Guidance for Improving Monitoring and Analysis Methods for Stormwater-Borne Solids

Recommandations pour l'amélioration des méthodes de mesure et d'analyse des solides provenant des rejets pluviaux

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RESUME

Une grande partie de voies d'eau altérées sont localisées dans ou à proximité de secteurs urbains et sont affectées par les solides présents dans les ruissellements d'orage. Aux USA, les méthodes actuelles de prélèvement, manipulation, et analyse de ces solides ne permettent pas une bonne compréhension de leurs effets sur les eaux réceptrices. Ce rapport présente des définitions communes et des procédures analytiques normalisées permettant de faciliter la compréhension des impacts de ces solides et la sélection des meilleures pratiques de gestion des eaux pluviales. Les solides de précipitations exceptionnelles peuvent d'abord être classés par granulométrie - solides dissous, fins, moyens et gros. Ils peuvent ensuite être classés selon leur capacité de décantation ou de mise en suspension par le biais d'une période de stabilisation au cours des analyses. Nous recommandons un protocole analytique de pointe pour standardiser les travaux de recherche et les actions de contrôle des eaux pluviales.

ABSTRACT

A large portion of impaired waterways are located in or near urban areas and are adversely influenced by stormwater-borne solids. The current methods in the United States for sampling, handling, and analyzing stormwater solids do not lead to a good understanding of these effects on receiving waters. Common definitions and standardized analytical procedures are recommended in this report to aid in understanding solid impacts and selection of stormwater best management practices. Stormwater solids can first be classified based on size into Dissolved, Fine, Coarse and Gross Solids. These solids can further be classified as settleable or suspended by allowing a settling time in the analytical procedure. An improved analytical protocol is recommended in order to standardize research and stormwater monitoring efforts.

KEYWORDS

Total Suspended Solids, Suspended Sediment Concentration, Gross Solids, Stormwater Monitoring, Water Quality.

1 INTRODUCTION

A large portion of impaired waterways are located in or near urban areas and are adversely influenced by stormwater-borne solids. Stormwater runoff transports dissolved, suspended, floating, washload and settleable solids that potentially negatively impact the ecology, geomorphology, and water quality. This paper concentrates on stormwater solids from surface runoff; it does not include analysis on combine sewer solids. Associated pollutants on the particulates may include heavy metals, phosphorus, nitrogen, pesticides, oxygen demanding substances (Woodward-Clyde 1999) and other complex substances. It is well recognized that solids transported in stormwater runoff have negative impacts to receiving water including loss of aquatic habitat, channel instability, and the transport of harmful pollutants potentially hazardous to human and ecosystem health (Pitt, 2001; Roesner and Bledsoe, 2003; Wolman, 1967; Roberts, 1989; Booth and Jackson, 1997; Maxted and Shaver, 1997; Wang and others, 2001; Sansalone and Buchberger, 1997; Ashley and others, 2004). Although these negative impacts are understood, there lacks a universal consistent definition of the stormwater solids, method of sampling, and analytical procedure. A clear method for consistent solids definitions, sampling, and measuring solids is deemed necessary for improving stormwater management.

Stormwater solids can first be classified by a size separation. *Gross Solids* include trash, litter, debris, and gravel sized sediment that travel as bedload, suspended, or floating in stormwater. These larger solids degrade aquatic habitat, smother productive sediments, leach harmful pollutants, and are an aesthetic problem (Rushton and others, 2006 Draft Report). Aquatic organisms can become entangled or ingest Gross Solids causing fatalities. *Coarse Solids* are large particles that can travel in suspension or as bedload. Sediment deposition may alter spawning habitats and make fish unable to lay eggs. Deposited particles may obscure sources of food, habitat, hiding places, and nesting sites (Wilber, 1983). *Fine Solids* can travel in suspension, and are typically settleable depending upon their density and size. Fine solids and coarse solids are often attributed to transporting harmful pollutants which can potentially bioaccumulate or cause chronic problems in organisms. In addition, fine solids degrade habitats by increasing turbidity which reduces light penetration. This negatively impacts photosynthetic organisms and can affect predator-prey relationships by decreasing visual abilities. In addition, fine and coarse solids can infill spaces between larger solids in river beds needed for habitat (Lenat, 1984; Waters, 1995; Snodgrass and others, 1997; Simons and Senturk, 1991) causing less diverse aquatic populations. Fine solids can also cause gill clogging, choke filter mechanisms on filter-feeding invertebrates, and clog feeding mechanisms of some zooplankton (McCabe and Sandretto, 1985). Finally, *Dissolved Solids* comprise fine clays, colloidal materials, microorganisms, bacteria, and dissolved chemicals. It is generally difficult to remove dissolved solids from stormwater runoff using BMPs relying on filtration or sedimentation.

