

Removal of Sediments and Oils from Urban Run-off Using the Downstream Defender™

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ABSTRACT

With increasing urbanisation, the problems of stormwater run-off from impermeable surfaces are becoming more apparent. Run-off from roads and parking areas often carries a high sediment load, and this, along with other associated pollutants, for example, oils, can have a detrimental impact on receiving watercourses. It is anticipated that such issues will come to form the focus of future enviro-legislative attention.

The paper describes the configuration, operation and applications of the Downstream Defender™, a hydrodynamic separator system that has been developed specifically for the treatment of urban run-off. The ability of the system to remove pollutants including sand, peat and oil has been independently assessed, with positive findings.

The Downstream Defender™ has a number of applications, whether the objective is to directly protect a watercourse, protect storage facilities, or reduce maintenance commitments on ponds and other BMPs. It might also be used to remove sediments and oils from stormwater prior to discharge into a combined sewer system. In all cases, application of the system has implications to both watercourse pollution, and also the maintenance commitment that is associated with the accumulation of sediments in drainage networks and their associated ancillary structures.

INTRODUCTION

Historically, discharges of industrial or foul sewer origin have been assumed to represent the major sources of watercourse pollution worldwide. Indeed, in the UK, it wasn't until the late nineteenth century that attempts were made to eliminate the practice of discharging untreated sewage to rivers. At this time, the first sewage treatment plants, known as 'sewage farms' came into being.

The evolution of sewer systems has followed a meandering path. The first sewer systems were combined systems, conveying both foul water along with surface run-off in a single pipe. A well known problem is that caused by the capacity of such systems being exceeded during intense storm events, and the resulting requirement for emergency overflow points (i.e. combined sewer overflows). For both technical and economic reasons, these systems have remained commonplace in all but the most modern urban developments, and in the majority of cases, the most practical approach to alleviating their impact on receiving waters has been to provide a remedial level of treatment to the overflows, rather than to eliminate them altogether. Indeed, this appears to be the main focus of attention in the current 2000-2005 AMP3 programme for the water industry in England and Wales.

During the later periods of colonisation of so-called 'new world' regions such as America and Australia, the opportunity was taken to adopt 'separate' sewer systems in new developments. The philosophy of using such systems was that all waste of 'foul' sewer origin was treated, and surface water run-off was disposed of safely and conveniently back to the environment. However, the

fundamental assumption here was that surface water run-off did not have a major polluting impact, an assumption that has been overturned in recent years. Given that the majority of modern developments now use separate sewer systems, the problems of pollution due to urban run-off have become increasingly prominent, and there are even arguments to suggest that a well designed combined system is actually a preferable option^[1].

NONPOINT SOURCE POLLUTION: SOURCES AND IMPLICATIONS



Figure 1 A Consequence of Nonpoint Source Pollution

Given the on-going moves to reduce the impact of foul sewer discharges on watercourses, nonpoint source or diffuse pollution is assuming an increasing proportion of the total polluting load on UK and other European watercourses. Indeed, in the USA, where nonpoint source pollution has been a focus for improvements for a number of years, it has been estimated that at least 50 % of water quality problems arise from its occurrence^[2]. Similarly in Australia, nonpoint source pollution also sits high on the agenda of required environmental improvements.

Nonpoint source pollution arises due to the passage of water (whether from rainfall, snowmelt or irrigation) from its point of initial contact with the ground surface to the watercourse. Run-off from agricultural land, urban developments, roads and construction sites contains a variety of pollutants, including pesticides, nutrients, sediments, heavy metals, solvents, oil and other hydrocarbons, road salts, street litter and organic waste^[3, 4, 5, 6, 7].

In urban locations, sediments and other solids tend to constitute the largest proportion of the pollutants loading, and it is often these that act as a carrier for other pollutants. Similarly, in foul sewer systems, sediments are being increasingly recognised as a major polluting source during storm spill events^[8].

Sediments and associated pollutants can smother streambeds, thus blocking out light and destroying aquatic vegetation, leading to a degradation in biodiversity. The heavy metals associated with sediments, along with other pollutants, lead to a general deterioration in water quality, and can give rise to biological defects in fish and other vertebrates, affecting respiration, and impacting on growth and spawning cycles. The adverse effects of oils are also of concern. In high amenity areas, these contaminants can also pose a health risk to those who pursue water contact based activities (Figure 1 illustrates this).

