Detailed spatial analysis of the plausibility of surface runoff and sediment yields at HRU level in a mountainous watershed in China

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Bundesministerium für Bildung und Forschung
YANGTZE PROJECT

Impacts of the Three Gorges Dam

Construction of the Three Gorges Dam

Reduced flow velocities

Higher risk of eutrophication

Land use change

Increase in erosion and landslides

Increasing diffuse inputs

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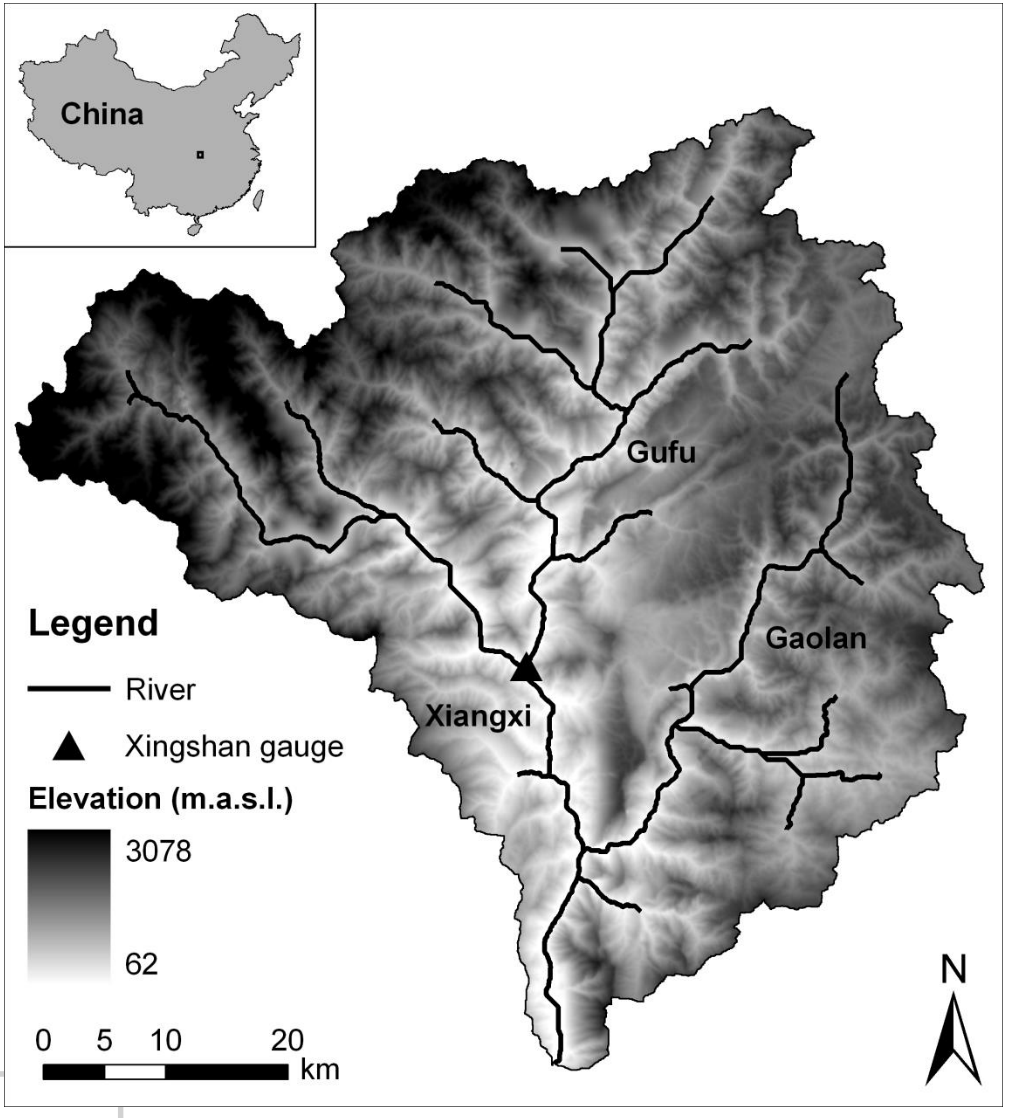
Land use change, erosion, mass movements and diffuse matter inputs in the Three Gorges Region

Coordination: Research Centre Jülich

Remote Sensing Potsdam	Land use change Giessen	Erosion Tübingen	Landslides Erlangen	Diffuse sediment and P inputs Kiel
Assessment of mass move-ments using remote sensing techniques	Classification of land use and assessment of vulnerability	Assessment and analysis of soil erosion	Assessment and analysis of landslides	Analysis of sediment and phosphorus inputs to rivers using SWAT

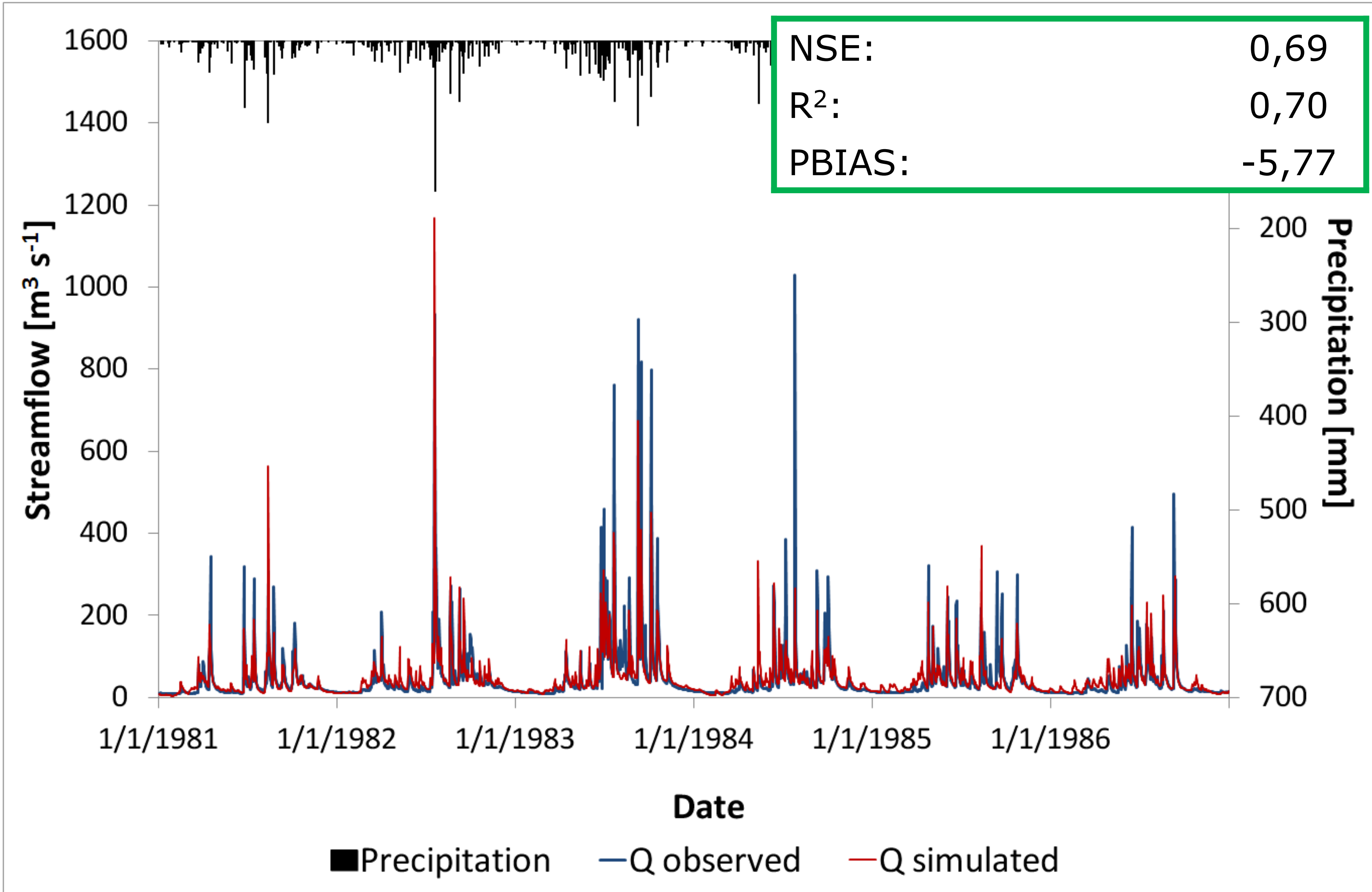
Aim:
Analysis of land use change and vulnerability, risk assessment of mass movements, soil erosion and diffuse inputs to rivers

