PROTOCOL FOR ASSESSING SEDIMENT RETENTION IN STORMWATER TREATMENT CHAMBERS

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ABSTRACT

In approving stormwater BMPs, regulators usually review sediment removal data as the basis for their decisions. One factor that is usually overlooked is the ability of a treatment device to retain captured material in the event of high flow rates. Lately, some agencies are requiring vendors to indicate washout prevention of their stormwater treatment systems. However, no standard protocol exists that measures how much of previously captured pollutant is resuspended and carried downstream of the treatment device during high flows.

This paper discusses an effective test protocol for evaluating the sediment retention efficiency of proprietary stormwater treatment systems. The sump of a full-scale treatment device is filled with a known mass of sediment or sediment tracer. The unit is run at steady-state for a specified duration that exceeds several multiples of its effective detention time. Repeated tests are undertaken at different flow rates and the amount of material retained in the device for each flow rate is determined. The sediment retention efficiency is then calculated based on a comparison between mass of material retained in the sump after running flows through the unit and the original mass of material deposited in the sump.

Test data using this protocol for different device configurations are discussed and this highlights the importance of chamber geometry and hydrodynamic regime on the sediment retention efficacy of stormwater treatment devices.

INTRODUCTION

The negative effects of sediment and associated pollutants from stormwater runoff are well documented (Krein and Schorer, 2000; Pitt *et al*. 1995). To help address the removal of sediment, trash, oils and grease, etc., from stormwater runoff, a wide range of proprietary treatment chambers with different configurations are available on the market.

The effectiveness of a 'flow-through' device can be described by two key parameters, namely:

Pollutants Removal Efficiency**:** This is the ability of a chamber to remove pollutants from the influent. For all flow-through devices, removal efficiency typically decreases with increasing flow.

Pollutant Retention Efficiency: This represents the ability of a chamber to retain pollutants once captured. While related to hydraulic loading rate in most practical cases, retention efficiency has been found to be strongly dependent on chamber configuration.

Typically the performance of treatment chambers are stated in terms of removal efficiency at discrete flow rates and the pollutant retention efficiency of a device is rarely considered. Pollutant retention may have been overlooked because of a lack of appreciation of its significance and the difficulty of measuring it in the field. The importance of this parameter in a treatment chamber is best explained using a typical storm event. During the early part of a storm event when flow rates are generally low and pollutant loads are high (due to first flush effects), removal efficiencies in hydrodynamic treatment chambers are generally high. On the other hand, when flow rates are high, removal efficiencies tend to lower. If the retention efficiency of a treatment chamber at moderate to high flows is low, the likelihood of 'washing out' the pollutants captured during the early part of the storm is very high. In effect, the chamber would capture pollutants during low flows and then flush the pollutants to downstream receiving waters during peak flows. Over the past few years, several studies have shown that pollutant retention is a parameter that needs to be carefully assessed in the selection of treatment chambers (Faram *et al.* 2003; Phipps *et al.* 2004, Phipps *et al.* 2005).

A simple laboratory based protocol is discussed in this paper that will aid regulators and engineers in assessing the pollutant retention efficiencies of stormwater treatment chambers. Laboratory testing under controlled conditions eliminates the uncertainties associated with field-testing. This makes it easier to compare different chambers or configurations under the same conditions. This protocol was applied to three full-scale chamber configurations and the results analyzed. The chamber configurations tested can be classified as:

- ***Simple In-line Vortex Separator (SVSC)*** – These rely on enhanced gravitational settlement to perform their function, through the use of a rotating flow field. Flow rotation results in extended particle residence times, and increased opportunity for settlement to take place. The configuration included an inlet with a chute.

- ***Simple In-line Vortex Separator with Skirt (SVSC-S)*** **–** This works on the same principle as the Simple In-line Vortex Separator with inlet chute (above). The SVSC-S has a skirt positioned above the sump to isolate the sediment storage zone from the active separation region.

- ***Advanced In-line Vortex Separator (AVS)*** – These operate in a similar manner to Simple Vortex Separators, but utilize specially designed internal components to control and enhance performance and provide isolated storage zones with shielding of captured pollutants.

These configurations (see Figure 1) represent features of some of the proprietary devices available on the market and were tested to emphasize the importance of pollutant retention as a treatment parameter and how this can be affected by the internal geometry of a chamber.

