

Design curves for suspended load estimation

G. FLEMING

Mr A. J. M. Harrison, Hydraulics Research Station, Wallingford

I should be interested to know what definition of suspended load was used by the Author. Was this the quantity of sediment sampled below a particular grain size, or, alternatively, was this the total quantity of all sizes sampled, in which case how close to the river bed was sampling carried out? In § 20 it is suggested that the difference between the calculated and measured results for the Clyde could be due to sand and gravel workings upstream. But surely these materials would not come within the definition of suspended load?

23. Would the Author also explain in more detail the vegetation zones used in Figs 3–6? A world map showing the different zones would be useful and the climatic limits—e.g. latitudes, mean annual temperatures, mean annual rainfalls—within which the plotted data fall, should be stated.

24. I should be grateful if the Author would give a brief explanation of the statistical parameters used in the Paper and extend the table of parameters on Fig. 1 so that it can be compared with Figs 3–6.

25. The good correlation of sediment load with catchment area on Fig. 1 is remarkable since this applies to all vegetational covers. I wonder whether Figs 3–6 are an advance on Fig. 1, since their degree of scatter is in general no less.

26. Fig. 3 shows an almost linear correlation of sediment load with discharge. Does the Author consider that this figure establishes any relationship other than the fact that the suspended load concentration for rivers in this vegetational zone is approximately 150 p.p.m.?

27. In § 16 the Author mentions a number of additional parameters which influence the sediment load. Since most suspended material is in the silt-clay range of sizes it is possible that factors such as the turbulence and the chemical impurities in the water affecting the flocculation and hence the fall velocity of the sediment are also important. Does the Author agree that such parameters as the shear velocity and the pH value should also be considered?

Mr J. H. Fleming, Partner, Sir M. MacDonald, Partners

The Author has made a useful compilation of sediment load data and has produced diagrams which can assist as a starting point for estimates of silting. I agree that the relationships plotted in Figs 1 and 2 are not meaningful, and indeed it would be surprising if they were. Generally, suspended load is the result of material being washed from the catchment area by sheet flow or small rivulets as a direct result of run-off. The sediment yield of a catchment thus depends upon the topography (steep ground erodes more quickly), geology (soft rocks erode more quickly), vegetation and rainfall intensity.

29. The Author has concentrated on vegetation cover as a variable in determining the diagrams in Figs 3–6. However, the band between the limit lines still covers a wide variation, although it looks narrow when plotted on multi-cycle logarithmic paper.

30. Figs 3–6 would be more illuminating if the abscissae were changed from cusecs to total annual discharge in cubic metres (or tons). The ordinates could then be re-plotted as percentages. Since 100 cusecs is equivalent to 90 million ton/year,

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the average sediment load throughout the year in Fig. 6 (desert and scrub) would range between 0.8 and 2.2%. I should like to examine this case because I was concerned with sediment estimation in such an area in Baluchistan.

31. In eastern Baluchistan, which is subject to monsoon rainfall and where the topography is barren and hilly, the average sediment load varied from 1.2% to 4.6% according to the catchment characteristics. Some measurements were made by sediment sampling and the construction of a sediment rating curve; others by measurements of silt accumulation in a reservoir.

32. It was possible to reconcile the variations in sediment content of different rivers by assuming that the run-off which caused erosion originated in the hilly parts of the catchment, and by determining the percentage of highly erodible rock in these areas by reference to a geological map and air photos.

33. An empirical relationship was evolved which related the percentage sediment load to the percentage of erodible catchment, so that after three years of observations it was possible to assign a value to the average suspended sediment transported each year in various catchments, with a probable accuracy of $\pm 25\%$.

34. A feature of Figs 3-6 is that the percentage sediment load is greater when the average discharge is smaller. This is difficult to explain, because the suspended load generally represents the sum of the material washed down in small streamlets over the whole of the catchment, but the suspended load in the headwaters of a river in flood will contain fairly coarse grades of sand, whereas in the lower reaches of the flood plain this material will have settled out or will be transported as bed load, and only clays and fine silts will remain in suspension.

35. However, it would be interesting if the Author could give an explanation for the apparent ten-fold decrease in percentage sediment load for a rise in average discharge from, say 10 to 10 000 cusecs. The sum of the parts cannot be greater than the whole, and it is hard to imagine 90% of the suspended load in the headwaters settling out by the time the flood plain is reached. In our studies in Baluchistan, with the average run-off from various catchments varying between 20 and 500 cusecs, no such variation in sediment load was apparent.

