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Sediment modelling and data sources: a compromise in assessment

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ABSTRACT The major problem in modelling sediment erosion, transport and deposition for the assessment of sediment yield is the shortage of reliable data with which to develop and test the desired model. This data source limitation restricts the model developer in selecting the appropriate theory to describe a model structure that accounts for the correct interaction between processes contributing to the sediment yield of drainage basins. It also restricts the application of developed models in their practical design application. This paper reviews the development of sediment modelling and discusses the compromise that must be made before models can be usefully employed in sediment yield assessment for design of water resource system.

REVIEW OF SEDIMENT MODELS

During the past 20 years (1960-1980) the development of sediment resource assessment methods has been in harmony with the accelerated development of land and water resources, and the evolution of computer technology. Models of sediment processes can be statistical, empirical or conceptual/deterministic, and can usually be grouped into methods that treat the land surface erosion processes only, the sediment transport processes only, or the combined erosion-transport-deposition processes of the total river basin.

Of the methods that assess the erosion process, the notable model developments are the Universal Soil Loss Equation (Wischmeier & Smith, 1960) and the upland erosion models of Meyer (Meyer & Wischmeier, 1969) and Kirkby (Kirkby, 1971).

Of the sediment transport models, a large number of alternative methods are available ranging from tractive force theories to regime methods. Notable techniques are the Einstein approach to sediment transport (Einstein, 1950) and the regime approaches of Blench (Blench, 1966) and Ackers (Ackers & White, 1980). Of the combined models for total river basin assessment the available models include the Negev model (Negev, 1967), and the Strathclyde sediment model (Fleming, 1975; Walker & Fleming, 1979).

REVIEW OF DATA SOURCES

Data sources for sediment processes have been and remain the single major constraint in the development of models for the better assessment of water and sediment resource development. Vast amounts of effort and money have been expended on sediment data collection programmes, yet the methodologies and models developed have inherent limitations on their accuracy in representing the natural processes and in their application to conditions or regions outside the original data collection programme.

In land surface soil erosion assessment, the development of the Universal Soil Loss equation (USLE) required the establishment of a large number of experimental plot stations representing the wide range of slope, vegetation, rainfall, cropping and conservation practices for the eastern USA. Many thousands of data years of plot experiment information were collected and analysed to develop numerical values of the parameters used in the USLE model. Application of the method however remains limited to providing a "guide" to "conservation *farm* planning" for the range of data measured and within the region of the eastern USA. Many researchers have used this method for drainage basins as far afield as Africa and South East Asia without altering the parameter levels of the original research or even checking their validity on plot experiments in the relevant region.

In sediment transport assessment, experiments in laboratory flumes and in irrigation canal systems conducted from as early as 1897 (Rouse, 1950) have built up enormous amounts of relevant data on the detailed relationship between sediment particles and the physical hydraulic conditions which interlink to produce dynamic sediment transport. Numerous tractive force and regime equations have evolved as a result of this research and understanding of the processes has been enhanced. The application of the various theories to the real river or irrigation system has however produced highly variable results which do not always bear comparison to the measured sediment rates. This results principally from the fact that the conditions in the experimental flumes and canals were not the same as in the practical problem and often the assumptions made concerning the rates of supply of sediment from upstream used as input to the experiments were not the same as those rates being eroded and supplied in a natural drainage basin.

In total river basin assessment of sediment erosion-transport-deposition processes, researchers have recognised the need to combine the sound theoretical and experimental understanding of the chain of processes contributing to sediment yield from drainage basins. This is important for the engineering design of projects involving water and sediment resources, but involves the use of a potentially large data base including time series of data on precipitation, streamflow, sediment concentration and physical data on soil particle size, land slope, vegetation cover, land use, stream channel geometry, geological information, and operational controls (Fleming, 1981). Models to accomplish total river basin assessment are available but the practical application and verification of these methods is difficult due to limitations in data sources. Often, for example, the civil engineer is faced with the design of a water resource system, involving sediment problems where neither hydrological nor sediment data exist at all, and when data are available they are often inadequate to represent the processes to be assessed.

The application of any sediment model for design is a compromise between the data available, the model or assessment technique to be used, and the importance of the problem to be solved. In most cases the data sources will restrict the method of assessment even when the problem to be solved is very important, costly and complex.

