Collection Systems 2004: Innovative Approaches to Collection Systems Management, August 8-11, 2004, Milwaukee, Wisconsin.

WHY SATELLITE TREATMENT WITHIN COLLECTION SYSTEMS MAKES SENSE

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ABSTRACT

The conventional approach to the rehabilitation and improvement of collection system service levels has been to enhance system capacity and transfer increased flows to central wastewater treatment facilities, which in turn often results in the need for upgrading the treatment works to handle increased flows. The paper highlights why the implementation of satellite treatment systems within the collection systems (away from end of pipe) provides significant benefits from both a process and public health standpoint compared with the conventional approach.

Aspects of wastewater characterization, in particular settling velocity distributions, and its relevance on the performance of physical unit processes such as sedimentation and filtration are described and used to explain why satellite treatment makes sense. The satellite CSO treatment facilities at Columbus, Georgia which have undergone more than 5 years of peer reviewed intensive monitoring are described and used as a case example to highlight the benefits and significant cost savings that accrue from implementing satellite treatment systems within collection systems.

KEY WORDS

Satellite Treatment; Combined Sewer Overflow; Sanitary Sewer Overflow; Stormwater; Sedimentation; Disinfection; Vortex Separation; Floatables Control; Wet-Weather Discharges

INTRODUCTION AND OVERVIEW

The passage of the Clean Water Act (CWA) in 1972 provided a comprehensive framework of pollution control standards, technical tools and financial assistance to address the noticeable water pollution problems of the late 1960s and 1970s. Prior to its enactment, many of the nation's rivers were little more than open sewers, choking from garbage, fecal matter, bacteria and chemicals with dead fish often being washed ashore.

From 1972 to 1990, federal funding in the form of construction grants provided up to 75% of the funding for building the nation's wastewater infrastructure. This coupled with the National Pollution Discharge Elimination System (NPDES) led to wastewater treatment effluents and other points sources of discharge coming under control resulting in the significant improvements in the quality of the nation's waters observed.

With point sources under control, the major focus and concern in recent times has been the control of wet-weather impacted flows such as Combined Sewer Overflows (CSOs), Sanitary Sewer Overflows (SSOs), Stormwater and other non-point pollution sources. This has resulted in the enactment of the Phase 1 and Phase II Stormwater rules and the recent codification of the CSO Control Policy in the 2000 amendment to the Clean Water Act.

Reviews of the quality of the Nation's Waters, in more recent times, have found that sediment (mainly from stormwater runoff) and bacteria are the major pollutants causing impairment of rivers; and CSO and SSO spills (of raw sewage, untreated industrial wastewater and street debris into receiving watercourses) are the leading cause of beach closures and shell-fishing restrictions.

Increasing urbanization and its associated increases in wet-weather flows are placing unprecedented strains on the existing (aging) urban drainage and wastewater treatment infrastructure. The wastewater infrastructure built in the 1970s now needs repair, replacement or expansion. The U.S. Environmental Protection Agency estimates an investment need of roughly \$300 billion through to 2019 for wastewater systems (including upgrades to existing and new wastewater treatment systems, upgrades to existing wastewater collection systems, CSOs etc). The needs of small communities are also significant with most of them lacking the basic infrastructure to address water quality needs.

The paper highlights why the implementation of an alternative wastewater collection and treatment strategy based on a "satellite treatment" systems approach provides significant benefits over the conventional approach of increasing collection system capacity which leads to the need to upgrade "end-of-pipe wastewater treatment facilities". The enumerated benefits include major cost savings, improved process efficacy and reduced public health risks. Aspects of wastewater characterization such as settling velocity distributions that have relevance and a bearing on the performance of physical unit processes (e.g. sedimentation and filtration) are described and used as a basis to explain why satellite treatment provides process advantages.

The paper goes on to describe the satellite CSO treatment facilities at Columbus, Georgia including the Advanced Demonstration Facility (ADF) which has undergone more than 5 years of peer reviewed intensive monitoring and uses this as a case example to draw attention to the benefits and significant cost savings that accrue from implementing satellite treatment systems within collection systems.

A description is also given of the process configurations at Columbus that has resulted in the concentrating and routing of the polluting solids, at these facilities, in a much smaller flow stream through the collection system to the central Wastewater Treatment Plant and how this resulted in the ability to handle increased wet-weather flows without the need to upsize the main interceptor (collector) sewer to the central wastewater treatment plant.

CONVETIONAL APPROACH

The conventional approach to the collection, conveyance and treatment of wastewater flows has been to route as much flow as possible to an "end-of-pipe" wastewater treatment facility. Most communities 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.

Because sewers have been traditionally designed on the basis of their peak flow capacity, the tendency has been to build bigger and bigger interceptor sewers and tunnels in response to the increasing urbanization process and to replace the aging infrastructure. This in turn has resulted in the conveyance of larger and larger flows to wastewater treatment plants necessitating the upgrade of these treatment facilities to cope with the increased flow regimes.

