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Output of bed load sediment from a small upland drainage basin in Hong Kong

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Abstract Sediment has been removed from a "natural" bed load trap in a small upland drainage basin in Hong Kong and from 1989 to 2003 annual yield has been determined. For the 15-year observation period the median yield was 607 kg with a highest yield of 3897 kg. Five years (1989, 1993, 1994, 1997 and 1999) recorded annual yields of over 2000 kg. Scattergraphs of annual bed load yield against annual maximum 24 and 48 h rainfall reveal a positive association with correlation coefficients of 0.69 and 0.67, respectively. Extreme rainfall events, as defined by high return periods, may be associated with annual bed load yields that are well above the median for the 15 years of observation.

Key words bed load; rainfall; return period

INTRODUCTION

Erosion of channel banks (e.g. Peart, 1995a) and hillslopes (e.g. Lam, 1977; Ruse *et al*. 2002) along with, for example, construction activities (e.g. So, 1989; Peart, 1995b) all provide material which can be transported by Hong Kong's streams and rivers. The movement of sediment and its deposition and accumulation may result in a number of problems: early studies highlighted siltation of reservoirs (e.g. Davis, 1949; Berry, 1955). Accumulation of sediment in channels may contribute to the flooding problem (Drainage Services Department, 1993) and Chui *et al*. (2005) observe that "Regular desilting and dredging of river channels are conducted so that their flood carrying capacities would not be adversely affected by sediment washed down from the upstream areas". For example, in 2004 some 284 000 m^3 of sediment were removed from 3279 km of watercourses, river channels and drains. Moreover, in 1996/7 170 polluted agricultural weirs were cleansed at a cost of HK$0.74 million (AFD, 1997). Dudgeon & Corlett (1994, p.15) note that much silt and sand may be washed off "badlands" during heavy rainfall and remark that "... the eroded sediments may have damaging effects on streams where they clog, smother or bury the natural substratum". Dudgeon (1994) illustrates how this may influence the zoobenthos of a stream. Given the problems associated with sedimentation, surprisingly little attention has been focused on evaluating sediment yield and identifying when most sediment is transported within channels in Hong Kong.

THE STUDY BASIN AND BED LOAD MEASUREMENT

The small, around 0.1 km^2, headwater study basin is located in the New Territories near Shek Kong and is part of the Kam Tin drainage basin. It has a maximum height of

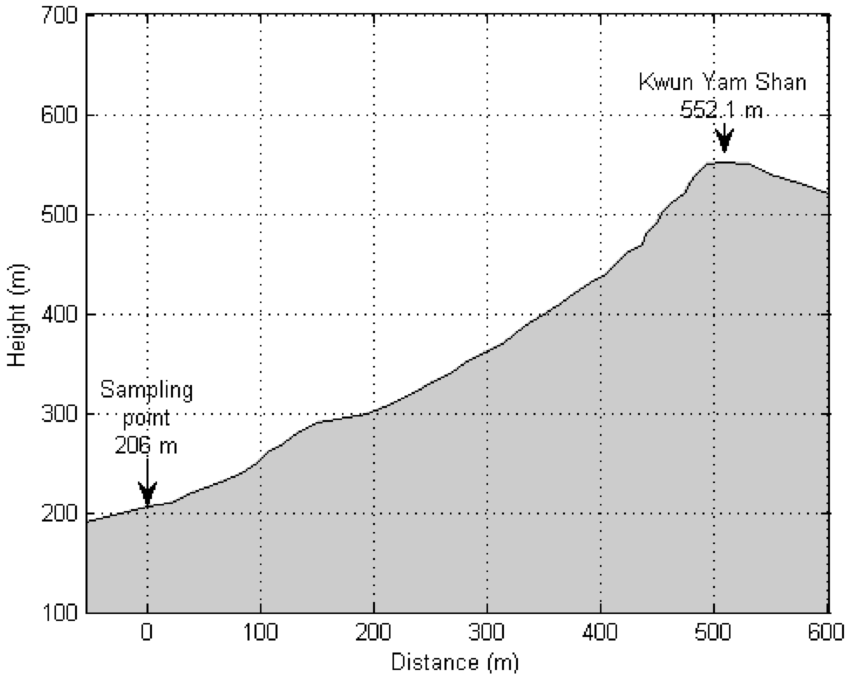

Fig. 1 Long profile of the study basin.

