

Treatment, Storage and Control of Stormwater in Urban Developments

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Abstract

A novel integrated system for stormwater management is described. The system is made up of three key elements: a stormwater treatment stage, a stormwater storage stage, and a flow control/attenuation stage. The use of the system within a 'preventative' rather than 'curative' framework provides flexibility and significant cost savings in the implementation of effective stormwater management, especially in the urban environment where it can be used in conjunction with other best management practices to develop more sustainable urban drainage systems. The system components are described in detail highlighting their benefits compared with conventional alternatives.

Introduction

The underlying philosophy governing the evolution of urban drainage systems over the last century has been centered on "disposing of rainfall-runoff as quickly as possible".

In the context of strategies to prevent flooding and reduce pollution caused by wet-weather discharges from overloaded combined sewer systems, conventional thinking has resulted in 'end-of-pipe' approaches, often involving the provision of interceptor/relief sewers, massive storage tanks in downstream locations and centralized treatment facilities. However, such approaches are rarely sustainable, having finite handling capacities, and despite good intentions, are unlikely ever to lead to the complete elimination of sewer overflows in the long term. With increasing urbanization, this has brought with it the inevitable question of what to do with the ever-increasing volumes of runoff.

The use of separate sewer systems, one for sanitary sewage, and one for stormwater runoff, goes a long way to control the discharge of combined sewage into watercourses. However, the direct discharge of untreated stormwater into watercourses is also now known to present a problem, with the realization in recent years that stormwater itself contains many harmful pollutants (CIWEM/IWA, 2000; Ellis, 1991). Runoff from parking lots, highways and other impervious surfaces has been found to contain high concentrations of pollutants. These include suspended solids and sediments, oil and other hydrocarbons, microbial organisms, heavy metals and other toxic micro-pollutants, many of which have been found attached to suspended solids and sediments (Sansalone, J.J. and Buchberger, S.G., 1997). The U.S. EPA have identified sediment as the most widespread pollutant in U.S. rivers and streams (U.S. EPA, 1998) and the solids' associated pollutants can have a chronic impact on the ecosystem of watercourses thereby inhibiting ecological development.

With increasing awareness of the polluting impact of untreated discharges of stormwater runoff, especially from highly urbanized catchments, legislative and regulatory instruments have been enacted in a number of developed countries, such as Australia and the USA (U.S. EPA, 2000). Innovative treatment technologies are needed to address regulatory requirements and mitigate the adverse environmental impacts of stormwater runoff.

To make a significant improvement in surface water quality, both treatment and quantity (attenuation) need to be considered hand-in-hand. Particularly in the case of ‘new’ developments where planning consents increasingly require that the increase in the rate of urban runoff be compensated by the provision of a sufficient volume of storage capacity and a certain level of treatment to act as a buffer to adjacent watercourses. In many modern developments where space is not an issue, land based systems such as open ponds and constructed wetlands have been created to address stormwater storage and treatment problems. In highly urbanized catchments, however, such approaches are not always practical due to space constraints.

For many years, a number of academics and industrialists have been advocating the application of distributed storage and source control approaches to stormwater management, representing both a sustainable and cost effective alternative to conventional approaches (Smisson, 1980; Urbonas and Stahre, 1993; Andoh and Declerck, 1999). Given current environmental pressures, increasing acceptance of Source Control, Distributed Storage and other Best Management Practices (BMPs) has heightened the move towards alternative innovative urban drainage systems. The development and use of innovative ‘hard structures’ in the upstream parts of highly urbanized catchments has provided alternative cost-effective stormwater management systems for the control of both water quantity (alleviating flooding and erosion) and water quality (preventing pollution). These innovative ‘hard structures’ have been found to be more efficient, more compact and more effective “controls” than conventional systems thereby providing significant cost savings in addition to improved efficacy.

The paper describes a novel integrated system for stormwater management - ‘The Hydro Stormwater Management System’. This system and its components have been applied successfully in the USA, the UK and other countries for a number of years.

