

## **Sediment yield and availability for two reservoir drainage basins in central Luzon, Philippines**

**SUE WHITE**

*Overseas Development Unit, Hydraulics Research, Wallingford, Oxfordshire OX10 8BA, UK*

**Abstract** Studies of two drainage basins in central Luzon, Republic of the Philippines, have been carried out by the Overseas Development Unit of Hydraulics Research in collaboration with the National Irrigation Administration, Manila. The projects have involved the measurement of sediment transport in rivers in order to assess sediment yield to the existing Magat reservoir and the one planned for Casecnan. In the Magat basin, measurements have also been made of soil loss from small, reforested areas and of sedimentation in the reservoir. The data collected so far have shown the overwhelming importance of cyclone events in the sediment transport process. One of these events can carry more sediment than the sum of all non-flood flows for the year. Of course these high discharges are the most difficult in which to monitor sediment transport. There is, however, evidence of a "cut-off" in sediment concentrations at high discharge, indicating an availability constraint on sediment yields. At the same time information is being amassed to show that sedimentation rates at Magat may be approximately twice those assumed during the feasibility study. Reasons for this, in the light of our results, are discussed.

### **Rapport et disponibilité en sédiment pour deux bassins versants de réservoirs dans la partie centrale de Luzon, Philippines**

**Résumé** Des études de deux bassins versants à Luzon central, République des Philippines, ont été entreprises par the Overseas Development Unit de Hydraulics Research en collaboration avec l'Administration de l'Irrigation Nationale, Manille. Les projets ont consisté à mesurer le transport des sédiments dans les rivières afin d'évaluer la quantité de sédiments pour le réservoir existant de Magat et celui prévu à Casecnan. Pour le bassin de Magat, des mesures ont aussi été effectuées concernant la perte en sol dans des petits bassins reboisés et la sédimentation dans le réservoir. Les informations obtenues jusqu'à maintenant ont montré l'importance cruciale des cyclones quant au procédé de transport des sédiments. Durant l'un de ces cyclones, le transport des

sédiments peut dépasser la somme des débits solides (cyclone exclu) pour l'année. Evidemment, ces apports élevés sont les plus difficiles à contrôler pour le transport des sédiments. Il existe, néanmoins, une évidence de "chute" dans les concentrations de sédiments à haut débit, indiquant une contrainte de disponibilité sur le transport de sédiments. Par ailleurs, les informations sont rassemblées pour montrer que les taux de sédimentation à Magat sont peut-être deux fois plus forts que ceux estimés au cours de l'étude de factibilité. Les raisons de cet écart sont discutées dans cette communication, à partir des résultats que nous avons obtenus.

## INTRODUCTION

In many countries when the need for sediment yield prediction arises, time, money and knowledge constraints mean that often the only recourse is to use a well known formula, such as the Universal Soil Loss equation, in combination with a sediment delivery ratio and to hope that the answer is somewhere near to the correct one. Usually it is not.

What is needed is a systematic approach which considers sediment supply and availability, together with the ability of the stream network to transport sediment, bearing in mind the constraints found in the developing world. It is also important to be able to give some measure of the reliability of sediment yield predictions which are, of necessity, based on a very limited data set. To be able to do this demands an understanding of the phenomena involved in erosion and sediment transport rather than development of yet another "model".

## MAGAT AND CASECNAN

The Overseas Development Unit (ODU) of Hydraulics Research (HR), Wallingford, UK has been involved in the measurement of erosion and sediment transport for some time. Since 1984 we have been working in collaboration with the National Irrigation Administration (NIA), of the Philippines, to quantify sediment yields to one existing reservoir at Magat and one planned reservoir at Casecnan (Fig. 1) in central Luzon. At the same time work in the UK has concentrated on the development of a new approach to sediment yield prediction which it is hoped will satisfy two needs. The first is to provide a sediment yield prediction technique, with estimates of confidence limits, which is not site specific. The second is to be able to use that technique to estimate the effect of catchment management decisions on sediment yields to the reservoir.

