FIELD EVALUATION OF NOVEL WET-WEATHER SCREENING SYSTEMS

Robert Y.G. Andoh, Ph.D.
Hydro International plc,
Shearwater House,
Victoria Road,
Clevedon, BS21 7RD, UK
Email: *bob.andoh@hrd.co.uk*

Adrian J. Saul, Ph.D.
University of Sheffield,
PO Box 600,
Mappin Street,
Sheffield, S1 4DU, UK
Email: *a.j.saul@sheffield.ac.uk*

ABSTRACT

The effects of the regulatory requirements for intermittent wet-weather discharges in Europe leading to the evolution of screening criteria, such as the Asset Management Plan (AMP2) requirements in England and Wales, are discussed. The resulting focus on aesthetic pollutants (including floatables) is set in context with regards to a holistic approach to resolution of environmental problems associated with CSOs and other intermittent wet-weather discharges. The most stringent consent standard (relating to discharges to 'high amenity' waters) calls for separation, from the effluent, of a significant quantity of persistent material and faecal/organic solids greater than 6 mm (1/4 inch) in any two dimensions.

Recent developments in CSO technologies are outlined, particularly screening devices for the control of aesthetic pollutants. The characteristics of the ideal intermittent wet-weather screening system are described together with the development and evaluation of a novel self-cleansing CSO device - The Hydro-Jet Screen™.

Results of independent field testing at the UK National CSO Test Facility at Hoscar Wastewater Treatment Works, Wigan, of the commonly used CSO chambers and the Hydro-Jet Screen™ are presented and compared. The results demonstrate that the commonly used chambers do not meet regulatory requirements and the use of a self-cleansing screening system such as the Hydro-Jet Screen™ provides significant performance enhancements. An assessment of mesh screens with differing aperture sizes - 1mm (1/24 inch), 2 mm (1/12 inch), 4 mm (1/6 inch) and 6 mm (1/4 inch) respectively - show the novel back-washing feature of the Hydro-Jet Screen™ to be effective over a range of mesh aperture sizes. The results suggest the optimum mesh configuration for CSO screening to meet the AMP2 requirements to be 4 mm (1/6 inch). The 4 mm (1/6 inch) mesh provided significant performance gains (in terms of gross solids removals) over the 6 mm (1/4 inch) mesh without incurring a penalty in hydraulic capacity.

Recognition of the need for adopting sustainability principles in the coming millennium coupled with lower capital and operating costs associated with non-powered self-cleansing CSO screening systems, such as the Hydro-Jet Screen™, is used as a basis for arguing their superiority.

KEY WORDS

CSO Chambers, Self-cleansing Screens, Gross Solids, Regulatory Guidelines, Field Evaluation

INTRODUCTION

The UK interpretation of the European Urban Wastewater Treatment Directive of 1991 [1] as applied to Combined Sewer Overflows (CSOs) and other intermittent wet-weather discharges is described by the AMP2 Guidelines [2]. These guidelines provided a basis for planning and implementation of improvement programmes and included minimum standards based on spill frequency and receiving watercourse sensitivity. The most stringent consent standard (relating to discharges to 'high amenity' waters) calls for separation, from the effluent, of a significant quantity of persistent material and faecal/organic solids greater than 6 mm (1/4 inch) in any two dimensions.

In the early 1990's there were an estimated 25,000 CSO discharges in the UK of which an estimated one third were deemed to be unsatisfactory [3]. Based on estimates presented in 1999, around 1700 unsatisfactory CSOs were expected to have been improved by the end of the AMP2 period (i.e. 1995-2000). This is a small figure when compared to the targets set by the UK Government for an improvement of 85 percent of the remaining 5500 identified unsatisfactory intermittent discharges within the AMP3 period (i.e. 2000-2005) [4]. This challenge has resulted in the emphasis for capital investment in the UK shifting towards reducing the polluting impact of CSOs and other intermittent wet-weather discharges from overloaded drainage systems, and at inlets to wastewater treatment works.

Recent tests by the UK Water Industry CSO Research Group (CSORG) of the commonly used CSO chambers (i.e. Stilling Ponds and High Sided Weirs), found the performance of each of the chambers to be poor at their design flows with regards to separation of gross solids. All chambers were observed to discharge a significant proportion of solids with dimensions greater than 6 mm in two dimensions in the spill flow [5]. These results suggest that the solids retention efficiency performance of CSO chambers designed to criteria outlined in the UK Foundation for Water Research report FR 0488 [6] will not meet the required regulatory standards.

Given the range and characteristics of sewer solids in urban drainage systems, especially with aesthetic pollutants such as panty liners and condoms approaching neutral buoyancy, the above results are hardly surprising. It is generally recognised that the most effective way of achieving 100% compliance with the AMP2 requirements is with a screening system. When the AMP2 standards were produced, however, screening systems for use within the sewer network were poorly developed and at best unreliable.

