Parameter Changes from Upscaling of a Local Scale, Process-Based Erosion Model

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1. Introduction and motivation

Soil erosion affects agricultural productivity, the natural environment and infrastructure security. Soil loss and its associated impacts are important environmental problems. Consequently, model-based prediction of erosion are beneficial of variety of applications. Process-based erosion models are used to forecast sediment transport concentrations as they vary temporally and spatially. Of these, the one-dimensional Hairsine-Rose model describes multiple particle size classes, rainfall detachment, flow-driven entrainment and deposition [1-3]. This model has been evaluated for different experiments, and has been shown to explain reliably experimental data in a consistent manner. In addition, recently it has been coupled with St. Venant equations, to facilitate the application of this model to complex scenarios [4]. Therefore it is appropriate to examine the Hairsine-Rose model applied at different laboratory scales, especially as it is documented that the scale of study can have a significant affect on soil erosion studies. One-dimensional parameter determinations, which are based typically on outflow data, implicitly average the two-dimensional flow. Here we compare experimentally and numerically this averaging process for Hairsine-Rose model.

2. Objectives and methodology

This study examines the consistency of the Hairsine-Rose model at different spatial laboratory scales. In other words, we are interested to look at the Hairsine-Rose model parameter changes corresponding to different transversal widths at the laboratory scales and, if these changes exist, investigate their origin. In order to achieve this, laboratory experiments were performed using different configurations of the 2 m 6 m EPFL erosion flume. The flume was divided into 4 transversal smaller flumes, with widths of 1 m, 0.5 m, and 2 0.25 m, but otherwise identical (figure 1).

A series of experiments provided data sets for analysis by the Hairsine-Rose model. After running the experiments, the amount of the eroded sediment in each subplot was assessed by comparing the temporal variation of eroded mass to evaluate the effect of, and sensitivity to, transverse width on erosion dynamics. The surface elevation changes due to erosion were examined to provide further understanding of the erosion data. A high resolution laser scanner provided details of the soil surface in the form of digital terrain models before and after the experiment.

3. Model

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

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

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 ar (kg/m^2)
I = the total number of size classes

4. Design of experiment

The erosion experiments were conducted at the EPFL erosion flume. The flume and sprinkling system are described elsewhere [5]. Here we describe the major modifications carried out on the experimental system: (i) we divided the EPFL flume into smaller flumes with different widths, (ii) we adapted the collector location regarding the new design of experiment, (iii) we manufactured a mechanical system to ensure a consistently smooth surface before the experiments and to assess manually any subsequent elevation.

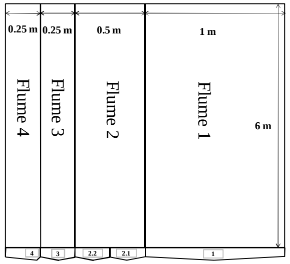


Figure 1. Design of experiment, flumes at different widths and collector locations.

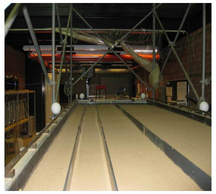


Image1. Before the experiment

Image 2. After the experiment

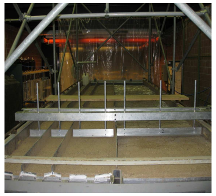
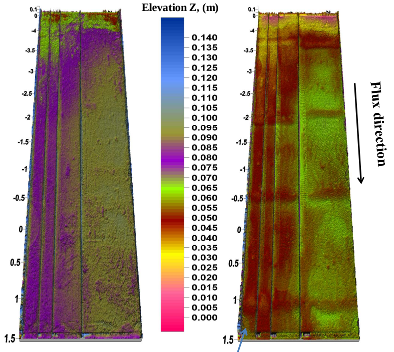


Image 3. Homogenizer system

5. DTMs investigation



Scan 1. Before the experiment

Scan 2. After the experiment

*Additional amount of deposited sediment in the corner generated by the collector's location.

Figure 2. DTMs of the flumes before and after the experiment were generated using a high resolution laser scanner.

