DAMSED model structure

Dams trap sediments and causes channel erosion downstream. Sediment replenishment from river bed is an essential process in estimating dams' effects on sediment (Ock et al. 2013). Our model therefore consists of four modules: i) soil erosion at landscape by Revised Universal Soil Loss Erosion (RUSLE); ii) suspended sediment (SS) transport in the river network, which hydrodynamically simulates SS delivering in the stream; iii) Sediment trapping by dams; iv) SS replenishment from river bed, which considers bedload as a source to SS replenishment after dam trapping (Figure 2). The module i) and ii) together simulate SS yield of the basin and transport in the stream without dam trapping. The module i) supplies SS boundary condition of module ii). Module iii) and iv) calculate dam trapping effects and reservoir sedimentation. It is notable that the DAMSED model does not calculate bedload transport but takes the simulated results from the CASCADE (CAtchment Sediment Connectivity And DElivery) model(Schmitt et al. 2016, Tangi et al. 2019), which is constructed to simulate dam effects on bedload connectivity.

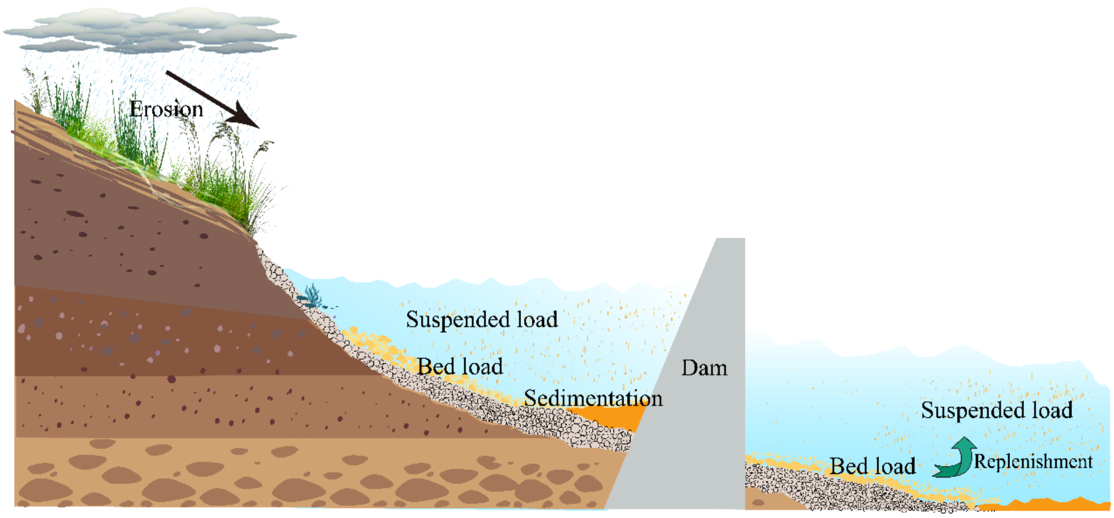

Figure 1. Conceptual flowchart of the DAM SEdiment trapping (DAMSE) model, describing its simulation process of ① erosion, ② sediment (suspended and bed load) transport, ③ dam trapping and ④ sediment replenishment from river bed.

Module i): soil erosion at the landscape

Revised Universal Soil Loss Erosion (RUSLE) was adopted to identify the land parcel's potential soil yield:

$$\mathrm{A} = \mathrm{R} \times \mathrm{K} \times \mathrm{L} \times \mathrm{S} \times \mathrm{C} \times \mathrm{P} \tag{1}$$

Where A = annual soil loss (t ha^{-1}), R = rainfall erosivity (MJ mm ha^{-1} h^{-1}), K = soil erodibility (t h MJ^{-1} mm^{-1}) (i.e. the soil loss per unit of erosivity for a standard condition of bare soil, 5° slope of 22 m length), L = slope length factor (dimensionless), S = slope steepness factor (dimensionless), C = the vegetation coverage and management factor (dimensionless), and P = the support practice factor (dimensionless).