Some wastewater treatment plants especially those served by combined sewer networks receive wet-weather flows with peaking factors in excess of **10:1** (i.e. ratio of peak flow to average flow in dry weather conditions). This in itself presents flow-handling challenges with the associated risks of washout of sensitive treatment process stages.

Municipal wastewater is typically composed of less than 1% solids (and their associated pollutants) and over 99% water. The implementation of bigger and bigger relief / interceptor sewers and tunnels inevitably results in the carting of larger and larger volumes of water over longer and longer distances which in turn has major cost implications. If an alternative strategy and approach can be found that provides scope for concentrating the polluting solids in a relatively smaller portion of the flow (for example increasing the dry solids content of wastewater from 1% to 2% effectively reduces the quantity of waster that has to be conveyed by 50%), then this should provide scope for major cost savings.

It is important to understand some aspects of the nature and characteristics of urban wastewater in order to appreciate alternative strategies that may prove to be more beneficial than the conventional way.

URBAN WASTEWATER: NATURE, CHARACTERISTICS AND CONTROL

Nature and Characteristics

Whilst dry weather flow is the major source of polluting material in urban wastewater, stormwater run-off brings accumulated pollutants, and sediments with associated pollutants, from urban surfaces as they are washed into collection systems. For example, heavy metals and polycyclic aromatic hydrocarbons (PAHs) have been found attached to sub-200 µm particles in sewer flows, the degree of contamination being a direct result of the land-use in the catchment area. As might be expected, heavily trafficked urban catchments produce more pollutants than lightly trafficked areas.

Combined sewer overflows and other uncontrolled discharges under wet-weather conditions (such as Sanitary Sewer Overflows) are characterized by the presence of fecal and other gross solids (e.g. thrash, floatables, persistent synthetic material – plastics etc); bacteria, pathogens; total suspended solids; BOD; ammonia; heavy metals (copper, lead, zinc, chromium etc.); toxic organics (benzene, phenols and other organic solvents); fertilizers; and pesticides. Other pollutants such as oils and grease may be present depending on the residential, commercial and industrial profile of the sewer network's service area.

The contaminants in urban wastewater include suspended particulate materials that exhibit different sizes, shapes, densities, and levels of biochemical activity. As a result, the different particles settle at different rates and undergo differing biochemical transformations. For instance, stones and other large inert solids settle rapidly to the bottom of sewers and are not easily re-suspended. Fine organic solids, however, settle under low or sluggish flow conditions, and are readily re-entrained by diurnal dry weather flow variations

Depending upon the transport regime and carrying capacity of wastewater flows in collection systems, pollutants are held in suspension, deposited, or eroded from the sewers. During wet weather events, increasing inflow, due to storm run-off, increases turbulence in catchbasins and collection system sewers with the consequent re-entrainment of accumulated sediments and the washout of intermediate products of organic biodegradation providing an increased pollution load. When the flows arriving at an ancillary structure (e.g. CSO chamber or diversion structure) exceed the rated continuation flow capacity of the collection system, excess flows are spilled to the nearest receiving environment. The environmental impact of the spilled flow is directly related to the quality of the spilled flow, which in turn is influenced by the ancillary structure's effectiveness as a water quality improvement device and the nature and type of unit processes in operation.

It is obvious that the various contaminants in urban wastewater will have differing polluting effects when they are discharged into receiving watercourses depending on their quantities and the interactions that occur. Contaminants in municipal wastewater, CSOs and SSOs tend to be unsightly, impair a water's use, elevate bacteria levels and reduce oxygen in the water creating conditions harmful to aquatic habitats and humans which necessitates their effective control.

Table 1 provides comparative characteristics for contaminant sources including stormwater, CSO and untreated domestic wastewater as measured by conventional parameters such as BOD_5, TSS and Total N. This shows for example that CSO has properties that are not too dissimilar to untreated domestic wastewater except for parameters such as Total N where increased volumes of water from rainfall-runoff may provide a dilution effect resulting in lower concentrations in CSO. CSO appears to have higher suspended solids concentrations and this may be due to increased solids load resulting from the re-suspension of sediments and other solid material deposited in sewers under low flow conditions in dry weather.

Table 1: Comparative Characteristics of Urban Wastewater (after: WEF, 1999)

Contaminant Source	BOD_5 (mg/l)	TSS (mg/l)	Total N (mg/l)	Total P (mg/l)	Fecal Coliforms (cts/100ml)
Untreated Domestic Wastewater	100 – 400	100 – 300	20 – 85	4 - 15	$10^7 – 10^9$
CSO	25 – 100	150 – 400	3 – 24	1 - 10	$10^5 – 10^7$
Stormwater	10- 250	67 – 101	0.4 – 1.0	0.7 – 1.7	$10^3 – 10^7$
Treated Wastewater - Secondary	<5 – 30	<5 – 30	15 – 25	<1 - 5	<200

Though Table 1 presents information on the relative contaminant levels in various urban wastewater streams, wet-weather impacted flows (such as CSO, SSO and Stormwater) are in reality highly variable in both their flow characteristics and contaminant levels because factors such as antecedent conditions, rainfall intensity, flow sources etc. all have a bearing on the wastewater characteristics. This poses challenges with regards the implementation of appropriate strategies, devices and systems for controlling urban wastewater.