Integrated System for Stormwater Management

The Hydro Stormwater Management System, depending on the specific application, comprises three key elements:

- a stormwater treatment stage – The Downstream Defender[®];
- a stormwater storage stage – The Stormcell[®] Storage System; and
- a flow control / attenuation stage – The Reg-U-Flo[®] Vortex Valve.

The component parts in themselves are standalone devices. These are novel technologies configured as highly optimized ‘hard structures’ offering substantial benefits, including significantly improved performance characteristics compared with their conventional counterparts.

The individual components can be used with other conventional systems, providing scope for retrofitting. However, the real benefits are gained when they are used together in an integrated fashion. The system provides a flexible integrated way of treating, containing and controlling stormwater in the urban environment especially where space is a major constraint. In

particular, significant cost savings are realized when the system is used within a preventative framework (i.e. within the upstream rather than downstream parts of urban catchments).

A schematic of a system incorporating each of these three components is shown in Figure 1. The component parts of the Hydro Stormwater Management System are described in more detail in the following sections where their benefits, compared with conventional alternatives, are highlighted.

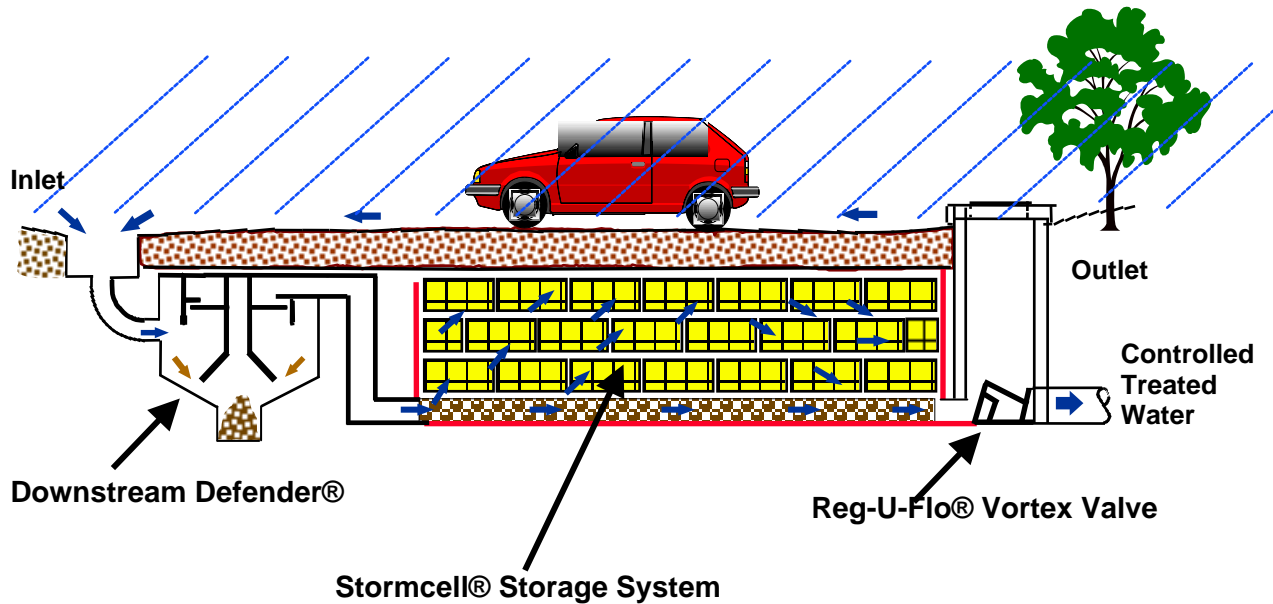


Figure 1: Hydro's Stormwater Management System Showing Treatment, Storage and Flow Control Elements

Stormwater Treatment Stage - The Downstream Defender[®]

While conventional sedimentation chambers are likely to enable some degree of treatment to be effected on contained water, they tend to have large footprints, are difficult to maintain and can be prone to washouts.