552 m while the outlet, where bed load and water level are monitored, is located at around 200 m. Bedrock geology consists mostly of granodiorite with some volcanic tuffs of the Shing Mun Formation (Geotechnical Control Office, 1988). Also mapped in the basin are Pleistocene and Holocene debris flow deposits which consist of unsorted sand, gravel, cobbles and boulders in a clay/silt matrix (Geotechnical Control Office, 1988) on the steep (30–40°) slopes of the basin. The basin is undisturbed by development and has a vegetation cover dominated by woodland and shrubland. The channel's long-profile shown in Fig. 1 evidences a steep gradient which averages around 30°. The stream channel shares some of the characteristics of a step-pool system described by Church (1992) and gradients are commonly bedrock or debris controlled.

Construction of a V-notch weir on a bedrock outcrop has led to the formation of a pool which acts as a "natural" bed load trap. At aperiodic intervals the bed load accumulated in the trap has been dug out and weighed after air drying. In general excavation has been carried out at the end of every year, and also after an individual storm event has caused larger than usual volumes of sediment to accumulate in order to avoid filling of the "trap". Monitoring began from April 1989 when the V-notch weir was emplaced, along with a Leupold and Stevens water level recorder. Rainfall has been recorded using a tilting-siphon raingauge located nearby, at around 200 m. In 1994, during the rainfall event of 21–23 July, the raingauge at the study basin failed, and for the May 2003 event it under-recorded. Under these circumstances, data from a gauge located at the adjacent Kadoorie Farm and Botanic Garden, sited at 305 m, were utilised. Extreme rainfall statistics have been evaluated using data from Tai Po Tau station operated by the Hong Kong Observatory. This station is located around 5.5 km NE of the study basin and has a similar mean annual rainfall (~2400 mm for the period 1961–1990) to that of the study basin (Lam & Leung, 1994).

RESULTS

Annual yield from 1989 to 2003 has been determined and the data are presented in Table 1. Total yield for the 15-year measurement period is 19 457.5 kg and the record reveals sediment production to be highly variable through time. The median annual sediment yield was 607 kg with a maximum yield of 3897 kg which amounted to 20% of the total. The two years with the highest annual yield (1994 and 1989) account for 40% of the total yield, whilst for the three highest load years the equivalent value is 54%. Five years recorded annual bed load yields of over 2000 kg, namely 1989, 1993, 1994, 1997 and 1999. The five lowest yielding years account for only 4% of total load.

For the years 1989, 1993, 1994, 1997 and 1999, due to the amount of sediment accumulated and frequent visits to the weir, it has been possible to ascribe much of the sediment accumulation to specific storm events. In 1989, for example, Typhoon Brenda and the associated rainfall was responsible for much of the sediment accumulation in the bed load trap, while in 1993 and 1999 Typhoons Dot and Sam, respectively, resulted in enhanced sedimentation. Active troughs of low pressure have also caused large accumulations of sediment in the bed load trap as, for example, in July 1994 and July 1997.

Table 1 presents annual bed load yield along with the annual maxima 24 h (or daily) rainfall and 48 h rainfall. The influence of heavy rainfall events, such as reported above, upon sediment accumulation in the bed load trap has been examined by plotting annual maxima of 24 h rainfall and 48 h rainfall against annual sediment yield (Fig. 2). A positive relationship between rainfall amount and bed load yield is evidenced in Fig. 2. Correlation coefficients of +0.69 and +0.67, respectively, are obtained for 24 and 48 h rainfall. Twenty four and 48 h annual maxima rainfalls explain some 48% and 45%, respectively, of the variability in bed load accumulation in the trap, with the 24 h rainfall being the better predictor (Fig. 2). Annual bed load

Table 1 Bed load yield and 24 and 48 h annual rainfall maxima and return periods.