Generally, screens fall into two main categories: mesh screens and bar screens. Screens placed in isolation in combined sewer environments are subject to rapid blinding due to hair pinning. Hair pinning results from fine fibrous material becoming wrapped around the wires of bar screens, and bridges the gap between the apertures of perforated (mesh) screens. This presents a major cleaning problem and to overcome this, conventional screening devices tend to rely on Electro-mechanical components to effect the cleansing of screens.

Bar screens, for example, typically utilise raking mechanisms and are only effective in screening in one dimension. A 3 mm (1/8 inch) wide string say a couple of metres long could easily pass through a 4 mm (1/6 inch) bar screen resulting in a failure of the 6 mm (1/4 inch) in two dimensions requirement. As such, bar screens are not as efficient as perforated screens with defined aperture sizes. Reported results of tests conducted at the UK National CSO Test Facility have highlighted that for screens with powered cleansing mechanisms, a 6 mm (1/4 inch) mesh screen appears to be more effective at retaining 6 mm (1/4 inch) solids than a 4 mm (1/6 inch) raked bar screen [7].

There are currently a growing number of screening devices and arrangements being used in CSO chambers. These include static screens (with or without a cleansing mechanism), self-cleansing non-powered screens and screens with a powered cleansing mechanism. The paper describes the requirements of the ideal intermittent discharge screening system and reviews the evolution and development of the Hydro-Jet Screen™. Results of independent field evaluation are presented and these are compared with the performance of the commonly used CSO chambers. The application of this novel wet-weather screening system is set in the context of a holistic approach to the resolution of problems associated with the impacts of CSOs and other intermittent wet-weather discharges on receiving watercourses.

THE IDEAL INTERMITTENT DISCHARGE SCREENING SYSTEM

CSOs and other intermittent discharges tend to be at remote sites and as such, screening devices should preferably be self-powered, self-cleansing and free from maintenance requirements. The attributes of an ideal CSO screen are highlighted below.

Robust Stop-Start Operation: This is a prime feature of the duty of a screen. Where multiple events occur in succession, repeated operation will be called for. There should therefore be no loss of performance from the moment of start of operation to the end of the storm event. This requires that the screening unit operates at full efficiency throughout its range. Static screening devices with no cleansing mechanisms do not fulfil this criterion, as they will be subject to progressive blinding through storm events.

Electrical Power: Should not be needed. Power failure is most likely to occur during severe weather conditions including heavy storms. A unit that does not perform whenever there is a power failure is unlikely to be sufficiently reliable.

Screenings Return: Because of the complex re-circulatory patterns of flow in chambers, it is important that screenings are not returned into a region of the flow where they stand a chance of being re-presented to the screen. This increases the risk of blinding and provides scope for gross solids that have been subjected to size reductions due to a raking, brushing or scraping cleansing mechanism, to pass through into the spill (screened) flow. The location of screenings return on a number of Electro-mechanical screens, for example, prevents the use of scum boards.

Low Maintenance: Is a prerequisite. Routine attention must be confined to occasional visits, and it should not be necessary to attend the site after each storm event. Static screens and powered Electro-mechanical screens do not meet this criterion. The need to keep Electro-mechanical gear at a CSO site in working order, in one UK Water Company, has resulted in an operational practice involving daily starting and stopping of an installed screening system to ensure there is no seizure during a spill event.

Low Head: The installation of a screen should ideally not pose an additional head-loss within the system as this poses potential problems of upstream flooding. This is especially the case with weir mounted Electro-mechanical screening systems susceptible to partial blinding. Powered screening systems with mechanically or pneumatically driven rakes, motor driven helical brushes, scrapers etc. have a tendency to push some of the screenings through the screen aperture resulting in partial blinding which in turn influences the hydraulic capacity of the screen. This can result in premature overtopping and an intermittent discharge failing to meet its consent conditions.

Tamper Proof: The majority of intermittent wet weather discharges are from CSOs and these tend to be at remote unmanned sites. A screening installation should ideally be unobtrusive in terms of visual impact and noise and should present no hazard to the public. The more the requirements for power and associated control equipment, the greater the associated risks.

The above suggest that conventional Electro-mechanical screening devices are not particularly suited to screening of CSOs and other intermittent discharge sources. Electro-mechanical screening devices require power, maintenance and are prone to failure due to seizure of moving parts after prolonged dry spells when the screens are not in service. These risks are increased during rainfall events – the period when the screen is expected to operate in as reliable and fail-safe a mode as possible. Failure can arise, for example, when no electrical power is available due to lightning strike at sub-stations.

The ideal intermittent discharge screening system would appear to be one that is robust, tamper proof, impacts a relatively low-head on the sewerage system, has low-maintenance, is self-cleansing, has a mesh rather than a bar screen and requires no external power source to operate. The Hydro-Jet Screen™, developed as a contender for the 'ideal intermittent discharge screen', has no moving parts, no power requirements and utilises a hydraulically sophisticated back-washing system to keep its mesh screen clean. The system has been shown to be capable of operating both reliably and effectively. Results of independent testing at the UK National CSO Test Facility at Hoscar Wastewater Treatment Works, Wigan, (presented later in the paper) have shown complete compliance with the AMP2 6 mm (1/4 inch) in two dimension screening requirements.

