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Significance, measurement, and analysis of sediment discharges of flashy streams

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ABSTRACT Because the water resources of the major rivers in the Punjab have already been fully developed, attention has been directed to the potential for harnessing the numerous flashy streams by creating low capacity reservoirs. These streams flow only in the monsoon season but transport high sediment loads. Sediment yields may exceed 15 000 t km^{-2} $year^{-1}$. Because of the need to determine the gross storage and economic life of such reservoirs, the problems of gauging the sediment discharge of flashy streams have become increasingly significant. This paper highlights the limitations of various standard methods for measuring sediment discharge and describes a simple technique suited to flashy streams. A comparative analysis of the performance of five sediment discharge formulae (DuBoys-Straub, Shields, Colby, Laursen and Engelund-Hansen) with reference to the sediment discharges of five flashy streams, is also presented. Since the standard error associated with the DuBoys-Straub formula is the least, it is concluded that this can be applied with confidence to flashy streams.

Signification, mesure et analyse des transports solides des cours d'eau intermittents

RESUME Dans l'état du Punjab (Inde) les ressources en eau des grandes rivières ayant été complétement utilisées, ceci a contraint les autorités responsables à amenager les nombreux cours d'eau intermittents en y réalisant des réservoirs a faible capacité. Ces cours d'eau coulent seulement pendant la mousson mais la charge en sédiments est élevée. La production annuelle de sédiments peut dépasser 15 000 t km^{-2}. Etant donné qu'il est nécessaire de déterminer le volume brut et la durée de vie économique de tels réservoirs, les problèmes liés à la mesure des transports solides de ces cours d'eau intermittents deviennent de plus en plus importants. Cette communication met en lumière les limites des diverses méthodes standard pour la mesure des transports solides et décrit une technique simple bien adaptée à ces fleuves intermittents. L'analyse comparative des résultats obtenus avec cinq formules pour évaluer les transports solides: à savoir celles de DuBoys-Straub, Shields, Colby, Laursen et Engelund-Hansen utilisées sur cinq cours d'eau intermittents est également présentée. Etant donné que l'écart type correspondant à la formule de DuBoys-Straub est le plus faible on en conclut qu'elle peut être appliquée avec confiance aux cours d'eau intermittents.

INTRODUCTION

The northern states of India, e.g. Punjab, Haryana, etc. contain numerous flashy (mountain) streams, locally called "Choes" and "Khads", flowing from the foothills of the outer Himalayas which extend a distance of about 400 km and occupy a belt 10 km wide with an average elevation of 1000-1300 m above sea level, in the northeastern parts of these states. The bed material in choes is predominantly sand while in khads it comprises a mixture of large cobbles, gravel and sand. The dynamics of these flashy streams are quite distinct from those of alluvial streams. For example, the drainage basins are small, flow occurs only in the monsoon season (i.e. June-September) or as a result of winter (January-February) storms, flood peaks are of short duration and comparatively rapid rise, bed slopes are steep, and high rates of sediment transport cause rapid changes in bed profile. The almost complete denuding of the hillslopes in their basins has caused vegetation to fall to less than 10 t km^{-2} and sediment yields to rise to about 15 000 t km^{-2} $year^{-1}$. These flashy streams discharge onto the plains and during times of severe floods widespread flood damage may occur, sand deposits are spread on fertile land and many of the farmers may be forced to abandon their lands and to seek employment elsewhere. Thus, in an attempt to reduce the flood peaks and associated flood damage and also to meet the increasing demands for water attempts are being made to harness these flashy streams by constructing small capacity (~100 million m^3) reservoirs in the Punjab and barrages in Haryana. The use of choes and khads has become particularly important in the states of Punjab and Haryana, since in the Punjab the water resources of all three major rivers have already been fully exploited, whereas in Haryana there are no major rivers.

The Sukhna Lake (Chandigarh, India) measuring 1.52 km long and 1.49 km wide with an initial capacity of 10.74 million m^3 was created (without any sediment transport data) in 1958 at the confluence of two such flashy streams, the Kansal and the Suketri, in order to meet the water supply and aesthetic requirements of the people of Chandigarh. Its geographical location is lat. 30°40'N and long. 77°E. The latest (October, 1979) hydrographic survey indicates that its available capacity has been reduced to 39.7% in spite of the provision of a number of check dams and grade stabilizers, and of two partial dredgings by manual labour.