Study area: Xiangxi Catchment

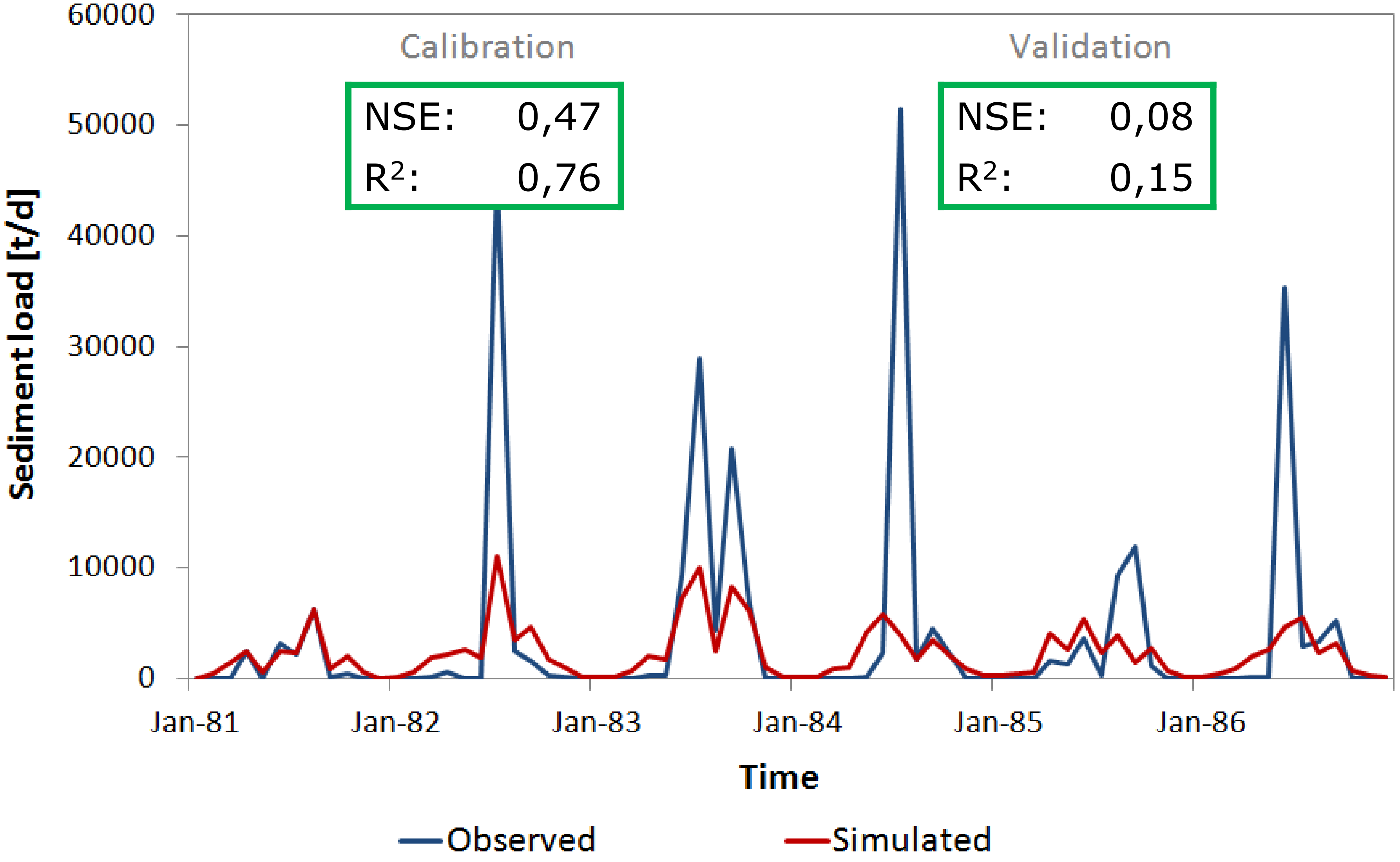


- Catchment area:
  3200 km^2
- Length of Xiangxi River:
  94 km
- Mean annual temperature:
  16,9°C
- Mean annual precipitation:
  1000 mm
- Mean discharge at gage:
  36,4 m^3/s
- Steep slopes:
  average 24°, maximum 76°