The Downstream Defender is derived from a family of high-rate rotary flow sedimentation devices generally classified as 'Hydrodynamic Vortex Separators'. The history, development and application of hydrodynamic vortex separators for improvements in environmental quality are described elsewhere (Andoh, 1998; Brombach, 1992). When compared to conventional sedimentation chambers, hydrodynamic vortex separators have been found to provide equivalent performance in a significantly smaller footprint (typically a quarter to a fifth) representing a significantly more compact process (Andoh and Smisson, 1994). The principles of hydrodynamic separation have been demonstrated to be appropriate for the removal of sediments and oils, as well as other debris, from urban run-off (Faram et al., 2000).

Another advantage of using a high rate rotary sedimentation type system is that pollutants are concentrated to a small area for periodic removal by a vacuum truck, simplifying maintenance.

Preventing pollutant re-entrainment is critical to water quality, particularly when pollutants are allowed to accumulate over several months (under variable flow conditions) between cleanouts. Possibly the most important advantage of the Downstream Defender comes from its internal components (Shown in Figure 2). These components minimize turbulence and provide separate shielded zones for the collection of sediments and oil/floatables thus making the device uniquely resistant to re-entrainment of captured material (Faram and Howard 2002). Stormwater is introduced tangentially into the side of the vessel generating a rotary flow regime. Oil and floatables rise to the water surface between the dip plate and the vessel wall where they are trapped. Settleable solids are directed towards the center and base of the vessel under the vortex chamber where they are protected from re-entrainment.

To date there are over 600 Downstream Defender installations providing environmental protection, removing settleable solids (including grits, silts and their associated pollutants), and oil from stormwater runoff.