In the UK, current water related environmental improvements for sewerage systems are focussed on the removal of solids “greater than 6 mm in two directions” from combined sewer overflows^[9]. It is anticipated that the next big focus will be on quality issues, and this will address pollution from storm or surface water sewers and other diffuse sources.

At present, a number of individual ‘pollution prevention guideline’ (PPG) documents exist (produced by the EA and SEPA), providing guidance on measures to avoid water pollution for

different industries. These are generally aimed at those industries where there is some threat of a pollution incident occurring, and have become increasingly prominent reference documents for those parties concerned.

Perhaps due to the fact that the UK has a large number of combined sewer systems, the issue of pollution due to urban run-off in general (i.e. from impermeable surfaces such as roads and car parks) tends to have been neglected to a degree. However, interest in this area is gaining momentum. It is anticipated that the respective environment agencies in the UK will ultimately extend their remit to focus increased attention on these sources, based on the activities and experience of other nations (e.g. USA and Australia), and that such issues will emerge to the forefront of environmental activity.

POLLUTION ALLEVIATION USING HYDRODYNAMIC SEPARATORS



Figure 2 Large Scale Storm King® Separator

stormwater treatment, giving rise to products such as the Downstream Defender™ and the Storm King® Overflow (Figure 2 shows the interior view of a large installation). With the UK requirement for a compact sediment/oil removal system in mind, recent developments have focussed on their oil and floatables removal capabilities^[11], and independent evaluation of an ‘enhanced’ configuration has been undertaken, with positive findings^[12].

The Downstream Defender™ has been successfully marketed in the USA and Australia for a number of years, where the impact of urban run-off on watercourses is high on the environmental agenda. Given the increased awareness in the UK of this pollution source, and the increasing obligation to deal with it, it is anticipated that the Downstream Defender™ will find much application locally.

A description of the key features of the Downstream Defender™ system is given in the following sections, along with an account of the principles involved in its operation.

THE DOWNSTREAM DEFENDER™

The principle of dynamic separation was first observed by Bernard Smisson, an Engineer from Bristol (UK), who later spent a lifetime researching the principle, and applying it to the practical problem of CSO treatment^[13]. Following initial research work in the UK during the 1950’s and

Hydrodynamic vortex separators are well known for their use as grit/sediment and floatables separators in both industrial and municipal applications^[10]. They are characteristically low energy, high loading rate devices, and as such, have a small footprint compared to conventional sedimentation systems (typically one fifth of the area required for a rectangular settlement chamber). Such systems have been applied to the problem of on-line

1960's, he continued his work in the USA as a consultant on an American Public Works Association (APWA) research programme, which culminated in the development of the US EPA "Swirl Concentrator"^[14], a predecessor to the enhanced systems of today.

Essentially, there are two dominating principles involved in the operation of a hydrodynamic separator. Hydrodynamic separators have been shown to have a stable near-plug flow regime^[15]. This means that fluid elements pass through a very long, spiral flow path prior to exiting via the overflow (this generally takes the form of a downward spiral at outer radial locations, and a smaller upward spiral at the centre). Since the path is long in terms of distance, compared to the physical dimensions of the system itself, it means that suspended particles have plenty of time in which to either rise or settle to the capture regions. A secondary effect caused by this type of flow structure, gives rise to a sweeping action on the base of such a unit, directing particles to a central location. A similar effect can be replicated by stirring a cylindrical vessel containing water and a small quantity of sand.

The Downstream Defender™ effectively utilises these principles to separate both grits/sediments and oils from stormwater. A schematic of the system is shown in Figure 3, illustrating the secondary flow effects described. Rotating flows are inherently unstable, and this can lead to poor separation performance if not adequately controlled. However, the internal components of the Downstream Defender™, which have evolved over decades of development, provide both a controlling and performance enhancing effect.