Mr Rees

Has the Author any advice to offer, or any new information, on dumping solids in suspension?

Mr G. W. Kite, Colorado State University

The Paper is a simplified example of a technique which should prove to be an important development in estimating sediment discharge. Some of the most popular estimation techniques in use today such as those of Einstein,⁴ and of Colby and Hembree⁹ involve long and complicated procedures without producing consistently good results. It would seem that a multiple regression technique could result in more significant answers with far less effort, provided a suitable choice of parameters could be made. The parameters must be physically meaningful and yet easily measured.

38. There are a number of points I would like to make regarding this interesting Paper.

39. The magnitude of the correlation coefficients quoted for Figs 3-6 (which, incidentally, should be termed simple linear correlation coefficients, not multiple correlation coefficients) seem to be rather high considering the visible scatter of the data on each graph. Selecting Fig. 5 as representative, I abstracted the co-ordinate pairs from the graph as logarithms and ran the data through a standard linear regression program. The resulting regression equation agrees very closely with that of the Author but the correlation coefficient is only 0.841, which would seem more reasonable. This, however, is still highly significant since from the corresponding coefficient of determination of 0.70 it can be seen that only 30% of the variance in

the annual suspended sediment load remains unexplained by the variance in the mean annual discharge.

40. It is interesting to note that Benson¹⁰ gives an equation which can be used to compute approximately the expected correlation coefficient between the product of two variables, x_1 and x_2 , and one of the variables, say x_2 , as follows:

$$r = \frac{r_{12}c_1 + c_2}{(c_1^2 + c_2^2 + 2r_{12}c_1c_2)^{1/2}}$$

where r_{12} is the correlation coefficient between variables x_1 and x_2 and c_1 , c_2 are the respective coefficients of variation.

41. In this case, of course, x_1 would be a form of concentration, computed as mean annual suspended sediment load divided by mean annual discharge, and x_2 would represent mean annual discharge. The expected value of r is computed to be 0.805, which suggests that most of the correlation between sediment load and discharge is due to this common factor.

42. This, of course, does not detract from the result, provided no attempt is made to derive other relationships between the variables using this correlation coefficient.

43. The Author leaves Indian data out of the correlation shown on Fig. 1 because of the peculiar conditions under which those rivers operate. The same condition of occasional flash floods bringing down very high sediment loads occurs in the arid southwest of the USA and probably in several other localities. A better procedure than excluding these data might be to introduce a parameter based on the number of days of high rainfall per year or some indicator of rainfall variability.

44. Agricultural engineers¹¹ using a slightly different approach have been able to obtain similarly high multiple correlation coefficients relating soil-loss to a number of other factors. An example is the Wischmeier-Smith equation:

$$A = RKLSCP$$

where A is the annual soil loss in ton/acre,

R is the erosive potential of the rainfall,

K is an erodibility factor depending on the soil type,

L is a slope length factor,

S is the degree of slope,

C is a cropping factor depending on the type of vegetation, and

P is a conservation practice factor.

It would seem that, with minor changes, this technique could be adapted to compute the overall soil loss from a watershed in terms of parameters easily estimated from general observation and accurate maps. Since one of the Author's parameters is mean annual discharge, presumably the other parameter should be labelled *mean* annual suspended sediment load and, of course, the two means would be computed from the same period of record in each case.

45. Some researchers¹² indicate that the sediment samplers in use today catch only about two-thirds of the available sediment, which may mean that the Author's method would underestimate the suspended sediment load to be expected in a river or canal.

Dr S. V. Chitale, Central Water and Power Research Station, Poona

The Author has presented general relationships to serve as a guide in estimating yearly suspended load using data of catchment area, mean yearly flow and the classification of vegetational cover. The empirical equations evolved are useful for preliminary estimates of the magnitude of suspended load in a given stream.

47. An important limitation of the statistical equations derived empirically is that their application is permissible only in the case of rivers which are similar to those whose data is used in deriving the equations. The original data are therefore

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of importance and would need to be referred to in making use of the Author's design curves. Would the Author please give the details of the data plotted in Figs 1-6?

