Erosion and Sediment Transport Monitoring Programmes in River Basins (Proceedings of the Oslo Symposium, August 1992). IAHS Publ. no. 210, 1992.

Towards the design of a strategy for sampling suspended sediments in small headwater catchments

R. C. JOHNSON
Institute of Hydrology, Balquhidder,
Lochearnhead, Perthshire, UK, FK19 8PQ

ABSTRACT Although several studies have provided valuable recommendations for sampling suspended sediments in river basins, little has been done for small, headwater catchments. Large variability in the meteorological and hydrological conditions are experienced which can be linked to the variable sediment release and transport. If a spot sampling strategy is being used then a large number of samples is required over a period of several years to minimise the potential errors.

INTRODUCTION

Published results from a wide range of sediment research sites show little comparability in the sampling strategies. Different sampling instruments, methods, periods, durations and analytical techniques are apparently used with little detail reported. This is not due to a lack of guidance from other studies (eg. Guy, 1965; Walling & Webb, 1988; Bogen, 1988) which have demonstrated potential problems involved and given recommendations of methods to use. This is a serious downfall of many studies which have a valuable contribution to make to a general understanding of sediment processes but which fail in their basic experimental design.

From a selection of studies in the UK it is interesting to note some of the different methods and sampling strategies reported. Walling & Webb (1982) took continuous turbidity measurements for a period of 5 years in a catchment of $46 km^2$. Finlayson (1978) worked on a small catchment ($0.18 km^2$) collecting 78 samples in one year. Leeks and Roberts (1987) took 'bulk samples' in a catchment of $3 km^2$ in area but gave no details of the method used. Ferguson et al (1991) used control and experimental catchments with areas of $1.51 km^2$ and $0.84 km^2$ respectively, using automatic pump samplers for almost 4 years. Most of the results in the UK are from small ($<10 km^2$) catchments but there is little consistency in the sampling strategies, making comparisons difficult.

The paper of Walling & Webb (1988) presented convincing evidence of a sampling strategy to be used for medium and large (in UK terms) sized catchments. There is, however, a significant difference between their catchments and the small, headwater catchments where the majority of UK research has been carried out. Sampling positions are much closer to source areas, sediment characteristics are more mixed and hydrological and meteorological regimes are very variable.

This paper is concerned with the sampling strategies in small, headwater catchments. Data from the Balquhidder catchments in Highland Scotland (Johnson, 1991) are used to develop a strategy for suspended sediment sampling covering sampling method, number of samples and period of experimentation.

SAMPLING METHOD

The recommendation of Walling & Webb (1988) to use continuously monitoring turbidity meters is not always possible to adopt in upland catchments. From observation of the range of sediment particle sizes collected from headwater catchments it has been considered unlikely that a reasonable calibration curve for the turbidity data can be obtained. However, the decline in credibility of rating curves has produced a major problem in load analysis and the turbidity option will have to be reconsidered. Without turbidity measurements the choice is whether to use manual depth integrated sampling or automatic pump samplers.

Manual sampling inevitably limits the eventual size of the data set and, ass will be shown later, this gives problems to the value of the data. But depth integrated, manual sampling has the advantage of smoothing the suspended sediment concentration (SSC) within the stream cross section. This variability is a problem and sampling has been attempted in one of the Balquhidder catchments where it was hoped to find an optimum point sampling position; no systematic distribution was found. Automatic samplers are a considerable asset when sampling at fixed time intervals over many years.

Short period SSC variations have also been found in the Balquhidder catchments which give rise to a large scatter in data collected by spot sampling (see Fig.2 Johnson, 1988). Several sets of multiple samples have been taken to illustrate this point. Results from sets of 10 dip samples of 600ml in volume are presented in Table 1. By comparing the maximum and minimum values with the median value it could be said that there is a very large variability in 11 out of the 15 sets. There are none of the sets where both the maximum and minimum values fall within 25% of the median value.

TABLE 1 Analysis of the variability in suspended sediment concentration (mg/l) in 15 sets of multiple (10) dip samples.

