Percentage Removal of (TSS) Claims for Hydrodynamic Separators Hinder NPDES Phase II Goals

Hans de Bruijn
Terre Hill Stormwater Systems
A Division of Terre Hill Concrete Products
Terre Hill, Pennsylvania

The EPA has estimated that 281 million people, approximately 94% of the population, live within ten (10) miles of an “impaired body of water”.

The Federal Water Pollution Control Act, commonly referred to as the “Clean Water Act” (CWA), 33 USCA § 1342, as amended by the Water Quality Act (WQA), required the EPA to establish regulations for the administration and enforcement of these laws.

The WQA extended the requirement for NPDES Permits to “non-point source” discharge locations.

The EPA responded by issuing the NPDES Phase II Regulations on December 8, 1999. Municipalities operating Municipal Separate Storm Sewer Systems (MS4s) and construction sites consisting of one (1) acre or more were included.

The NPDES program mandate is to “preserve, protect and improve the nation’s water resources” from polluted stormwater runoff. Operators of Municipal Separate Storm Sewer Systems, (MS4s), are required to remove pollution to the “maximum extent possible”.

In response to this regulatory mandate, several companies entered the market with hydrodynamic separator stormwater treatment devices. To date, vendors promote their product by publishing its Percentage Removal of TSS Rates.

This paper will explain why reliance on these claims hinder attainment of the NPDES program goals.

Several states have established independent verification programs to certify the performance claims of vendors of hydrodynamic separator stormwater treatment devices. The purpose of these programs is to ensure that the products offered for sale can be reliably compared with the various device performances of other products, so that the engineering community can make a reasonable selection of device size and design to satisfy ; the specific project site requirements.

The focus on verification and certification of hydrodynamic separator stormwater sediment removal devices has been stated as a Percentage Removal of TSS. It is not clear whether this criteria for establishing performance was derived from vendors performance claims or whether vendors performance claims were modified in response to regulatory initiative
Regardless of its origin, publication of a Percentage Removal of TSS performance claim without detailed information concerning the conditions existing at the time of the verification test is not useful or comparable, and may, in fact, be misleading. Clearly verification of NPDES goals is problematic.

For example, Percentage Removal of TSS of 50% with influent containing sediment with a d50 of 1000 µm and a flow rate of 1cfs cannot be compared to a device with a Percentage Removal of TSS of 50% with influent containing sediment with a d50 of 75 µm and a flow rate of 10 cfs.

Obviously, Percentage of TSS Removal Rate, without reference to uniform constant conditions, is not useful and does nothing to advance the goals of the NPDES Program.

Sediment removal from stormwater, described in its most simple terms, requires that sediment particles sink more rapidly than the rise rate of the stormwater flow within which the particle is located.

Sedimentation removal efficiency of particles in a stormwater flow is determined by several physical laws of nature:

a) **Gravity**: The downward force drawing the particle vertically down

b) **Shear Stress**: Gravity force on the particle, parallel to the sedimentation surface

c) **Normal Stress**: Gravity force on the particle, perpendicular to the sedimentation surface

d) **Friction**: Coefficient of friction is determined by the surface texture of the particle

e) **Particle Density**: Sedimentation of a particle requires a particle density greater than the density of the Stormwater flow

f) **Kinematic Viscosity**: Measure of a liquids inability to flow (water has unusually high viscosity)

g) **Particle size**: Measure of degree that affects the sinking velocity exponentially.

h) **Temperature**: Inversely related to viscosity

i) **Polarity**: Can cause flocculation

The above physical references to nature are constants that behave in a consistent law like mannerr. They apply uniformly in all stormwater flow analyses.

In addition to the laws of nature important variable stormwater characteristics need to be identified, before Percentage Removal of TSS has any value. These variable are :

1. TSS Influent Characteristics

a) **Mean Influent Sediment Concentration** of the sediment in the stormwater flow is important to quantify. Typical rainfall events result in stormwater runoff containing sediment concentrations from 100 mg/L to 300 mg/L. Thus, influent test samples taken, either in laboratory conditions or during field testing, should reflect levels of mean sediment concentration within this range. If the influent mean sediment concentration level exceeds 300 mg/L, then any hydrodynamic separator stormwater treatment device performance claim based upon test samples taken from the effluent will be unfairly reported at a higher Percentage Removal of TSS result than that which would actually be attained under the above stated typical stormwater mean concentration levels. This result will continue to be skewed in direct proportion to the level by which the test influent exceeds the target mean influent sediment concentration levels.