Dr J. G. Herbertson, University of Strathclyde

Dr Fleming is to be congratulated on the presentation of an interesting and useful Paper. As he has rightly stressed, a great number of simplifying assumptions have been made and the design curves are intended for use in the preliminary stages of design evaluation. There is still an underlying need for a theoretical basis for design calculations. Mention is made of the regime and bed load formula approaches which recent work^{13,14} has shown to be limited to very restricted circumstances.

49. For the past four years I have been concerned with the application of a particular form of similitude theory, the method of synthesis,¹⁵ to certain aspects of sediment transportation.^{13,14,16-18} From an examination of Fleming's approach it is suggested that the method of synthesis may be applied to the correlation of field sediment transport data in the following manner.

50. The discharge of water, Q (or of sediment, Q_s) from a catchment results from climatic, vegetational, gravity and viscous actions on the catchment, which may be characterized by the square root of its area, A , some representative slope, S , and sediment size, D . It is thought that \sqrt{A} provides a convenient measure of the catchment size and that climatic and vegetational parameters may be combined on the basis of cause and effect. Using the linear proportionalities variant of the method of synthesis,¹⁵ this leads to an equation of the form

ϕ (climatic term, D , \sqrt{A} ,

$$\frac{Q^{2/5}/(Sg)^{1/5}, Q^{2/5}/g^{1/5}, Q^{2/5}/(g'w)^{1/5}, Q/v, v^{2/3}/(Sg)^{1/3}, v^{2/3}/g^{1/3}, v^{2/3}/(g'w)^{1/3}}{4^*} = 0 \quad (6)$$

in which 4* signifies any four terms so chosen as to include the action of each active force at least once

v is the kinematic viscosity of water

g is the gravitational acceleration

$g'w$ $\left(= \frac{\rho_s - \rho}{\rho} \cdot g \right)$ represents the action of the submerged sediment grains on the surrounding fluid

ρ_s and ρ are the sediment and water densities respectively.

51. A similar equation may be formed with Q_s appearing in place of Q . After manipulation and combination of equations a non-dimensional functional equation can be formed:

$$\phi \left(\text{group incorporating the climatic term, } \frac{Q_s}{Q} \frac{Qg^{1/3}}{v^{5/3}}, \frac{g'w}{g}, \frac{A^{1/2}g^{1/3}}{v^{2/3}}, \text{ term incorporating grain size} \right) = 0 \quad (7)$$

52. Neglecting viscous and sediment density variations, equation (7) leads to a correlation among Q_s/Q , Q , \sqrt{A} , climatic or vegetational effect, and sediment size effect. The term Q_s/Q is equivalent to the sediment charge introduced in regime theory studies. In this case the sediment discharge Q_s is the total sediment discharge, i.e. bed load plus suspended load. Fleming's correlations take account of three of the aforementioned terms, namely, sediment load (yearly suspended load), mean yearly discharge and vegetation type.

53. The foregoing statement of the problem is applicable to somewhat idealized catchments and climatic influence. Other factors as mentioned in § 16 are of undoubted importance. However, the simple model presented may serve as a first approximation to the problem and as a base for future study.

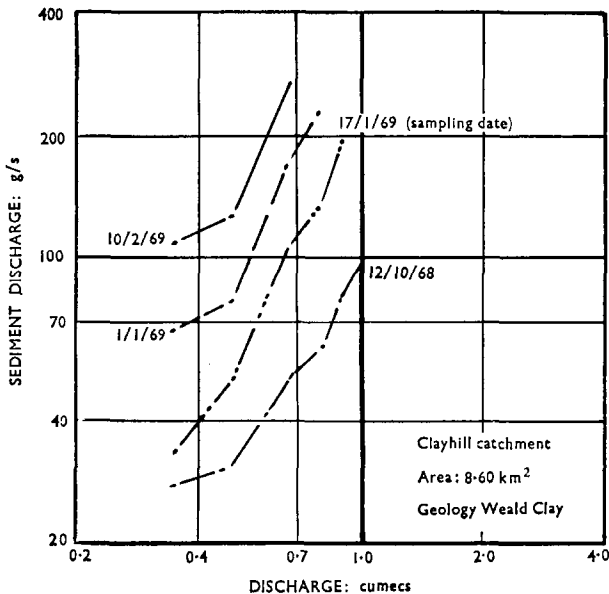


Fig. 7

Mr M. B. Collins, Department of Civil Engineering, Brighton College of Technology

The Author is to be congratulated on producing a Paper outlining the problems of sediment load computation. It would, however, seem an over-simplification of an extremely complex phenomenon, and the value of the graphs produced must surely be questioned.