The cone shaped sections above the grit pot and below the floatables/oil trap illustrated in the figure provide stagnant zones which help to prevent the re-entrainment of collected matter once captured. Treatment chambers that do not incorporate such components tend to be prone to the phenomenon of 'washout', whereby previously collected material is disturbed and subsequently lost to the discharge during intense storm events. This function has been verified by a study that used computational fluid dynamics (CFD) simulation to compare the performance of different

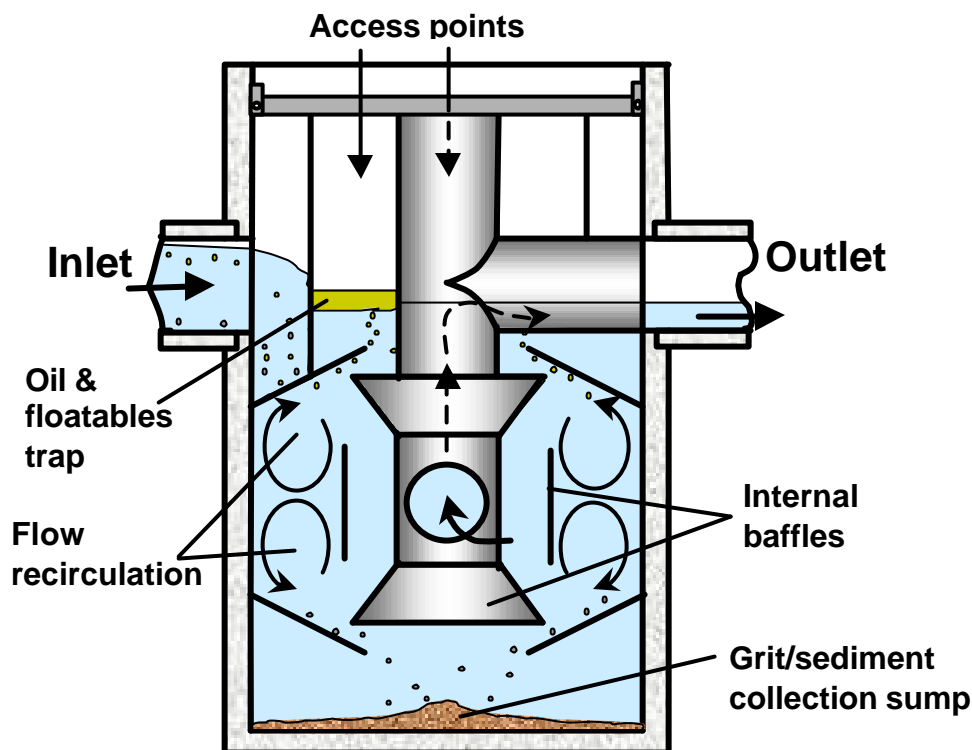


Figure 3 Schematic of the Downstream Defender™ Illustrating Mechanism of Operation

