Plate 7.4 Sediment Concentration and Suspended-Load Transport in Rivers

The transport of solid matter in rivers

The solid matter transported by rivers can be divided into three different types: bed load, suspended load and floating matter. Bed load comprises those solid particles which are transported along the bed of the river. These are mostly material from the river bed itself. The fine particles suspended in the water by the current and by water turbulence make up the suspended load. Floating matter has by definition a density equal to or less than that of water and comprises mainly organic material (especially wood) or ice.

The load carried by the river originates from erosion in the catchment area (weathering, soil erosion), erosion of the river bed and resuspension of sediments deposited on the river bed. The within-river transport process is largely controlled by hydraulic factors such as gradient, water depth, and flow rate, but the generation of source material is strongly influenced by basin-related parameters such as precipitation, wind, temperature, soil type, vegetation, land-use and slope gradient. The combination of these various factors – known as erosion potential – has a decisive influence on whether the suspended matter or the bed load plays a more important role. In the case of a river in the midlands of Switzerland, where gradients are small, the suspended load is more important, while in steep mountain torrents the bed load constitutes the larger part of the solid matter transported.

In certain sections of rivers the concentration of suspended particles can be increased through human interference, such as introduction of waste water or water from gravel pits, or structural changes made to the river.

Lakes have a considerable effect on the transport of suspended load. On the one hand, a large part of the particles transported is deposited in lakes and, on the other, organic particles are produced through the development of plankton. Along with anorganic soil and rock particles, living plankton and dead organic material can make up a large part of the suspended load in the river downstream of a lake.

It is important both for the protection of waters and for their use that the load carried by rivers is regularly observed. The following aspects are of special relevance: erosion in the catchment area, land accretion in reservoirs and lakes, flushing reservoirs, siltation of certain stretches of a river, influence on spawning, adsorption of colloid or dissolved solids, corrosion of technical installations and changes in sand beds in water intakes.

Sediment concentration

Since 1962 the Swiss National Hydrological and Geological Survey (SNHGS) has been measuring concentrations of suspended load at a certain number of selected hydrometric stations. In addition, cantonal offices and universities have been carrying out surveys regularly or as part of their research, which have often included measuring the concentrations of suspended load. The present map is thus based on data from a selection of stations from within various measurement networks where regular results are available for the period 1979 to 1993. The sources are given in the table for map 7.1 or in table 1 for the present map.

The SNHGS takes a random sample for measurement twice a week whereas the cantonal offices do so mostly only once a month. This means that for the 15-year period in question each SNHGS station can supply data for around 1500 measurements, and each cantonal station for roughly 180. For this reason, a distinction has been made between these two measurement networks. In addition, the SNHGS investigated the transport of suspended loads at 15 further stations in 1993. These approximately 100 values per station are also shown on the map in order to demonstrate the difference between the results (cumulative frequency) for the single year 1993 and those for the whole period 1979–1993. In view of the large range of values obtained it was necessary to use a logarithmic scale.

In most cases the concentration of suspended load in rivers is mostly measured in the laboratory on the basis of samples taken either manually with a scoop or mechanically using a suitable sampler. So far it has not been possible to quantify the samples using indirect methods such as measuring turbidity or ultrasonic analysis. A method often used in connection with flushing reservoirs involves an Imhoff-cone used on the spot. Thanks to the sedimentation principle, this method provides relatively rapid information as to the concentration of suspended load in ml/l. However, the results can at best be approximately converted into mg/l after being adjusted to allow for the solid particles already in the water analysed.

The SNHGS uses specially developed sampling apparatus for obtaining the samples for their suspended-load analyses [1]. With this apparatus, a plastic bottle is filled with 1 l of water through a 4 mm diameter nozzle. The bottle is sent by post to the SNHGS laboratory where the water is analysed using a membrane filter (0.65 μm) method corresponding to regulations by the Federal Department of the Interior [2].

The concentration of suspended load in a cross-section of a natural river is not homogeneous. There are clear differences along the vertical axis especially, but also along the horizontal axis. In most cases the concentration increases towards the river bed for purely physical reasons. This trend can vary according to the runoff volume. The ratio between the concentration of suspended load near the surface and the mean concentration of the whole cross-section can be obtained using cross-profile measurements provided by the SNHGS measuring unit for example [1].