The rainfall erosivity factor (R) represents rainfall energy. Based on available precipitation data, we chose the equation proposed by Xu et al. (2007) to calculate monthly value and aggregated to the annual R factor as following:

$$\mathrm{R} = \sum_{m=1}^{12} R_m$$

$$R_m = 0.689P^{1.474} \tag{2}$$

Where R_m is the rainfall erosivity in mth month ($\mathrm{MJ} \cdot \mathrm{mm} \cdot km^{-2} \cdot h^{-1} \cdot month^{-1}$), P is the precipitation in mth month (mm).

Soil erodibility factor (K) was estimated based on the model proposed by (Sharpley and Williams 1990):

$$K = \left\{0.2 + 0.3exp\left[0.0256SAN(1 - \frac{SIL}{100})\right]\right\} \times \left(\frac{SIL}{CLA+SIL}\right)^{0.3} \times \left[1.0 - \frac{0.25TOC}{TOC+\exp{(3.72-2.95TOC)}}\right] \times \left[1.0 - \frac{0.7SN}{SN+\exp{(-5.51+2.95SN)}}\right] \tag{3}$$

Where, SAN, SIL, CLA are the sand content (%, 0.05-2 mm), silt content (%, 0.002-0.05 mm) and the clay content (%, <0.002 mm) of subsoil, respectively. TOC is the topsoil organic carbon content (%). SN = 1-SAN/100.

Slope length (*L*) and steepness (*S*) factors are estimated from the digital elevation model (DEM) with 30 m resolution by Shuttle Radar Topography Mission (SRTM). *L* is calculated by equations proposed by (Wischmeier and Smith 1978). *S* is estimated by coupling methods (Liu et al. 1994, McCool et al. 1989):

$$L = (\frac{\lambda}{22.13})^{\beta} \tag{4}$$

$$\beta = \frac{(\frac{\sin\theta}{0.0896})/[3\cdot(\sin\theta)^{0.8}+0.56]}{1+(\frac{\sin\theta}{0.0896})/[3\cdot(\sin\theta)^{0.8}+0.56]} \tag{5}$$

$$\lambda = Flow_{accumulation} \times \text{cellsize} \tag{6}$$

$$\mathrm{S} = \begin{cases} 10.8 sin\theta + 0.03, \theta < 5^{\circ} \\ 16.8 sin\theta - 0.5, 5^{\circ} \leq \theta < 10^{\circ} \\ 21.9 sin\theta - 0.96, \theta \geq 10^{\circ} \end{cases} \tag{7}$$

Where θ is the slope of DEM (%); λ is the horizontal slope length, and β is the index related to slope.

Vegetation coverage and management factor (*C*) is defined as the ratio of soil loss from land cropped under specific conditions to the corresponding loss from clean-tilled, continuous fallow. *C* is calculated from the Normalized Difference Vegetation Index (NDVI) data as following (Gutman and Ignatov 1998):

$$\mathrm{C} = 1 - \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \tag{8}$$

The support practice factor (*P*) is the ratio between the soil losses under a specific soil conservation practice and that of non-conservation practice. Here we take *P* from published results: Paddy rice is set as 0.01 (Chen et al. 2012), dry cropland as 0.4, forest as 0.7 (Li et al. 2011) and other land uses are all set as 1.

Module ii) SS transport in the river network

Sediment entering the river network through source reaches, is the sediment boundary condition of the module ($SS_{boundary}$) and obtained from soil erosion at landscape through a delivery ratio ($r_{delivery}$).

$$SS_{boundary} = r_{delivery} \cdot A \tag{9}$$

$r_{delivery}$ is a calibrated parameter, in the range of 0~1.

As the transporting processes differ greatly of different grain size classes, we calculate transport capacity for each grain size in each reach. This means that if the flux of sediment into a reach exceeds the transport capacity of that reach, part of the sediment will be deposited on the river bed; and resuspension occurs for the opposite condition. Resuspension is limited by the maximum transport capacity and available sediment from deposited SS and the movable river bed layer.

