How the Stormwater Industry Can Improve the Performance and Approval Process of Solids Removal Devices

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Introduction

Suspended solids in stormwater can have a number of negative impacts on the health of water bodies. Total Suspended Solids (TSS) concentrations of 300-400 mg/l may inhibit the capture of food by fish through reduced visibility, while sustained high concentrations could reduce primary production[i]. Additionally, some solids may settle to the bottom of water bodies, damaging invertebrate populations, blocking spawning gravels, impacting dissolved oxygen, and increasing the dredging frequencies required for shipping traffic[ii]. The inclusion of trash in the runoff (possibly including medical wastes) can be damaging and is certainly aesthetically undesirable. Because of these issues, the United States Environmental Protection Agency issued the Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters in 1993. The guidance established a standard to remove 80% of TSS. It should be noted that when used in this context, the acronym TSS refers to solids suspended in a fluid flow and not to the concentration analysis methodology as described later in this paper. There has been much confusion regarding the general use of the term "TSS Testing", by both regulators and industry.

In order to evaluate the performance of a stormwater solids removal device, many state regulatory agencies and local municipalities have established acceptance criteria for targeted pollutant removal. These criteria must be proven with testing data before the regulatory agency will permit the sale of the device within their district. To discourage erroneous data and ensure reliable results, many agencies have added the requirement that the testing (field and/or laboratory) be performed by qualified, independent third-party organizations. Design engineers will now have the ability to confidently select the appropriate device for a given application and to select the best value based on the actual percent removal efficiency of key constituents. However, there can still be uncertainties in the test data obtained. As we now know, testing of stormwater devices is a complex process.

Field and laboratory testing has been conducted by universities and private companies (including manufacturers' testing labs) in an attempt to establish the solids removal efficiencies of various Best Management Practices (BMP's). Field testing reflects real world conditions and is, therefore, extremely relevant. However, the inherent problems associated with collecting valid and meaningful sediment data also make this type of measurement very challenging. To circumvent the difficulties associated with field-testing programs, manufacturers have focused on conducting full scale testing in a controlled laboratory environment, with the hope of producing accurate results in a relatively short period of time. By submitting approved laboratory data, many agencies are permitting the manufacturer to sell their unit within their districts while awaiting results from the field tests. Of particular interest is the definition of “approved laboratory data.” Currently, there are no federally mandated acceptance criteria for stormwater units. Hence, each state or local agency is left to develop its own protocols for removal efficiencies and to develop its own set of performance testing matrices. The one protocol that appears to be universally accepted is the 80% sediment removal rate at a determined flow for a given test sediment grain size.

Laboratory Testing Methodology

Established testing protocols typically do not dictate the specific test methodology to be used. Common elements required for testing hydraulic structures that apply to stormwater units include a water supply, head source, transfer conduits, flow controls, and flow measurements. Specifically for stormwater testing, the mechanism for introducing test sediment and the method for establishing the removal efficiency are critically important. These basic components of test setup can be established by any qualified laboratory that is familiar with hydraulic testing. However, there are almost as many methodologies for measuring removal efficiency as there are laboratories trying to satisfy them.