Experience with the performance of the Sukhna Lake led to the introduction of sediment gauging on flashy streams. A 38.5 m high earth-fill dam is now under construction on Dholbaha Choe (Punjab, India) (Fig. 1) with a drainage basin of 56.13 km^2, and this will provide a gross storage of 31.45 million m^3, to feed an irrigation channel with 1.132 m^3 s^{-1}. Several other dams on similar flashy streams e.g. the Janauri, Chohal, Thana and Maili are being planned. The gauging of flashy streams for sediment and

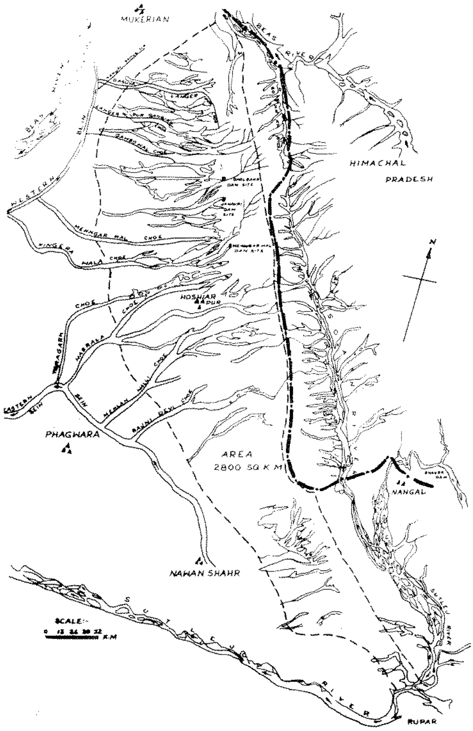

Fig. 1 Flashy streams in the Punjab, India.

water discharge has therefore recently assumed considerable significance in order to determine the gross/dead storages, the economic life and the water potential of reservoirs or ponds upstream of planned barrages.

LIMITATIONS OF STANDARD METHODS

Different agencies have suggested various techniques and methods for sediment sampling in canals and rivers, i.e. under steady flow conditions. The limitations of a number of these for sediment sampling in flashy streams characterized by unsteady flows of high velocity and short duration and shallow depths and where the deployment of boats is impractical, are discussed below.

Measurement of suspended sediment discharges

The point-integration method has been recommended by Brown (1950) for use on streams where depth, velocity or other conditions make the depth-integration method unsuitable. Variations of the order of 70% of the mean sediment concentration in a vertical from the average concentration for the entire cross section have been reported by the Task Committee (1969) in the case of some small streams. These may be compared to 10-15% variations found across the width of wide rivers and call for judicious selection of verticals in the cross section for accurate determination of suspended load discharges in flashy streams.

Location of verticals The Indian Standard (1968) states that the section should be divided into a large number of segments, either equally spaced or with approximately equal discharge, and that the verticals should be located at 25, 50 and 75% of the width in channels less than 30 m wide, whereas in channels between 30 and 305 m wide, verticals should be at 20, 35, 50, 60 and 80% of the width. Instructions issued by the Central Board of Irrigation and Power (CBIP, 1970) lay emphasis on the use of a large number of verticals for accurate assessment of sediment discharge, yet require the selection to be such that the best results are obtained in the shortest possible time. They suggest adoption of three verticals, located at 1/6, 1/2 and 5/6 of the width of the channel and that 1 litre samples should be collected from the surface and from 0.1, 0.3, 0.5, 0.7 and 0.9 depth in each vertical and mixed together. Singhal *et al.* (1980) have shown in the case of the River Yamuna that five verticals at 1/6, 1/3, 1/2, 2/3 and 5/6 of surface width should be used. The Task Committee (1969) recommended the use of single stage suspended sediment samplers. However, data on suspended sediment equipment as reported by Benedict (1979) reveal that 3244 USDH-48 and 1329 USD-49 samplers were in use by April 1977. The main limitation of the single stage suspended sediment sampler is that it is only operative during the rising stage. In flashy streams wading is not possible. The USD-49 sampler requires predetermination of the correct rate of traversing which may change considerably in flashy streams. *In situ* measurement of suspended sediment transport by means of ultrasonic scattering, as developed by Jansen (1978), is also limited, for example because of severe disturbance due to air bubbles, and restrictions on the upper limit of sediment concentration.

Measurement of bed load discharge

Leopold & Emmett (1976) have shown that the discharge of bed load in small streams can be obtained by direct measurements. The measurement of bed load in flashy streams is particularly difficult because it is not possible to lower or hold standard bed load samplers such as the Sphinx, Karyoli, VUV, and Russian types. Acoustic instruments measure only the relative bed load transport in the cross section and relative variations with time in streams having coarse bed material. The ultrasonic method involves many questionable assumptions, for example that the size distribution of the bed load is the same as that of the bed material, and that the velocity of the sediment particles equals the average velocity of the flow. Of all the bed load measuring methods, the use of a complete trench across a river (Painter, 1972) appears to be the most reliable. Murphy & Amin (1979) have developed an improved version of the trench method. Hollingshead (1971) reported the application of multiplication factors to the bed load discharges obtained using large basket samplers and full sized VUV samplers, based on the filling rates of a bed excavation (trench). Singhal *et al.* (1980) used a Russian type sampler for measurement of bed load discharge in the Ganga Canal and the River Yamuna and showed that at the 5% level of significance three verticals at 1/6, 1/2, and 5/6 of surface width could be used in canals and five verticals at 1/6, 1/3, 1/2, 2/3, and 5/6 could be used in rivers.