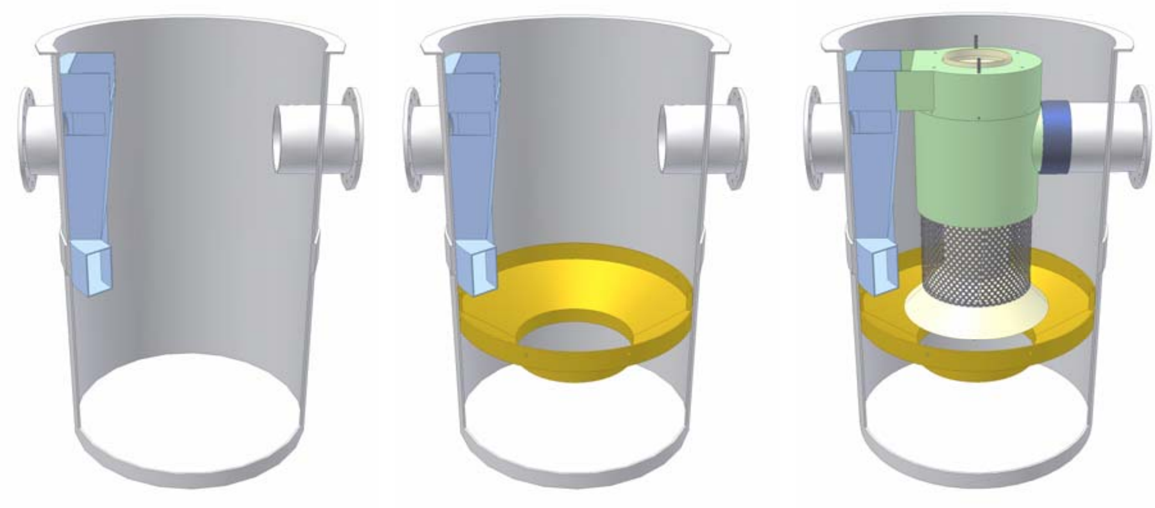

Figure 1 In-line chamber configurations considered:

a)	SVSC	Simple Vortex Separator with inlet chute.
b)	SVSC-S	Simple Vortex Separator with inlet chute and skirt.
c)	AVS	Advanced Vortex Separator.

TESTING METHODOLOGY (PROTOCOL)

A known mass of material is deposited in the sump of the stormwater treatment chamber. The material should be of a particle size distribution and specific gravity or settling characteristics similar to what the unit is designed to remove. Flow is introduced into the chamber until the water reaches just below the outlet and stopped. This is done to ensure the conditions are similar to typical field conditions with standing water in the chambers up to the invert of the outlet pipe between storm events. Flow is then introduced into the chamber at the specified treatment flow rate and allowed to run for 15 minutes. During this period, the flow rate must be periodically checked to ensure it is fairly constant. The water is then allowed to sit in the chamber for 10 minutes to allow the retained material to settle. The water is then drained from the chamber and the sediment remaining in the sump is collected and dried for at least 8 hours at 105^{o}C. The dry mass of material is then weighed and compared with the initial amount deposited in the chamber to determine the material retention efficiency at the specified treatment rate.

The procedure should be repeated at a number of flow rates including the flow rate specified as the maximum hydraulic flow rate through the system. This is very important since it is at higher flow rates that washout and scour of previously captured pollutants most likely would occur.

A comparison should then be made between the retention efficiencies at the treatment flow rate and the full capacity flow rate. This test protocol was used on a chamber with different internal geometric configurations to highlight how retention efficiency is affected by the geometry of a chamber.

TESTS UNDERTAKEN IN THIS STUDY

A 4-foot diameter polyethylene full-scale prototype unit was used for the studies. It had an approximate operating volume of 420 gallons. The chamber was designed such that it could be modified to accommodate different internal flow modifying configurations (Figure 1). The inlet chute is attached to the chamber to introduce incoming flows tangentially resulting in rotary (vortex) flow within the chamber.

For each configuration, the chamber was seeded with 3 lbs of Purolite PFC 100H. Purolite PFC 100H is a commercially available resin with a mean density of 1200 kg/m^3 and an average particle size of 500 microns, giving similar settling characteristics to a 150 micron sediment with a density of 2650 kg/m^3 settling in water at 10^{o}C. This makes the material suitable for simulating sediment retention in a treatment chamber, as it is non-cohesive and relatively easy to quantify and observe.

Flow was introduced into the chamber to spread the purolite evenly within the unit. Once the material was well distributed within the unit, water was pumped to the chamber at a constant flow rate of 0.8 cfs (22 l/s) using a variable frequency drive. Flow was measured using an ISCO UniMag Magnetic Flowmeter and confirmed with the time to fill a calibrated vessel. The duration of a test was 15 minutes after which the unit was drained and the mass of material remaining in the chamber collected and dried overnight. The test procedure was repeated for each of the chamber configurations at a flow rate of 1.7 cfs (48 l/s). This flow rate exceeds the typical treatment flow rate of the 4-ft diameter chamber and represents a relatively high hydraulic loading rate. Device configurations with inadequate protection of captured sediments would be expected to begin to washout under high flow conditions. The tests were run at two different flow rates to highlight the drop in retention efficiencies that can be experienced by simply doubling the treatment flow rate. Still photographs for flows within the different chamber configurations were obtained during the tests and are shown in Figure 2.

