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Human impact upon sediment in rivers: some examples from Hong Kong

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Abstract Examples of human impact upon sediment in water courses from Hong Kong are outlined. In the Kam Tin basin under baseflow conditions, two undisturbed upland streams exhibit low concentrations of suspended sediment as typified by median values of 4.8 and 1.6 mg l^{-1}, while in contrast the river at Kam Tin has a median sediment concentration of 36.3 mg l^{-1}. At Kam Tin values of suspended sediment concentration in excess of 20 mg l^{-1} account for a much higher proportion of samples than in the upland basins. The higher suspended sediment concentrations downstream at Kam Tin can be explained by the disposal of domestic, agricultural and industrial waste in the river. Evidence is also presented for the occurrence of higher suspended sediment levels in the Lam Tsuen River, which has been impacted by construction activity, in comparison to an undisturbed upland basin. In the future more attention might need to be given to the transport of plastic, polystyrene and other debris.

INTRODUCTION

Hong Kong is a city state with a land area of around 1070 km^2 and a population of nearly six million. It consists of the island of Hong Kong, Lantau Island, the Kowloon Peninsula and New Territories and over 200 small islands. Although many people regard Hong Kong as an urban area, only around 16% of the territory is classified as such (Ashworth *et al.*, 1993). Approximately 14% of the territory is woodland (including plantations), some 15% is grassland and a further 1.3% is in agricultural use. There are also "hundreds of streams, rivers and open nullahs" in Hong Kong many of which are "short streams having fast flowing upper reaches with rocky substrates, and sluggish flowing lower reaches with silty bottoms" (Environmental Protection Department, 1995).

As Lo (1992) indicates, the territory has become one of the world's great ports and trade centres. It is also an important financial centre and significant manufacturing activity remains. Currently, major infrastructure programmes are in progress, most notably the new airport at Chek Lap Kok and related schemes. Given the small land area the success and expansion of Hong Kong may be expected to put pressure upon the environment. This paper attempts to document the human impact upon sediment in Hong Kong's water courses.

STUDY AREAS AND METHODS

Sampling has been carried out in the Lam Tsuen River near the village of Pak Ngau Shek (Fig. 1), at which point it has a catchment area of around 2 km^2. The river rises on the slopes of Tai Mo Shan which at 957 m is the highest peak in Hong Kong.