b) **Mean Particle Size Distribution** should not exceed 100 µm for the total amount of sediment contained in the above stated Mean Influent Sediment Concentration levels. If the Mean Particle Size Distribution is greater than 100 µm then, again, any water quality sediment removal percentage of TSS removal claim will be unfairly reported at levels than that which would actually be attained during typical rain events. This skewed result will continue in direct proportion to the level by which the Mean Particle Size Distribution exceeds 110 µm.

c) **Flow Rate and Volume** of the influent during any sampling event also significantly affects the resulting Percentage Sediment Removal Rate. The lower the flow rate of the influent stream, the higher resulting Percentage Sediment Removal Rate, that can be attained. Thus, at lower flow rates, greater sediment removal rates will be attained, at any Mean Sediment Concentration Level and any Mean Particle Size Distribution. The slower the stormwater flow rises the probability of greater sediment removal by sedimentation increases.

The testing protocol used to determine the Percentage of TSS Removal Rates of a hydrodynamic separator is critical and must be consistently applied to obtain results for each device that allows for useful comparisons.

In a laboratory environment, samples can be drawn manually by causing the respective flows to be captured in sterile containers. The placement of the sample container, relative to the flow, (e.g. top or bottom right or left) can significantly affect the influent and effluent sediment particle size distribution and concentration levels actually sampled. This is so because the size and coarseness of a particle determines where in the vertical column of the water flow the particle will be carried. Thus, the captured samples may not come from or reflect a representative portion of the stream. The non-representative samples can result in accumulation of inaccurate data which will result in inaccurate test results.

In field tests, where there is no control of particle size distribution or concentration levels, the samples captured by automatic samplers must be analyzed to establish this data. Again, the placement and the reliability of the sampling equipment will have a significant impact on the final test results. A site with concentration levels higher than 300 mg/L may result in higher Percentage Removal of TSS Rates than the tested device would attain at normal stormwater concentration levels; which concentration levels are normally between 100 mg/L and 300 mg/L.

The samples must then be analyzed by conducting tests to establish the Percentage of TSS Removal Rate. Depending on the test method used different results may be obtained even when applied to the same sample. This is yet another variable that may affect Percentage of TSS Removal Rates.

The New Jersey Corporation for Advanced Technology (NJCAT), and the New Jersey Department of Environmental Protection (NJDEP) have established testing and analysis protocol for verification and certification of vendor performance claims of hydrodynamic separators for TARP TIER I purposes. This protocol is as follows :

a) Mean Sediment Concentration between 100 mg/L and 300 mg/L; with the average being 200 mg/L;

b) Mean Particle Size Distribution :

a.	500- 1000 µm (coarse sand)	05%
b.	250- 500 µm (medium sand)	05%
c.	100- 250 µm (fine sand)	30%
d.	50 – 10 µm (very fine sand)	15%
e.	8 – 50 µm (silt)	25%
f.	2- 8 µm (silt)	15%
g.	1- 2 µm (clay)	05%

c) Test Methods :
   a. Laser Diffraction
   b. Visual Accumulator
   c. Pipette Method
   d. Coulter Counter
   e. Wet Sieve
   f. Serial Filtration
   g. ASTM D-3977 : Suspended Solids Concentration (SSC)

h. EPA 160.2 : Total Suspended Solids (TSS)
i. SM 2560 Particle Size Distribution (PSD)

Even though NJCAT has established these detailed criteria for product performance verification; a close review of the vendor verifications submitted and the verification and certification results issued by NJCAT and NJDEP reveal inconsistencies in the process. For example, some products received certification even though their data was not collected using the defined protocol. In at least one instance the failure to follow protocol was compounded by the submission of the data without independent third party verification.

The NJCAT and NJDEP experience shows how difficult it is to begin and administer a certification program. Early entrants followed different parameters and both NJCAT and NJDEP , to their credit, made equitable adjustments to balance the equities for the vendor and the public.

Only in a controlled laboratory setting, with identical parameters established and maintained throughout the sampling and analytical testing procedures, all of which are performed by an independent verifying entity, can the Percentage Sediment Removal Rate be useful for relative comparison of competing hydrodynamic separators.

The sales and marketing claims of vendors of various hydrodynamic separator water quality devices, are based on data that was gathered using different sediment concentrations, particle size distribution, sampling, and analysis. In addition, some claims are not supported by independent third party verification. Thus, at present, some published Percentage Removal of TSS Rates are not useful in comparing the relative effectiveness of water quality devices and provide little, if any, useful data to assess whether or not the goals of NPDES are being attained.

