H11E-0868

Modeling Size-Selective Soil Erosion and Nutrient Transport in Flume-Scale Experiments

Peter Heng[1], Alona Armstrong[2], Jim Chandler[1], John Quinton[2], Graham Sander[1], Cecil Scott[1], and Andrew Wheatley[1].
1) Loughborough University, Loughborough, UK. 2) Lancaster University, Lancaster, UK.

Funded by: NATURAL ENVIRONMENT RESEARCH COUNCIL

A. Introduction

Soil erosion is a major environmental problem in many parts of the world, often impacting surface water quality and aquatic ecosystems as the eroded sediment and associated nutrients are carried by overland flow into water bodies.

Since (a) sediment transport is a size-selective process, and (b) the highest concentrations of sorbed nutrients are associated with the finest particles, it is important to understand and model the size selectivity of soil erosion for better predictions of sediment and nutrient fluxes.

Here we use a multiclass soil erosion model with a simplified nutrient transport component to reproduce observations from a series of flume-scale soil erosion experiments with simulated rainfall.

B. Experimental Setup

Soil: Silt loam, particle size distribution (PSD) shown in Fig. 1.

Flume dimensions: 3.9 × 1.4 m.

Slopes: 3%, 6% and 9%, with triplicate runs (R1, R2 and R3).

Rainfall intensity: 47 mm/h.

Further details in [1].

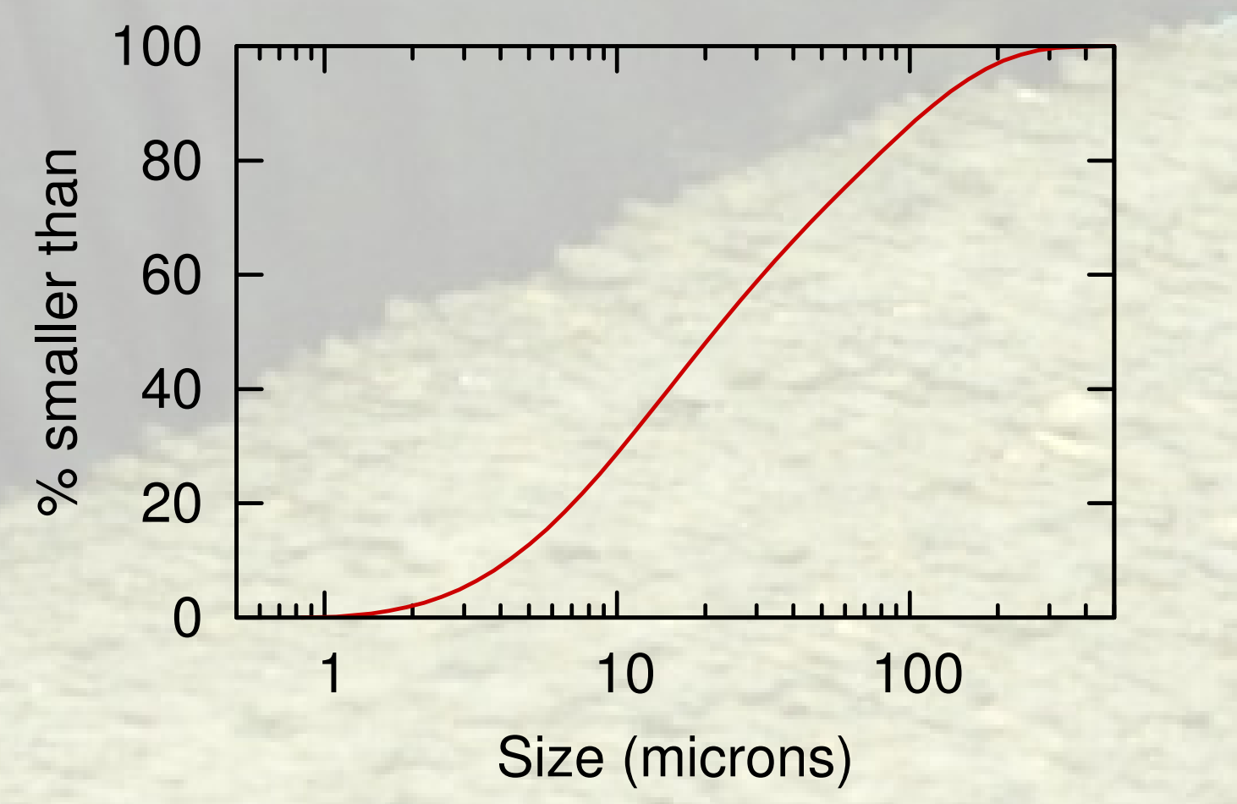

Fig. 1. Soil PSD.