Year	Bed load (kg)	24 h rainfall (mm)	Return period (years)	48 h rainfall (mm)	Return period (years)
1989	3871	670	314	723	204
1990	36	175	1.2	210	1.0
1991	68	106	0.5	165	0.6
1992	985	351	8.5	440	10.6
1993	2645	348	8.2	564	38.6
1994	3897	335*	7.1	415*	8.1
1995	1155	266	3.2	332	3.4
1996	607.5	143	0.8	218	1.0
1997	2350	314	5.6	377	5.5
1998	410	228	2.1	427	9.2
1999	2468	493	42.4	737	236
2000	130	264	3.2	340	3.7
2001	315	275	3.6	414	8.0
2002	251	139	0.8	221	1.1
2003	269	437*	22.7	485*	17
TOTAL	19 457.5				

* From Kadoorie Farm and Botanic Garden (305 m).

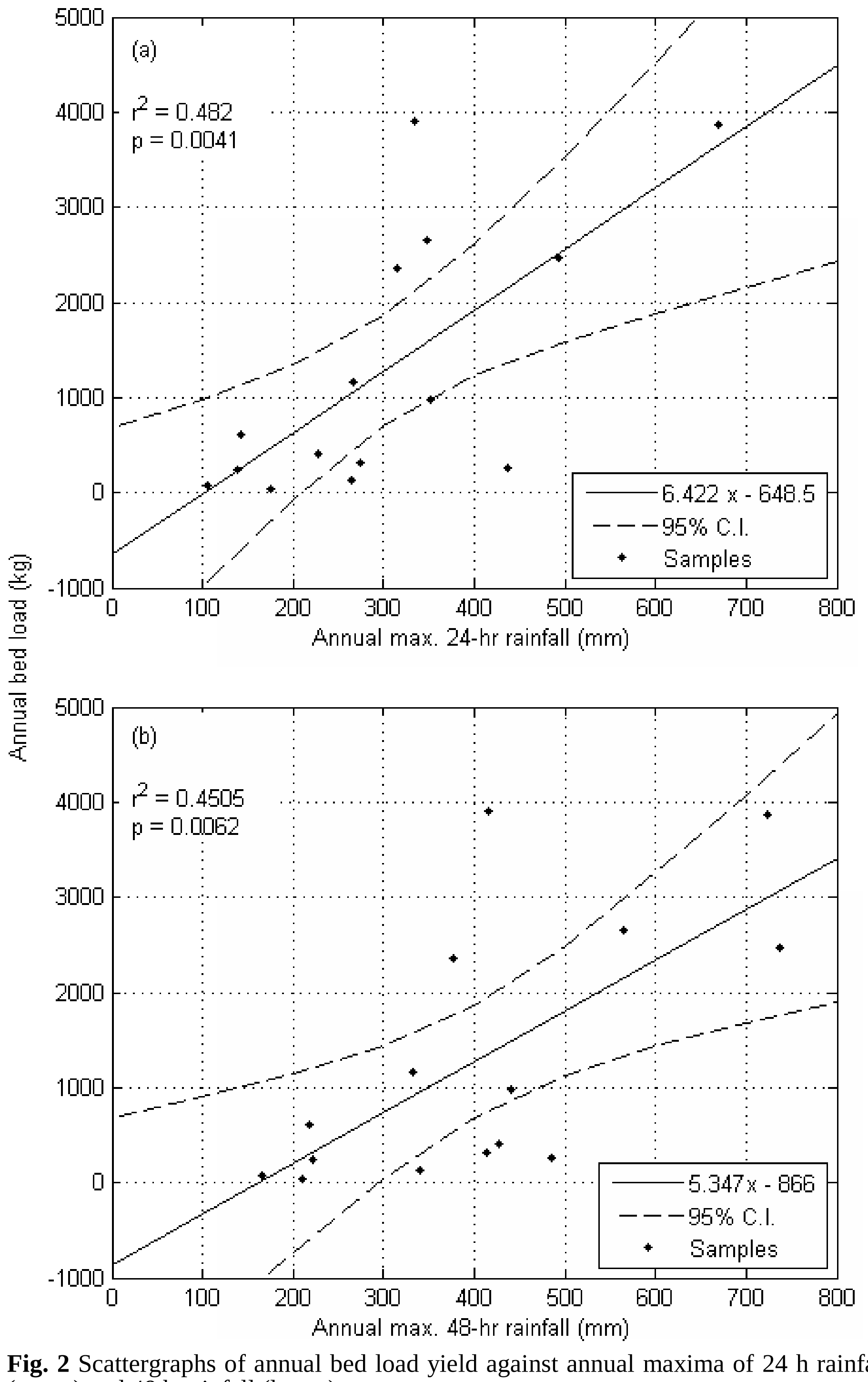

Fig. 2 Scattergraphs of annual bed load yield against annual maxima of 24 h rainfall (upper) and 48 h rainfall (lower).

yield has been correlated with annual rainfall at the study basin in an attempt to explore if annual rainfall may reflect extreme rainfall events and serve as a predictor for bed load yield. However, the low correlation coefficient of +0.37 reveals little association between the two variables.

There have been some notable rainfall events involved in generating the recorded bed load sediment yields. Utilising the extreme rainfall statistics generated by Lam & Leung (1994) for Tai Po Tau permits the placing of the rainfall values of Table 1 in perspective in terms of their return periods. In terms of 48 h rainfall, three years, 1989, 1993 and 1999, exhibit high return periods (204, 39 and 236 years, respectively) for the rainfall events that generated bed load. These three years ranked 2, 3 and 4 in terms of annual yield and they represent some 46% of total yield for the 15 year record. For 24 h rainfall, three years, 1989, 1999 and 2003, have much higher return periods (314, 42 and 23 years, respectively) than other bed load generating events. Extreme rainfall