Effect of Rock Fragment Coverage on Soil Erosion

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1. Motivation and objectives

Soil surface coverage has a significant impact on water infiltration, runoff and soil erosion yields. In particular, surface rock fragments protect the soil from raindrop detachment, they retard the overland flow therefore decreasing its sediment transport capacity, and they prevent surface sealing. Several physical and environmental factors control to what extent rock fragments on the soil surface modify erosion rates and the related hydrological response. Among the most important factors are the moisture content of the topsoil, rock fragment size, emplacement, coverage density and soil texture. Owing to the different inter-related processes, there is ambiguity concerning the quantitative effect of rock fragments, and process-based understanding is limited. The objectives of this study were to:

(i) Quantify how rock fragment features affect the hydrological response and eroded sediment yields

(ii) Understand the local effect of isolated surface rock fragments, that is, the changes of the soil particle size distribution in the vicinity of a rock fragment

(iii) Model the observed data using a physics-based soil erosion model

2. Design of the experiment

Flume Size: 6-m long, 2-m wide, divided into 2 × 1-m wide flumes

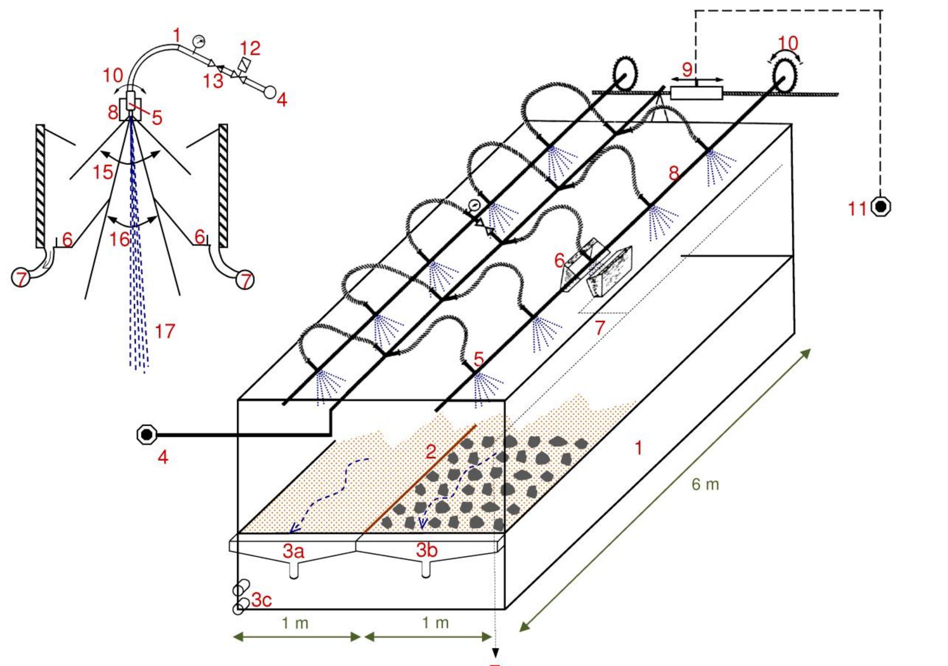
Soil: 4% clay, 29% silt, 41% sand, 26% fine gravel

Slope: 2.2%

Preparation: The top 0.2 m of the soil surface was hand cultivated and any gravel (> 20 mm) removed. Then, the soil surface was smoothed using a mechanical scrapping device in order to ensure the same initial roughness and uniform slope

Rainfall simulator: 10 Veejet nozzles mounted 3-m above the soil surface, with rainfall intensity controlled by oscillation frequency

Experiments: A series of experiments using the EPFL 6-m × 2-m erosion flume were conducted at different rainfall intensities (28 and 74 mm h^{-1}) and rock fragment coverage (20 and 40%). The total sediment concentration, the concentration of the individual size classes and the flow discharge were measured