Until uniform, defined testing and verification protocols are established and enforced the present reliance on Percentage Removal of TSS Rates will continue to have the following negative impacts :

a) NPDES Phase II goals are frustrated as the preservation, protection and improvement of the nation's water resources are compromised;

b) Removal of stormwater pollution to the "maximum extent practicable" is misstated as performance claims are overstated;

c) The burden on the public is increased as the ultimate responsibility for implementation and attainment of NPDES Phase II goals rest with local government. .Whether an operator of a combined sewer system suffering from combined sewer overflows (CSO); or a Municipal Separate Storm Sewer System,(a MS4), as identified in the NPDES Phase II regulations, the water quality of the effluent at each municipal owned or controlled outfall (which bears the burden from all upstream water quality treatment devices overstated performance claims) will be the logical locations for enforcement of NPDES regulations.

How can protection of the general health, safety and welfare of the public and attainment of the NPDES goal of preservation, protection and improvement of our natural water sources be to the "maximum extent practicable" be promoted and verified with reasonable assurance?

The laws of nature are immutable. Gravity, stress forces, friction, density and kinematic viscosity, particle size, temperature and polarity have constant effects upon the sedimentation process.,. Stokes Law and the Hjulström Diagram take into account these various forces and are proven formulae for the calculation of particle settling characteristics in a flow of water.

Sir George Gabriel Stokes in the 1840s developed Stokes Law. This is an equation relating the terminal velocity of a smooth, rigid sphere in a viscous fluid of known density and viscosity to the diameter of the sphere when subjected to a known force field.
Under Stokes Law, the settling speed of a particle in a particular liquid is directly proportional to its radius squared and gravity acceleration. Thus, if Particle Size Distribution, Influent Concentration and Flow rates are established, using Stokes Law, the Percentage of TSS Removal Rate can be reasonably predicted.

The Hjulström Diagram plots 2 curves :

a) First curve plots the minimum stream velocity required to erode sediment of varying sizes from a stream bed;

b) Second curve plots the minimum stream velocity to continue to transport sediment of varying sizes

c) Second curve illustrates that density of particles below 20 micron cannot be efficiently removed by a hydrodynamic separator. The water turbulence prevents the small particle's settling.

Using this Diagram, it can be predicted whether a particle settles, stays in suspension, or erodes depending on the size of the particle and the flow rate. Thus, just as with Stokes Law, the Percentage of TSS Removal Rate can reasonably be predicted if Particle Size Distribution, Influent Concentration and Flow Rates are known.