Mean	Median	Maximum	Minimum	Standard deviation
86.7	89.3	107.0	56.5	18.8
35.3	20.2	138.0	12.1	42.8
27.6	27.9	35.2	13.7	6.9
26.1	24.7	38.3	20.2	5.6
23.5	21.8	35.2	14.7	6.7
19.9	15.5	49.4	4.0	16.2
18.8	11.3	56.2	3.8	18.1
14.0	14.3	18.8	8.3	4.2
12.5	10.0	28.3	5.8	7.5
12.2	9.2	25.5	2.7	7.7
10.0	9.5	14.8	8.3	1.9
9.5	9.5	20.5	1.3	5.5
8.2	8.5	10.4	6.3	1.4
5.5	3.3	20.3	2.5	5.5
3.7	3.7	5.0	1.8	0.9

NUMBER OF SAMPLES

The large number of samples needed to overcome the cross sectional and temporal variability in SSC and to reasonably describe the SSC in an headwater catchment is illustrated by using three years of data (1988-90) from the Balquhidder catchments. Samples were collected at 8 hourly intervals using an automatic pump sampler with suction tubes at a fixed height above the river bed. The total sample size in the Kirkton catchment was 2600 and the Monachyle catchment 2100.

From the complete data sets a series of sub-sets have been randomly selected each time decreasing the sample size by 100. The sub-sets are therefore independent of stream-flow and time. Without the actual sediment load to compare with the sub-sets, and avoiding the problems with regression equations, the simple option of the arithmetic mean was chosen as the parameter to enable comparison between data sub-sets. Two analyses on the mean values for each catchment are presented here: a sequential reduction in size down to 100 samples and 10 random selections of the data sub-sets for different sample sizes.

The mean SSC for each randomly selected data sub-set are given in Table 2. A minimum acceptable sample size is arbitrarily defined here as the smallest sample size which remains within two standard errors of the mean of the complete data set (6.8 Monachyle; 16.6 Kirkton). This

TABLE 2 Mean suspended sediment concentration (SSC) for randomly selected sub-sets of data with a sequential reduction in the sample size.

N	M	K	N	M	K
2600	-	135.9	1300	42.5	127.3
2500	-	136.9	1200	46.4	151.4
2400	-	134.2	1100	48.5	125.8
2300	-	135.2	1000	40.8	141.1
2200	-	135.2	900	52.9	121.6
2100	44.0	135.0	800	52.3	125.4
2000	43.5	136.9	700	39.8	146.6
1900	43.3	145.2	600	41.2	136.4
1800	42.9	123.5	500	41.4	112.5
1700	44.5	142.3	400	42.7	157.2
1600	43.5	138.8	300	48.3	123.1
1500	44.1	134.0	200	49.5	115.5
1400	44.3	127.4	100	31.8	93.6

N - number of samples in data sub-set;
M - Mean SSC (mg/l) for the Monachyle catchment
K - Mean SSC (mg/l) for the Kirkton catchment

gives minimum values of 1000 for the Monachyle and 600 for the Kirkton.

Fig.1 shows a sensitivity analysiss on a selection of mean values in Table 2. The random selection of data has been repeated 10 times for sample sizes of 1500, 1000, 500 and 100. There is an enormous variability shown in the smaller sample sizes especially in the Kirkton catchment. Again using twice the standard error as defining the minimum acceptable sample size then the curves of best fit to the extreme values cross this limit at 500 samples for the Monachyle and 700 samples for the Kirkton.

Although the analysis here is only using a mean value this simple, unambiguous analytical method has been used to show the very large number of data required before a mean value can be calculated. It is accepted that other analytical methods could perhaps be used requiring fewer data.