THE HYDRO-JET SCREENING™ SYSTEM

The Hydro-Jet Screening™ System has been developed as an effective low cost, low maintenance, non-powered screening system for CSOs and other intermittent discharges such as Storm Tank Overflows, Emergency Overflows at Pumping Stations and Overflows at Inlets to Sewage Treatment Works. The system has two main variants – a rotary version and a linear version.

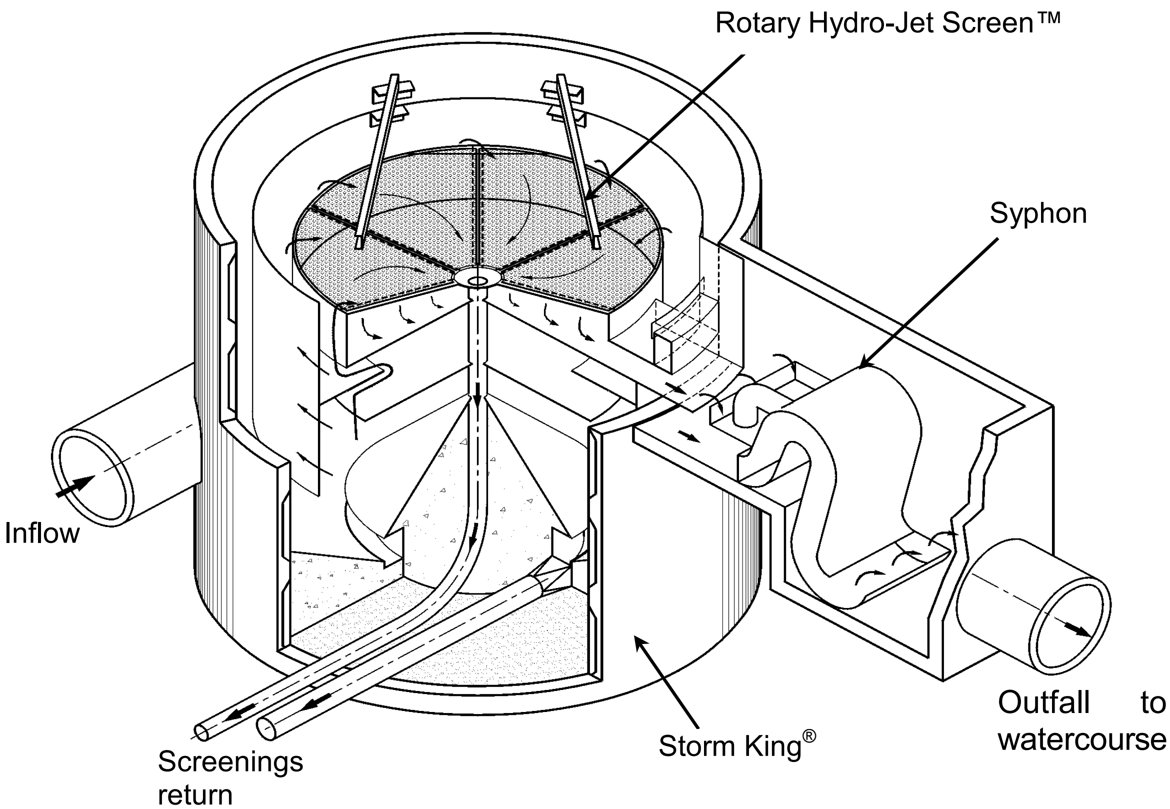


Figure 1: Cut-Away View of the Rotary Hydro-Jet Screen™ System (with Storm King® Overflow Hydrodynamic Vortex Separator)

Rotary System

The rotary version described in more detail elsewhere [8] and shown in Figure 1, is fitted in the overflow of a Storm King® Overflow hydrodynamic vortex separator (HDVS) and provides water quality improvements in addition to the control of aesthetics. HDVS's are well known for their application as high rate sedimentation devices [9], and as such, in this case, the hybrid system is able to remove a high proportion of the sediment load and associated pollutants in addition to the neutrally buoyant components of the gross solids. This is a functionally superior system providing added benefits over and above the AMP2 requirements such as removal of suspended solids, particulate BOD and other pollutants associated with "fluid sediments [10]".

Linear System

The linear version, developed specifically to provide aesthetic control meeting the 6 mm (1/4 inch) in two dimensions aesthetic pollutant requirement outlined in AMP2, provides scope for retrofit into existing CSO chambers (e.g. High Sided Weir and Stilling Ponds). The linear version shown in Figure 2 is used to describe the novel back-washing system that operates in both the rotary and linear versions to keep the mesh screen clean. The configuration and operation of a single-sided linear Hydro-Jet Screen™ during a spill event is shown in Figures 2 - 4.