## MEASUREMENT PROGRAMME

Details of the measurement techniques used in Magat and interim results

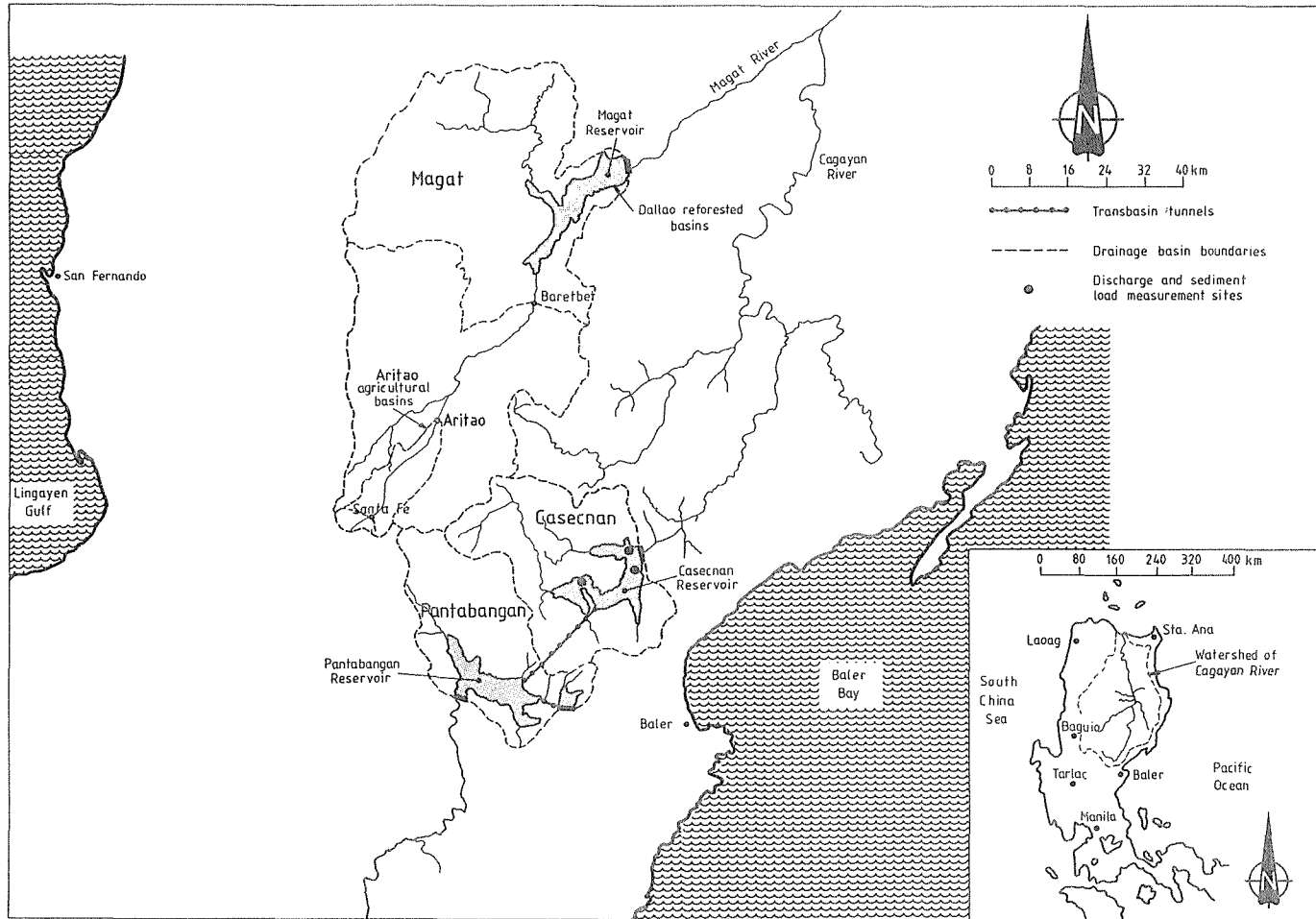


Fig. 1 Location map and measurement sites.

have been given in other publications (Amphlett & White, 1986; White, 1987; Amphlett *et al.*, 1987; Dickinson, 1988; Wooldridge, 1986; Amphlett, 1988), and will therefore not be repeated. Measurement has been at three scales: soil loss from small reforested and agricultural basins; echo-sounder surveys to ascertain reservoir sedimentation rates; and measurement of sediment transport rates in a series of nested basins, at Santa Fe, Aritao and Baretbet (Fig. 1).

## RESULTS AND DISCUSSION

Results from both drainage basins have been extremely interesting, and some of the more important points are noted below.