events, as defined by high return periods, may be associated with annual bed load yields that are well above the median for the 15 years of observation. For the annual 24 h rainfall maxima, with the exception of 2003, years with bed load yield below the median have return periods of 3.6 years or less.

DISCUSSION

In evaluating geomorphological effectiveness of floods, Newson (1980) observes that it is possible to distinguish between “slope” floods and “channel” floods. None of the rainfall events generated evidence of slope failures such as gullies or landslides. Much of the material was probably derived from within or close to the channel system. For example, field reconnaissance after the occurrence of Typhoon Dot in September 1993 revealed scouring of the channel in the upper areas of the basin. Such a distinction has also been made by Nicholas *et al.* (1995) in terms of large scale fluctuations in fluvial sediment transport rates as represented by sediment slugs, which they suggest can be categorized into endoslugs and exoslugs. The former are generated from within the channel whilst the latter are caused by sources external to the river.

Based upon analysis of Plynlimon (Wales) bed load data, Moore & Newson (1986) observe that “a few large floods are very influential and point to the need for very long records to estimate long-term yields reliably”. Data from the small headwater catchment also evidence the fact that a few years dominate in terms of sediment production: for example the two highest yielding years account for 40% of the total yield for the 15-year study period. Newson (1980) also presents data which illustrate the high temporal variability of bed load production, which is also a feature of the data from the study in Hong Kong as reported in the results.