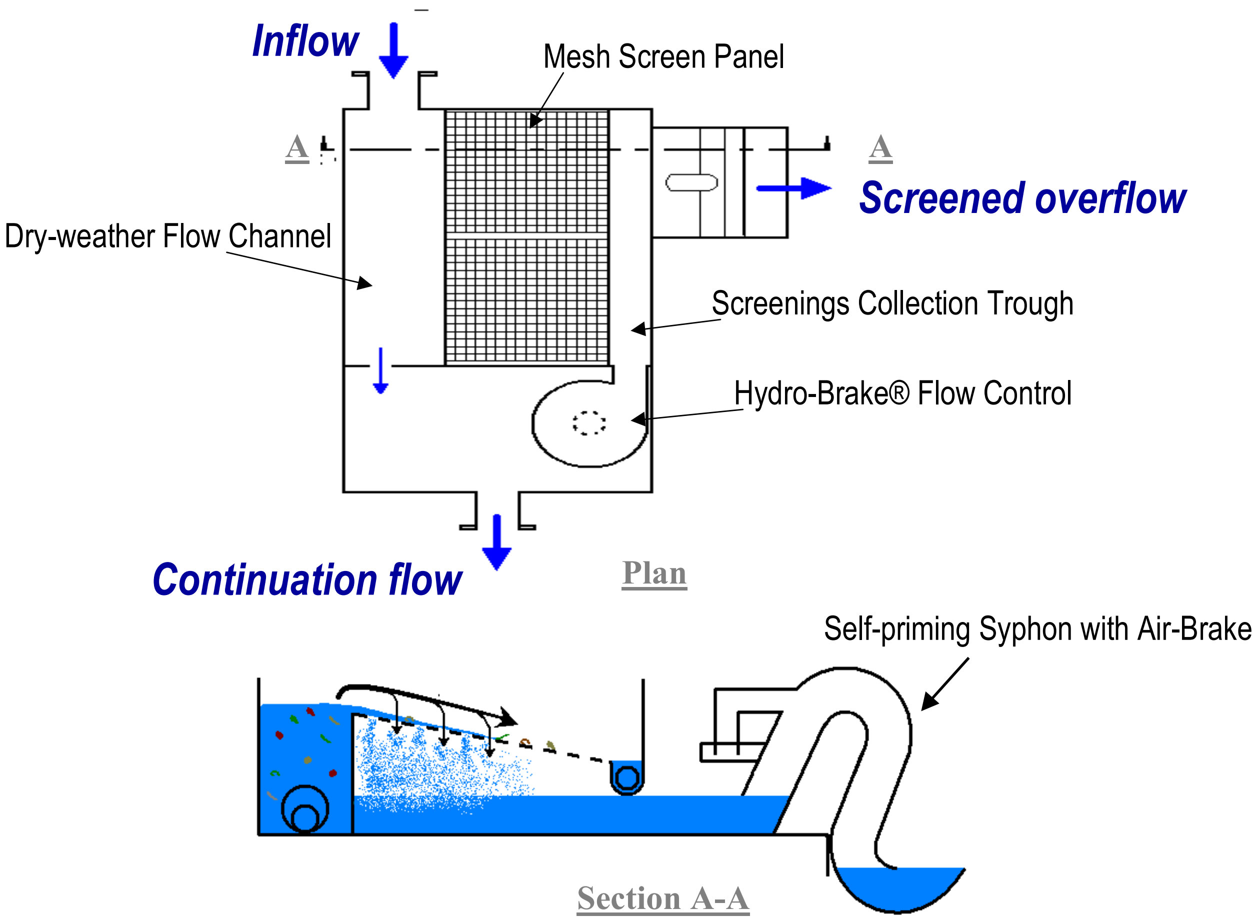
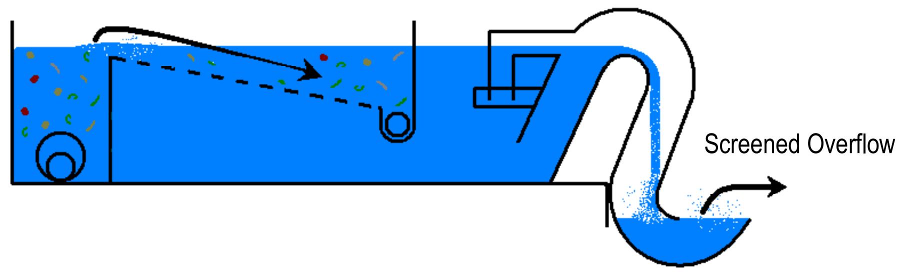