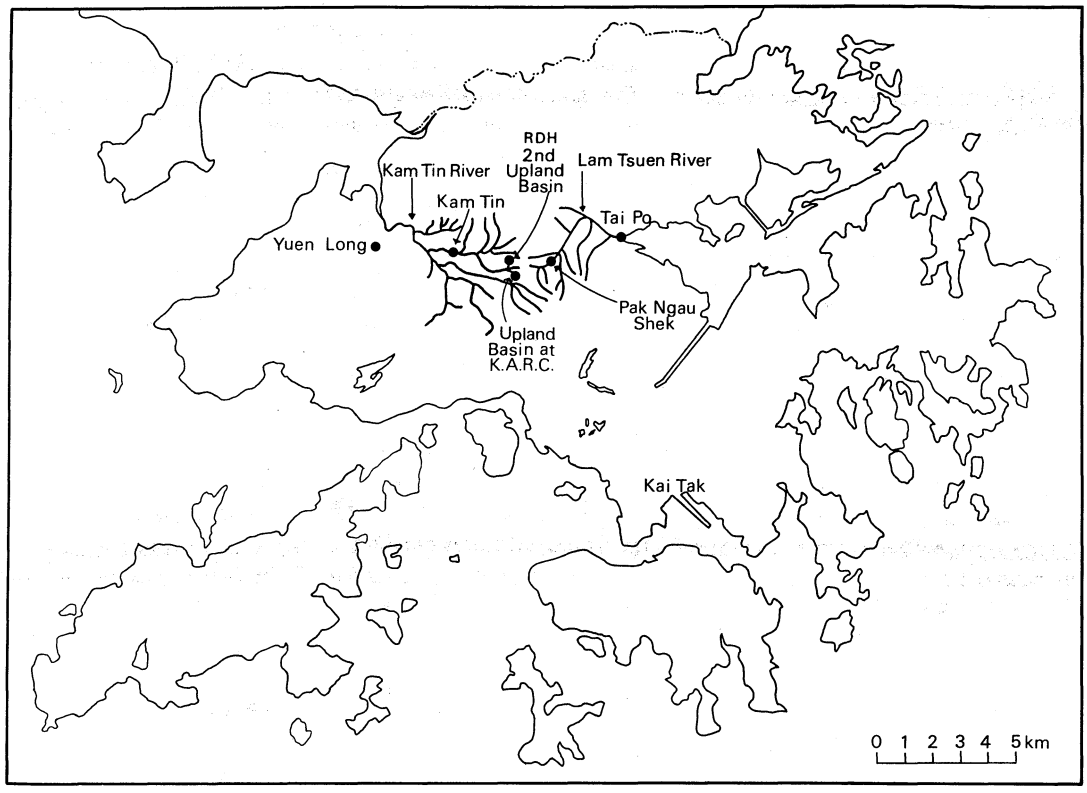

Fig. 1 Location of sampling sites.

From near Pak Ngau Shek, the Lam Kam road follows the river valley. A road improvement scheme began in 1991 and the work impinged upon the river upstream of Pak Ngau Shek, with much of the work being completed by 1994. Land-use is predominantly ferns/grass, shrubland and, woodland and includes the Kadoorie farm and botanic garden.

Suspended sediment concentrations have been monitored in a second drainage basin in the New Territories, that of the Kam Tin River (Fig. 1). This is adjacent to the Lam Tsuen catchment and also has its origins on Tai Mo Shan. In terms of physiography, the Kam Tin basin has two distinct parts: steep uplands and an alluvial plain. The former area is covered in natural vegetation; grass, shrubs and woodland. The alluvial plain was characterized until recently by agricultural land use, in the form of vegetable and flower growing, along with chicken and pig rearing accompanied by village settlement. However, since the late 1980s an increasing amount of agricultural land has been given over to open storage. Two upland tributaries have been monitored and their locations are shown in Fig. 1. They are both steep and their major differences are in their vegetation cover: the stream located at the University's Kadoorie Agricultural Research Centre (KARC) is predominantly woodland, while the other upland stream, near Sheung Tsuen identified as RDH, is covered by grassland and fernland. A further sampling point was operated just upstream of the village of Kam Tin on the flat alluvial plain, at

which point the basin has an area of around 18 km^2 and where water quality might be expected to reflect the human impact.

In the absence of continuous monitoring equipment or automatic samplers, manual dip sampling has been adopted at the Lam Tsuen and Kam Tin rivers. The data for the two upland streams also comes from dip sampling. Baseflow sampling has been conducted all year round while most of the stormflow samples relate to the summer wet season. Suspended sediment concentration was determined using 500 ml samples filtered through pre-weighted GFC filter papers. In 1991 and 1992 some additional dip samples were collected in the Lam Tsuen River by Dr. D. Dudgeon and use of his additional data is gratefully acknowledged.

RESULTS

Frequency distribution histograms of baseflow suspended sediment concentrations for all sampling points in the Kam Tin River basin for the period 1993 to 1995 are presented in Fig. 2. Downstream at Kam Tin the modal class is 10 to 19.9 mg l^{-1}. In contrast, for both upland basins the modal class is 0-9.9 mg l^{-1}, suggesting that sediment concentrations are higher downstream. This is supported by median concentrations of 4.8, 1.6 and 36.3 mg l^{-1} respectively for the two upland basins and Kam Tin. The station at Kam Tin also exhibits a greater frequency of suspended sediment concentrations in excess of 20 mg l^{-1} than the two upland streams. At Kam Tin 72% of all baseflow samples exceed 20 mg l^{-1} and around 5% are over 200 mg l^{-1}. In contrast, in the upland basin at KARC 9% of the samples exceed 20 mg l^{-1} and no sample exceeded 90 mg l^{-1} and for the second upland stream only 4% of the samples had concentrations greater than 20 mg l^{-1} and only one sample exceeded 200 mg l^{-1}. In general, therefore, suspended sediment concentrations under baseflow conditions are lower in the upland streams in comparison to the lowland river at Kam Tin. This is supported by interquartile ranges of only 6.2 and 2.5 mg l^{-1} respectively for the KARC and Sheung Tsuen (RDH) upland basins, while at Kam Tin the value is 56.6 mg l^{-1}. It is also worth recording that for the 234 baseflow samples collected at Kam Tin the upper quartile value is 75.2 mg l^{-1}, while in contrast at the KARC basin it is 8.9 mg l^{-1} and at the second (RDH) upland basin the upper quartile sediment concentration is 3.1 mg l^{-1}. These values also suggest that sediment concentrations are higher downstream at Kam Tin.