55. It is difficult to conceive any simple relationship between annual suspended load and area or mean discharge for any particular catchment without consideration of geological and climatic conditions. A somewhat more sophisticated method of prediction of sediment yield for engineers would have been preferable and resulted in reduced errors.

56. I am at present engaged in research in conjunction with the Sussex River Authority into sediment being transported by small streams in Sussex, and can provide what I feel may be useful information on *small* catchment areas. Quantities of annual suspended load are calculated for the water year 1968-69 and based, for the purpose of this discussion, on flow-duration data combined with a single sediment rating curve. In fact, results have shown that each major rise in stage has its own rating curve, dependent on antecedent catchment conditions. This effect is probably more critical and marked in small catchment investigations. Fig. 7 shows a number of sediment rating curves for different storms. It would be of interest to know how the Author computed his 'yearly sediment load'.

57. Details of the research work are shown in Fig. 8, a reproduction of Fig. 1, omitting the Author's points for clarity but including regression lines. Also shown are details of work carried out by Marshall¹⁹ at the University of Leeds, and that of Kennedy²⁰ and Jones²¹ on Georgia and Pennsylvania streams respectively. Length of data records and method of load computation vary in each case, and one would recommend consulting the individual references.

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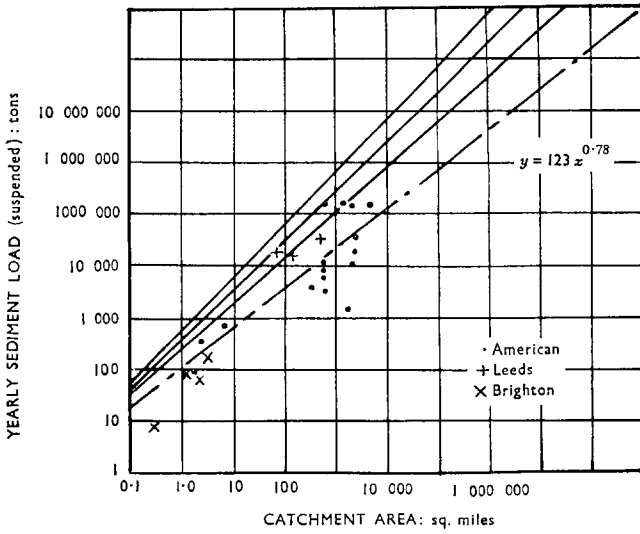


Fig. 8

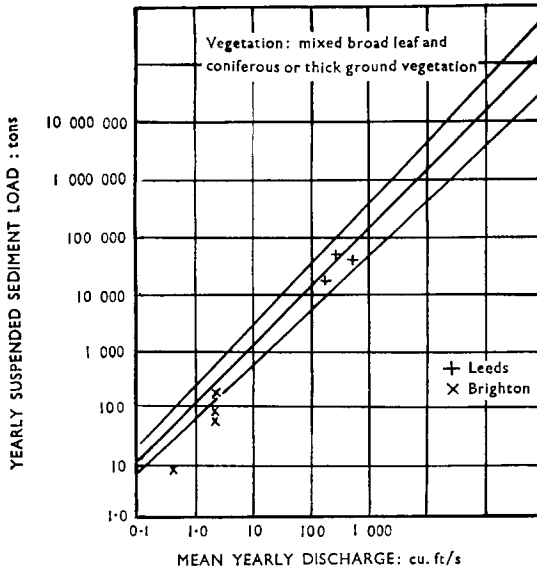


Fig. 9

Table 1. Transport of suspended sediment at Clayhill gauging station: 1968-69 water year

