Some observations on bed load movement in a small stream in Hong Kong

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Abstract There is a sedimentation problem in Hong Kong. However, there has been little attempt to evaluate sediment yield and to establish under what conditions sediment transport occurs. A small, steep sided drainage basin in the New Territories, Hong Kong has been monitored since early 1989. In this basin a bed load trap has been used to investigate the movement of bed material. Only two events have caused sediment accumulation much higher than background levels. They are the storm of May, 1989 when 3792 kg of material was recovered, and September, 1993 when 2605 kg of sediment was removed from the trap. Analysis of hydrological and rainfall data reveals these two events to be "extreme". Annual bed load sediment yield is shown to be highly variable. The implications of the observation for monitoring programs and sediment yield determination are discussed while other data sources are explored in an attempt to independently assess the findings of the small basin study.

INTRODUCTION

Sediment transported and deposited by rivers and streams in Hong Kong may result in a number of problems. For example, some early studies highlighted siltation of water reservoirs (e.g. Davis, 1949; Berry, 1955). Currently, due to remedial action, it does not affect Water Supplies Department operations. Sediment deposition in river channels has contributed to the flood hazard in parts of Hong Kong (e.g. Territory Development Office, 1989; Drainage Services Department, 1991). The Drainage Services Department remove sediment from drains and channels in a maintenance programme. The Government of Hong Kong (1992) reports that the Drainage Services Department "... maintains 2800 km of water courses, drains and sewers increasing at the rate of 40 km per year. Some 80 000 m^3 of silt are removed from drains and water courses each year to keep their pollution level low and keep them free flowing". Data obtained from Drainage Services suggest that the annual figure of 80 000 m^3 is an underestimate. The Port Works Division of the Civil Engineering Department operates a maintenance programme for tidal reaches. They indicate that the material trapped in such areas, which can include livestock and other waste, may create "adverse visual and smell impacts upon the environment" (Port Works Division, 1988). Irrigation is important to agriculture in Hong Kong and is needed to ensure successful vegetable production. Sediment can accumulate behind weirs used to obtain water for irrigation thereby

Table 1 Sedimentation problems in irrigation systems.

Year	No. of weirs cleaned	Sediment removed (tonnes)	Cost $HK
1985-1986	146	1400	200 000
1986-1987	133	610	300 000
1987-1988	179	1282	243 000
1988-1989	204	1662	343 000
1989-1990	238	1579	420 000
1990-1991	218	919	450 000
1991-1992	167	1017	516 760

Source: Agriculture and Fisheries Department Annual Reports.

hindering their usefulness. The Agriculture and Fisheries Department operate a maintenance program for sediment removal and Table 1 evidences the size and cost of the problem.

In view of the problems associated with sedimentation, surprisingly little attention has been focused on evaluating sediment yield and establishing when most material is transported. Notable exceptions include the work of Lam (1974) and Port Works Division (1988). This study examines bed load sediment production in a small drainage basin in Hong Kong.

THE STUDY BASIN AND BED LOAD MEASUREMENT

The small, less than 1 km^2, study basin is located in the New Territories near Shek Kong. It has a maximum height of 546 m above principal datum while the bed load, water level and rainfall are all monitored around the 200 metre level. Bedrock geology consists mostly of intrusive granodiorite while debris flow material occurs on the steep (30-40°) slopes. The basin is undisturbed by development and has a vegetation cover dominated by woodland and shrubland. It is a second order basin.

At the basin outlet water level has been continuously monitored at a V-notch weir from April 1989 by means of a Leopold and Stevens recorder. The weir was completed in early 1989 which represents the beginning of sediment accumulation. A tilting siphon rain gauge has been operational near the site of the weir at the Kadoorie Agricultural Research Centre.

Construction of the V-notch weir for streamflow gauging has led to the formation of a pool which acts as a 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 after an isolated storm event has caused larger than usual volumes of sediment to accumulate. This sampling scheme has been permitted by almost daily visits to the weir and the small volumes of bed load produced by most storm events.

