연속점 채취를 이용한 유사량 계산

SEDIMENT DISCHARGE BASED ON A TIME-INTEGRATED POINT SAMPLE

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1. Introduction

In conventional point-integrating sampling, velocity and concentration are measured at a number of points in the vertical to estimate the average concentration. The more points, the more precise and reliable this method is. However, it quickly becomes too time-consuming to be practicable for frequent routine sediment measurements. Less time-consuming and less costly methodology is required for collecting near-continuous sediment data, time-integrated point sampling, or automated sampling. A one-point suspended sediment sampling method has many potential advantages, and is probably necessary for any practical automated system.

Recently Ingram et al. (1991) suggested that time-integrated suspended-load point samples would result in better evaluation of the sediment load. They proposed a procedure (TSL procedure) to measurement and other stream data. The proposed technique used the concentration "in the bed-load zone" based on the Einstein bed load formula (1950) and dmodifications by Burkham and Dawdy (1980). The measured point-sample concentration and the calculated "bed-load" concentration were used to find z in the Rouse (1937) sediment concentration distribution equation. This is a major deviation from the theory of suspended sediment behavior and is a rather artificial concept. It is near the bed that all concentration distributions are suspect for several reasons.

The notion that point sampling has definite advantages has much merit, and Ingram et al. demonstrated the possibilities. This study is an effort to refine and improve their proposed procedures.

2. Problem definition

The following relationships for vertical velocity distribution and vertical suspended-sediment concentration distibution were used in this investigation to compute sediment load using single-point sampling data. These distributions were integrated over the vertical, and a bed-load equation was used (Jung 1993). Both concentration and compsition values are needed for the suspended sediment sample.

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$$\frac{\bar{u}}{\bar{U}} = (x+1)\left(\frac{y}{D}\right)^{x} \qquad (1)$$

$$\frac{C}{C_a} = \left(\frac{a}{y}\right)^{\frac{w}{\beta\kappa\sqrt{\tau_o/\rho}}} \qquad (2)$$

A hypothetical bed-material composition that is compatible with the measured suspended-load composition can be obtained by turning the Laursen total sediment load relationships (1958) around. This hypothetical composition can then be compared to the measured bed material composition. The differecne between the two should help to explain the usual scatter plots of sediment load versus discharge. The computed bed material, rather than the measured bed material, is used to compute the bed load.

One of the primary features that sets this one-pointprocedure apart from other methods is computation of the "best a," the level where the average concentration, C_m, equals the measured concentration, C_a. The "best a" for a single sediment size is easily obtained - assuming the defining relationships are correct. The "best a" for a sediment mixture, however, is difficult to define and is very dependent on whether the principal interest is in the concentration or in the composition of the sediment load.

Basic data needed for the computation are: cross-section shape, width, area, and hydraulic radius of the sampled section; flow depth D at the sampled vertical; sampling height above the channel bed; concentration and composition of the suspended-sediment sample; channel discharge; water temperature; and channel slope.

Manning's equation can be used to cumpute the overall roughness (Manning n). Using this n (or a local n if that seems more reasonable), slope, and depth, the local mean velocity can be found. Values of $\tau_o = \gamma DS$, $\kappa = 0.4$, and $\beta = 1$ are used except when variations ofthese factors were tested.

In this investigation the computation steps were as follows:

1. Calculate the z value for each size fraction of the point sample; fall velocity, w, for a natural sediment particle; and shear velocity, $\sqrt{gys}$. Use $\kappa = 0.4$, $\beta = 1.0$ in computing the Rouse exponent (unless experience indicates otherwise).

2. Integrate $\int C\bar{u}dy$ from α to D for each size fraction. divide the integral by flow rate per unit width to obtain average concentration, Cm , (Jung 1993).

$$C_m = \frac{JC_s {y_s}^{z}}{(J-z)D^{J}}\left(D^{J-z} - a^{J-z}\right) \qquad (3)$$

where J is equal to x+1 and ranges from 5/4 to 8/7; y_s is the level at which the point sample is collected; and C_s is the concentration of each size fraction of the point sample collected at the level y_s . The mean concentration can be multiplied by the discharge per unit width to find the total suspended load of that size fraction. The C_m of each size fraction can be summed to find the total suspended-sediment concentration in the vertical.