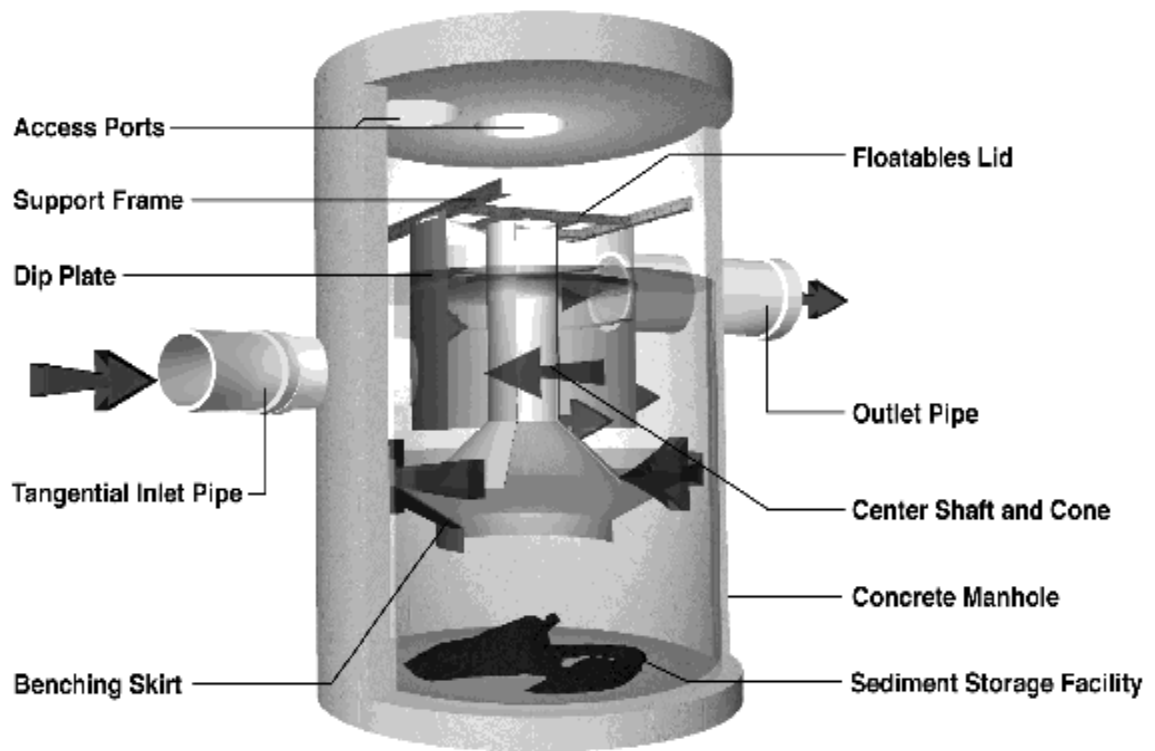


Figure 2: Sectional View through Downstream Defender®

Case Study: Belleville, Ontario

Much of the stormwater runoff generated by the City of Belleville discharges into the Moira River. The Moira River discharges into the environmentally sensitive Bay of Quinte and is monitored by the Moira River Conservation District. Like many conservation districts and municipalities in the USA and Canada, the Moira River Conservation District and the City of Belleville have implemented stormwater management policies to improve water quality and protect the receiving water body from the adverse effects of stormwater discharges.

The engineering firm of JHA Lassing & Associates of Trenton, Ontario proposed a redevelopment plan for 40 non-profit housing units on a site on Station Road in Belleville. The site is adjacent to the Moira River. Therefore, an important aspect of the site redevelopment was the stormwater drainage system. The conservation district required treatment of stormwater runoff, up to the 1:5 return period storm. However, the conventional retention pond option was not feasible because its large plan area (approximately two building lots) would have eliminated a small strip park located between the site and the river.

The selected stormwater management plan entailed removing fine sand and grit from stormwater runoff. This was followed by a percolation and infiltration stage using a 24-inch (600-mm) diameter perforated pipe. The total draining area to the stormwater treatment system was 5 acres (2 Ha) of which the area of new development was 1.25 acres (0.5 Ha), the remainder being existing roads and impervious surfaces.

To remove the sand and grit prior to the perforated pipe, the engineer selected an 8.0-ft (2-meter) diameter Downstream Defender. The unit was designed to meet the following removal efficiency criteria:

- At a flow of 7 CFS (200 l/s) - remove 95% of grit particles greater than 150 microns
- At a flow of 8.8 CFS (250 l/s) - remove 95% of grit particles greater than 250 microns
- At a flow of 10.6 CFS (300 l/s) - remove 95% of grit particles greater than 300 microns

The Downstream Defender was designed as a flow-through treatment device with storm flows fed into the unit through an 18-inch (450-mm) diameter inlet pipe. The captured sediments are collected in the base of the unit where they are removed annually using a vactor. The overflow discharges into a drop box that discharges into the perforated pipe where the sediment-free stormwater percolates into the granular fill surrounding the pipe.

Photographs of the facility are shown in Figure 3.



Moira River, Belleville, Ontario



8.0 Ft. (2.4 m) diameter Downstream Defender



40-Unit Non-profit Housing Complex

Figure 3: Belleville, Ontario Site Photographs

While the Downstream Defender was undergoing an annual inspection and pump-out, a 1-gallon (4-liter) sediment sample was divided into two equal parts. One sample was sent to a soils laboratory to determine the particle size distribution and the second was sent to an environmental laboratory for both sizing and chemical analysis.

The results of the particle size distribution analysis are graphed in Figure 4.