METHODOLOGY ADOPTED

In order to measure the suspended sediment discharge of five flashy streams, i.e. the Kansal, Dholbaha, Janauri, Thana and Chobal, steel wire cableways were established across all the streams except the Kansal Choe, where use was made of an available single-span foot bridge. The cableways were equipped with frictionless pulley systems (Fig. 2), which enabled easy

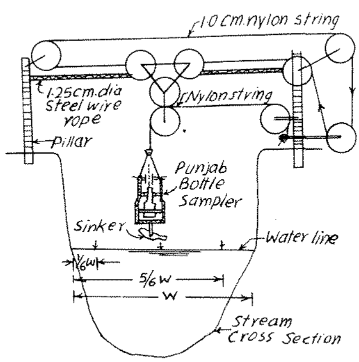

Fig. 2 The cableway system used for suspended sediment sampling.

movement of the suspended sediment sampler from one bank to the other and also to the desired depth below the water surface. The Punjab bottle sampler (Indian Standard, 1966) which has been recognized as standard sampling equipment in India was adopted for sampling. Appropriate streamlined weights were also used as sinkers to facilitate its lowering to 0.6 depth below surface in low and medium floods. Samples were taken in three verticals at 1/6, 1/2, and 5/6 of surface width. At high flood stages samples were taken from the surface. Samples were taken continuously at half-hour intervals during the rising, peak and falling flood stages and were mixed together and analysed to determine the coarse (>0.2 mm), medium (0.2-0.075 mm), and fine (<0.075 mm) fractions. Correction factors obtained by comparing the efficiency of this sampler with a Turbide Sonde L-80 sampler (CBIP, 1974) were applied to each fraction to obtain correct concentrations.

For the measurement of bed load discharge in the Kansal Choe, a Russian type sampler with an efficiency of 73% was employed. Since its optimum sampling time is 1200 s, samples were taken continuously at half-hour intervals. All the samples were mixed and analysed to determine the mean concentration. Since the bed load was computed to be between 1 and 1.5% of the suspended load, this sampler was not used in the other four streams. There, trenches extending across the stream and having a slot width equal to 200 times the maximum expected particle diameter have been installed. The results are not yet available.

OBSERVATIONS AND RESULTS

All five flashy streams were surveyed over 750 m reaches upstream and downstream of the discharge observation sites in order to determine stream bed slopes. The cross sections at the gauging sites are shown in Fig. 3. The average stream bed slopes of the Kansal, Dholbaha, Janauri, Thana and Chohal choes were calculated as 0.0085, 0.0058, 0.0082, 0.0083 and 0.0053 m m^{-1} respectively. Bed material samples, from up to 0.9 m depth were collected and analysed to determine geometric mean, mean, D_{35}, D_{50} and other sizes for use in sediment discharge formulae. The product of average discharge (as computed from discharge hydrographs) and mean total sediment concentration yields the sediment discharge.

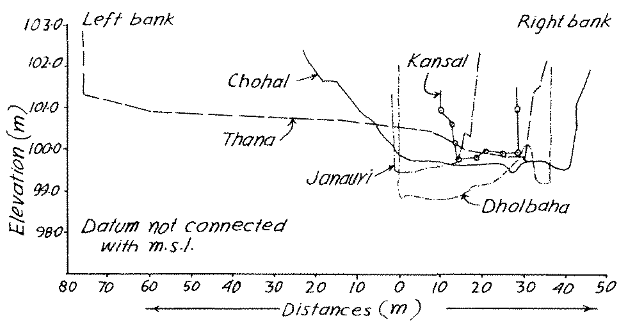

Fig. 3 Cross sections of various flashy streams at observation sites.

Since the appearance of the famous tractive force relationship of DuBoys (House Document, 1935), a number of sediment discharge formulae have been proposed and evaluated for their validity in design problems (CBIP, 1980). The Task Committee (1971) evaluated 13 formulae and observed that no precise recommendation on the selection of appropriate formulae could be made. However they showed that the Colby (1964), Toffaleti (1969), and Engelund-Hansen (1967) formulae yielded consistently better agreements with observed data. Tarapore & Dixit (1972) refuted this conclusion and showed that the DuBoys relationship gave a better fit. Gole *et al.* (1973) undertook a comparative analysis of five formulae using data from four streams and concluded that the Engelund-Hansen (1967) formulae gave the lowest standard deviation while, in situations involving extrapolation, the DuBoys-Straub formula furnished the best results.

