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Some remarks on the determination of the sediment delivery ratio

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Abstract Since soil erosion represents a major factor in the pollution of surface water, its transport out of a watershed needs to be better understood. A summary of the main parameters controlling the soil erosion process as well as a review of the difficulties inherent in the black box concept of the sediment delivery ratio are given in this paper. The variation of the sediment delivery ratio due to spatial and temporal influences is discussed. Suggestions for illuminating the black box sediment delivery system, based on physical or stochastic principles, are provided. Finally, the need for a systematic classification of major environmental factors controlling the delivery process, to assist comparison of basin sediment delivery ratios, is advanced.

INTRODUCTION

In central Europe as well as in other areas with intensive agricultural land use, soil erosion represents a major surface water pollutant. Certain nutrients and pesticides and many heavy metals are strongly absorbed onto soil particles (Adriano, 1986; Müller *et al.*, 1989). Sediment accumulation in water bodies affects not only the water quality, but also the biological activity. The often underestimated loss of storage capacity in reservoirs is already a well known problem (Clark *et al.*, 1985).

All these problems are related to the process of soil erosion by surface runoff in a catchment. The bulk of the eroded material is deposited at intermediate locations, if the surface runoff cannot sustain transport. Finally, however, some of the sediment eroded from the source can reach the river (Fig. 1). This is the basis for defining the sediment delivery ratio [SDR] as the ratio of the sediment delivered at the basin outlet (the sediment yield SY in t km^{-2} $year^{-1}$) to gross erosion within the basin (t km^{-2} $year^{-1}$), including landsurface erosion as well as channel erosion (Glymph, 1954; Maner, 1958; Roehl, 1962). Looking at the same problem on a much smaller scale, the definition of the SDR should be the ratio of the SY at a measuring device, to the total material eroded from the investigated site or drainage area upstream of the observation point, where only soil erosion takes place.

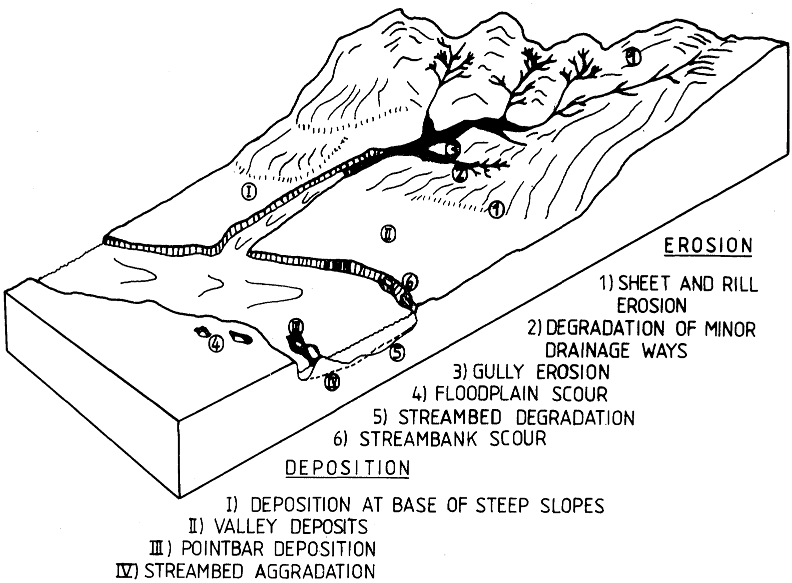

Fig. 1 Typical erosion and deposition occurrences (based on Vanoni, 1977).

THE SOIL EROSION PROCESS – PARAMETERS AND MODELS

The numerous investigations of soil erosion and deposition processes have given rise to a variety of methods for predicting these processes. Probably the best known method for predicting soil erosion rates is the stochastically conceived Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978). Long-term observations from standardized plots were used in a statistical analysis to identify significant sheet and rill erosion controlling parameters, such as the rainfall erosivity (*R* index), the soil erodibility (*K* index), the length and steepness of the slope (*LS* factor) and crop and conservation practices (*C* and *P* factors). A sensitivity analysis (Auerswald & Schmidt, 1986) showed that the slope gradient has a major influence on the result of the USLE, in comparison to the other factors (Fig. 2).

