Urban Water Management: Innovations and Paradigm Shifts to Address 21st Century Needs

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Abstract
Globally, the water and wastewater industry faces major challenges, both in developed and developing world regions. The developed world has enjoyed the benefits of the foresight of prior generations, with major strides gained in public health simply from innovations such as the humble sewer which has contributed more to human health than all developments in the medical field. Challenges faced in different regions are diverse in nature, magnitude and scale. Some are local in nature but others such as the impacts of Climate Change are truly global. The paper examines the status and evolution of innovations within urban water management (with particular reference to stormwater management) including impacts of regulation, barriers to innovation, current trends and paradigms. It is argued that there is a need to change the way we approach urban water management challenges, particular if the goal is to achieve more sustainable development in an increasingly urbanizing world.

Keywords
Urban water management, sustainability, paradigm shift, stormwater, wet-weather

Introduction

Urban water infrastructures (e.g. sewer systems) have evolved as part of the human development process to meet challenges such as the effectual draining of urbanizing areas. It is doubtful whether any process-response system in the natural environment has proven to be as susceptible to human interference as the natural drainage system. The urbanization of a watershed can have far reaching effects on the finely balanced hydro-geological cycles producing adverse water *quantity* impacts (e.g. flooding) and water *quality* impacts (e.g. pollution).

Water Quantity - Replacing natural vegetation with buildings, roads and parking lots increases the volume of runoff and reduces the response time of the drainage system, with the net result being an increased occurrence of downstream flooding. Furthermore, the removal of natural regulators and control mechanisms, and the construction of manmade drainage channels, sewer pipes and conduits only serve to exacerbate the problem.

Flooding has become a major concern for many major cities around the world. Flooding kills thousands every year and ruins the lives of millions more; and they are becoming more frequent. It is evident that if we continue to apply and pursue traditional approaches to urban water management, these problems are likely to get worse.

In the UK for example, urban drainage systems are coming under increasing pressure, with a projected 3.8 million new homes required by 2021 to meet housing needs, particularly in the South East where an estimated 2 million new homes are required. The UK is not unique in this respect as urbanization is continuing at an increasing pace across the globe in line with demographic shifts and population growth.

Existing urban drainage systems are failing to cope at present and with the increased volumes and rates of runoff associated with urban development, there are concerns that over the course of this century, the frequency and severity of flooding will increase. The problems are likely to be exacerbated further due to the impacts of Climate Change.

Water Quality – Flooding is not the only problem associated with overloaded water management systems. Surcharging and overflows from combined and sanitary sewer systems subject to wet-weather ingress lead to intermittent discharges of a broad spectrum of pollutants, ranging from trash to suspended solids and fecal bacteria, into receiving water bodies. There has been a tendency to separate sewage and urban runoff into sanitary and stormwater sewers. Separating sanitary and stormwater sewer systems' however does not solve the problem of wet weather pollution.

In recent times, discharges associated with stormwater runoff from separate storm sewer systems have also been identified as a leading source of water quality impairment, with regulations such as the National Pollution Discharge Elimination System (NPDES) and Phase I & Phase II Rules, targeting discharges from stormwater drainage systems, being put in place in the USA, and the Water Framework Directive being implemented in the European Union. These regulations are typically aimed at both existing and new development and ultimately require the treatment of stormwater runoff and related wet-weather flows to remove a wide range of pollutants including trash, sediment, heavy metals, nutrients and hydrocarbons.

Water quantity and water quality are inexorably linked and need to be addressed from an integrated holistic approach. Conventional approaches to resolving problems associated with urban water management have traditionally been one-dimensional with a focus on the current or strongest driver, responding to the most immediate problem or perceived threat. There is a growing awareness that conventional urban water management infrastructure provision is costly (GAO, 1979; WIN, 2001) and may not be the most appropriate for the 21st century. This, coupled with the fact that developing countries and emerging economies, with the greatest urban water management infrastructure development needs but least ability to afford to adopt traditional approaches, suggests a requirement for new more cost-effective and holistic approaches to managing the water in a watershed; approaches that draw on experiences of the past but include new technologies and know-how to ensure the development of viable and sustainable watersheds in the future.

Unfortunately, most 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 (Andoh and Iwugo, 2002).

Sustainable Urban Water Management?

Awareness of the need for new approaches to urban water management has been growing in recent decades. For example in the 1970s, drainage engineers became aware that existing drainage infrastructure was overloaded and that the frequency of flooding was often reaching unacceptable levels. A number of the more forward thinking engineers realized that the traditional approach of increasing hydraulic capacity through the installation of larger and larger pipes was not necessarily the answer.

Wholesale replacement of pipes and culverts with larger pipes is expensive, in addition to being disruptive, and often transfers the problem downstream. The use of source control and distributed storage (attenuation storage and flow control) began to emerge as an effective technique (Smisson, 1979; Smisson, 1980; HRD, 1992) to address the growing problem of urban flooding.