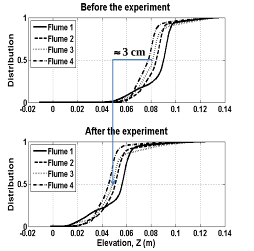


Figure 3. Elevation distributions for each of the flumes, before and after the experiment. The distribution maintains the same behaviour after the experiment although the curves are translated. Despite, the horizontal lines in figure 2, the rainfall distribution is relatively uniform over the flumes. The range of the elevation change due to erosion is 1.5-3 cm. These results were confirmed manually using the surface smoothing system (image 3).

The scans in figure 2 show with a high accuracy the soil surface variations before and after the experiment. The first scan shows the smooth top soil surface before the experiment. Despite the fact that different techniques were used to avoid local depressions within the flumes, they were not enough to obtain an uniform roughness accurate within 1 mm. The second scan shows the elevation distribution over the flumes after an erosive event. This scan highlights the effects of the rainfall patterns, and the distribution of the eroded and deposited zones over the flumes.

6. Experimental results and numerical approximations

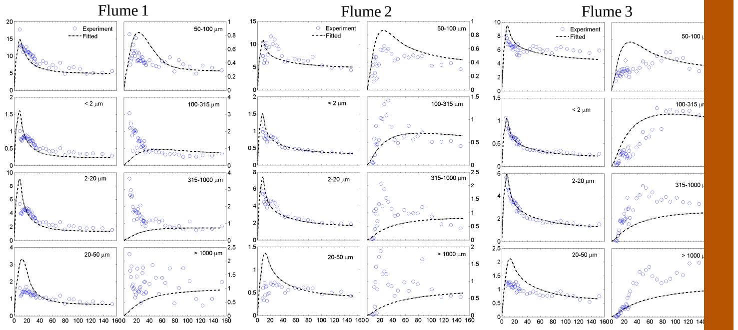


Figure 4. Sediment concentration (g/l) as a function of time (min)

Table 1. Best-fit parameters for the flumes

Best-fit parameters	a (mg/cm^3)	a_d (mg/cm^3)	m_{dt}^* (mg/cm^2)
Flume 1	60	25,000	0.65
Flume 2	30	20,000	0.75
Flume 3	30	20,000	0.90
Flume 4*	20	10,000	0.30

*The behaviour of the flume 4 (figure 5) is different from the other flumes. DTMs have shown that the position of the collector 4 has generated an additional amount of the larger particles in the corner (figure 2). However, the concentrations of finer particles were consistent in comparison with the rest of the flumes.

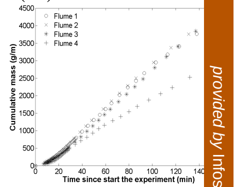


Figure 5. Cumulative mass per unit w as a function of time for the flu

7. Discussion

Estimation of the values of the detachability of the original bare soil (a), the detachability of the deposited layer (a_d) and the mass per unit area needed for the complete shield layer (m_{dt*}) was difficult due to the low water depth and the roughness of the soil surface. Nevertheless, these parameters were optimized manually, accounting for constraints like the fact that (a_d) should be greater than (a). With the same optimized values, the numerical approximations could represent the total sediment concentrations well but could not represent the measured sediment concentration of the all individual size classes, especially of the large particles. But, by adjusting these empirical parameters individually for each flume we improved the fitting of the concentrations of individual size classes (figure 4, table 1). Therefore, the consistency of the soil erosion behaviour is due to particular factors, such as; initial roughness, collector's location. To better assess the origin of these variabilities, the DTM study was conducted.

8. Conclusion

By comparing the experimental results and the numerical approximations, taking into consideration the DTM investigations we concluded:

- The Hairsine-Rose erosion model is consistent at different laboratory scales, however, its consistency is controlled by some parameters (initial roughness, collector location, rainfall pattern).
- The concentrations of the mid-size and the larger particles are more sensitive to these parameters than the finer particles, however, the finer particles are consistent independent of the change in transverse flume width.
- A high resolution laser scanner is a promising method for the identifying the spatial distribution patterns of eroded soil.
- The spatial distribution of the rainfall over each flumes is near uniform (figure 3), however, locally the rainfall pattern is not uniform (figure 2).

9. References

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