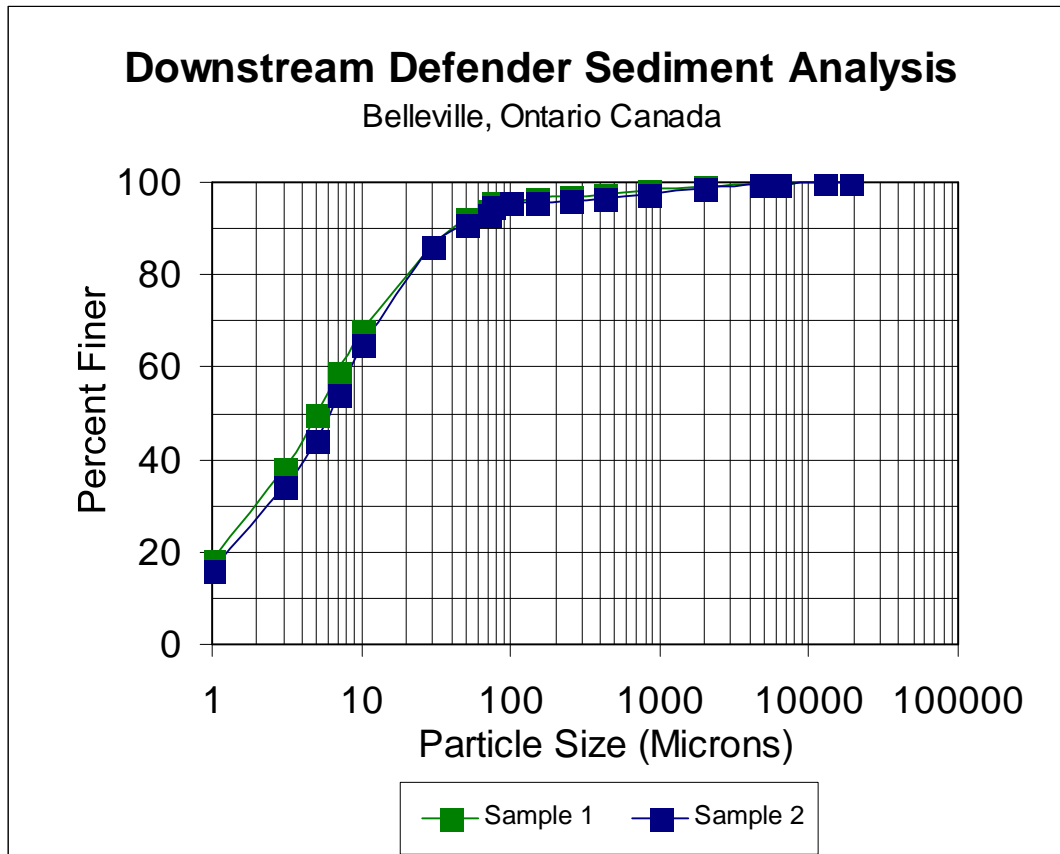


Figure 4: Particle Size Distribution

The sediment collected from the solids collection facility contained a significant fraction of fine silt and clay particles with over 95% of the particles finer than 75 microns. While the removal efficiency of the Downstream Defender cannot be verified from the sample, as it doesn't relate to a particular flow rate, the results indicate that the unit is capable of removing and retaining extremely fine particles throughout the course of a year under variable flow conditions. This is significant as the chemical pollutants and heavy metals tend to be associated with the finer particles.

The results of the chemical analysis are summarized in Table 1.

Table 1. Chemical Analysis

Parameter	Data	Units	MDL*
Arsenic, total	7.5	mg/kg	0.1
Barium, total	30	mg/kg	30
Cadmium, total	2.1	mg/kg	0.5
Chromium, total	34	mg/kg	5
Copper, total	101	mg/kg	3
Lead, total	242	mg/kg	5
Mercury, total	0.36	mg/kg	0.03
Nickel	16	mg/kg	5
Selenium, total	0.67	mg/kg	0.03
Silver, total	5	mg/kg	5
Zinc, total	465	mg/kg	3
Oil & Grease	2.3	percent	0.1 percent
Phosphorus, total	1500	mg/kg	300
Total Solids	38.47	percent	0.01 percent

*MDL - Minimum Detection Limit, units mg/kg unless stated otherwise.

From the chemical analysis performed on the sediment, cadmium, copper, lead, silver, zinc and phosphorus levels were all notably high.

In summary, the City of Belleville achieved their stormwater treatment goals in a significantly smaller plan area than the conventional solution. As a result they minimized construction costs and retained the use of the park. Annual maintenance is a straightforward vector process.