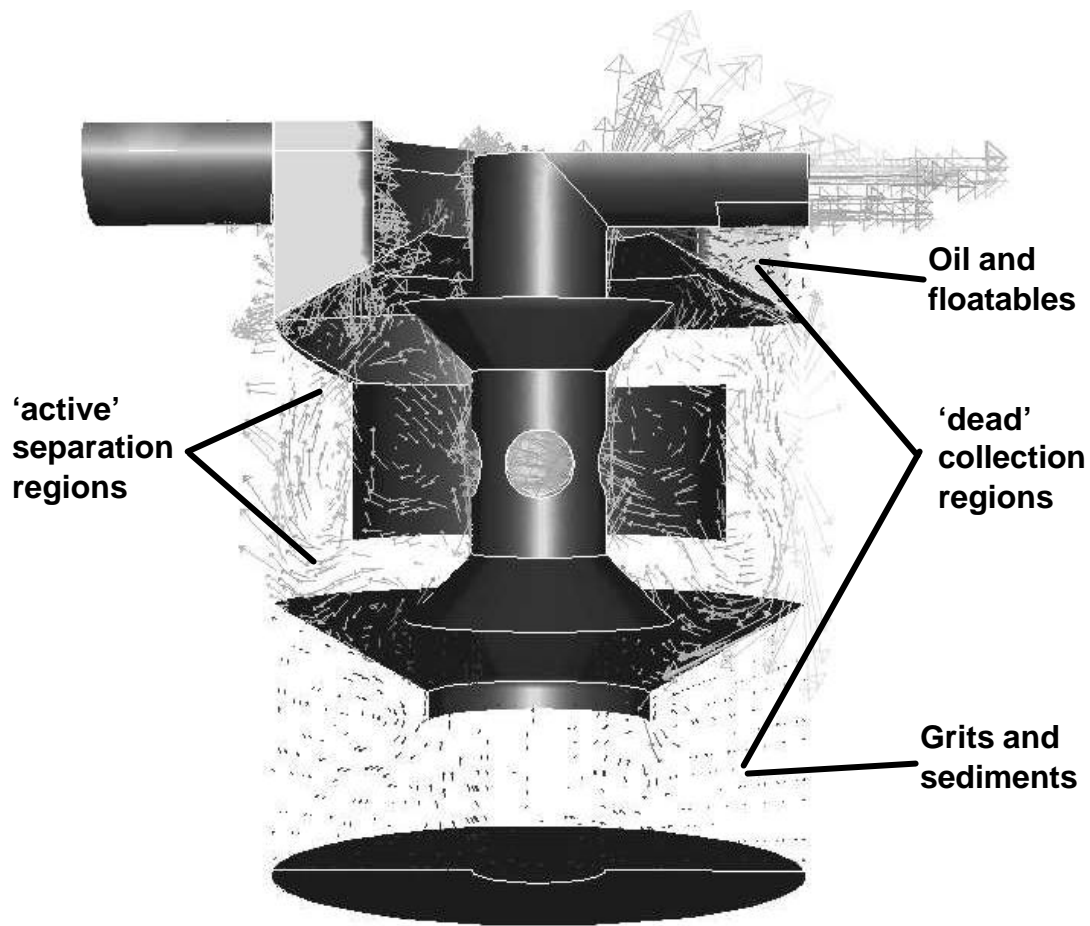


Figure 4 CFD Simulation of the Downstream Defender™: Velocity Vectors

types of stormwater treatment chamber. A typical graphical output for the Downstream Defender™ is shown in Figure 4, in which the quiescent nature of the fluid in the sediment and oil collection chambers is predicted.

The system, by means of a sophisticated flow receiving and diverting chamber, has an in-line inlet-outlet configuration, eliminating the requirement for an upstream manhole, as dictated by some other systems. Additionally, the flow-receiving chamber incorporates an emergency by-pass facility that diverts flows directly to the discharge when the flow exceeds a preset level. These features are identified in Figure 5.

The clean-out of particulate matter and oil is achieved by means of a vehicle mounted “gully sucker”, with clear paths of access being available to both the grit receptacle and the oil trap.