THE COMPROMISE IN ASSESSMENT

This paper considers the specific engineering problem of assessing river basin sediment yield as it relates to civil engineering and considers the compromise that must be made between the methodology chosen to model the problem and the data sources available for input to the model.

The assessment of sediment yield from river basins will depend on the definition of the problem and the terms of reference of the study. For example, the problem may be defined as the estimation of the sedimentation rate in a single reservoir and the terms of reference may limit the scope of the assessment to current conditions. When the engineer considers the problem in detail he may find that no sediment load measurements have been conducted on the river in question and he may then propose a data collection programme for the duration of the study. This duration may only span the next 6 months and will not reflect the full seasonal or long-term fluctuations in the sediment yield and hence the potential sedimentation in the reservoir. Logically the engineer will then propose that data collection be continued over the whole design and construction phase of the reservoir, with the recommendation that the provisional assessment of sediment yield be reviewed with the improved data base. Usually such a recommendation will allow a number of years of data to become available. The engineer is now faced with the problem of his initial assessment and he proceeds with the implementation of his data collection programme while at the same time considering the conditions prevailing in his drainage basin. If the drainage basin is located in a temperate climate, with good coverage of vegetation, minimum present and future disturbance, mild slopes and cohesive soils, he may draw some early conclusion that the sediment yield will probably be low. However, if the drainage basin is situated in a monsoon climate, with good vegetation cover, minimum present disturbance, but maximum future disturbance (due to forest clearance), steep slopes and highly erodible soils, the engineer may draw the early conclusion that while present conditions of sediment yield may prove to be reasonably low the future conditions may be many orders of magnitude greater. He is required, therefore, to make an initial coarse assessment of sediment yield, then to refine this with his improved short term data base, and to refine it further with his long term data base. Once sediment yield estimation is defined the next step in this particular problem is to assess the trap efficiency and hence the sedimentation rate and distribution in the proposed reservoir. The engineer may elect to do this by considering a physical model of the system or, as an alternative or even complementary to the physical model, he may use a mathematical model to predict sedimentation.

This type of problem is fairly simple compared to another example where the single reservoir described above exists within the River

Po or the Colorado River and where a complex system of water and sediment resource allocation already exists. In the more complex problem, the data sources may be greater in volume but may still not fully describe the dynamic response of the system being analysed.

To meet the need of the engineer in his requirement for a first approximation method of sediment yield assessment, Fleming (Fleming,

