Relativity in Performance of a Water Quality Treatment Device, the Solids Distribution, and the Surface Loading

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Introduction

Specific stormwater treatment goals should include a percentage reduction in suspended solid concentrations in the effluent. In many cases however, the particle size distribution in the influent is not provided. Other characteristics, such as flow rate, water temperature, particle density, hydraulic radius of the device, and dissolved solids are relevant in how successful the sedimentation of particles will be according to the effects of natural law.

Background

In one-way or another, particulate separation from water occurs because of differences in density (i.e. floating or sinking), or physical restraint (i.e. screening and filtering). Chemical bonding (i.e. agglutination) changes the density by creating a floc that floats or sinks. Evaporation and absorption are more subtle forms of separation and are not evaluated here. The separation discussed in this context is depending on baffles, screens, and gravity. We emphasize that in flowing water there is a fundamental difference between transportation of fine particles (silt and clay) and larger particles (sand grit, and gross pollutants). Low flow turbulence holds fine particles in suspension. The size and specific gravity of the particle has a huge effect on whether the particle ①floats ②sinks or ③remains suspended at a given flow rate.

Topic

The Hjulström Diagram graphically shows particle behavior relative to flow rate. By using this diagram, it can easily be determined whether a particle settles, stays in suspension, or erodes. Knowing the Total Suspended Solids (TSS) particle distribution for the influent is necessary to select the particle sizes that will yield the desired TSS removal performance. Thus, the projected grit-chamber-sedimentation area, of a Water Quality Treatment device can be sized based on a desired removal rate of the non-colloidal fraction of TSS.

Discussion

We view stormwater as turbulent flow in a pipe that has accumulated the pollutants carried by the run-off. Properly designed stormwater systems are necessary in our built environment to collect and convey the water. However, particle pollutants can only be separated again from the water if we reverse conditions and create minimal turbulence. The engineering problem can be described as a “hurry-up and wait” dilemma. The “hurry-up” philosophy is necessary for safe roads and dry homes (i.e. get the water away quickly) and the “wait” is necessary to reduce the pollution load to the environment (i.e. slow the water to allow sedimentation). The ultimate “wait” phase can be seen when infiltrated water follows a laminar flow pattern as ground water where the Reynolds number is less than 400. Filtered water is of course cleaner water, but filters are relatively expensive and maintenance intensive. The current regulatory environment justifies pretreatment with a hydrodynamic separator to clean the water. The economic goal is to find the most efficient hydrodynamic separator.

The Hydrodynamic Separator

Hydrodynamic separators provide treatment to improve water quality before stormwater is discharged to surface waters or infiltrated to recharge ground waters. Baffles and screens can trap floating particles or relatively large particles, (Gross Pollutants), which are found in the water along with the sediment load. Scouring of collected sediment, as well as wash out of collected scum, oil and gross pollutants must be prevented if a device is to be effective between cleanings. A well-designed sedimentation chamber, or grit chamber, offers great benefit to a system by removing particles that otherwise would stay suspended in the flow and be discharged from the device.

Particle behavior has been graphed as size vs. flow rate and this can be used to effectively document the performance of a hydrodynamic separator. The New Jersey Department of Environmental Protection (NJDEP) soil sample in the Draft proposal of October 3, 2003 for the Total Suspended Solids Laboratory Testing Procedure matches very closely with the river deposits in the Netherlands. “Keileem” (translated is “Rock-loam”) is a product of the deposits from the rivers in western Europe. The Hjulström Diagram, Figure 1, shows the global relationship between flow intensity and particle size if the particle density is 165 $\#/ft^3$ and the hydraulic radius of the flow channel is 3.28 ft. Further, the diagram presumes relatively clean water and no strong turbulence. Using this diagram, it can easily be determined whether a particle settles, stays in suspension, or erodes depending on the flow intensity without performing a calculation.

