FINE SEDIMENT REMOVAL USING A CONTINUOUS DEFLECTIVE SEPARATION UNIT

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Abstract

Fine sediments play an important role as a pollutant transport tool in runoff from urban areas. The adsorption of hydrophobic pollutants such as heavy metals to finer particles is of particular concern since adsorption to sediment surfaces is important for the growth and survival of many organisms native to the aquatic environment.

Urban stormwater management structural measures generally have limited impact on the removal of fine sediments, especially pre-treatment measures such as gross pollutant traps. This can lead to very high loads of fine sediment reaching secondary treatment such as wetlands and ponds or receiving waters and ultimately lead to significant costs in maintenance and degradation of water quality. This paper will report on a study carried out at the Louisiana State University in the United States where a Continuous Deflective Separation (CDS) unit tested in the field for fine sediment removal. The study found that by carefully choosing screen aperture and introducing secondary flow paths, a relatively high percentage of fine sediments could be removed in the unit. It found that more than 90% of particles above 75μm could be removed as well as 53% of particles in ranging between 25-75μm and up to 43% of particles smaller than 25μm.

INTRODUCTION

The introduction of treatment trains in urban stormwater quality management can greatly enhance pollutant removal and significantly reduce capital cost and maintenance costs of urban stormwater management measures. However, determining and applying appropriate treatment mechanisms can be difficult even though they are fundamental in successful removal of pollutants and the life expectancy of pollution control devices. The development of inappropriate treatment trains lead to large amounts of funds improperly spent on treatment and maintenance.

A stormwater treatment train normally consists of a pre-treatment device in the form of a gross pollutant trap or similar and secondary treatment in the form of filter media or wetlands. The aim of the pre-treatment device has generally been to remove coarse sediments and litter while secondary treatment is generally aimed at removing pollutants associated with finer sediment. The effectiveness of the secondary treatment is generally dependant on the performance and effectiveness of the pre-treatment. Continuous performance throughout the storm event is essential for any pre-treatment since premature bypass could lead to deteriorating performance of any secondary treatment or unacceptable water quality in downstream reuse tanks. Maintenance of the pre-treatment device is also essential to ensure that both the pre-treatment device and downstream systems are performing adequately.

CDS units have successfully been used as a highly efficient pre-treatment device as well as a stand alone treatment device. They are generally known for their ability to effectively remove gross pollutants and sediments via a unique vortex system that uses rotational energy. They are also a non-blocking unit which means that a guaranteed treatable flow rate and continuous treatment can be achieved in all events. However, as with any pre-treatment device, their impact on the pollutants associated with fine sediments can be limited and is not clearly understood. The research described in this paper investigated the fine sediment removal in a CDS unit by partitioning of solids in real urban stormwater events. There are significant benefits involved with pre-treatment devices removing fine sediment loads. These benefits
primarily relate to the reduced size and capital cost of the secondary treatment. Similarly, maintenance costs for pre-treatment devices are generally lower than maintenance costs for the secondary treatment and an increased capture of fine sediments in conjunction with efficient removal of litter and coarse sediment in a pre-treatment device would significantly reduce the overall maintenance cost of the treatment train.

The importance of fine sediments in urban water quality has been attributed to their association with hydrophobic pollutants such as heavy metals and hydrocarbons (Liebens 2001; Evans et al. 1990). Fine sediments have a relatively high surface area which leads to an increased adsorption of pollutants and they also tend to stay in suspension longer and is therefore transported a greater distance by urban runoff (Dong et al. 1984). Vaze and Chiew (2002) found that less than 15% of the investigated pollutants at a central business district in Melbourne were attached to particles coarser than 300μm. Furthermore, as Andral et al. (1999) noted, finer sediments can be a significant component in runoff, contributing to as much as three quarters of the weight of solids.

This paper will describe how a relatively high removal of fine sediments in urban stormwater by using a CDS unit was achieved. A number of real storm events were investigated and the results are presented here.

**METHODOLOGY**

The tests were undertaken by A/Prof John Sansalone of Louisiana State University at Baton Rouge in Louisiana, USA. A CDS unit was setup to collect bridge runoff from East Lakeshore Drive at City Park Lake in Baton Rouge. The total catchment area draining to the CDS unit was 1088m$^2$ and consisted solely of paved areas with an average surface slope of 2%. Two pipes, one from the east and the other from the west abutment of the bridge (>6% grade), were transporting the runoff water to a data logger and drop box where influent sampling occurred. Flow measurements were carried out using an American Sigma Datalogger which had a 1-minute reporting interval. The water was then transported by gravity to the CDS unit and finally discharged into large tanks after treatment. The layout of the site is shown in Figure 1 below.

