Assessment of laboratory test protocols for determining the pollutant removal capabilities of stormwater separators

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ABSTRACT

Laboratory testing of stormwater separators can overcome many of the technical challenges associated with field testing. With laboratory testing, sediment characteristics and the flow rates at which a device is tested are known and measurable before, during, and after the test. This controlled environment ensures that test programmes can be set up to meet specific objectives, and data can be obtained in a repeatable and timely fashion. However there are differences in laboratory test protocols that can have a significant bearing on test results which, if overlooked, can result in invalid comparisons being made between different systems. This paper looks at two protocols for testing separators in the laboratory, normally referred to as the Direct Test Method and the Indirect Test Method. The test methodologies are described and the similarities and differences shown. Results from tests on a stormwater treatment separator using the two protocols are presented. The results show that for the same sediment gradation and flow rate, a difference of over 20% in measured removal efficiency is possible. They also show that the Direct Test Method produces outputs that are more consistent, conservative and representative of the removal efficiencies expected for stormwater treatment separators.

KEYWORDS

Field testing; grab sampling; laboratory testing; stormwater; test protocols

INTRODUCTION

The effects of water quality impairment have become topical in the last few decades. Stormwater treatment has received increased attention as the negative effects of sediments and associated pollutants to water bodies have been highlighted. This is more so as sediments and nutrients continue to be the primary pollutants of concern.

Conventional stormwater management systems like wet and dry ponds, grass swales and wetlands have been the systems of choice for many years. There is a considerable amount of work that has taken place to determine the performance of these systems (Fletcher *et al.*, 2002; Barrett, 2004; Fortunato, 2005; Lee *et al.*, 2006). In the last decade or so, proprietary treatment systems have also become an integral part of stormwater treatment as municipalities and developers implement systems to meet legislative requirements. These systems tend to have smaller footprints than conventional systems and are particularly suited for the urban environment where space is at a premium.

One of the biggest debates within the stormwater industry, in particular in the United States, has been how to assess the performance of proprietary systems and how well they perform relative to conventional methods of stormwater treatment. Typically, in the US, systems are designed for a given treatment flow rate at which they are expected to provide a certain percentage of sediment removal. Most regulatory agencies require 80% removal of Total Suspended Solids (TSS) for sediments and anywhere between 40-60% removal for nutrients. Whereas this has been the primary means of assessment, some within the industry argue that a better way to obtain pollutant control is to define an effluent concentration limit as is used in the wastewater industry (Strecker ***et al.***, 2001). The method of looking at percent removal also discounts the effects of parameters like particle size distribution, specific gravity and temperature on the ability of a separator to provide adequate treatment.

Depending on regulatory agency requirements, treatment systems are tested using field or laboratory protocols, or both. Regulatory agencies often grant approval for limited use of treatment systems based on laboratory data, but require field data before a treatment system can be considered for general use.

FIELD TESTING

Field studies provide an opportunity to evaluate a system’s performance under field conditions. This provides information that helps the designer assess whether the level of control specified for the device is provided at the given flow rate. However, there are many variables associated with field testing that make it difficult to use as a means of assessing differences and similarities between proprietary stormwater treatment systems. A number of these variables are highlighted below:

Land use: Beyond broad considerations, it is difficult to determine the pollutant loadings from a site prior to starting any monitoring and sampling work. Different land uses not only present different challenges with respect to the treatability of pollutants; they often possess different environmental factors that can compromise treatment performance. For example, a land use that typically produces a large amount of organic, low specific gravity debris can be present greater challenges, from a treatment perspective, than a land use that typically produces inorganic, high specific gravity sediment. Considerable time can be spent “shopping” for a site with the “right” characteristics.

Climatic conditions: The climatic conditions in a locale also have a significant bearing on removal efficiency. Whereas some areas see large volumes of rainfall annually, other areas see very little rainfall. Rainfall intensities can also vary significantly between locations. This makes it difficult to compare data from different locations when assessing different devices.