1. Erosion flume
2. Flume divider
3. Flow collection troughs
   3a. Flume 1
   3b. Flume 2
   3c. Subsurface flow
4. Lake water supply
5. Water outlet tube
6. Collection troughs
7. To storm water drain
8. Rotating bar
9. Oscillator
10. Direction of oscillation
11. Compressor
12. Magnetic vane
13. Regulator
14. Manometer
15. Maximum oscillation amplitude (α = 90°)
16. Actual water outlet (β = 30°)
17. Water jet

Figure 1. Schematic overview of the EPFL erosion flume (modified from [1])

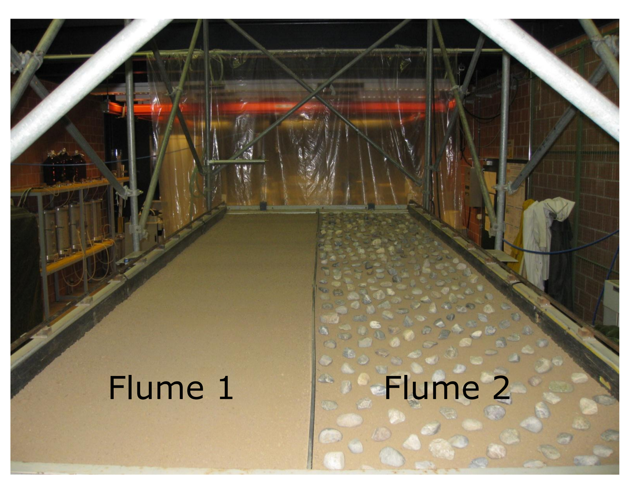


Figure 2. The 2-m × 6-m EPFL erosion flume (before the experiment)

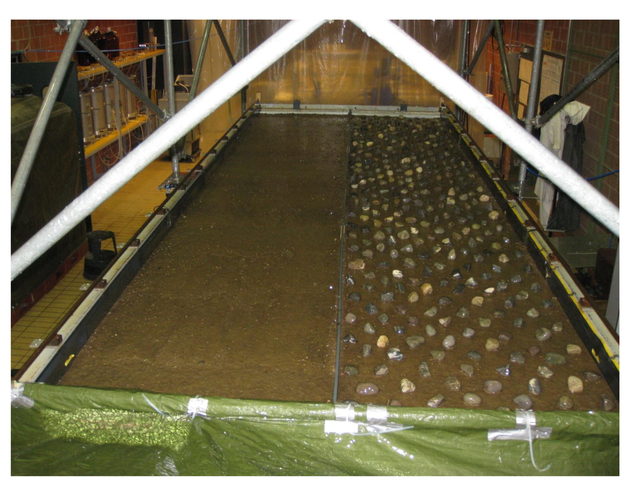


Figure 3. During the experiment

This study was supported by the Swiss National Science Foundation (Grant 200021-113815)

3. Model

The Hairsine-Rose (H-R) model [2] was modified taking the surface rock fragments into account. The rock fragments reduce the average cross-sectional area and provide an additional protection to the original soil. It is therefore appropriate to adjust the H-R model by adjusting the water and sediment mass conservation equations:

$$\eta\frac{\partial h}{\partial t}+\frac{\partial q}{\partial x}=R$$

$$\eta\frac{\partial hc_i}{\partial t}+\frac{\partial qc_i}{\partial x}=\eta(e_i+e_{ri}-d_i)$$

$$\frac{dm_i}{dt}=d_i-e_{ri}$$

where

$$\eta=(1-C_s)$$

Notation

η = proportion of the cross-sectional area not covered by rock fragments
h = water depth (m)
q = ηuh = unit discharge (m^2/s)
u = water velocity (m/s)
c_i = class i sediment concentration (kg/m^3)
e_i = rainfall detachment (kg/m^2/s)
e_{ri} = rainfall re-detachment (kg/m^2/s)
d_i = deposition (kg/m^2/s)
m_i = mass of deposited class i sediment per unit area (kg/m^2)
C_s = rock fragments coverage (%)