Stormwater Storage Stage - Stormcell[®] Storage System

Hydro's Stormcell Storage System is a geoplastic media produced in block form and is used as an alternative method of achieving underground storage or infiltration at low cost. Made up of a matrix of polypropylene structural members, Stormcell[®] blocks have a very high void ratio (95%), and excellent structural integrity (capable of withstanding loads of up to 400 kN/m²). This compares with conventional crushed stone or aggregate systems with void ratios of typically less than 40%.

One of the most appealing attributes of the system compared with traditional box culverts, oversized pipes and concrete tanks, is its flexibility, where factors such as the shape and depth of the storage volume are not critical, expanding its range of applicability. When used as a hydraulic storage media, Stormcell is installed directly under other civil engineering constructions, such as parking lots and roadways, where a cost-effective, practical solution is being sought (Andoh et. al., 2000).

The application of Stormcell is straightforward. Figure 5 shows the basic components that produce a typical 'on-line' storage facility. Dry weather flows pass through the perforated distribution pipe-work maintaining the usual self-cleansing regime. As the surface water flows increase during a storm event, the water level rises or 'backs up', with the restriction

generally provided by a flow control such as a vortex flow control. Flows are contained within the Stormcell while displaced air escapes through the venting arrangement. Water levels are allowed to subside after the storm.

The product was first used for surface water storage in France in 1986. Since the first UK installation in 1995, over 500 further installations have been made, with a total storage volume of over 130,000 cubic metres. While the majority of installations have been in commercial and industrial developments such as supermarkets, warehouses and factories, a growing area of interest for its use is with the housing developers, where the Water Service Companies are beginning to accept such installations for adoption. In most UK installations, Stormcell media has been used in conjunction with a vortex flow control.

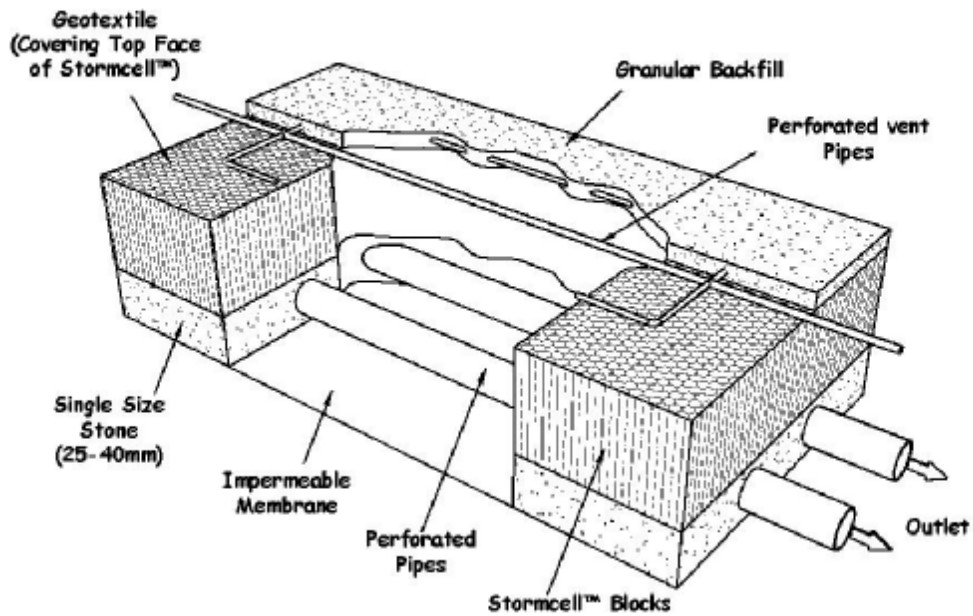


Figure 5: Sectional View through Stormcell® Storage System

Flow Control / Attenuation Stage - The Reg-U-Flo® Vortex Valve

Vortex Flow Controls (e.g. The Reg-U-Flo Vortex Valve) are self-activating passive flow control devices with no moving parts and no external power requirements. These devices are well known for their advantages over orifice plates, throttle pipes, and other conventional flow control devices (Brombach, 1989). Vortex flow controls utilise the head loss across a fluid vortex to regulate flows and are less prone to blockage due to the fact that they have an open area, which is typically 400% to 600% larger than that of equivalent conventional devices (such as orifice plates).

