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Ability of One-Dimensional Hairsine-Rose Erosion Model to Predict Sediment Transport over a Soil with Significant Surface Stones

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Motivation and objectives

Surface stones affect erosion rates by reducing raindrop-driven detachment and protecting the original soil against overland flow induced-hydraulic stress.

The aim of this study was :

(i) to quantify how the stone characteristics affect the total sediment concentration and the concentrations of the individual size classes,
(ii) to test if stones affect preferentially a particular size class within the eroded sediment,
(iii) to determine whether the 1D Hairsine-Rose (H-R) erosion model can represent the experimental data.

Experiments were conducted:

- at the 2-m × 6-m EPFL erosion flume for different rainfall intensities (28 and 74 mm h^{-1}) and with a gentle slope (2.2%),
- for different initial conditions (see Table 1),
- and with two stones coverage proportions (20 and 40%).

Design of experiment

- The 2-m × 6-m EPFL erosion flume was divided into two identical 1-m wide flumes (Figs. 1, 2 and 3).
- Both flumes were prepared identically. Before the experiment, the top 0.2 m of the soil surface was re-ploughed and smoothed then any gravel (> 20 mm) removed.
- The top surface of flume 2 was filled with natural shape stones at 20 and 40% coverage. The location of the stones was determined with triangulation to ensure an as homogenous distribution as possible.
- Flume 1 remained bare soil.
- Five experiments were conducted at different circumstances (H6, H7-E1, H7-E2, H7-E3 and H7-E4) . (see Table 1).

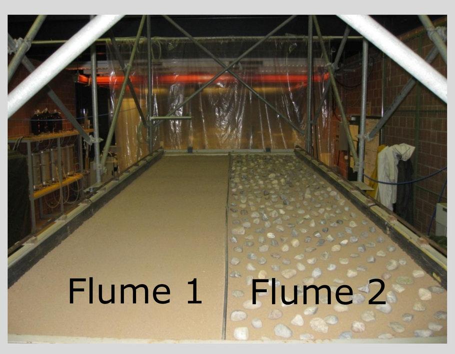


Fig.1. The 2-m × 6-m EPFL erosion flume (before the experiment)

Fig. 2. The EPFL flume during the experiment

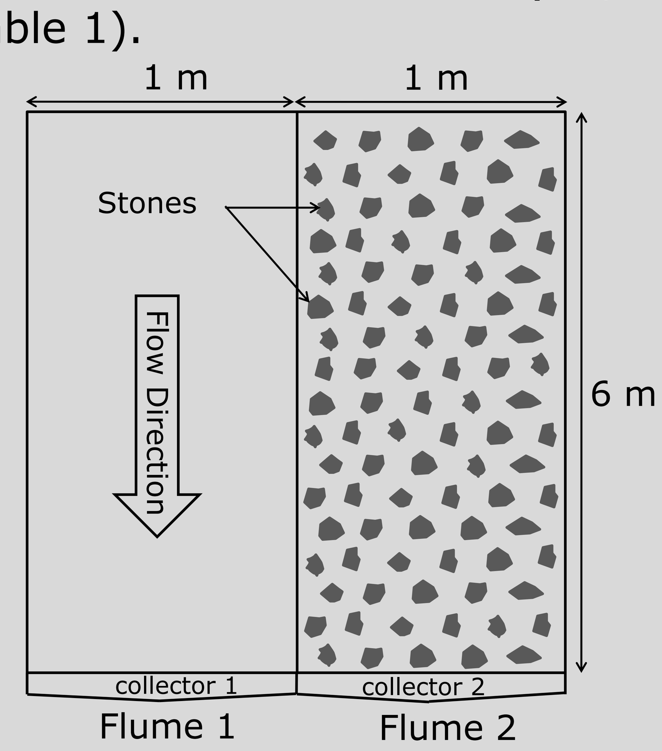


Fig. 3. Experimental design

Model

The H-R model [1] was modified taking the surface stones into account. The stones reduce the sectional area and provide an additional protection to the original soil. It is therefore appropriate to adjust the HR 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 = porosity of the cross sectional area,
h = water depth (m)
$q = \eta uh$ = unit discharge (m²/s)
u = water velocity (m/s)
c_i = class i sediment concentration (kg/m³)
e_i = rainfall detachment (kg/m²/s)
e_{ri} = rainfall re-detachment (kg/m²/s)
d_i = deposition (kg/m²/s)
m_i = mass of deposited class i sediment per unit area (kg/m²)
C_s = stones coverage (%)

Reference

[1] P. B. Hairsine and C. W. Rose (1991), Rainfall detachment and deposition: sediment transport in the absence of flow-driven processes, *Soil Science Society of American Journal* **55**(2):320-324.