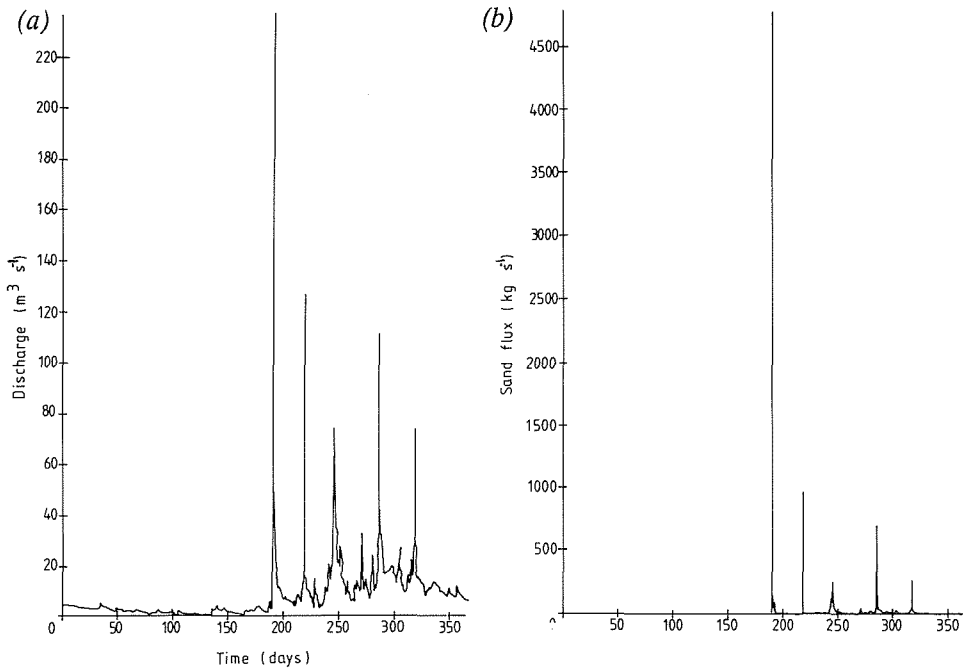
Before construction of the Magat dam, the reservoir sedimentation rate was estimated to be  $5.5 \times 10^6 \text{ m}^3 \text{ year}^{-1}$ , equivalent to a mean catchment erosion rate of  $20 \text{ t ha}^{-1} \text{ year}^{-1}$ . The first reservoir survey, in 1984, indicated that since impoundment (a period of 21 months), the sedimentation rate has been  $11 \times 10^6 \text{ m}^3 \text{ year}^{-1}$  which is equivalent to a mean erosion rate of  $38 \text{ t ha}^{-1} \text{ year}^{-1}$ . If this is a correct figure for reservoir sedimentation, it would mean that the useful life of the reservoir would be reduced from 100 to 25 years. Confirmation of a  $38 \text{ t ha}^{-1} \text{ year}^{-1}$  sedimentation rate comes from the sediment yield measurement at Baretbet for 1986 of  $34 \text{ t ha}^{-1}$ .

This under estimation of sediment yield is by no means unusual or surprising. Other examples from around Asia show predicted rates of between two and sixteen times lower than the actual measured rates. It seems that there are two contributory factors here. Firstly, the prediction techniques available are not reliable and often have to be based on an extremely limited data set. Secondly, there is much evidence that sediment yield rates increase dramatically after reservoir impoundment, and as population in the area increases. It seems that in Asia, increases in sediment yield of 50% per decade can be expected. This is rarely included in feasibility studies on reservoir projects.

Yearly discharge hydrographs from all measurement sites show the extreme flashiness of the rivers in both Magat and Casecnan basins (Fig. 2(a)). The largest discharge events are cyclone-related floods, and these are very important in terms of both sediment supply and transport. Measurements of wash load ( $<63 \mu\text{m}$ ) and suspended bed material load ( $\geq 63 \mu\text{m}$ ) at Santa Fe, Aritao and Baretbet, have enabled relationships between sediment concentration and discharge to be developed. Normally, no correlation is expected between wash load and discharge because the supply of these finer soil particles is dependent on rainfall energy and basin conditions. The transport of the coarser sand size particles, which are intermittently supported in the flow, is however dependent on river discharge.

For the Magat basin, a dependence on discharge was found for both silt and sand concentrations, of the form

$$X = a Q^b$$



**Fig. 2** (a) Instantaneous discharge record for Aritao;  
(b) instantaneous sand flux for Aritao.

where  $X$  is concentration;  $Q$  is discharge; and  $a, b$  are constants. These relationships are based on measurements taken at the lower end of the discharge range, and there is some question as to whether the formulae can be applied at the higher discharges. Some evidence exists that a "cut-off" in concentration values occur at high discharges (Fig. 3), indicating that even in the highly erosive environment of the Philippines sediment yield is constrained by sediment availability for some events.

Even taking this availability limit into account, the amount of sediment transported in cyclone related floods is immense (Fig. 2(b)) and far outweighs all other sediment transport during the year. This information, together with statistical distributions of cyclone occurrence and resultant flood magnitude, was used in a study to estimate sediment yield to the proposed Casecan reservoir (White, 1987).

On the question of a sediment delivery ratio for the Magat basin, results so far have not shown a reduction in sediment yield with basin area (Table 1). There does, however, appear to be a relationship between the factor  $b$  in the formula

$$X(\text{silt}) = a Q^b$$

and basin area, at least in wet years. This suggests that the supply of wash load to the rivers is, in such years, limited only by the area available for supply.