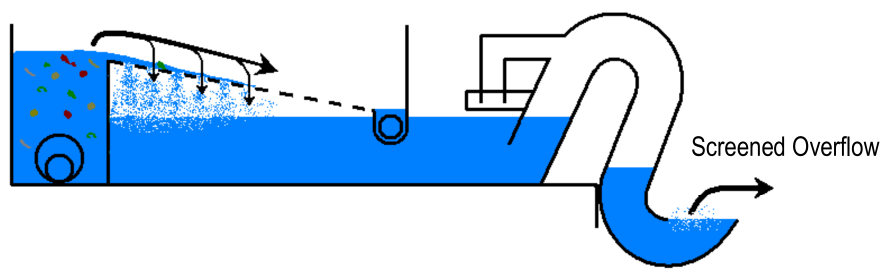
Figure 2: Plan and Sectional Views through the Linear Hydro-Jet Screen™ System

The sectional view in Figure 2 shows a rectangular channel on the left-hand side. This is the dry weather flow channel and incorporates both an inlet and pass-on flow pipe to convey flows to treatment. When the inflow rate exceeds a predetermined pass on flow to treatment (i.e. during storm flow conditions), an overflow occurs. Under storm conditions, the flow weirs over and through a mesh screen on which the solids in the screened flow are deposited. The screened water is initially prevented from being discharged by a self-priming syphon with an air brake pipe. The function of the syphon is to act as an open or closed valve and thus cause the water level to rise and fall in the chamber. As the screened water level is rising towards the apex of the mesh screen panel, deposited material is removed by the following three mechanisms (see Figures 3 and 4):



Syphon primed and beginning to lower water level

Figure 3



Air-brake pipe causes syphon to stop and cycle repeats

Figure 4

Hydro-Jet Screen™ Cleansing Mechanism

1. The screened water rises in the chamber, displaces the trapped air and flows back up through the screen lifting material off the screen. The relatively low open area of the screen holes (22% for a 4 mm (1/6 inch) screen and 27% for a 6 mm (1/4 inch) screen) has the effect of increasing the pressure, and thus velocity, at which the back-flushing water and air passes through the screen.

2. The rise in water level increases the air pressure under the screen "blowing" air through the screen holes. This effect becomes more pronounced as the water level rises and air is forced out from beneath a curtain of water. This mechanism is particularly useful for cleaning the top portion of the screen. During overflow, this portion is continually covered in water and would otherwise blind.

3. The scouring action of the water flowing across the surface of the mesh has the effect of transporting the screenings towards the screenings collection trough for ultimate disposal, via a vortex flow control, with the continuation flow to treatment.

The screened overflow, free from aesthetic pollutants, is discharged to the receiving watercourse. The mechanism by which the screen back washes is essentially a cyclic process. The key element responsible for this is the novel patented discharge syphon, shown on the right hand side in the sectional views (see Figures 3 - 4). When the water level has risen to the crest of the syphon, the syphon primes, discharging the screened effluent to the watercourse. This lowers the water level and the air brake pipe causes the syphon to shut-off before the cycle repeats.

The Hydro-Jet Screen™ system has been subject to an extensive development, testing and evaluation program. Computational fluid dynamics (CFD) has been utilised to optimise its hydraulic characteristics [11]. The device has also been independently tested at the UK National CSO Test Facility at Hoscar Wastewater Treatment Works, Wigan with its performance, assessed in terms of gross solids removal efficiencies when using crude sewage, being shown to be superior to that of other CSO systems [7].

In order to evaluate the scope for providing CSO screening performance better than the AMP2 regulatory requirements, the Hydro-Jet Screen™ system was also tested with screens with 6 mm (1/4 inch), 4 mm (1/6 inch), 2 mm (1/12 inch) and 1 mm (1/24 inch) aperture sizes. This enabled an assessment to be made of the performance gains that can be achieved by using a finer mesh size and also established the potential hydraulic penalty incurred in terms of possible reduced screen loading rates for finer mesh sizes. A detailed account of this testing is presented elsewhere [12] and summarised in this paper.

FIELD TESTING OF THE HYDRO-JET SCREEN™

The test protocol adopted for the field tests were in accordance with those developed by the UKWIR CSORG [5]. The test involves the use of 6 mm (1/4 inch) aperture mesh sacks to collect gross solids from the various streams such as the continuation flow and the screened overflow (or spill flow in the case of CSO chambers), with crude sewage used as the influent feed.

The efficiencies of the screens and CSO chambers are assessed by comparing the mass of material collected from the screened overflow (or spilled flow) with that from the continuation flow. A characteristic of this test procedure is that the 6 mm (1/4 inch) mesh sacks themselves rapidly become coated with a papier-mâché type material and are subject to progressive blinding. The sacks therefore end up trapping material far smaller than 6 mm (1/4 inch) in two dimensions. The test therefore provides an indication of total gross solids removals.