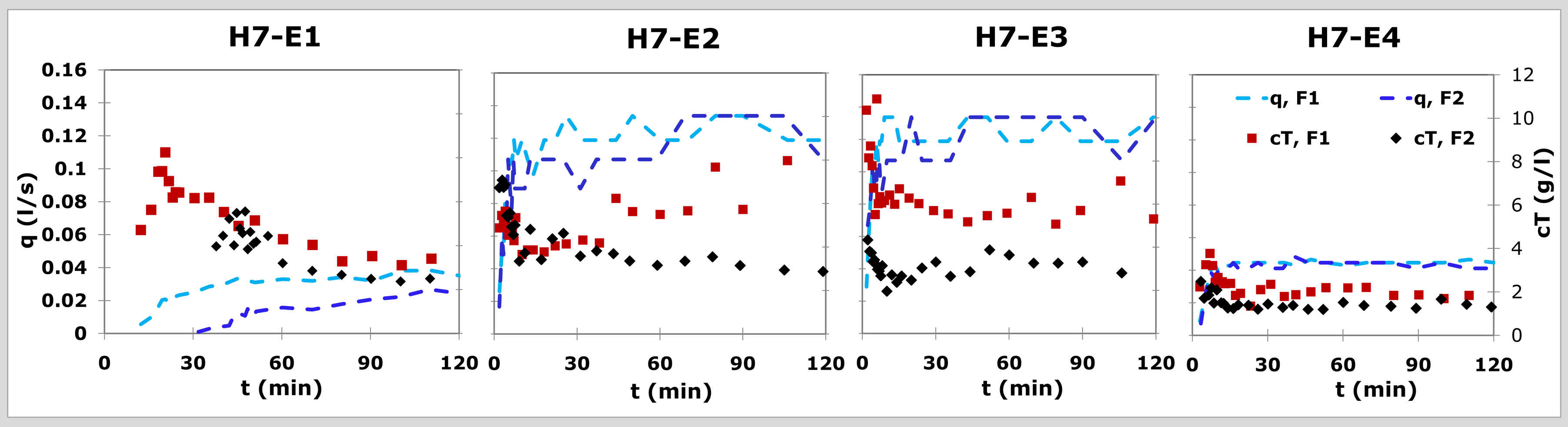
Discussion and Conclusions

- The surface stones reduce the sediment concentrations and increase the infiltration rates (Figs. 4, 5 and 6).
- The stones' effect is controlled by the rainfall intensity and the initial conditions, such as the initial moisture content, and the rate of the development of the shield layer.
- The stones provide less protection to the finer particles, however they provide greater protection for the larger size classes (Fig. 7).
- By adjusting the H-R model taking the surface stones into account, the model predictions agree with the measured sediment concentrations, especially for the long time behaviour (the steady state).
- This agreement demonstrate the potential of the HR model to be used for complex scenarios (Fig. 5).

Results

Table 1. Summary of the experiments

Experiments		Precipitation (mm h^{-1})	Stones coverage (%)	Moisture content (%) Initial	Final	Final infiltration (mm h^{-1})	Time-to-runoff (min)
H6	Flume 1 (F1)	74	-	6.81	19.15	5.8	6.07
	Flume 2 (F2)		20	6.52	23.91	20.6	8.28
H7-E1	Flume 1 (F1)	28	-	7.74	18.28	8.3	14.32
	Flume 2 (F2)		40	8.84	30.91	13.6	27.13
H7-E2	Flume 1 (F1)	74	-	19.15	21.96	2.8	1.34
	Flume 2 (F2)		40	24.79	29.53	10.6	2.06
H7-E3	Flume 1 (F1)	74	-	20.42	22.03	0.4	1.23
	Flume 2 (F2)		40	25.20	29.77	6.4	2.09
H7-E4	Flume 1 (F1)	28	-	22.14	22.62	1.9	1.58
	Flume 2 (F2)		40	26.36	27.35	2.5	2.46



