Modelling of erosion processes on the local, regional and national scale.

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Cumulative Global Change is occurring through the removal of forests, conversion of land to cultivation and pasture, and intensification of the land use. Systemic Global Change, in the form of changes in climate and atmospheric chemistry, is likely to alter land use patterns in future decades. All of these changes will influence rivers and their catchments, altering the fluxes of water, sediment, nutrients, carbon and pollutants. There is therefore a clear need for a better understanding, and a better modelling strategy, of the response of fluvial systems to land use and climate change, in order to anticipate and predict future changes, as well as to understand current dynamics.

Although most of the relevant scientific research has been conducted in small catchments, most interest in future responses relates to large basins, regions and countries. The multy-scale and cross-scale modelling tools are required to reach this target. One of such universal tools is the sediment budget approach. 1D sediment budget equation is applicable for any fluvial system defined as a 2D net of 1D flowlines. For some special cases, such as sedimentation on floodplains, in reservoirs and lakes, 2D sediment budget equation is used, coupled with 2D and 3D fluid dynamics models. This approach can be used at most scales, ranging from the small rills on a slope to large river basins.

The sediment budget for the water flow can be described by the equation of mass conservation, which can be written in the simplified form:

$$\frac{\partial}{\partial}\frac{Q_s}{X} = q_{sl} + M_0 W + M_b d - C\frac{d}{D}V_f W \qquad (1)$$

Here $Q_s = QC$ represents the volumetric sediment discharge ($m^3\ s^{-1}$); Q = water discharge ($m^3\ s^{-1}$); X = longitudinal co-ordinate (m); C = mean volumetric sediment concentration; q_{sl}= specific (for a unit of the length) sediment discharge of the lateral input from the river basin ($m^2\ s^{-1}$); M_0 = upward sediment flux from the river bed ($m\ s^{-1}$); M_b = sediment flux from the channel banks ($m\ s^{-1}$); W = flow width (m); d = flow depth (m); V_f = sediment particle fall velocity in turbulent flow ($m\ s^{-1}$); D = the bed load particle size. The left side of the equation of mass conservation (1) defines the sediment budget for the channel reach. The right hand side of the equation defines the sediment fluxes: the first term is the lateral flux from hillslopes in the basin, the second is the upward flux from the river bed, the third is the sediment flux from the banks, and the fourth is the downward flux to the river bed. These fluxes are of different importance at different types of fluvial systems, and several cases can be identified:

1. The flow velocity is much greater than the critical velocity for particle detachment, and the upward particle flux is significant. Fall velocity is also high so that intensive exchange of sediment between the channel and the flow occurs in the fluvial system. This is the most complicated regime of the fluvial system, and Equation (1) in its general form must be used for modelling.

2. Exchange of sediment between the channel and the flow is intensive, but upward and lateral fluxes are equal to the downward flux. This is the case of channel bed

dynamic equilibrium, which is common for medium and large rivers. In this case, the left-hand side term in Equation (1) is equal to zero.

3. The flow velocity is much greater than the critical velocity for particle detachment, and the upward particle flux is significant. Flow turbulence is high and the fall velocity is low. Deposition is limited and erosion is intensive. Such a regime is common for active rills, for the initial stages of gully erosion and for channel erosion in cohesive sediments. In Equation (1) the deposition term on the right-hand side can be omitted.

4. Flow velocity is less than the critical velocity for particle detachment, and the upward particle flux is limited. At the same time, catchment erosion delivers only fine particles in the lateral flux and the flow turbulence is sufficiently intense to reduce the fall velocity. This is the case of channel static equilibrium, with limited (zero) erosion and deposition. All terms in Equation (1) are equal to zero, flow channel morphology is constant in time, and sediment concentration is constant along the flow.

5. A significant lateral flux of sediment from the catchment and/or upper reaches of the channel. Flow velocity is less than the critical velocity for particle detachment. This situation is common for reservoirs, floodplains, and river deltas. In Equation (1) the upward flux term on the right-hand side is omitted.

Two main scale-related options for modelling the sediment budget of a fluvial system can be distinguished.

1. Process-based modelling of the whole basin. There is an important difference in the way in which individual processes contribute to sediment budget. This lies in the distinction between flow-driven and mass movement processes. Flow-driven processes are more or less spatially continuous along flow lines and are temporally continuous at least for the duration of a process-driving event. Accordingly, they can be described by Equation (1). By contrast, mass movement is spatially discrete and is only triggered by the process-driving event. The effect of mass movement will be to occasionally change initial conditions for the continuous processes that can be represented in terms of Equation (1). The spatial limits are set by initial data accuracy and DTM resolution. This approach requires large quantities of initial data, involves many model parameters, and is currently used only for small and medium-sized catchments.

2. The calculation of sediment budgets in large fluvial systems and up to national scale can be based on the combination of integrated estimates of the sediment supply to the river network from the hillslopes: landslides, rills, gullies and other ephemeral channels, with accurate evaluation of the sediment budget in the distributed permanent river network. Equation (1) is applied only to permanent streams. The volume of erosion from the hillslopes must be calculated for a given period of time with the help of simplified empirical models. The Sediment Delivery Ratio (SDR) must be estimated for each hillslope complex. The volume of erosion combined with the value of SDR gives the value for the lateral flux in Equation (1) for each stream or river segment. Other terms in Equation (1) are calculated based on regional data on channel and floodplain processes. The solution of (1) gives the change in sediment discharge along the river network over a given period of time. The main limitation of this approach is the empirical estimation of the SDR, which needs to be applied to the sediment load transported from the hillslopes to the rivers. The data requirements for the calculations can generally be met; therefore this approach can be used for long-term modelling of fluvial systems of various sizes, up to regional and national scale.