Control

Conventional urban wastewater control and treatment practice has involved the use of a number of unit processes (usually of increasing complexity) in a sequential manner at a wastewater treatment plant typically located at the outfall of a collection system (‘end-of-the-pipe’). This has often involved the use of physical or physico-chemical unit processes at the “Preliminary” and “Primary” treatment stages where screenings (such as large debris and gross solids); grits (including sediments); floatables (including scum and grease) and readily settleable solids (e.g. fecal matter, other organic solids and sediments) are removed from the wastewater stream. These are then typically followed by the use of biological treatment processes (for “Secondary Treatment”) to remove finer solids, dissolved pollutants and nutrients. The final effluent is then disinfected to inactivate fecal coliforms and pathogenic organisms.

Figure 1 outlines the various unit processes in relation to particle size showing the appropriate process for a given particle size range. A general observation is that more complex unit processes and treatment stages are required with reducing particle sizes. Comparing the contaminant concentrations in CSO and stormwater with those in urban wastewater treated to secondary treatment levels suggest that the major contaminants that need controlling in wet-weather impacted flows are solids, their associated pollutants (e.g. BOD) and fecal coliforms. This suggests that wet-weather discharges can potentially be controlled by physical (or physico-chemical) treatment processes such as “Screening”, “Sedimentation”, “Filtration”, “Chemical Coagulation” (if necessary), followed by “Disinfection”.

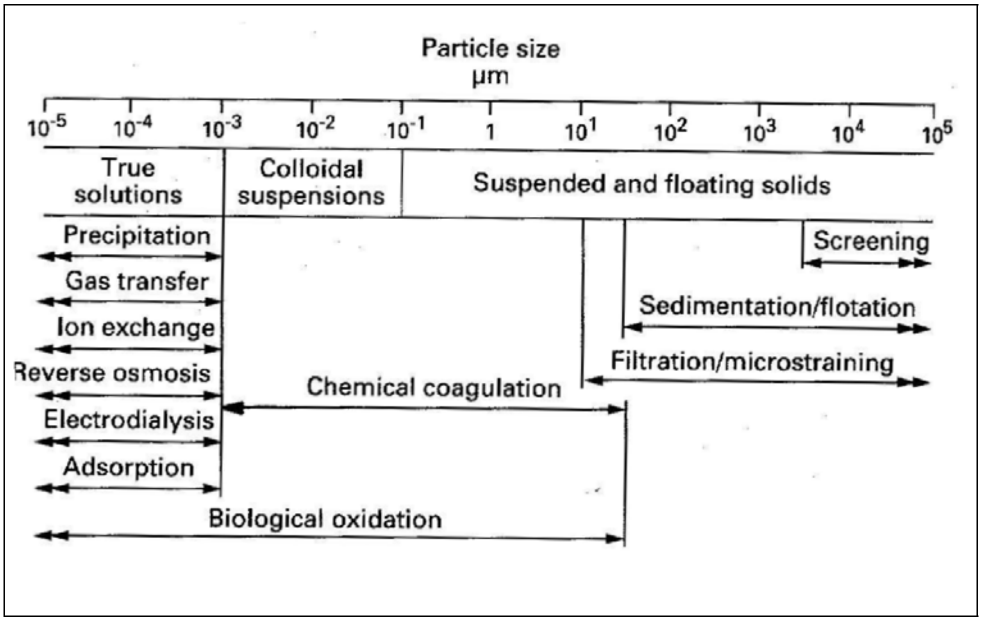

Figure 1: Particle Size and Unit Processes

After screening to remove large debris and thrash, the next major unit process utilized in conventional wastewater treatment is sedimentation. Sedimentation is one of the most important and commonly used unit process for water and wastewater treatment. Sedimentation involves the use of clarification vessels to separate settleable (or floatable) solids and their associated pollutants from water.

SEDIMENTATION AND SOLIDS CONTROL

Settling Characteristics

The time it takes for solids of different sizes and specific gravities (relative densities of 2.65 for an inert sediment and 1.2 for an organic solid respectively) to settle through a column of water about a foot (300mm) tall under quiescent settling conditions is presented in Table 2. This shows that as you get significantly below 100µm (e.g. ~ 10µm) in size, you get into impractical time-scales for material to settle. Sedimentation as a unit process therefore is seen to be only effective down to a particle size of about 20 – 30 µm with the need for the use of Filtration, Chemical Coagulation or other unit process to remove very fine solids (of the order of silt or less in size).

