Supporting Information for "A process-based soil erosion model ensemble to reduce model uncertainty in climate change impact assessments"

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1 Text S1: Soil Erosion Model Ensemble

1.1 DHSVM

1.1.1 Detachment by raindrop impact

Detachment by raindrop impact is based on the sum of the momentum squared for rain (M_R) and the momentum squared for leaf drip (M_D) (Wicks and Bathurst, 1996):

$$D_R = k_r\ F_w\ (1 - C_G)\,[(1 - C_C)M_R + M_D] \tag{S1}$$

where D_R is the soil detached by raindrop impact (kg m^{-2}s^{-1}), k_r the raindrop soil erodibility coefficient (J^{-1}), C_G the ground cover (fraction, -), C_C the canopy cover (fraction, -), M_R the momentum squared for rain (kg^{2}s^{-3}) and M_D the momentum squared for leaf drip (kg^{2}s^{-3}).

The original DHSVM model accounts for the protective effect of ponding on detachment by raindrop impact by model parameter F_w (Park et al., 1982). The hydrological model SPHY does not account for ponding, hence, we assume $F_w = 1$.

The momentum squared for the rain (M_R) is determined as follows:

$$M_R = \alpha\ I^{\beta} \tag{S2}$$

Where I is the rainfall intensity (mm h^{-1}) and α and β are empirical coefficients (Wicks, 1988). The rainfall intensity I is determined from the infiltration excess surface runoff formulations of the hydrological model SPHY. In these formulations, the hourly rainfall is assumed to decrease linearly over time, where the fraction of the daily rainfall that falls in the first hour is a model parameter. Hence, from these assumptions the hourly rainfall intensity was determined as input for the DHSVM model. Values for α and β for each rainfall intensity interval are given in Table S1.

Table S1. Values for the empirical coefficients α and β used to determine the momentum squared for the rain.

Range for I (mm h^{-1})	α	β
0 - 10	2.69×10^{-8}	1.6896
10 - 50	3.75×10^{-8}	1.5545
50 - 100	6.12×10^{-8}	1.4242
$\geq$ 100	11.75×10^{-8}	1.2821

Momentum squared for leaf drip (M_D) is calculated as follows:

$$M_D = \frac{\left(\frac{V\ \rho\ \pi\ D^3}{6}\right)^2 DRIP\%\ DRAIN}{\left(\frac{\pi\ D^3}{6}\right)} \tag{S3}$$

where V is the leaf drip fall velocity (m s^{-1}), ρ the density of water (kg m^{-3}), D the leaf drip diameter (m), $DRIP\%$ the proportion of drainage that falls as leaf drip and $DRAIN$ the canopy drainage rate (m s^{-1}). The proportion of the drainage that falls as leaf drip ($DRIP\%$) is assumed to be equal to the canopy cover (C_C). The canopy drainage rate ($DRAIN$) is assumed to be equal to the daily precipitation intensity in m s^{-1}.

The leaf drip fall speed V is calculated as follows (Epema and Riezebos, 1983):

$$V = \sqrt{\frac{M}{\beta_V} g \left(1 - e^{-\frac{2X\ \beta}{M}}\right)} \tag{S4}$$

where X is the average leaf drip fall distance (m), M the average mass of leaf drips (kg), β_V a friction constant (kg m^{-1}) and g the acceleration due to gravity (m s^{-2}).

The fraction $\frac{M}{\beta_V}$ is a function of the leaf drip diameter D and two coefficients, a and b.

$$\frac{M}{\beta_V} = a + b\ D \tag{S5}$$

where a and b are a function of the drip diameter and fall distance and are given in Table S2.

Table S2. Values for the empirical coefficients a and b used to determine the fraction $\frac{M}{\beta_V}$.

Drip diameter D (m)	Fall distance X (m)	a	b
< 0.0033	all X	0	2200
≥ 0.0033	< 7.5	1.93	1640
≥ 0.0033	≥ 7.5	5.14	6600

1.1.2 Detachment by runoff

Detachment by runoff is calculated as follows:

$$D_{of} = \beta_{de}\ dy\ v_s\ TC \tag{S6}$$

where D_{of} is the soil detachment by overland flow (kg m^{-2}s^{-1}), β_{de} the detachment efficiency (-), dy the length of a grid cell (m), v_s the settling velocity (m s^{-1}) and TC the transport capacity (m^3 sediment m^{-3} water).

The detachment efficiency β_{de} is calculated as follows:

$$\beta_{de} = 0.79\ e^{-0.6COH} \tag{S7}$$

Where COH is the soil cohesion (kPa), which is determined from the combination of soil cohesion (COH_s) and root cohesion (COH_r). The values for soil cohesion were obtained from the EUROSEM manual (Morgan et al., 1998, Table A9.2), which gives soil cohesion estimates per soil type based on the USDA soil texture classification. The root cohesion was also obtained from the EUROSEM manual (Morgan et al., 1998, Table A9.3), which gives estimates of the root cohesion range for several land use classes.

The settling velocity is calculated following the method as used in the KINEROS model (Woolhiser et al., 1990):

$$v_s = \sqrt{\frac{\left(4/3\ g\ \frac{\rho_s}{\rho} - 1\right) d_{50}}{C_d}} \tag{S8}$$

where ρ_s the sediment density (kg m^{-3}), d_{50} the median grain size (m) and C_D the drag coefficient, which is a function of the particle Reynolds number:

$$C_D = \frac{24}{R_n} + \frac{3}{\sqrt{R_n}} + 0.34 \tag{S9}$$

where R_n is the particle Reynolds number, defined as:

$$R_n = \frac{v_{s_0}\ d_{50}}{\nu} \tag{S10}$$

where v_{s_0} is an initial estimate of the settling velocity (m s^{-1}) and ν is the kinematic viscosity of water (m^2 s^{-1}), assumed to be equal to 0.0015 m^2 s^{-1}. The initial estimate of the settling velocity v_{s_0} is calculated as follows:

$$v_{s_0} = \sqrt{\left(4/3\ g\ \frac{\rho_s}{\rho} - 1\right) d_{50}} \tag{S11}$$

The transport capacity (TC) is determined according to the unit stream power method from the KINEROS model (Woolhiser et al., 1990):

$$TC = \frac{0.05}{d_{50}\left(\frac{\rho_s}{\rho} - 1\right)^2} \sqrt{\frac{S\ h}{g}}\ (SP - SP_{cr}) \tag{S12}$$

where S is the slope (m m^{-1}), h the water depth (m), SP the stream power (kg m s^{-3}) and SP_{cr} the critical stream power (kg m s^{-3}).