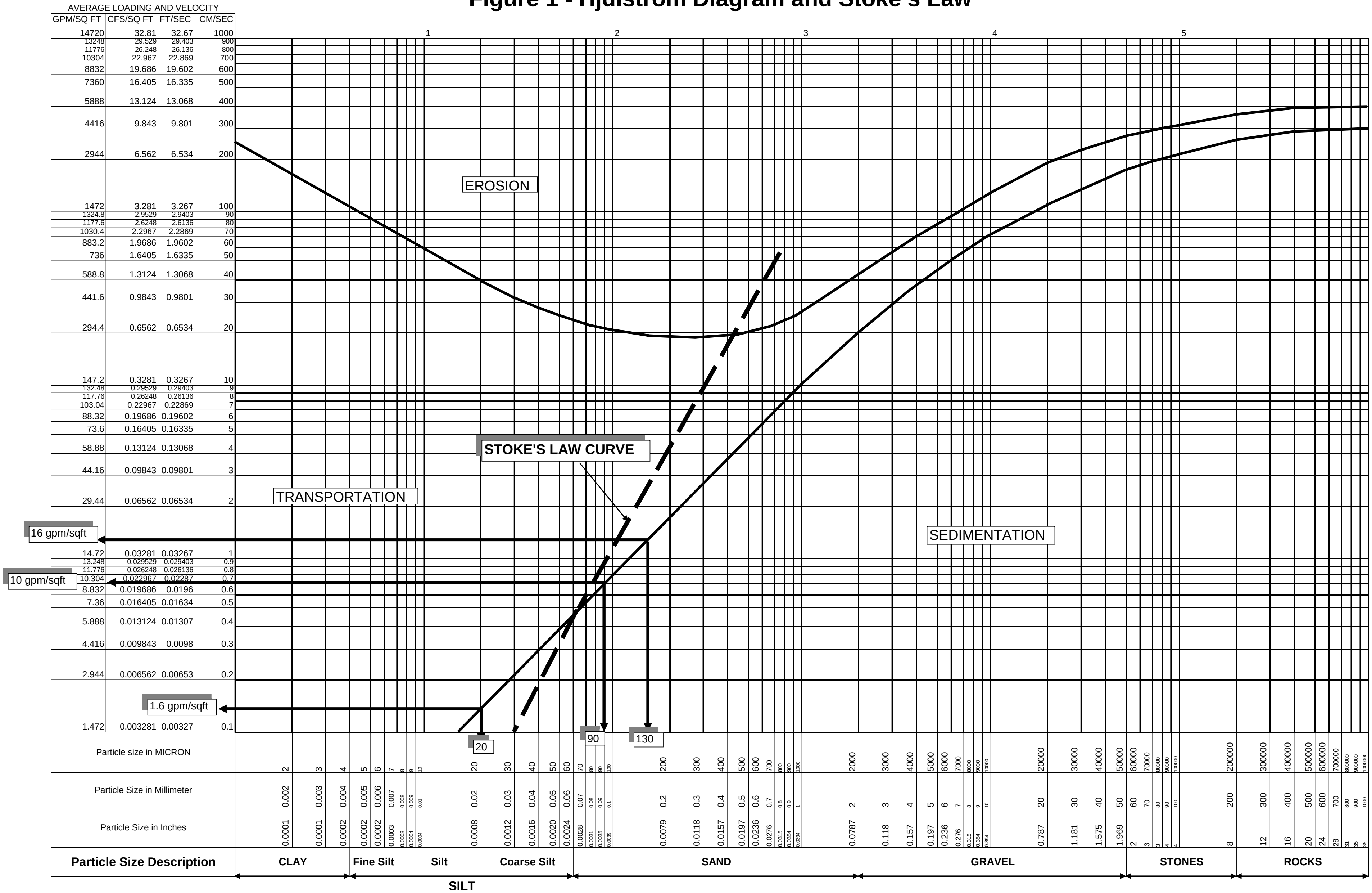
While Stokes Law and the Hjulström Diagram differ slightly in how each calculate and plot similar variables, the unifying theme is that they both relate the effects of gravity, friction and kinetic velocity on particles in a stream of water. Clearly, the most significant factor is the gravitational exerted on a particle.
The greater opportunity for gravity to affect a particle, the higher particle removal rate.

Figure 1 shows the Hjulström Diagram and Stoke's Law plotted together.

The force of gravity must be exerted while the particle is located in a stream of water while that stream is flowing over a sedimentation area because rise rate is directly proportional with the flow rate and the sedimentation area.

This means that TSS Removal is directly related to the amount of sedimentation area in the hydrodynamic separator stormwater device. If the sedimentation area is known, any performance claim stated as a Percentage of TSS Removal Rate can be checked against Stokes Law and the Hjulström Diagram to verify its accuracy. Stokes Law and the Hjulström Diagram show that the amount of sedimentation area in a hydrodynamic separator stormwater device is the most important factor when comparing the relative published Percentage of TSS Removal Rates. The more sedimentation area within a hydrodynamic separator stormwater device, then the higher Percentage of TSS Removal Rate that it should attain.

Figure 1 - Hjulström Diagram and Stoke's Law



The NPDES Phase II regulations' goal to remove stormwater pollution to the "maximum extent practicable" will be focused and enhanced, if scientific principles are applied to evaluate hydrodynamic separator stormwater treatment devices. Sedimentation area is a clear and simple to benchmark. It is clear and easy to calculate.. It is the most critical portion of any hydrodynamic separator stormwater treatment device. Gravitational force is the dominant force in the sedimentation process. Sedimentation can be reasonably predicted by Stokes Law and the Hjulström Diagram. All other factors are insignificant in comparison to gravity's downward pull on a particle in a flowing stream of water.

Pollutant removal design criteria must be more specifically defined and must reference Particle Size Distribution, Particle Size Density, and Influent Concentration Levels. With these design criteria, the Hjulström Diagram can be used to determine the size of the sedimentation area necessary to produce the desired level of pollutant removal at designed flow rates.

The authors propose the creation of Solids Runoff Maps, similar to soil maps, with associated particle distribution charts that list expected particle distributions in run-off of geographical areas. State and local authorities can then establish the removal requirements that apply a specific site in order to attain pollutant removal "to the maximum extent practicable".

Until specific pollution reduction goals are established, design engineers can write project specific requirements with an assumed sample distribution. This will guide the selection of a hydrodynamic separator with enough projected surface area to meet the removal requirements. The performance of the device is predictable because horizontally projected surface area or rise rate versus particle sinking rate and not depth is the controlling factor in sedimentation efficiency.