Table 2: Particle Size, Specific Gravity and Time to Settle

Particle Size (mm)	Particle Size (microns)	Order of Size	Time Required to Settle (sg = 2.65)	Time Required to Settle (sg = 1.2)
10	10000	Gravel	0.4 sec	1.2 sec
1	1000	Coarse Sand	3.0 sec	9 sec
0.1	100	Fine Sand	34 sec	5 min
0.01	10	Silt	56 min	8 hours
0.001	1	Bacteria	4 days	32 days
0.0001	0.1	Colloidal	1 year	9 years
0.00001	0.01	Colloidal	> 50 years	> 50 years
0.000001	0.001	Colloidal	> 50 years	>50 years

Additionally, Table 2 shows that colloidal material barely settles, suggesting that colloidal-sized particles are generally entrained within flow zones, whereas sand, gravel and large organic solids tend to settle readily to form the bulk of the sediments in sewers. Indeed, flows in sewer systems are stratified with the discernible modes of solids transport being described as suspended, wash and bed loads. The various sediment and particulate pollutant types are found in different quantities and typically exhibit different levels of associated pollution loads (Ashley *et al*., 1999).

The characteristics of a sample of urban wastewater will therefore reflect the sampling location as much as the cumulative characteristics of its contributing sources. Typically, a sample taken close to the surface, and reflecting the suspended load, is bound to have different particle size distribution and associated settling characteristics compared to a sample taken close to the bottom, reflecting the bed load.

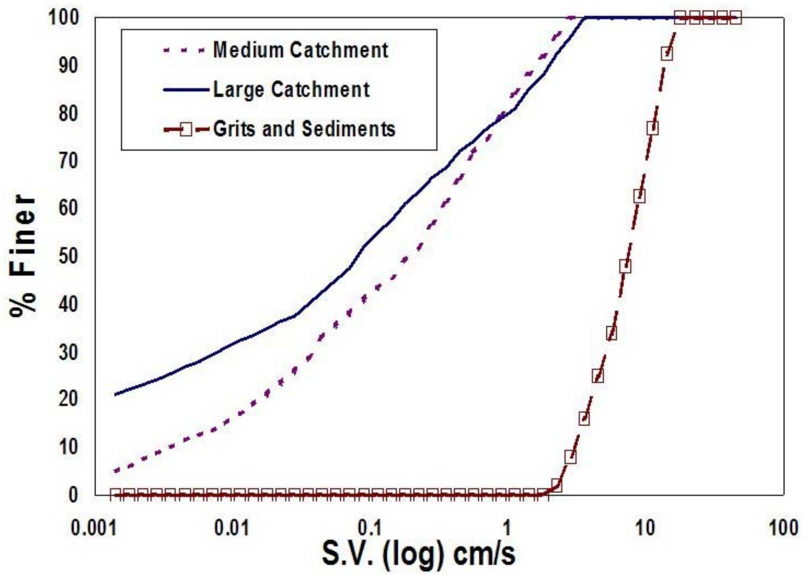

Figure 2

The settling velocity distributions for municipal wastewater from different sized contributing catchment areas and, grits and sediments are presented in Figure 2. These show that the proportion and distribution of settleable material in a waste stream can vary significantly depending upon the source and the type of material.

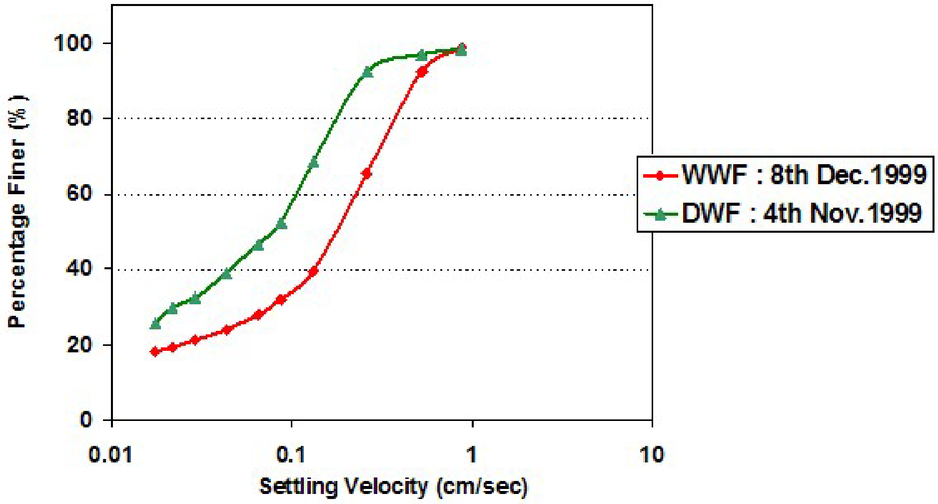

Figure 3

Figure 3 shows an example of the settling velocity distribution for two wastewater samples taken for the same site on different days; one during dry-weather conditions and the other during wet-weather. If the practical limits of settling is taken to be within the range of 0.01 to 0.1cm/sec, then this shows that the wet-weather sample has just over 20% of its suspended solids being non-settleable whereas the dry-weather flow sample has approximately 40% non (readily) settleable solids. The difference in settling velocity distributions for the two samples is evident with the wet-weather sample shown to contain a greater proportion of readily settleable solids compared with the dry-weather sample.

