Civil & Environmental Engineering Laboratory Exercise
Sedimentation for Pollutant Removal
EGGG 101 Introduction to Engineering
Lab Report Due One Week after Lab Exercise

Background

The replacement of the Indian River Bridge provides an opportunity to upgrade systems for treating stormwater runoff from this structure. Given the location of this bridge, one treatment option that might be considered is a sedimentation/filtration unit. Commercial units like this are readily available (e.g., www.stormwaterinc.com).

As the name implies, a sedimentation/filtration unit uses two treatment technologies: sedimentation and filtration. Sedimentation utilizes gravity to remove heavier-than-water contaminants from water. Filtration removes most contaminants by sorbing them to the filter medium. Various filter media can be used, with the specific medium selected based on the type of pollutants expected.

Turbidity is a measure of the cloudiness of water and is significantly impacted by the presence of small particles (http://www.water.ncsu.edu/watershedss/info/turbid.html). For example, very small particles – colloids – are what make milk white. Turbidity in natural waters is often not good, because it blocks sunlight and can have a negative impact on aquatic life. Turbidity is commonly measured in Nephelometric Turbidity Units (NTU). Higher values of NTU mean the water is “cloudier” and has higher concentrations of particles. Turbidity is an indirect measure of the concentration of suspended particles in water.

Purpose

The purpose of this laboratory exercise is to design, construct, and test a sedimentation basin for removing stormwater pollutants. Analysis of the removal efficiencies for this basin will provide insight into the effectiveness of similar sedimentation systems that might be used at the Indian River Bridge.

Methods

1. Construct sedimentation basin – COMPLETE BEFORE NEXT CLASS
   • Pick up basin materials: 2ft x 2.5 ft Styrofoam, duct tape, and ruler.
   • Using the 2ft x 2.5 ft section of Styrofoam provided to each group, construct your sedimentation basin. Use duct tape to secure all edges. Your basin should have the following components:
     i. Place where tube containing the influent water can be placed into your basin.
     ii. Internal baffles. These will be cut from Styrofoam and taped into place with duct tape. Baffles control the internal water flow in the basin and can
be used to (1) direct flow, (2) slow water down, and (3) control the level of water in the basin.

iii. Outlet structure. Normally, this is just a notch or hole in the wall of the Styrofoam where the water exits. The outlet location and elevation controls the water flow path and the water level in the basin.

To assist you in basin construction, you MAY work on your basins in room 021 Spencer Lab on Tuesday from 10am-12noon; 3pm-5pm. There will be a TA in this room to help and knives to cut the Styrofoam.

2. Install sedimentation basin
   - Using duct tape, position your sedimentation basin securely on top of the plastic tub.

3. Measure flow rate from stormwater reservoir
   - Using the graduated cylinder and stopwatch provided, measure the volumetric flow rate of water from your stormwater reservoir. Place the effluent tube from the stormwater reservoir in your graduated cylinder; open the spigot completely from the stormwater reservoir, record the volume filled and the time it takes to fill the measured volume.
   - Dump the water collected in the graduated cylinder back into the stormwater reservoir.
   - Repeat this measurement so that two measurements are made.

4. Measure influent turbidity
   - With the “bubbler system” turned on and the stormwater mixed, open the spigot and fill a 50ml sample beaker with stormwater.
   - Stir the solution in this beaker, and fill 2 sample vials with well-mixed stormwater. Label these vials with your section number, group letter, “I” for inlet, and sample number. e.g., “010-A-I-1” for sample one from the inlet for Lab Group A in section 010.
   - LABELS SHOULD BE PLACED ON CAPS – NOT GLASS VIALS. Turbidity measurements are made by passing light through the glass vial.
   - Give your samples to the TA for measurements.

5. Measure effluent turbidity
   - IMMEDIATELY after sampling the influent, place the influent tube back into the basin, tape the tubing in place so it does not move, and allow your basin to operate.
   - Fill a beaker with the effluent from your basin as soon as water exits the basin.
   - Stir the solution in this beaker and fill 2 sample vials with well-mixed stormwater. Label the vials as above, using “O” for outlet.
   - Give your samples to the TA for measurements.

6. Measure the dimensions of the “quiescent” zone of basin
   - Measure the depth of water in the “quiescent” area of the settling basin - $H$. This is the region where the water flow is mostly horizontal and relatively slow.
   - Measure all internal dimensions for your basin so that a sketch can be made. Include the locations of all baffles. Make sure you are particularly careful in measuring the dimensions of the “quiescent” zone(s), where particles settle out. For example,
\[ H = \text{depth of water in settling zone (region of quiet water)} \]
\[ L = \text{length of settling zone} \]
\[ W = \text{width of settling zone} \]

Calculations (to be completed after lab exercise):

1. Draw a sketch of your basin. The sketch should include enough detail so that someone could re-construct your basin from the sketch, assuming they had the initial plastic container to start with. Your sketch should include all relevant dimensions. Because most of you have not had engineering drawing yet, i.e. AUTOCAD, you can make this sketch using the built-in drawing package in MSWord. You can draw this by hand, but use a straightedge in making the sketch.
2. Compute the mean volumetric flow rate, \( Q \), from your measurements.
3. Compute the total volume of your “quiescent zone,” the region of the basin where water flows slowly and the smallest particles in your system will settle out. Big particles settle out in the inlet, but the small particles settle out in your sedimentation zone or quiescent zone. This zone is basically the volume that the water occupies exclusive of the inlet zone and (possibly) the effluent zone. In these two regions water flow is not horizontal.