Stokes’ Law predicts the settling rate of a smooth rigid spherical particle in a liquid of a given viscosity. For example, a particle size of 75 Microns will settle at about $^{3}/_{16}$ inch/second in water with a normal viscosity. By comparison, the Hjulström Diagram shows the same settling rate of $^{3}/_{16}$ inch/second for the same particle size of 75 Microns. For the purpose of this paper, we reference the Hjulström Diagram because it is more conservative towards the larger particle fraction of a sample. That is, it predicts a lower settling velocity than Stokes’ Law for particles larger than 75 Microns. A lower settling velocity equates to a lower surface loading rate for the design of a treatment device, which makes the device larger in horizontally projected settling area, hence a conservative design. For particles smaller than 75 Microns, the Hjulström Diagram shows higher velocities than those calculated with Stokes’ Law. Here too we reference the Hjulström Diagram because in this range the resultant effect of gravity on the settling velocity diminishes. Additions such as filters and floc forming agents should be introduced to help remove particles smaller than 20 Microns.

It must be understood that there is a fundamental difference between transportation of fine particles (silt and clay) and coarse particles (fine sand) in flowing water. During transportation, fine particles are largely held in suspension. This means the concentration of the particles in the water is independent of the water depth. In fact, there is a nearly uniform distribution of particles in the vertical cross-section. It is an en-masse type of transportation. The fine particles move at the same speed as the water. The coarse particles are predominantly transported near the bottom of the flow channel. It is a type of bottom transportation where the particles more or less jump across the bottom. The coarse particle speed is much less than the speed of the water. The flow conditions that exist in a hydrodynamic separator will create a practical limit to the size of the smallest particles that can be removed without chemical addition and/or filtration. As a secondary effect, a hydrodynamic separator can remove nutrients, dissolved solids, or bacteria only due to adherence to a particle that is itself removed.

