Flume Data Collection and Analysis

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1 Introduction

This document outlines the main data collection and analysis techniques for working with the flume, and comments on each method's advantages and drawbacks.

2 Instruments/Tools

2.1 LISST

The LISST is used to measure particle concentration over time in the flume. The collected data is then used to compute the particle capture rate k and, in turn, the effective capture efficiency η'.

2.1.1 Advantages

- familiarity of use in the literature
- code is available to quickly process and interpret LISST data

The main advantages of the LISST are that the infrastructure to integrate its data into analysis is already present. For one, the LISST has been used in past papers, so its utility and problems are well-documented. In addition, various scripts are easily accessible to process the data and calculate key parameters.

2.1.2 Disadvantages

- low ease of use
- transmission is restrictive
- uncertain data quality

The LISST is not comfortable to set up and install for use in the flume. First, a background scatter must be collected each time. Second, its physical weight (both the device and the battery) makes it harder to lift and position in the flume, especially with one person. Third, the software processes the raw data very slowly, often taking on the order of a few hours to process data from a 3-hour long experiment.

The LISST optical transmission is also another constraint on its performance. The device will not be able to collect data if the water is too clear or turbid; data tends to also be less reliable for more extreme transmission values. This fact must be taken into account when determining the amount of sediment to add to the flume such that one optimizes transmission for data quality.

Next, the LISST data may not be accurate. First, when collecting the background scatter, the software claims a normal error is within 0.3 μL/L but this low a value has never been achieved (lowest error is usually around 10 μL/L, sometimes exceeding 100 μL/L). Second, the flume may contain small particles (e.g. residual sediment from previous experiments), which produce large error in particle concentration if their sizes are less than the minimum detectable particle size for the LISST (7.5 μm). Third, the record of LISST data so far in flume experiments has featured inexplicable patterns (e.g. increasing particle concentration even when flocculation is not expected, lack of particles in certain bins, contradictions with peristaltic pump data).

2.2 Vectrino

The Vectrino is used to measure flow velocity over time in the flume. The measured flow velocity may then be used to compute η' and collector Reynolds number Re_c.

2.2.1 Advantages

- high ease of use
- familiarity of use in the literature

The Vectrino is relatively easy to set up in the flume. The device is attached to an 8020 frame, which rests above the flume and may be rested over the flume while not in use. The software is responsive and easy to navigate. The Vectrino has also been used in previous papers, which guide its use here.

2.2.2 Disadvantages

- restricted to a particular depth
- requires presence of particles to operate

The Vectrino measures flow velocity in a limited range from its position in the water column. Many computations require an average flow velocity, which is difficult to obtain or discern from recording at a single depth.

The Vectrino requires particles in the water to be able to collect measurements. If the water contains too few particles, the Vectrino will not be able to operate.

2.3 Peristaltic Pumps

The peristaltic pumps sample water upstream and downstream of the test section over the course of the experiment, giving a mass concentration. From the paired nature of the data, one can perform hypothesis tests to assess the influence of upstream/downstream position and depth on mass concentration. The ability to measure concentration also gives an independent dataset for concentration over time to supplement/check LISST data.

2.3.1 Advantages

- versatility
- empirically collected

The peristaltic pump data are versatile because, as mentioned earlier, they can evaluate influences of depth and position in the flume as well as give an idea of concentration over time. Second, the peristlatic pump data are collected empirically, a fact that eliminated the possibility of instrument error (for example, the LISST).

2.3.2 Disadvantages

- low sample rate
- requires substantial time and effort to collect and process samples

The fact that the water samples must be collected and recorded by hand restricts the sample rate. The time required to fill each sample container through the peristaltic pumps is another barrier to increasing the sample rate. The low sample rate means that the resulting data contain fewer data points, which may invalidate subsequent data analysis. In particular, k may be estimated from the data to provide an alternative method to the LISST; however, the estimate may be poor because of the lack of data points.

The sampling requires precise timing and alertness to ensure data quality. The fact that there are two positions for the pumps means that at least two people are needed to comfortably collect samples during an experiment. Once the samples have been collected, a considerable amount of time is needed to filter, dry, weigh, and record each sample.

2.4 Sediment Traps

Sediment traps collected settling sediment over the course of a flume experiment. This data may be used to separate the particle capture rate due to settling k_s and capture rate due to direct interception k_c.

2.4.1 Advantages

- empirically collected

The empirical nature of the sediment trap data precludes instrument error. This also serves as a check against the LISST data, and thus may be used to diagnose instrument errors in the LISST.

2.4.2 Disadvantages

- low spatial resolution
- sensitivity to perturbations

The spatial resolution of the sediment traps over the test section is limited because there are only nine sediment traps. Thus, we must infer about settling from only these data points, over the entire test section.