The water depth (h) is determined with the Manning equation. We assumed a triangular shaped profile on which the Manning equation is applied, where the width-to-depth ratio is a model parameter. First the flow area is determined with an algebraic re-arrangement of the Manning equation:

$$A = \left[\frac{Q\ n \left(2\sqrt{\frac{WD^2+1}{WD}}\right)^{2/3}}{\sqrt{S}}\right]^{3/4} \tag{S13}$$

where Q is the discharge (m^3 s^{-1}), n the Manning's coefficient (s m$^{-1/3}$) and WD the width-to-depth ratio (-). The discharge (Q) is obtained from the hydrological model SPHY and the Manning's coefficient (n) is defined per land use class.

The water depth (h) is calculated as follows:

$$h = \sqrt{\frac{A}{WD}} \tag{S14}$$

The stream power (SP) is calculated as follows:

$$SP = \rho\ g\ Q\ S \tag{S15}$$

1.1.3 Sediment transported

The sediment taken into transport is simply the sum of detachment by raindrop impact and runoff:

$$sed = D_R + D_o f \tag{S16}$$

Where sed is the sediment taken into transport (kg m^{-2}s^{-1}).

1.2 HSPF

1.2.1 Detachment by raindrop impact

The original HSPF model accounts for the surface water storage ($SURS$), for instance as a result of ponding. Since the hydrological model SPHY does not account for ponding, we assume the surface water storage to be equal to 0. The detachment by raindrop impact, which is called washoff of detached sediment by raindrop impact in Bicknell et al. (1993), is calculated as follows:

$$WSSD = \begin{cases} DETS & \text{for } STCAP > DETS \\ STCAP & \text{for } STCAP < DETS \end{cases} \tag{S17}$$

Where $DETS$ is the sediment storage (ton acre^{-1}) and $STCAP$ is the capacity for removing detached sediment (ton acre^{-1}).

The sediment storage is calculated as follows:

$$DETS = DETS\ AFFIX + DET \tag{S18}$$

Where DET is the sediment detached from the soil matrix by rainfall (ton acre^{-1}) and AFFIX is the fraction by which DETS decreases each day as a result of soil compaction (-).

The sediment detached from the soil matrix by rainfall DET is calculated as follows:

$$DET = DELT60\ (1 - CR)\ SMPF\ KRER \left(\frac{RAIN}{DELT60}\right)^{JRER} \tag{S19}$$

Where $DELT60$ is the number of hours per interval (-), CR the fraction of the land covered by vegetation (-), $SMPF$ the supporting management practice factor (-), $KRER$ the detachment coefficient dependent on soil properties (-), $RAIN$ the rainfall (inch interval^{-1}) and $JRER$ the detachment exponent dependent on soil properties (-).

The supporting management practice factor $SMTP$ is assumed to be 1 for all land use classes. The detachment coefficient dependent on soil properties $KRER$ is estimated with the USLE K-factor developed by Wischmeier et al. (1971):

$$KRER = \frac{0.00021 M^{1.14}(12 - OM) + 3.25(c_{\text{soilstr}} - 2) + 2.5(c_{\text{perm}} - 3)}{100} \tag{S20}$$

Where M is the particle-size parameter (-), OM is the organic matter content (%), c_{soilstr} is the soil structure class (-) and c_{perm} is the profile permeability class (-). The particle-size parameter is calculated as follows:

$$M = (m_{\text{silt}} + m_{\text{vfs}})(100 - m_{\text{c}}) \tag{S21}$$

Where m_{silt} is the silt content (%), m_{vfs} is the very fine sand content (%) and m_{c} is the clay content (%). The profile permeability classes are defined according to the saturated hydraulic conductivity, which was determined from pedotransferfunctions (Saxton and Rawls, 2006). Due to the absence of data, we set $m_{\mathrm{vfs}} = 0$ and $c_{\mathrm{soilstr}} = 2$, which corresponds to the fine granular class.

The capacity for removing detached sediment $STCAP$ is calculated as follows:

$$STCAP = DELT60\, KSER \left(\frac{SURO}{DELT60}\right)^{JSER} \tag{S22}$$

Where $KSER$ the coefficient for transport of detached sediment (-), $SURO$ the surface outflow of water (inch interval^{-1}) and $JSER$ the exponent for transport of detached sediment (-). The surface water storage $SURS$ is estimated by the (routed) runoff from the hydrological model SPHY.

1.2.2 Detachment by runoff

Detachment by runoff, which is called scour of matrix soil in Bicknell et al. (1993), is calculated as follows:

$$SCRSD = DETL60\, KGER \left(\frac{SURO}{DELT60}\right)^{JGER} \tag{S23}$$

Where $SCRSD$ is the scour of matrix soil (ton acre^{-1}), $KGER$ is the coefficient for scour of the matrix soil (-) and $JGER$ the exponent for scour of the matrix soil (-).

1.2.3 Sediment transported

The sediment taken into transport is simply the sum of detachment by raindrop impact and runoff:

$$SOSED = WSSD + SCRSD \tag{S24}$$

Where $SOSED$ is the total removal of soil and sediment from the surface by water (ton acre^{-1}).