Storm period suspended sediment concentration frequency distribution diagrams for the period 1991-1995 are shown in Fig. 3 for the Lam Tsuen River and the neighbouring upland basin at KARC. In the upland basin at KARC, low suspended sediment concentrations generally prevail, with the frequency distribution exhibiting positive skewness and being bi-modal in the classes 0-99 and 10-19.9 mg l^{-1}. In contrast the Lam Tsuen River exhibits negative skewness and the frequency distribution has a modal class of over 200 mg l^{-1}. Table 1 presents suspended sediment concentration values for the median along with the upper and lower quartiles for each year and also a summary of the complete data set. The data for 1991 and 1992 in the Lam Tsuen River have been amalgamated to represent the period when roadworks were most extensive and to increase sample size. In terms of the complete data set the median value and both upper and lower quartile values are

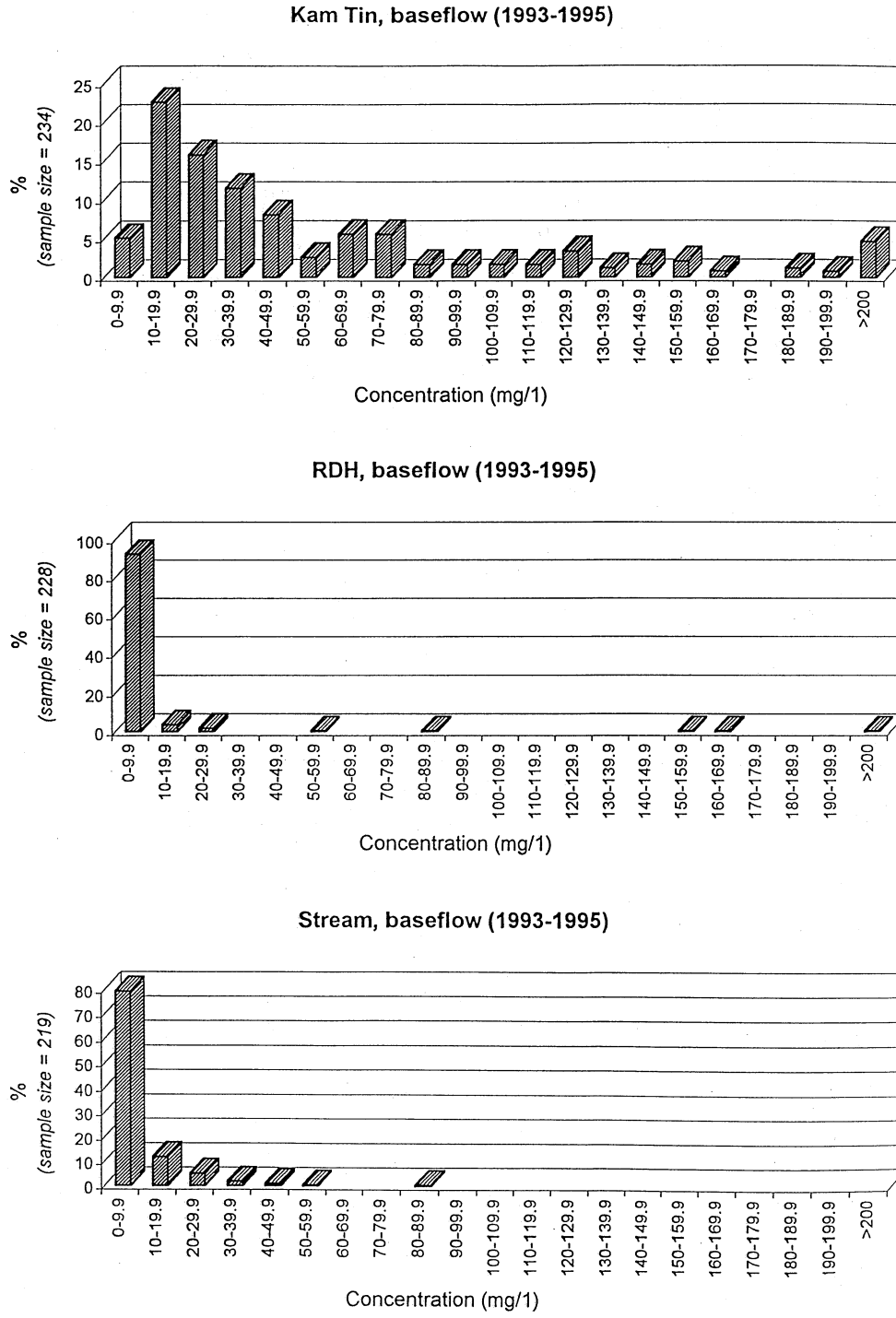

Fig. 2 Baseflow suspended sediment frequency distributions in the Kam Tin basin.

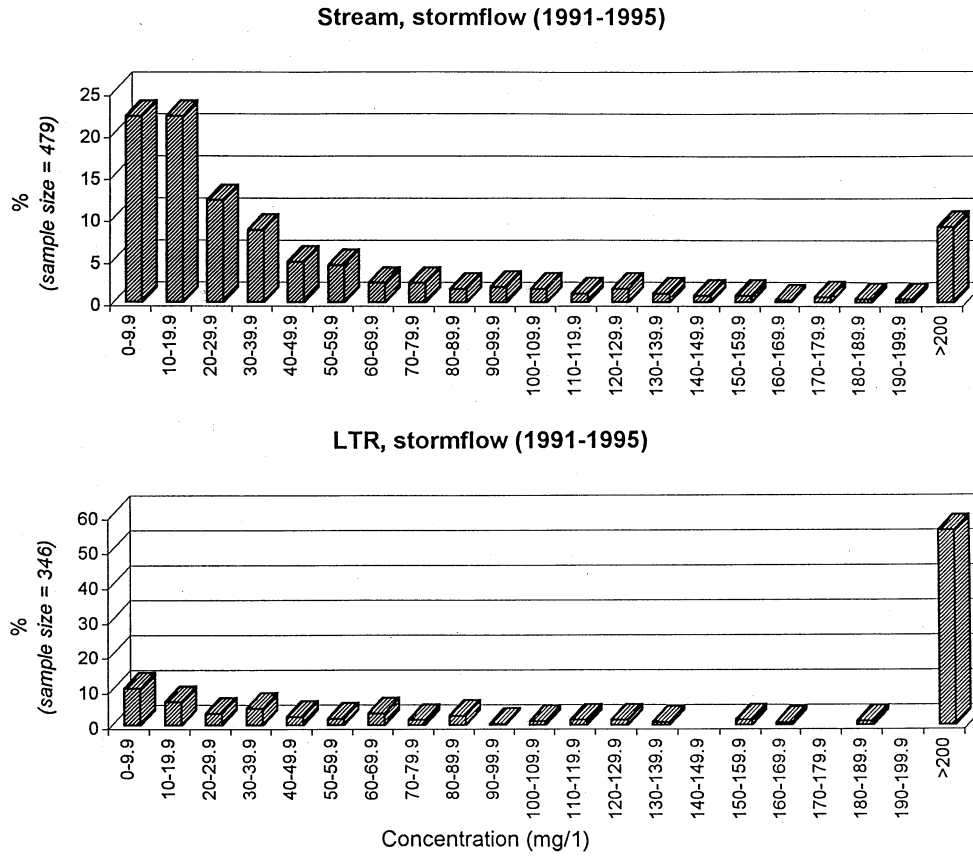

Fig. 3 Stormflow suspended sediment frequency distributions in the undisturbed upland basin at KARC and the Lam Tsuen River.

much higher in the Lam Tsuen River in comparison to the upland stream. In each year, that is to say 1991/1992, 1993, 1994 and 1995, the values of the median and upper and lower quartiles are much higher in the impacted Lam Tsuen River in comparison to the undisturbed upland basin. However, there is some evidence that as vegetation recovers the sediment levels are declining in the Lam Tsuen River. For example, the upper quartile value for suspended matter declines from 1666 mg l^{-1} in 1991/1992 to 311 mg l^{-1} in 1995, while the median value falls from 978 mg l^{-1} in 1991/1992 to 62 mg l^{-1} in 1995. In contrast the upland stream at KARC evidences no trend.

