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An examination of the role of sampling strategies in the study of suspended sediment transport

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Abstract The paper examines the errors associated with automatic synoptic sampling strategies which result from temporal variability in storm suspended sediment responses. Synthetic storm event series are used to examine the impact on sediment loads of variation in the temporal relationship between stream discharge and suspended sediment concentration. The implications of various synoptic sampling strategies are examined. Where the temporal sampling strategy is inadequate, errors in load calculation can result. It is concluded that continuous monitoring using an indirect technique such as turbidity may result in a more accurate data set despite the inherent problems involved in such techniques.

Examen du rôle de la stratégie d'échantillonnage dans l'étude des transports de sédiments en suspension

Résumé La note relève les erreurs associées aux stratégies d'échantillonnage automatique synoptique résultant de la variation temporelle de la réponse aux averses des sédiments en suspension. Une série d'averses artificielles est utilisée pour observer l'impact sur la charge en sédiments des variations dans la relation temporelle entre le débit du cours et la concentration de sédiments en suspension. Les effets de diverses méthodes d'échantillonnage synoptique sont examinés. Lorsque la stratégie d'échantillonnage dans le temps est inadéquate il en résulte des erreurs dans le calcul de la charge en sédiment. Il est conclu, que le système de surveillance continue par l'utilisation de techniques indirectes telles que la mesure de turbidité, peut produire des données plus exactes et plus précises en dépit des problèmes inhérents à ce type de méthodes.

INTRODUCTION

Studies of contemporary stream sediment transport have been used to determine erosion and denudation rates. This information has often been used to infer long term erosion rates, as evidenced by the development of the

Bubnoff unit (1B = 1 mm/1000 years), despite the fact that it is based on very limited data bases covering very short time spans. Throughout the literature there has been considerable concern with the errors involved in contemporary sediment yield determinations, with most of this concern being related to field and laboratory techniques and estimation techniques such as sediment rating curves. Little attention has been given to the very important temporal relationships which exist between suspended sediment and stream discharge and the errors introduced by deficiencies in the temporal bases of sampling programmes which do not adequately sample variability through time. This paper examines this problem in relation to the determination of storm suspended sediment loads and outlines problems involved in various sampling strategies.

ERRORS IN SEDIMENT LOAD DETERMINATION

Early studies of sediment load determination have focused on the accuracy of field sampling techniques, particularly in relation to the accuracy of various sediment samplers (e.g. Inter-Agency Committee on Water Resources, 1963). Further studies were concerned with the accuracy of laboratory techniques used for sediment concentration determination (e.g. Loughran, 1971; Douglas, 1971). More recently, considerable research has been carried out assessing the procedures used for load calculation, particularly in relation to sediment rating curves. Walling (1977a, b, 1978) and Walling & Webb (1981) have shown that major errors can be associated with rating curve determinations of suspended sediment load. Similar results have been reported in Australian studies (Geary, 1981; Olive *et al.*, 1980). Ferguson (1987) examined the validity of several load calculation techniques. These results, coupled with the increasing availability of automatic samplers, have resulted in a concentration on direct measurement of suspended sediment on a storm event basis. This has greatly increased our knowledge of storm sediment transport and has illustrated the variability which may occur in the temporal relationship between suspended sediment concentration and stream discharge (Olive & Walker, 1982; Olive & Rieger, 1985). No consideration has, however, been made of the adequacy and accuracy of such sampling programmes. Any errors are particularly important if the data are to be used to infer sediment loads, because the errors associated with storm sampling are magnified, when the short term record is extended over much larger time scales to infer longer term sediment transport rates.

In determining storm suspended sediment loads the sampling programme much be sufficiently detailed to enable a realistic measurement of the temporal variation of suspended sediment concentration. If the storm response of concentration is variable, such as is the case in some basins (Olive & Rieger, 1985), then it is critical that concentration peaks are sampled and their temporal relationship with stream discharge peaks determined. This requirement is more important in small catchments, where stream discharge responses are rapid and sediment concentration has an even more "flashy" response. In most recent studies pump samplers have been utilized, using either a constant time interval between samples (frequently 1 h) or a "rate of rise" sampling system (cf. O'Loughlin, 1981). These have resulted in relatively detailed information on suspended sediment concentration during storms, but do not guarantee that sediment peaks have been sampled, giving rise to potential errors.