The irregular intensities of rainfall make it difficult to predict runoff rate, pollutant transport, sediment deposition and re-suspension, channel scour, etc. Pollutant sources in the areas such as landscape practices, spills, construction activities, and vehicle use drastically alter the solids load in terms of mass, timing and composition. It is not surprising that pollutant characteristics can be very different from location to location as well as from storm event to event. Therefore, it is difficult to target one size of solid as the most problematic. Site specific investigation should be done and a specialized monitoring plan developed to meet the specific goals.

Current methods in the United States for describing stormwater solids include Total Suspended Solids (TSS) and Suspended Sediment Concentration (SSC).

The primary difference between TSS and SSC is that TSS requires the withdrawal of a subsample, while SSC analyzes the entire sample. Although both TSS and SSC require a filtration and evaporation, it is important to note that even though SSC and TSS values are often used interchangeably, the analytical methods are very different and therefore the two terms should not be substituted for one another (Gray and others, 2000). Neither the TSS nor SSC analytical procedure attempts to distinguish rapidly settling solids from solids that will remain in suspension. Reporting settleable solids offers a lot of information on the transportation, treatment, and ultimate fate of solids transported in stormwater runoff.

A common definition and standardized analytical procedure is outlined in this report to aid in understanding solid impacts and selection of stormwater best management practices. The purpose of the study is to complete a literature review of current stormwater monitoring practices and develop a draft protocol addressing analysis and reporting practices to examine stormwater-borne solids in order to improve assessment and monitoring protocol.

2 METHODS

An extensive literature review was conducted to summarize the current methods for sampling, handling and analyzing stormwater solids. There are several immediate concerns with respect to stormwater solids. These concerns are addressed in this section.

There is currently no single internationally recognized standard for classification of solids (dissolved, suspended, gross, settleable, and floatable). This makes it problematic to implement stormwater management techniques and compare research results. In particular, data regarding Gross Solids sampling, handling and analysis is limited and often inconsistent. The minimum size limitation in the literature varies between 75 µm (Rushton and others, 2006 Draft Document) to 20 mm (Armitage and Rooseboom, 2000a, 2000b) (Butler and others, 2002; Allison and others, 1998; Cornelius and others, 1994). A common definition of size that differentiates Dissolved, Fine, Coarse and Gross Solids is needed.

In the United States, the filter size used to distinguish “TSS” from “Total Dissolved Solids (TDS)” is not consistent from laboratory to laboratory. An inconsistent filter size is a problem because the use of a standard 2 micron filter will produce different results than using a 0.45 micron filter (commonly used to analyze TSS), but any size smaller than 2 µm is acceptable according to the APHA Standard methods for the Examination of Water and Wastewater (SM 2540, 1998) test protocol. In addition to filter size, there are inconsistencies with mixing speed and subsample withdrawal location that result in discrepancies.

SSC provides a more accurate result for the solids in water than TSS because of the error associated with subsampling. TSS usually under-predicts the solids actually in the sample (Gray and others, 2000; Bent and others, 2001). There is a problem with changing the standard test to SSC because a relatively small proportion of larger particles can comprise the majority of mass and volume of the total solids in the sample. In addition, stormwater solids traditionally have reported solids concentration as TSS. Using SSC in place of TSS analysis would allow for percent removal efficiencies to be met by only capturing larger particle, which will not result in the same water quality impacts as removing the smaller particles that are associated with transporting harmful constituents to the waterways.

Using the information obtained from the literature review a classification of stormwater solids is proposed. The analytical procedure used in the United States was investigated and a draft protocol was developed to quantify the concentration of solids. The analytical procedures within are recommendations based on existing literature and have not been tested for validation, but should serve as improved guidelines for future research.