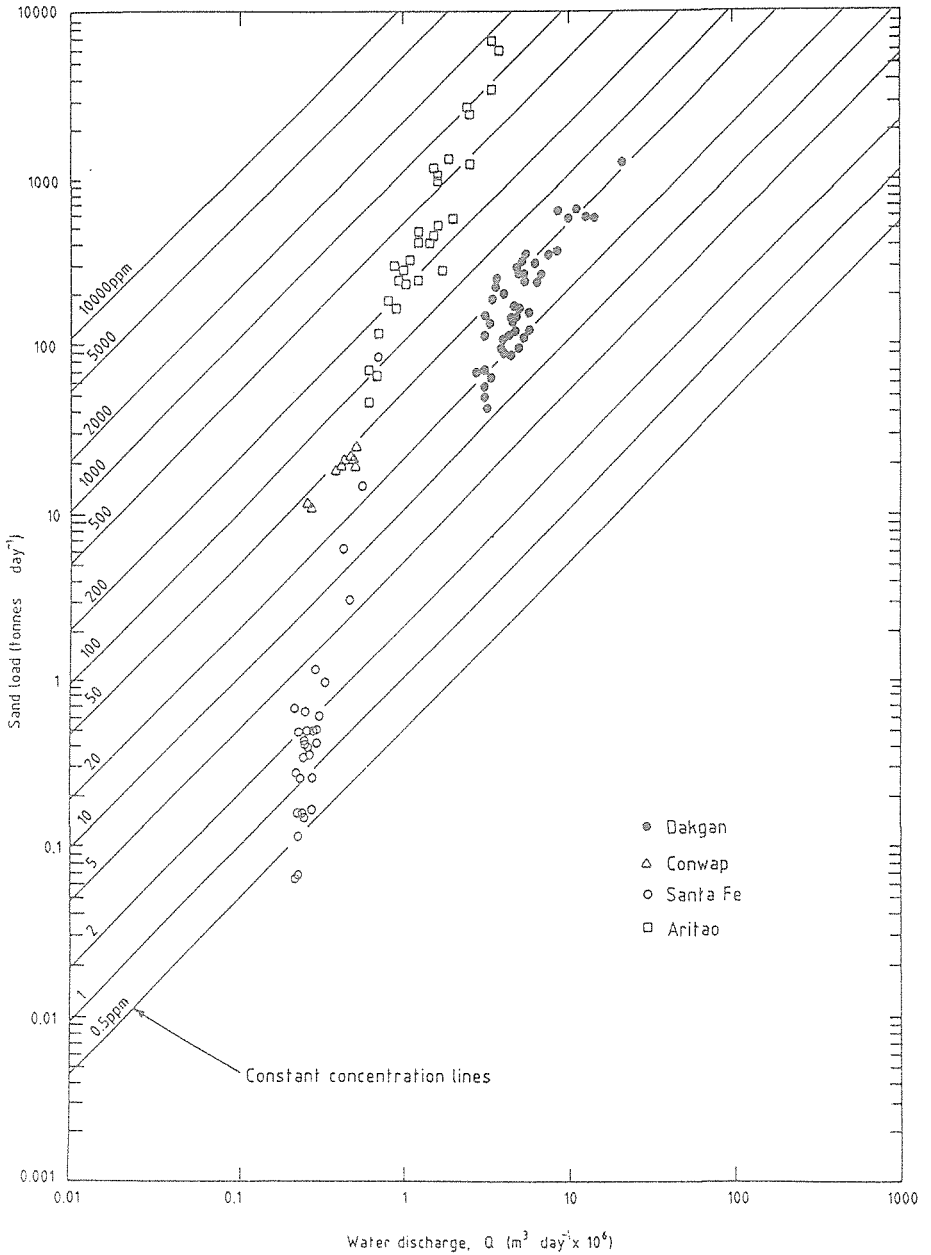


Fig. 3 Sand load vs. water discharge for rivers in Magat and Casecanan catchments.

For sand, however, the constants  $a$  and  $b$  show no dependence on drainage area. This corresponds with our ideas that the sand component of sediment yield is dependent on the transporting capacity of the river, rather than on the supply of sand from the drainage basin. This will hold true until the concentration "cut-off" limits are encountered when the supply of sand

Table 1 Sediment yields for nested catchments

	Drainage area (km <sup>2</sup> )	Sediment yield (t ha <sup>-1</sup> year <sup>-1</sup> )
<i>Santa Fe</i>	18.86	39.7
<i>Aritao</i>	159.9	22.0
<i>Baretbet</i>	2041	33.5

becomes the limiting factor. The factors *a* and *b* in the sand concentration relationship are therefore likely to be related to some aspect of river or basin morphology such as channel slope or hydraulic radius rather than drainage area.

Results from both the Magat and Casecnan basins are beginning to improve our understanding of sediment supply and transport. It is hoped that this, together with the use of modern micro-computer systems and perhaps satellite imagery, will enable more reliable and usable sediment yield prediction techniques to be developed.

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