PERIOD OF EXPERIMENT

Fluvial sediment loads are controlled by a number of factors: sediment availability, meteorological and hydrological events, land disturbance etc. If the impact of one of these is to be quantified then the influence of the other controls needs to be known or controlled. Catchment experiments are often divided into control and

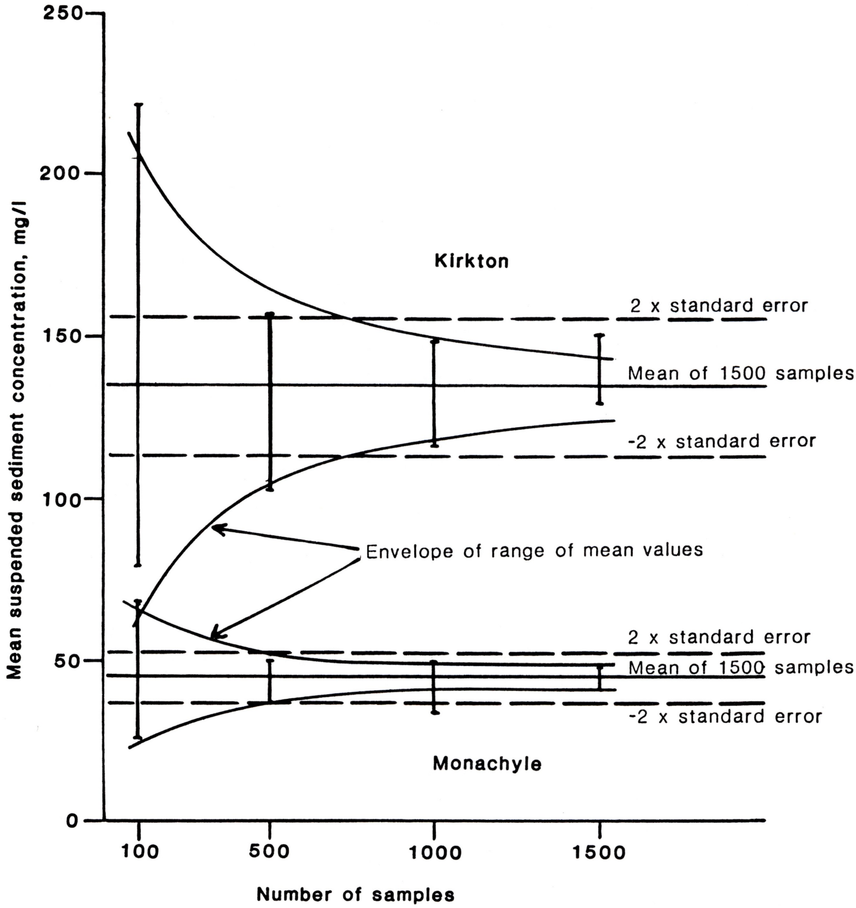

FIG. 1 Sensitivity analysis of the randomly selected data sub-sets to calculate the mean suspended sediment concentration.

experimental periods of different durations. In the Balquhidder study a control period of 3 years was available before land use changes occurred. Catchment recovery rates are expected to be much longer than this, maybe 15-20 years, so it is inevitable that different meteorological and hydrological events will occur in the two periods. Other studies are noticeably shorter in duration with some reported as having control periods of only several months. Using the Balquhidder catchments as an example of the different meteorological and hydrological conditions which can be experienced, table 3 shows the annual precipitation and flood frequencies during 1983-1989 for the Monachyle catchment. The contrasts are significant in that the 'experimental' period is wetter than the 'control' period but also the two extreme years occur in the 'experimental' period. As the Monachyle sampling was intended to determine the effect of land use change (ploughing) in 1986 then it is questionable whether any significant change in SSC was solely related to the land use change. It is more likely to be a combination of changes in all of the sediment controls.

Looking back through reports from other research sites, including those described earlier in this paper, there are many studies carried out over short (<3 years) periods and some of only several months. It is doubtful whether these studies were sufficiently long enough in the period of experimentation.