Baseflow suspended sediment concentrations have also been monitored in the Lam Tsuen basin. In 1991 and 1992 when construction work involved machinery working in and close to the river some comparatively high suspended sediment concentrations were recorded. For examples, in 1991 and 1992 two samples contained in excess of 2000 mg l^{-1} and of the 56 samples 27% exhibited sediment concentrations in excess of 100 mg l^{-1}. The median value of 18 mg l^{-1} and the fact that some 27% of samples were below 10 mg l^{-1}, suggest that the impact was not always recorded in baseflow samples and was restricted to times when construction

Table 1 Sediment concentration data.

	1991	1992	1993	1994	1995	All data
KARC stream						
Upper quartile	75.8	89.5	39.3	122.1	82.1	61.6
Median	19.2	31.7	19.3	29.9	29.4	24.5
Lower quartile	7.5	12.6	9.58	13.5	10.7	11.0
Sample size	54	158	152	57	58	479
Lam Tsuen River						
Upper quartile	1666*		772.8	782.7	305.8	954
Median	977.7		155.4	313.6	61.65	256.3
Lower quartile	404.6		28.2	82.9	19.8	41.1
Sample size	57		148	84	57	346

* 91+92

work was being carried out. During the years 1991 to 1992 in the undisturbed upland basin no baseflow samples in excess of 100 mg l^{-1} were recorded and 68% of the 199 samples were below 10 mg l^{-1}, providing some evidence of the effects of disturbance in the Lam Tsuen River.

DISCUSSION

Evidence has been presented which suggests that under baseflow conditions suspended sediment levels in upland streams are very low. In contrast, downstream suspended matter concentrations at Kam Tin are much higher and may be attributed to human impact. In a water pollution study Binnie & Partners (1973) reported that the principal sources of pollution were: pig and poultry farms, animal slaughtering and carcass disposal, other farming activities, human wastes, small factories and cottage industries, and domestic and industrial refuse. With the exception of the animal slaughtering trade these activities to a greater or lesser extent still have an impact on water quality in the Kam Tin basin and provide a source of material for removal in suspension. Although improvements have been made in the Kam Tin basin, it remains a "priority water course" (Environmental Protection Department, 1995). The Environmental Protection Department (1995) report zero compliance with the suspended solids water quality objective (annual median $\leq$ 20 mg l^{-1}) in 1994 and report that the Kam Tin River remained badly affected by the discharge of livestock waste. With median suspended sediment concentration values of 23.3, 56.8 and 40.2 mg l^{-1} respectively for 1993, 1994 and 1995, and given that only 28% of all baseflow samples collected during the study period were less than 20 mg l^{-1}, achieving this objective would seem to be some way off.

In addition to the Environmental Protection Department data cited earlier, supporting evidence for the human impact in the Kam Tin basin can be gathered from a number of other sources. Binnie & Partners (1974) undertook a study of pollution in New Territories streams and at 25 of their sampling points the impact of agriculture is cited as causing pollution. The median suspended sediment concentration for these 25 streams was 96 mg l^{-1} while the inter-quartile range was from 264 to 35 mg l^{-1}. Minimum and maximum concentrations were 798 and 8 mg l^{-1}

respectively. In the North Western Water Scheme Pollution Study, Binnie & Partners (1973) measured suspended sediment concentrations in the Kam Tin basin at Au Tau Bridge, approximately 3.5 km downstream of the current sampling point. They report maximum and minimum suspended sediment concentration values for 81 samples collected in 1965-1967 of 880 and 8 mg l^{-1} respectively with an average of 83.8 mg l^{-1}. In 1972 maximum and minimum values of suspended matter were 74 and 3.6 mg l^{-1} for 14 samples, with an average of 35 mg l^{-1}. More recently, the Port Works Division (1988) estimated that in the Kam Tin River some 96 000 t per year of artificial loadings occurred in the basin and this was dominated by the annual input of 84 000 of raw manure from agricultural waste. They suggest that artificial sediment loadings exceed natural erosion in this basin and account for around 86% of annual sedimentation. They also report that the Sha Tin, Tuen Mun and Yuen Long river channels are also impacted by artificial loadings.