It is of interest to observe that in this small headwater drainage basin the high bed load yield years of 1989, 1997 and 1999 are followed by years with low bed load accumulation in the trap. This is in contrast to the observation of Newson (1980) in the Tanllwyth catchment in Wales where, after storms generating high bed load yields, there was a slow return to relatively low yields. It is possible that part of the high bed load yield for 1994 reflects the transport of material made more readily transportable during the passage of Typhoon Dot in September 1993.

The scattergraphs of 24 and 48 h rainfall and their associated correlation coefficients indicate that “heavy” or “extreme” rainfall events may exert a control upon bed load yield in the small headwater catchment. However, the scatter exhibited by the plots along with coefficients of determination (r^2) of 48% and 45%, respectively, for the 24 and 48 h rainfall indicate other controls or influences operate. The influence of "extreme" events and their extended temporal impact, as documented by Newson (1980) and reported earlier, is one possible influence.

Some of the scatter in the plots of 24 and 48 h annual rainfall maxima against bed load results from the fact that whilst for many years, such as 1989, bed load production is dominated by one major event, in some years more than one event may generate significant amounts of bed load. For example, in 1994, whilst much of the bed load was generated by a trough of low pressure during 22–24 July, a spell of heavy rain occurred in August in association with an unstable southwest monsoon that may also have contributed to sediment production. Similarly in 1997 heavy rain in early July associated with a trough of low pressure, which caused clearance of the bed load trap, was followed by excavation of bed load on the 16 August after Typhoon Victor. A third event associated with Typhoon Zita in late August 1997 may also have generated sediment. In such years bed load yield might exceed that predicted from the scattergraphs in Fig. 2. Such is the case for both 1994 and 1997. In terms of 1994, the isohyet map of monthly rainfall (Hong Kong Observatory, 1994) reveals the presence of a strong vertical rainfall gradient in the area of Tai Mo Shan (including the study area) with a monthly rainfall total of around 1100 mm at the lower levels and a maximum of 2223.5 mm recorded at Tai Mo Shan no. 2 station situated at 950 m. This station had a 24 h maximum of 875.5 mm, which may indicate that for the July 1994 rainfall event, the actual rainfall in the upper areas of the study basin may have exceeded those recorded at lower altitudes. It may be, therefore, that the rainfall maxima utilized in 1994 is an underestimation.

During periods of high bed load accumulation the possibility of underestimation of yield cannot be ruled out. As Lewin (1981) remarks "Neither basket nor pit samplers will continue to operate well when nearly full .....". Although attempts were made to limit accumulation during the large yielding periods, the bed load trap did become very full and there is the possibility that some material may have been lost.

Use of 24 and 48 h rainfall totals permits assessment of event magnitude by means of estimates of return period for rainfall. Table 1 reveals that the years with the second, third and fourth ranked bed load yields (1989, 1993 and 1999) are associated with very high return periods for either or both 24 and 48 h rainfall. "Extreme" events therefore appear to be associated with enhanced bed load yield. However, 2003 with a 24 h return period of 22.7 years is not associated with high yield. Newson (1980) reports the effects of two storms in the Plynlimon area which had maximum rainfall return periods of 20–50 years and 100–1000 years for the 3 August 1973 and 15 August 1977 floods (return period varied according to duration). In the Tanllwyth catchment enhanced bed load yields were recorded for both storms.

CONCLUSION

Some 15 years of bed load yield have been recorded in a small headwater drainage basin in Hong Kong. Considerable temporal variability is evidenced by the data whilst the two highest yielding bed load years account for 40% of total sediment production. Scattergraphs of bed load yield against annual maxima 24 and 48 h rainfall reveal a positive relationship. Extreme rainfall events may be associated with annual bed load yields well above the median.

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REFERENCES

AFD (1997) Annual report for the financial year 1996/7. Agriculture and Fisheries Department, Hong Kong.

Berry, L. (1955) Effects of erosion in Hong Kong. *Far Eastern Econ. Rev.* **19**, 98–100.