The important restrictions of the original USLE, which relate to its ability to estimate only the erosion from a site with similar conditions to those of the standard plot over a period of several years, can be overcome by several modifications (e.g. Rosenkranz *et al.*, 1988). Improved versions of the USLE have facilitated the evaluation of erosion during individual storms, extended its spatial applicability, allowed gully erosion and a variety of different agricultural management methods to be taken in account, and consequently form the basis of several widely used erosion models, such as CREAMS (Knisel, 1980), ANSWERS (Beasley & Huggins, 1981), EPIC (Williams *et al.*, 1984) and WEPP (USDA, 1987). These models have become increasingly more deterministic and they are also adaptable to central European conditions to an increasing degree.

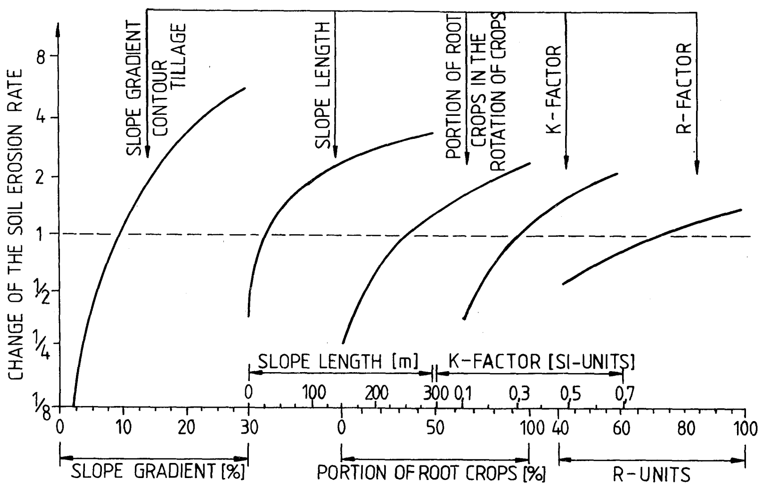

Fig. 2 Changes in the soil erosion rate due to variation of the factors influencing this process, as represented by the USLE (based on Auerswald, 1987).

THE COMPLEXITY OF THE SEDIMENT DELIVERY RATIO

The soil loss from a watershed is influenced by a wide range of environmental factors and conditions. Their spatial as well as temporal variability results in a discontinuity of the sediment production process. Therefore it is very important to specify both, the scale in terms of size of the drainage area and the time period of investigation involved in order to distinguish clearly the controlling parameters (Table 1).

Table 1 Factors influencing soil loss at different areal scales (Morgan, 1990).

Scale of analysis:			Evidence
micro	meso	macro	
climate	lithology, relief		sediment yield of rivers
climate	lithology, relief	microclimate, lithology (soil)	drainage density
climate	altitude, relief		studies of erosion rates
climate		plant cover, microclimate	studies of soil losses from hillslopes

The influence of time on the SDR can easily be seen in the temporal distribution of the SY of rivers. For example, the Austrian Danube, originating in the Alps, transports more than 90% of its sediment within a short time period of only a few days. This is similar to the hydrologically different Huanghe River of China (Deyi, 1984), which flows through the highly erodible loess region of northwestern China. However, available SDR concepts (Vanoni, 1977) which are often applied in SY models all over the world, assume a sediment intake into the river network which is independent of season and which depends only on the basin area. These SDR estimates are based on long term observations and hence represent an average value as well as the specific characteristics of the basins used in their derivation.

A soil erosion study undertaken by Klaghofer & Summer (1990) concluded that the SDR of Vanoni (1977) is not directly applicable to lower alpine conditions. The erosion rates estimated for a typical 100 km^2 Danube tributary basin using the EPIC erosion model did not correlate well with the measured SY of the river during individual storms or during an average hydrological period (Fig. 3).