Vortex flow controls typically have two distinct modes of operation. In the first mode, termed pre-initiation, the device behaves like an unrestricted orifice, allowing relatively high flows to be discharged at low operating heads (see Figure 6). As the operating head increases, the upstream water energy is converted into rotary motion within the device. This has the effect of generating high peripheral velocities and the creation of an air-core occupying most of the outlet of the device and producing a backpressure opposing the through flow. The throttling effect results in the device behaving like an orifice with a significantly smaller opening. This mode of operation is known as the post-initiation mode.

The implication of this ‘switching’ effect is that flow restriction is only provided when it is required, allowing storage volumes to be utilized economically. Figure 6 shows an example of a 200-mm diameter (outlet aperture) vortex flow control in its post-initiation mode, operating like a 107-mm diameter orifice plate. As the example shows, when a 200-mm SXH vortex flow control is used, the storage volume will not fill up significantly until the design flow of 25 l/s is reached. In comparison, when the 107-mm orifice plate option is used, the storage volume will fill up to a level of over 1.2 meters before this stage is reached. In practice, this will dictate the requirement for a larger storage volume, and therefore elevated costs.

Due to the rotary motion of the flow within the volute of the vortex flow control, the discharge from its outlet is in the form of a spiraling flow with a central core of entrained air. This pattern of flow is different from the jet emitted from an orifice or partly closed penstock (or slide gate valve) in that it does not contain the same high energy per unit of cross-sectional area. Vortex flow controls are therefore less likely to cause scour and structural damage to downstream structures or cavitation within the control device. The entrained air results in the aeration of the flow and helps prevent the onset of septicity. To date, over 15,000 units have been installed within both surface water drainage and sewerage systems.

