APPROACHES TO URBAN DRAINAGE SYSTEMS MANAGEMENT FOR THE 21ST CENTURY

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ABSTRACT

The need for a more holistic approach in the development of solutions to wet-weather induced problems in urban drainage systems is advocated. A review of current approaches to resolving problems of premature overflows and flooding is presented outlining a case example of the successful application of non-conventional approaches, techniques and devices that assist in the better management and control of wet-weather flow sources. This involves the seeking of solutions within the upstream portions of drainage systems by intercepting, containing, controlling and treating excess wet-weather flows before they cause hydraulic and water quality problems in downstream areas (sections of the drainage system). These approaches have been found to be more cost-effective than conventional solutions and involve the implementation of distributed/decentralised schemes which in turn offer improved opportunities for wider community and other stakeholder involvement leading to the realisation of amenity and other non-structural benefits.

INTRODUCTION

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. In the relatively recent history of human development, a shift occurred with wet-weather induced overflows from combined and sanitary sewer systems being deemed to be a major cause of water quality impairment in urban streams, rivers and other receiving waters. The general move was towards separate sewers, one to convey foul water (sewage) and the other to convey the supposedly cleaner stormwater runoff to the nearest watercourse.

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). It has now generally recognised that stormwater and diffuse pollution sources have a greater impact than had originally been envisaged especially when a 1990s study indicated that roughly one third of identified water quality impairments in the US were attributable to stormwater with sediments being the leading pollutant.

There is now a trend towards a Watershed approach with combined/sanitary sewage overflows and stormwater discharges being classified under the general umbrella of **"urban wet weather" discharges** and assessments being made of Total Maximum Daily Loads (TMDL) of various pollutants causing water quality impairments. Convergence is now occurring in the planning and development of solutions to problems caused by urban wet weather discharges.

There is a need for a more holistic approach to be adopted in the development of solutions to wet-weather induced problems in urban drainage systems. Current approaches to resolving problems of premature overflows and flooding are outlined in a case example which describes the successful application of non-conventional approaches, techniques and devices that assist in the better management and control of wet-weather flow sources. The approach involves the seeking of solutions within the upstream portions of drainage systems by intercepting, containing, controlling and treating excess wet-weather flows before they cause hydraulic and water quality problems in downstream areas (sections of the drainage system).

The approach have been found to be more cost-effective than the conventional approach and involves the implementation of distributed/decentralised schemes which in turn offer improved opportunities for wider community and other stakeholder involvement leading to the realisation of amenity and other non-structural benefits.

The Conventional Approach

The evolutionary path leading to the development of conventional urban drainage and wastewater treatment systems has resulted in an approach to the collection, conveyance and treatment of urban stormwater runoff and wastewater flow that involves the routing of as much flow as possible to an "end-of-pipe" facility which may be an outfall or a wastewater treatment facility. Most communities and municipalities are therefore served by a collection of combined or separate sewers subject to varying degrees and levels of wet-weather induced inflows that cause the discharge of untreated stormwater and wastewater overflows (e.g. CSOs and SSOs) into the receiving environment.

Sewers have traditionally therefore been designed on the basis of their peak flow capacity in order to convey as much water away as quickly as possible. This has resulted in the tendency to build bigger and bigger interceptor sewers and tunnels in response to the increasing urbanization process and to replace the aging infrastructure. The conveyance of larger and larger flows to outfalls and wastewater treatment plants presents flow handling challenges with the associated risks of washout of sensitive treatment process stages and often necessitates costly upgrades in infrastructure to cope with the increased flow regimes.

WHY DISTRIBUTED FLOW MANAGEMENT AND SATELLITE TREATMENT?

Though conventional systems 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).

Source control, distributed flow management and satellite treatment systems present alternative approaches 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 to improve water quality.

The development and use of innovative technologies in the upstream parts of highly urbanized catchments to provide alternative cost-effective urban water management and control are described elsewhere (Andoh *et. al*., 2001). These innovative systems have been found to be more efficient, more compact and offer more effective treatment and control compared with conventional systems thereby providing significant cost savings in addition to improved efficacy. In recent times, these systems are increasing being adopted in the main stream, though there are 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).

Given that one of the main functions and objectives of sewerage systems and wastewater treatment is to prevent direct human contact and to separate the contaminants or pollutants from the wastewater, this 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) which predicates satellite treatment.