1.3 INCA

1.3.1 Detachment by raindrop impact

Detachment by raindrop impact (S_{SP}) is calculated as follows:

$$S_{SP} = c_{X1}\, p_{Sed}\, E_{sp}^{\left(\frac{10}{10-V}\right)}\, 8.64 \times 10^{10} \tag{S25}$$

Where S_{SP} is the detachment by raindrop impact (kg km^{-2}), c_{X1} a scaling parameter (s m^{-1}), p_{Sed} the precipitation throughfall (mm), E_{sp} a soil specific erosion potential parameter (kg m^{-2} s^{-1}) and V the vegetation cover (-), here estimated with the canopy cover from the vegetation module multiplied by 10.

1.3.2 Detachment by runoff

Detachment by runoff (S_{FL}) is calculated as follows:

$$S_{FL} = \frac{K(S_{TC} - S_{SP})}{S_{TC} + K} \tag{S26}$$

Where S_{FL} is the detachment by runoff (kg km^{-2}), K a function of runoff (kg km^{-2}) and S_{TC} the transport capacity (kg km^{-2}).

The function K is calculated as follows:

$$K = a_1\ E_{FL} \left(\frac{A\ q_{dr}}{L} - a_2\right)^{a_3}\ 86400 \tag{S27}$$

Where E_{FL} is the soil erosion potential (kg km^{-2} s^{-1}), A the grid cell area (km^2), q_{DR} the routed runoff (m^3 s^{-1} km^{-2}), L the slope length (km), a_1 is the flow erosion scaling factor (s m^{-2}), a_2 the flow erosion direct runoff threshold (m^2 s^{-1}) and a_3 the flow erosion non-linear coefficient (-).

Sediment transport capacity (S_{TC}) is calculated as follows:

$$S_{TC} = a_4 \left(\frac{A\ q_{dr}}{L} - a_5\right)^{a_6}\ 86400 \tag{S28}$$

Where a_4 is the transport capacity scaling factor (kg m^{-2} km^{-2}), a_5 the transport capacity direct runoff threshold (m^2 s^{-1}) and a_6 the transport capacity non-linear coefficient (-).

1.3.3 Sediment transported

The amount of sediment that is taken into transport depends on the amount of sediment in the sediment storage. The daily change in sediment storage is calculated as follows:

$$\frac{dS_{store}}{dt} = \begin{cases} S_{SP} - S_{TC} & \text{for } S_{store} + S_{SP} > S_{TC} \\ \dfrac{-K(S_{SP} - S_{TC})}{S_{TC} + K} & \text{for } S_{store} + S_{SP} < S_{TC} \end{cases} \tag{S29}$$

Where S_{store} is the sediment storage (kg km^{-2}), which is subsequently updated following:

$$S_{store} = S_{store} + \frac{dS_{store}}{dt} \tag{S30}$$

The amount of sediment taken into transport is calculated as follows:

$$M_{out} = \begin{cases} S_{TC} & \text{for } S_{store} + S_{SP} > S_{TC} \\ S_{SP} + S_{FL} & \text{for } S_{store} + S_{SP} < S_{TC} \end{cases} \tag{S31}$$

Where M_{out} is the mass of sediment taken into transport (kg km^{-2}).

1.4 MMF

1.4.1 Detachment by raindrop impact

Detachment by raindrop impact (F) is determined for each of the soil texture classes separately and subsequently summed and is calculated as follows:

$$F_i = K_i \frac{\%i}{100} (1 - GC)\ KE \times 10^{-3} \tag{S32}$$

Where F is the detachment by raindrop impact for textural class i (kg m^{-2}), i the textural class, K the detachability of the soil by raindrop impact (g J^{-1}), GC the ground cover (-) and KE the kinetic energy of the effective precipitation (J m^{-2}).

The total kinetic energy of the effective precipitation (KE) is calculated as follows:

$$KE = KE_{DT} + KE_{LD} \tag{S33}$$

Where KE_{LD} is the kinetic energy of the leaf drainage (J m^{-2}) and KE_{DT} is the kinetic energy of the direct throughfall (J m^{-2}).

The kinetic energy of the leaf drainage is based on Brandt (1990):

$$KE_{LD} = \begin{cases} 0 & \text{for } PH < 0.15 \\ LD(15.8\ PH^{0.5} - 5.87) & \text{for } PH \geq 0.15 \end{cases} \tag{S34}$$

Where LD is the leaf drainage (mm) and PH is the plant height (m).

Leaf drainage is (LD) calculated as follows:

$$LD = P_{eff}\ CC \tag{S35}$$

Where P_{eff} is the precipitation throughfall (mm) and CC is the canopy cover (fraction, -), which is obtained from the vegetation module.

The kinetic energy of the direct throughfall is based on a relationship described by Brown and Foster (1987):

$$KE_{DT} = DT(29(1 - 0.72e^{-0.05I})) \tag{S36}$$

Where DT is the direct throughfall (mm) and I is the intensity of the erosive precipitation (mm h^{-1}), which is obtained from the hydrological model SPHY.

Direct throughfall (DT) is calculated as follows:

$$DT = P_{eff} - LD \tag{S37}$$

1.4.2 Detachment by runoff

Detachment by runoff (H) is calculated as follows:

$$H_i = DR_i \frac{\%i}{100} Q^{1.5} (1 - GC) \sin^{0.3} S \times 10^{-3} \tag{S38}$$

Where H is the detachment by runoff (kg m^{-2}), DR the detachability of the soil by runoff (g mm^{-1}), Q is the volume of accumulated runoff (mm) and S is the slope (m m^{-1}).

A proportion of the detached soil is deposited in the cell of its origin as a function of the abundance of vegetation and the surface roughness. The percentage of the detached sediment that is deposited (DEP) is estimated from the relationship obtained by Tollner et al. (1976) and calculated separately for each texture class:

$$DEP_i = 44.1 N_{f_i}^{0.29} \tag{S39}$$

Where N_f is the particle fall number (-), defined as:

$$N_{f_i} = \frac{l v_{s_i}}{v d} \tag{S40}$$

Where l is the length of a grid cell (m), v_s the particle fall velocity (m s^{-1}), v the flow velocity (m s^{-1}) and d the depth of flow (m).