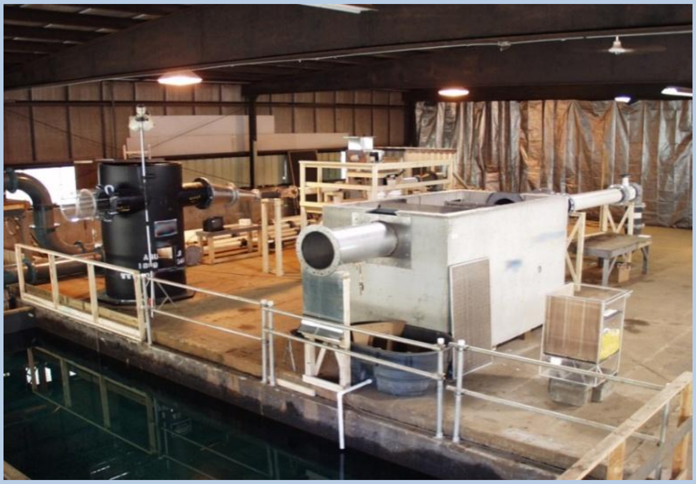


Figure 1: Stormwater testing facility at Alden Research Laboratory

The methods chosen are typically based on the following factors: laboratory space (or lack thereof), costs (equipment and services), and ease of use. The accuracy of test data may be sacrificed by any or all of these factors. In the absence of a standardized methodology, it is up to the test engineer to decide which methods will be used and what level of accuracy will be achieved. This is a critical issue when the regulatory requirement of 80% removal is taken into account. More than one regulator has stated that if the efficiency of a device is 79%, it will not be passed, apparently without regard to the accuracy level of the measurement. This leads us to two crucial questions:

1) "Is 80% really 80%?"
   If the efficiency is actually higher than reported, then the manufacturers are not benefiting from a higher flow rating approved for their device. This could force a manufacturer to either oversize the unit or add more units in order to handle the expected flows at the given site. If, on the other hand, the efficiency is lower than reported, then the regulators are accepting products that do not meet their acceptance criteria.

2) "Is 80% at one lab equal to 80% at another lab for the same device?"
   If two different labs produce two different results, how are we to determine which one is correct? Are differences in methodology responsible for the varying results? This issue makes it imperative that competing devices be tested following the same protocol and the results reported in some consistent fashion, so that the design engineers and end users of the devices will have a true "apples-to-apples" comparison.

Testing Methodologies and Variables

It was stated above that fundamental elements are required in order to test a stormwater device. Some of these elements have a range of methodologies associated with them that could affect testing accuracy, namely flow measurements, the introduction of the test sediment, and the method for establishing the removal efficiency. The Environmental Protection Agency (EPA), American Society of Mechanical Engineers (ASME) and American Society for Testing and Materials (ASTM) standards and guidelines exist for some of the methodologies discussed and will be sited accordingly.

<u>Flow Measurements</u>

There are numerous methodologies available to measure flow in a hydraulic system. Some have a very high level of accuracy, while others have extremely low accuracy levels. Higher cost and sometimes a higher level of sophistication, possibly requiring special training can be associated with higher accuracy. More affordable, low-cost meters, however, may not have the accuracy required to produce reliable data in the laboratory setting. The goal, therefore, is to use a method that produces the accuracy required at an affordable price. The following discussion presents the methodologies most commonly used in a laboratory setting.

Flow meters can be categorized into two basic groups: closed-conduit (full pipe) and open-channel meters. The most common types of closed-conduit meters are known as differential-pressure (DP) meters. These meters utilize the basic principles of conservation of energy and mass; where a change in cross-sectional area results in a change in fluid velocity and corresponding pressure. There are currently no active ASTM standards for governing DP meters. However, the American Society of Mechanical Engineers (ASME) has published the following guideline for fabrication, installation and operation of these meters:

- MFC-3M (2004) Measurement of Fluid Flow in Pipes Using Orifice, Nozzle, and Venturi.

Open-channel flow conditions require the application of velocity-based meters. These include propeller or turbine meters, paddle meters, pitot-static probes, Laser Doppler Velocimeters, Acoustic Doppler Velocimeters, and Electromagnetic Current meters. There are currently a number of active ASTM standards related to open-channel velocity measurements. The more relevant ones are:

- D5389-93(2002) Standard Test Method for Open-Channel Flow Measurement by Acoustic Velocity Meter Systems.
- D4409-95(2003) Standard Test Method for Velocity Measurements of Water in Open-Channels with Rotating Element Current Meters.
- D5089-95(2003) Standard Test Method for Velocity Measurements of Water in Open-Channels with Electromagnetic Current Meters.
- D3858-95(2003) Standard Test Method for Open-Channel Flow Measurement of Water by Velocity-Area Method.
- D5413-93(2002) Standard Test Methods for Measurement of Water Levels in Open-Water Bodies.