Transport capacity of each edge is calculated based on the equation proposed by Zhang et al.(Zhang 1998), which has been widely used in Yangtze upper reach:

$$S^* = k\left(\frac{U^3}{gR\omega}\right)^m \tag{10}$$

Here S^* is the volumetric transport rate of grain per unit width (dimensionless); U is the flow velocity (m/s); g is the gravity acceleration (m^2/s); R is the hydraulic radius (m). Hydraulic parameters of flow velocity (U) and hydraulic radius (R) are obtained from hydraulic solver of CASCADE toolbox(Tangi et al. 2019). k and m are the constants and taken as 0.163 and 0.92, respectively, in our case as recommended by *China Institute of Water Resources and Hydropower Research* and *Yangtze River Scientific Research Institute* (Liu et al. 2022). Both institutes have rich working experience in Yangtze River and suggest the two values based on estimation from long-term field data. ω is settling velocity of the grain (m/s), defined as:

$$\omega = \sum_i^n p_i \omega_i \tag{11}$$

Where p_i is the fraction component of grain in size i, ω_i is settling velocity of grain in size i, which is calculated as:

$$\omega_i = \sqrt{(13.95\frac{\nu}{d_i})^2 + 1.09\frac{\gamma_s-\gamma}{r}gd_i} - 13.95\frac{\nu}{d_i} \tag{12}$$

Where ν is the viscosity coefficient，taken as 1.24 m/s; d_i is the grain size (m); γ_s is the sediment density (kg/m^3); γ is the water density kg/m^3.

Module iii) sediment trapping by dams

The DAMSED model supplies (Brune 1953), (Brown 1950), (Gill 1979) and (Jothiprakash and Vaibhav 2008) equation to calculate trapping rate of dams. It also allows self-defined equations. In this case, we adopt the equation of (Li and Jin 2014) to calculate sediment trapping rate of dams (TE), which was developed from Brune equation and then improved for the Yangtze River:

$$TE = \frac{8010-35\times(\frac{C}{I})^{-0.82}}{78.85+(\frac{C}{I})^{-0.2}} \tag{13}$$

Where C is dam capacity (m^3), I is annual inflow of the reservoir (m^3)

After allocating dams on the river network, dam effects on sediment transport are estimated based on the trapping rate (TE):

$$S_{out} = S_{in}(1-TE) \tag{14}$$

Where TE is the reach trapping rate, S_{out} is sediment flux after trapping by dams (t), S_{in} is sediment inflow to the reach (t).

Amount of sedimentation on individual reach (S_r) is calculated as following:

$$S_r = S_{in} \cdot TE \tag{15}$$

Module iv) sediment replenishment from the river bed

Dams trap sediment and interrupt sediment connectivity. Lower channel is eroded and replenish SS from bedload. We simplified this process and used CASCADE model to calculate transportable bed load. Then we take the transported bedload as a source to replenish SS after dam trapping. Together with originally residual SS, they transport further down limited by the transport capacity.

Generally, the dimensionless transport capacity of bedload in CASCADE model is calculated as following:

$$\mathrm{q} = \begin{cases} \frac{0.05}{\mathrm{C_f}} \cdot \tau_*^{\frac{5}{2}}, if\ d < 2mm \\ m \cdot (\tau_* - \tau_{*\mathrm{c}})^n, else \end{cases} \tag{16}$$

In the above equations, *m* and *n* are the constants and directly taken from Wong and Parker (2006) (*m*=3.97, *n*=1.5). $\mathrm{C_f}$ is the local friction factor, τ_* is shear stress, $\tau_{*\mathrm{c}}$ is the critical shear stress, calculated as following:

$$C_f = \frac{2 \cdot g \cdot I_e \cdot h_e}{{v_e}^2} \tag{17}$$

$$\tau_* = \frac{I_e \cdot h_e}{\rho_s \cdot d} \tag{18}$$

Where I_e is the channel gradient of edge e, h_e and v_e is flow stage (m) and flow velocity (m/s), respectively. ρ_s is the relative density of sediment, d is the grain size (mm). Detailed description of CASCADE model refers to Schmitt et al.(Schmitt et al. 2016).