(a) Simple Vortex Separator with Inlet Chute (SVSC)

(b) Simple Vortex Separator with Inlet Chute and Skirt (SVSCS)

(c) Advanced Vortex Separator (AVS)

Figure 2 Photo shots taken of each configuration at high flows (from left to right)

In each sequence from left to right
- (i) Starting condition with sediment stimulant in the sump of the chamber
- (ii) Fully developed flows during the test
- (iii) Chamber drain down at end of test with sediment stimulant at the base

RESULTS

The retention efficiency outputs for the study are presented in Figure 3 and Figure 4. Retention efficiency is defined as:

$$\text{Retention Efficiency}\,(\%) = 100 \times \frac{\text{sediment mass remaining in sump after test run of 15 minutes}}{\text{sediment mass initially stored in the sump}}$$

At normal 'design' flow rates

The retention efficiencies for the chamber configurations ranged from 85% for the chamber with the inlet chute (SVSC) to almost 100% for the advanced vortex separator (AVS) and the inlet chute with skirt (SVSC-S) configurations when the flows were 0.8 cfs. These results are graphed in Figure 3.

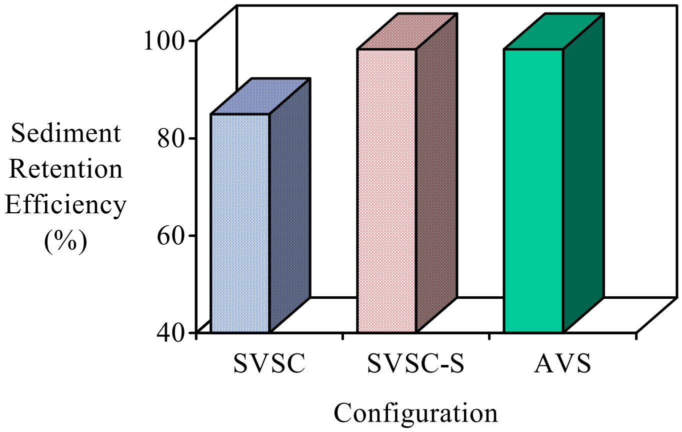

Figure 3 Sediment retention efficiencies for the different chamber configurations at normal flow rates

At 'high' flow rates

At the high flow rates of 1.7 cfs, the retention efficiencies followed a different pattern. The SVSC retained 55% of the test material. The observed retention efficiency for the SVSC-S dropped to 25%, whereas there was very little change in the retention efficiency of the AVS. The unit retained 95% of the seeded material. These results are graphed in Figure 4.

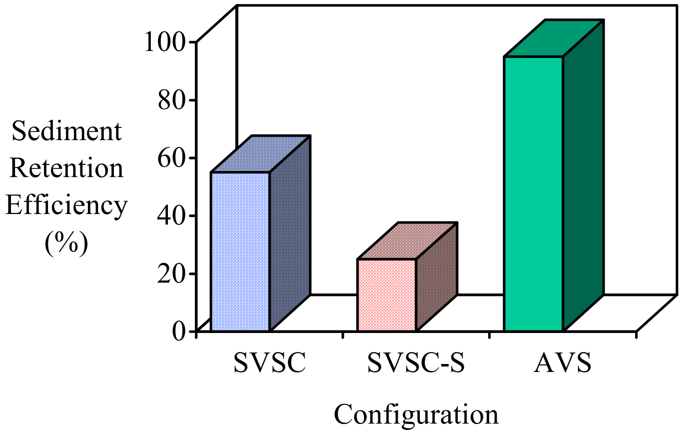

Figure 4 Sediment retention efficiencies for the different chamber configurations at high flow rates

Intuitively, one would expect the SVSC-S configuration to provide better sediment retention at high flow rates than the SVSC on account of a skirt providing an isolated zone for sediment storage. The lower retention efficiency observed for the SVSC-S configuration can be explained by reference to the observed flow fields (see Figure 2).

During high flows, the SVSC exhibited a strong vortex flow, which though penetrating all the way to the sump, had a tendency to hold material within a skewed vortex core (Figure 2 (a) (ii)). The resuspension caused by the vortex flow resulted in material being washed out. It was observed that the material was drawn towards the area directly below the inlet chute with the chute shielding part of the material from being washed out even though most of the retained material remained in suspension.