This paper examines the magnitude of errors resulting from:

(a) relative shifts in the timing of sediment concentration and stream discharge peaks,

(b) the time interval between samples.

SIMULATION OF SEDIMENT LOADS

To obtain an idea of the possible errors involved, synthetic storm event series for discharge and suspended sediment were generated at one minute intervals over a ten hour period. The time period is characteristic of small basins, and while larger basins may involve longer duration storms the relativities remain similar. The three types of storm event series used are shown in Fig. 1 and represent common suspended sediment responses. The responses are:

Event 1: single rise hydrograph with sediment concentration lead.

Event 2: double rise hydrograph with sediment concentration lead and sediment depletion.

Event 3: multiple rise hydrograph with no identifiable pattern to suspended sediment concentration.

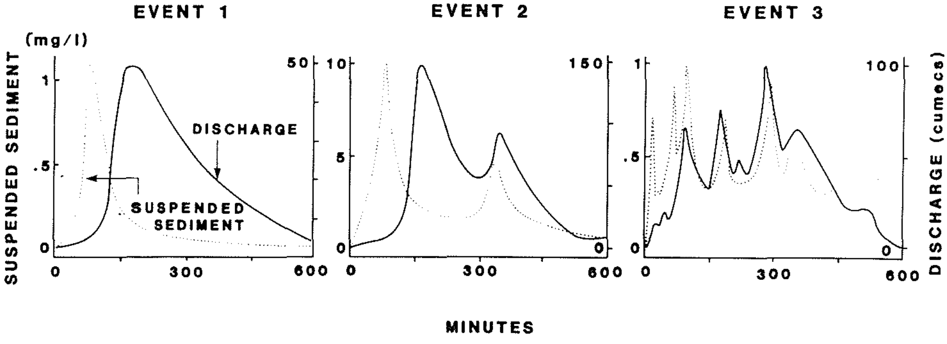

Fig. 1 Storm event series used in simulation.

Relative timing of responses

The importance of the accurate determination of suspended sediment concentration and stream discharge storm responses has been examined by comparing loads for one of the simulated storms (Event 1) by changing the temporal relationship between suspended sediment concentration and stream discharge (Fig. 2). The temporal shift of sediment concentration in relation to stream discharge results in a range from a sediment lead (clockwise hysteresis) through sediment/discharge correlation to sediment lag

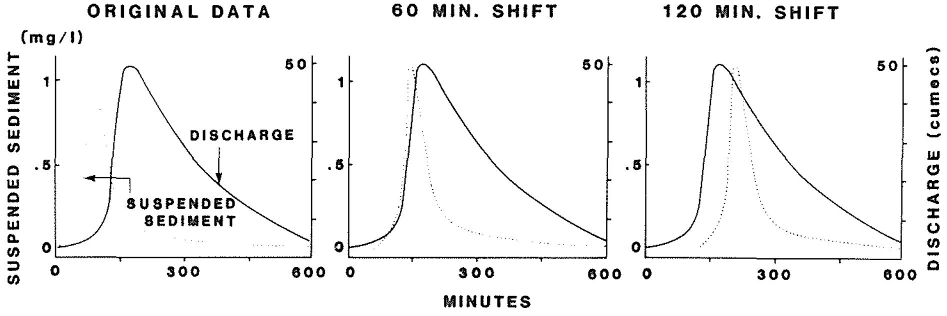

Fig. 2 Shifts in suspended sediment curve for Event 1.

(anticlockwise hysteresis), a range of responses frequently reported in the literature. Load was calculated by averaging suspended sediment and discharge between adjacent points in the series, then multiplying the results.