Hjulström Diagram

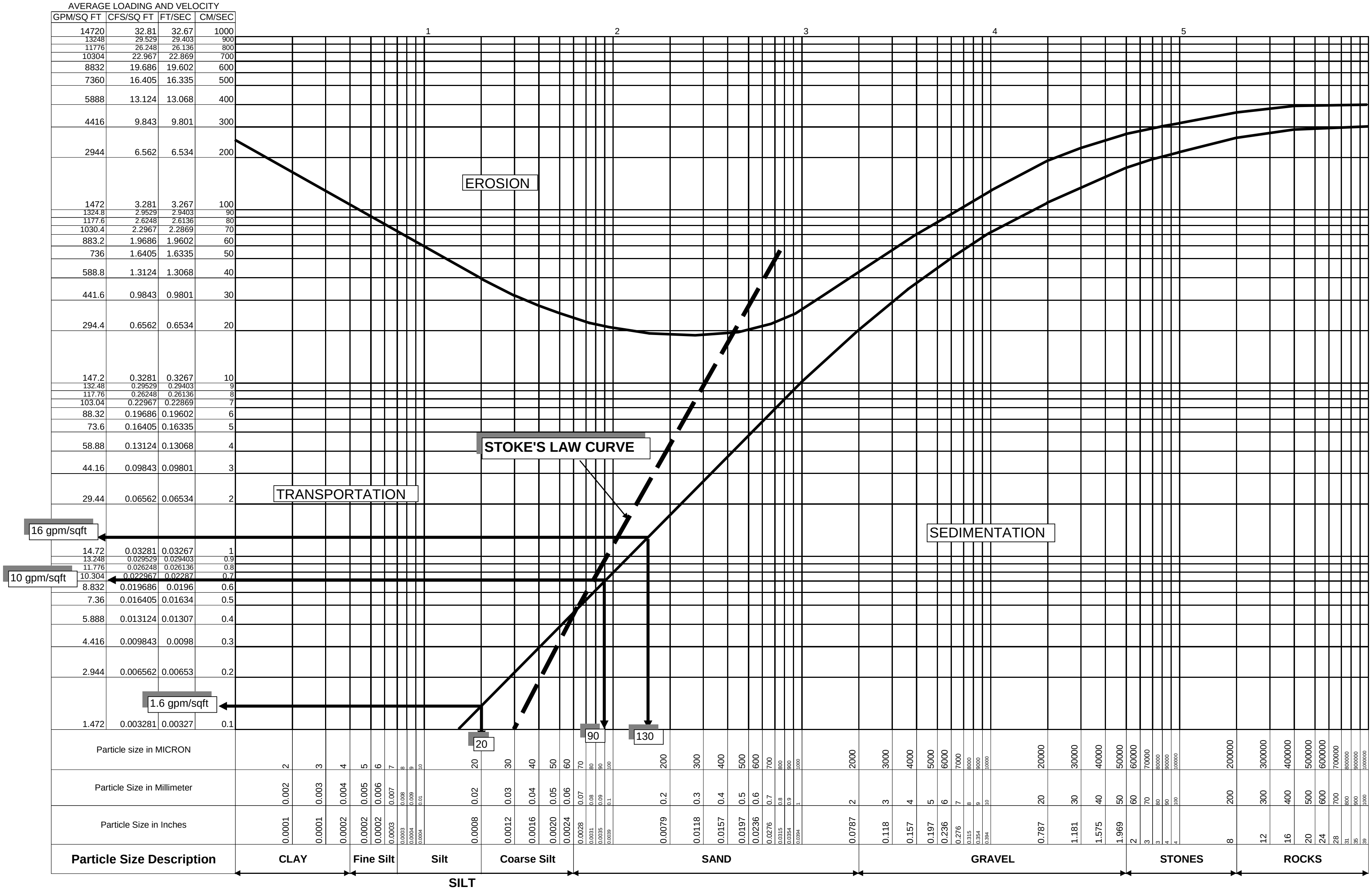

FIGURE 1

Design Scenario

Figures 2a, 2b, and 2c show the particle distribution of four soil samples and the NJDEP sample. In the case of the dune sand, Fig. 2a, it is clear that all particles larger than 130 Microns must be removed to obtain a 50% removal rate and all particles larger than 90 Microns to obtain an 80% removal rate. Using these particle sizes in the Hjulström Diagram, Fig. 1, this means the projected surface area in a hydrodynamic separator must be sized for a surface loading of 16 gpm/ft^2 to remove 50% of the suspended solids or a surface loading of 10 gpm/ft^2 to remove 80%. From Fig. 2b, the best results with clay are about 25% removal because 75% of the particles will be smaller than 20 Microns. The surface loading to remove particles of this size, 1.6 gpm/ft^2, is very low for a hydrodynamic separator. Figure 2c shows the removal rate for the NJDEP Laboratory sample will be about 65% for the size limit of 20 Microns. A filter is required to increase the removal percentage because the particles are too fine to settle in these devices.

Flow conditions that exceed design flows will settle fewer solids in the grit chamber, because the surface loading rate is also proportionally increased. Gross pollutants and hydrocarbons should be screened and trapped prior to the grit chamber and remain trapped even above design flow conditions.