Chui, S. K., Leung, J. K. Y. & Chu, C. K. (2005) The development of a comprehensive flood prevention strategy for Hong Kong. In: *Environment Hydraulics and Sustainable Water Management* (ed. by J. H. W. Lee & K. M. Lam), 1441–1447. Taylor and Francis Group, London, UK.

Church, M. (1992) Channel morphology and typology. In: *The Rivers Handbook: Hydrological and Ecological Principles* (ed. by P. Callow & G. E. Petts), v.1, 126–143. Blackwell, Oxford, UK.

Davis, S. G. (1949) *Hong Kong in its Geographical Setting.* Collins, London, UK.

Drainage Services Department (1993) *Territorial Land Drainage and Flood Control Strategy Study—Phase II* by Binnie Maunsell as Consultants to Drainage Services Department, Hong Kong, China.

Dudgeon, D. (1994) Functional assessment of the effects of increased sediment loads resulting from riparian - zone modification of a Hong Kong stream. *Verh. Internat. Verin. Limnol.* **25**, 1790–1792.

Dudgeon, D. & Corlett, R. (1994) *Hills and Streams: An Ecology of Hong Kong*. Hong Kong University Press, Hong Kong, China.

Geotechnical Control Office (1988) *Yuen Long: Solid and Superficial Geology*. Hong Kong Geological Survey Map Series. HGM 20, sheet 6, (1:20 000), first edn. Geotechnical Control Office, Civil Engineering Department, Hong Kong, China.

Hong Kong Observatory (1994) *Monthly Weather Summary July 1994.* Hong Kong Observatory, Hong Kong, China.

Lam, C. C. & Leung, Y. K. (1994) Extreme rainfall statistics and design rainstorm profiles at selected locations in Hong Kong. Royal Observatory Hong Kong, Technical Note no. 86.

Lam, K. C. (1977) Patterns and rates of slopewash on the badlands of Hong Kong. *Earth Surf. Proc.* **2**, 319–322.

Lewin, J. (1981) River channels. In: *Geomorphological Techniques* (ed. by A. Goudie), 196–212. Allen & Unwin, London, UK.

Moore, R. J. & Newson, M. D. (1986) Production, storage and output of coarse upland sediments: natural and artificial influences are revealed by research catchment studies. *J. Geol. Soc. London.* **143**, 921–926.

Newson, M. (1980) The geomorphological effectiveness of floods—a contribution stimulated by two recent events in mid-Wales. *Earth Surf. Proc.* **5**, 1–16.

Nicholas, A. P., Ashworth, P. J., Kirkby, M. J., Macklin, M. G. & Murray, T. (1995) Sediment slugs: large scale fluctuations in fluvial sediment transport rates and storage volumes. *Progr. Phys. Geog.* **19**(4), 500–519.

Peart. M. R. (1995a) An example of riverbank erosion in Hong Kong. *Hong Kong Geologist* **1**, 30–33.

Peart, M. R. (1995b) Fingerprinting sediment sources: an example from Hong Kong. In: *Sediment and Water Quality in River Catchments* (ed. by I. Foster, A. Gurnell & B. W. Webb), 179–186. Wiley, Chichester, UK.

Ruse, M. E., Waring, D. P., Kaldy, A. Chan, K. S. & Ng, K. C. (2002) Initiation and runout characteristics of a swarm of 121 landslides in the Tsing Shan Foothills, Hong Kong. In: *Natural Terrain—a Constraint to Development* (ed. by C. Franks, J. Hall, Martin, R. P., S. Ng, S. Parry, G. Pinches & G. Thorn), 77–87. Institute of Mining and Metallurgy, Hong Kong Branch, Hong Kong, China.

So, C. L. (1989) Geomorphic constraints on urban development in Hong Kong. In: *Resources, Environment and Regional Development* (ed. by C. K. Leung, C. Y. Jim & Zuo Dakang), 81–112. Centre of Asian Studies, University of Hong Kong, Hong Kong, China.