The usual concern regarding satellite treatment schemes often relates to potential increases in maintenance and operational costs and their associated commitments with the proliferation of treatment sites and the possible lack of adequate control to prevent cross-contamination and direct human contact with contaminated sources. Appropriate systems for implementing distributed flow control systems with satellite treatment 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, advanced 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 satellite CSO treatment facilities at Columbus, Georgia which came on line in 1995 and have since undergone more than 5 years of peer reviewed intensive monitoring under the auspices of United States Environmental Protection Agency (EPA) and the Water Environment Research Federation (WERF) are described and used as a case example to highlight the benefits and significant cost savings that accrue from implementing distributed flow control systems with satellite treatment.

COLUMBUS CASE EXAMPLE

The City of Columbus, Georgia 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 1**).

Faced with the regulatory mandates of the Clean Water Act and a then forthcoming EPA CSO policy, the water utility and service provider for the catchment, Columbus Water Works (CWW), initiated a phased program to address wet-weather induced water quality problems in the middle reach of the Chattahoochee River.

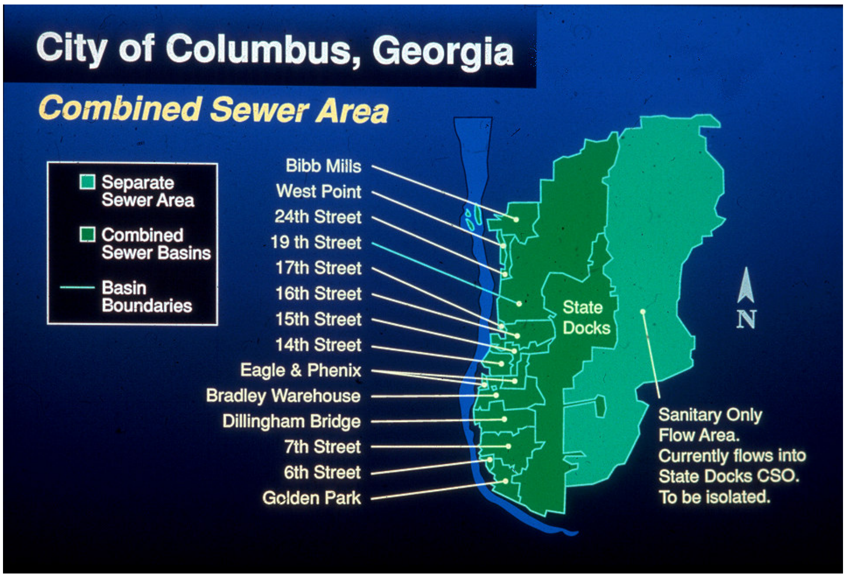


Figure 1

Initial planning studies, which were based on the "conventional approach" involving the implementation of a new interceptor/relief sewer to pick up all the overflows points and convey the combined 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 including a satellite treatment approach showed that implementation of a full satellite system involving provision of high-rate sedimentation devices and chemical contact vessels for disinfection, utilizing hydrodynamic vortex separators, at each of the CSO sites would result in a scheme costing in the region of \$30 million. This approach had the potential to save over 80% of the costs of the conventional approach. At the time, vortex separation technology was deemed to be novel and unproven but given the potential scope for major cost savings, a pilot study was initiated to compare the vortex system with a conventional system.

The pilot study, conducted between 1992 and 1993, evaluated the effectiveness of hydrodynamic vortex separators compared with a conventional flow-through mixing sedimentation basin. This was done in terms of both solids removal and disinfection. The results showed the vortex system to be up to 10 times more effective for the removal of total suspended solids and other pollutants, and approximately three times as effective at disinfection, compared to the mixed basin system (Boner *et al.*, 1992).

Following the successful results of the pilot study, CWW decided to adopt a satellite treatment approach and opted to construct two (2) Satellite CSO treatment sites which use vortex flow controls for regulating flows and vortex separators for solids separation and chemical disinfection (**see Figure 2**). The satellite CSO treatment facilities have a combined capacity of 5258 l/s (83,3333 US gpm) and became operational in 1995.