The particle fall velocity v_s is estimated from:

$$v_s = \frac{1/18 \delta^2 (\rho_s - \rho) g}{\eta} \tag{S41}$$

Where δ is the diameter of the particle (m), ρ_s the sediment density (kg m^{-3}), ρ the flow density (kg m^{-3}), g gravitational acceleration (m s^{-2}) and η the fluid viscosity (kg m^{-1} s^{-1}).

The flow velocity v is obtained by the Manning formula:

$$v = \frac{1}{n'} d^{2/3} S^{1/2} \tag{S42}$$

Where n' is the modified Manning's roughness coefficient (s m$^{-1/3}$), which is a combination of the Manning's roughness coefficient for the soil surface and vegetation, defined as (Petryk and Bosmajian, 1975):

$$n' = \sqrt{n_{\text{soil}}^2 + n_{\text{vegetation}}^2} \tag{S43}$$

Where n_{soil} is the Manning's roughness coefficient for soil (s m$^{-1/3}$) and $n_{\text{vegetation}}$ the Manning's roughness coefficient for vegetation (s m$^{-1/3}$).

For tilled conditions the following equation is applied to obtain the Manning's roughness coefficient for the soil:

$$n_{\text{soil}} = \exp(-2.1132 + 0.0349 RFR) \tag{S44}$$

Where RFR is the surface roughness parameter (cm m^{-1}).

The Manning's roughness coefficient for regular spaced vegetation is obtained from the following equation (Jin et al., 2000):

$$n_{\text{vegetation}} = \frac{d^{2/3}}{\sqrt{\frac{2g}{D\ NV}}} \tag{S45}$$

Where D is the stem diameter (m) and NV the stem density (stems m^{-2}).

1.4.3 Sediment transported

The amount of sediment that is taken into transport is determined from the sum of the detached sediment from raindrop impact (F_i) and runoff (H_i), subtracting the proportion of the sediment that is deposited within the cell of its origin (DEP_i):

$$G = (F_i + H_i)(1 - (DEP_i/100)) \tag{S46}$$

Where G is the amount of sediment taken into transport for textural class i (kg m^{-2}). The amount of sediment that is routed to downstream cells is the summation of the individual amounts for clay, silt and sand.

1.5 SHETRAN

1.5.1 Detachment by raindrop impact

Detachment by raindrop impact is determined with the following empirical equation, which is derived Wicks (1988):

$$D_r = k_r\ F_w\ (1 - C_g - C_r)(M_r + M_d) \tag{S47}$$

where D_r is the rate of detachment of soil (kg m^{-2}s^{-1}), k_r the raindrop impact soil erodibility coefficient (J^{-1}), C_g the proportion of ground shielded by near ground cover (fraction, -), C_r the proportion of ground shielded by ground level (rock) cover (fraction, -), M_r the momentum squared of raindrops reaching the ground (kg^{2}s^{-3}) and M_d the momentum squared of leaf drip reaching the ground (kg^{2}s^{-3}).

The original SHETRAN model accounts for the protective effect of ponding on detachment by raindrop impact by model parameter F_w (Park et al., 1982). The hydrological model SPHY does not account for ponding, hence, we assume $F_w = 1$.

The momentum squared of raindrops reaching the ground (M_r) is based on the formulations by Marshall and Palmer (1948):

$$M_r = (1 - C_c)\ a_1\ I^{b_1} \tag{S48}$$

Where I is the rainfall intensity (mm h^{-1}) and a_1 and b_1 are coefficients dependent on I and are given in Table S3.

Table S3. Values for the empirical coefficients a_1 and b_1 used to determine the momentum squared of raindrops.

Range for I (mm h^{-1})	a_1	b_1
0 - 10	2.6893 × 10^{-8}	1.6896
10 - 50	3.7514 × 10^{-8}	1.5545
50 - 100	6.1192 × 10^{-8}	1.4242
$\geq$ 100	11.737 × 10^{-8}	1.2821

The momentum squared of leaf drip reaching the ground (M_d) is calculated as follows:

$$M_d = \frac{\pi}{6}\ V_d^2\ \rho^2\ d_l^3\ L_d\ DRAINA \tag{S49}$$

Where V_d is the leaf drip fall speed (m s^{-1}), ρ the density of water (kg m^{-3}), d_l the leaf drip diameter (m), L_d the proportion of drainage that falls as leaf drip (fraction, -) and $DRAINA$ the water drainage rate from canopy (m s^{-1}). The proportion of drainage that falls as leaf drip (L_d) is assumed to be equal to the canopy cover (C_C). The water drainage rate from canopy ($DRAINA$) is assumed to be equal to the daily precipitation intensity in m s^{-1}.

The leaf drip fall speed (V_d) is calculated as follows:

$$V_d = \sqrt{\frac{M}{\beta} g \left(1 - e^{-\frac{2X\ \beta}{M}}\right)} \tag{S50}$$

where X is the average leaf drip fall distance (m), M the average mass of leaf drips (kg), β the friction constant (kg m^{-1}) and g the acceleration due to gravity (m s^{-2}).

The fraction $\frac{M}{\beta}$ is a function of the leaf drip diameter d_l and two coefficients, a_2 and b_2.

$$\frac{M}{\beta} = a_2 + b_2\ d_l \tag{S51}$$

where a_2 and b_2 are given in Table S4

Table S4. Values for the empirical coefficients a_2 and b_2 used to determine the fraction $\frac{M}{\beta}$.