Observed and simulated streamflow



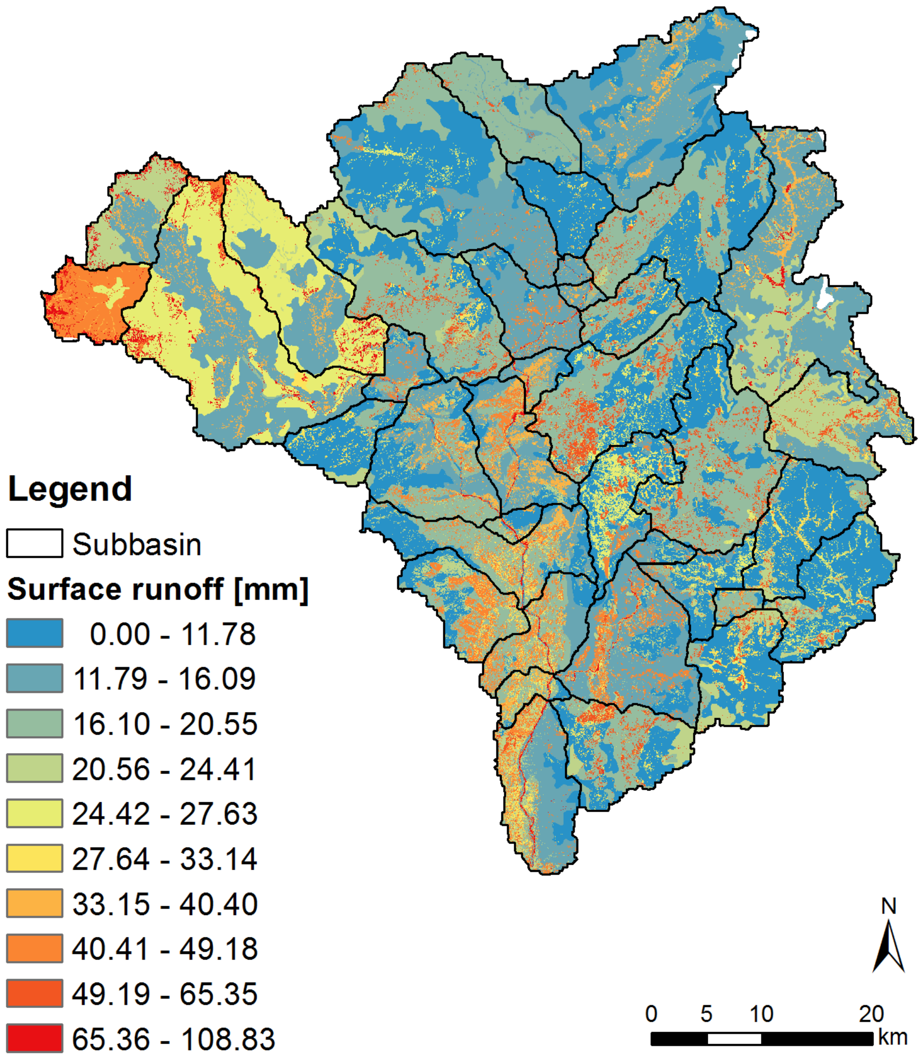
Observed and simulated sediment loads

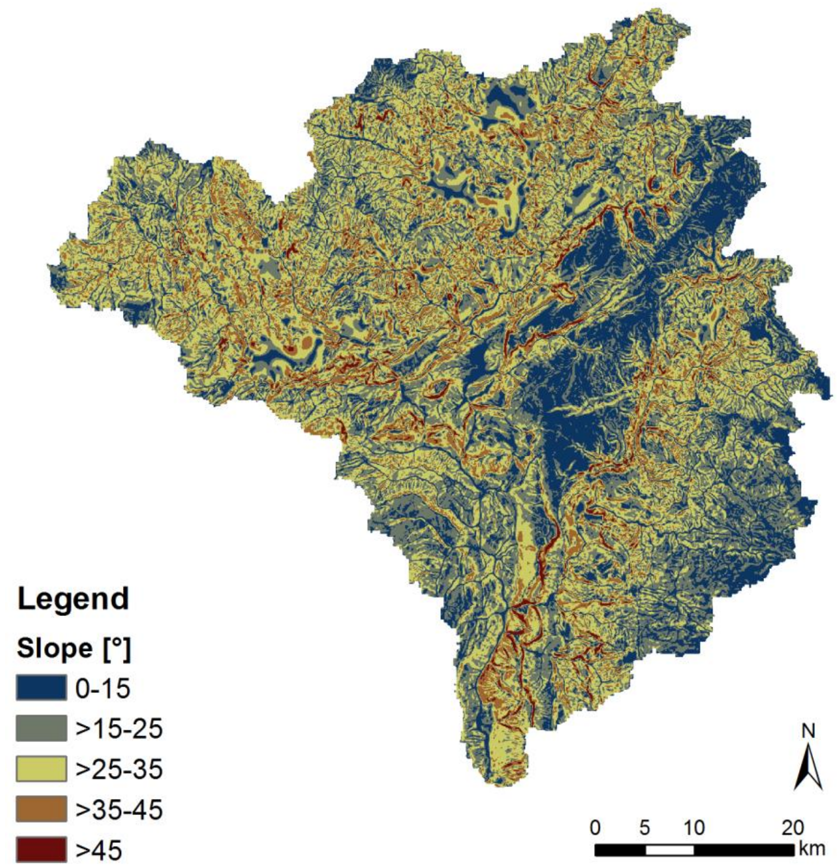


Analysis of output at HRU level

- More precise targeting of Best Management Practices
- Plausibility check for spatial variability of processes within the watershed based on expert knowledge
- Surface runoff and sediment yield
    - forest < orange orchard < cropland
    - Yellowbrown soil (sandy) < Limestone soil (clayey)
    - slope class 1 (<15°) < 2 (15-25°) < 3 (25-35°) < 4 (35-45°) < 5 (>45°)