Sediment load is a function of both sediment concentration and stream discharge and is very much dependent on the relative magnitude of concentration and discharge at any point in time. Where the peaks of both occur simultaneously, then they will be multiplied to give large changes in load. Where the response curves are offset (e.g. lead or lag), loads will be considerably lower. This is clearly shown in Fig. 3, where the calculated load

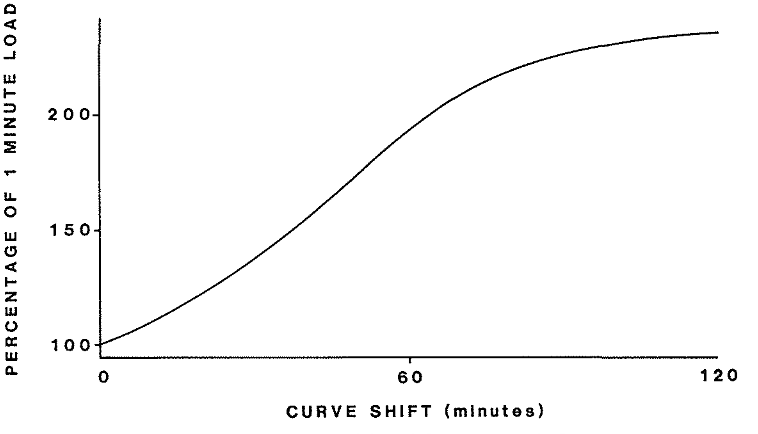

Fig. 3 Variations in estimated load for curve shifting as in Fig. 2.

increases substantially as the two peaks correlate. Relatively small time shifts can result in relatively large changes in load, for example in Event 1 a 10 min shift can result in changes in load of over 12%. With pump sampling programmes temporal errors are often greater than 10 min. From this illustration it is clear that to calculate a meaningful sediment load it is critical that the determined sediment concentration and discharge responses are accurate, particularly in respect to their temporal relationship. Timing errors may be more important than errors in the determination of sediment concentration. The sampling programme used must be capable of adequately determining not just absolute values of sediment concentration, but also establishing the temporal relationship with discharge.

Variations in sampling interval

To examine the adequacy of different sampling programmes a simulation was carried out based on the use of different sampling time intervals for the calculation of loads. The load determined for each different time interval of sampling was expressed as a percentage of the load calculated using the original one minute data series. Figure 4 shows the series based on 60-min sampling intervals for the three original storm events. When compared with Fig. 1, it clearly demonstrates the loss of information and changes in the nature of the series which result from using a less frequent sampling interval.

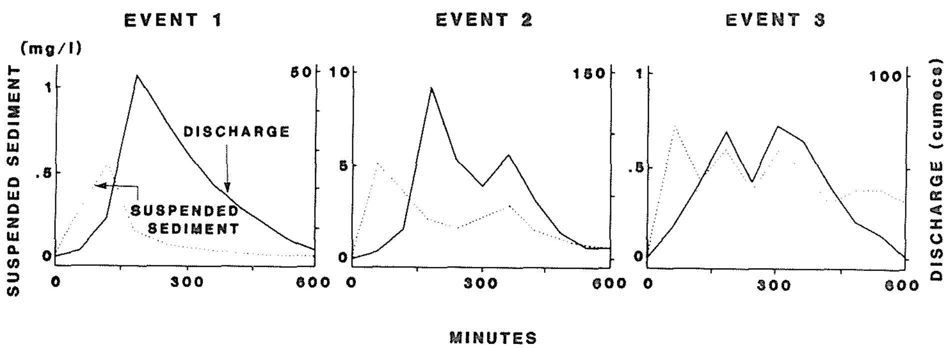

Fig. 4 Storm event series defined by a 60-min sampling interval.

As the shape of the curves in Fig. 4 are determined by the starting point for a particular sampling interval, the simulation of loads incorporated a sampling scheme which used a number of different starting points for each sampling time interval. The adequacy of the sampling program depends very much on the timings of the start of sampling and the timing of sediment peaks. If sampling happens to correspond to the peaks then the results may be reasonable, however, as sampling normally commences at a predetermined stage the possibility of this corresponding with later events such as peaks is random. For each sampling time interval, t = 5, 10, 15, ..., 120 min, 50 different starting points between 1 and 60 were determined using a random number generator and loads calculated for the 50 series based on these random starting points.

The results of the simulation were expressed in terms of the mean and range of the 50 samples for each sampling time interval and are summarized in Fig. 5. For a particular sampling time interval, the top and the bottom of the line give the maximum and minimum values, while the horizontal tick designates the mean of the 50 samples with different starting points.