The SVSC-S configuration retained almost all the material when the flow rate was 0.8 cfs. This was because at that flow rate the velocities were generally low and the skirt was able to shelter the sump from any turbulence. However, when the flow rate was ramped up to 1.7 cfs, almost all of the material was washed out. A vortex flow was also developed, however, due to the presence of a circular opening in the skirt, the core of the vortex penetrated into the sump and resuspended and washed out the deposited material (Figure 2 (b) (ii)). It was obvious that if the test had continued all the material would have been washed out and the skirt was unable to provide protection for the material in the sump. Interestingly, the efficiency was worse than when only the chute was used. The positioning of the skirt prevented the inlet chute from providing the shielding effect that was observed in the SVSC configuration.

The AVS exhibited different characteristics to the other chamber configurations. The internal components prevented extreme flow penetration into the sump region. It can be seen from Figure 2 (c) (ii) that even at the high flow rate the material was not suspended and not washed out unlike with the other configurations. Almost all of the material deposited in the sump at the beginning of the test was retained. The retention efficiency of the device was almost double that of the SVSC and quadruple that of the SVSC-S. It appears that the internal geometry of the AVS provided both an isolated storage zone and shielding of the material captured.

DISCUSSION

The results from the tests using this protocol have highlighted the importance of retention efficiency as a parameter that needs to be considered in assessing treatment devices. Even though similar sized chambers may claim equivalent pollutant removal efficiencies, their pollutant retention efficiencies may vary greatly based on their internal configuration. It is clear that at the normal treatment flow rates, most chambers are able to retain the bulk of sediment that is in the sump. However most devices are designed to hydraulically handle flows far in excess of their treatment flow rates and it is imperative that tests on sediment retention efficiency are carried out at the maximum flow through capacity of a device. The results from the series of tests conducted have shown huge differences in retention efficiencies depending on the internal configuration of a device. For instance without testing it would have been hard to tell that the efficiency of the SVSC-S would drop from almost 100% to 25% by doubling the treatment flow rate. It is also interesting that the addition of an inlet chute to the chamber formed a shielding effect resulting in the retention of some material that would otherwise have been washed out. By far the best chamber configuration was the AVS. The induced rotary flows and internal arrangements and flow modifying components of this chamber arrangement isolates the storage region from the main treatment region and provides shielding/sheltering of the captured material. Utmost care needs to be taken in selecting treatment chambers since chambers that wash out practically all the sediment that is deposited during previously low storm events have very little environmental benefit.

Faram and Harwood (2002) and Faram *et al.* (2003) used computational fluid dynamics (CFD) to evaluate different treatment chamber designs, looking at both removal and retention efficiencies. Their findings confirm the relevance of pollutant retention as a performance parameter. More recently, Phipps *et al.* (2005) also simulated pollutants through small prototype treatment chambers and found that poorly designed chambers would washout all the material in the sump when flows are fairly high.

In selecting a material for testing pollutant retention in chambers, there is the need to choose a material that has similar settling characteristics to fine sediment. Recent studies have shown that the bulk of particulate pollutants are attached to the very fine fractions of sediment (Pitt *et al.* 2005; Vaze and Chiew 2004). Thus it is important for chambers not only to capture but also retain fine sediment. This again highlights the significance of retention efficiency, since finer material is more likely to be washed out of chambers than larger sized sediment.

CONCLUSIONS

This work has demonstrated the practicality and effectiveness of a simple laboratory protocol for determining sediment retention efficiency that will enable decision makers to differentiate between stormwater treatment chambers based on pollutant retention efficiencies. The tests using this protocol have confirmed work done earlier, which highlights pollutant retention efficiency as an important parameter that needs to be considered in the selection of hydrodynamic chambers for stormwater treatment. The key findings from the tests using this protocol are:

- There is the need to take into account the pollutant retention efficiencies in the selection of stormwater treatment devices.
- The rate of stored pollutants washout is very sensitive to chamber design. In the tests carried out washout rates ranged from 25 – 95%.
- Chambers with the isolated sediment storage regions that are properly shielded from the main treatment region are the most effective in retaining material in the sump.

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Speaker bio

Kwabena holds an MS in Civil & Environmental Engineering from University of Vermont where for his thesis he monitored the performance of a stormwater detention pond. He also has a BS in Civil Engineering from KNUST, Kumasi, Ghana. For the past 2 years he has been a Research and Development Engineer at Hydro International in Portland, ME, where his duties include the development and testing of a range of stormwater treatment products.