C. Soil Surface Measurement Using Digital Photogrammetry

Soil surface microtopography affects surface runoff and hence sediment transport. Close range digital photogrammetry was used in our study to generate digital elevation models of the soil surfaces before and after experiments [2]. The high resolution topographical data (Fig. 2) helps explain some of the experimental variability observed, and provided spatial input into the soil erosion model.

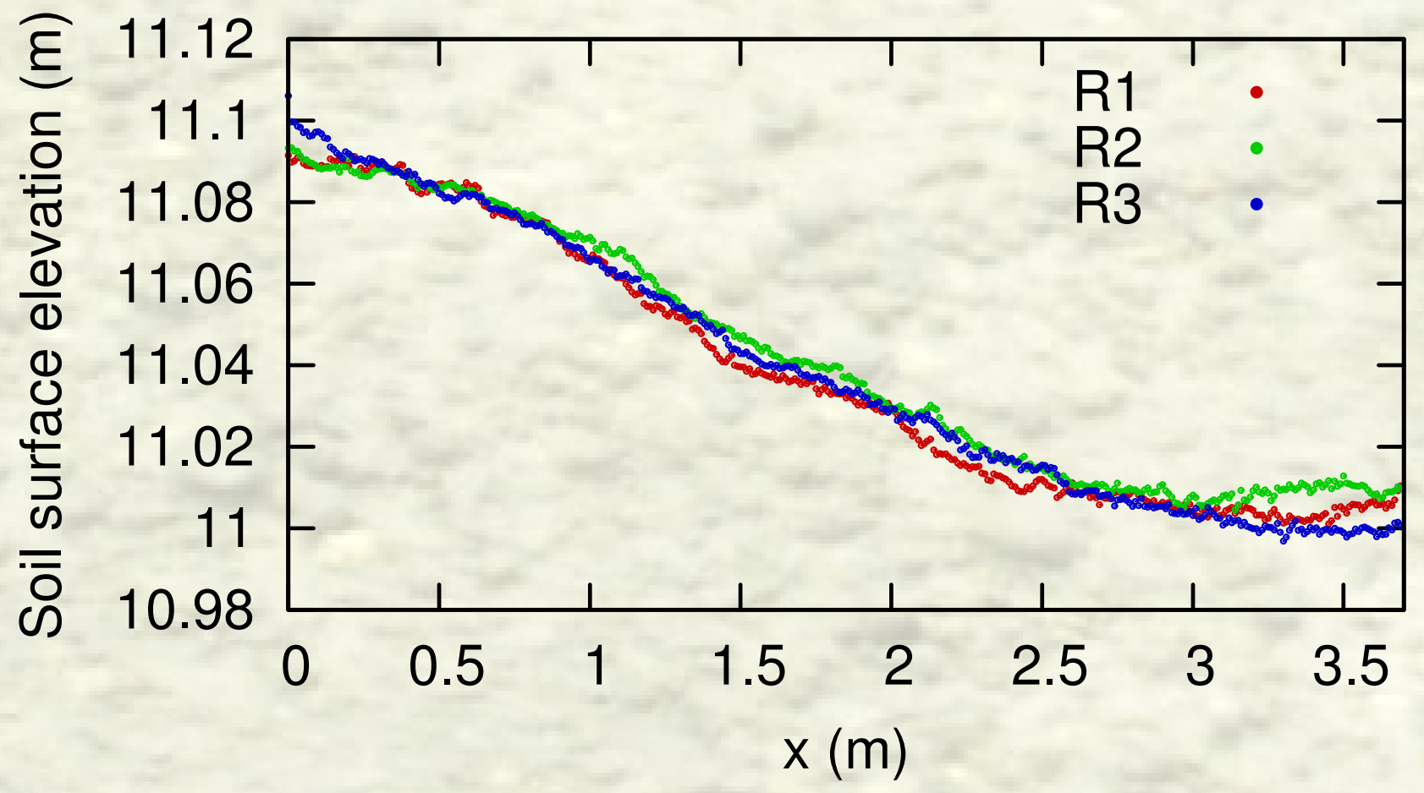

Fig. 2. Longitudinal profiles of the 3% slopes (averaged over 3 transects). Differences between the slopes explain in part the sediment flux responses observed (Fig. 3).

D. Modeling: Runoff and Sediment Fluxes

The Hairsine-Rose (H-R) soil erosion model [3] is capable of modeling the complex dynamics of soil erosion, including the evolution of the surface soil, under both net erosion and net deposition conditions. Using a 1-D numerical implementation of the model coupled with the Saint-Venant equations [4], we can simulate more closely the experimental conditions, including the initial period prior to ponding and runoff generation, the decline in infiltration with surface sealing, and unsteady flow over non-uniform topography.

We defined 10 sediment size classes based on the soil PSD. Table 1 shows the model parameters optimized to fit the experimental observations for runoff and sediment fluxes (Fig. 3). The variation in the model parameters reflect to some extent the experimental variability. We note that the model reproduces the coarsening of the eroded sediment (reflecting the evolution of the surface soil) as well as the total sediment concentration (c_t) in the runoff.

Table 1. Optimized model parameters. f_0, f_c and k relate to the Hortonian infiltration model. a denotes the detachability of the parent soil, and a_d that of the deposited sediment. m_t is the sediment mass required to shield the parent soil completely.*

Slope	Replicate	f_0 (mm/h)	f_c (mm/h)	k (10^{-3} s^{-1})	a (kg/m^3)	a_d (kg/m^3)	m_t^* (kg/m^2)
3%	R1	53	16	0.80	22	250	0.6
	R2	60	4	0.50	18	230	0.8
	R3	50	13	0.75	35	250	0.9
6%	R1	39	11	0.71	15	220	0.5
	R2	49	22	0.94	15	210	0.5
	R3	46	5	0.93	17	260	0.8
9%	R1	60	13	0.69	15	200	0.8
	R2	57	0	0.44	14	330	1.4
	R3	48	4	0.82	35	1000	3.0