Interval no.	Lower limit <i>cumecs</i>	Upper limit <i>cumecs</i>	Occurrences	Unit yield <i>g/s</i>	Gross yield <i>lb</i>	Proportionate yield %
1	0-0	0-0017	78	0-005	74-2	Neg
2	0-0017	0-0021	1	0-005	1-0	Neg
3	0-0021	0-0026	0	0-006	0-0	Nil
4	0-0026	0-0033	15	0-007	20-0	Neg
5	0-0033	0-0042	0	0-008	0-0	Nil
6	0-0042	0-0053	0	0-010	0-0	Nil
7	0-0053	0-0066	14	0-020	53-3	Neg
8	0-0066	0-0084	0	0-040	0-0	Nil
9	0-0084	0-0105	16	0-060	182-7	Neg
10	0-0105	0-0133	10	0-082	156-1	Neg
11	0-0133	0-0167	15	0-125	356-8	0-1
12	0-0167	0-0210	60	0-200	2 283-7	0-5
13	0-0210	0-0265	27	0-270	1 387-3	0-3
14	0-0265	0-0333	17	0-520	1 682-3	0-4
15	0-0333	0-0420	16	0-850	2 588-2	0-6
16	0-0420	0-0528	20	1-250	4 757-7	1-1
17	0-0528	0-0665	16	1-700	5 176-4	1-2
18	0-0665	0-0837	14	2-800	7 460-1	1-7
19	0-0837	0-1054	5	3-400	3 235-2	0-7
20	0-1054	0-1326	9	5-400	9 249-0	2-1
21	0-1326	0-1670	6	8-000	9 134-8	2-1
22	0-1670	0-2103	3	12-000	6 851-1	1-6
23	0-2103	0-2647	2	18-000	6 851-1	1-6
24	0-2647	0-3332	4	26-000	19 792-1	4-5
25	0-3332	0-4195	6	38-000	43 390-3	9-8
26	0-4195	0-5281	3	56-000	31 971-8	7-2
27	0-5281	0-6648	2	83-000	31 591-2	7-2
28	0-6648	0-8370	1	120-000	22 837-0	5-2
29	0-8370	1-0538	3	180-000	102 766-5	23-3
30	1-0538	1-3265	1	270-000	51 383-3	11-6
31	1-3265	1-6700	1	400-000	76 123-3	17-2

Gross total yield for 1968/69 water year=197-0 tons.

Mean daily flow for year=0-061 cumecs.

Neg.=negligible.

58. Using the above mentioned data, a regression line is shown on Fig. 8.

$$y = 123x^{0.78}$$

where y = annual suspended sediment load in tons

x = catchment area in square miles

with a correlation coefficient of 0-805.

59. This is in no way put forward as an alternative to the Author's analysis, but rather to point out the number of prediction equations which could be evolved, dependent entirely upon the available information. In fact, if sufficient data were available, one would probably find a wide scatter band of points, as experienced by the Author in plotting load against mean yearly flow.

60. One might criticize the Author for his technique of quoting, on the one hand regression lines, and on the other omitting Indian data on the basis of its being monsoon conditions. The same argument could be applied to Chinese results.

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61. For the sake of completeness, my data are shown in Fig. 9, an extension of Fig. 3, placing catchment vegetation into the 'thick ground vegetation' classification.

62. In all forms of hydrological study, length of record is a principal factor in analysis and it would be advantageous to have details of this for catchments listed in the Paper.

63. Table 1 indicates that samples of suspended sediment and accuracy of discharge measurements at high flow ranges have an enormous influence on annual load computation.

Dr G. Fleming

I am grateful to Mr Harrison for his comments and questions. The definition of suspended load has long been a subject of much discussion and definition varies from one researcher to another. For my own research work on the Clyde, suspended load included all sizes sampled to within approximately 10 cm of the bed.

65. The removal of substantial portions of sand and gravel from the upper reaches of the Clyde does influence the transport of suspended sediment in the lower reaches since the larger size fraction, in the course of transport downstream, is abraded and forms to some extent a source of suspended sediment supply.

66. The vegetational zones used in Figs 3-6 are general classifications based on information on basic data* contained in the individual publications (see Bibliography). Where no information was available in the relevant publication, geographical maps were used in order to define vegetational classifications. The main vegetational classifications are:

- (a) mixed broadleaf and coniferous;
- (b) Mediterranean scrub forest;
- (c) conifer forest;
- (d) tall grassland;
- (e) short grassland;
- (f) subtropical forest;
- (g) desert;
- (h) tundra.

Where there was an overlap of different types of vegetation the predominant type was selected for the study. In the course of a more detailed study, the use of percentage vegetational cover would be more desirable, where and when accurate map coverage of the many catchments involved is available. Many of the parameters mentioned in § 16, including temperature and rainfall, were not in all cases available at the time of the research. As stressed in § 21 this study must be developed further, as more information and data become available.