**FIGURE 1 Layout of the CDS unit testing (adapted from Sansalione 2004)**

Influent sampling occurred at the drop box so that the entire cross section of flow was sampled. By sampling the entire cross section of flow instead of commonly used autosamplers, an accurate particle size distribution of the solids in the runoff was achieved. 12-L samples were taken at critical points throughout the storm to quantify the sediment size fraction. 1L and 250mL samples were also taken to quantify the settleable/suspended fraction. Replicate samples of all samples were taken to ensure that the solids concentration measured
was accurate. Effluent concentrations were taken from the CDS effluent pipe. Full cross sectional flow samples of the effluent were taken and 4L samples were used to quantify the sediment fraction while 1L and 250mL samples were used to quantify the settleable and suspended solids fractions respectively. Replicates of all effluent samples were taken. The solids removed from the CDS unit was dried and weighed to determine the total weight of solids removed in the CDS unit. All samples then went through a partitioning process in the laboratory.

Partitioning of the samples occurred by first sieving the sample through a 75μm sieve. This size class (>75μm) was labeled sediment and contained all material trapped on the sieve. Secondly, an Imhoff cone was used to separate the remaining two size classes (25-75μm and <25μm). Quiescent settling for 60 minutes was applied to the Imhoff cone. The size class 25-75μm was labeled settleable solids while the <25μm were labeled suspended solids. Duplicates of all samples were taken.

The CDS unit used had a screen diameter of 500m and a screen height of 500mm. The capacity flow rate of the unit was approximately 10L/s and the total volume of the unit was approximately 450L. The CDS unit had all the characteristics of a standard stormwater CDS unit except for the screens chosen. Two different screens were tested in the different stormwater events, the first one had apertures of 2.4mm while the second screen had apertures of 1.2mm. The standard stormwater screen in Australia has apertures of 4.7mm except for the smallest CDS unit (0506 model) which has 2.4mm aperture screen as standard. Oil baffles were also fitted at the outlet of the CDS unit in some of the storms which introduced a secondary flow path in the unit. The oil baffle was 200mm high and placed below invert so that the top 200mm of fluid in the CDS unit could be oil.

Three real storm events were captured by the CDS unit configuration and tested. The storm events occurred on the 24th April 2004, 20th August 2004 and 14th October 2004. Influent and effluent concentrations were measured as well as flow rates and total volume of water and pollutants captured. Characteristics of the four storm events are presented in Table 1 below.

**TABLE 1 Storm event characteristics**

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**RESULTS AND DISCUSSION**

The first storm event occurred on the 24th April 2004 and had multiple peak flows as can be seen in Figure 2 below. High sediment, settleable solids and suspended solids concentrations were observed during the first peak flow which indicated a first flush effect. A second concentration peak was observed for the sediment and settleable solids during the second and third peak flow of the event as shown in Figure 2. This spike in concentration was lower than the first spike but indicated that continuous treatment is important throughout the event for efficient pollutant capture.
FIGURE 2  Sediment and settleable solids influent and effluent concentrations during the storm event occurring 24\textsuperscript{th} April 2004 (adapted from Sansalone 2004)

A total of 94.4\% of the sediments were captured in the CDS unit during the event and the sediment fraction represented approximately 54\% of the overall solids. The overall removal for the CDS unit exceeded 74\% (total removal for all particles). The CDS unit also showed more than 50\% removal of settleable solids as can be seen in Figure 3. Suspended solids removal was 14.2\%. In total, around 40\% of particles below 75\textmu m were removed during the event while 94.4\% of particles above 75\textmu m were removed during the event. The total mass balance error was calculated to 0.8\% and the maximum flow rate recorded during the event was 1.78L/s (approximately 20\% of the CDS design flowrate).

FIGURE 3 Capture rates for 24\textsuperscript{th} April 2004 storm event (adapted from Sansalone 2004)

The second storm event occurred on the 20\textsuperscript{th} August 2004 and was characterized by its high intensity and short duration as shown in Figure 4. Additionally, as can be seen in Figure 4, a relatively sharp decrease in sediment and settleable solids concentration occurred prior to the peak flow indicating a first flush effect. The suspended solids concentration was relatively constant during the event but had a small but less significant first flush. The maximum flow rate of the event was 17.5L/s. This was above the specified design flow rate of the CDS unit and the unit was therefore pressurized during the peak flow.
Similar to the previous event, the CDS unit showed high levels of removal in the sediment particle size class with a removal percentage of 79.1% and around 6kg of sediment was removed. The settleable solids removal was 21.2% while the suspended solids removal was as high as 36.8%. The total solids removal for the event was 62% while the total removal of particles less than 75μm was approximately 30%. The removal figures for each size class can be seen in Figure 5.

