Flume Parameter Calculations

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May 2018

1 Preparing scripts and data

The required scripts may be accessed in the Google Drive folder “Biogeomorphic Flume.” In the folder, navigate to “R code” for the scripts. Download the scripts

• bin visualization.R

• k calculation.R

• settling velocity kc estimates.R

• peristaltic pump k estimation.R

• mass balance.R

You will also need the processed LISST data for the experiment (.asc file), sediment trap data, and peristaltic pump data. The readme files may be useful when working with the scripts. Refer to the readme file if there are any unclear steps in the explanations below. The scripts themselves also contain comments next to lines of code, which may be useful for understanding them.

2 collector Reynolds number

The collector Reynolds number Re

c

is defined as

Re

c

ud

c ν

where u is flow velocity, d

c

=

is collector diameter, and ν is the kinematic viscosity of water. Computing Re

c comes down to measuring the flow velocity (e.g. with Vectrino) since all other parameters are well-known. However, the interpretation of the value is much less clear because of the ill-defined transition between turbulent and laminar flow. Espinosa-Gayosso et al. (2013) suggest that Reynolds numbers for circular cylindrical collectors behave according to the following:

Re

c

behavior 0 to 47 steady two-dimensional flow regime 47 to 180 two-dimensional vortex shedding 180 to 260 three-dimensional vortex shedding 260 to 1000 “another kind” of three-dimensional vortex shedding

>1000 instability of the separating shear layers from cylinder side

As of the time of writing, all experiments with dowels in the flume have had Re

c

= 179.09.

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3 Particle capture rate estimation

3.1 Selecting an appropriate bin

Estimating the particle capture rate k relies on the assumption that particle concentration follows an expo- nential decay. Specifically, it is parametrized by equation 10 in Fauria et al. (2015)

φ(t) = φ

0

e−kt

where φ is the particle volumetric concentration (μL/L), φ

0

is the initial particle volumetric concentration, k is the particle capture rate (s−1), and t is time (s). This applies for a specific particle size, so we want to select a LISST bin for which the calculation will be performed. This equation is also independent of height, so we take the reference height to be that of the LISST sensor during the experiment.

• Open the script bin visualization.R.

• Replace the variable values in lines 5-8 with appropriate values and run the script.

• Inspect the resulting plot for a pattern that matches exponential decay over time. Call the correspond- ing bin number B.

3.2 Computing k

These next steps work on estimating the two unknown parameters in the previous equation, φ

0

and k, from LISST data. φ

0

is not directly useful, but may be able to serve as a check if initial particle concentrations for a particular size is known. The script uses nonlinear least squares to estimate these parameters.

• Open the script k calculation.R in R.

• Replace the variable values in lines 4-10 with appropriate values and run the script (most importantly, set the variable “bin k” to B).

• The final k estimate is contained in the variable “k exp.” An error may occur if the data poorly fit an exponential decay (then there’s not much you can do, except possibly choose a different bin).

• The script produces a plot of the actual data points vs fit, which is useful for qualitatively determining the goodness-of-fit.

3.3 Computing effective capture efficiency

Combining equations 3 and 9 from Fauria et al. (2015) and rearranging yield a useful expression for calcu- lating the effective capture efficiency η . This expression is

η =

k ud

c

l

c

where u is the flow velocity (m/s), d

c

is the collector diameter (m), and l

c

is the stem density(m−2).

• Provided the script was able to compute k successfully, it will also compute η (last two lines of code).

• Make sure to save all your changes to the script k calculation.R. You will need this later.