3. Multiply C_m by an area factor to find the overall mean concentration. The area factor will be site specific and requires specific studies at several flows for definition. Determining the area factor was not a part of this research, but hopefully the value should not very different from unity because of lateral turbulent mixing.

4. Use the results of step 2 and find the "best a" for each size fraction, the point in the vertical where C_m/C_a = 1. Now we can write (Jung 1993):

$$\frac{C}{C_a} = (\frac{a}{y})^z \tag{4}$$

$$\frac{C}{C_s} = (\frac{y_s}{y})^z \tag{5}$$

and using C_m form Equation (5) as C

$$\frac{C_m}{C_s} = (\frac{y_s}{a})^z \tag{6}$$

where C_s is concentration of point-integrated sample for a size fraction; y_s is the level at which the sample was collected, a is the "best a: for that size fraction (where C_m/C_a =1); and C_m is average concentration of the size fraction in the vertical.

Variations on these four steps can be used to investigate several aspects of sediment transport and sediment transport measurement.

3. "Best a" for a natural sediment mixture

The level at which to sample a sediment mixture so that C_m = C_a is difficult to determine. Each fraction (fine to coarse) should be sampled at a different elevation, and this cannot be done in single-point sampling. The difficulty can be overcome by using correction coefficients to convert sampled concentrations (of the various size fractions) to the concentration at the "best a" for each fraction.

To find the correction coefficients to relate the sampled concentrations of each size fraction to the mean concentration of that fraction in the vertical, the Laursen concentration distribution can be used,

$$\frac{C_m}{C_s} = (\frac{y_s}{a})^z$$

$$C_m = KC_s \tag{7}$$

$$K = \left(\frac{y_s}{a}\right)^z \qquad (8)$$

where C_m is mean concentration of the size fraction in the vertical, y_s is the level where the sample was taken, C_s is concentration of the field sample, a is the "best a" where average concentration of that size fraction can be measured directly, and K is a correction coefficient for converting the sampled concentration of each size fraction to mean concentration of the fraction in the vertical.

For fine sediment, the sampling height y_s would be less than the best a, but because z is small, the correction coefficient K would be only slightly less than unity. For coarse sediment, the same sampling height y_s would be greater than the best a, and the correction coefficient could be considerably greater than unity.

Samplers as presently designed cannot physically sample "close" to the bed, and conditions close to the bed are vairable in space and time, especially with a duned or anti-duned bed. This can lead to errors that may be large, especially for coarse sediment.

4. Comparison of results

Computed concentrations of four size fractions and total suspended load determined by four methods, based on data at three field stations, are compared on Figures 1, 2, and 3. The methods used are labeled as follows:

The M1 value in each group is the depth-integrated sample uncorrected.

The M2 value is a corrected depth-integrated concentration taht takes into consideration the difference in concentration when integrating to a lower limit ($2d_{50}$) with a nominal z value. The correction, as the figures indicate, is small for the finest fractions, relatively large for the coarsest fraction, and substantial for the next less coarse fraction. The overall correction is also substantial. The M2 value is considered most likely to be correct.

The M3 value is integrated based on the lowest point sample (with a lower integration limit of $2d_{50}$) and a nominal z for each size fraction. In almost all cases the point samples give higher concentrations than the corrected depth-integrated sample.

The M4 value is that estimated using the Laursen suspended load relationship. The prediction for total suspended load is high for one station and low for two stations, and it is better for total suspended concentration than for each size fraction. The measured bed material composition was used in this prediction.

6. Conclusions

It has been shown that a single-point sample of suspended-sediment concentration of a stream can be integrated over the vertical to find the averae concentration and composition of the suspended load in the vertical. An initial site survey of the entire cross section is needed to estanlish a coefficient to be applied to values for the vertical to determine the total suspended sediment load of the stream.

The power law velocity distribution and simplified concentration distribution used in this study are easy and fast to use in computations. Generally accepted coefficients and exponents in those equations descirbe the distributions adequately, but measurements in the field can improve the accuracy of those descriptions. The measurements needed for this purpose are the velocity and concentration distributions at different rates of flow. More needs to be known about details of turbulent flow behavior; at this time the effect of secondary flow and large-scale vortices can only be speculated on. Those large-scale features of flow, which exist and can be seen and/or measured, could influence the mixing of momentum and sediment sufficiently to explain the empirical coefficients needed to match measured and theoretical values.