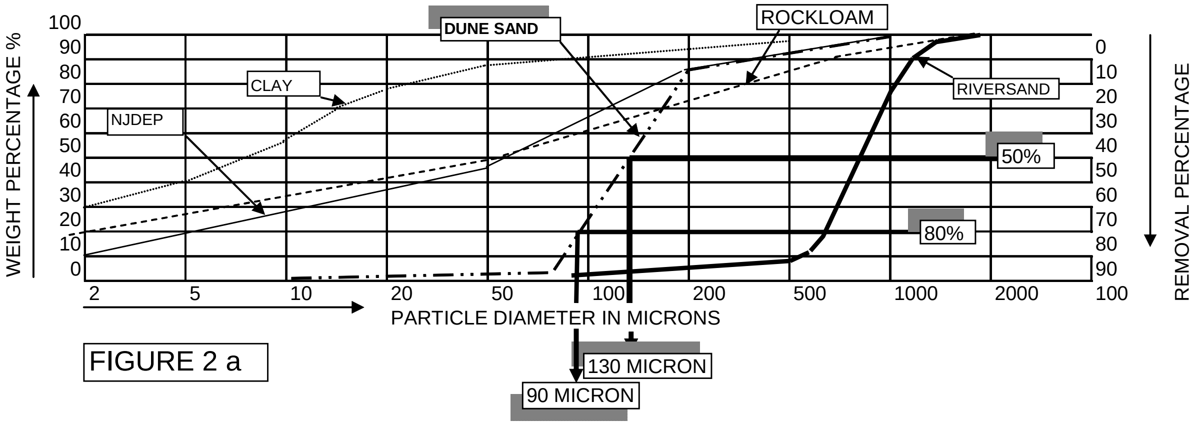

FIGURE 2 a

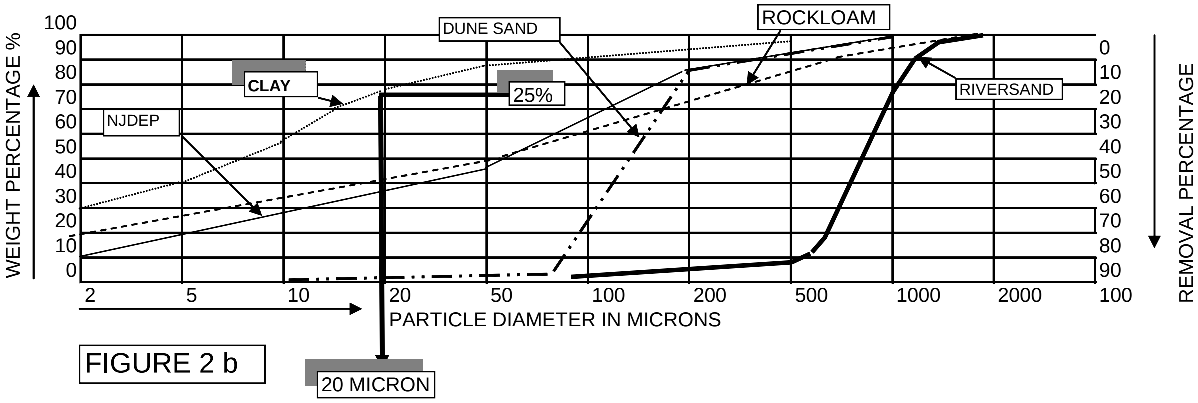

FIGURE 2 b

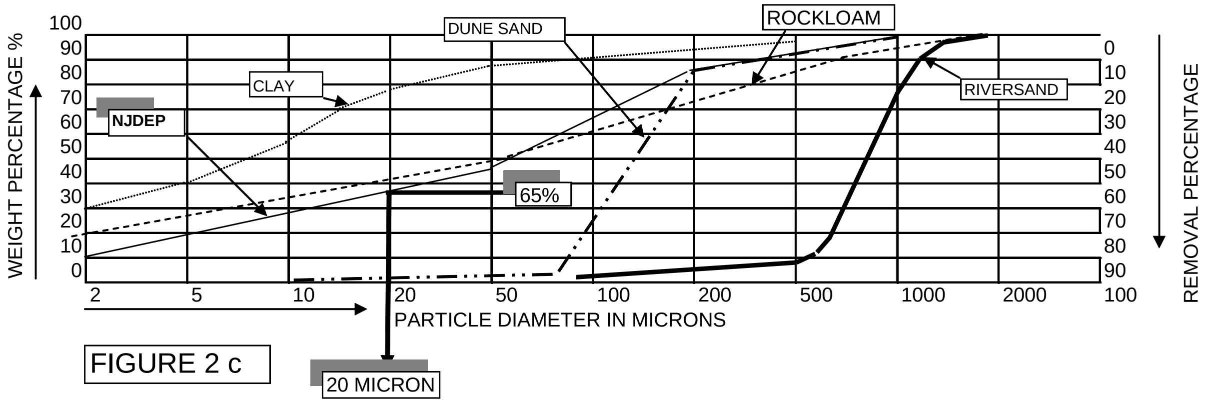

FIGURE 2 c

Conclusion

Some statements have been made about the performance of a treatment device expressed only as a percentage removal of TSS. Using this kind of statement as a design requirement is unrealistic without also listing the sample distribution of particle sizes that are expected at the device location. 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 must then establish the removal requirements that apply to their location.

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 and not depth is the controlling factor in sedimentation efficiency.