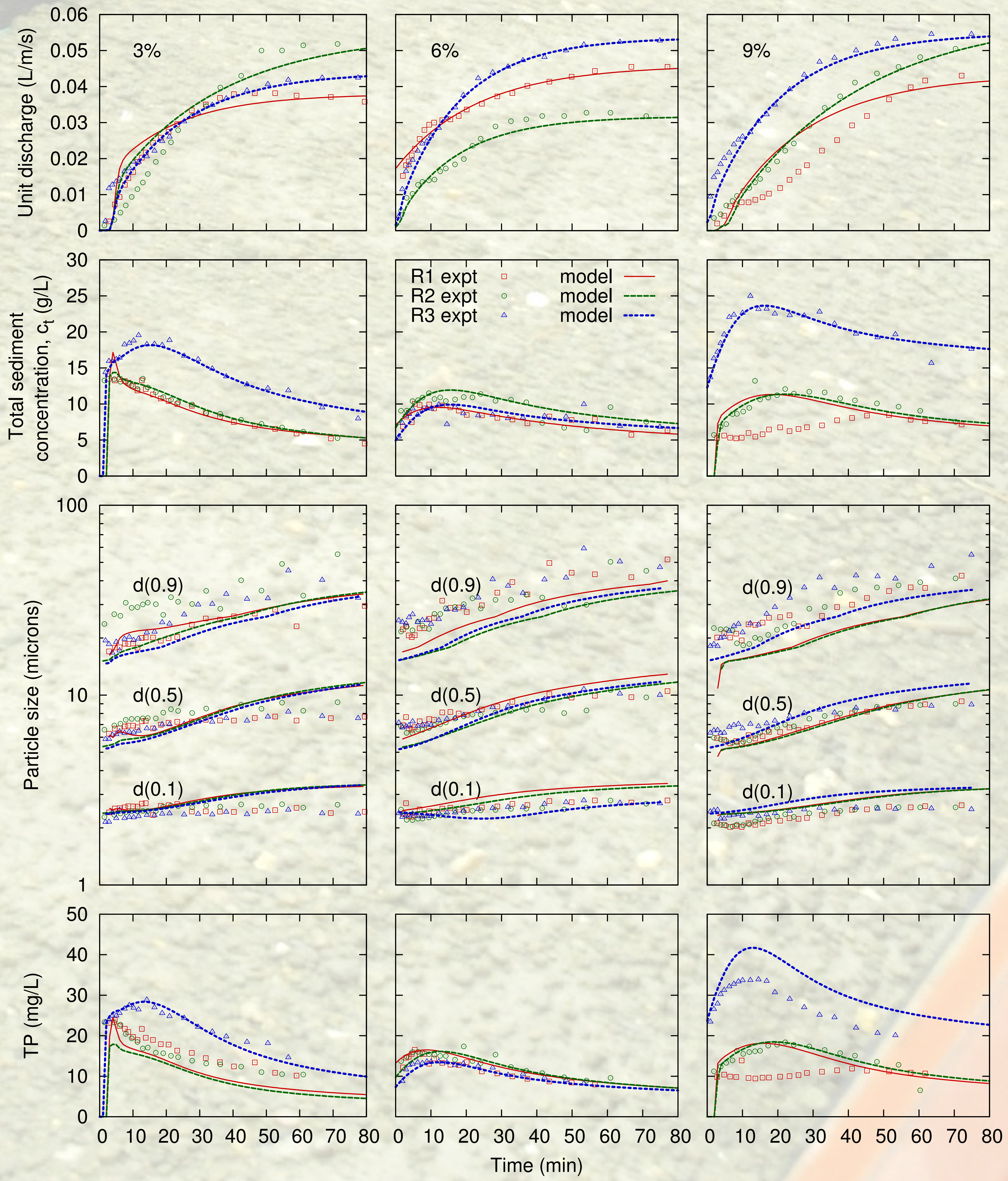

Fig. 3. Comparing model output with experimental data for 3% (left), 6% (center) and 9% slopes (right), with triplicates R1, R2 and R3. d(0.1), d(0.5) and d(0.9) denote particle sizes at the 10th, 50th and 90th percentiles respectively.

E. Modeling: Nutrient Fluxes

The total phosphorus concentrations (TP) were modeled assuming near-instantaneous equilibrium partitioning between dissolved P (TDP) and sediment-sorbed P, with a different partition coefficient K_i^{eq} for each sediment class i, that is,

$$TP = TDP\left(1 + \sum K_i^{eq} c_i\right).$$

Using measured TDP and c_i data, and by minimising the difference between the modeled and observed TP across all runs, we obtained a set of optimized K_i^{eq} for the soil used in our study (Fig. 4). The size dependence is evident. The $K^{eq} - d$ relationship appears to be an exponential one.

