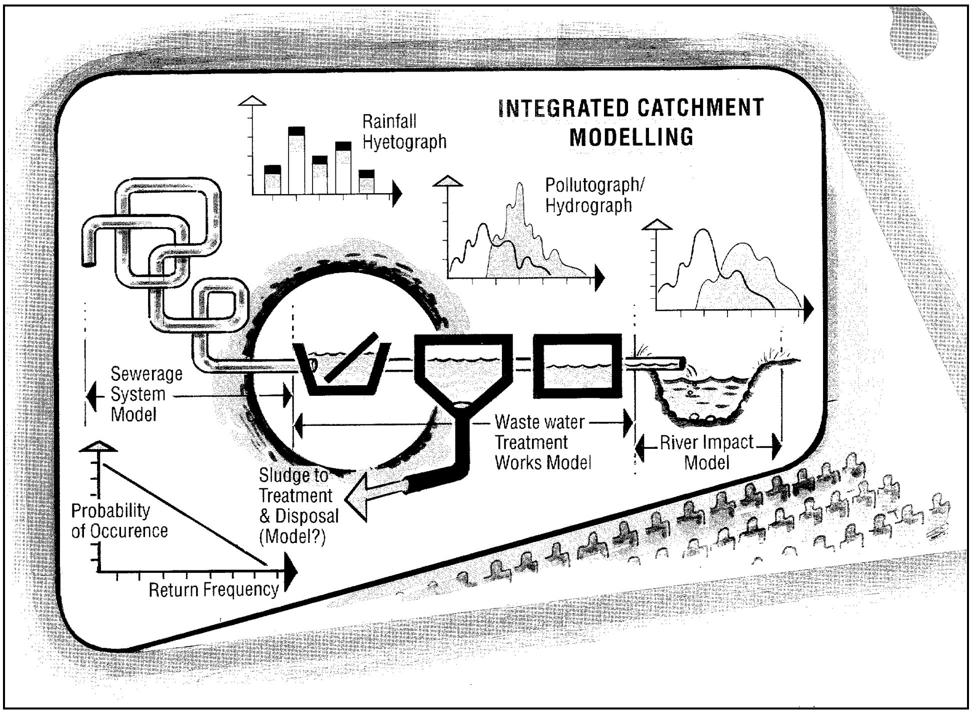

Figure 5: Schematic of Urban Drainage and Wastewater Modeling Sub-components

Also with the focus shifting towards water quality and issues relating to use related water quality standards in receiving waters, sewer network models have evolved to include water quality modules. Unfortunately, the core principle underlying the evolution of the majority of the available software tools for sewer network water quality modeling has been "determinism". The base premise being that all the processes involved are deterministic (known) and can be represented by appropriate mathematical algorithms. Water Quality impacts have however been found to be more difficult to assess in a deterministic way because their inter-relating variables include uncontrollable environmental factors and system states that are ill defined.

Increasingly in addition to being design and analysis tools, the software platforms are evolving into system operational / optimization tools with developments in Real Time Control and the use of Genetic Algorithms. Developments in Hydro-informatics are also paving the way for the evolution of system descriptors into appropriate knowledge based and learning tools.

The current emphasis and search however continues to be for better deterministic descriptors which in turn is leading to more complex models despite the apparent fact that the potential interactions and constraints for achieving multi-objective goals in urban runoff and wastewater management control are ill-defined, complex and best assessed within appropriate integrated systems framework which are based on fundamental principles. Gupta and Saul (1996) for example have demonstrated that sewer water quality profiles can be described by very simple semi-empirical formulations. This approach has been corroborated in the USA by Turner and Boner (1998). It would appear that the aggregate effects of large-scale environmental systems are described by very simple lumped parameter formulations.

There is a need therefore to go back to basics (first principles), reverting back to the basic scientific principles of the use of "rule of thumb" and "empirical descriptors" as '***a priori'*** descriptors until better knowledge leads to the evolution of more deterministic descriptors. In this context, both probabilistic and deterministic modeling approaches will have their roles and the scope exists then to evolve more representative system descriptors and tools at differing levels of abstraction as appropriate.