3 RESULTS AND DISCUSSION

3.1 Classification

As described above, solids in stormwater should be classified into four size fractions: Gross, Coarse, Fine and Dissolved Solids, based on ecologic impact, geomorphic considerations, and the ability to sample and treat the solids. Physical separation can be used to measure the size fractions of each of these four classes of solids in a stormwater sample. These solids can then be further classified as settleable and non-settleable, and volatile or non-volatile to further identify the impacts the solids have on receiving waters. It is proposed that Gross Solids be defined as the solid material that can be captured on a 5 mm screen because this size represents the separation between coarse sand and gravel (ASTM Standard D 2487-92). A 5 mm size classification is also consistent with studies in Australia (Allison and others, 1998) and California (Sullivan, 2005) on Gross Solids. It is also convenient since the No. 4 sieve in the US standard sieve size corresponds to 4.75 mm (close to 5 mm) and the size also is appropriate for sampling Gross Solids in the field using a net or screening device. Gross Solids can further be divided into three classifications; litter, debris, and coarse sediment. Litter includes human derived trash, such as paper, plastic, Styrofoam, metal, and glass. Debris consists of organic material including leaves, branches, seeds, twigs, and grass clippings. Coarse sediments are inorganic breakdown of soils, pavement and building material (Rushton and others, 2006). Separation into these classes can be done by visual separation if the monitoring program requires it.

Coarse solids are recommended to include the solid material greater than 75 µm and less than 5 mm including sand and silt size particles. These solids are attributed with sedimentation destroying habitat, smothering benthic organisms, and transporting toxic elements into the ecosystem. Particles larger than 75 µm are generally not effectively collected using automatic water quality samplers therefore a combination of bedload samplers and autosamplers may be needed to sample this size range. The No. 200 mesh in the U.S. standard sieve size corresponds with 75 µm and is considered the separation between clay and silt and fine sand (ASTM Standard D 2487-92).

Fine solids are recommended to include the material that passes through the No. 200 sieve in the U.S. standard sieve size (75 µm) but is retained by a 2 micron filter (Whatman grade 934AH or equivalent). Fine solids are commonly transported as suspended solids and attributed to increased turbidity, transporting harmful toxins into the ecosystem, and embeddedness characteristics. A diagram of this solids classification is shown in Figure 2-1.

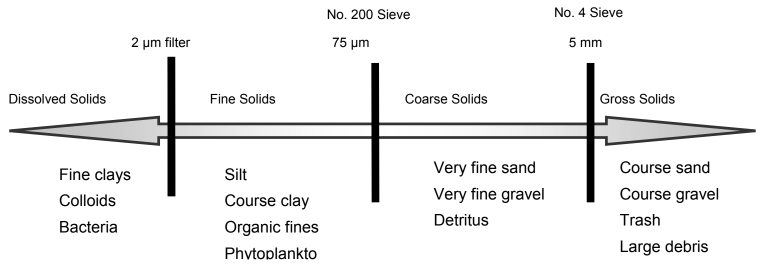

Figure 1. Size Classification of Stormwater Solids

3.2 Analysis

Inconsistencies in the current methods to analyze TSS include mixing speed, pipette location, and pipette size. The TSS and settleable solids test were originally designed to analyze wastewater. Solids in wastewater typically have a specific gravity near 1.0, therefore requiring little agitation to become completely mixed. Particle density in urban runoff is generally much higher, ranging from 1.0-2.86 g/cm^3 (Karamalegos and others, 2005), and in most cases, stormwater particulates have specific gravities in the range of 1.5 to 2.5 (Pitt, 1979). Sample mixing is not sufficient to keep sand or heavier material in suspension when withdrawing a subsample (Kayhanian and others, 2006).These particles with higher densities require more aggressive mixing to prevent solids settling. The Standard Methods for Examining Water and Wastewater does not specify a mixing speed or pipette size before taking the subsample.

The pipette sampling point within the sample varies with individual researchers and differences in pipette orifice size limits the size of solids that can be sampled. The pipette orifice size limits the solids that will be sampled. If the subsample is withdrawn using a pipette that is too small it may clog and prevent a representative amount of solids to be sample. In contrast, if the pipette is too large, solids may settle out of the pipette when the energy of mixing is lost. These issues can markedly alter the solids recovered in the subsample. It is recommended that at a minimum the protocol for performing the current TSS method be revised to include an identified mixing speed and pipette for standardization purposes.