A possible reason for this observation is that the material mobilized from a sewer network during wet-weather periods is a function of the intensity and duration of the rainfall and its interaction with the network. Factors such as antecedent conditions also have an influence. However generally with the exception of a dilution effect, wet-weather flow would tend to contain more settleable solids compared with dry-weather flows owing to the re-mobilization of sediments and related materials that has previously settled in the sewer under dry weather conditions.

Suspended Solids – An Incomplete Picture!

One of the most important measures of water quality is the amount of material suspended in the water. A commonly used measure of suspended material in a water or wastewater sample is the Total Suspended Solids (TSS) analytical test which was originally developed for use on effluent samples and is now routinely used for water quality assessments and process performance evaluations including stormwater, combined sewer flows and influents to sedimentation processes.

Conventional parameters such as TSS (shown in Table 1) are typical surrogate measures of water quality and provide useful indications of the waste stream's likely polluting effects from a physical, chemical or bio-chemical standpoint. These parameters however do not necessarily provide direct correlations to measures that give useful insights on appropriate unit processes for controlling the pollutants in the wastewater stream.

Using TSS and sedimentation as an example, the TSS surrogate measure provides an indication of the particulate solids content in a wastewater stream including the inert sediment and biodegradable solids fractions and involves the filtering of an aliquot of the original sample through a filter paper of approximately 1µm pore size to determine the mass of solids in a known sub-sample volume.

The TSS measure by its very nature however does not provide any information on (or differentiation between) the particulates in the wastewater in terms of their size, relative density, propensity to agglomerate or their settling characteristics. TSS only depicts the mass of solid material above ~1 µm (micron) in size in the wastewater sample.

It is therefore possible to have two wastewater samples with similar TSS concentrations (say 300mg/l) that exhibit very different settling characteristics and hence different levels of pollutant control when they undergo sedimentation because of differences in their distributions and proportions of solid particulates. For example one sample could have the greater part of its solids above 100µm whereas the other could contain solids predominantly in the 1 - 10 µm size range. Both samples could have the same measured TSS concentration however, observed solids removal efficiencies will be higher for the waste stream that has a greater proportion of larger sized particulates especially if these particulates have higher relative densities.

Because traditional sampling methods based on small-bore tube samplers normally sample only the suspending fluid, most CSO monitoring and evaluation schemes have taken no account of the readily settleable solids, the sediment fractions and their associated pollutants though these are probably the most polluting portions of urban sewer solids particularly in terms of chronic impacts on receiving watercourses.

Though TSS is a good surrogate measure of the fine particulate fraction in a wastewater stream, the fact that it does not discriminate between solids fractions in terms of particle size distribution coupled with the very nature of the sampling and test procedures associated with this measure, results in a significant bias and the missing out of a significant fraction of the solids spectrum in urban wastewater including the sediment and gross sewer solids fractions.

Sediments and Gross Solids – The Missing Dimension

Research and operational experiences have shown that considerable sediment deposition occurs in most collection systems as self-cleansing velocities are hardly attained during dry-weather flow conditions (Ashley and Crabtree, 1992). The re-mobilization of gross sewer solids, the settled sediments and their associated pollutants during storm events accounts for the observed first-foul flush during storm events especially after a prolonged period of dry weather. This highly polluting first flush including what has been described as the "fluid sediment" (Ashley *et al*., 1999) can results in a shoal of detritus with varying amounts of organic pollutants and heavy metals accumulating immediately below intermittent discharge outfalls or where the first slack length of river occurs causing possible ecological impairments (especially during low summer flow conditions).

When sewer sediments and attached pollutants are discharged, they settle to the bottom (benthos) in the sluggish regions of receiving waters creating sludge banks and causing chronic pollution impacts. Deposits on streambeds also inhibit ecological development and impair the establishment of healthy ecosystems. The organic solids in the benthos cause a delayed oxygen demand (chronic impact) on the overlying waters and the heavy metals cause a progressive build up of toxicity levels presenting a potential 'time bomb'.

A significant proportion of the inert visually offensive substances found in sewage (e.g. floatables, thrash, sanitary products etc.) do not necessarily biodegrade to cause a direct stress on the receiving environment in terms of ecological impact, they are however unsightly and often cause an aesthetic pollution problem and need to be controlled. There has been a tendency in recent times (in line with the nine minimum controls enshrined in the CSO policy) to focus on these aesthetic pollutants presumably because this category of pollutants is visual and is what causes public complaints. This has in turn resulted in screening becoming one of the principal technologies utilized to address CSO control challenges (Saul, 1998).

