Plate 7.8 Bed-Material Loads in Selected Catchments

Introduction

Whether they be natural or modified by man, rivers and streams are able to modify the topography of their bed by erosion, transporting particles (even those heavier than water) and depositing material. Knowledge of this phenomenon is extremely important from both an economic and a scientific point of view. Material can be transported in a river or stream in two ways: either suspended in flowing water (see plate 7.4) or driven along the river bed.

The material that is transported is the result of erosion of the catchment due to atmospheric factors (wind, precipitation, temperature), erosion of the river bed and the disturbance of material that has already been deposited (sediment). The volume of solid material that may be transported depends on the characteristics of the catchment in question, including its lithology, gradient, climate, vegetation, land-use, aspect and the availability of solid material. A river's capacity to transport solid material is a function of hydraulic factors such as the depth, speed and gradient of flow, the roughness of the surface of the river bed and the material already being carried. Solid material is transported principally during flooding.

In mountain torrents, especially those issuing from small, steep catchments, the transport of solid material may show different characteristics, in particular after intense precipitation or a sudden inflow of water. A distinction can be made between bed load and debris flow: in contrast to sediment that drifts along the stream bed more slowly than the stream itself and suspended particles, debris flow (a mixture of water and extremely heterogeneous solid material) moves at the same speed as the water, often in a series of surges, through the force of gravity. The solid part of the mixture may include other material apart from detritus. In forested catchments in particular, there is often a large proportion of dead wood.

Managing the sediments carried by mountain streams is a complex business. The spatial and temporal interactions between run-off, mobilisation, transport and sedimentation during flooding may vary considerably. As yet we have insufficient understanding of these processes. Although useful qualitative descriptions may exist, there is still a good deal of uncertainty regarding quantities. When measures need to be taken to provide protection against natural hazards involving the transport of solid material in rivers and streams, however, it is essential to have information concerning the volume of material involved. The functional diagram (fig. 1) and the photos (fig. 2) show the components of the system and the processes that come into play in the catchment.

The present plate provides firstly a general picture for the whole of Switzerland of specific loads produced by selected catchments and transported downstream to bed-material traps. As far as concerns other catchments for which no information is available but which show similar morphometric and lithological characteristics to those included in the Solid database, the specific loads estimated here indicate the order of magnitude of material that could potentially be involved. Secondly, the plate gives examples of links between specific loads and certain lithological and morphometric characteristics of the catchments. Additional data (e.g. field observations [1,4]) would be necessary for a more detailed analysis of the catchments.

The Solid database

Following the natural disasters that occurred in Switzerland in 1987 and caused enormous damage in various parts of the country, the Working Group for Operational Hydrology (GHO) proposed setting up a national database of bed-material loads transported by mountain streams. The database was given the name Solid and set up by the federal and cantonal authorities and research institutes; it is now run by the Hydrology Division of the Federal Office for the Environment (FOEN). The GHO set out the aims of the database and the criteria for selecting measuring stations [2,3]. At present 103 measuring stations contribute information while Switzerland has several hundred solid material traps. The data included is supplied by cantonal authorities and research institutes and cover the volume of sediments produced by catchments and transported by streams and rivers to solid material traps. The volume of sediments that builds up in the traps has been estimated using direct methods (counting or weighing the lorries required to remove the deposited sediments) as well as indirect methods (topographic and photogrammetric surveys). The data supplied include not only the volume of sediments transported but also other information such as:

- the frequency of measurement (once a year or less),
- isolated event or repeated occurrence,
- the specific causes (storm, long period of heavy rainfall),
- the composition of the solid material (bed load, suspended material, wood),
- the dynamic aspect of the transport (bed-material load or debris flow).

The Solid database also includes general information about bed-material traps and the geology and morphometry of the catchment and the water course, as well as information about land-cover, land-use, climate and the return period of extreme precipitation.

In 2003 the Hydrology Division of the FOEN started a project to describe in detail the catchments that are included in the Solid database. In order to enable them to be classified and compared, the maximum volume of material that could potentially be carried is estimated using field observations for each catchment. These observations are extremely important for analysing and understanding the transport of bed-loads, and are a valuable addition to the volume measurements.