Sampling Equipment: A lot has been written about monitoring equipment currently used to sample stormwater flows. There are errors associated with flow meters which are hard to discern, let alone resolve. The inability of samplers to capture the entire spectrum of solids skews data towards the finer fraction of sediment, which in turn has a negative effect on the reporting of system performance.

Resources: The time required to go through a full program of field testing can be in excess of two years. Agencies often require that test data be collected for an entire year in order to account for seasonal variations in rainfall. Even then, some storms may have to be discarded from the data set if they do not meet certain qualifications such as rainfall depth and duration.

In addition, equipment breakdown during a storm event can often occur, leading to the loss of more test data. This results in a lot of commitment being required in terms of human and financial resources. If the time required for site selection, site preparation, equipment set-up and pre-monitoring and de-commissioning of the system are all factored in, it could be many more years before data is available for analysis.

LABORATORY TESTING

The major issue associated with laboratory studies has to do with the fact that the system is not being tested under real-world conditions. This makes it difficult for engineers to specify treatment devices that have not been tested under the same conditions as where they will be installed. Whereas this argument has merit, the easiest and most effective way of comparing differences between systems is to test them under the same conditions and this can only be effectively done in a laboratory because it is a controlled setting.

The primary advantage of laboratory testing is the ability to control the test to minimize and/or eliminate most of the variables and hence technical challenges associated with field testing. The researcher has the ability to control a lot of the variables mentioned in the discussion on field testing. This is critical if the identification of similarities and differences between systems is the primary objective of the test program. The flow rate and particle size distribution to be used in the tests are determined beforehand. Treatment units are selected according to the flow rates and treatment objectives chosen for the verification. Laboratory studies do not depend on weather conditions, and different storm scenarios can be simulated. Results can be obtained within a relatively short period of time. Changes can be made to the test set up, protocols, etc. without necessarily having to put more resources into the test program. Laboratory test programs have the added advantage of allowing testing for sediment re-suspension and at the flow rates where this can occur for different systems and different size units.

Test Protocols

Various laboratory testing programs have revealed that testing protocols can have as much of an impact on removal efficiency results as the particle size distribution of the influent solids. The commonly used laboratory test protocols are the Indirect and Direct Test methods. These protocols differ significantly in their approach with the Indirect method based on the sampling of material entering and escaping the test device and the Direct method based on the total mass of material inputted into and captured within the test device. A description of the two test procedures is provided below.

Indirect Testing

The more commonly used “Indirect Test” method involves obtaining grab samples before the flow enters the test unit (influent) and after the flow exits the unit (effluent). Figure 1a below illustrates the Indirect test method. A sediment slurry is dosed into the influent flow stream of clean water and samples are taken prior to the mixed flow reaching the test device. After flow exits the test device, grab samples are taken at the overflow. This method of testing is prone to error, depending on the sampling region within the influent stream, how well the slurry integrates into the influent stream, and the type of sampling port used. The efficiency of the test device is calculated based on its inefficiency as is typically done in field studies because the sediment captured within the device is not considered in the calculation. The results from Indirect tests tend to be inconsistent, with potential for large variations for tests at the same flow rate and using the same feed material. Interestingly, this is the preferred method of laboratory testing within the stormwater industry. Samples may be composited to form one large sample for which an aliquot is taken for analysis or discrete samples are analyzed and concentrations averaged on the influent and effluent to calculate the removal efficiency. The analysis method can also have a significant effect on the reported test results (Guo 2005; Clark and Pitt, 2008).