RESULTS

In Table 2 the date and amount of bed load removed from the trap is presented. Also included is information on the prevailing hydrologic and weather conditions which prompted the emptying of sediment from the trap when larger than normal accumulations have occurred. The weights include the normal slow accumulation of material, however, and at most these would be a few percent of the weight recorded for the higher yielding events.

Using, where appropriate, a linear apportionment of sediment accumulation it is possible to estimate from Table 2 annual bed load sediment yield. The results are presented in Table 3, and it can be seen that the production of sediment is highly variable, reflected in a mean annual value of 1513 kg, a sample standard deviation of 1681 kg and a coefficient of variation of 1.11. The dominance of the 2 years with extreme events is clear.

Table 2 Bed load sediment production.

Date of clearance	Weight of sediment (kg)	Weather	Maximum rainfall (mm) period of 1 day	Maximum rainfall (mm) period of 2 days	Maximum water level (mm)
30/5/89	3792	Typhoon Brenda	670	723	910
31/7/89	72	Typhoon Gordon	106	207	242
17/6/90	14	-	-		-
10/6/91	58	-	-		-
7/5/92	65	-	-		-
11/5/92	114	Trough of low pressure	171	237	560
16/8/92	845	Typhoon Faye	351	440	740*
5/10/93	2605	Typhoon Dot	348	564	928

* Record incomplete.

Table 3 Annual bed load sediment yield.

Year	Sediment yield (kg)
1989	3871
1990	36
1991	68
1992	985
1993 (to October only)*	2605

* Very little sediment has accumulated since this date.

For the period from 1989 to 5 October 1993, a total bed load yield of 7565 kg has been measured. The largest amount of sediment produced was associated with Typhoon Brenda in May 1989. Nearly 3800 kg of material was removed from the trap. This total, however, includes a small amount of material produced by a storm on 22 April 1989. The sediment removed after Typhoon Brenda represents 50% of the total yield over the study period. The second highest bed load yield was generated by Typhoon Dot in September 1993, when over 2500 kg of material were removed from the bed load trap. This represents 34% of the total yield. Only these two events during the monitoring period have generated over 1000 kg of sediment. The other observations listed in Table 2 all indicate substantially less sediment than produced by these two events.

DISCUSSION

Two storm events account for around 85% of the bed load produced from the drainage basin. Their dominance may be explained by examining the precipitation and water level records of the study period and the longer term rainfall record for Hong Kong. The event of May 1989 was associated with a 24-h rainfall total of 670 mm which was by far the highest daily rainfall recorded since measurement of sediment began in 1989. It generated the second highest recorded maximum water level of 910 mm at the V-notch weir while the highest storm hydrograph peak is the 928 mm associated with Typhoon Dot in September 1993. Furthermore, although the maximum daily rainfall associated with Dot of 347 mm has been matched on a few occasions, the maximum 48-h total of 564 mm has only been exceeded by Typhoon Brenda in 1989. These observations suggest that these two events may be unusual or "extreme". This can be confirmed by looking at the long-term precipitation record for the Royal Observatory. Peterson & Kwong (1981), on the basis of a Gumbel analysis of rainfall data at the Royal Observatory for 1884-1939 and 1947-1980, report that a 24-h rainfall of 626 mm is associated with a return period of 200 years. A two day rainfall total of 511 mm has a return period of 20 years. Examination of the Royal Observatory records from 1884-1939 and 1947 to September 1993 has failed to reveal any days with rainfall in excess of 600 mm. The extreme daily value recorded at the Observatory is the 534.1 mm reported on 19 July 1926. This is well below the daily maximum observed at the study site, even allowing for the 10% higher rainfall that might be expected to occur at the study site due to its higher altitude in comparison to the Royal Observatory. The 10% value is based on Chin (1971), who used observations from 115 stations of mean annual rainfall from 1952-1968.