Analysis and estimation of loads

Mean and maximum annual specific loads and maximum specific loads transported during an isolated event were estimated for each of the measuring stations shown in the plate. The mean annual specific load for each catchment can be calculated by dividing the total volume of the material deposited by the number of years observations were made. As a general rule, the periods of observation are not the same and are often not continuous (see table 2). It may happen that the material in the trap measured after one year for example is the result of a single event such as a debris flow, and therefore corresponds to the annual specific load. In some catchments the bed-material load is deposited in more than one trap (BE-08, GR-01, SG-03, SG-04, SG-06). This was taken into account when the specific loads of these catchments were calculated.

The Solid database also enables a comparison to be made of the volume of material transported to a trap with the climatic (fig. 3), geological (figs. 3, 4, 5 and 6) and morphometric (figs. 4 and 5) characteristics of the catchment in question. Figure 4 shows that the annual maximum specific load decreases the greater the surface of the catchment (e.g. BE-01: surface of the catchment 0.3 km^2, maximum specific load 8667 m^3/km^2; TI-16: surface of the catchment 317 km^2, maximum specific load 9 m^3/km^2). A similar deduction can be made from figure 5: for the same frequency of non-exceedance the annual specific load decreases the greater the size of the catchment. The fact that larger catchments produce smaller annual specific loads than smaller catchments can normally be explained by a lesser mean gradient in the former, which include more areas with a less significant gradient where sediments can be temporarily deposited upstream from the bed-material traps, which results in a reduction in the specific solid discharge.

Figure 5 compares annual specific load to geological and morphometric characteristics of catchments. Having classified the catchments according to their dominant lithology, surface, mean gradient and shape, we studied the frequency of non-exceedance of the different categories. For the same level of frequency (e.g. 50 %), catchments with a smaller surface area, a steeper mean gradient (e.g. AG-02: mean gradient of the main channel 10.9°, maximum specific load 17 m^3/km^2, and TI-16: mean gradient 55.4°, maximum specific load 585 m^3/km^2) or a more elongated form (e.g. VS-11: shape factor 0.12, maximum specific load 5912 m^3/km^2, and TI-13: shape factor 0.98, maximum specific load 18 m^3/km^2) produce a greater annual specific load. In contrast, the relationship between the frequency of non-exceedance and annual specific load is not clear in the lithological classification. This means that the morphometric characteristics of a catchment (surface, gradient and shape) have a marked influence on the volume of sediment transported by the river or stream.

Figure 6 shows the mean and maximum annual specific loads as well as maximum loads that result from an isolated event, separated according to the four main geological types (molasse, calcareous, flysch, crystalline). The mean annual specific load for each category is obtained by dividing the sum of the specific loads estimated at the traps in that category by the total corresponding observation period. The maximum annual specific load for each category represents the largest load observed at a trap in that category. The same applies to the maximum specific load resulting from an isolated event. The calcareous and crystalline categories reveal the greatest estimated specific loads, which can be explained by not only the geology of the catchments in these two categories but also their generally steeper gradient.

Table 1 shows the geographical coordinates and the geological and morphometric characteristics of the catchments and rivers where there are measuring stations that are included in the Solid database. With these characteristics it is possible to draw up empirical estimation models for maximum solid loads likely to be transported by mountain streams and rivers. The morphometric characteristics have been obtained from the 1:25 000 digital hydrographic network (dgn2599). If the trap is fed solely by a temporary watercourse, and in view of the fact that only permanent watercourses have been digitised, the length of the main channel shown in the table is equal to 0 and some of its morphometric characteristics are no longer defined. This is the case, for example, for the Pöschrüti-Seedorf measuring station (UR-03).

The table also provides information about land use in the catchments according to the Swiss Statistics on Land Use published by the Swiss Federal Statistical Office (SFSO), as well as about return periods of extreme regional precipitation (see plates 2.4 and 2.4[2]). In the case of catchments with an area of over about 25 km^2, given that rainfall will not be uniform across the catchment, extreme regional precipitation is calculated using a areal reduction factor (see plate 2.5). The figures for extreme regional precipitation given in table 1 are specific to the present plate and should only be applied elsewhere with caution.

References

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