The mass collected in the sediment traps is sensitive to perturbations in the flume. For example, post-experiment handling may inadvertently re-entrain or introduce mass into the sediment traps. This poses a larger problem when dowels need to be sample, a process which may impact the collected mass by disturbing the surrounding water column. Finally, the time scale is key for sediment traps because settling will continue to occur even after flow stops. Sediment trap covers need to be placed carefully over the openings to restrict collection to the experiment time.

3 Analysis Methods

3.1 k estimation

Estimating k relies on fitting particle concentration data to the equation $\phi(t) = \phi_0 e^{-kt}$ where ϕ is particle concentration for a given time t and ϕ_0 is initial particle concentration. Most often, the fit is performed on LISST data, although the peristaltic pump data may also be fitted to the model. The current method uses nonlinear least squares to fit the given equation and thus estimate k.

3.1.1 Advantages

- scripts are available
- provide reasonable fits

The scripts to perform this task are easily accessible and provide reasonable fits to data that follow the model.

3.1.2 Disadvantages

- difficult to automate
- data may not fit exponential decay model

This task is difficult to automate because the of the particularities of each dataset. For example, the sediment is added after data collection begins, so the starting time for data analysis must be adjusted to match.

A frequently encountered problem is that the LISST data do not follow an exponential decay. Often, the particle concentration will resemble exponential decay for some bins, but other bins will feature exponential growth instead. More rarely, the data will have a sporadic pattern, precluding any model fitting. In these cases, fitting the model is impossible and a choice must be made to fit the model to a particular bin. This choice may highly influence the result, and it is unclear which bin should be selected beyond an arbitrary criteria.

3.2 k_s estimation - sediment traps

The sediment traps may be used to estimate k_s, the capture rate due to settling. Kinematically, the mass in a given sediment trap at a given time t should follow the equation $m(t) = \rho A_c w_s t$ where ρ is the particle density, A_c is the sediment trap cross-sectional area, and w_s is settling velocity. Some manipulation gives the form $w_s = \frac{dm}{dt}\frac{1}{\rho A_c}$ and then we can substitute $\frac{\Delta m}{\Delta t}$ for $\frac{dm}{dt}$ to solve for the settling velocity. Dividing by the water depth then gives k_s.

3.2.1 Advantages

- simple to compute

In addition to the advantages from using sediment trap data, the main attraction of this method is that it is simple to compute once the sediment traps have been filtered and weighed.

3.2.2 Disadvantages

- assumptions may not be valid

The drawbacks to this method are that its assumptions may not hold. Namely, this method assumes that settling velocity is constant and that $\frac{\Delta m}{\Delta t}$ is a good estimate for $\frac{dm}{dt}$. If any of these assumptions are violated, then the final estimate for k_s is incorrect. A poor estimate of k_s is particularly harmful because k_s is needed to back calculate k_c.

3.3 k_s estimation - Stokes' law

Stokes' law may be used to find k_s since computing k_s relies on finding the particle settling velocity.

3.3.1 Advantages

- simple to compute
- parameters are well-known

Stokes' law is easy to compute via a simple formula that may be coded as a function. In addition, the inputs in that equation (sediment density, water density, gravitational acceleration, and particle radius) are, for the most part, known and do not need to be estimated.

3.3.2 Disadvantages

- assumptions may not be valid

The validity of Stokes' law depends on many assumptions, all of which may not hold for flume experiments. Chiefly, Stokes' law requires the assumptions that particles are spherical and flow is laminar. For one, the particles may not be spherical (although it may be a justified approximation). Next, flow in the flume may not be laminar, especially considering the interactions of the dowels with flow.

3.4 k_c estimation

There are two methods of estimating k_s (sediment trap and Stokes' law). Since the k_c must be back-calculated from k_s, there are also two estimates for k_c. Each estimate inherits the advantages and disadvantages from its respective calculations and assumptions.

3.5 Mass balance

A mass balance argument may be used to estimate the mass of sediment that settles out in the test section and the mass of sediment that is captured by dowels.

3.5.1 Advantages

- provides a check for data analysis

3.5.2 Disadvantages

- assumptions may not be valid
- all disadvantages associated with sediment trap and peristaltic pumps

The mass balance assumes that, in the peristaltic pump data, the upstream concentration is larger than the downstream concentration. The difference is a "removal rate," which is positive for a reduction in concentration downstream. However, the data do not consistently have the upstream concentration larger than the concentration downstream, leading to negative removal rates. In addition, the low temporal resolution of the peristaltic pump data makes estimating total removal (and thus sedimentation) subject to larger error.

The sediment trap data must be interpolated across the entire test section. The use of only nine sediment traps reduces the accuracy the estimation. The use of inverse distanced weighted spatial interpolation allows for heterogeneity of the settled mass across the test section, but the the decay parameter for the influence of nearby data points is still subject to interpretation.