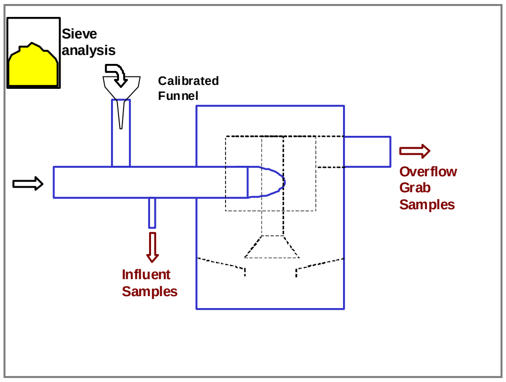

Figure 1a. Schematic for sampling using the Indirect Test method

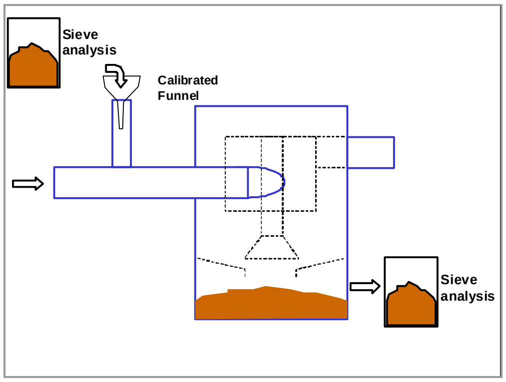

Figure 1b. Schematic for sampling using the Direct Test method

Direct Testing

The "Direct Test" involves measuring the mass of sediment actually captured within the unit and comparing this to the known mass of material fed in to the test unit during the test. Any losses in material during the drain down and recovery stage after a test will reflect in reduced device efficiency and, as such, results in a conservative estimate of performance. A known mass of sediment is fed through the system at the required concentration and flow rate. After the test, the water in the device is decanted and the actual sediment captured within the device is vacuumed out, dried and weighed. The Direct test method is illustrated in Figure 1b. A series of tests performed using this protocol has shown that removal efficiencies are very consistent from test to test. With this method, the efficiency of the device is directly calculated based on the recovered sediment. A subsample can be taken from the sump material and a particle size gradation performed. The gradation analysis can be used to determine if there have been shifts of the gradation from the original gradation. Based on that information, the particle size analysis shows the flow rates and gradations for which the device is effective at sediment removal.

Direct testing also provides the best means of assessing sediment retention within separators. The effect of potential sampling errors with Indirect testing makes it an unreliable method of assessing pollutant washout in separators. With Direct testing a known mass of material can be deposited in the sump of a separator. The flow rate at which washout occurs can be easily determined based on the amount of material remaining in the sump after a run. This information can be used to develop a pollutant retention curve for a separator.

The drawback of direct testing is the inability to use it for systems that make use of sediment trapping like filters and infiltration systems. However, as separators primarily rely on particle settling, the Direct test method is probably the most accurate and conservative way of assessing them.

Direct versus Indirect

To compare the Direct and Indirect test methods, a series of tests were run on a 1.2m (4-ft) diameter separator using the two protocols while maintaining the same feed material and flow rates. The results of the tests are shown in Figure 2. The plot shows that the derived removal efficiencies are similar at low flow rates. However, as the flow rates increase, there is a significant difference in the results from the two test methods. The Indirect method consistently gives higher removal efficiencies than the Direct test method.

At the highest flow rate considered (0.06 m^3/s), there is a 25% difference between the derived efficiencies. Even though the Indirect testing provides better removal efficiencies, it becomes less reliable with higher flows through the treatment system.

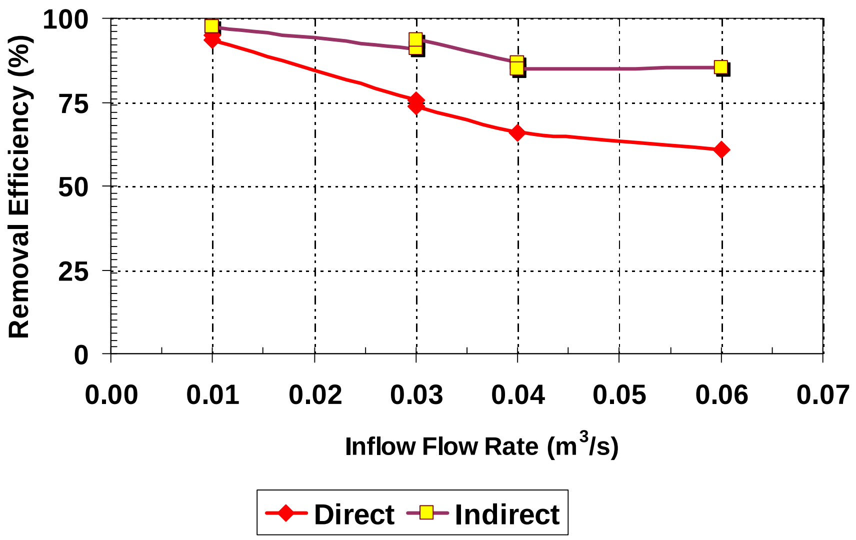

Figure 2. Comparison of Direct and Indirect test results for a 1.2 m Separator using F-95 silica sand