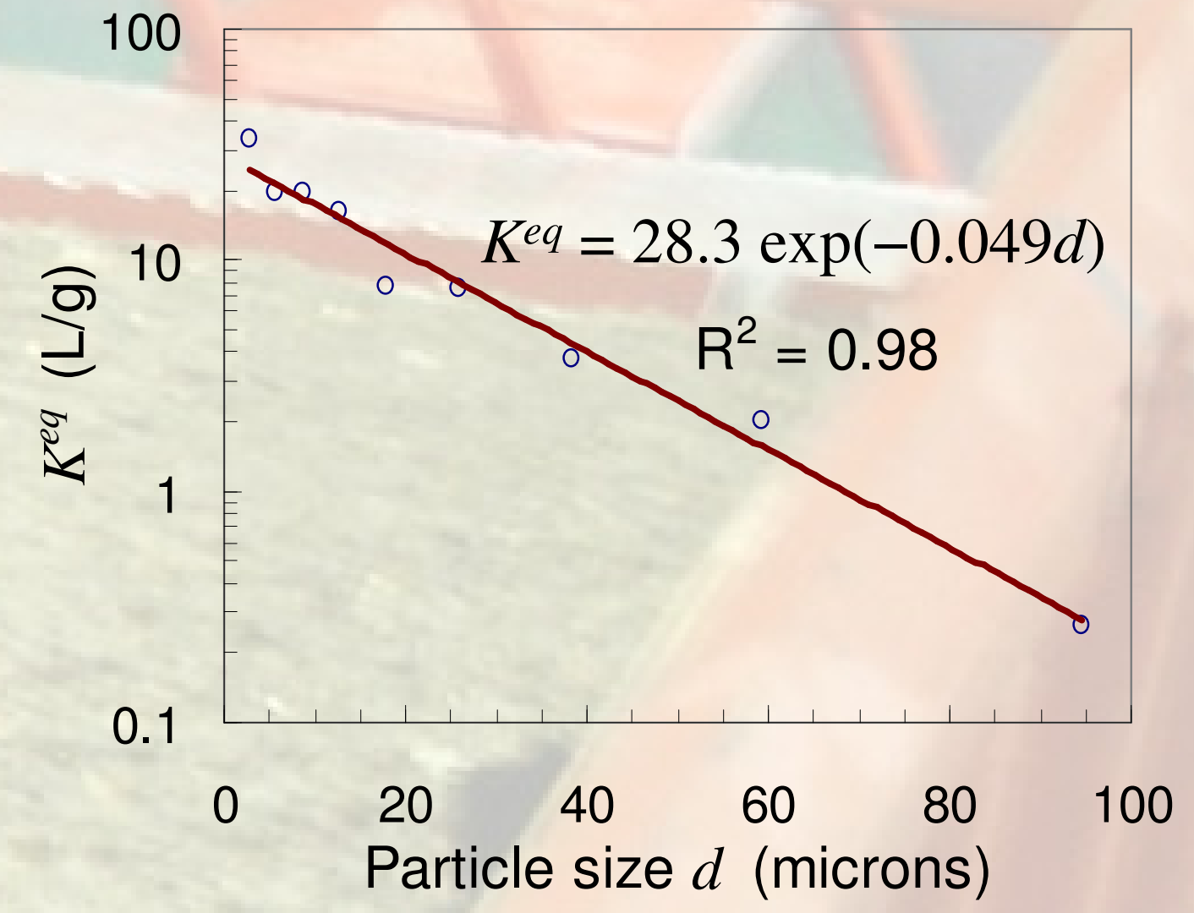

Fig. 4. Variation of the equilibrium partition coefficient with particle size. Points are optimized values derived from the experimental data. Line shows exponential trend.

Replacing the measured c_i with the solution of the H-R model, we obtain a composite model output (Fig. 3, last row) that gives some indication as to the model's ability to predict nutrient fluxes, from estimates of TDP alone.

F. Conclusions

The observed sediment fluxes and PSD trends are generally well reproduced by the H-R soil erosion model. This is requisite to obtaining accurate nutrient flux predictions, as the sorption of nutrients such as phosphorus is dependent on particle size. The simplified approach to nutrient transport modeling is shown to yield useful predictions of nutrient fluxes. There are important applications of this work in the light of governmental legislations on water quality such as the EU's Water Framework Directive.

References

[1] A. Armstrong, et al. Dominant controls over interrill soil erosion at low slopes. *ESPL*, in review.

[2] B. C. P. Heng, J. H. Chandler and A. Armstrong. Applying close range digital photogrammetry in soil erosion studies. *Photogramm Rec*, in review.

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

[4] B. C. P. Heng, G. C. Sander and C. F. Scott. Modeling overland flow and soil erosion on nonuniform hillslopes: A finite volume scheme. *WRR*, 2009, **45**(5):W05423.

Contact

E-mail: b.c.p.heng@lboro.ac.uk. Web: http://multisem.lboro.ac.uk.