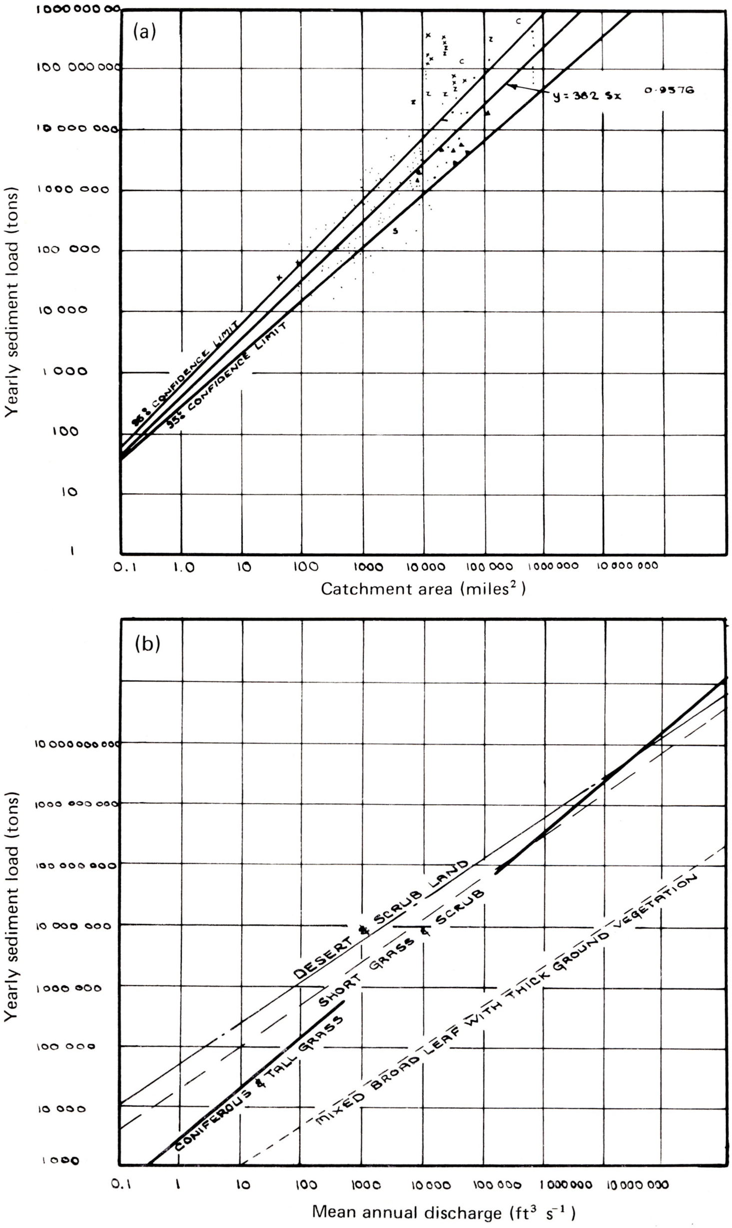

FIG.1 Design curves for suspended sediment load estimation after Fleming (1969).

1969) produced a set of statistical design curves (Fig.1) to assess suspended sediment load, with drainage basin area, mean annual water discharge and vegetation cover as the predictive indices. In a recent study of sediment yields from rivers in Kenya, Edwards (1979) concluded, "Most of the latter (data), ... lie on or below the Fleming curve". The comparison with other curves is made in Fig.2. However, the result from such a set of curves is a very coarse approximation of what might occur in a particular river basin. It is generally accepted that the influence of rainfall, slope, vegetation cover, soil type and land disturbance can cause large variations in the sediment yield of a catchment. Further research (Fleming, 1981) into this influence using existing data produced an alternative design curve (Fig.3) to allow a second approximation of sediment yield as affected by drainage basin characteristics. In this approach the relative importance of each factor, called a weighting factor, is set within a range 1 to 5 as an initial estimate. A study to refine the weighting factor was then undertaken (Al Kadhimi, 1982) and it was found that other authors (Icona, 1969) proposed different weighting factors which had the effect of changing the scale of the design curve, and hence giving a closer understanding of the interaction of the physical factors with one another. Al Kadhimi then proposed the use of a river basin sediment model to examine this "interactive factor". In this

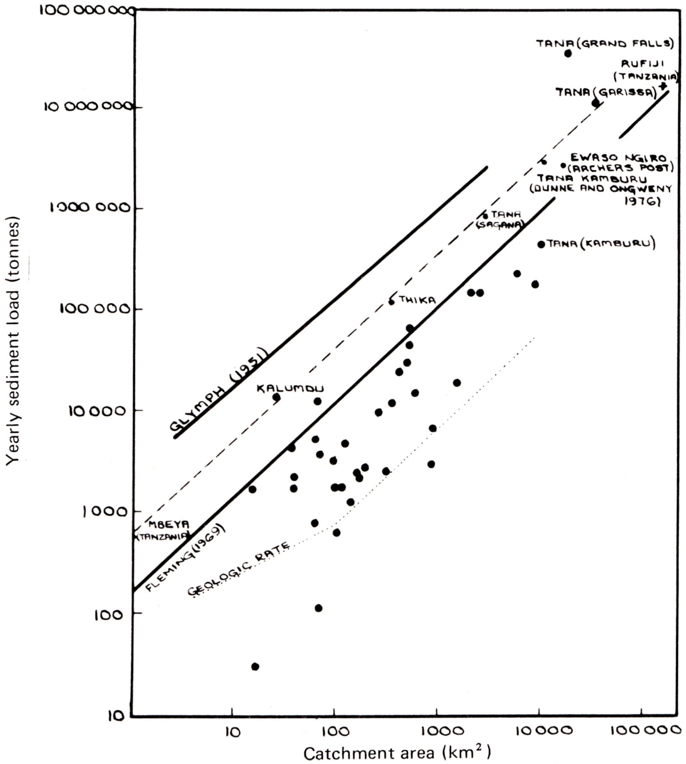

FIG.2 Relationship between sediment yield and size of drainage basin after Edwards (1979).