The Internet may provide the scope for the establishment of extensive data and information stores and opportunities for effective distance learning, research collaboration, consultation etc. thereby facilitating the evolution of more appropriate urban drainage and wastewater treatment systems to meet the challenges of the 21st century.

Discussions

Flooding and pollution in most urban centers is caused by increase in runoff rates and volumes resulting from expansion and growth beyond the core area coupled with uncontrolled discharges of contaminated wastewater. The search for conventional solutions of larger relief sewers or detention basins and "end-of-pipe" wastewater treatment facilities in the areas where the problems are manifest (i.e. the urban center), are fraught with problems of lack of space, congestion of services etc. and inevitably leads to very costly schemes.

Though conventional systems are effective and have generally provided adequate levels of service in developed economies during the 20th century, they are costly both in capital and recurring operating costs especially where pumping systems and energy intensive wastewater treatment processes are deployed. This may not be a major problem for developed countries with stable, robust economies and where acute adverse environmental impacts of urban water are generally under control with the major challenges currently faced being those of improving upon the levels of service and maintaining the useful life of ageing urban water infrastructure, addressing issues of increasing levels of pesticides and endocrine disruptive substances in water sources etc., and the likely impacts of climate change.

The situation in most developing / emerging economies is however very different. The provision of appropriate and effective urban water infrastructure in these vulnerable environments given the pace of urbanization and population growth, requires special attention as the solution matrix is complex and necessitates a multidisciplinary approach taking into account the need to integrate differing facets of urban infrastructure provision.

If there are to be public health gains and reductions in the risks of catastrophic epidemics, practitioners must draw on global experiences gained to date and capitalize on the beneficial attributes of both conventional and emerging systems. The goal should be that of evolving more sustainable systems in the 21st century.

The adoption of a distributed systems approach provides greater flexibility in choosing and locating the type of facilities to attenuate and/or store and treat urban water. ***A distributed system is also 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.

It is therefore suggested that schemes implemented in the 21st century follow a simple model or construct that mimics nature's way by catching and dealing with a problem at an early stage (i.e. Prevention rather than cure). It is also argued that adopting nature's way involving the effecting of controls at an early stage in the Collection, Transport, Treatment and Disposal (CTTD) cycle means looking at for example ways in which flows into and through urban centers can be reduced or attenuated before they arrive at the problem areas and effecting water quality improvements as close to source as possible.

For effective implementation of the distributed systems and source control approaches to be possible, there is the need also for changes in institutional structures to facilitate and reflect integrated urban water management service provision. Changes in institutional structures should however be coupled with increased stakeholder involvement and participation (including the general public by means of improved educational programs and public awareness campaigns).

Without a major shift in paradigm and approach from the conventional "reactive-curative" to a "proactive-preventative" one, the likelihood is that more of the same will be the norm in this new millennium missing an opportunity to evolve more sustainable urban drainage and wastewater systems. Time will tell whether future generations will judge the current generation of public health practitioners as a "far-sighted anticipatory" breed or a "short-sighted reactive" breed.

Conclusions

Urbanization is the major challenge for this new millennium. Some estimates suggest that for every person in the world to reach present U.S. levels of consumption with existing technology would require four more planet Earths. Planet Earth clearly cannot sustain this intensity of development and its associated provision of urban drainage and wastewater infrastructure along the conventional approach that evolved to address the needs of developed countries in the 20th century. In this new millennium we need to:

- Go back to basics and learn from nature by adopting a preventative rather than curative approach to urban water infrastructure provision.
- Apply "feed-forward" loops in addition to our traditional feedback approach. This should help with the evolution and implementation of urban water schemes that include both pro-active and reactive elements as appropriate.
- Leverage the power of "Information Technology" and not get lost in the maze of knowledge explosion and intensity by keeping an eye on the "Big Picture" and not forget first principles.
- Remember we have only one planet earth, one human race and be prepared to help the less fortunate.

New paradigms in urban water infrastructure provision are required if the public health gains achieved in developed countries in the 20th century are to be replicated in the developing world in the 21st century. Water is a precious resource and every drop should be used wisely. ***Water should be treated immediately on passing it away as waste and not only when we need it again.***

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