One-dimensional Hairsine-Rose Erosion Model: Parameter Consistency in the Presence of Rainfall Splash

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1. Introduction and motivation

Process-based erosion modeling has proven to be an efficient tool for description and prediction of soil erosion and sediment transport. The one-dimensional Hairsine-Rose (HR) erosion model, which describes the time variation of suspended sediment concentration of multiple particle sizes, accounts for key soil erosion mechanisms: rainfall detachment, overland-flow entrainment and gravity deposition [1-3]. In interrill erosion, it is known that raindrop splash is an important mechanism of sediment detachment and therefore of sediment delivery. In addition, studies have shown that the mass transported from a point source by raindrop splash decreases exponentially with radial distance and is controlled by drop characteristics and soil properties. Here we test experimentally and numerically the HR parameter consistency at different transversal widths and in the presence of splash. To achieve this, experiments were conducted using different configurations of the 2 m 6 m EPFL erosion flume. The flume was divided into four identical smaller flumes, with different widths of 1 m, 0.5 m, and 2 0.25 m. From these experiments, total and the individual size classes sediment concentrations were obtained.

2. Model

The 1D fixed-bed Hairsine-Rose model coupled with the shallow water equations is [4]:

$$\frac{\partial}{\partial t}\begin{bmatrix}\eta\\ hu\\ hc_1\\ \vdots\\ hc_I\end{bmatrix}+\frac{\partial}{\partial x}\begin{bmatrix}hu\\ hu^2\\ huc_1\\ \vdots\\ hcu_I\end{bmatrix}=\begin{bmatrix}P\\ -gh\left(\frac{\partial\eta}{\partial x}+S_f\right)-Pu\\ e_1+r_1+e_{r1}+r_{r1}-d_1\\ \vdots\\ e_I+r_I+e_{rI}+r_{rI}-d_I\end{bmatrix}$$

As a function of time the protective layer of deposited sediment develops according to:

$$\frac{\partial}{\partial t}\begin{bmatrix}m_1\\ \vdots\\ m_I\end{bmatrix}=\begin{bmatrix}d_1-e_{r1}-r_{r1}\\ \vdots\\ d_I-e_{rI}-r_{rI}\end{bmatrix}$$

Notation

η = water surface level (m)
h = water depth (m)
P = rainfall intensity (m/s)
S_f = friction slope
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)
r_i = runoff entrainment (kg/m^2/s)
r_{ri} = runoff re-entrainment (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)
I = the total number of size classes

The effective settling velocity for each size class, which takes into consideration the effect of the raindrop splash on the deposition force of the particles, is:

$$V_{effective_i}=\frac{V_i}{1+\alpha D_{Splash}\dfrac{V_i}{q}}$$

α = the proportion of raindrops that will generated the splash process (1/10)
D_{splash} = the average splash length ranged from 4 to 23 cm, here taken as 10 cm
V_i = the settling velocity of each size class (m/s)
q = the overland flow per unit width (m^2/s)

3. Design of experiment

Fig. 1. The EPFL erosion flume divided into 4 smaller flumes

Fig. 2. Interrill erosion

Fig. 3. Raindrop splash

4. Discussion and conclusion

The experimental results indicate that the raindrop splash dominated in the flumes having the larger widths (1 m and 0.5 m). In addition, this process generated a short time peak in all individual size classes. However, the effect of raindrop splash was less in observed sediment concentrations of the collected data from flumes having the smaller widths (0.25 m). For these flumes, the detached sediment was controlled by the transversal width of the flume. An amount of detached sediment adhered to the barriers instead of being removed in the overland flow. Moreover, the experimental results showed that the boundary conditions could affect the concentration of the mid-size and the larger particles.

The one-dimensional Hairsine-Rose model was used to fit the integrated data and so provide parameter estimates according each flume. The analytical results agreed with the total sediment concentrations but not the measured sediment concentrations of all individual size classes. However, the observed sediment concentrations for the individual size classes could be predicted only when the initial sediment concentration was adjusted and a new calculation of the settling velocities was used. This new settling velocity calculation was conducted by taking into account the effect of the raindrop splash on the deposition force of the particles.