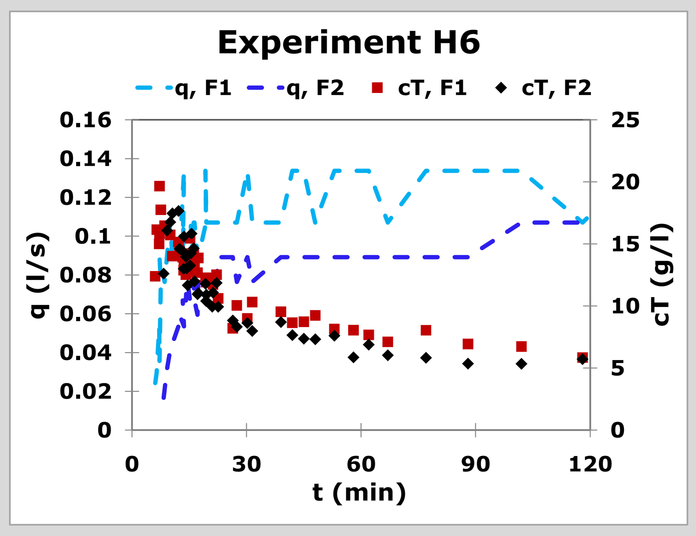


Fig. 4. The collected total sediment concentrations and the discharges of flumes 1 and 2 for the experiments H6, H7-E1, H7-E2, H7-E3 and H7-E4. Results revealed that the stones' effect is sensitive to the rainfall intensity, the antecedent soil conditions (initial moisture content and the protective layer's development) and to the surface stones coverage.