If you have rectangular quiescent zone, then the volume is simply the product of \( H, L, \) and \( W \) (see sketch above). For more complicated designs, compute the surface area of your quiescent zone based on the geometry of your baffles. Then, multiply this surface area by the average depth of the water in this region, \( H \).

Compute the average travel time for water in the “quiescent” zone:

\[
T = \frac{\text{volume of quiescent zone}}{Q}.
\]

4. Compute the critical downward vertical velocity of your reactor - \( v_c \). All particles with velocity larger than \( v_c \) will be “captured” by the basin in the quiescent zone.

\[
v_c = \frac{H}{T}
\]

5. Compute the collection efficiency of your basin. The efficiency, \( \eta \), can be computed using the mean turbidity measurements of your influent and effluent:

\[
\eta = \frac{\text{mean influent turbidity} - \text{mean effluent turbidity}}{\text{mean influent turbidity}}
\]
Under certain assumptions it can be shown that the measured collection efficiency is related to the critical velocity by

\[ \eta = \frac{v}{v_c} \]

where \( v \) is the average vertical velocity of particles in your basin. \( v \) and \( v_c \) are shown in the diagram in the powerpoint lecture notes that can be downloaded from the course website.

**Lab Report:**

1. Follow the general format outlined in the “template” that was attached to the course syllabus and handed out during the first class:
   a. Introduction
      - State the objective of the lab exercise.
   b. Methods
      - Briefly summarize the experimental methods followed. Note any changes to the methods described in the lab handout.
   c. Results
      - Provide a sketch of your basin design. Include dimensions and locations of outlet and any baffles.
      - Summarize the calculations performed above and the measured efficiency of your basin.
   d. Conclusions
      - In this section answer the following questions (A through E):

A. Based on the analysis in this handout and your calculations, what design features are most important for achieving the maximum removal of suspended solids?

Hint. Think about the following equation for the critical velocity.

\[ v_c = \frac{H}{T} = \frac{H Q}{\text{volume}} = \frac{H Q}{H \ (\text{surface area})} = \frac{Q}{\text{surface area}} \]

Discuss any design factors for your sedimentation basins NOT included in the analysis above that will affect particle removal efficiency.

B. Stokes law is commonly used to estimate the settling velocity of particles. This equation is derived based on a force balance on particles, where gravity (or buoyancy) acts to pull particles downward and a viscous drag force resists this movement. (Stokes law is derived in most Fluid Mechanics textbooks.) Stokes law can be written as

\[ v = \frac{2 r^2 g (\rho_p - \rho_f)}{9 \mu} \]
where \( r \) is the radius of a spherical particle; \( g \) is gravity; \( \rho_p \) and \( \rho_f \) are the densities of the particle and the fluid, respectively; and \( \mu \) is the dynamic viscosity of the fluid.

Using your basin and your computed critical velocity, \( v_c \), what is the smallest diameter of a spherical particle of brake dust that would always be collected in your basin? Use the following information in your calculations:

\[
\begin{align*}
\rho_p &= 3.50 \text{ g/cm}^3 \text{ for brake dust particles} \\
\rho_f &= 1.0 \text{ g/cm}^3 \text{ for water (water at } \sim 25^\circ\text{C)} \\
\mu &= 0.00890 \text{ dynes – sec/cm}^2 \text{ (water at } 25^\circ\text{C)}
\end{align*}
\]

Note that 1 dyne = g-cm/sec².

C. Brake dust that is emitted from automobiles has a wide range of particle sizes. Recently, researchers at the University of Delaware collected brake wear debris from several representative automobiles and measured the particle sizes. The results are shown below, where particle size (dp) is plotted versus the differential volume, which is an indirect measure of the mass of the particles.

Based on the results from part B and the plot below, comment on the utility of your sedimentation basin for removing brake dust in the water that comes from the 4 automobiles represented in this figure. Will your basin remove a significant portion of the brake wear debris? From which automobiles will the removal be most efficient?

D. Removal efficiency was evaluated using turbidity. To a first approximation, assume that the efficiency of turbidity reduction is equivalent to the efficiency of solids removal. Thus, 50% efficiency in reducing turbidity is equivalent to 50% efficiency in removing solids, where the concentration of solids is in units of mg of solids per liter of solution.
Solids almost always “carry” contaminants with them, since contaminants sorb or attach themselves to solid particles. If the solids in your stormwater contained 3 micromoles of copper per gram of solids, and if the solids concentration in the stormwater was 100 mg (of solids) per liter of stormwater, how much mass of copper is removed via sedimentation in your system if 1000 liters are processed (1000 liters of stormwater pass through your basin)? Note: If for some strange reason your basin had a removal efficiency of 100% based on your measurements, assume the removal efficiency is 95% for this question.

E. The second stage of the stormwater treatment system discussed in class is a filtration unit, where stormwater passes through a medium that contaminants sorb to. While sedimentation is efficient for removing larger particles, filtration is effective for removing dissolved compounds. A filtration unit may not be needed, if dissolved contaminant concentrations are “acceptably small.”

Suppose the dissolved concentration of copper in the stormwater is 25 micrograms per liter. Assume also that the hardness of the water is 150 milligrams per liter as CaCO₃. Is this stormwater toxic to aquatic life? Use the Delaware Department of Natural Resources and Environmental Control (DNREC) guidance document on Water Quality Criteria (Surface Water Quality Criteria), which may be downloaded from http://www.dnrec.state.de.us/DNREC2000/Divisions/Water/WaterQuality/Standards.htm.

F. Describe some of the negative impacts of high turbidity in surface waters. (hint: check website listed in background.)

e. References
   • Site any reference used.

f. List all team members