A similar plot is shown in Figure 3, where the same separator and a finer gradation of silica sand was used for both the Direct and Indirect tests. Once again, the Direct tests produce more conservative results whereas the Indirect tests result in higher removal rates but are less consistent. Unlike the Direct test results which show a progressive decline as flow rates increase, there is very little difference in removal efficiencies between 0.008 – 0.02 m^3/s for the Indirect tests. The difference between the removal efficiencies at a given flow rate between the Direct and Indirect method appear to be more pronounced in Figure 3 compared to Figure 2. This suggests that a finer sediment gradation produces more variability with the Indirect test method.

From the graphs presented in Figures 2 and 3, it is clear that the Direct method of laboratory testing is not only more consistent, as confirmed by repeat tests, but also more representative of the processes causing pollutant capture within a separator. In a laboratory environment where hydraulic processes and protocols can be controlled, the Direct test method provides the most effective and accurate means of assessing the performance of treatment devices. Although this protocol has potential drawbacks like sediment accumulation in the pipe network that cannot be accounted for, there is less likelihood of errors being introduced by the sampling and analysis methods. The Direct test approach also provides enough sediment within the sump of the unit to sieve for determining gradation. The sump gradation can be compared to the gradation of the original test sediment. The shifts observed between the two gradations can provide extremely valuable insights into the performance of the system in terms of what particle size the unit is capable of removing.

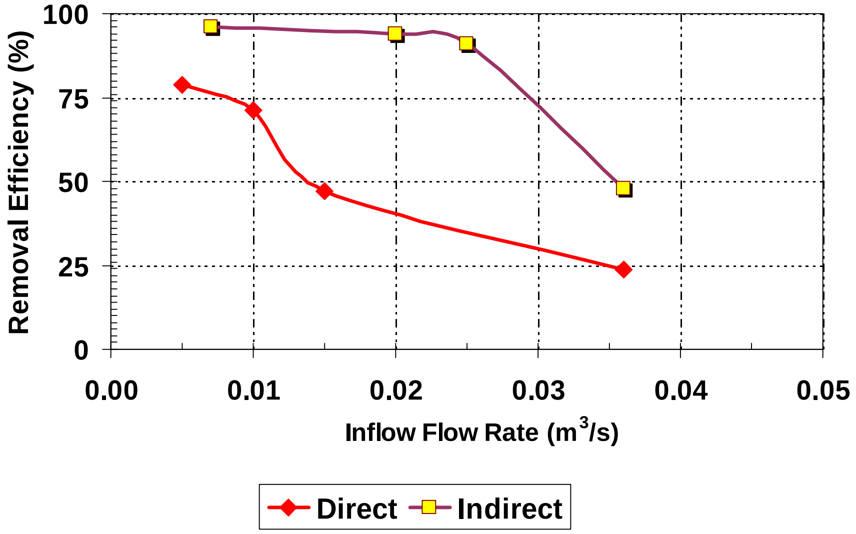

Figure 3. Comparison of Direct and Indirect test results for a 1.2 m Separator using OK-110 silica sand

Table 1. Actual and calculated concentrations for the Indirect test method

Flow rate (m^3/s)	Calculated Concentration (mg/l)	Sampled Concentration (mg/l)	Percent Difference (%)
0.01	270	318	-18
0.03	233	516	-121
0.04	216	613	-184
0.06	264	937	-255