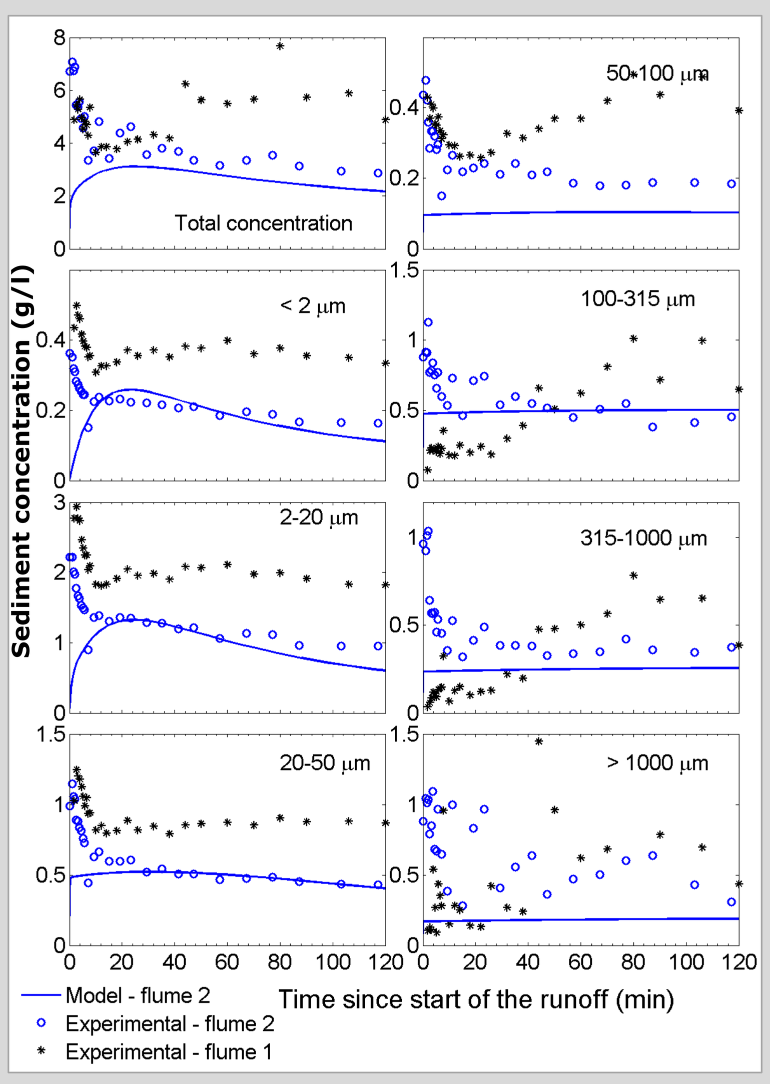


Fig. 5 . Experimental results and the model predictions of the H7-E2. The H-R model represents the steady state of the individual size classes, when it was adjusted taking the surface stones into account.

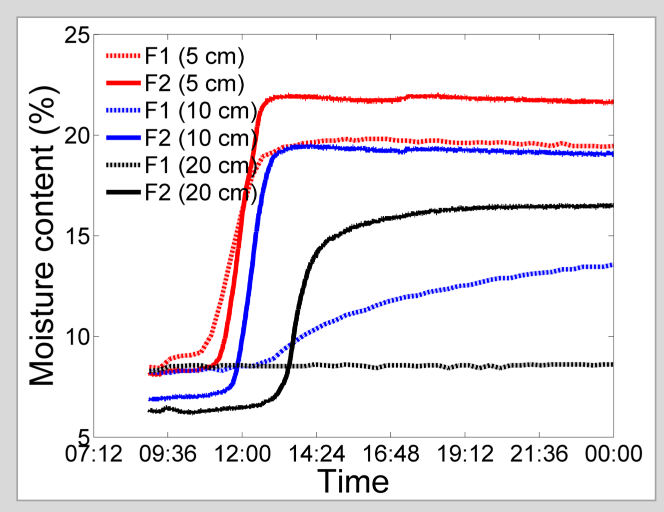


Fig. 6. Measured moisture content during H6 at different soil depths.

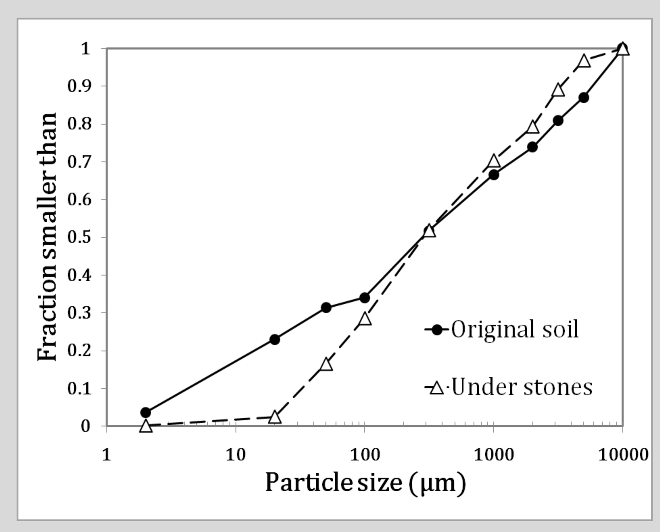
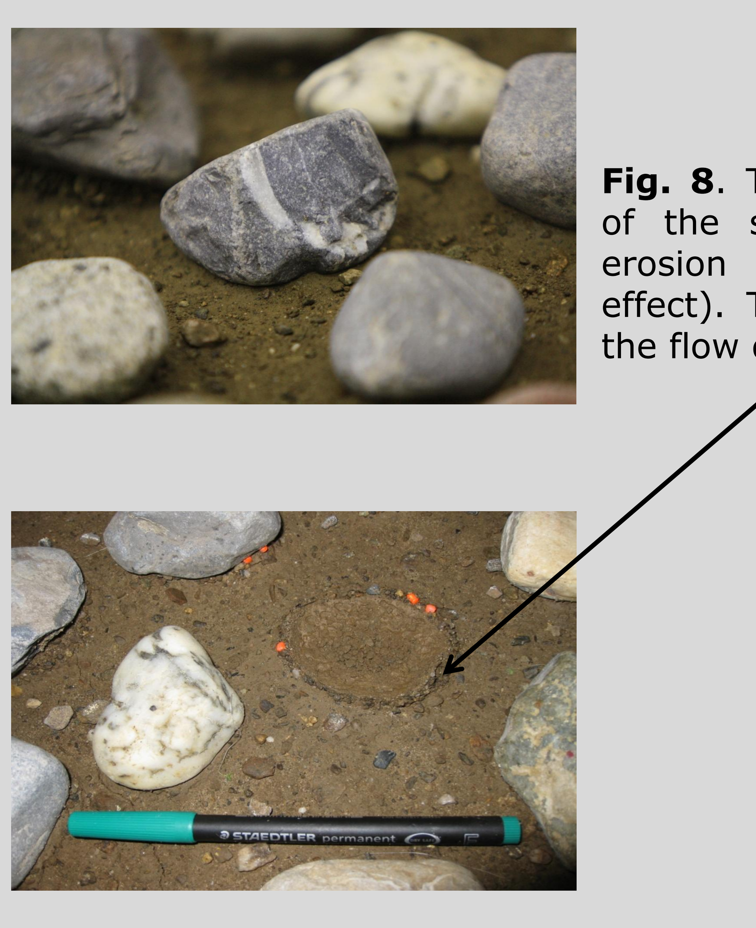