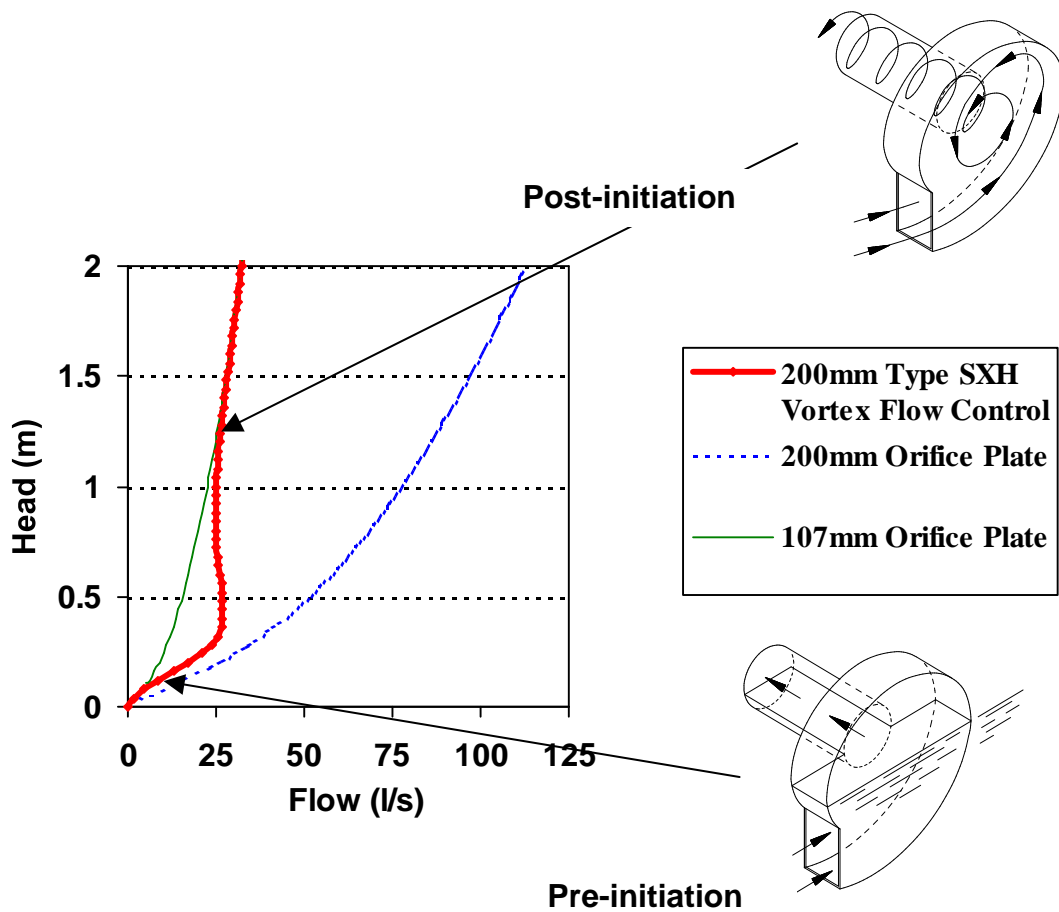


Figure 6: Comparative Head Flow Characteristic for Flow Controls

Case Study: Springfield Park, Horsham, England

The Springfield Park development comprises 48 two, three and four bedroom homes in an area of expanding population where stormwater drainage to the Water Company's (Southern Water) sewerage infrastructure has to be carefully regulated. The site layout is shown in Figure 7. The stormwater drainage system was designed to discharge to a Southern Water main line at one end of the site and the maximum discharge restrictions imposed by Southern Water meant that they would have had to provide storage to ensure controlled discharge to the mains. However, there was not enough room for onsite storage using either oversized manhole constructions or a granular storage area, the later of which only has a maximum void space of 35-40%.



Figure. 7: Site Layout

By proposing the Stormcell storage and vortex flow control system, which was subsequently adopted, consulting engineers Dixon Hurst Kemp provided a highly effective solution within the space constraints of the site. With its high void ratio (95%) and structural modular block form, a shallow layer of Stormcell was installed to provide 80 cubic meters of storage, partly under a grassed area and partly under a driveway. A 145-mm vortex flow control was used to regulate the discharge rate and to optimize the use of the storage volume.

Providing a space saving load bearing storage and discharge control package makes the system highly suitable for installation where development land is at a premium. A typical Stormcell installation is shown in Figure 8.



Figure 8: Typical Installation of Stormcell® Blocks

Conclusions

Increasing the use of novel integrated techniques in the drive for more sustainable urban drainage systems is providing an Eco-friendly alternative to conventional systems for stormwater management in the urban environment.

The control of oil/floatables and sediments together with their associated pollutants can be achieved in a compact high-rate rotary-flow sedimentation device – the Downstream Defender. A novel modular geoplastic media with 95% void ratio and high structural integrity (Stormcell) provides a flexible system for storing stormwater and a passive vortex flow control (Reg-U-Flo Vortex Valve) enables the controlled release of the stored stormwater with minimal risks of blockage. The components making up the integrated system have no moving parts and no power requirements and as such have very little maintenance requirements

Increasing urbanization increases the requirements for improvements in urban drainage and stormwater management infrastructure. In the drive for more sustainable urban drainage systems, the following should be considered:

- To make a significant impact on surface water quality, both treatment and quantity (attenuation) need to be considered hand-in-hand.
- ‘End-of-pipe solutions’ have been found to be costly and fraught with difficulties due to lack of space, and additional factors such as disruption to local communities.
- A novel integrated system for stormwater management comprising treatment, storage and flow attenuation components provides a flexible cost-effective system with major benefits compared with conventional systems. This is particularly the case when applied in an upstream rather than downstream location in urban catchments.

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