4. Results

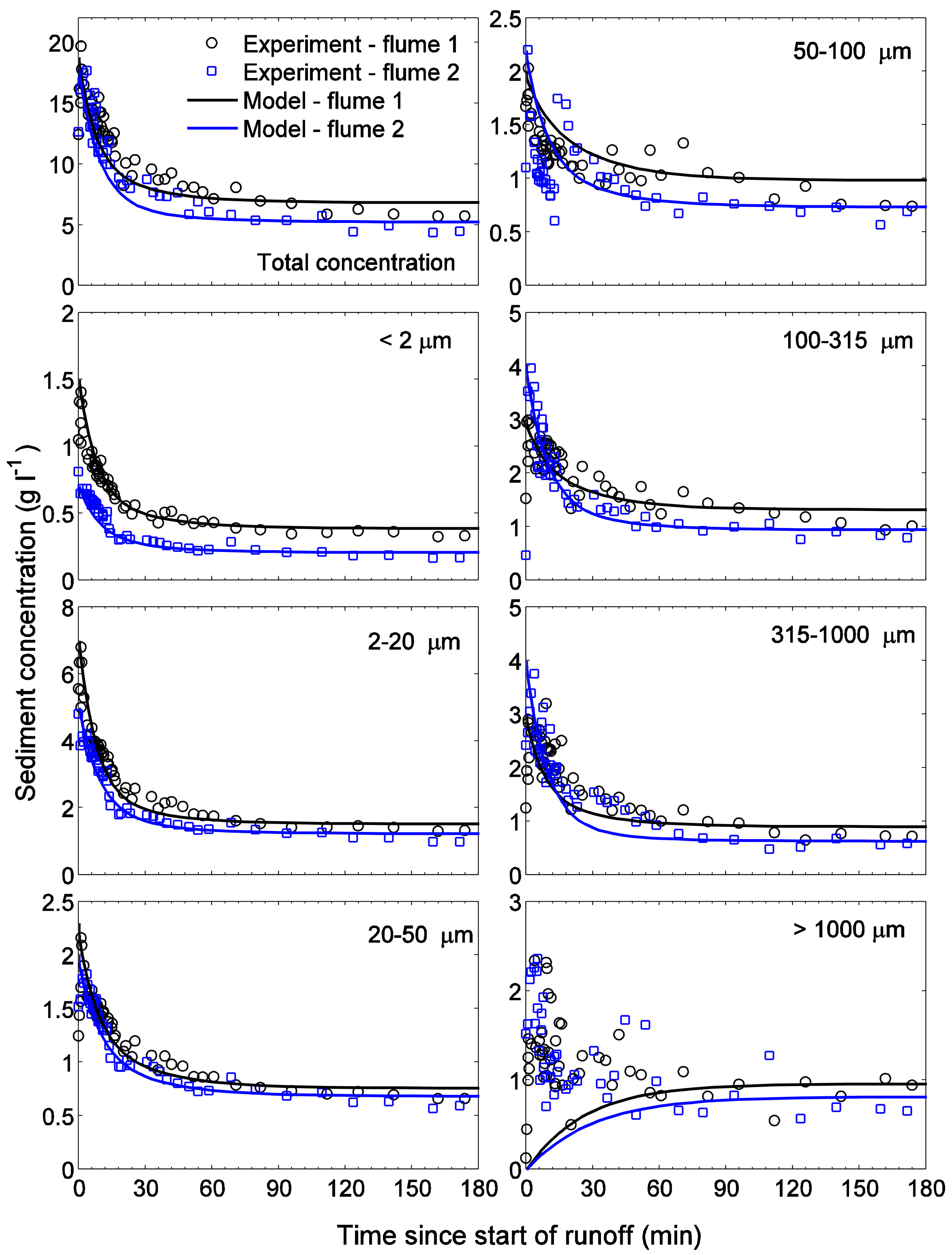


Figure 4 . Experimental results and model predictions for experiment H6 (R = 74 mm h^{-1}, 20% rock fragment coverage). The results shown here for experiment H6 are typical for all experiments

5. Observations

Figure 5. The local effect of the rock fragments on soil erosion (the umbrella effect). The pen shows the flow direction