Flow within an open-channel can also be measured using fixed control structures such as weirs and flumes. When installed and operated correctly, a weir is an effective device for measuring flow in an open-channel flow regime. However, installing weirs incorrectly and measuring water elevations at the wrong location can seriously compromise the accuracy of the data obtained. Like weirs, a properly constructed flume can measure open-channel flows fairly effectively. Flumes are typically desired for their low head loss, which can range from 10% to 25% of that of a sharp-crested weir. However, flumes have a relatively small band of depths at which they are designed to operate, beyond which the measurement accuracy is reduced. Active ASTM standards related to weirs and flumes are:

- D5640-95(2003) Standard Guide for Selections of Weirs and Flumes for Open-Channel Flow Measurement of Water.
- D5614-94(2003) Standard Test Method for Open-Channel Flow Measurement of Water with Broad-Crested Weirs.
- D5242-92(2001) Standard Test Method for Open-Channel Flow Measurement of Water with Thin-Plate Weirs.
- D5390-93(2002) Standard Test Method for Open-Channel Flow Measurement of Water with Palmer-Bowlus Flumes.
- D1941-91(2001) Standard Test Method for Open-Channel Flow Measurement of Water with the Parshall Flume.

The primary method for flow measurements that can be conducted on both closed-conduit and open-channel systems is the volumetric or gravimetric method. This is performed by timing the collection of effluent into a vessel and either determining its volume or weight per unit time. The gravimetric method is the more accurate of the two. However, a large capacity system (preferably with an automatic switch way and timer) is required to achieve a significant level of accuracy at higher flows. For this reason, these methods are typically only used as secondary verification for flows under 20 gpm.

A common but undesirable methodology for setting a flow is the constant-head method. This is used with a closed-conduit system of known diameter and an elevated constant-head source of known height. A theoretical flow can be calculated using the known parameters and velocity-head equation. However, care must be taken to account accurately for all the losses within the system to achieve a desired result.

All of the above methods have varying accuracies (<±1% to >±5%) associated with them under ideal conditions. Two additional factors can further impact these accuracies: the methodology and frequency of data recording. Computerized Data Acquisition (DA) systems can continuously monitor and record data, allowing fine adjustments to be made (if necessary) to assure flows stay within a desired tolerance throughout the duration of the test.

Introduction of Test Sediment

The method of introducing the test sediment into the influent line is one of the most crucial parameters affecting stormwater testing accuracy. Most stormwater protocols for laboratory testing require a sediment inflow concentration of 100 to 300 mg/l. How and where the test sediment is introduced into a system can significantly impact the test's outcome. Two common but very different approaches for introducing sediment are dry injection and pumped slurry. Each method requires special equipment and careful preparation in order to maintain control over the influent concentration.

Dry injection requires a device such as a variable-speed auger or screw feeder to control the feed rate of the sediment. More than one screw size may be required to meet the injection rates needed for a range of flows. Each feed screw must be calibrated with the test sediment through the entire range of control speeds in order to establish a relationship between the screw rotation rate and the sediment injection rate. These straight-line relationships will allow an accurate and consistent sediment feed rate for any given test flow. The unit also requires an adequate storage hopper to guarantee a constant supply of sediment throughout the duration of the test.

The second approach is to introduce the sediment as slurry. This method requires that a predetermined amount of sediment be mixed with a known volume of water in a separate tank, which is then pumped into the influent pipe at a known rate. While in the tank, the slurry needs to be continuously mixed in order to maintain its concentration uniformity. A calibrated peristaltic-style pump is needed to pump the slurry into the influent line at the appropriate feed rate. The question of homogeneity is always an issue when dealing with slurry mixtures. Because the mixing system is dynamic, it may not be possible to ensure that the injected concentration will remain within acceptable limits throughout the test.