In order to ascertain the applicability of such sediment discharge formulae to flashy streams, sediment discharge as computed from the DuBoys-Straub (House Document, 1935), Shields (Brown, 1950), Colby (1964), Laursen (1958) and Engelund-Hansen (1967) formulae for the Dholbaha Choe are plotted against discharge in Fig. 4. The sediment discharges observed during the years 1976-1979 in the five streams have been plotted against the values computed from these five formulae in Fig. 5. It is apparent that the DuBoys-Straub formulae produces better agreement

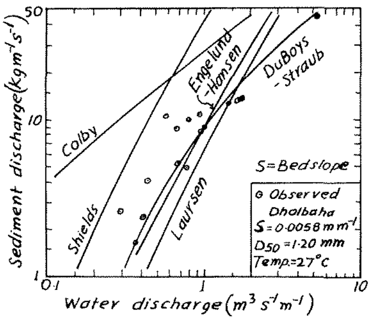

Fig. 4 Observed and computed sediment discharge *vs.* water discharge for the Dholbaha Choe.

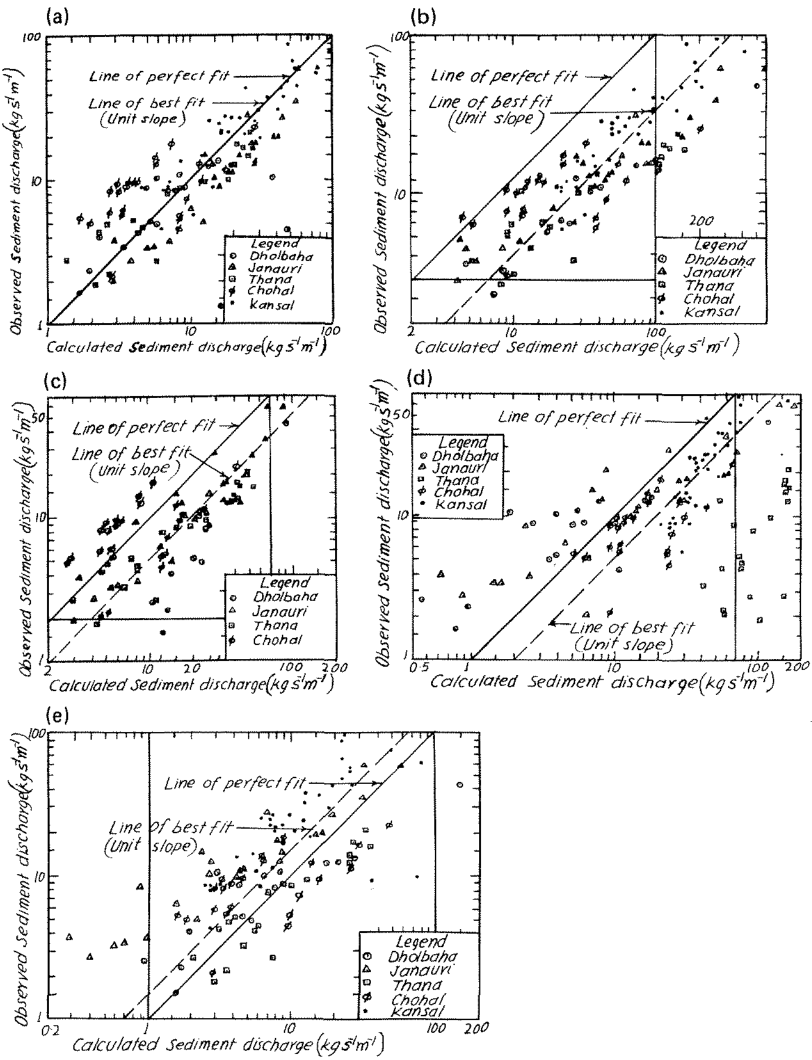

Fig. 5 A comparison of observed sediment discharge and that calculated by (a) the DuBoys-Straub formula, (b) the Shields formula, (c) the Colby formula, (d) the Laursen formula and (e) the Engelund-Hansen formula.

with the observed data. The standard error for the various formulae is as follows

	DuBoys-Straub	Shields	Colby	Laursen	Engelund-Hansen
Standard error %	2	82	13	12	17

Since the lowest standard error is associated with the DuBoys-Straub formula it is suggested that this can be utilized with confidence in flashy streams.

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