67. The statistical analysis used in the study was based on a standard computer program available on an ICT 1905 computer. The different parameters were selected as the general parameters most often required for direct comparison with other research, to determine the level of statistical validity in the relationships obtained.

68. A comparison between the scatter in Fig. 1 and that in Figs 3-6 indicates no real improvement with the available data. However, the intention of plotting Figs 3-6 was to demonstrate the breakdown of the data in Fig. 2 rather than those in Fig. 1, and in this respect it shows clearly the effects of vegetational cover on sediment availability. The use of a technique such as this as an initial approach is important in the step-by-step development of an understanding of the interacting effects of the parameters influencing sediment transport. In § 16 some of the many additional variables which also influence sediment erosion and transport processes are outlined, but many other parameters will have importance in future studies, as more basic data become available. To say that most suspended material is in the 'silt-clay range' tends to be

* The detailed data in the form of a table are available on request from the Institution.

a generalization based on particular streams. It is true for the suspended sediment of the Clyde, but not for that of some of the mountainous Californian streams I have observed. Such parameters as turbulence, fall velocity, shear velocity and pH will affect the transport processes of certain size ranges and naturally should be considered. Available data on more than a few parameters are grossly limited for the application of detailed analysis on natural streams, which creates a situation requiring greater effort in basic data collection.

69. **Mr Fleming** rightly emphasizes the importance of topography, geology, vegetation and rainfall intensity on the erosion processes of a watershed. In § 6 and in other publications^{22, 23} I have outlined this basic approach to the study of sediment transport in natural streams.

70. The use of statistical methods to derive relationships is always open to criticism that the relationships derived do not take into account the extremes. In addition, the use of multi-cycle logarithmic paper reduces the wide scatter in the points, when for design purposes it would be better to know the extremes. The use of multi-cycle log paper was intended to demonstrate what the relationships were with the available data and to point to the existence of trends.

71. It is agreed that the units used in the Paper for sediment load would be better expressed in terms of total volume or total weight rather than mean values, and that the use of percentage amounts of sediment would be more illuminating.

72. The example presented for Baluchistan is of considerable interest and outlines a practical technique of estimating potential sediment transport rates for any watershed.

73. The tendency for Figs 3–6 to give a greater percentage sediment load with smaller average discharge can be explained in terms of a combination of influences which are difficult at present to separate. The main comment on this feature is that in smaller streams or in the headwaters portion of a main stream there is a greater tendency to erosion and transportation of sediment, whereas on the larger streams or in the downstream portion of major streams the main process is one of deposition. More energy is available to the transport of suspended sediment in the headwaters than in the lower reaches leading to a larger percentage of suspended load in the upper stream. It is agreed that the suspended load in the lower stream represents the fine material washed from the 'whole' catchment together with the finer sizes of material formed by abrasion. The criterion which best explains the feature of greater sediment load for lower average discharge is one of availability of material for transport combined with the ability of the stream to transport available material. The apparent ten-fold decrease in percentage sediment load for a rise in average discharge from 10 to 10 000 cusec is a significant indication of the various stages a stream goes through in its erosion, transportation and deposition processes. The order of magnitudes may tend to be high due to the method of analysis, but observations on some major streams have in the past shown this to be possible although not necessarily the general rule, as demonstrated by the example quoted for Baluchistan.

74. The question posed by **Mr Rees** is an interesting one, which unfortunately has not received widespread study. The study contained in the Paper concerns itself mainly with natural sediments; however the dumping of solids in suspension in the form of effluent, waste, etc. does form yet another factor in modern sediment transportation problems.

75. **Mr Kite** is sincerely thanked for his remarks. I would agree that the selection of parameters in a multiple regression analysis must be meaningful and stress that this initial approach aims at isolating those parameters and directing research toward further parameters that show significance.

76. I was very interested in **Mr Kite's** re-analysis of the linear (I agree it is not multiple) regression using a standard regression program, since this initial analysis was carried out using a standard statistical program available on British ICT 1905 computers. The correlation coefficients do appear to be high from the initial analysis

even though the regression is highly significant. The research by Benson¹⁰ is highly important to the type of analysis used in the Paper. Mr Kite's points on the application of Benson's theory are well taken and serve to stress the dangers in deriving relationships which may only hold good due to a common factor.

