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Estimation of extreme sediment transport from torrential drainage basins in the East Alps

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ABSTRACT A knowledge of the dangers and possible damage caused by torrents is one of the most important preconditions of sensible land use planning. Torrent erosion and sediment yield here include the whole process of excessive erosion (soil erosion, landslides, gully erosion) as well as bed load transport and deposition of bed load on debris cones or on valley floors. Whilst our understanding of soil erosion has reached a high level, the quantitative estimation of torrent erosion and torrential sediment yields is much more difficult. Based on both special investigations in experimental drainage basins and the systematic sampling of data relating to all extreme events associated with torrents in the East Alps, general formulae for calculating extreme sediment yields from torrential drainage basins during floods and mud flows have been developed. These are discussed and compared with other procedures.

INTRODUCTION

A thorough knowledge of torrent erosion and possible sediment yields is necessary for all planning in mountainous areas, especially in densely populated countries, in order to introduce torrent and avalanche control measures and to develop the zoning of danger areas. The term torrent erosion is taken to embrace all erosion phenomena related to sediment discharge. It includes soil erosion, landslides, gully erosion and also bed load transport and accumulation problems, because all these phenomena are closely related. The estimation of torrent erosion becomes increasingly difficult with a decrease in drainage basin size. Therefore special investigations in so-called experimental drainage basins as well as sampling of data from all torrential events were started in Austria after the catastrophies in 1965 and 1966, in order to improve the basis for planning and zoning. In this paper some of the results of this research which have led to the development of general formulae for calculating extreme torrential sediment yields will be described. The initial form of these formulae has been discussed at meetings of the relevant IUFRO Working Group, but this opportunity is taken to present them in a more developed state to a wider audience.

THE BASIC ELEMENTS AND PROBLEMS OF SMALL DRAINAGE BASINS

Based on a knowledge of individual erosion rates, channel conditions, and deposition areas within the gorge and on the alluvial fan, an estimate of sediment yield from torrential drainage basins may be obtained, but many difficulties are involved. The main problem lies in the fact that erosion rates range over many orders of magnitude. Erosion rates for entire drainage basins or for vegetation-covered slopes range from 0.01 mm to several mm per year, superficial erosion on bare rocky areas may involve either mm or cm dimensions whilst rates of erosion on bare erosion scarps may involve dm. Longitudinal and lateral erosion and landslides may represent erosion rates of several m. Creeping mass movements reach greater depths, up to 100 m, but seldom lead to sudden slides and falls and more often produce large amounts of scree and detritus. The estimation of sediment yields is therefore only possible by mapping the erosion potential of the whole drainage basin.

Due to its protective effects, the influence of vegetation and especially forest cover is of major importance. New research results from Kenya show that well forested drainage basins exhibit significantly lower sediment yields than drainage basins covered by grassland (Dunne, 1979). In humid alpine conditions grassland protects the soil at gradients of up to about 30°. On the other hand, bare erosion scarps have to be revegetated as soon and as completely as possible in order to avoid the transport of millions of m^3 of sediment within a few years (e.g. Kronfellner-Kraus, 1975).

Forests have, in general, the best protective effect against soil erosion. The tree canopies protect the soil against splash erosion. The infiltration rates are higher within forests in comparison with grassland and these can be measured with infiltrometers, although on steeper terrain rainfall simulators produce better results. For example, runoff measurements undertaken by Schaffhauser (1979, 1981) showed that whereas runoff from forested plots reached only 10%, that from ski slopes was up to 30%, and that from grassland was up to 60%, although erosion was not found on these plots. On the other hand, erosion on steeper bushland occurred in the form of slips. The forest also protects the soil through the reinforcing effect of the tree roots. The likelihood of landslides is therefore significantly greater in bushland than in forests. The effects of tree roots in binding the soil decreases after clear cutting, because the roots rot after a few years. The probability of landslides is therefore greatest from 5-20 years after clearcutting until new roots develop (e.g Megahan *et al.*, 1978).

Forests also work as a biological drainage system, especially in higher regions by snow interception. This positive effect can be used to stabilize landslides. For example, in the case of a 2 km^2 zone of mass creep of rock in the Gradenbach (Carinthia), mathematical functions could be developed relating precipitation amounts during winter, spring and summer and the rates of slope creep. The different functions relating to the periods before and after drainage work on the upper part of the slope show that the upper drainage work undertaken after 1975-1976 was especially effective. The relationship between precipitation and slope movement may also be used for forecasting and warning

(Kronfellner-Kraus, 1978). A kinetic study of slope movement based on three dimensional geodetic surveys has led to a better understanding of sediment production because the slow ruptural creep of the rock mass results in a steady production of detritus in the form of rock falls.