The third and last sampled storm event occurred on the 14th October 2004 and had a relatively small intensity and small runoff volume compared to the other storms as can be seen in Figure 6 below.
The low intensity resulted in the sediment fraction only representing about 17% of the total solids. The suspended solids fraction accounted for approximately 62% of the total weight of solids in the event. The third event was also different to the other two events in regards to the CDS screen used. In the third event, a 2.4mm aperture screen was used in the CDS unit. An oil baffle was also fitted to the unit which introduced a secondary flow path out of the unit since flow had to pass under the baffle to get out. As can be seen in Figure 7, the removal of particles in the sediment fraction was once again high, this time 93.6% of the particles in this size range were removed. More interesting is the removal of particles below 75μm, where the CDS unit showed a total removal of 48%. The settleable solids particle size class had a removal efficiency of 57% while the suspended solids size class had a removal efficiency of 42.6% as shown in Figure 6.

Even though the screen aperture was larger in the event occurring on the 14th October 2004, removal efficiencies in particles smaller than 75μm were highest (48%) in this event. This can be attributed to the different rainfall and runoff characteristics of the events. The event on the 14th October 2004 was a relatively low intensity event and the average flow rate was lower than the other events. Hence, the residence time inside the CDS unit increased which had a positive impact on the settling of smaller particles. This can be compared to the event occurring on the 20th August 2004, which had a relatively high intensity rainfall and the highest peak flow rate, where the removal efficiency of settleable solids and suspended solids were lower. However, the overall removal efficiency of particles in the event was significantly higher in the 20th August 2004 storm event which is attributed to the hydrodynamic separation of the CDS unit by its screen characteristics. Hence, it is proposed that the screen and its characteristics has a lesser impact on the overall removal efficiencies during low flows and that the residence time inside the unit and the volume of the unit plays a more important role in these low flow events (up to 10% of the design flow of the unit). However, efficient removal during all flows up to and including the design treatable flow is proposed to be related to the screen of the CDS unit rather than the residence time inside the unit.
unit. Consequently, it can be proposed that a CDS unit can provide three different treatment processes, namely retention, separation via the vortex action and filtering via the screen.

CONCLUSION
A continuous deflective separation unit was tested to determine its ability to remove fine sediments from urban stormwater. Three real storm events and its runoff were investigated by staff from the Louisiana State University. The CDS unit was situated underneath a bridge and runoff water from a total area of 1088m² of pavement was collected and treated by the unit. Three different storm events were captured and treated. Two different screens were used in the CDS unit, one of which is standard in smaller size CDS units in Australia (0506 unit is equipped with a 2.4mm screen).

Runoff was sampled at the inlet and outlet of the CDS unit with the entire cross section of flow being sampled. This enabled a mass balance approach to be undertaken.

Up to 57% of particles in the settleable solids size class (25-75μm) were removed in the CDS unit and particles larger than 75μm had a minimum removal of 79% independent of runoff event and CDS screen. The highest overall removal efficiency (74.4%) was observed in the longest duration rainfall event while the highest removal figure for solids below 75μm (48%) was observed in the low intensity rainfall event. These observations indicate that the CDS unit is highly effective in removing all types of solids and its removal mechanisms changes with the incoming flow. In low intensity rainfall events, the particle size distribution is much finer than in a high intensity rainfall events and the CDS unit would only operate at around 10-20% of its design flowrate. In this flow, the CDS unit was very effective in removing both fine and coarse sediments. In higher flows (up to the design flow), the CDS unit was still removing a significant quantity of fine sediments (30-40%) and around 80% of particles above 75μm were captured and removed.

It has been shown that by using 1.2mm and 2.4mm screens in the CDS unit and using secondary flow paths by installing internal oil baffles, the CDS unit can remove significant quantities of solids smaller than 75μm. This in turn could have a significant impact on downstream secondary treatment in terms of the size and capital cost as well as life cycle costs of the treatment train. The CDS unit would also provide important treatment to stormwater harvesting facilities with the removal of finer sediments.

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REFERENCES