Fig. 7. Comparison between the original soil and the deposited material under the stones.



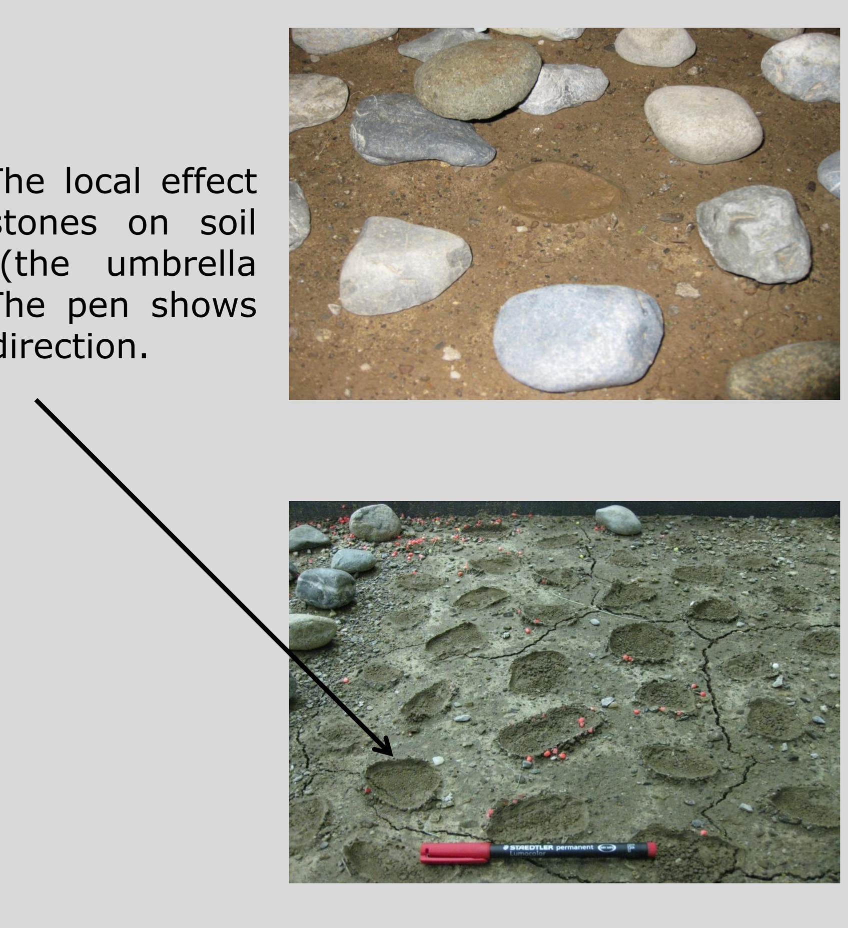


Fig. 8. The local effect of the stones on soil erosion (the umbrella effect). The pen shows the flow direction.