Surface runoff at HRU level



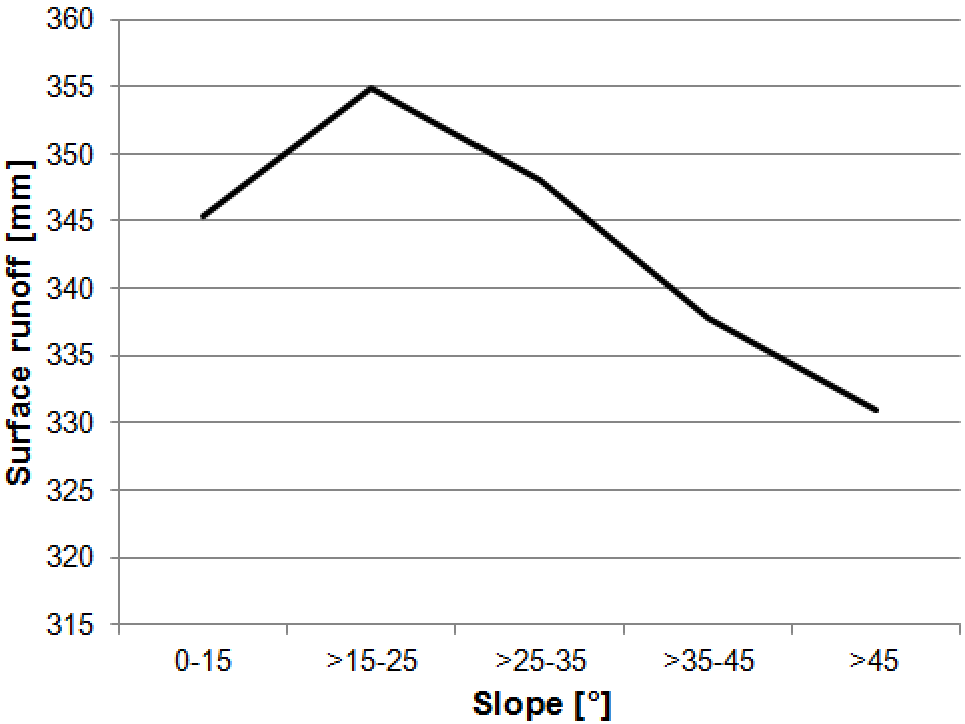


Small-scale variation of slopes hampers spatial analysis

Yellowbrown soil (sandy): 259 mm

Arable land: 549 mm

Surface runoff and slope gradient



Problems with steep slopes in SWAT

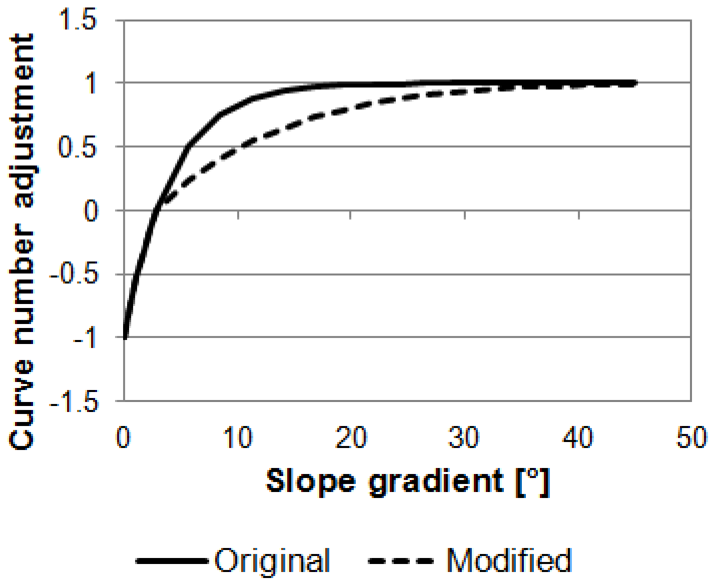
1. Modification of equations for calculating surface runoff and lateral flow (Modifications A and B)

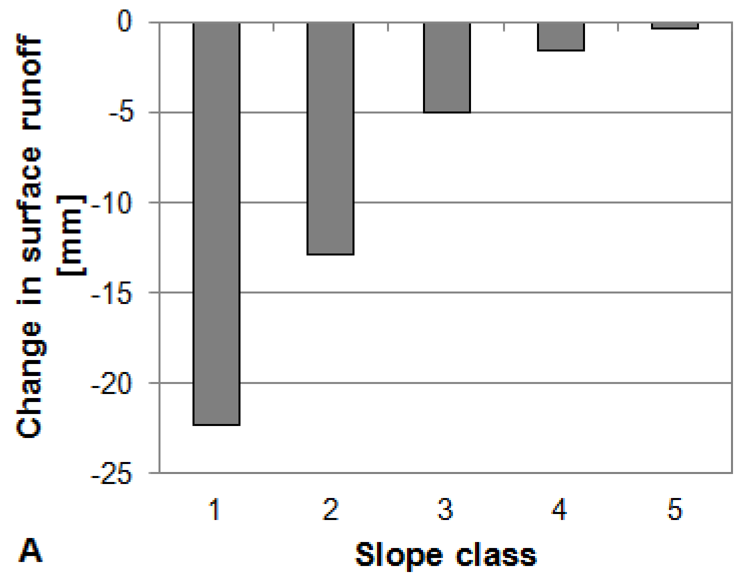
2. Recalibration of slope length and daily curve number calculation method (Modifications C and D)

A: Slope adjustment of CN values

Original equation: $$CN_{2s} = \frac{(CN_3 - CN_2)}{3} \cdot [1 - 2 \cdot \exp(-13.86 \cdot slp)] + CN_2$$

Modified equation: $$CN_{2s} = \frac{(CN_3 - CN_2)}{3} \cdot [1 - 1.3 \cdot 1.5^{(-12.941 slp)}] + CN_2$$



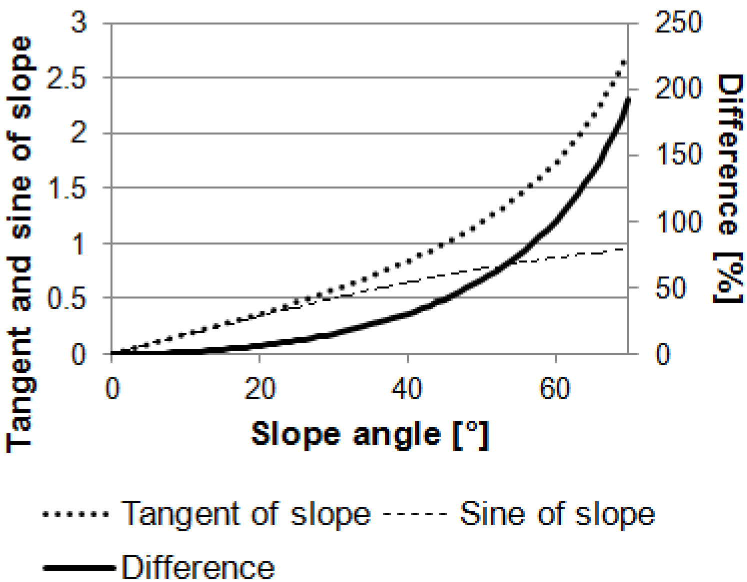


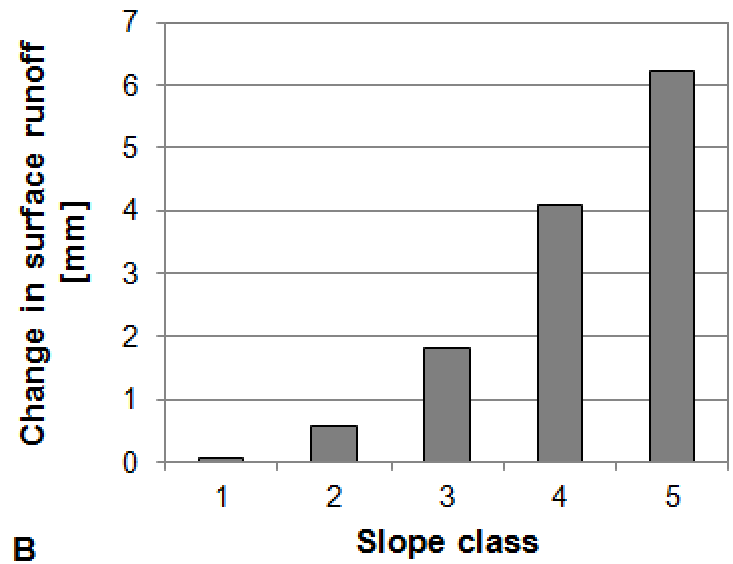
B: Equation for lateral flow estimation

$$Q_{lat} = 0.024\left(\frac{2 \cdot SW_{ly,excess} \cdot K_{sat} \cdot slp}{\phi_d \cdot L_{hill}}\right)$$

$$v_{lat} = K_{sat} \cdot \sin(\alpha_{hill})$$

$$slp = \tan(\alpha_{hill})$$





C: Recalibration of average slope length

$$Q_{lat} = 0.024\left(\frac{2 \cdot SW_{ly,excess} \cdot K_{sat} \cdot slp}{\phi_d \cdot L_{hill}}\right)$$