Vortex separators are typically designed to operate with an underflow portion of about 10-percent (10%) of their peak design inflow. The underflow component usually exits from the base region of the vessel and contains the separated solids in a relatively smaller portion of the inflow. This results in a typical turn down ratio of 10:1 which means that the settleable solids (e.g. faecal solids and sediments) in the inflow to the vortex vessel are concentrated in a significantly smaller portion of the flow to the unit, typically a tenth ($1/10^{th}$).

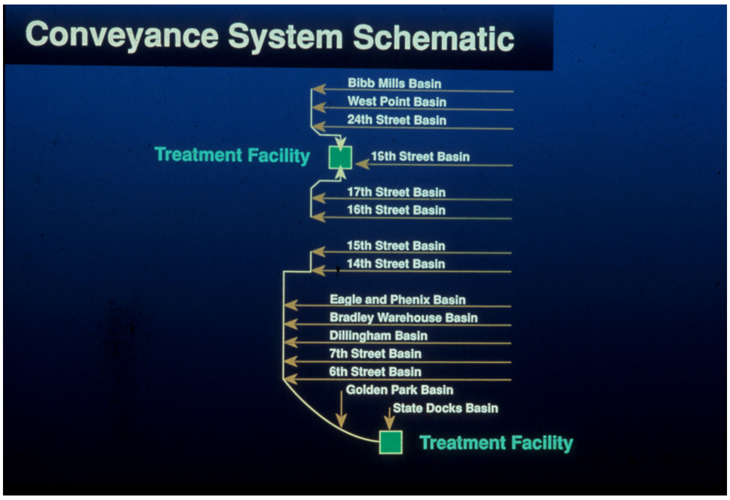


Figure 2

As shown in **Figure 3** for one of the satellite sites, the vortex vessels were laid out in a series arrangement with five (5) primary units and one secondary unit. The underflows from the primary units were conveyed to the Grit Dewatering and Control Building which housed a vortex grit separating unit. This arrangement provided scope for routing the underflows from the five primary (1°) vortex units to a secondary (2°) unit, after degritting to remove sands and sediments. The vortex units were also utilised as contact chambers for chemical disinfection using sodium hypochlorite.

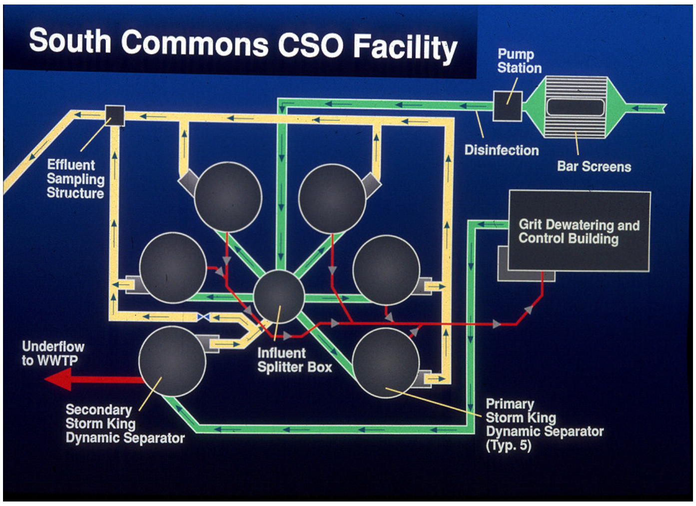
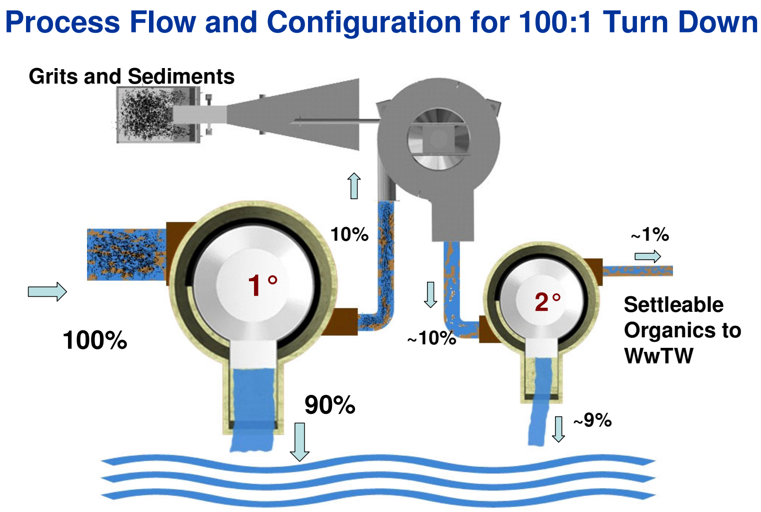