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4 Separating settling and capture effects

The previous steps only considered total particle capture, not accounting for capture due to settling vs capture onto collectors. We define k

s

to be the particle capture rate due to settling and k

c

to be the particle capture rate onto collectors. From equation 8 in Palmer et al. (2004), we have that

k

s

w

s h

where w

s

=

is the particle settling velocity and h is the depth of water in the flume. In general, k = k

s

+ k

c but we need to correct for the periodic exposure of the particles to the collectors (e.g. k

c

should only occur in the vegetated test section). In equation 11, Fauria et al. introduce a scaling coefficient such that

k

c

=

V

T Lwh

(k − k

s

)

where and larger h than V

is T

the is k. the water These volume depth. two of equations water Note that in the will Lwh

V

flume, T be L is the length of the vegetated region, w is the flume width,

will be larger than 1 so if k

s used to compute k

s

and k

c

.

is small compared to k, k

c

may be

4.1 Computing k

s

and k

c

Computing k

s

relies on estimating the settling velocity since water depth is known. There are two methods for this: sediment trap data and Stokes’ law.

4.1.1 Sediment trap method

For a given sediment trap, the mass at any time during an experiment is

m(t) = ρA

c

w

s

t

where m is the mass of the captured particles, ρ is the particle density, A

c

is the sediment trap cross-sectional area, w

s

is settling velocity, and t is time. Taking a time derivative gives

dm dt

= ρA

c

w

s

w

s

1 ρA

c

dm dt

in which we can approximate dm

dt

=

as time).

∆m ∆t

(accumulation of mass in sediment trap divided by experiment

4.1.2 Stokes’ law method

The Stokes’ law estimate for settling velocity is given by the equation

w

s

2 9

(ρ − μ

ρ

f

)

gR2

where ρ

f

=

is the fluid density, μ is the fluid dynamic viscosity, g is gravitational acceleration, and R is particle radius (all in mks units). The key assumptions for Stokes’ law are laminar flow and spherical particles (which may not hold in the flume).

• Open the script settling velocity kc estimates.R. This script refers back to k calculation.R, which is why you need to have saved your changes earlier.

• Replace the variable values in lines 5-12 with appropriate values (importantly, set “bin” to the same as earlier, B) and run the script.

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• The data frame “ST estimates” contains the estimated settling velocity and k

c

for each sediment trap (using sediment trap method).

• The data frame “stokes estimates” contains the estimated settling velocity for the median particle size for each bin. The variable “kc stokes” contains the estimated k

c

using Stokes’ law for the selected bin.

• The script does not explicitly return k

s

. Probably the easiest way to compute k

s

is to divide settling velocities by water depth.

5 Estimating k from peristaltic pump data

Estimating k from the peristaltic pump data is useful because it provides a check against LISST data. The same nonlinear least squares procedure is performed on the mass concentrations from the peristaltic pumps to fit an exponential decay model.

• Open the script peristaltic pump k estimation.R.

• Replace the variable values in lines 5-8 with appropriate values and run the script.

• The script produces an estimate of k, a plot with the fitted exponential and the data, and the mean- squared error.

6 Mass balance

The mass balance incorporates the sediment trap and peristaltic pump data. The basic steps are to estimate the sediment mass that settled on the test section using the sediment traps and to estimate the total mass that was removed from flow using the peristaltic pump data. The difference will be the mass that was captured on the collectors.

The mass that settled on the test section may be estimated by interpolating the sediment trap data points over the test section. Spatial interpolation by inverse distance weighting (with inverse distance power = 2) gives the settled mass per area for each 10 by 10 cm square cell in the test section. Multiplying each cell by the area and summing the cells in the interpolated surface yield the estimated settled mass over the test section.

The total mass removed may be estimated from the peristaltic pump data. Each time point has an upstream and downstream observation at three heights from the bed. For a given time point and height, the upstream concentration minus the downstream concentration represents a volumetric removal rate (mass/vol- ume). This volumetric removal rate may be multiplied by the discharge to obtain a general removal rate (mass/time). We assume concentration and height are independent, so we average across heights to obtain a single removal rate for a given time point. However, we may also assume that the removal rate is constant since the particle capture rates (and thus rates of decay) of the upstream and downstream sections are identical. Thus, we average across time to obtain a constant removal rate, which is multiplied by the total time to obtain a total removed mass.

• Open the script mass balance.R

• Replace the variable values in lines 6-9 with appropriate values and run the script.

• The script produces estimates of settled, collected, and total mass.

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