The absence of sanitary products and other visually offensive pollutants from intermittent discharges however does not imply that these discharges are free from pollution or do not pose a health risk. Microbial organisms (including pathogens), heavy metals and other toxic micro-pollutants for example are attached to sewer sediments. Toxic micro-pollutants have a chronic effect on fish and other invertebrates and are also dangerous to humans if ingested through the food chain. Polycyclic Aromatic Hydrocarbons (PAHs), often found attached to sediments, are carcinogenic. Becker and others (1996) for example found pollutants such as COD and Phosphorous to be associated with the suspended solids that have settling velocities in the range of 0.04 – 0.90 cm/sec.

Though effective, screens do not remove the particulate solids fractions that have the associated pollutant loads. A lack of characterization of waste streams in terms of settling velocity distributions has resulted in mixed performance reviews and a lack of realization of the relative importance of collection system ancillary structures (such as CSO chambers) in controlling water quality.

The efficacy of sedimentation as a unit process for controlling CSOs and other wet-weather flows depends very much on the hydrodynamic characteristics of the ancillary structure together with the Settling Velocity Distribution or profile of the waste stream as these to a large extent determine what levels of removals are attainable. The relevance and use of wastewater settling characteristics in design is described elsewhere (Andoh and Smisson, 1996) and the need for taking wastewater characteristics particularly particle size distribution and settleability into account in CSO pollutant studies and control is increasingly being recognized and advocated (Shin *et al*., 2001). It is only when these issues are taken into account routinely that optimum chamber configurations and collection system arrangements will be selected to facilitate the required water quality improvements.

WHY SATELLITE TREATMENT?

Within extensive sewerage networks conveying foul or combined sewage, 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.

As shown in Table 2, the larger a solid is, the easier it is to remove by physical separation processes (such as sedimentation). Fecal solids discharged into water closets (WCs) at the top end of the collection system tend to be larger solids that settle rapidly and are thus readily removed from wastewater streams using sedimentation as a unit process. These solids also have a propensity to degrade into smaller and smaller sizes as they are transported through collection systems. As fecal solids degrade, they release more and more of their associated pollutants (e.g. fecal coliforms, pathogens and heavy metals) into the surrounding water increasing the public health risks associated with the discharge of untreated portions of the wastewater into the environment.

The above would suggest that with regards separating solids and their associated pollutants from wastewater, the earlier this separation is implemented in the cycle of collection, conveyance and treatment (i.e. upstream within the collection system), the easier it is to achieve water quality benefits.

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

These predicate the use of satellite wastewater treatment systems distributed as far upstream as is practicable as this provides the greatest opportunity for achieving high levels of solids and associated pollutant removals without recourse to more complex treatment process stages. 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) and provides better scope for community and other stakeholder involvement.

With conventional schemes where treatment plants tend to be “out-of-sight”, there generally is very little scope for stakeholder involvement as and an “out-of-sight-out-of-mind” type mentality develops with no communal sense of “duty of care”. Localized schemes on the other hand provide scope for local community involvement, an awareness of the need for schemes to be sustainable and increased scope for beneficial reuse and recycling. The satellite approach would appear to have other benefits including possible reductions in the extent of the associated collection systems infrastructure as the wastewater does not have to be carted over long distances. This in turn translates into major cost savings.

The usual concern regarding satellite wastewater 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. In fact this may be the case where factors such as poorly constructed systems (e.g. septic tanks) are sited in close proximity to ground water aquifers that are 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. This may also be the case for treatment systems, equipment and devices that require external sources of power, sophisticated control, regular inspection, high levels of maintenance and offer inadequate control pathways.

Appropriate systems for implementing a satellite treatment approach 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 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.

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 WERF and the EPA are described and used as a case example to highlight the benefits and significant cost savings that accrue from implementing satellite treatment systems (based on physical unit processes) within collection systems.

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 4).

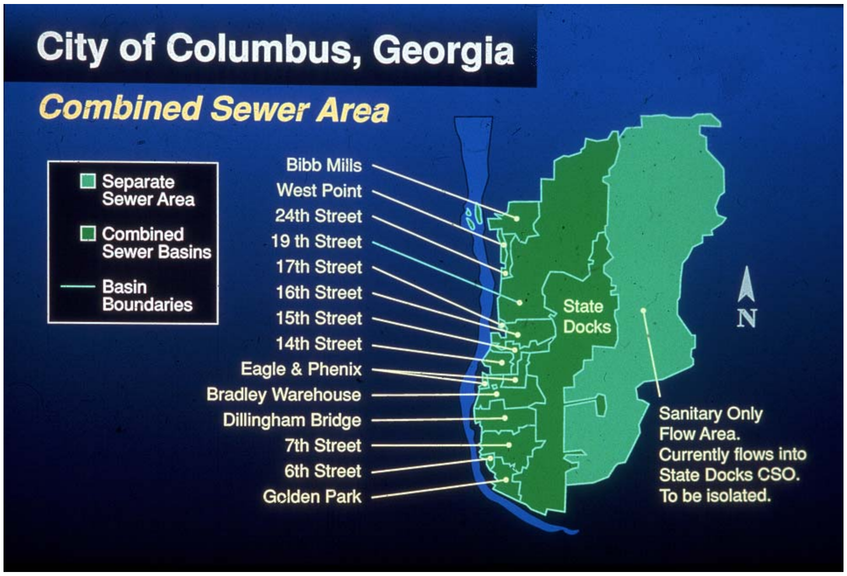

Figure 4

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.