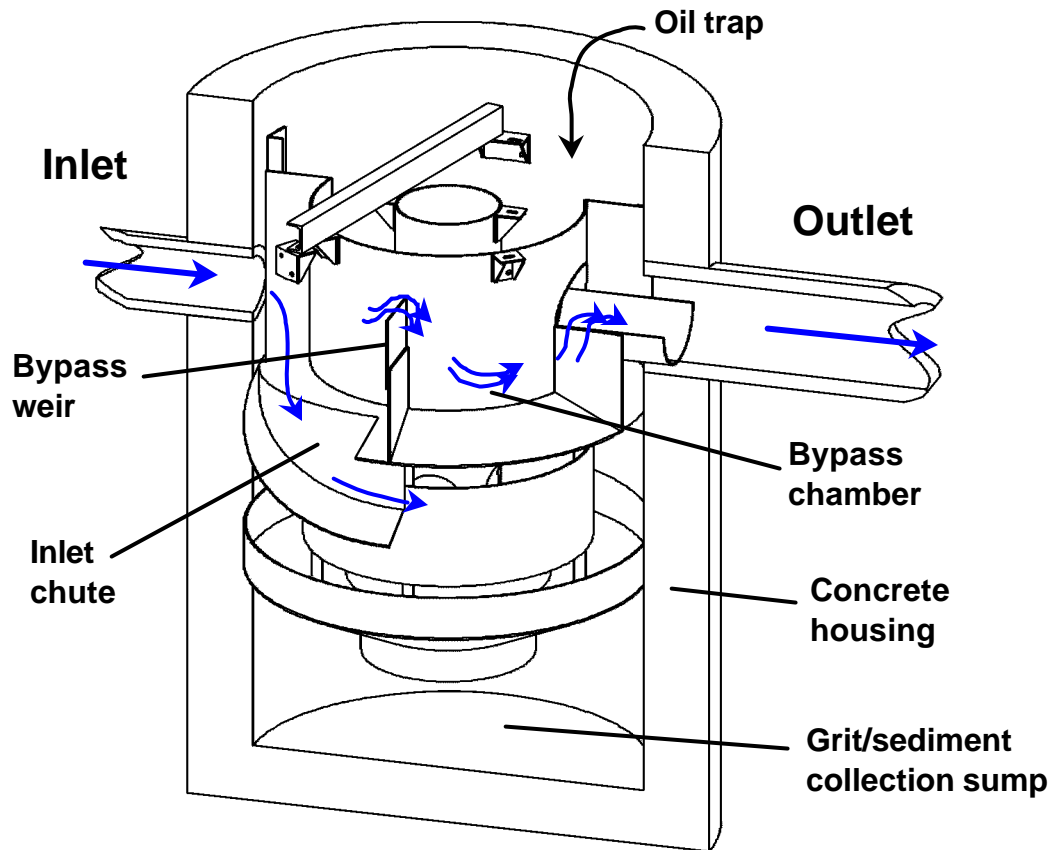


Figure 5 Sectional View of the Downstream Defender™ Illustrating Key Features

SYSTEM PERFORMANCE CAPABILITIES



Figure 6 Testing at Coventry University

Independent Evaluation

During late 1999, Hydro International commissioned a programme of independent evaluation of the Downstream Defender™ (enhanced configuration). This work was undertaken by Coventry University, and focussed on assessing the ability of the system to remove sand, oil and peat from a contaminated influent^[12].

Using a 1.2 m diameter prototype (Figure 6), tests were performed at flowrates up to the flowrate at which the internal bypass operated. This was preset to occur at around 17 l/s. For each pollutant considered, separate tests were undertaken, in which material was added gradually over the duration of a 20-27 minute test. The test duration was selected so as to ensure that at least four fluid volume changes occurred during a run (based on theoretical considerations).

For the tests performed using sand and peat, material was added at a rate of 300 mg/l throughout the test period. The sand used was a readily available ‘builders’ sand (of which over 50 % was finer than 300 microns). For the oil tests, Shell gas oil ‘CI/SH’ was added to the system at a rate of 5 ml/l (4100 mg/l, taking into account the density). The oil, and associated test procedure was selected to conform with the recommendations of the European Standard defining the requirements of Class I and Class II oil interceptors^[16]. For the last 5 minutes of each test, samples were taken from the effluent, which were subsequently analysed using appropriate standard procedures.