Source control seeks to find solutions in the upstream parts of the system rather than the downstream parts where the problems manifest themselves (Andoh and Smisson, 1995). The benefits and efficacy of source control, distributed storage and satellite treatment systems can be seen when addressing both quantity and quality issues associated with the management of water in urban catchments. These systems are deemed to be more sustainable than conventional drainage methods because they: manage runoff flow rates; reduce the impact of urbanization on flooding; protect or enhance water quality; are sympathetic to the environmental setting and the needs of the local community; improve habitats in urban watercourses; and, encourage natural groundwater recharge, where appropriate (Andoh, 1994; Beck *et al.*, 1994; Harremones, 1997; Andoh and Declerck, 1999; Butler and Davies, 2000; McKissock *et al.*, 2001; Iwugo *et al.*, 2002; Andoh, 2004).

Though these systems and practices, including the development of approaches that recognize 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, are becoming more common, with several acronyms emerging such as Sustainable Drainage Systems (SUDS); Best Management Practices (BMPs); Water Sensitive Urban Design (WSUD) etc., there are still significant barriers to their widespread use (Andoh and Iwugo, 2002). This is 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 conventional approaches (Boner, *et al.*, 1992; Barber *et al.*, 1996; Andoh *et al.*, 2001; Coombes and Kuczera, 2001).

Over time, a number of these non-traditional techniques have emerged for the treatment of urban runoff and currently involve the use of 'soft' engineered structures such as swales, constructed wetlands, bio-retention systems and ponds; and 'hard' engineered structures, such as underground flow-through interceptors and filter devices. These systems have been and continue to be successfully applied and add to a diverse toolkit of innovative systems for addressing urban water management in a more sustainable fashion. "*Sustainability in this context being defined as a goal to be aimed for that involves an inclusive process charting more sustainable paths from current unsustainable norms towards a more sustainable future.*"

'Soft versus Hard Solutions': Within the advocates for more sustainable urban water management, a one-dimensional approach appears to be emerging which relates to the issue of "Soft" solutions versus "Hard" solutions with ardent advocates for 'Soft' solutions believing that only non-hard-engineered-structural systems such as swales, detention / retention ponds, constructed wetlands, etc. are appropriate technologies for urban water management. This is in spite of the fact that the so-called 'Hard' solutions such as Hydrodynamic Vortex Separators, Geo-cellular Storage Systems, Modular Filter Systems and Vortex Flow Controls are widely used and have been proven to offer effective innovative solutions to urban water management challenges, particularly in highly urbanized catchments (Andoh *et al.*, 2001).

A benefit of 'hard' engineered systems is that they can be installed under urban surfaces, and as such provide additional flexibility in terms of the range of options that can be deployed to achieve the goal of improved urban water management. These systems have been applied in a variety of contexts and offer particular opportunities in situations where land is either scarce or expensive, for example, in built up areas, where they can be used as a complement and retrofit to conventional drainage infrastructure.

They have also been found to be equally compatible and applicable for use in conjunction with 'soft' engineered structures, where they serve to both reduce overall drainage system land-take, while also reducing or easing the process of maintenance. Flow-through interceptor systems, for example, operate by concentrating pollutants, including non-degradable components, to a central, accessible location. In the UK, the use of "hard structures" is helping to overcome barriers relating to adoption and issues regarding maintenance of SUDS.

Appropriate systems for draining developments in highly urbanized catchments which already have extensively developed conventional urban drainage infrastructure with poor hydro-geological conditions (e.g. poor sub-soils for infiltration and contaminated land), would be different from that for a development on a green field site with good hydro-geological conditions (e.g. sub-soils with high infiltration rates and no risks of groundwater pollution). Butler and Parkinson (1997) for example advocate an incremental approach to sustainable urban drainage incorporating both "high-tech" and "low-tech" answers with each case decided on its merits.

In the case of ultra-urban catchments, solutions may have to center on the implementation of compact efficient 'hard' structures usually within the adoptable segments of the urban drainage infrastructure (Andoh *et al.*, 2001) whereas 'soft' solutions involving infiltration for example may be more appropriate for the green field site (Iwugo *et al.*, 2002).

The management train concept advocated in the UK (CIRIA, 2000) for example starts with prevention or good housekeeping measures at the household level and progresses through local source controls to larger downstream site and regional controls. It promotes the division of the catchment area to be drained into sub-catchments with different drainage characteristics and land uses, each with its own drainage strategy to suit prevailing conditions, land use types, hydrogeology of the site, etc. This concept does not necessarily pitch alternative systems such as BMPs against conventional piped drainage systems or "Hard" solutions but rather advocates a broad framework of prevention and beneficial re-use (reduce, recycle and reuse).