Increase in *slp*

↓

Increase in Q_{lat}

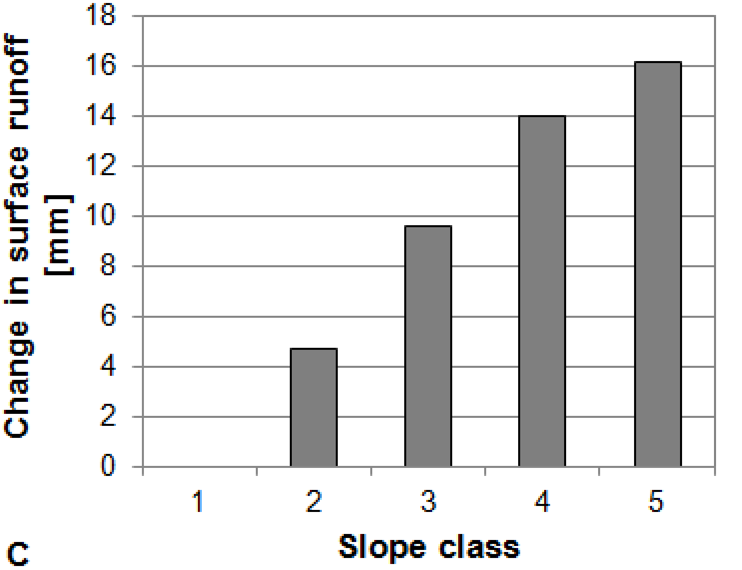
↓

Decrease of soil moisture

↓

Decrease of Q_{surf}

→ Increase of L_{hill} necessary

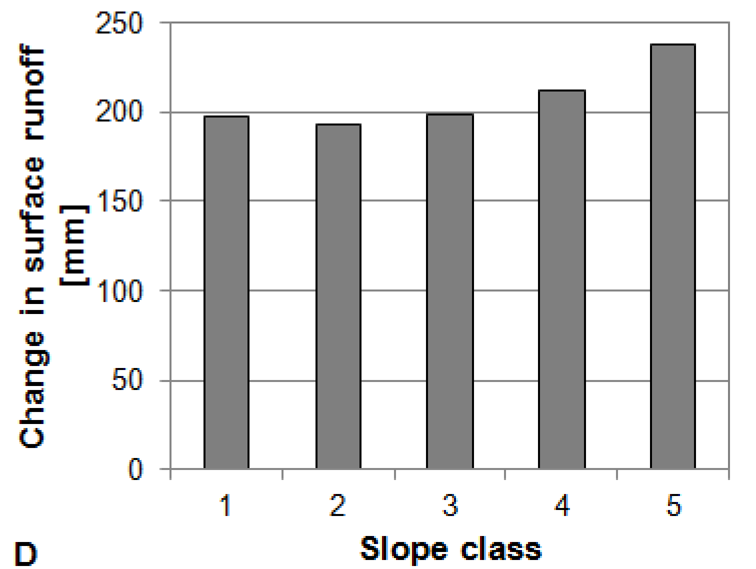


D: Daily variation of CN values

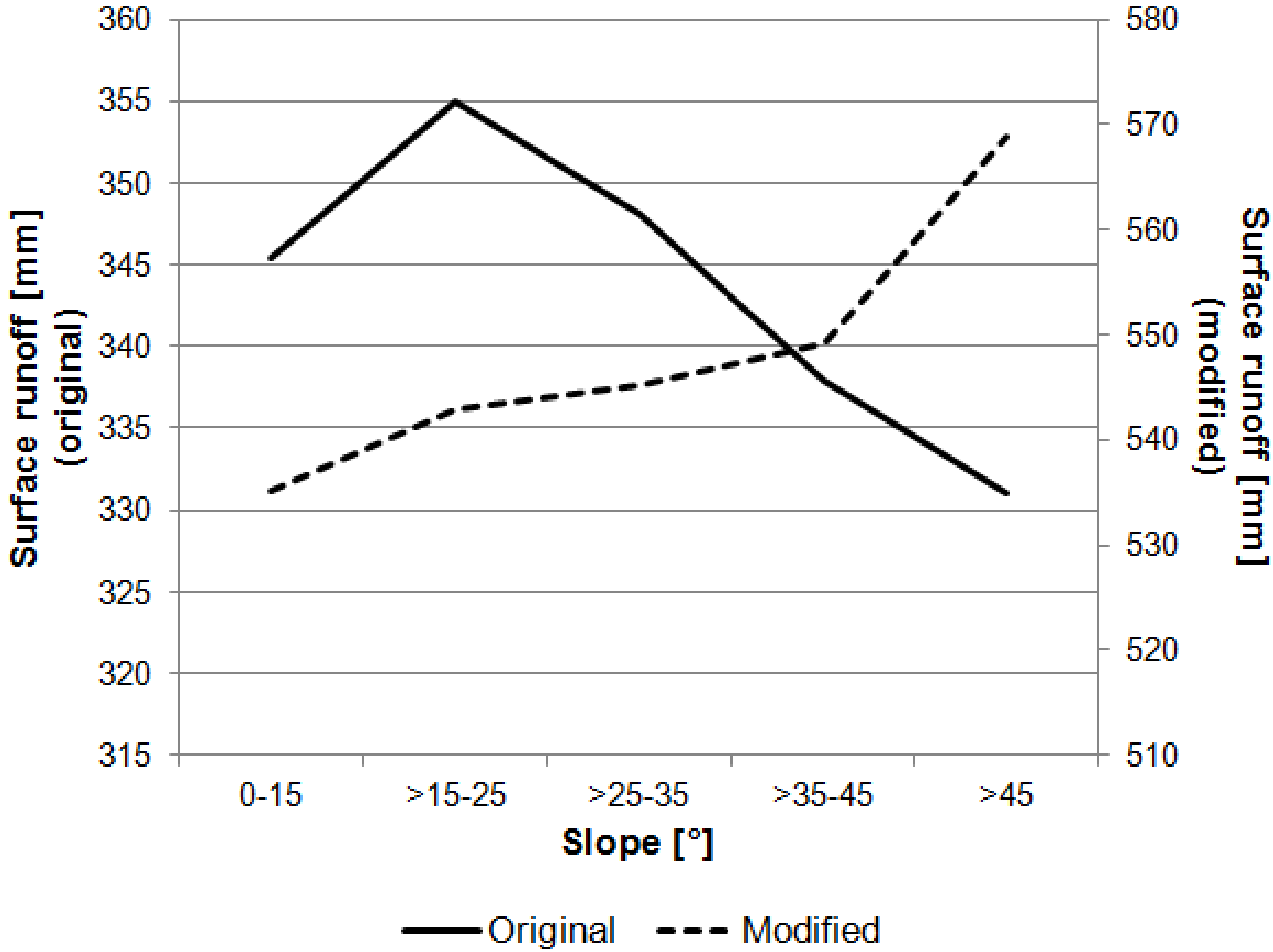
Soil moisture method: $$S = S_{max} \cdot \left(1 - \frac{SW}{SW + \exp(w_1 - w_2 \cdot SW)}\right)$$