Range for d_l (m)	Range for X (m)	a_2	b_2
$<$ 0.0033	all X	0	2200
$\geq$ 0.0033	$<$ 7.5	1.93	1640
$\geq$ 0.0033	$\geq$ 7.5	5.14	6600

1.5.2 Detachment by runoff

Detachment by runoff is determined using the approach of Ariathurai and Arulanandan (1978):

$$D_q = \begin{cases} k_f\ (1 - C_g - C_r) \left[\dfrac{\tau}{\tau_{cr}} - 1\right] & \text{for } \tau > \tau_{cr} \\ 0 & \text{for } \tau < \tau_{cr} \end{cases}$$

where D_q is the rate of detachment of soil per unit area (kg m^{-2} s^{-1}), k_f the overland flow soil erodibility coefficient (kg m^{-2} s^{-1}), τ the shear stress due to overland flow (N m^{-2}), τ_{cr} the critical shear stress for initiation of sediment motion (N m^{-2}).

The shear stress due to overland flow (τ) is given by:

$$\tau = \rho\ g\ h\ S \tag{S52}$$

with ρ the water density (kg m^{-3}), g the acceleration due to gravity (m s^{-2}), h the water depth (m) and S the water surface slope in the direction of the flow (m m^{-1}).

The water depth (h) is determined with the Manning equation. We assumed a triangular shaped profile on which the Manning equation is applied, where the width-to-depth ratio is a model parameter. First the flow area is determined with an algebraic re-arrangement of the Manning equation:

$$A = \left[\frac{Q\, n \left(2\sqrt{\frac{WD^2+1}{WD}} \right)^{2/3}}{\sqrt{S}} \right]^{3/4} \tag{S53}$$

where Q is the discharge ($m^3\ s^{-1}$), n the Manning's coefficient ($s\ m^{-1/3}$) and WD the width-to-depth ratio (-). The discharge (Q) is obtained from the hydrological model SPHY and the Manning's coefficient (n) is defined per land use class.

The water depth (h) is calculated as follows:

$$h = \sqrt{\frac{A}{WD}} \tag{S54}$$

The critical shear stress τ_{cr} is calculated as follows:

$$\tau_{cr} = (\rho_s - \rho)\, g\, D_{50}\, a_3\, R_*^{b_3} \tag{S55}$$

where ρ_s is the density of sediment particles (kg m^{-3}), D_{50} the median sediment particle diameter (m), R_* the particle Reynolds number (-), and a_3 and b_3 are given in Table S5.

Table S5. Values for the empirical coefficients a_2 and b_2 used to determine the particle Reynolds number (R_*).

Range for R_*	a_3	b_3
0.03 - 1	0.1	-0.3
1 - 6	0.1	-0.62
6 - 30	0.033	0
30 - 135	0.013	0.28
135 - 400	0.03	0.1
$>$ 400	0.056	0

The particle Reynolds number R_* is calculated as follows:

$$R_* = \max\left[0.03, \frac{D_{50}\sqrt{\tau/\rho}}{\nu}\right] \tag{S56}$$

where ν is the water viscosity ($m^2\ s^{-1}$).

1.5.3 Sediment transported

The total sediment taken into transport (G) is calculated as follows:

$$G = \begin{cases} D_r + D_q & \text{for } D_r + D_q < TC \\ TC & \text{for } D_r + D_q > TC \end{cases}$$

Where TC the transport capacity (kg m^{-2} s^{-1}), which is calculated as follows:

$$TC = G_{tot}\ \frac{\rho_s}{A_{cell}} \tag{S57}$$

Where G_{tot} is the capacity particulate transport rate for overland flow (m^3 s^{-1}) and A_{cell} the cells area (m^3).

The capacity particulate transport rate for overland flow (G_{tot}) is determined with the formulations from Engelund and Hansen (1967):

$$G_{tot} = \begin{cases} \dfrac{0.05\ Q^2\ S^{\frac{3}{2}}}{\sqrt{g\ h}\left(\frac{\rho_s}{\rho} - 1\right)^2 D_{50}\ l} & \text{for } h > 0 \\ 0 & \text{for } h < 0 \end{cases}$$

Where l is the width of the flow, Q the water flow rate (m^3 s^{-1}). The width of the flow l is determined as $l = W D\ h$.

Text S2: Input Data

All input maps were interpolated or resampled to the 50 m model resolution. The digital elevation model was obtained from a Spanish national LiDAR dataset (Ministerio de Fomento de España, 2015) with a 5 m resolution. Land use was obtained from a land use map from 2017 (Rodríguez-Valero and Alonso-Sarria, 2019) with a 30 m resolution. Soil texture and organic matter were obtained from the LUCDEME dataset (Faz Cano, 2003), which includes soil profile data and a soil class map for the Region of Murcia, where the study area is located. We aggregated the textural data per soil class, to obtain average sand, silt and clay fractions per soil class. The organic matter map was aggregated per land use class, to obtain average organic matter content per land use class. The spatially distributed rock fraction map was obtained by applying the empirical formulation from Poesen et al. (1998), which determines rock fraction based on slope gradient. For the calibration and evaluation periods, we obtained daily climate data from 30 precipitation and temperature stations surrounding the study area. The data were interpolated on a 5 km grid using the meteoland R package (De Cáceres et al., 2018) (R version 3.6.3).

NDVI images were obtained from bi-monthly Moderate Resolution Imaging Spectroradiometer (MODIS Didan, 2015) data for the period 2001-2018. No NDVI images were available for the reference and future periods considered in this study. Therefore, we separated the NDVI data into inter- and intra-annual NDVI estimates, which were combined to obtain NDVI time series needed for the model runs. To determine the inter-annual NDVI we applied a land use specific log-linear model based on annual precipitation and temperature time series, as described in detail in Eekhout et al. (2018). The intra-annual NDVI was obtained from the long-term average bi-monthly (16 day) NDVI for the period 2001-2018, also differentiated per land use class.