SOIL EROSION INDEXES

SLOPE (SC)		RAINFALL EROSIVITY (ER)		SOIL ERODIBILITY		COVER TYPE (C)		SOIL DISTURBANCE	
0-2 % →	1	TEMPERATURE ARID $(0 < \frac{P^2}{P} < 30)$	1	CLAY	1	VIRGIN FOREST	1	(1) IN 100 YEARS	1
2-4 →	2	SUB ARID $(30 < \frac{P^2}{P} < 50)$	2	COARSE SAND	2	WOODLAND	2	(1) IN 50 YEARS	2
4-6 →	3	SEMI ARID $(50 < \frac{P^2}{P} < 70)$	3	MEDIUM SAND	3	PASTURE	3	GRAZING	3
6-8 →	4	SUB TROPIC $(70 < \frac{P^2}{P} < 90)$	4	FINE SAND	4	AGRICULTURAL	4	ANNUAL CROPS	4
7-8 →	5	TROPIC $\frac{P^2}{70} > 90$	5	SILT	5	BARE FALLOW	5	MULTIPLEANNUAL	5

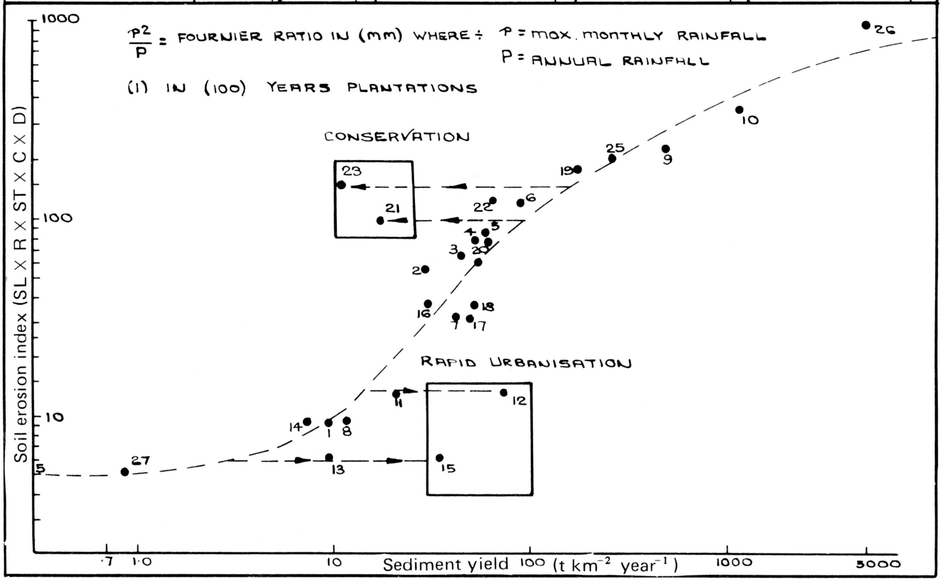

FIG.3 Sediment yield and erosion indices after Al Kadhimi (1981).

analysis the model chosen was the Strathclyde Sediment Model (Fleming & Walker, 1979) which was calibrated to reproduce the hydrological response of a number of catchments, and which was further calibrated to produce the sediment response of the River Clyde (Al Kadhimi, 1982). The model was then used in a predictive mode to assess the interaction between the various combinations of physical indices - slope, rainfall, vegetation, soil and disturbance. The result showed that the weighting factors chosen in the first approximation needed refinement to produce greater sensitivity for certain interactions of the indices. This produced a curve shown in Fig.4, which compares in trend to the results of Icona (Icona, 1969).

The compromise in assessment can be illustrated by Fig.5 showing the trade-off between the risk of not representing a system, the difficulty in obtaining a solution and the complexity of the model used.

In practice, recourse is made to design curves to establish a general understanding of the magnitude and interaction of the sediment yield problem corresponding to point A on Fig.5. When this magnitude interaction is found to be extreme and to influence the future of the project being designed then the second stage in the assessment should demand an improved data base and assessment method in keeping with the scale of the problem corresponding to point B on Fig.5. The assessment method can therefore be a marriage between the simple design curve models and the complex physical and

