Geomorphology
Geology 450/750 – Spring 2004

Lab Exercise 5 – Flume Hydraulics and Sediment Transport

Due Wednesday, April 28

Name________________________

Introduction

This exercise is intended to help link the observations of water and sediment motion that we made in the laboratory flume with the theory we've been discussing in lecture. You will use the measurements we made to ask some basic questions about what happened in the flume as we varied the discharge by a factor of two. In the next assignment, you will take your insight from the laboratory to the field, when you analyze the channel geometry of the reach of Redwood Creek at Santos meadow.

As in previous lab exercises, *show all your work on attached sheets*.

The Data

Here are the basic flow measurements we made. Recall that we measured depth at three places along the flume, and found that the upstream and middle depths were roughly the same, but that the downstream depth was greater. I've only included all three depth measurements for the lowest discharge; in the subsequent calculations you should use the middle depths only.

Discharge (gal/min)	Discharge (m^3/s)	Depth (m) Upstream	Depth (m) Middle	Depth (m) Downstream	Slope (m/m)
220	0.014	0.067	0.067	0.073	0.010
330	0.021	-	0.085	-	0.011
440	0.028	-	0.102	-	0.012

Useful constants

Flume Width (W) = 0.26 m

Water density (ρ_w) = 1000 kg/m^3

Sediment density (ρ_s) = 2600 kg/m^3

Sediment grain size (D_s) = 0.0051 m

Gravitational acceleration (g) = 9.81 m/s^2

Mean Velocity and Roughness

For each of the three discharges, calculate the mean flow velocity, using the conservation of mass equation. You can then use this result to estimate a value of the Mannings '*n*' roughness coefficient. To do this, first calculate the hydraulic radius and then solve for *n* using the Manning equation. Also calculate the width to depth ratio and the ratio of hydraulic radius to flow depth.

Discharge	Velocity	Hydraulic	Mannings *n*	Width/Depth	Radius/Depth
(m^3/s)	(m/s)	Radius (m)	$m^{1/3}$/s	(m/m)	(m/m)
0.014					
0.021					
0.028					

Questions:

(a) As we double discharge, what percentage of that increase in water flux is accommodated by deepening of the flow, and what percentage by the increase in velocity?

(b) In the field, we often make the assumption that we can use flow depth in place of hydraulic radius in calculating boundary shear stress ($\tau_b=\rho gRS \sim \rho ghS$). Would that assumption be valid here and if not, what is the problem?

(c) The typical low end of the range of Mannings *n* for real (i.e. not laboratory) channels is around 0.02, for concrete lined canals. How does your calculated n value compare, and if it is lower, why might that be the case?

(d) Does the Mannings 'n' change with depth? Can you think of a reason why we might expect it to change with depth in a natural channel?

Bedload Sediment transport

Recall that we did not observe any sediment transport at the lowest discharge (at least once the bed had adjusted to the fact that water was flowing over it). After we increased the discharge by 50%, we observed weak and irregular sediment transport, especially after we turned on the sediment feed at the upstream end of the flume. Once we increased the discharge to double the initial flow we saw strong and sustained bedload transport. These observations reflect two key aspects of bedload sediment transport in rivers: (1) the existence of a threshold shear stress that must be exceed to initiate sediment motion, and (2) the non-linear relationship between bed shear stress and sediment transport rate.

These two aspects are accounted for in equations that predict the potential rate of sediment transport ('capacity') for a given shear stress, grain size, and density of sediment. Here is a simple example, the equation of *Fernandez-Luque and van Beek (1976)*

$$q_t = 5.7\left(R_b g D_s^3\right)^{1/2}\left(\tau^* - \tau_c^*\right)^{3/2}$$

where q_t is the volumetric sediment transport capacity per unit width (in cubic meters per second per meter), ρ_s is the sediment density, R_b is the non-dimensional buoyant density of sediment

$$R_b = \rho_s/\rho_w - 1$$

ρ_w is the density of water, g is the acceleration due to gravity

$$\tau^* = \tau_b/[(\rho_s\text{-}\rho_w)gD_s]$$

is the non-dimensional form of the boundary shear stress (τ_b), and τ_c^* is the value of τ^* at the threshold of particle motion.

For each of the three discharges, calculate the boundary shear stress (τ_b) and the non-dimensional 'Shields' stress (τ^*). Assuming a value of 0.05 for the critical Shields stress (τ_c^*), calculate a predicted bedload sediment transport rate for each discharge. Listed in the table below are also the observed sediment flux rates out of the downstream end of the flume and the rate at which sediment was being supplied, converted from lb/min to kg/s (submerged weight). So that you can compare predicted with observed transport rates, convert your calculated transport capacity into a predicted (submerged) mass flux (in kg/s) for this flume by multiplying by the submerged density (ρ_s-ρ_w) and the flume width (W).

Discharge (m^3/s)	Shear Stress (Pa)	Shields Stress	Sed Flux Out (kg/s)	Sed Flux In (kg/s)	Sed Transport Capacity (kg/s)
0.014			0.0000	0	
0.021			0.0011	0.0106	
0.028			0.0068	0.0106	

Questions

(e) Why was the flux-out not equal to the flux-in for the medium and high discharge cases? What would have happened if we had left the flume running like that for a long time?

(f) How does your predicted sediment transport capacity compare with the flux out of the flume that we measured? If you don't have good agreement, how large is the difference? Can you think of reasons why you don't have good agreement (assuming the equation works)?

To place our observations in a larger context, plot our observed flux out measurements and your predicted transport capacity values on the attached graph, which shows experimental (flume) data and the predictions of a number of bedload sediment transport equations including the one you've been using. To do this you need to convert the dimensional sediment flux values to the non-dimensional number used on the plot (q^*). This number is called the 'Einstein' number, after Hans Einstein, Albert's son, who was a pioneer in sediment transport research in the Civil Engineering Department at UC Berkeley. To make this conversion, divide the submerged mass flux (in kg/s) by the submerged density and the flume width, and then divide by $(R_b g D_s^3)^{1/2}$. You should have five points, your three predictions plus the two observations for the medium and high discharges (remember that you can't plot zero flux on a log axis).

(g) Looking at your data plotted on the graph, how would you interpret the differences between your predicted and the measured sediment fluxes? Does this shed any light on your answers to question (f)?