Total solids retention efficiency (TE) as defined below, was used to assess the performance of the different CSO chambers and screens.

$$\text{Total Efficiency (TE)} = \frac{\text{Total Mass of Solids Retained}}{\text{Total Mass of Solids in Inflow}} \times 100$$

RESULTS AND DISCUSSION

The comparative performance of the Hydro-Jet Screen™ with the conventional CSO chambers (i.e. High Sided Weir and Stilling Ponds) is shown in Figures 5 - 6. Figure 5 shows that for a range of flow splits (i.e. ratio of continuation flow to inflow) for a set inflow, the High Sided Weir is more effective than the Extended Stilling Pond and the Hydro-Jet Screen™ System offers significantly enhanced performance compared to both. This is in terms of performance measured by total gross solids removals. Both the High Sided Weir and the Extended Stilling Pond types of CSO chambers only offer removal efficiencies marginally above that which can be attributed to the flow split.

Figure 6 shows the results for a range of inflows at a flow split of 0.1 (i.e. ten percent of the inflow continuing on to treatment). Here again, the High Sided Weir is shown to be more effective than the Extended Stilling Pond. In all cases, however, the Hydro-Jet Screen™ is seen to offer significant performance gains across a range of flows. Figure 5 shows that the Hydro-Jet Screen™ offers performance gains (i.e. add on efficiency values for the screen) ranging from over 30% at a flow split of 0.4 to over 50% at a flow split of 0.1.

A summary of the results of the assessment of the relative improvement in Total Efficiency with decreasing mesh aperture size for the Hydro-Jet Screen™ is presented in Figure 7. Figure 7 shows a general trend of increasing Total Efficiency with decreasing mesh aperture size as would be expected. The observed performance gains ranged from 40% for the 6 mm (1/4 inch) mesh to ~ 80% for the 1 mm (1/24 inch) mesh. The 1 mm (1/24 inch) and 2 mm (1/12 inch) mesh screens were found to have limited hydraulic capacities and were generally tested over a smaller range of flows compared with the 4 mm (1/6 inch) and 6 mm (1/4 inch) mesh screens [12].