Figure 3

A schematic of the arrangement which enabled the settleable organic solids such as faecal solids to be concentrated in approximately 1 percent (1%) of the facilities' peak design flow -resulting in an overall turn down ratio of 100:1 (i.e. two sequential 10:1 turn down ratios) is shown in **Figure 4**. This provided the ability to handle increased wet-weather flows without the need to upsize the main interceptor (collector) sewer to the central wastewater treatment plant.

An assessment of the cost breakdown for the adopted scheme shows that the "Conveyance Component" (i.e. associated sewer system), cost in the region of $55 million with the "Treatment Component" costing ~ $30 million. This highlights the fact that the major cost elements in sewerage schemes lie in the carting of wastewater around (i.e. the sewer network) and that any reductions in the extent of the sewer network, by adopting a satellite treatment approach, translates into major cost savings.



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One of the facilities was specifically constructed to serve as a national full-scale Advanced Demonstration Facility (ADF) for Wet Weather Treatment Technologies to test vortex separators followed by a compressed media filter and several alternative disinfectants such as UV, for CSO treatment.

The CSO program which was envisioned and implemented with integrated community benefits such as a River Walk, parks and an Oxbow Environmental Learning, has served as a catalyst for a new community spirit resulting in a tremendous increase in riverfront development and recreational use of the Chattahoochee River.

Performance monitoring over a five year period has confirmed that the vortex separators accomplish several treatment operations including: 1) the reduction of a significant number of CSO discharges with about 40 percent of the annual volume captured by interception and storage and 82 percent of the annual volume treated; 2) high level removals of oil and grease (90 percent); 3) grit and gross solids removals of over 90 percent; 4) primary removals for the lighter fraction total suspended solid (TSS) contaminants on an annual basis; 5) metal removals of 50 percent; and 6) phosphorous removal of 60 percent. The vortex vessels have also been found to be very effective contact chambers for chemical disinfection helping to significantly reduce capital and operating costs associated with CSO controls while providing necessary and effective preliminary and primary treatment operations and disinfection.

The final WERF Report (WERF, 2003) produced following the review of the Capital and Maintenance and Operational costs after the five-year program of operations and performance testing shows that water quality objectives are being met and that the system adopted at Columbus is equivalent or better than conventional systems. Estimates suggest that optimized configurations of the technologies demonstrated at Columbus would cost one-half (1/2) and occupy one-tenth ($1/10^{th}$) of the footprint of conventional primary clarification and disinfection.

Turner and Boner (1998) estimated that adopting the approach demonstrated at Columbus throughout the United States would result in potential savings of 50% in the then 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.

As demonstrated at Columbus, Georgia, the use of Satellite treatment systems located within sewer networks provides the scope for resolving some of the challenges in urban wastewater infrastructure provision in a cost efficient manner. In 2001, the US EPA awarded CWW the National First Place Award for Combined Sewer Overflow Control Program Excellence.

DISCUSSION AND CONCLUSIONS

Under the current climate of tighter environmental regulations, increasing urbanization coupled with aging urban drainage and wastewater treatment infrastructure, several communities and municipalities are faced with the tasks and challenges of rehabilitating or upgrading their sewer networks and wastewater treatment plants to provide the requisite levels of service and comply with standards.

Conventional systems are costly. This coupled with the funding constraints and issues of affordability clearly highlights the need for more innovative, cost-effective and sustainable "alternative approaches" to resolving the current urban drainage and wastewater treatment needs and challenges. This is especially the case if we want to avert the risks of reversing the gains in environmental water quality that have been achieved in the 20^{th} century.

Passive flow control systems and high-rate sedimentation and filtration systems that harness the inherent energy within collection system flows have been shown to be very effective for controlling CSOs and other wet-weather impacted discharges. Their use within collection systems in a satellite treatment context provides scope for maximizing the utilization of existing wastewater infrastructure while eliminating or minimizing the large costs associated with transporting wet-weather flows to central wastewater treatment facilities.

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