Plant ET method: $$S = S_{prev} + ET \cdot \exp\left(\frac{-cncoef \cdot S_{prev}}{S_{max}}\right) - R_{day} + Q_{surf}$$

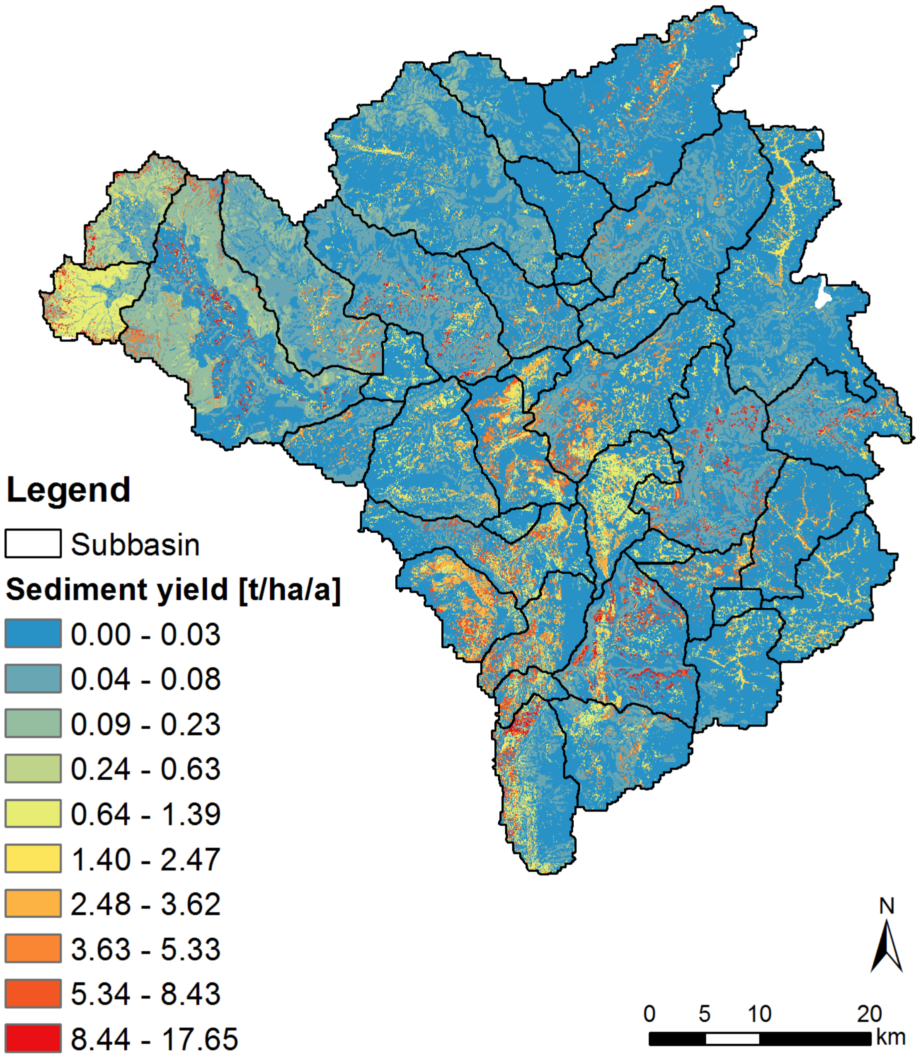
Strong impact on water balance, so appropriate method should be selected in an early stage of calibration!