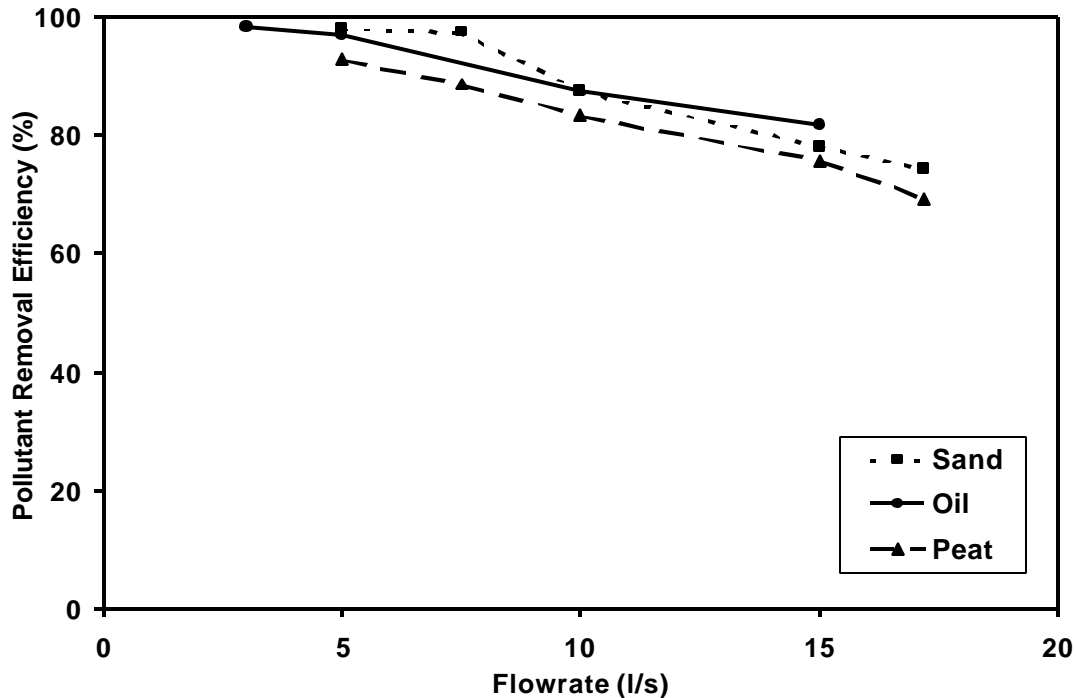


Figure 7 Derived Removal Efficiencies for Sand, Oil and Peat: 1.2 m Unit

Presented in terms of net removal efficiency at each flowrate, calculated on the basis of the inlet and outlet contaminant concentrations, the results are shown in Figure 7 for sand, oil and peat. In all cases, the 1.2 m diameter system is seen to be capable of removing at least 70 % of each of the contaminants over the range of flowrates considered. Further to this, the results also suggest that for flowrates of up to around 4 l/s, the system is able to perform to the level of a Class II oil interceptor, as defined by the European Standard (defined by an effluent oil concentration of less than 100 mg/l when oil is added at a rate of 5 ml/l, which corresponds to an efficiency value of close to 98 %).

Event Mean Efficiency Studies

While it may seem most convenient to size a sediment/oil trap on the basis of an assumed ‘constant’ peak flow, this is inefficient, as generally, the ‘peak’ will only occur for a very small proportion of the overall annual storm profile.

A study has been undertaken to assess the overall net efficiency of the Downstream Defender™, taking into account a range of storm profiles and the resulting flow profile fed to the unit. This is based on a defined impermeable area and a simple receiving drainage system.

By summing instantaneous pollutants removal efficiencies at each time increment on a profile, cumulative net 'event mean' efficiencies can be compiled for different sets of conditions. Figures 8 (a) and (b) show typical outputs for the oil removal of a 1.2 m unit, corresponding to 30 minute and 240 minute 1 year storm events, and based on a drainage area of 1800 m². Generally, longer storm events tend to have a lower peak; during such events, the Downstream Defender™ pollutants removal efficiency can be very high, often approaching 100 %.

The above procedure has been applied to a range of different Downstream Defender™ sizes. Storm profiles ranging from 15 to 960 minutes have been considered, allowing recommendations to be made for optimum unit sizing, based on a knowledge of either a peak flow or drainage area. With recommended design flowrates ranging from 21 to 160 l/s for the proposed 1.2 to 3 m diameter chambers, predicted net removal or event mean efficiencies for oil and sand generally fall between 80 and 100 % for the range of events considered, and between 76 and 100 % for peat. Upsizing is appropriate where more stringent treatment criteria are required.

