Predicting sediment concentration profiles in an open channel

Background
Sediment concentration profiles in rivers can be predicted with knowledge of fluid flow properties and sediment characteristics. Sediment concentration in rivers typically shows an exponential decay in concentration from the channel bed to the water surface (Fig. 1).

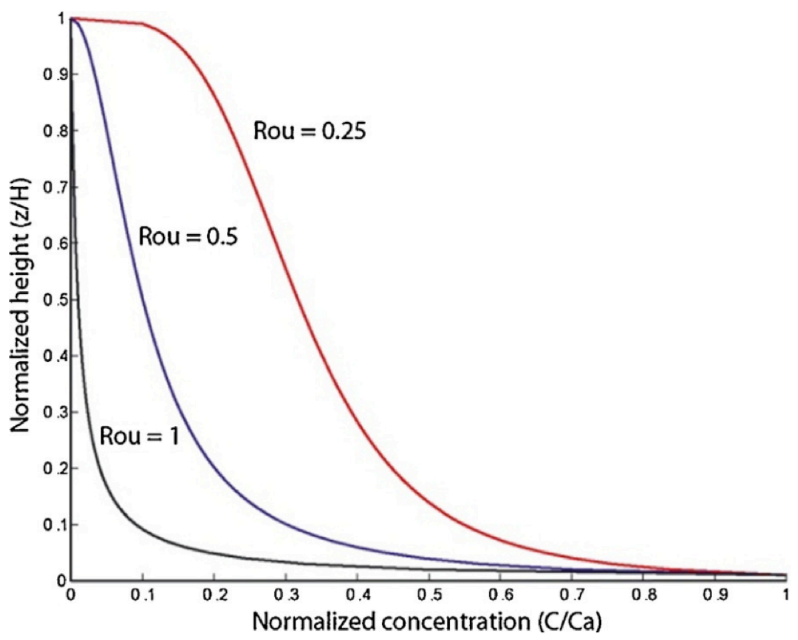

Figure 1. Modeled sediment concentration as a function of distance from the channel bed. "Rou" is the Rouse number (Rouse 1937), which is a ratio of sediment settling velocity and shear velocity of the flow. Figure from *Teles et al. 2016*.

To model suspended sediment concentration profiles, we use the following strategy:
1) Determine a reference height, b, at which we will predict a near-bed sediment concentration. For this exercise, we will simply assume $b=H*0.05$, where H is water depth.

2) Determine near-bed shear stress, τ_b. For this exercise, τ_b is an adjustable parameter. We will explore the role of τ_b for suspended sediment concentrations.

3) Predict near-bed sediment concentration, c_b, as a function of sediment entrainment, E, from the channel bed. There are many relationships for sediment entrainment, but for this exercise we use a formula that employs an excess shear stress to determine the sediment entrainment rate (McLean 1992). This means sediment entrainment is a function of τ_b and τ_c, the critical shear stress, which is the stress required to entrain a grain. In cases that lack cohesion, this is size dependent, and can be determined by the Shields curve (Fig. 2).