Similar phenomena of bed load production were found in the Dürnbach, Salzburg region. Here there is an area of mass creep of rock extending over about 3 km^2 and scree and detritus is produced as at Gradenbach. The bed load transport can be measured behind dams and in debris basins and related to the measured flood discharges.

As different flood discharge measurements show, the hydrographs of well-forested drainage basins are in general influenced by greater infiltration, accumulation and storage capacity. On the contrary, the hydrograph of a drainage basin mostly covered by grassland in higher regions shows greater direct runoff rates.

Although vegetation, and in particular forests, decrease flood peaks, the flood volumes are often the same and independent of vegetation or the occurrence of forests, because of the attenuation of the flood wave. The sediment discharge or sediment yield may however depend on the point at which the sediment transport begins. Continued erosion may lead to the development of armoured pavements on the river bed and these natural pavements can only be eroded by subsequent greater floods. On the other hand, medium floods may transport all the debris coming from small landslides and similar sources. Thus a torrent can be without sediment transport for a long time and may quickly transport a hundred thousand times more sediment, according to the amount of sediment produced.

ESTIMATION OF EXTREME SEDIMENT YIELDS

As mentioned above, bed load transport in torrents is a rather irregular process and must therefore be distinguished from that in rivers. The transportation capacity of rivers may be calculated fairly exactly by investigating the so-called "bed load function". In small torrents such correlations are difficult to establish. Therefore, with respect to torrents it is only worthwhile to estimate extreme values. For this purpose different procedures may be used.

In general, sediment yields (S = sum of bed load and suspended load) depend on the size of the drainage basin (A) and the appropriate specific degradation rates (h_s). A part of the degradation is, however, removed without any damage by minor floods, while the other part may accumulate for many years as debris storage, until it is finally removed by larger floods. This debris storage, together with its respective period (t), must be taken into consideration in an adequate formula for estimating sediment yields from torrents: $S_t = A\ h_s\ t$.

Another possibility is to correlate sediment transport directly with flood discharge. In the case of an extreme mudflow, the sediment transport may be equal to the flood discharge. According to Müller (1960), the flood volume factor varies between 20 000 and 60 000 m^3, and in extreme cases up to 100 000 m^3, although an average form of 40 000 $A^{1.17}$ can be proposed. Analysis of measured flood discharges and flood hydrographs by Kreps (1962) suggests that the volume of a 100 year flood may be estimated as 65 000 A.

In torrents, however, bed load discharges will seldom correlate with flood discharges. The bed load transport depends instead on the character of the drainage basin and the activation of bed load source areas. It is acceptable, therefore, to predict future torrent development from the current circumstances. Hoffmann (1970) and Hampel (1977, 1980) developed approximate formulae for these relations. Hoffmann found that the width of the stream bed (an important influence on bed load transport) together with the gradient and the bed material size may be used to characterize a given drainage basin. Hampel (1977, 1980) draws conclusions from the previous debris cone formation for future bed load or mudflow discharges, and he determines the bed load or mudflow discharge from the gradient of the alluvial fan and an index of flood volume.

In practice, it is difficult to determine exactly the relevant width of a stream and the gradient of an alluvial fan. The problem of predicting newly developing bed load source areas or erosion scarps with unknown granulometry and sediment content, which occur during catastrophies, remains unsolved. There are also unknown abrasion processes working in different sediment mixtures, causing another factor of uncertainty for long term forecasts. Therefore the author (Kronfellner-Kraus, 1979, 1981) developed another correlation between extreme sediment yields, maximum flood volumes and the gradient conditions prevailing in gorges where erosion and transportation are predominant. Regional and specific features must be introduced for individual drainage basins by a value (K) for the torrentially effective erosion rate, which also depends on the size of a drainage basin:

$$K = 1750/e^{0.018\ A} \tag{1}$$

Thus the following formula for extreme sediment yields (S in m^3) from torrential drainage basins (with the size A in km^2) and with relevant gorge gradient (J in %) was found:

$$S = K\ A\ J \tag{2}$$

The formula is based upon considerations of local analogy which are subject to improvement. It supplies an indication of the maximum capacity for erosion and transportation of a torrent and of when bed load potential will be mobilized in a catchment area. The evaluation of this bed load potential will be very important.

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