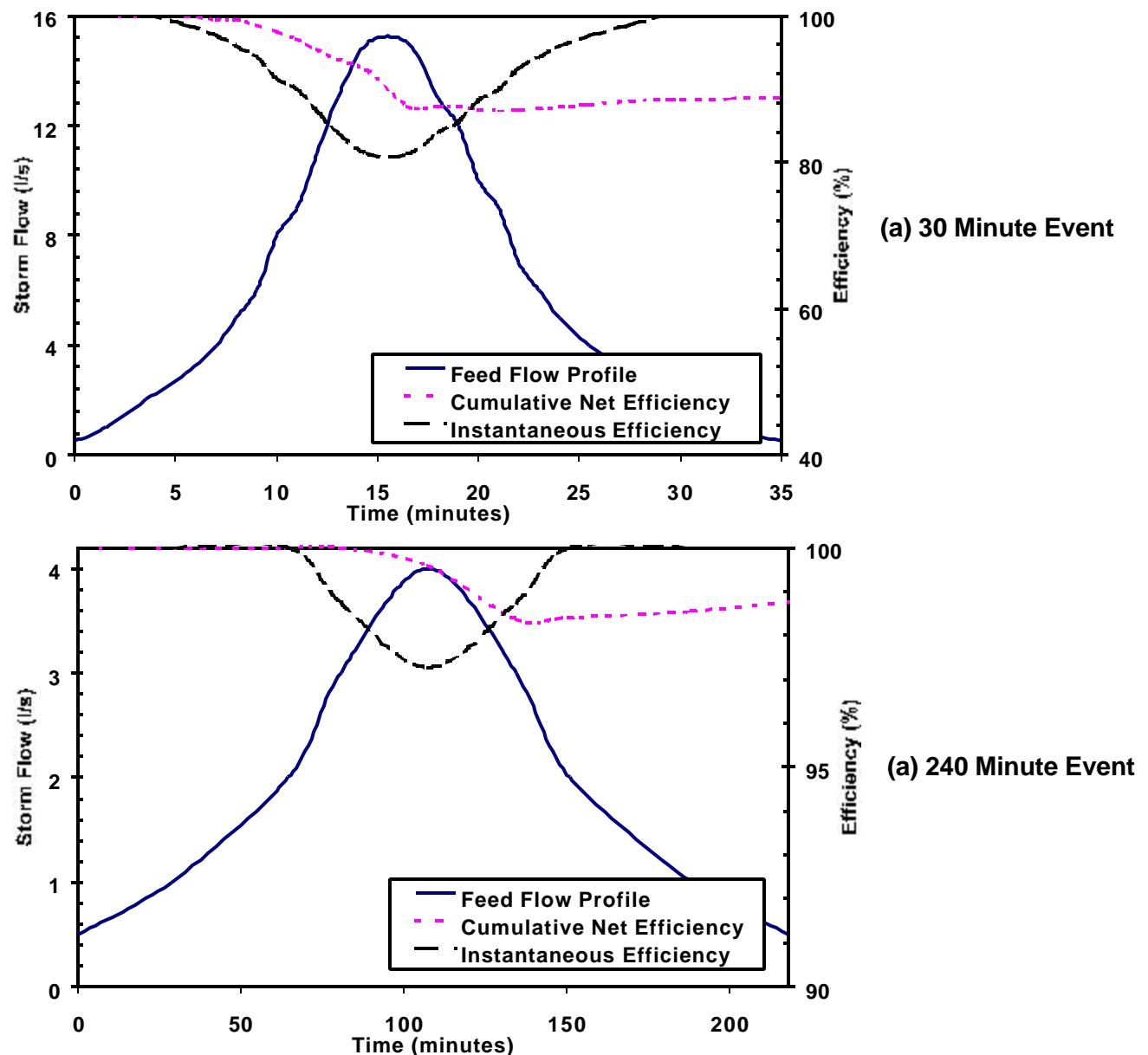


Figure 8 Cumulative Net and Instantaneous Oil Removal Efficiencies for 1 year Storm Events (based on a 1.2 m Unit and an 1800 m² Drainage Area)

SYSTEM APPLICATIONS



Figure 9 Installation of a Downstream Defender™

The Downstream Defender™ can be used to remove oils and sediments from stormwater run-off in a number of different situations. Figure 9 shows a unit during installation (in future, internal components will be prefitted to the concrete housing prior to delivery).

The most common application in the USA and Australia is where the system is used to directly treat urban run-off prior to being discharged to a watercourse, or storm drain that passes to a watercourse. An example of this would be the situation where a developer is constructing a car park, and must employ some means of sediment retention system to protect the watercourse to which flows will ultimately feed. Similarly, the Downstream Defender™ can be used to remove contaminants from highway run-off.

Another mode of application is that in which the Downstream Defender™ is used to remove contaminants prior to entry to stormwater attenuation/storage facilities. When stormwater enters a large chamber such as a storage vessel,

settable material tends to accumulate on the base. This can build up, dictating a maintenance commitment. In this instance, the Downstream Defender™ serves to collect and concentrate debris to a central location. Although this, of course, also requires maintenance, in the form of collection of accumulated material, it can be performed more quickly and effectively. Figure 10 illustrates a typical application scenario in which the Downstream Defender™ is being used to intercept and concentrate pollutants upstream of a detention pond.