77. The exclusion of the Indian data from the regression analysis in Fig. 1 was due to the fact that its peculiarities indicated the need to include another factor such as the rainfall intensity in the analysis. This was considered, but was not implemented in the Paper due to lack of available data. When these data become readily available such an analysis will be considered.

78. The techniques used by agricultural engineers provide an important method of relating soil loss to a number of other factors. However, there is a limit to the number of factors that can be combined in such an analysis, before the researcher begins to lose sight of some of the complex interactions between parameters. It was for this reason and because the present study highlights the complexity of the sediment-erosion-transport processes that further research into the computer simulation of this problem was considered.²⁴ Mathematical simulation of hydrology has already been proved not only feasible but practical by Crawford and Linsley²⁵ and is now commercially available. This type of programming has already been developed to the point where its use as an aid in sediment erosion and transport simulation has been demonstrated,²⁴ and it is my opinion that by such computational tools more rapid advances will be made in the practical understanding of this subject.

79. The effect of sampling techniques and undersampling of the suspended sediment load should be taken into account as this undoubtedly will affect the data used in an analysis. My own research²² also demonstrated that some laboratory techniques underestimate the magnitude of sediment concentrations by as much as -34%. These factors must be taken into account.

80. I agree with **Dr Chitale** that care should be exercised in applying equations to streams that are not similar to those used in the derivations of the equations.

81. Sincere thanks are expressed to **Dr Herbertson** for his very important remarks on the necessity for a theoretical basis for design calculations. I am familiar with the method of synthesis and agree that it has an important place when applied to the correlation of field sediment transport data. This approach provides a basic theoretical means of obtaining correlation between significant parameters obtained from field data, and considers other parameters. The use of grain size in the approach is most important since this parameter has been shown²³ to be highly important. The cause and effect assumption between climatic and vegetational parameters in the initial idealized model is considered permissible.

82. Dr Herbertson's model could be extended to account for the additional parameters mentioned in § 16 and in its present form should serve as an interesting basis for future study.

83. **Mr Collins** emphasizes the complexity of the sediment transport problem. Consideration of many other facets must be made and a more sophisticated method must be devised for use by engineers. However, the present study gives in a convenient form a larger spectrum of measured data, simply analysed, than is readily available to the practising engineer. The use of the resulting curves was intended, as stated, to provide the engineer with an initial guide to the sediment problem to help him decide on the necessity of a more detailed study. Too frequently the sediment problem is considered to be insignificant in relation to certain design projects, and this is not a satisfactory situation.

84. The research discussed by Mr Collins is of considerable interest since not enough information is available on small catchments. The use of flow duration data combined with a single rating curve is a standard method of computing annual sediment loads, but may lead to error, since, as Mr Collins points out, each flood has its own rating curve depending on antecedent conditions. Hall²⁶ demonstrated this feature from his research in the Tyne and I have demonstrated it for the Clyde.²²

Due to this factor, the method used in computing the annual sediment load was based on the results of continuously monitoring the sediment concentration over a three year period using automatic suspended solids monitors, calibrated in the laboratory and check-calibrated in the field, with hand-sampling techniques. Comparison of the results obtained by this method to the flow duration method and to a third method based on hourly discharge measurements and a single rating curve showed that the monitored concentration method yields higher results than the flow duration method. The method of estimation based on hourly discharge data and a single rating curve gave lower results than the flow duration curve method.

85. The results in Fig. 8 are of interest since they supply information on a wider basis. The possibility of finding a wide band of scatter in Fig. 1 with an increase in the available data is a possibility. The reasons for this could be considered by analysing the watersheds in terms of effective area, the effective area being obtained from consideration of the geomorphology of the catchment.

86. The data plotted in Fig. 9 are interesting since they are compatible with the analysis already obtained for the data used in the study.

87. The length of record used in establishing the points on the various figures in the Paper is included where possible in the supplementary data.

88. Table 1 further highlights the problems discussed previously, i.e. the accuracy of estimating sediment load. Many factors influence this estimation including discharge measurements, sampling techniques, laboratory analysis and computation techniques, to name only a few.

89. Future developments in sediment transport studies must make use of computer simulation techniques if many of the complex interactions within the sediment erosion and transport processes are to be accounted for and understood. The Paper, together with the discussion, highlights the problems that confront a detailed understanding and representation of the processes involved in sediment erosion and transport.

Erratum

In Fig. 5 the value of σ_c should be 0.2774.

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