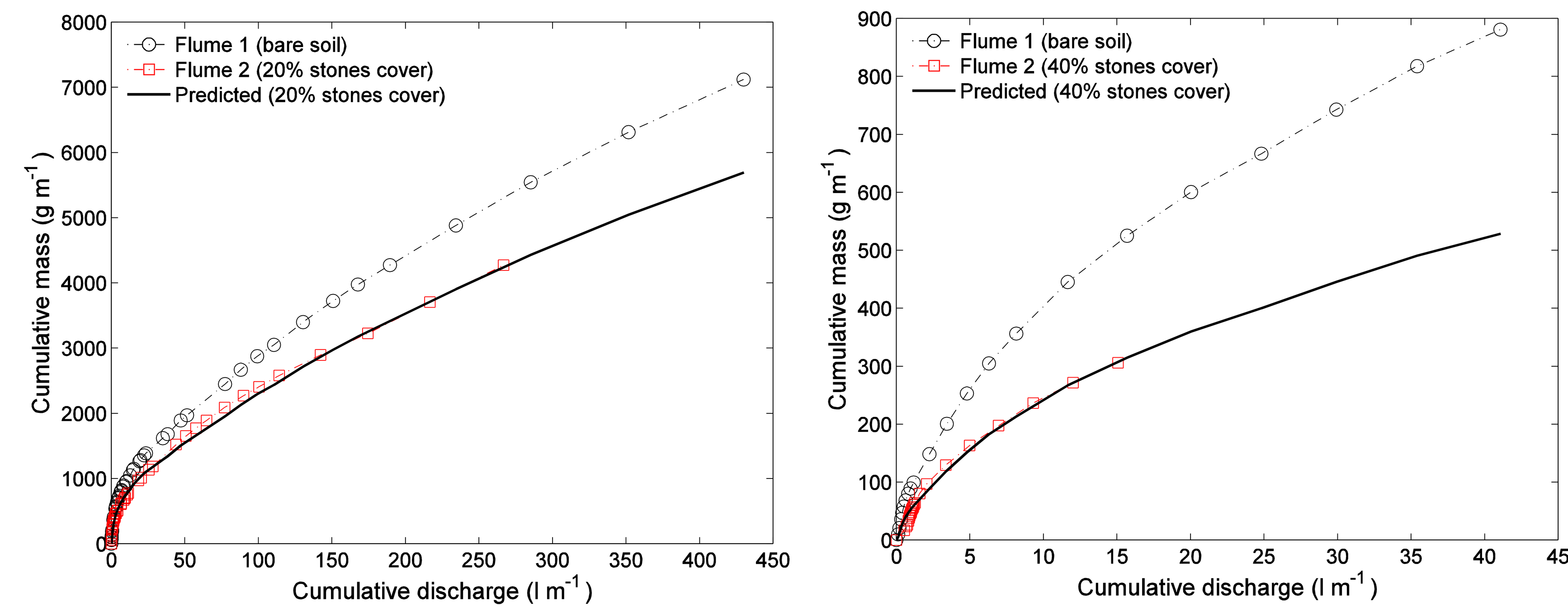


Figure 6. The cumulative eroded mass as a function of the cumulative discharge for experiments H6 (left panel) and H7-E1 (right panel)

6. Conclusions

- When carefully controlled conditions were used, the soil erosion is proportional to area exposed and effective rainfall for the entire duration of the experiment (Fig. 6)
- When more complex initial conditions (bulk density and moisture content) were used, soil erosion is proportional to the area exposed only at steady-state behavior. However, soil erosion collected from field data generally is not proportional to the exposed area only [3].
- Surface rock fragments retard runoff generation, decrease soil erosion delivery, and increase considerably the infiltration rate
- The effect of rock fragments on the soil erosion and hydrological response is controlled by the initial soil state (surface roughness, moisture content and bulk density) and rainfall intensity
- At steady-state, the rock fragments reduce the sediment concentration of all particle size classes proportionally (Fig. 4)
- The H-R model could predict the total as well as the individual size class sediment concentrations using parameters corrected by the area not covered by the rock fragments (Fig. 4)
- The adjusted H-R model could reproduce reasonably the total and the individual size classes only when high precipitation and low rock fragment coverage were used [4].

References

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