Improved plausibility of surface runoff

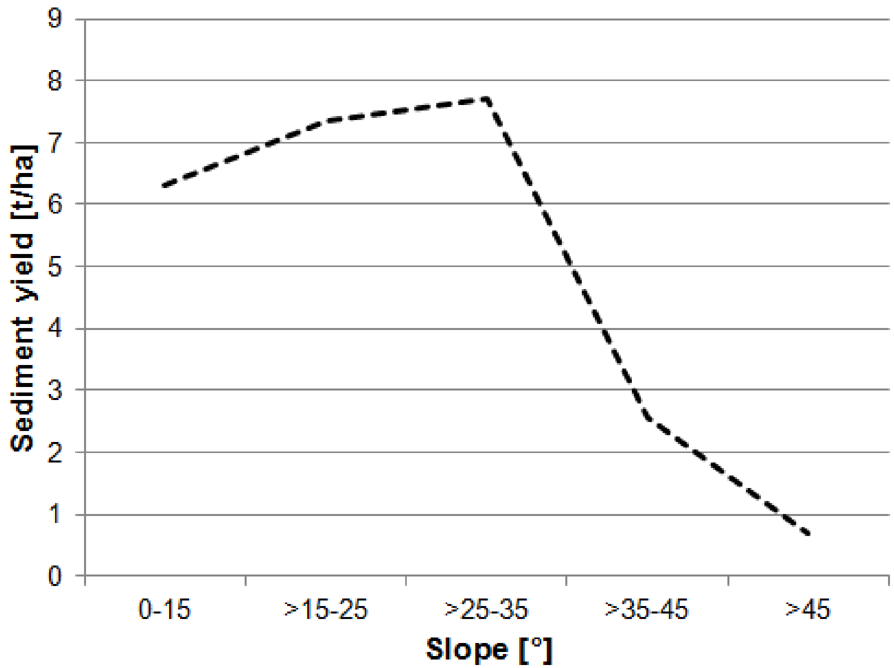


Sediment yield at HRU level

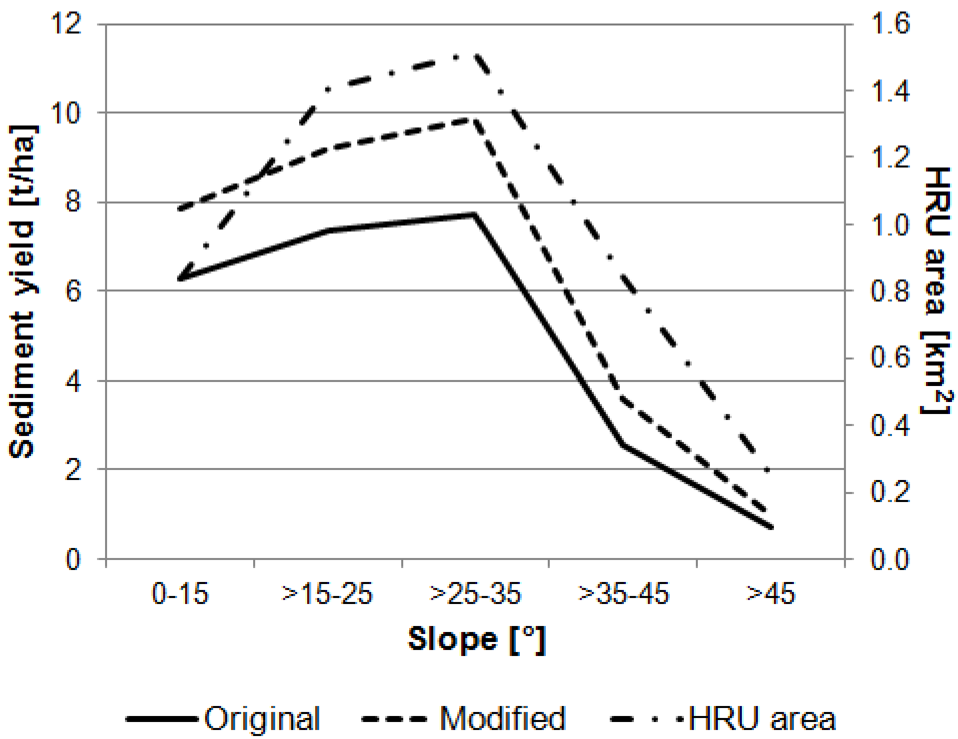


Plausible variation with land use, soils and precipitation

Average sediment yield per slope class:



Sediment yield and slope gradient



Modifications do not impove plausibility of variation of sediment yield with slope gradient

Strong impact of HRU area (non-linear relationship)

$$q_{peak} = \frac{C \cdot i \cdot area_{hru}}{3.6}$$

MUSLE: $sed = 11.8 \cdot (Q_{surf} \cdot q_{peak} \cdot area_{hru})^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG$

Conclusions

- Detailed analysis of model output at HRU level is highly recommendable
- In mountainous watersheds, particular focus should be placed on the dependence of surface runoff and sediment yield on slope
- The plausibility of surface runoff can be improved by modifying key algorithms and recalibrating selected parameters
- Sediment yields are highly dependent on HRU area

Thank you for your attention!

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Impact of HRU area on sediment yield

$$sed = 11.8 \cdot (Q_{\text{surf}} \cdot q_{peak} \cdot area_{hru})^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG$$

$$q_{peak} = \frac{C \cdot i \cdot area_{hru}}{3.6}$$

1 HRU with an area of 100 ha:

$$q_{peak} = \frac{1 \cdot 1 \cdot 100}{3.6} = 27.8$$

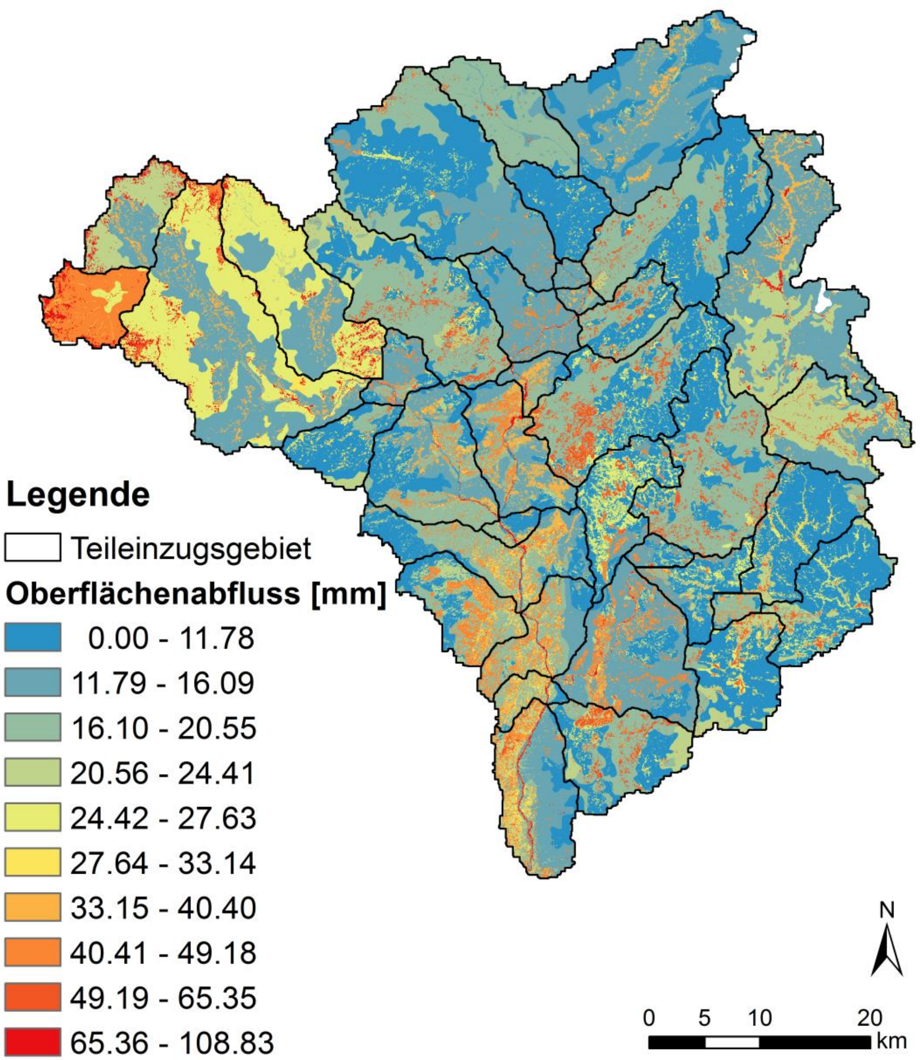
$$sed = 11.8 \cdot (1 \cdot 27.8 \cdot 100)^{0.56} \cdot 1 \cdot 1 \cdot 1 \cdot 1 \cdot 1 = 1001.26$$