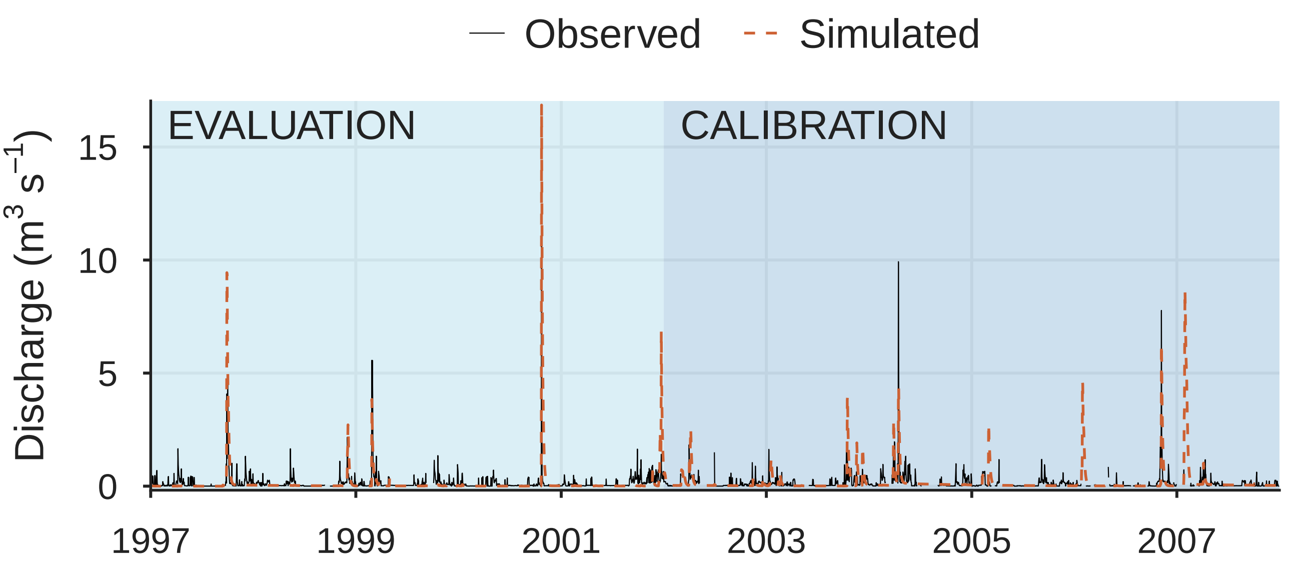

Figure S1. Discharge time series for the calibration (a) and evaluation period (b). The solid line correspond to the observed time series and the dashed orange line corresponds to the simulated time series.

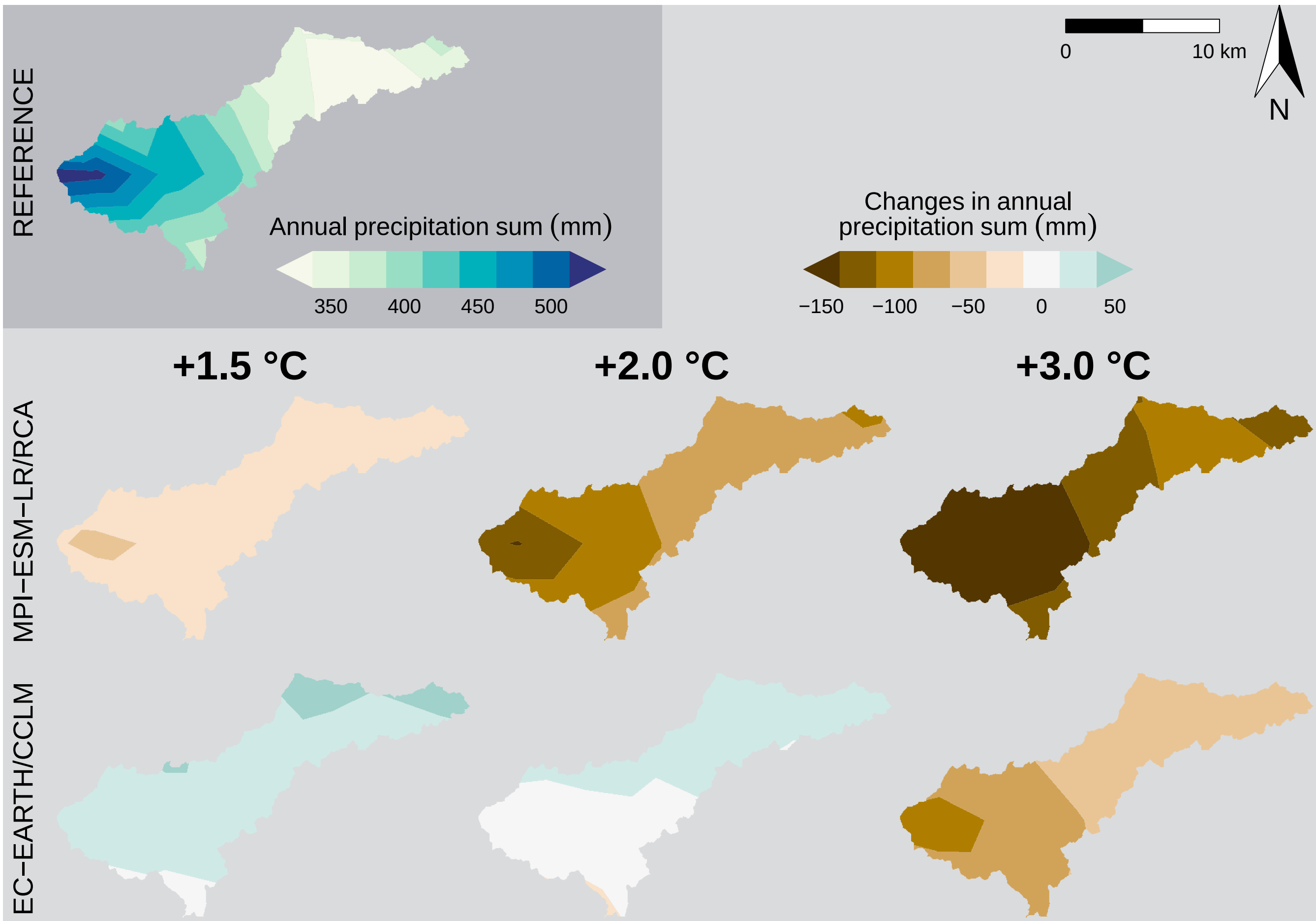

Figure S2. Annual precipitation sum (mm) for the reference scenario (1971-2000; top) and changes between the reference scenario and the future scenarios (RCA/MPI-ESM-LR, middle; CCLM/EC-EARTH, below).