A key unknown for both injection methodologies is the phenomenon of air attachment to the sediment particles, which reduces the particle fall velocity. While some argue that dry-injection encourages the attachment of air, whereas wet injection does not, air is typically present in water at some level and may be increased by outside factors, such as pumps and mixers during wet injection. The amount of air attachment to the sediment due to its injection state (wet or dry) or interaction within the slurry tank or influent pipe is unknown at this time. Therefore, the affect of air attachment on the accuracy of these methodologies requires additional study.

The location at which the sediment is injected can greatly affect the accuracy of the test results. This is especially true when the sampling of the influent line is part of the experimental protocol (see below). Introduction of the sediment through the crown of the pipe allows better dispersion through the water column and increases the chance for uniform and consistent samples. Sediment that is introduced at the invert of the pipe will tend to travel as bed load, resulting in sample concentrations that may be higher or lower than the target, depending on the method of sampling. Another variable is the injection location along the pipe in relationship to the sample port. If the injection port is too far upstream or downstream, either excessive settling of the material will occur or the sediment will not have the opportunity to become fully mixed within the water column.

Establishing the Removal Efficiency

There are two ways to establish the removal efficiency of a test unit: the indirect method (sampling) and direct method (mass balance). Each method possesses its own inherent challenges in establishing accurate removal efficiencies. This test component, more than any other, has the greatest influence on the accuracy of the efficiency rating for a given unit.

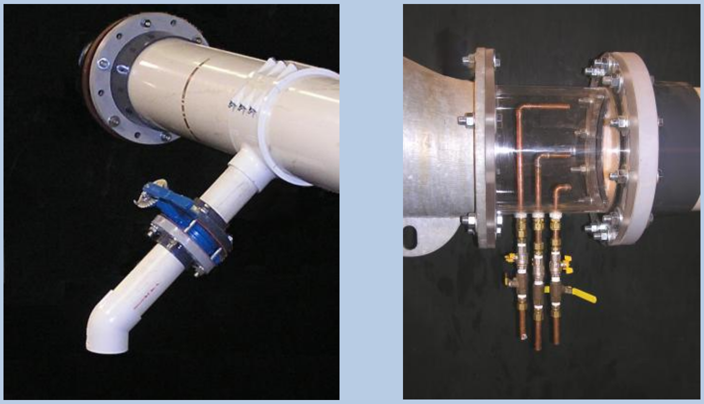
Indirect Method

The indirect method requires samples to be taken from both the influent and the effluent piping. The concentration (mg/l) of each sample is established using standard methods (see below) and the overall efficiency is determined. While this may appear straightforward, there are as many ways to collect the samples as there are labs collecting them. One of the more popular sampling methods is through the use of automatic samplers. This method is reported to be vulnerable to blinding if the sediment particle size is too large. Another method is to use a sampling pipe oriented either horizontally or at a downward angle off the main influent pipe. The sample pipe or port is equipped with either a slide gate or butterfly valve, which must be flushed just prior to collecting the sample. There are inherent problems with this type of system. First, the port is flush with the pipe wall; thus the sampler preferentially collects material that is traveling along that region. A second challenge is the question of how much to open the valve when drawing the sample. If the valve is opened too much, an excessive amount of material may be drawn into the sample, overestimating the concentration. The opposite is true if the valve is opened too little. A fairly consistent method of determining the sediment concentration is isokinetic sampling. This is performed by installing an array of rigid sampling tubes facing into the flow and setting the velocity in each tube to match the flow velocity at that location within the pipe. The number of tubes used is generally dependent on the sample tube and pipe diameters. The tubes are equipped with control valves for setting the target flows. A preliminary calibration must be performed on each sample tube prior to testing to match the target flow velocity.

Collected samples are processed and analyzed for sediment concentrations using one of two methods: Total Suspended Solids (TSS) and Suspended Solid Concentration (SSC). TSS is a methodology that is widely used for determining the concentration of organics in a sample. The sample is mixed thoroughly and then split into smaller sub-samples for analysis. The drawback to this method is that it is difficult to keep the sediment fully suspended while the sample is being split, resulting in sub-samples that are not accurate representatives of the original sample. The second method, SSC, uses the entire sample in the analysis, resulting in higher accuracy of the collected sample analysis.