Continuing to show the problems of detecting the changes due to, say, land use change in headwater catchments, the SSC data from the Monachyle catchment is also given in Table 3. Numbers of samples are only sufficient, according to the earlier analysis, in two years, 1988 and 1989 but from Fig.1 a realistic range for the mean value can be derived. Using the probable maximum and minimum limits derived from Fig.1 it could be said that there are significantly different years. The 1983 to 1988 period possibly conforms to an expected pattern before and after the land use change but the 1989 value is better linked to the number of flood events. Precipitation

TABLE 3 Comparison between years of the precipitation, number of flood events and suspended sediment concentrations in the Monachyle catchment during the control and experimental periods.

Year	P	F	N	M	Mx	Mn
'Control' period						
1983	2857	50)				
1984	2648	35)	453	14.0	22.2	5.2
1985	2612	52)				
'Experimental' period						
1986	3280	53	179	40.9	57.4	24.4
1987	2255	38	438	58.9	67.3	50.5
1988	2952	45	741	25.0	31.7	18.3
1989	2985	59	739	40.5	47.2	33.8

P - Annual precipitation, mm
F - Number of floods > 1mm/hour
N - Number of samples
M - Mean suspended sediment concentration, mg/l
Mx- Probable maximum concentration, mg/l
Mn- Probable minimum concentration, mg/l

totals do not appear to be dominating the SSC as demonstrated in 1986 and 1987.

The value of this analysis is to demonstrate that within an 8 year period there are significant variations in more than one sediment controlling factor. To chose a sampling period of less than 3 years in headwater catchments would be very risky but also comparing two periods with different meteorological and hydrological conditions is maybe even worse.

CONCLUSIONS

Using the suspended sediment data sets from the Balquhidder catchments several results have been obtained which should help in the design of a strategy for sampling suspended sediments in small, headwater catchments.

The sampling method would preferably be by continuous monitoring as spot samples are affected by small scale spatial and temporal variations. To reduce the errors in the data caused by these variations at least 500 and maybe 1000 samples are required. In headwater catchments the mixed meteorological and hydrological regimes make it important to sample over similar periods. This might mean sampling over many years but it important to carry out a comparative analysis to determine whether two similar periods are being compared.

REFERENCES

Bogen, J. (1988) A monitoring programme of sediment transport in Norwegian rivers. In: Sediment Budgets (Proc. Porto Alegre Symp., Dec. 1988) IAHS Publ. no. 174, 149-159.

Ferguson, R.I., Grieve, I.C. & Harrison, D.J. (1991) Disentangling land use effects on sediment yield from year to year climatic variability. In: Sediment and stream water quality in a changing environment: trends and explanation (Proc. Vienna Symp., Aug 1991) IAHS Publ. no. 203, 13-20.

Finlayson, B.L. (1978) Suspended solids transport in a small experimental catchment. Z. Geomorphol. N.F. 22, 2, 192-210.

Guy, H.P. (1965) Fluvial sediment measurement based on transport principles and network requirements. IAHS Publ.no.67, 395-409.

Johnson, R.C. (1988) Changes in the sediment output of two upland drainage basins during forestry land use changes. In: Sediment Budgets (Proc. Porto Alegre Symp., Dec. 1988) IAHS Publ. no.174, 463-471.

Johnson, R.C. (1991) Effects of upland afforestation on water resources: The Balquhidder experiment 1981-1991. Institute of Hydrology Report no.116. Institute of Hydrology, Wallingford, UK.

Leeks, G.J.L. & Roberts, G. (1987) The effects of forestry on upland streams - with special reference to water quality and sediment transport. In: Environmental aspects of plantation forestry in Wales. Institute of Terrestrial Ecology Symp.no.22, 9-24.

Walling, D.E. & Webb, B.W. (1982) Sediment availability and the prediction of storm-period sediment yields. In: Recent developments in the explanation and prediction of erosion and sediment yield (Proc. Exeter Symp., July 1982) IAHS Publ.no. 137, 327-337.

Walling, D.E. & Webb, B.W. (1988) The reliability of rating curve estimates of suspended sediment yield: some further comments. In: Sediment Budgets (Proc. Porto Alegre Symp., Dec. 1988) IAHS Publ. no.174, 337-349.