The information in Table 1 provides insights into the quantity of sand required to obtain a given concentration for the Indirect test results shown in Figure 2. The calculated concentration is the theoretical concentration derived from the mass of sediment and volume of water introduced into the flow stream at the inlet of the separator for the duration of the test. The sampled concentration is the value obtained from analyzing the grab samples using the suspended sediment concentration method. The difference between the two values for a given flow rate clearly shows that the mass required to achieve a given concentration for the Indirect test method is much smaller than the theoretical calculated mass. As the flows get higher, the ratio between the calculated and the actual concentration increases. This supports the plots in Figures 2 and 3 as generally the gap between efficiencies for the Direct and Indirect test methods increase as the flow rates increase. This highlights the difficulties in achieving a known influent concentration and raises questions concerning results derived from testing using the Indirect test method. The exclusion of grab sampling from the Direct test method eliminates any errors associated with concentrations.

On the other hand, for the Direct test method, the silica sand is fed into the flow stream using a calibrated funnel. This ensures that for the test period, the intended influent concentration is achieved and the actual feed concentration is based on the calculated value. This eliminates variations and spikes and provides better control.

CONCLUSIONS

Whereas field testing provides valuable information on the performance of treatment systems under real world conditions, the problems encountered in setting up a test site and the numerous parameters that cannot be controlled in a field setting make it difficult to use as a means of comparing and contrasting the performance of stormwater treatment systems. On the other hand, laboratory testing provides a means by which the efficacy of treatment systems can be compared under the same conditions. In selecting a protocol for laboratory testing, it is important to use test methods that best represent the efficacy of treatment systems.

From assessing the Direct and Indirect test protocols, it is clear that the Direct test method provides a level of repeatability and consistency that is difficult to replicate for Indirect tests. The Direct test method has the added advantage of investigating particle size distribution and retention within devices, which is a key component of assessing device performance. Data from the Direct test method is a better representation of what is happening within the treatment device.

The sampling methodologies and protocols typically deployed during field testing are similar to the Indirect laboratory testing methodology described in this paper. The inconsistencies observed in the laboratory for test results based on the indirect methodology are bound to be replicated and exacerbated in the field. This makes current field testing approaches unpredictable.

It is recommended that protocols based on the Direct testing methodology be adopted for testing of stormwater sediment separation devices.

REFERENCES

Barrett, M. E. (2004). Retention pond performance: Examples from the International Stormwater BMP Database. *Critical Transitions in Water and Environmental Resources Management: Proc. 2004 World Water and Environmental Resources Congress*. American Society of Civil Engineers, Reston, VA. CD-ROM. 10 pages.

Clark, S. E. and Pitt, R. (2008). Comparison of stormwater analytical methods for performance evaluation of manufactured treatment devices. *Journal of Environmental Engineering,* Vol. 134, No 4., 259-264.

Fletcher, T. D., Peljo, L., Fielding, J., Wong, T. H. F. and Weber, T. (2002). The performance of vegetated swales for urban stormwater pollution control. *Global Solutions for Urban Drainage, Proc. of the Ninth Int. Conf. on Urban Drainage, Sept 8-13 2002, Portland, OR*, CD-ROM.

Fortunato, C., McDonough, O. and Chambers, R. (2005). The effectiveness of dry and wet storm water detention basins as sediment and nutrient processors. *Proc. 2005 Watershed Management Conf. - Managing Watersheds for Human and Natural Impacts: Engineering, Ecological, and Economic Challenges*. Am. Society of Civil Engineers. 1157-1168.

Guo, Q. (2005). Development of adjustment and scaling factors for measured suspended solids removal performance of stormwater hydrodynamic treatment devices. *Proc. World Water Environmental Resources Congress,* Anchorage, Alaska, American Society of Civil Engineers, Reston, VA.

Lee, B. H., Scholz, M. and Horn, A. (2006). Constructed wetlands: Treatment of concentrated stormwater runoff (Part A). *Environ. Eng. Sci*. 23(2):320-331.

Strecker, E. W., Quigley, M. M., Urbonas, B. R., Jones, J. E. and Clary, J. K. (2001). Determining urban storm water BMP effectiveness. *J. Water Resour. Plan. Man*. 127:144.