In the case of combined sewer systems, it has been recognised that a key pollutant during an overflow situation is the sediment proportion of the flow. Sediments tend to settle out in sewer systems during ‘dry weather’, and become re-mobilised during intense storm periods, giving rise to the phenomenon of the ‘first foul flush’. Unfortunately, current rapid treatment systems consisting of screens alone are unable to remove this component. One solution to the problem is to simply prevent these components from entering the sewer in the first place. It is perceived that the majority of sediments that enter the sewer system are of urban surface origin; in this instance, the Downstream Defender™ could be utilised to intercept pollutants at an early stage, by being placed at a location between the stormwater entrance point, and the foul sewer connection.

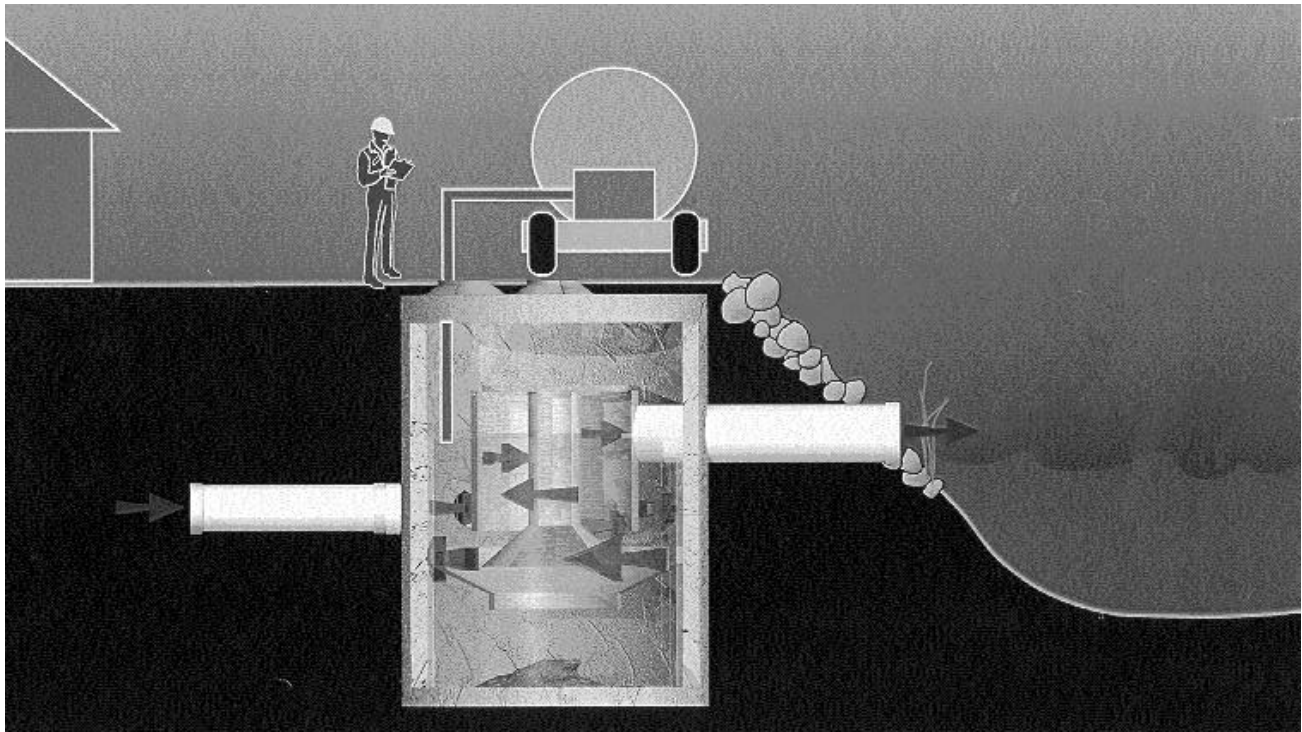


Figure 10 Example Application of the Downstream Defender™

CONCLUSIONS

Urban run-off is acknowledged to contribute significantly to the polluting load of our watercourses. The problem has been recognised worldwide, although it has only been relatively recently that moves have been made to limit its impact. It is anticipated that the associated issues will move closer to the forefront of enviro-legislative activity in the next few years.

The Downstream Defender™ represents one contender for the alleviation of urban run-off associated pollution. Independent testing has demonstrated its ability to remove pollutants including sand, peat and oil from a contaminated inflow. Other work has suggested that the system is also likely to be less prone to the phenomenon of ‘washout’ than simple chamber based systems.

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