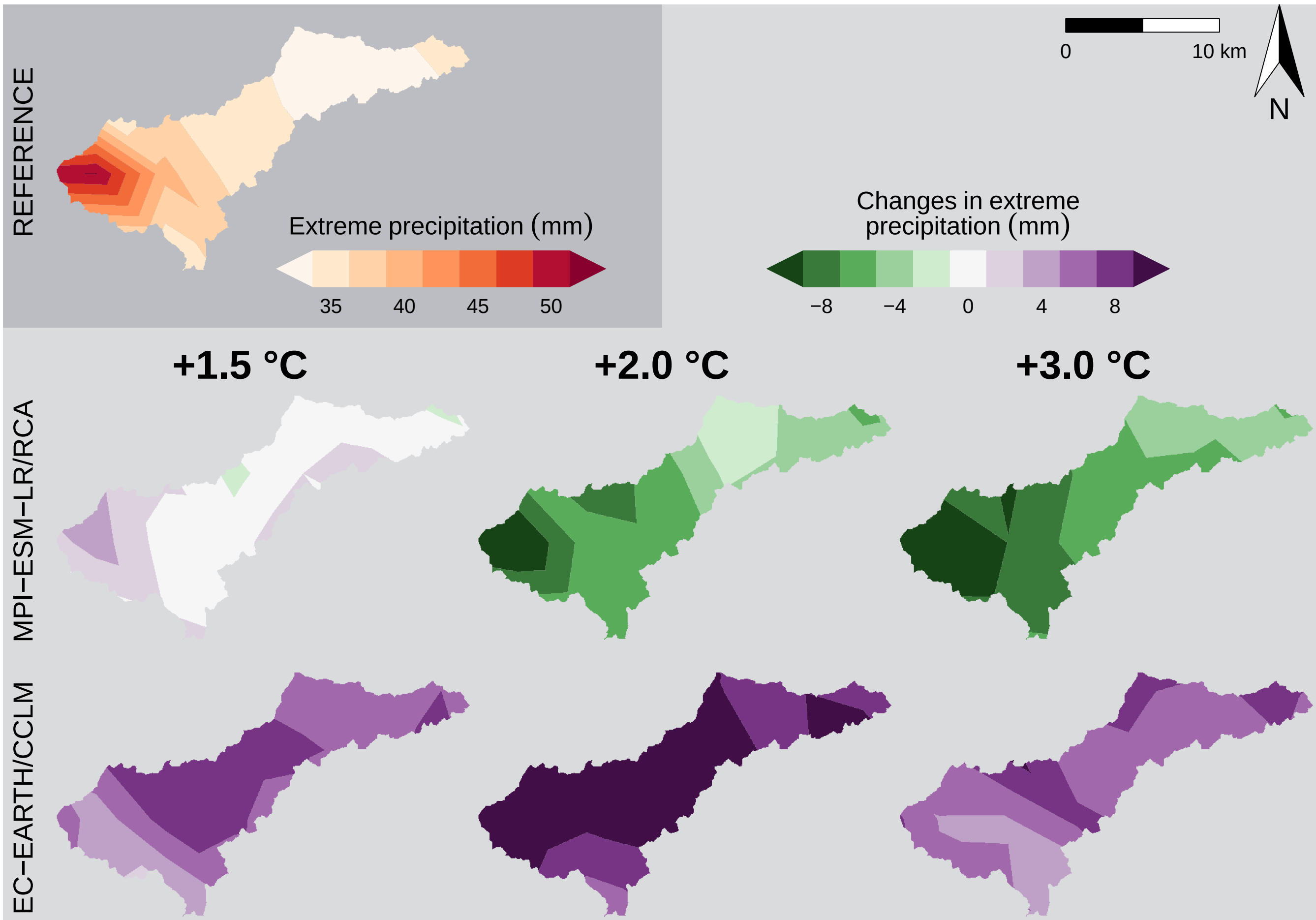

Figure S3. Extreme precipitation (mm), defined as the 95th percentile of daily precipitation, considering only rainy days (>1 mm day^{-1}; Jacob et al., 2014)), for the reference scenario (1971-2000; top) and changes between the reference scenario and the future scenarios (RCA/MPI-ESM-LR, middle; CCLM/EC-EARTH, below).

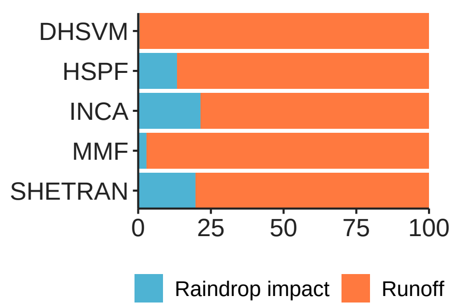

Figure S4. The catchment-scale ratio between detachment by raindrop impact and detachment by runoff for the reference scenario.