Suspended-load transport

If the suspended particles are distributed homogeneously the transport rate (g/s) can be calculated by simply multiplying the concentration by the runoff. But in view of the fact that distribution is not homogenous, as mentioned above, either the measurements must be taken at a point in the cross-section which is representative of the whole, or the ratio must be known between the results obtained at a certain point and the average concentration.

In order to calculate the volume of the load [t] over a certain period of time (day, month or year) the transport rate for the corresponding period must be taken into account. If random samples are taken it is but indirectly possible to consider this factor, for example via the ratio between the concentration of solids (c) and the runoff rate (Q). Since the SNHGS stations continually record the runoff rate, the c/Q ratio is an obvious choice for calculating the volume of solid matter transported. At the SNHGS the concentration of suspended load is compared with the daily mean runoff rate on a double-logarithmic scale and the correlation is calculated each for calm low-water and increasingly turbulent mean and high-water levels. After the values have been reconverted, two exponential c/Q ratios are obtained for the various runoff rates, which can be used to estimate daily loads and then combined to calculate monthly (fig. 2) and yearly loads (fig. 1, table 2).

Since these c/Q ratios tend to show low correlation coefficients depending on the station, the SNHGS is trying to improve its method of calculating loads through corresponding analyses. Automatic samplers are being used to take daily random samples, for instance. The results obtained from such measurements made at the Lütschine station near Gsteig (no. 2005) in 1995 are shown in figure 3. It can be seen that the concentration of suspended load can increase very rapidly when the velocity of water first increases, but then drops more quickly than the runoff rate. In the c/Q ratio this temporal trend takes on the form of a hysteresis loop rather than a straight line. The daily load values shown in figure 4 (daily concentration multiplied by the mean daily runoff) clearly show that on a yearly scale the concentration of suspended load in the low water of the winter months is almost negligible. In contrast, a large proportion of the annual load can be transported in one single day at high water, in this case on 3 July 1995, when around 19 % of the total load for that year was measured. Figure 2 shows an extreme monthly load recorded by the Bellinzona station (no. 6007) for October 1979, when at one single high-water level the amount of suspended load transported obviously resulted in a mean annual volume for the Ticino that exceeded the average by six times (cf. also table 2).

Fig. 3
Deflusso e concentrazioni, 1995 (rilevazioni quotidiane)
Runoff and concentrations 1995 (daily measurements)
Lütschine, Gsteig (N. / No. 2005)

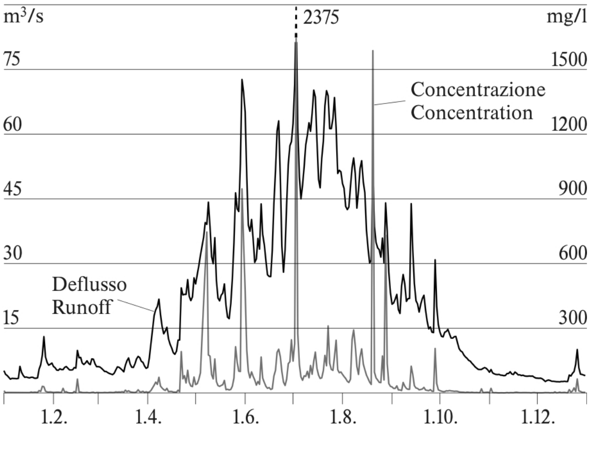
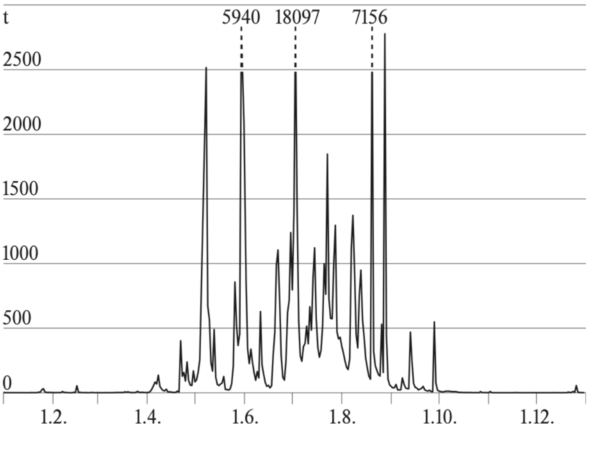


Fig. 4
Carichi quotidiani, 1995
Daily loads 1995
Lütschine, Gsteig (N. / No. 2005)



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