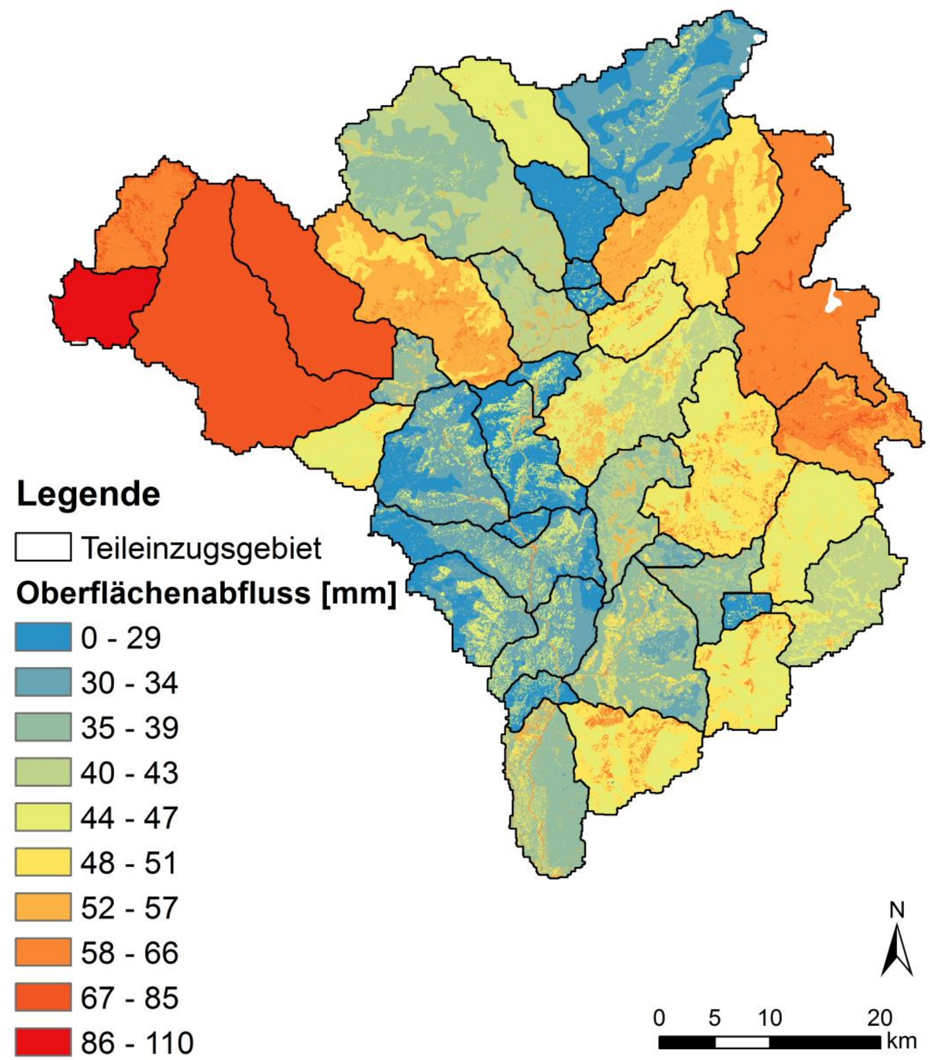
10 HRUs with an area of 10 ha each:

$$q_{peak} = \frac{1 \cdot 1 \cdot 10}{3.6} = 2.8$$

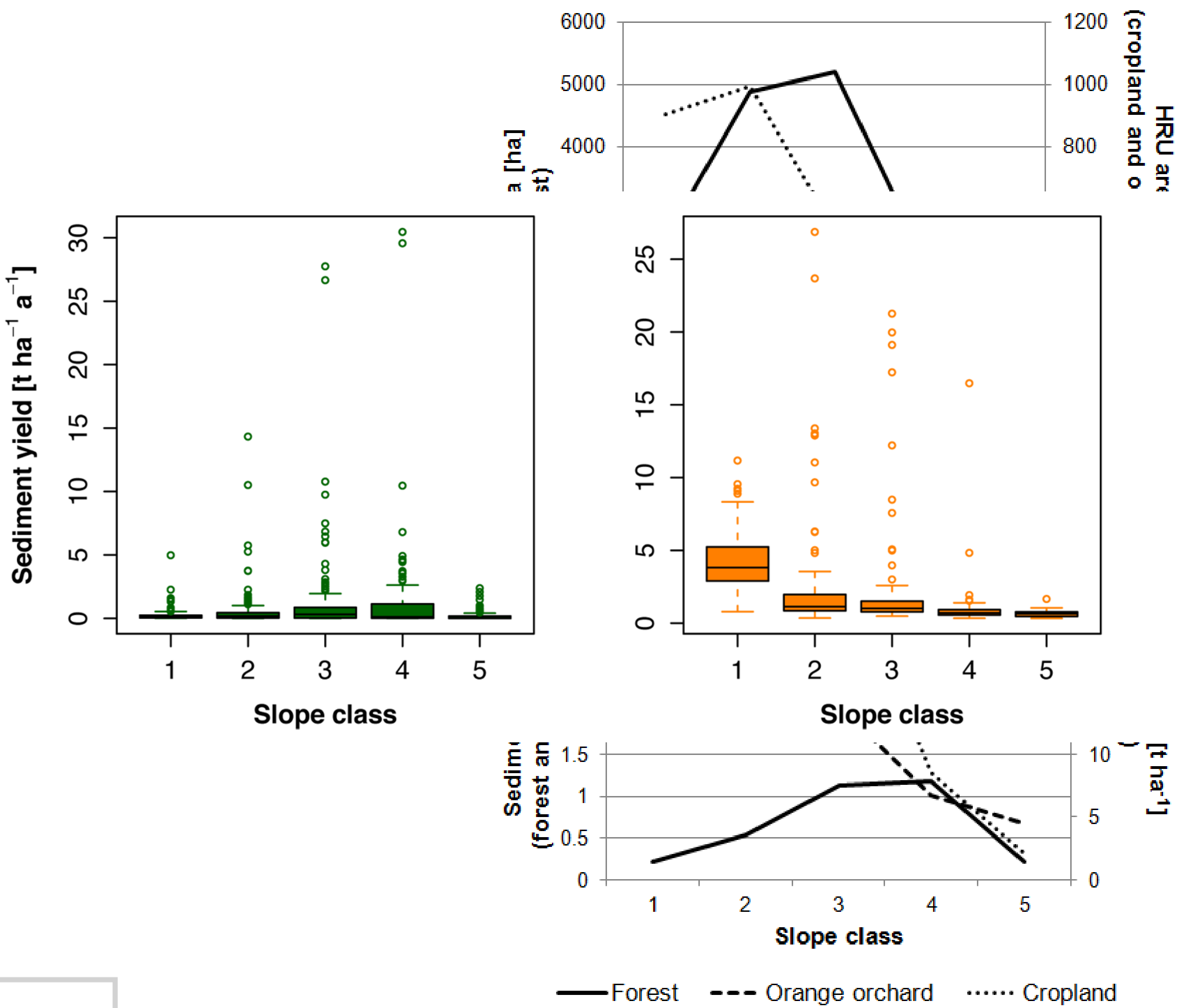
$$sed = 10 \cdot (11.8 \cdot (1 \cdot 2.8 \cdot 10)^{0.56} \cdot 1 \cdot 1 \cdot 1 \cdot 1 \cdot 1) = 762.6$$

Comparison of spatial output





Sediment yield from different land use types



Comparison of variants