The ultimate in data acquisition for sediment load estimation is an automatic sampling system. The research presented herein establishes ways to evaluate such automatic measurements and provides guidance to designing equipment and procedures. The sampling level should, if possible, change during a flood hydrograph; thesampling should be coordinated with the changing water surface and bed elevations. The technical and practical considerations of sampling were not studied in this research, but this research should be helpful in guiding and evaluating those aspects of the sediment load measurement problem.

References

(1) Burkham, D. E., and Dawdy, D. R. (1980). "General study of the modified Einstein method of computing total sediment discharge." Water-Supply Paper 2066, US Geological Survey, Washington, D.C.

(2) Culbertson, J. K., Scott, C. H., and Bennett, J. P. (1972). "Summary of alluvial channel data from Rio Grande Conveyance Channel, New Mexico, 1965-69." Professional Paper 562-J, US Geological Survey, Washington, D.C.

(3) Einstein, H. A. (1950). "The bed-load function for sediment transportation in open channel flows." Technical Bulletin NO. 1026, US Department of Agriculture, Soil Conservation Service, Washington, D. C.

(4) Ingram, J. J. (1988). "Total sediment load measurement using point-source suspended-sediment data."Technical Report HL-88-28, U.S. Army Engineer Waterways Experiment Station, Vicksburg MS.

(5) Jung, K. S. (1993). "A sediment discharge computation procedure based on a time-integrated point sample." Ph.D.Dissertation, Department of Civil Engineering and Engineering Mechanics, University of Arizona, Tucson, AZ.

(6) Laursen, E. M. (1958). "The total sediment load of streams." J. Hydr. Div., ASCE, 84(1), 1530-1 - 1530-36.

(7) Rouse, H. (1937). "Modern conceptions of the mechanics of fluid turbulence." Transactions, ASCE, 102, 463-543.

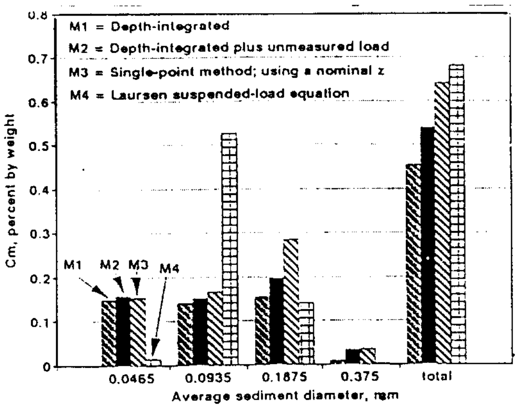

Figure 1 Comparison of average suspended sediment concentrations (Cm) data at station 2249 (no correction).

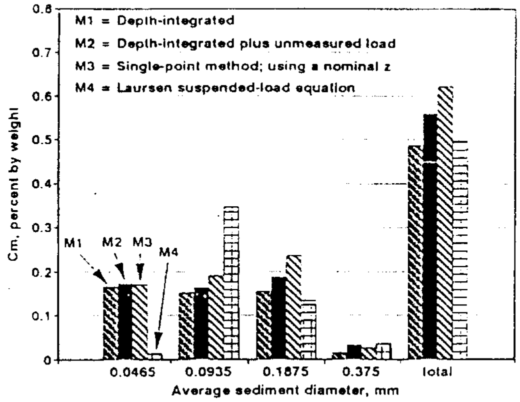

Figure 2 Comparison of average suspended sediment concentrations (Cm) at gaging station 2243 (no correction).

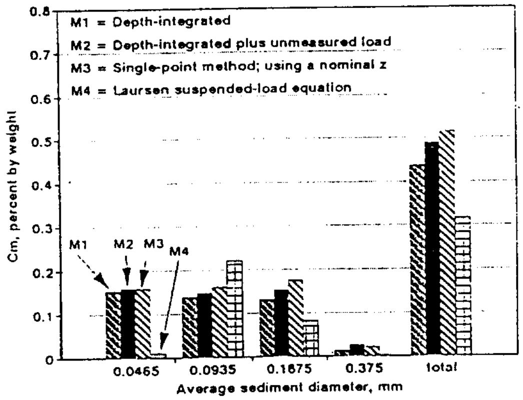

Figure 3 Comparison of average suspended sediment concentrations (Cm) at gaging station 1318 (no correction).