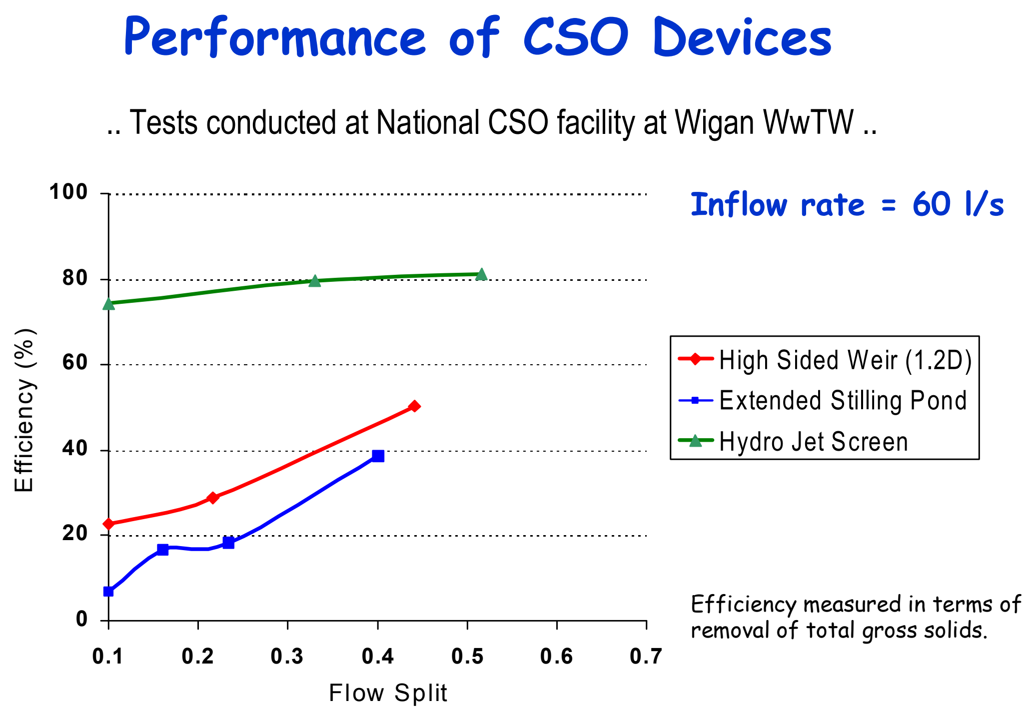


Figure 5

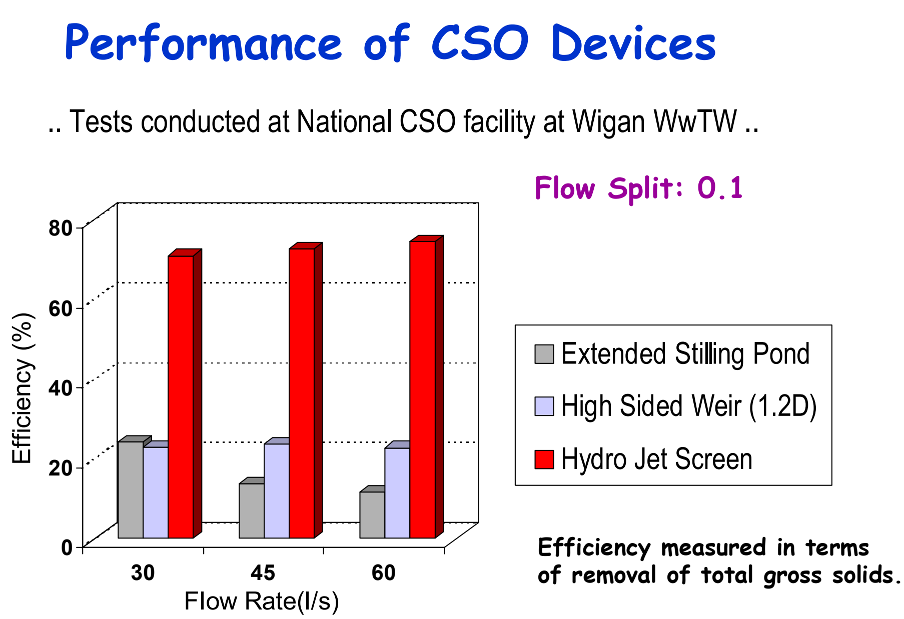


Figure 6

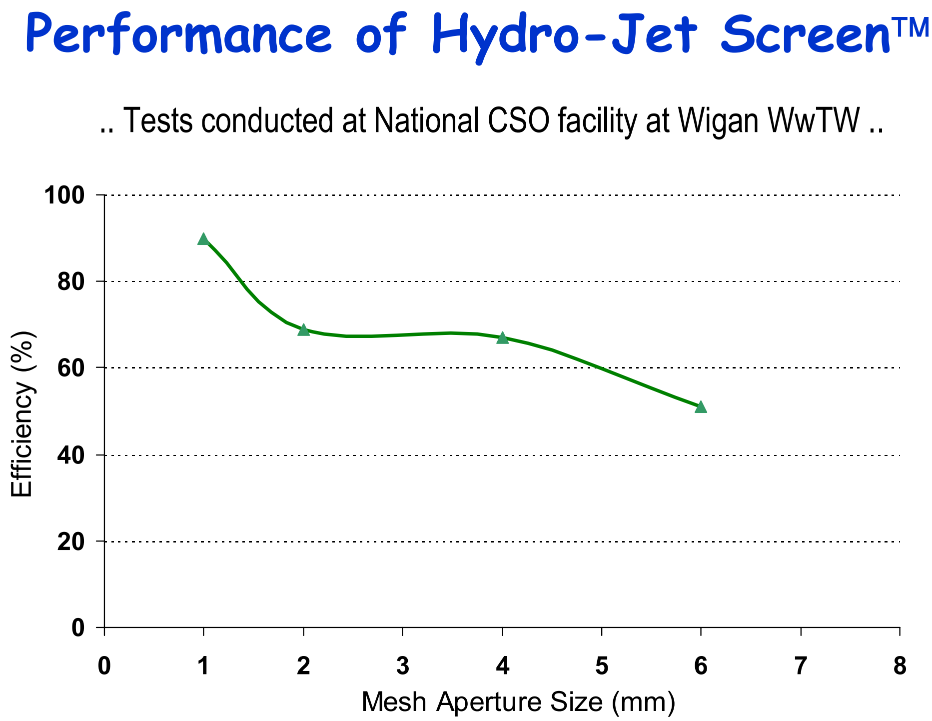


Figure 7

Figure 7 also shows significant differences between the total gross solids removal efficiencies of the 6 mm (¼ inch) and 4 mm (~1/6 inch) aperture mesh screens but not between the 4 mm (~1/6 inch) and the 2 mm (~1/12 inch). These results are significant as they indicate that from a performance perspective, in a wet-weather screening application, a 4 mm (~1/6 inch) mesh screen will offer distinct performance advantages over a 6 mm (¼ inch) mesh screen without necessarily incurring a penalty of reduced hydraulic loading capacity. In practice this means that a 4 mm (~1/6 inch) mesh screen can be provided at the same relative cost as the 6 mm (¼ inch) mesh screen with no financial penalty whilst potentially giving some 25% - 30% relative gain in gross solids removal.

HOLISTIC VIEW TO WET-WEATHER SCREENING

The primary components of combined sewer flows are raw sanitary wastewater, industrial wastewater and stormwater runoff. The characteristics of CSOs and other intermittent wet weather discharges are dependent on the ratio of these three primary components. These discharges are characterised by the presence of faecal and other gross solids (e.g. persistent synthetic material – condoms, panty liners, cotton buds, etc); faecal coliforms; total suspended solids; BOD; 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 and contaminated sediments (silts and sands) may be present depending on the residential, commercial and industrial profile of the system's service area. These various constituents will have varying polluting effects when discharged into receiving watercourses. The impacts of intermittent discharges include immediate (acute) or delayed (chronic) effects relating to the following possible impairments.