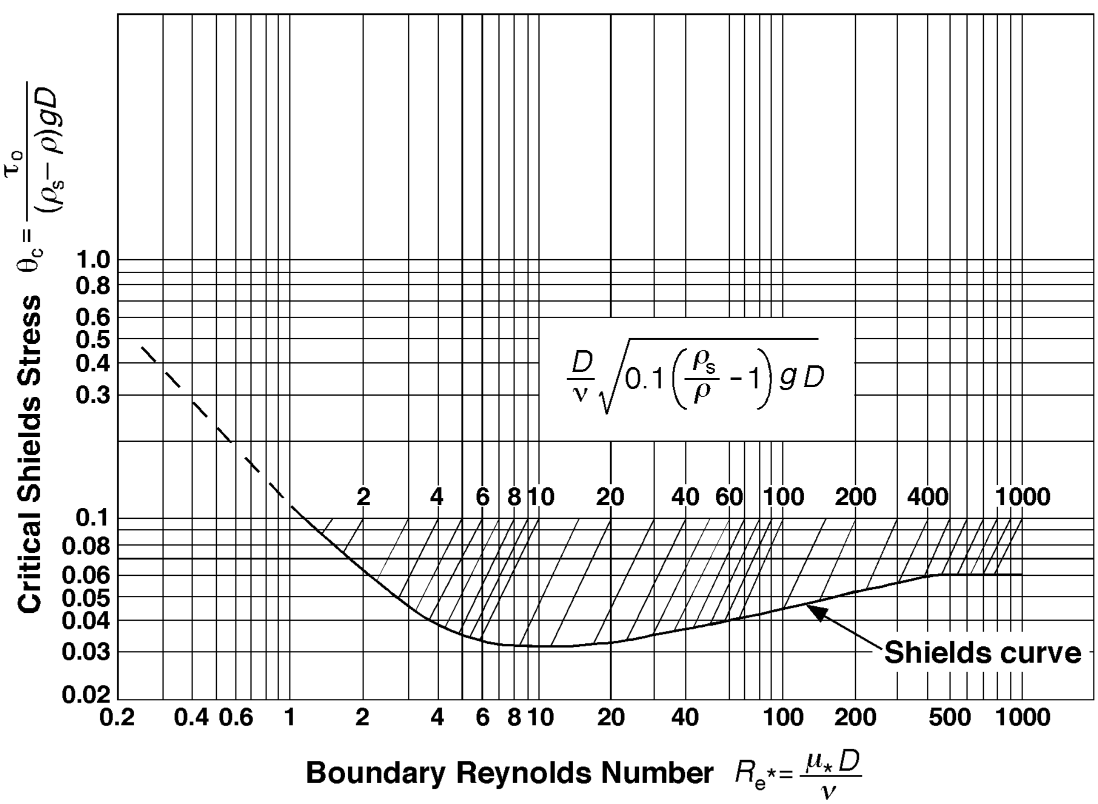

Figure 2. The Shields curve is used to determine the critical shear stress, τ_c, required to entrain sediment, which is a function of grain size. Here, the axes for the Shields curve are non-dimensional, where τ_c can be solved for the grain size, D, of interest.

The Shields curve is appropriate for non-cohesive environments. For cohesive environments, particles stick together when they are entrained into the water column. These aggregates can be represented by a wide range of τ_c, and in some cases are best represented by a single τ_c value for all grain sizes. In this exercise we will evaluate suspended sediment concentration profiles *both with τ_c values determined from the Shields diagram and using a single τ_c value that is representative of cohesive, multi-particle aggregates*. The *McLean (1992)* equation for c_b is:

$$c_b = \frac{0.004(1-\varphi)E}{1+0.004E}$$

where $E = T^* - 1$ and $T^* = \frac{\tau_b}{\tau_c}$.

4) Finally, the concentration profile can then be predicted for the water column as

$$\frac{c}{c_b} = \left[\frac{(H-Z)/Z}{(H-b)/b}\right]^{Rou}$$

where c is the concentration evaluated at an elevation Z above the bed, H is the total flow depth, and *Rou* is the Rouse number:

$$Rou = \frac{w_s}{\kappa u_*}$$

where w_s is the velocity at which a particle settles through the water column, and is determined by grain size using *Ferguson and Church, 2004*, u_* is the shear velocity, and κ is the von Karman constant (0.41). In this exercise, u_* is solved from the adjustable parameter τ_b using the relationship $\tau_b = c_f \rho u_*^2$, where c_f is the coefficient for friction (assumed to be 0.004), and ρ is the fluid density (1000 kg/m^3).

Problem Set: Testing controls on suspended sediment concentration profiles
For this exercise, each model run will produce two suspended sediment concentration profiles, one which uses τ_c values determined from the Shields diagram (green line) and one which uses a single τ_c value representative of cohesion. Adjustable parameters in this exercise are grain size, D, τ_b, and the cohesive τ_c value. Explore the adjustable parameters to answer the following questions.

1. Evaluate the model at the initial conditions (D = 300 μm, τ_b = 0.7 Pa, and τ_c = 0.28 Pa). Which model has the highest c_b? Why? Where in the water column do the two models approach the same value? Why?

2. Leave the initial conditions for grain size and near bed shear stress, but increase the cohesive critical shear stress. What happens? Why?

3. Hit the “Reset” button. Leave the initial values for grain size and critical shear stress, but increase/ decrease the near-bed shear stress. What happens? Why? How do the model results change relative to each other?

4. Hit the “Reset” button. Leave the initial values for near-bed shear stress and cohesive critical shear stress, but increase/decrease the grain size. Use the Shields curve to describe what happens? Why does this happen?

5. Set the near-bed shear stress to the minimum value and the cohesive critical shear stress to the maximum value. What happens to each model and why?

6. Set the near-bed shear stress to the maximum value and the cohesive critical shear stress to the minimum value. What happens and why?

7. Some combinations of grain size, near-bed shear stress, and cohesive critical shear stress generate unrealistic model results. Describe one of these scenarios and explain why the model result is unrealistic.

Works Cited

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