5. Results

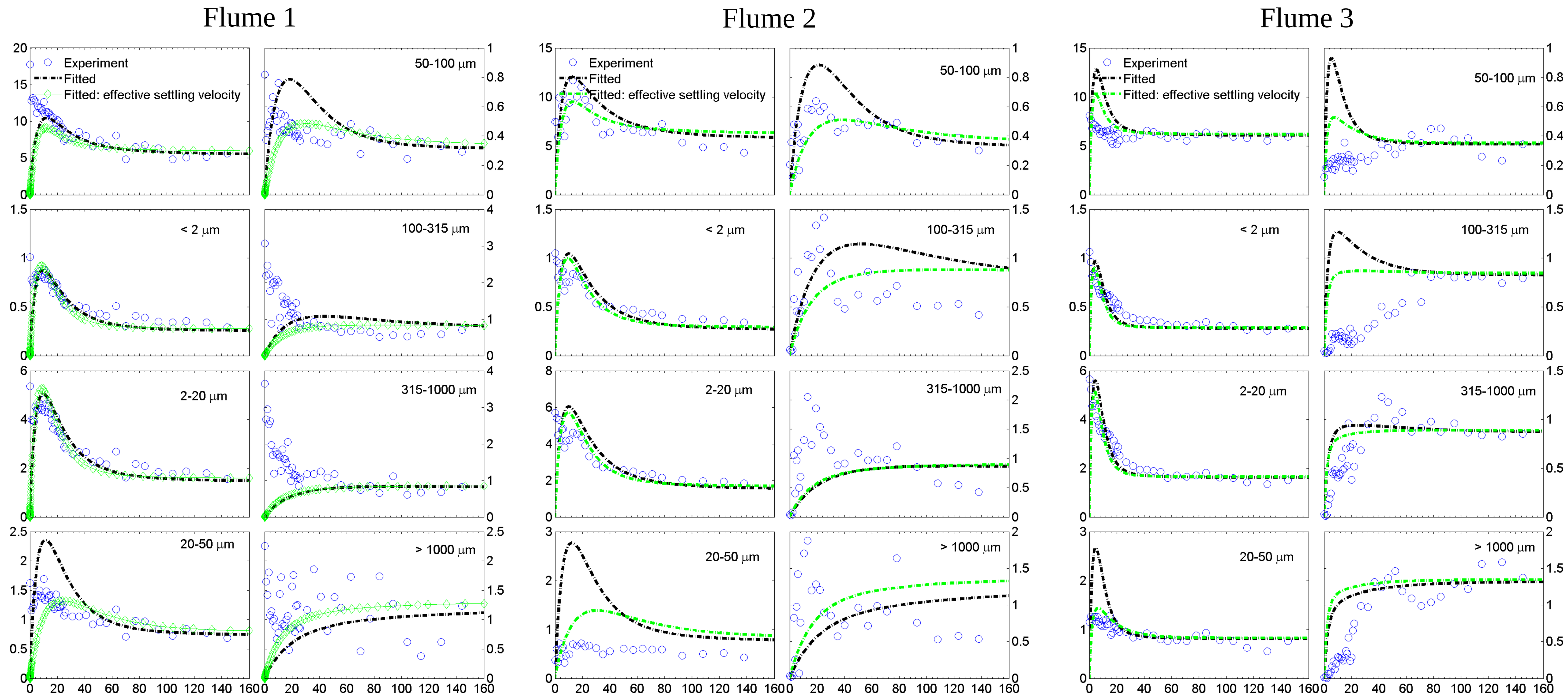

Fig. 4. Sediment concentration (g/l) as a function of time (min)

Table. 1. Best fit-parameters of the flumes

	a (mg/cm^3)		a_d (mg/cm^3)		m_{dt}* (mg/cm^2)	
	Fitted	Fitted: Effective settling velocity	Fitted	Fitted: Effective settling velocity	Fitted	Fitted: Effective settling velocity
Flume 1	35	30	8700	1600	0.30	0.30
Flume 2	35	35	8800	1700	0.40	0.40
Flume 3	75	70	8700	1500	0.10	0.10
Flume 4*	35	40	8000	2000	0.20	0.15

* The behaviour of the flume 4 s different from the other flumes. the position of the collector 4 has generated an additional amount of larger particles in the corner. However, the concentrations of finer particles were consistent with the other flumes.

6. References

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