Initial planning studies, based on the “conventional way” 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 way. Uncertainties at the time regarding the efficacy of vortex separators, which were viewed then as novel technology, led to the initiation of a pilot study.

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 with CSO diversion structures and collector conduits providing limited conveyance (see Figure 5). A full satellite treatment approach was not adopted because of the risks and maintenance issues associated with storage of sodium hypochlorite at several multiple sites.

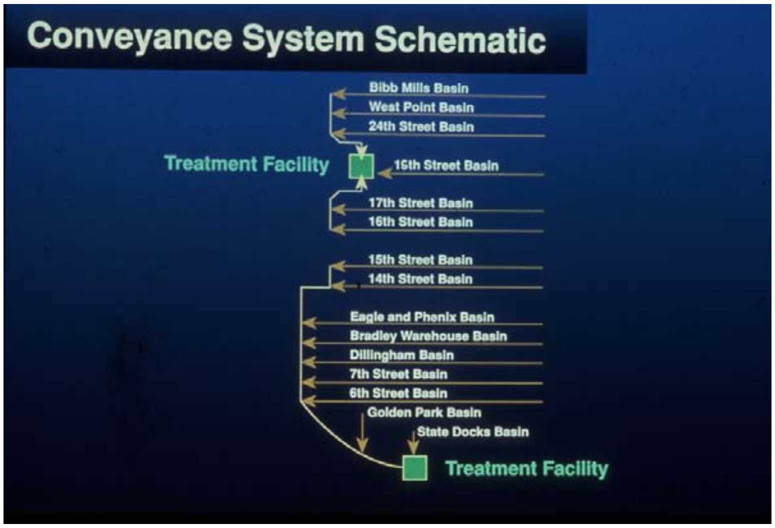

Figure 5

The satellite CSO treatment facilities, which use vortex separators for solids control and chemical disinfection became operational in 1995. Each site is capable of treating up to 3,500 l/s (55,475 US gpm). 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, as CSO treatment technologies. 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 Chattahooche River.

The total CSO treatment scheme at Columbus was implemented at a cost of ~ $85 million which represents savings of at least $50 ~ $160 million over the previous estimates for the solution based on the conventional approach of a new interceptor sewer that would have necessitated the upgrading of the existing main wastewater treatment facility. The implemented satellite approach resulted in a **minimum** saving of ~ 40% compared with the least cost option for conventional interceptor scheme initially proposed.

An assessment of the cost breakdown for the adopted scheme shows that the Conveyance Component (i.e. associated collection 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 lies in the carting of wastewater around (i.e. the collection system) and that any reductions in the extent of the collection system, by adopting a satellite treatment approach, translates into major cost savings.

The ADF (shown schematically in Figure 6) includes coarse screens followed by six 32 feet diameter vortex separators, a compressed media filter with a 30 inches bed of 1-inch fabric balls, followed by UV disinfection. Each vortex unit has a volume of about 380 m^3 and the facility handles combined sewer flows from a contributing urban catchment area of about 390 hectares.