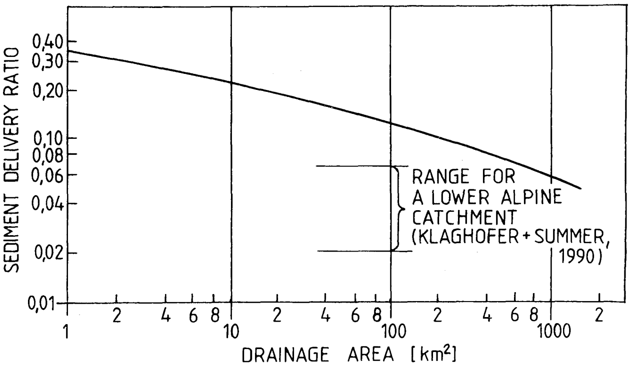

Fig. 3 Comparison of the sediment delivery ratio calculated for a lower alpine basin of a tributary of the Austrian Danube with the relationship proposed by Vanoni (1977).

Another study by Klaghofer (1987) further emphasises the complexity of the soil erosion process. When sprinkling a small plot at an intensity of 1 mm min^{-1} using a rainfall simulator (Klaghofer, 1988), the soil erosion was significantly reduced if a mulch covered the bare soil (Fig. 4). However, the mulch did not influence the surface runoff, which is only controlled by the infiltration behaviour of the soil. From these results it can be seen, that surface roughness plays a major role in the downhill transport of eroded soil particles.

This behaviour is considered in the use of the kinematic wave concept (Schmid, 1986, 1989; Smith, 1976a,b; Smith & Woolhiser, 1971), to represent flow routing from a basin. Schmid (1987) successfully tested this concept on data obtained by Klaghofer (1985). The use of a sediment transport equation such as the Unit Stream Power Concept (Yang, 1972), the well known transport equations for suspended load (Einstein, 1950) and bed load by Meyer-Peter & Müller (Graf, 1971) or the concept of sediment transport in shallow flows (Aziz & Prasad, 1985) enables local transport capacities to be evaluated.

CONCLUSION

The SDR concept is a simple black box concept which involves considerable

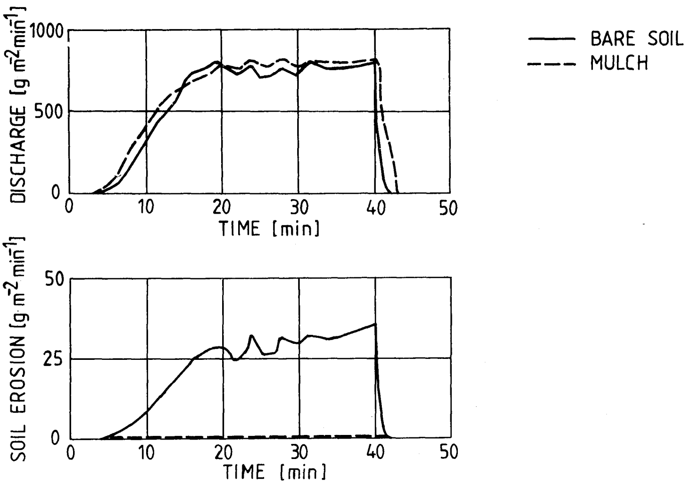

Fig. 4 Rainfall simulation experiments under different surface cover conditions (based on Klaghofer, 1988).

uncertainty, especially in a spatial and temporal context. To illuminate this black box, the physical process of soil erosion and sediment transport must be understood. For example, the use of the kinematic wave concept combined with a sediment transport equation provides a reasonable approach to achieve this goal. However, the SDR concept remains a tool which is easy to use. Relating the SDR not only to the size of a catchment, but also to other geomorphological parameters such as the bifurcation ratio, a relief factor or an index of drainage density, which are now easier to determine using geographic information systems, could result in improved estimates. Finding the most important factors influencing the SDR of a series of basins with contrasting charactertistics could shed further light on this problem. As research studies show (Klaghofer & Summer, 1990), the transfer of existing SDR estimates (Vanoni, 1977) cannot be undertaken without an understanding of the differences in catchment characteristics involved.

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