The data from the Royal Observatory also reveals that two day rainfall totals in excess of 500 mm (10% lower than at the study basin to allow for altitude) are rare. Only six instances being recorded; these being 29 and 30 May 1889 with 841 mm; 30 and 31 May 1889 when 521.4 mm were recorded; the 18 and 19 July 1926 (560 mm) and the 19 and 20 July 1926 (561 mm) and finally the 24 and 25 of August 1976, with 511.6 mm. Therefore, in the 101 year data set, only six occurrences have been recorded. However, they more correctly reflect three heavy rainfall events, because the 1889 and 1926 occurrences reflect daily rainfalls of 520.6 mm and 534.1 mm, which are common between the two cases in each year. This agrees closely with the return period information based on the Gumbel analysis.

Table 2 indicates that "extreme" events are required to move large sediment volumes in the study basin, while Table 3 confirms the variability of bed load production. This has implications for assessing average bed load sediment yield. Clearly, extreme events need to be sampled and short term one to three year investigations may not achieve this satisfactorily. Other studies, such as Newson (1980) and Dickinson & Bolton (1992), also illustrate the significance of extreme events in bed load monitoring programmes. It may also be argued that the present study period may be biased towards extreme events, with two having been monitored in five years. Furthermore, the 1993 1:50 000 land use map shows the basin to be dominated by woodland and tall shrub. However, the 1954 land use survey reveals the area of woodland and scrubland to be much less extensive. Rough grassland and scrubland under 30 mm was more widespread. This variation of vegetation may make it difficult to extrapolate the current observations of bed load production too far into the past. Catt (1986) and Hill (1990) provide further evidence of the extent of land use alteration and vegetation change due to the impact of humans and natural succession.

Newson (1980) contrasts slope and channel floods in terms of geomorphic effectiveness. Slope floods are those events during which change on the slopes dominate such as gully bursts and slides. Neither the May 1989 or the September 1993 events showed evidence of spectacular slope failure such as gullies or landslides. Much of the material probably was derived from within or close to the channel system. Certainly after the September 1993 flood scour of the channel in the upper reaches of the channel could be seen. Given the frequency of occurrence of landslides in Hong Kong (e.g. So, 1971; Brand, 1985) a comparison of slope and channel floods in terms of geomorphic effectiveness and sediment yield would be of interest given the significance of mass movement in Hong Kong.

The observations made in the study basin indicate that extreme events move most of the bed load. This suggests, and Table 3 confirms, that on an annual basis, a year with an extreme event would have a very high sediment yield. An attempt has been made to obtain additional data sources in Hong Kong to verify the findings in this study. Table 1 presents information on the sediment removed from weirs used for irrigation in the agricultural areas of Hong Kong. In its present form the data do not permit assessment of the role of extreme events to be examined due to the reporting being on an aggregated basis. An attempt is currently being made to obtain sediment data for individual weirs. However, many of these weirs are sited in agricultural areas and they are often affected not only by natural sediment but by organic waste produced from poultry and pig farming. The majority of waste from livestock farms has traditionally been dumped untreated into water courses and this can cause streams to become clogged with manure which also accumulates at weirs. Hence, estimating the production of sediment and when it is transported from slope and soil erosion may be difficult.

The Port Works Division of the Civil Engineering Department is responsible for removing sediment accumulating in tidal sections of rivers. However, dredging is not done on a regular basis, or in the same places. Hence, although an estimate of yield may be available it would not be possible to ascertain which event produced the material. It would also be difficult to assess the variability of sediment production.

CONCLUSION

Some sedimentation problems in Hong Kong have been identified and the results of bed load sediment yield for a small basin presented for 5 years from 1989 to 1993. The data evidences the variability of bed load sediment production which has been caused by the occurrence of "extreme" events. This dependence upon high magnitude events has implications for sediment monitoring programmes. Other sources of data are being sought to confirm this variability.

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