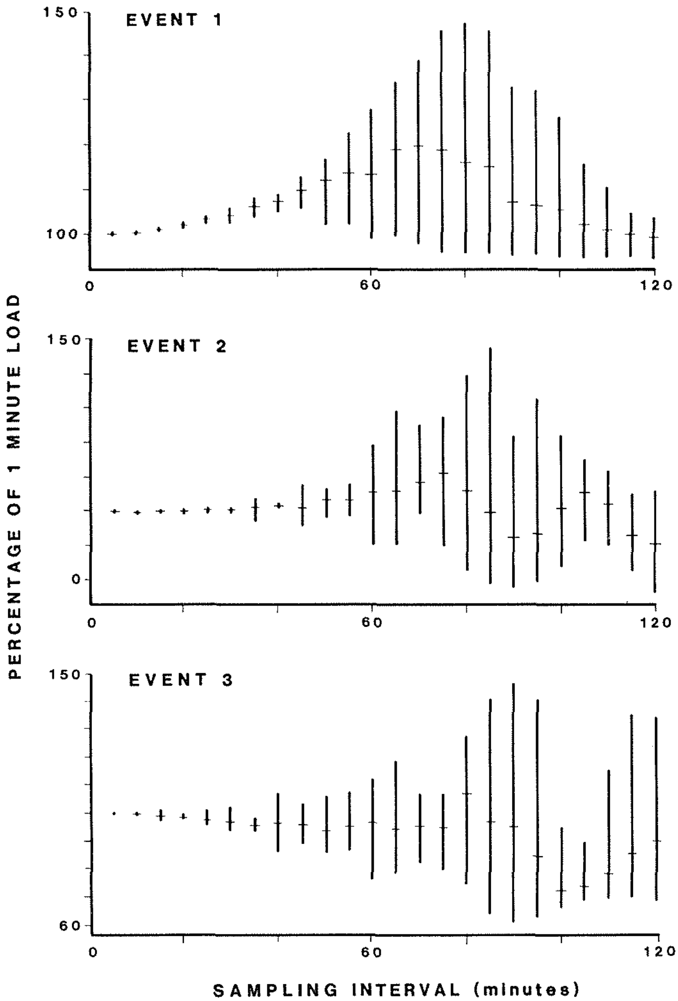

Fig. 5 Variations in estimated sediment load for different sampling intervals.

While these results refer specifically to the synthetic curves used in the simulation, some general characteristics are indicated:

(a) there are relatively small errors in load estimation for sampling time intervals less than 30 min;

(b) the starting point for the estimation of load for a given sampling time interval is critical as seen in the range of values for the different starting points. In a real situation this starting point is random and so there is no guarantee that a representative response pattern will be obtained.

In this simulation, sampling frequency has been based on a constant time interval. If a rate-of-rise sampler was used many of the problems outlined above would also apply and there would be the additional problem of varying time intervals between samples. Such a sampler is based on the assumption that changes in suspended sediment concentration correspond to changes in discharge and sampling is based on stage increments rather than time increments. Commonly sampling is more frequent on the rising stage than on the falling stage. In streams with variable responses there will be greater variability in the results than is the case if sampling is done at constant time intervals.

DISCUSSION

From the simlation carried out it is apparent than an accurate representation of the storm responses of sediment concentration and stream discharge and of their temporal relationship with each other is essential to produce meaningful load calculations. In the case of synoptic sampling using direct measurement of concentration from automatic pump samples, this is only possible if the time interval between samples is small. As the sampling interval increases, there is a distinct loss of information introducing errors. Also, the probability of sampling the sediment peak reduces and as this is random, it introduces greater variability into the calculated loads.