- Bio-chemical
- Aesthetic
- Biological
- Bacteriological
- Toxicological
- Use of river water

The current standard in the UK (AMP2 Guidelines) for CSOs and other intermittent wet-weather discharges is based around the removal of aesthetic pollutants and the reduction of spill frequency [2]. This suggests a focus on only aesthetic and possible acute bio-chemical impairments. It would appear that as most combined sewerage systems are in the older urban areas, the aesthetic objection to these overflows is all the greater, because streams are accessible to more people. Especially in the case of small streams, objectionable solids of noticeable sewage origin will drape themselves on any convenient obstruction and remain for all to see when fair weather returns at the end of a storm.

Other possible impairments such as chronic biological, bacteriological and toxicological effects are by inference deemed of less importance. Recent work on sewer sediments and their potential impacts has shown that considerable sediment deposition occurs in most sewerage systems as self-cleansing velocities are hardly attained during dry weather flow conditions. The re-mobilisation of 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" [10] 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. These sediment fluxes are a source of both acute and chronic impacts on receiving watercourses.

Owing to the rapid settling velocities of these sediment fluxes, water quality monitoring campaigns using conventional small bore tube sampling equipment mostly do not pick up this material and as such their potential polluting impacts are not accounted for. It is the authors' view that the lack of adequate attention to this component of combined sewer flows and other intermittent discharge sources (i.e. the sediment fluxes), accounts for the current lack of adequate water quality model verification for solids associated pollutants in a number of on-going Urban Pollution Management type studies in the UK.

The history of sewerage and sewage treatment in the UK [13] shows that the Royal Commission on Sewage Disposal (1898 – 1915) in their fifth report in 1908 suggest provision of settlement for flows up to three times the normal dry weather flow and the provision of standby tanks capable of holding one quarter of the daily dry weather flow (i.e. 6 hours detention at dry weather flows) prior to overflowing under storm conditions. The view was that this arrangement would result in no storm sewage arriving at an outfall being discharged into the receiving environment without some form of settlement ("sedimentation").

Sadly, in more recent times, storm overflows have been seen more as "safety valves" in hydraulic terms only, to protect the sewer system and the sewage treatment works from excess flows as depicted by the Jeger Committee in 1968. This Committee defined a storm overflow as: "*a device on a combined or partially separate sewer system, introduced for the purpose of relieving the system of flows in excess of a selected rate, the excess flow being discharged to a convenient watercourse.*"

It would appear that at this stage, the water quality implications recognised in the early part of the 20th century had in effect been relegated to secondary importance compared with the water quantity (flooding) issue. In more recent times as other sources of pollution (such as continuous discharges from wastewater treatment works) have been removed or controlled to acceptable levels, pollution from CSOs and other intermittent discharges have assumed greater importance.

The current focus and emphasis on resolving problems associated with CSOs is a natural progression in the "traditional" water control policy which has been to cure problems when they arise (i.e. a reactive-curative) rather than the more holistic approach (proactive-preventative) [14]. In this regard, it may well be that in focusing mainly on aesthetics (visual pollutants), a unique opportunity to effect a combination of aesthetics and sediment associated pollutants control is being missed by the Water Industry. The adoption of a more holistic approach should result in sediments and their associated pollutants, which are a source of both acute and chronic impacts on receiving watercourses, being given equal attention.

CONCLUSIONS

Fine screening of sewage presents many technical problems. For CSOs these problems are exacerbated by their often-remote location or difficult access coupled with the intermittent nature of operation. Electro-mechanical Screens with their moving mechanical parts are often more prone to failure when not operating continually because of the harsh environment in combined sewer systems. Most CSOs typically operate for less than 100 hours a year [15]. In addition, level or flow sensors and switchgear is required to start and stop the raking systems of Electro-mechanical screens. This provides another potential point of failure within the system.

The Hydro-Jet Screen™ provides the ideal characteristics of a CSO screening device. The screen operates reliably in the sewer environment, is hydraulically fail-safe, has no moving parts and requires no external sources of power. The device overcomes many of the concerns about screens raised in the UK guidance document for the design of CSO structures [6]. Field tests carried out to date show complete compliance with the UK national consent standards for the discharge of CSOs to high amenity waters.

The results of the work presented in this paper show that significant performance gains are obtained with a 4 mm-aperture mesh screen in comparison with a 6 mm-aperture mesh screen with relative performance gains of the order of 25% – 30%. The Hydro-Jet Screen™ utilising a 4 mm mesh panel, represents a BATNEEC (Best Available Technology Not Entailing Excessive Cost) approach to the screening of intermittent wet-weather discharges.

We are now in a new millennium with global concerns about the pace of utilisation of our non-renewable resources and the need for sustainability, there are increasing calls for cleaner technologies and the need to take account of whole life costs. The Hydro-Jet Screen™ utilising applied hydraulics to harness inherent energy within flow fields to effect required water quality and quantity controls without incurring upstream penalties qualifies as a true "millennium product". It is the only non-powered self-cleansing intermittent discharge screening system offering future proofing. It guarantees total compliance with current standards and scope for compliance with potential tighter standards in the future.

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