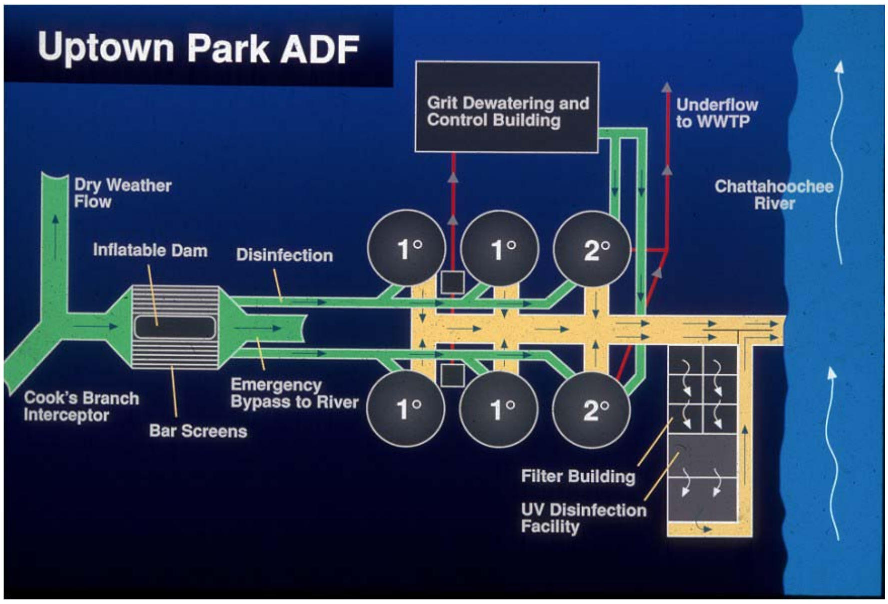

Figure 6

The sequence of operation for the ADF depends on the incoming flow rate with wastewater flows up to 10 mgd continuing in the interceptor to the main wastewater treatment plant. Once the flow exceeds 10mgd, flow is directed to the six vortex units, and disinfectant addition is initiated. Each vortex vessel provides about 3 minutes detention time for chemical disinfection. After the vortex tanks are full flow than is directed to the compressed media filters and UV. Flows greater than the CSO facility capacity are bypassed to the river. All the six vortex separators are operated in parallel until the vessels are full at which time the sixth unit is used to concentrate the underflow from the remaining five units on-line after their underflows have been de-gritted using a vortex grit removal unit housed in an adjacent building (Grit Dewatering and Control Building) shown in Figure 6.

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 ration of 10:1 which means that the settleable solids (e.g. fecal 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 (1/10th). The vortex vessels at the ADF (and the other CSO treatment facility site at Columbus) were laid out in a series arrangement, which provided scope for routing the underflows from primary (1°) vortex units to a secondary (2°) unit, after degritting to remove sands and sediments. This enabled the settleable organic solids such as fecal 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) providing the ability to handle increased wet-weather flows without the need to upsize the main interceptor (collector) sewer to the central wastewater treatment plant.

Performance monitoring over a five year period has shown 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 high-rate compressed media filter was found to successfully remove the fine particulate matter (10 to 20µm) with 70 percent reduction in TSS, 80 percent reduction of oil and grease, 60 percent removal of phosphorus and 50 to 70 percent removal of metals. The vortex units followed by compressed media filter provided sufficient pretreatment for the medium pressure high intensity UV lamps to achieve the requisite reductions in bacteria counts. UV disinfection of the pre-treated CSO was found to be cost-effective and environmentally sensible especially for the more frequent CSO events. The final WERF Report produced following the review of the Capital and Maintenance and Operational costs after the five-year program of operations and performance testing recommends combined chemical and UV disinfection for reliable and effective CSO application.

The report also 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 combination of Vortex Separators followed by compressed media filters and UV disinfection would cost one-half (1/2) and occupy one-tenth (1/10th) of the footprint of conventional primary clarification and disinfection.

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. In 2001, the US EPA awarded

CWW the National First Place Award for Combined Sewer Overflow Control Program Excellence.

DISCUSSION AND CONCLUSIONS

Discussion

Amendments to the CWA in 1987 which began the transition from grants to loans through state revolving funds has meant a substantial increase in the share of urban water infrastructure expenditure borne by local governments and hence local residents. Recent reports by the Water Infrastructure Network (WIN) highlight a wastewater spending need of $22 billion per year over the next 20 years. With current spending levels of around $10 billion per year, this leaves a potential funding gap of $12 billion per year.

States lack adequate funds to undertake the required level of Capital and Operations and Maintenance investments without a potential near doubling of local rates and fees. It has been suggested that doubling of local rates and fees 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). These cost estimates and projections have been based on the use of conventional approaches to resolving urban wastewater infrastructure needs (including collection systems and wastewater treatment).

Under the current regime of tighter environmental regulations, increasing urbanization coupled with an aging urban drainage and wastewater treatment infrastructure, several communities are faced with the tasks and challenges of rehabilitating or upgrading their collection systems and wastewater treatment plants to provide the requisite levels of service and comply with standards. Conventional systems are costly and 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 collection systems 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 since the passage of the CWA.

The use of Satellite treatment systems located within collection systems provides the scope for resolving some of the challenges in urban wastewater infrastructure provision in a cost efficient manner as demonstrated at Columbus, Georgia. Full-scale operation of the ADF has confirmed that high-rate processes such as vortex separator followed by compressed media filter can be used to remove the gross solids and the lighter fraction of fine particulates while passively optimizing in-system storage.

Conclusions

Sediment has been identified as the most widespread pollutant in the Nation’s rivers and streams. In addition to sediment itself being a major pollutant, many trace elements such as heavy metals and toxic organics (e.g. PAHs) are associated with sediments. This fraction of sewer solids is not however routinely characterized in CSO and other wet-weather monitoring and evaluation studies resulting in a general lack of appreciation of the relative importance of ancillary device (e.g. CSO chamber) efficacy as sedimentation and water quality control systems.

The use of settling velocity distribution in addition to the conventional contaminant measurements such as TSS provides improved wastewater characterization particularly with regards to the settleable particulate fraction and their associated pollutants, and leads to better insights with regards potential unit processes such as sedimentation and filtration for solids control in collection systems and at wastewater treatment works sites.

Passive 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 statellite 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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