To overcome the problems, a short sample interval is required, but this raises logistic problems in processing the volume of samples obtained. A more satisfactory program is some form of continuous monitoring of sediment concentration which usually involves indirect measurements, the most common of which is the use of continuous recording turbidity meters. As turbidity is an indirect measure, queries have been raised about the calibration of meters for suspended sediment concentration. Turbidity values will vary with changes in sediment characteristics such as size and shape as well as for changes in sediment concentration (Oades, 1982; Gippel, 1988). These variations introduce errors in sediment estimation. Despite these problems, many studies have shown a strong correlation between turbidity and suspended sediment concentration (Walling, 1977a; Grobler & Weaver, 1981; Lammerts van Bueren, 1984). It does appear that the prediction errors in the relationship between turbidity and suspended sediment may be outweighed by the increased accuracy from the more detailed temporal data base obtained. The resulting errors in load calculations are less than those related to the various temporal sampling problems associated with direct sediment concentration determinations. Turbidity meters offer a considerable saving in data collection and laboratory analysis and, despite their shortcomings, overcome many of the temporal problems associated with automatic samplers. The increased information supplied by continuous monitoring and the problems associated with pump samplers is clearly shown in Fig. 6. This shows sedigraphs based on a continuous recording turbidity meter and pump samples taken at hourly intervals for a storm in the Molonglo River, a basin of approximately 1500 km^2. Even in this relatively large basin suspended sediment concentrations can vary rapidly and in the storm illustrated the pump sampler failed to sample either of the peaks in the early part of the storm. Many of the problems outlined above are highlighted where there is

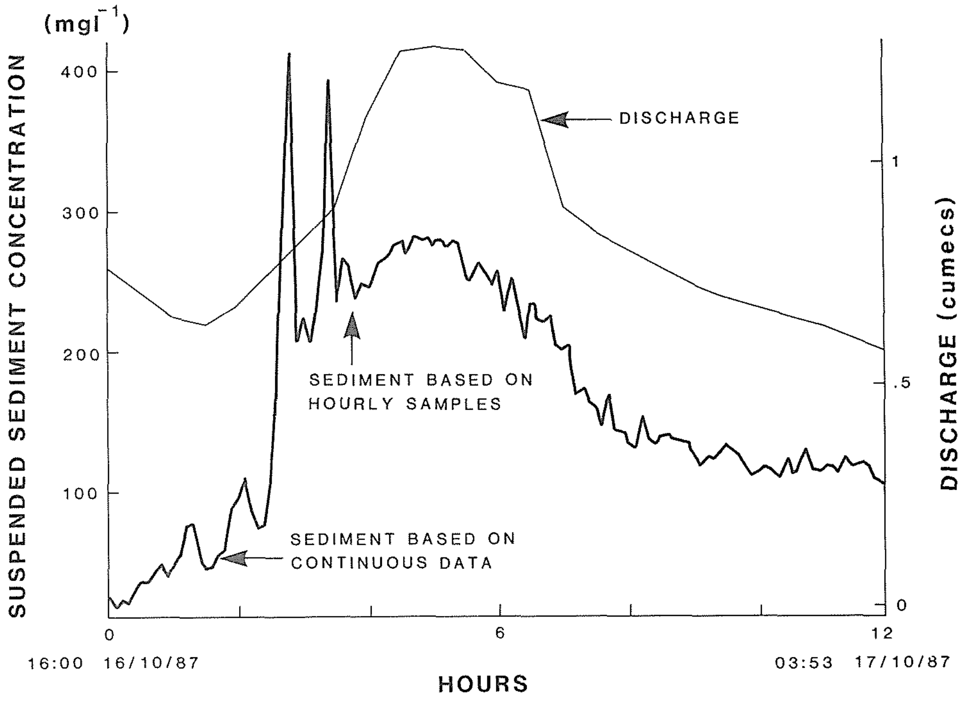

Fig. 6 Storm event for Molonglo River, October 1987.

high variability in stream flow regimes and sediment responses as appears to be the case in many Australian basins (Finlayson & McMahon, in press; Olive & Rieger, 1985).

CONCLUSIONS

Considerable effort has been expended in the study of contemporary suspended sediment transport to evaluate the accuracy of sampling equipment and laboratory and estimation techniques. Little research has been undertaken to evaluate the adequacy of temporal sampling strategies, particularly with increasing use of automatic samplers. This paper shows that significant errors can be introduced in such sampling programs and that it is likely that better results can be obtained by continuous monitoring using an indirect technique such as turbidity. While there are inherent problems in using such techniques, the increased temporal data obtained more than offsets these problems.

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