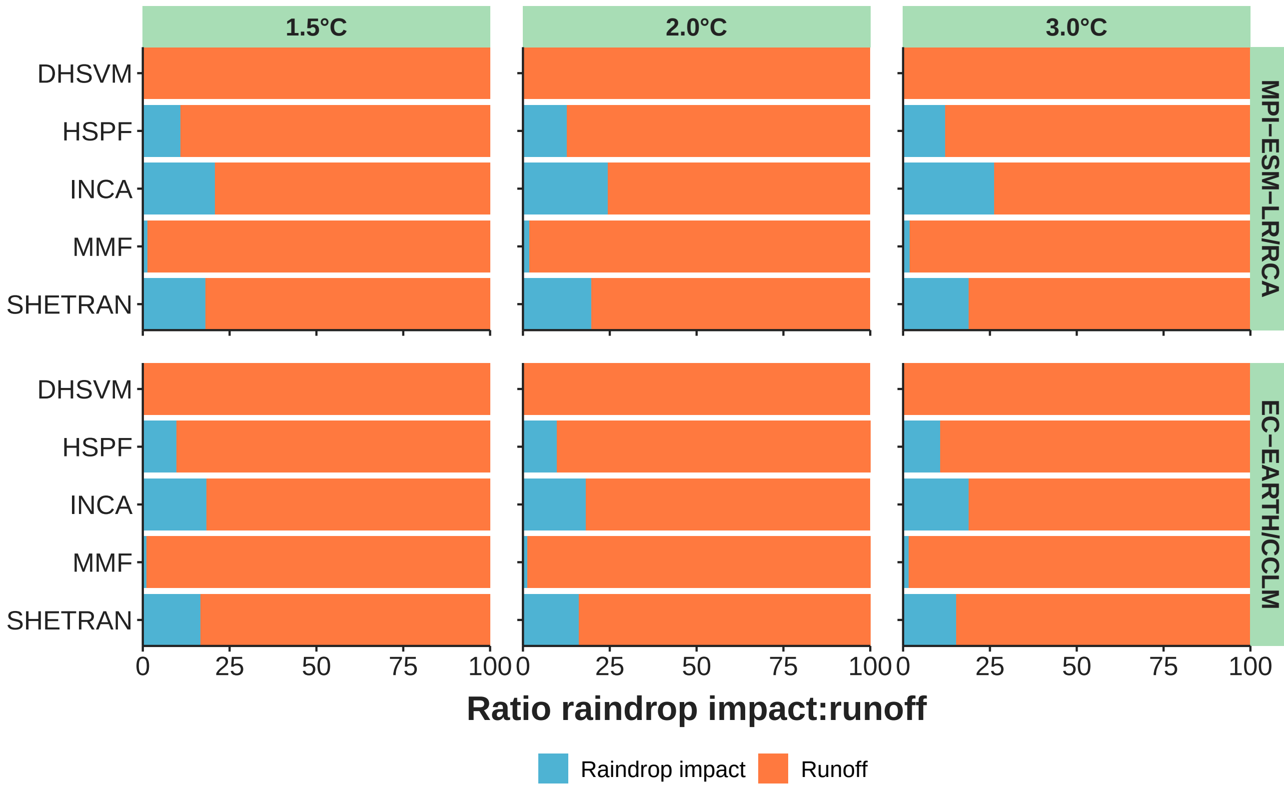

Figure S5. The catchment-scale ratio between detachment by raindrop impact and detachment by runoff for the climate change scenarios.

Table S6. Overview of the parameters that were used to calibrate the hydrological model.

Acronym	Description	Units	Calibrated value	Parameter range
RootDepthFlat	Thickness of the root zone	mm	300	0-2000
SubDepthFlat	Thickness of the subsoil	mm	150	0-2000
CapRiseMax	Maximum allowed capillary rise	mm	0.25	0.01-10
Alpha	Fraction of daily rainfall that occurs in the hour with the highest intensity	-	0.32	0-1
Labda_infil	Infiltration excess parameter	-	1.65	0-1
kx	Flow recession coefficient	-	0.765	0-0.999

Table S7. Optimized values of the model parameters related to the erodibility of the soil and the transport capacity of the five soil erosion models.

Model	Raindrop impact soil erodibility		Runoff soil erodibility		Transport capacity	
DHSVM	k_r	1.25			SP_{crit}	1.85
HSPF	$JRER$	1.25	$JGER$	1	$KSER$	2.05
					$JSER$	1.02
INCA	E_{SP}	0.33	E_{FL}	10.5	$a6$	0.32
MMF	K_c	0.041	DR_c	30		
	K_z	0.205	DR_z	48		
	K_s	0.123	DR_s	45		
SHETRAN	k_r	1.02	k_f	4.16 e^{-10}		

Table S8. Optimized values of the land use-specific model parameters of the five soil erosion models.

Model	Parameter	Forest	Herb. crops	Tree crops	Shrubland
Multi-model	Plant height† (m)	10	0.75	2	0.5
	Manning's coefficient‡ (s m$^{1/3}$)	0.2	0.1	0.05	0.1
DHSVM	Leaf drip diameter d_l (m)	0.003	0.005	0.005	0.005
	Ground cover C_g (-)	0.95	0.51	$<$0.01	0.51
	Root cohesion COH_r (kPa)	19.1	7.45	5	13.1
HSPF	Ground cover CR (-)	0.865	0.2	$<$0.01	0.73
	Scour coefficient $KGER$ (-)	0.03	0.61	0.87	0.207
INCA	Ground cover GC (-)	0.8	0.48	$<$0.01	0.5
	TC scaling factor a_4 (kg m^{-2} km^{-2})	0.6	4.08	5	1.28
MMF	Stem density NV (stems m^{-1})	n/a	400	n/a	n/a
	Stem diameter D (m)	n/a	0.027	n/a	n/a
	Ground cover GC (-)	0.553	0.2916	$<$0.01	0.53
SHETRAN	Ground cover C_g (-)	0.548	0.26	$<$0.01	0.55

† X in DHSVM, PH in MMF, X in SHETRAN

‡ n in DHSVM, $n_{\text{vegetation}}$ in MMF, n in SHETRAN (obtained from Chow (1959))

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