Based on the literature review (Stenstrom, personal communication, 2006; and Kayhanian and others, 2006), it is recommended that the sample be mixed with a magnetic stirrer at a speed of 600 rpm in order prevent settling. Prolonged mixing may result in a change of particle size, therefore it is recommended to mix for no longer than one minute before taking the subsample. It should be noted that as particle size increase, it is increasingly harder to keep the solids well mixed. For example, solids with a diameter less than 100 µm have a higher percent recovery than solids with a diameter greater than 250 µm with the same density and mixing speed. The sampling should be done with a wide bore pipette or sewage pipette from *mid-depth* in the sample. TSS aliquots collected from the upper section tend to be biased low, while aliquots collected from the lower section tend to be biased high because of settling and the inability to maintain a well mixed sample. Kayhanian and others (2006) found lateral concentration gradient was observed in a study to improve the method of suspended solids measurements with higher TSS concentrations near the wall of the sample container and lower TSS concentrations near the vortex. It was concluded that the sample should be taken midway between the vortex and the wall of the container.

Better mixing and a large mouth pipette dramatically improve recovery (Stenstrom, personal communication, 2006). A summary of the improved TSS analysis is listed below.

- Mix sample using a magnetic stirrer for one minute at 600 rpm
- Use a large bore pipette
- Withdrawal the subsample from mid-depth and midway between the vortex and the wall of the container (Kayhanian and others, 2006).
- Use a consistent 2 µm filter (Whatman grade 934AH or equivalent)

The preferred recommendation for analysis of stormwater solids is to perform an SSC analysis to determine the total concentration of solids in the water sample followed by a TSS analysis which allows a short settling time to allow for rapidly settlable solids to separate from solids that will remain in suspension. A draft protocol was developed to allow a settling time prior to filtration in the TSS analytical procedure to address the solids ability to rapidly settle out of suspension. This procedure would include mixing the sample for one minute at 600 rpm followed by a 5 minute settling time (similar to Stahr and Urbonas, 1990) to allow for coarse solids separation. A subsample would then be withdrawn from the midpoint of the container in a similar manner as described in the TSS analysis. The residue on the filter would represent the solids that would remain in suspension while the difference between the traditional SSC analysis and the TSS allowing a settling time would represent the solids that would rapidly settle out of suspension. Adapting the TSS procedure to allow coarse separation may better represent the solids that will remain in suspension offer incite into transportation and treatment methods. A figure showing how solids can be classified by size and analytical procedure is shown in Figure 3.2.1.

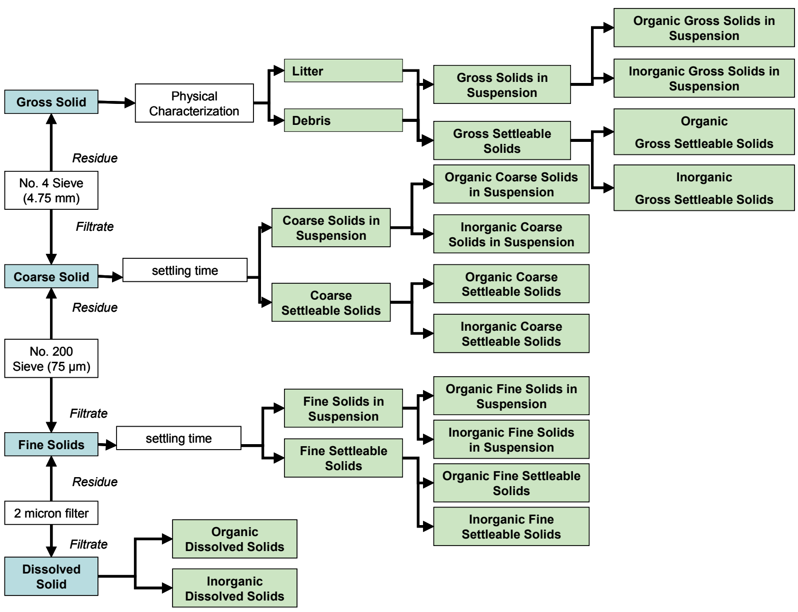

Figure 2. Solids Analytical Classification Diagram

4 CONCLUSION

Stormwater-born solids degrade water quality, ecologic habitat, aquatic plants and animals, and may cause direct harm to humans. While the potential impacts of various stormwater-borne solids are recognized and regulatory action is being taken, progress is hindered by the lack of common definitions or standardized monitoring procedures. This document has summarized the current state of stormwater solids characterization and analysis techniques. From a literature review and studied environmental impacts of solids on receiving waters, a common definition of solids based on size was developed for dissolve, fine, coarse, and gross solids. It is recommended that other researchers examine and test the protocols to arrive at an international standard for classifying stormwater solids.

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