EPA and ASTM standards related to sediment analysis are:

- TSS – EPA Method 160.2
- Standard Method 2540D
- SSC – ASTM D3977-97(2002) Standard Test Methods for Determining Sediment Concentration in Water Samples.



a) sampling pipe b) isokinetic sampling

Figure 2: Images depicting indirect sampling methods.

Direct Method

The direct (mass balance) method is an accounting of all the sediment within the system including the total mass injected, the total mass captured, and the total mass in the effluent. The primary difficulty of this method lies in collecting the fully suspended sediment from the effluent flow. Even at low flows, this is no small task and usually requires a large investment on the part of the testing laboratory or manufacturer, becoming untenable at higher flows approaching 1 cfs because of the enormous facility space required for material settling. Therefore, a modified form of mass balance is often utilized. This simplified method only accounts for the material introduced into the system and captured by the test unit. This is accomplished by weighing the injection system before and after the test to determine the injected mass, and collecting, drying and weighing the captured sediment from the test unit. The ratio of the captured to injected mass yields the removal efficiency of the unit and the remainder is assumed to have been carried out by the effluent. There is currently no known standard for this simplified approach.

Towards an Industry Solution

On June 3rd, 2008, a group of water quality industry leaders gathered on the Alden Research Laboratory campus to help establish the Stormwater Equipment Manufacturers Association (SWEMA). The formation of this organization was a landmark event for the water quality industry, as the group will address the concerns outlined above.

Figure 3: Inaugural Meeting of Stormwater Equipment Manufacturers Association (SWEMA) June 2008.

The meeting for the formation of the association was initially envisioned by John Moll of CrystalStream Technologies. He was joined by many others who felt the need for such an organization. The new association is anchored by the following companies: AquaShield Inc., Best Management Products, Inc. (The Snout), Bio-Clean Environmental Services, Inc., BaySaver, Inc., Contech Stormwater Solutions, CrystalStream Technologies, Cul-Tech, Inc., Environment 21, LLC, Hydro International, KriStar Enterprises, Inc., Imbrium Systems Corporation (Stormceptor), Rinker Materials, Royal Environmental Systems, Inc., StormTech, LLC, StormTrap, LLC, and UltraTech International, Inc. The founders presented their association for others to join as charter members at StormCon 2008 in Orlando.

Through this collaboration from so many stormwater treatment leaders and competitors, along with local and federal regulators, it is hoped that a common protocol for stormwater testing can be achieved.

Summary

The presence of suspended solids in storm water runoff has become a recognized environmental problem in recent decades. Significant technological advances have been made in the design of treatment devices that separate solid material from storm water, but there remains a lack of clarity in the performance of these systems, because while there are many testing methodologies with varying degrees of accuracy in practice, there has not been a uniform protocol for testing. Luckily, the industry is now recognizing that this confusion is limiting the benefits of the new technology and the business growth of the technology vendors. With the recent formation of the Stormwater Equipment Manufacturers Association (SWEMA), it is hoped that interaction between vendors and regulators will result in a common testing protocol that will allow municipalities to choose the best BMP for their various applications, thereby leading to higher water quality and enhanced industry growth.

Jim Mailloux is a hydraulic engineer with over 18 years of experience in physical modeling and testing. He is responsible for engineering and model design, procurement of materials, supervision of construction and testing, instrumentation, data acquisition and analysis, as well as preparing proposals, presentations and reports. He currently serves on the ASTM and ASCE/EWRI Stormwater Testing Standards Committees.

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[i] Center for Streamside Studies, 1991, College of Forestry and College of Ocean and Fishery Sciences, University of Washington Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska, EPA/910/9-91-001

[ii] James, Roger B. 1999. Solids in Storm Water Runoff. http://www.stormwaterauthority.org/assets/45solids.pdf.