Discussion

There is an increasing awareness and emerging consciousness globally that water is life. Recent events suggest that what was once deemed 'extreme' weather (such as persistent droughts and massive flooding events) are becoming the norm with Climate Change, and its implications being actively debated.

The human response to the development of urban water management systems has evolved around a curative-reactive framework with a control action sought and implemented only when an undesirable effect or state of affairs is observed (Andoh, 1994). This has inevitably resulted in the evolution of conventional approaches that focus on end-of-pipe and downstream solutions that are not necessarily sustainable.

Approaches to resolving urban runoff and wet-weather related issues for example have tended to be site or community specific and involve a matrix of solutions ranging from increasing the conveyance capacity of municipal sewer systems, either by building new, "separate" sewers, treating combined sewer overflows at satellite sites within the collection system or by significantly expanding the capacity of end-of-pipe treatment plants to treat the excess wet-weather flows. These approaches, particularly where they involve deep tunnel schemes, can be very expensive (GAO, 1979) and in the case of separating sewers, if the separated stormwater does not receive water quality improvements, this may not necessarily address the problem of environmental degradation and poor water quality resulting from the discharge of untreated wet-weather flows into receiving waters.

In the US for example, with the reduction in available Federal Funding sources such as the Construction Grants Program and the Clean Water State Revolving Fund (CWSRF), communities now have to bear the brunt of the costs associated with urban water management projects. Most of these costs are passed on to residents in the form of sewer fees, but other costs are also impacting individual communities already struggling to pay for education, public safety, environmental clean-ups and community programs. Many sewer separation projects that extend for miles through busy downtown areas run well into the tens and hundreds of millions of dollars.

Separating sewers in busy downtown areas also imposes disruption costs on the community in the form of closed streets for extended periods. Communities are therefore looking for more cost-effective ways of addressing the urban water management challenges whilst meeting consent limits for their discharges. A report by the Water Infrastructure Now network (WIN, 2001) stated that "*New solutions are needed to what amounts to nearly a trillion dollars in critical water and wastewater investments over the next two decades. Not meeting the investment needs of the next 20 years risks reversing the public health, environment and economic gains of the last three decades*."

Globally, there are a number of major challenges in both the developed and developing world relating to the provision of appropriate urban water infrastructure. The developed world has enjoyed the benefits of the foresight of prior generations with major strides gained in public health simply from developments and innovations such as the humble sewer which has contributed more to human health than all of the developments in the medical field. With issues such as security of supply, reliability and adverse health impacts under control, the developed world now faces a fresh set of challenges with an aging infrastructure and micro-pollutants such as endocrine disruptors (estrogen analogs) with their long-term, diffuse and potentially chronic impacts.

In contrast, the sorry state of affairs for a third of the world's population who do not have ready access to potable water and adequate sanitation in the developing world is generally recognized as unacceptable. Challenges faced relate to provision of basic infrastructure, reliability of supply and service and short term acute impacts such as diarrhea and water borne and related diseases. The Millennium Development Goals are aimed at addressing these challenges within a generation.

Challenges faced in different regions of the world are obviously different in nature, magnitude and scale. Some are local in nature but others such as the impacts of Climate Change are global. It is clear however that in order to meet the demands of the 21st century there is a need to change the way we approach the challenge of dealing with urban water management, be it tackling the problems associated with existing drainage systems and infrastructure, or the problems associated with new build and the ever increasing pressures of urban development.

Conventional "text book" approaches that have tended to focus on downstream end-of-pipe solutions may no longer be relevant or appropriate to address the 21st century challenges. There is a need now for more holistic approaches to be adopted in the development of solutions to wet-weather induced problems in the drainage of urban catchments. Current trends include approaches that seek solutions within the upstream portions of the urban water infrastructure by intercepting, infiltrating, containing, controlling and treating excess wet-weather flows before they cause hydraulic and water quality problems in downstream areas.

It is envisaged that the need for the evolution and implementation of increasingly innovative and more sustainable designs and systems should result ultimately in the adoption of more integrated approaches in which clusters of techniques are deployed depending on overall control needs, treatment objectives and system or device attributes.

Without innovation and changes in current paradigms some of the looming local and global scale challenges appear insurmountable, particularly given the costs associated with conventional approaches to urban water management.

Conclusions

There are more effective and more sustainable approaches to the effectual draining of our increasingly urbanizing catchments than the conventional approach that has been the norm in the period leading up to the 21st century. The fact that non-conventional and innovative approaches are being adopted suggests that we are prepared to change and that we are also recognizing the need to redirect our approach away from the conventional and seek out new ideas and solutions that are both effective and more sustainable. However this process needs to be accelerated and we need to think outside the box and embrace new technologies and sustainable solutions that can solve both existing problems and prevent new ones occurring.

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