There is a clear contrast between stormflow suspended sediment levels in the undisturbed upland basin and the Lam Tsuen River. This reflects the impact of construction associated with a road improvement scheme. Removal of vegetation exposed the soil to erosion in the Lam Tsuen River and resulted in high sediment concentrations. High sediment concentrations were also assisted by the steep nature of some of the exposed cut slopes and the fact that many of these led straight into the river, thereby ensuring very high sediment delivery rates.

The frequency distributions of the upland basin clearly provide evidence for the protective effects of the vegetation layer. In contrast to the Lam Tsuen River, concentrations rarely exceed 200 mg l^{-1}, and in the upland basin the modal class is 0-9.9 and 10-19.9 mg l^{-1}. The Lam Tsuen River itself offers evidence of the benefits of vegetation cover The construction activity was at its height in 1991/1992 and by 1995 the exposed slopes were developing well established vegetation. As indicated in the results section, there is evidence that sediment concentration levels are now declining. The decline may also be due, at least in part, to the occurrence of large storms in late 1993 and 1994 which flushed out any residual deposits from the road works.

The results from the Lam Tsuen River are significant because they illustrate the impact that construction can have upon sediment concentrations in water courses. Given the amount of construction being undertaken in Hong Kong, it is clear that it has the potential to make a significant contribution to sedimentation. Additional evidence of the consequences of vegetation removal has recently been gained in the area. An electricity supply expansion scheme has seen the construction of pylons for the suspension of cables and part of the route is through the Lam Tsuen valley and the upper parts of the Kam Tin basin. At the site of pylon building the vegetation layer is removed to facilitate installation of the foundations, and the soil is left exposed. In April 1996 a heavy downpour led to suspended sediment concentration values in the stream at KARC ranging from 10 to 732 mg l^{-1} for seven samples, with a median of 61 mg l^{-1}. In contrast about 300 m downstream sediment was being washed into the water course from a pylon site on the nearby divide. Here concentrations ranged from 589 to 22 571 mg l^{-1} with a median of 755 mg l^{-1} for the five samples. Peak values of sediment below the construction work were far in excess of those upstream in the undisturbed section of the channel.

The examples cited in this paper refer to the "rural" areas of the New Territories. Examples of human impact can also be found in the urban area. Dr M.

Vis kindly pointed the author to a good example at Kai Tak nullah in Kowloon. Construction work associated with the Kai Tak housing estate led to the accumulation of significant amounts of sediment in the nullah and occupied about 320 downstream of the site. Using a width of 5 m and a depth of 0.75 m around 1200 m^3 of sediment have accumulated in the channel.

The observations reported in this paper refer to suspended matter in the water column. However, in Hong Kong attention might also need to focus upon other materials transported in the water courses. At the Kam Tin River, especially during large storm events, copious amounts of plastic and polystyrene along with aluminium cans, bottles and other refuse can be seen moving downstream. It accumulates in significant amounts upstream of bridges and forms a major component of trash lines. The existence of this debris provides evidence of the river's use as a garbage disposal system and of the human impact. In contrast no such rubbish has ever been seen at the two upland sites.

CONCLUSIONS

The record of sediment concentrations under baseflow conditions for the period 1993-1995, in the Kam Tin basin indicates that consequent upon the disposal of domestic, agricultural and domestic waste suspended matter levels are higher downstream than in two undisturbed upland basins. In the Lam Tsuen River, the sediment concentration record illustrates the fact that disturbing the vegetation cover can result in elevated suspended sediment concentrations. There may also be a need to pay more attention to plastic and other such debris in lowland water courses.

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