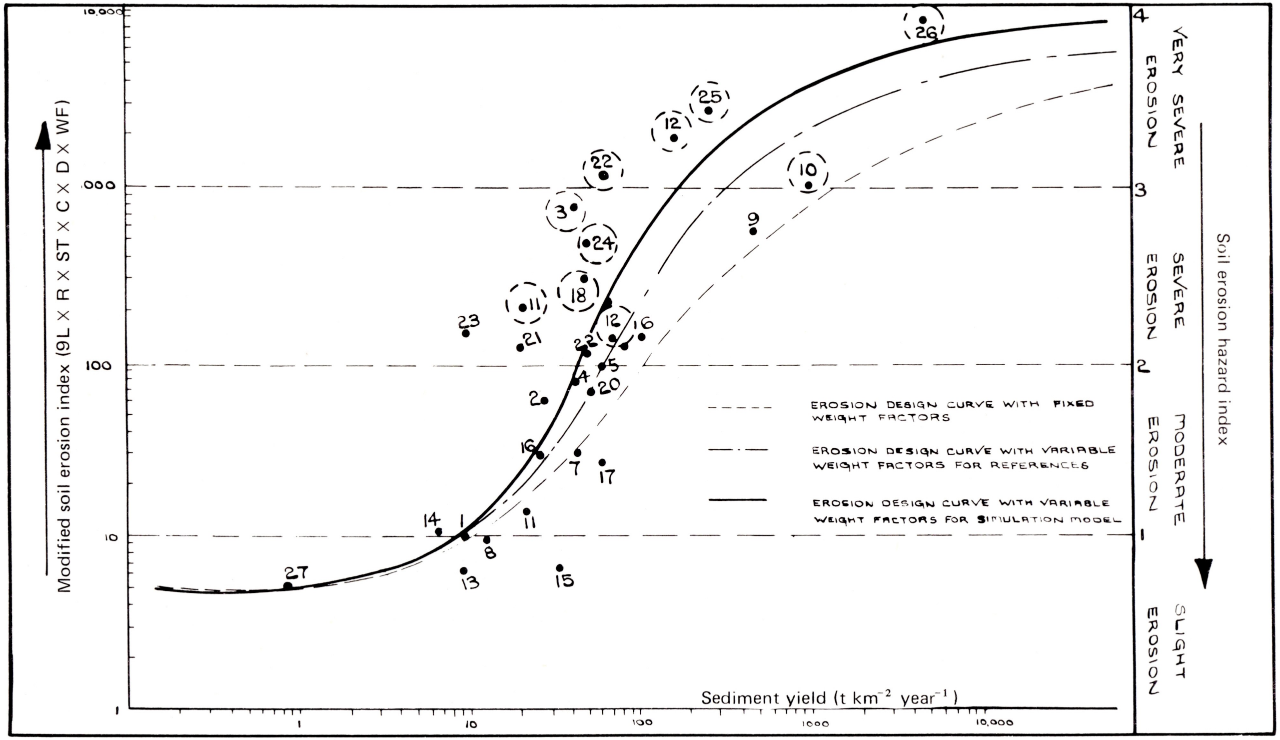

FIG.4 Comparison of sediment yield curves derived using different weight factors for the indices. Based on Al Kadhimi (1981).

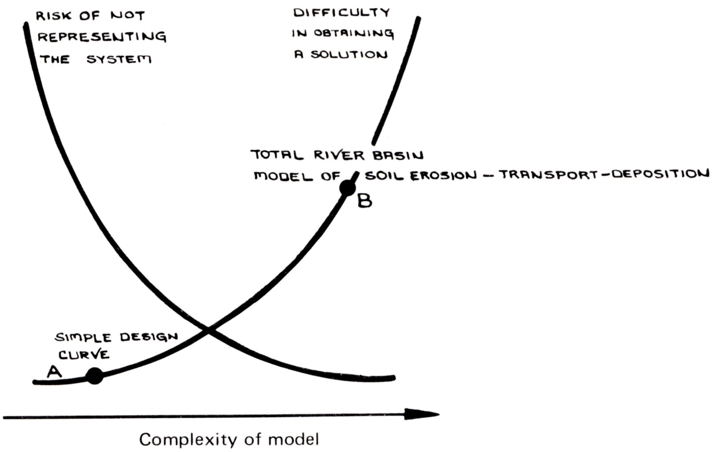

FIG.5 The trade-off diagram after Overton & Meadows (1976).

mathematical simulation models, with maximum utilization of the data sources.

CONCLUSIONS

Further study is urgently required to evaluate the effect of the interaction between physical river basin characteristics on sediment yield response. The use of total river basin sediment-hydrology models can play an important part in bridging the gap between limited data sources and understanding of the relation between factors affecting drainage basin response.

There is little doubt that the increased development of our land and water resources will continue and with it the need for the development of improved, standardized criteria and methods for assessing river sediment and water response.

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