MODELLING of OVERLAND FLOW and TRACER TRANSPORT EXPERIMENTS under SIMULATED RAINFALL at PLOT SCALE

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1 - Context & objectives

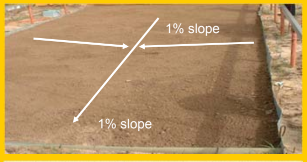
The Saint-Venant equations have consistently proved capable of accurately simulating hydrographs at plot scale. However, recent works showed that even though the hydrograph is satisfyingly reproduced, the flow velocity field within the plot might be wrong, with the highest velocities largely underestimated. Moreover, the choice of roughness models is most often done in the purpose of increasing the hydrograph quality, while the actual travel time of water is ignored.

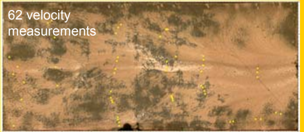
This poster presents a tracer experiment made on a 10-m by 4-m rainfall simulation plot, where travel time and tracer mass recovery as well as local flow velocity have been measured. Four roughness models are tested: (i) Darcy-Weisbach's model, (ii) Lawrence's model, (iii) Manning's model with a constant roughness coefficient, and (iv) Manning's model with a variable roughness coefficient which decreases as a power law of the runoff water depth.

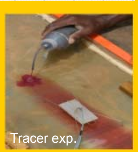
2 - The Rainfall Simulation Experiment

Experiments performed by IRD at Thies (Senegal) :

- 10 m long x 4 m wide plot, with 1% slope and sandy soil
- Rainfall simulator: rainfall at a constant average intensity of 70 mm.h^{-1}
- Plot preparation: well organized flow pattern







Surface runoff experiment: (Tatard *et al.*, 2008)
- Miniaturized salt velocity gauge (Planchon *et al.*, 2005)
- 62 mean local velocity measurements

Transport experiment: (Mügler *et al.*, 2011)
- Injection of 1 g.s^{-1} of tracer during 30 s at 8 locations in the plot
- Conductivity and ^{18}O measurements at the outlet of the plot

3 - Models

Overland flow :

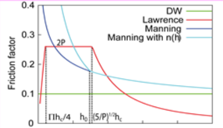
- Diffusive-wave approximation of the Saint-Venant equations

$$\frac{\partial h}{\partial t}-\vec{\nabla}.\left(\frac{\alpha h^{\beta+1}}{\sqrt{S}}\right)\vec{\nabla}\left(z_l+h\right)=R-I$$

with: *h*, the local water depth, *S*, the mean local slope, z_l, the land surface elevation, *R*, the rainfall intensity, *I*, the infiltration rate, $\beta=1/2$ and $\alpha=(8g/f(h))^{1/2}$.

- Friction factor *f(h)*

Model	Friction factor f(h)	Parameters
Darcy-Weisbach (DW)	f(h)=cste = f	f
Lawrence (Lawrence, 1997)	for $0 < h < \pi h_c/4$, $f(h) = (8P / \pi h_c) \times h$ for $\pi h_c/4 < h < (5/P)^{1/2}h_c$, $f(h) = 2P$ for $(5/P)^{1/2}h_c < h$, $f(h) = \min(10\times (h_c/h)^2, (1.64 + 0.803\times\ln(h/h_c))^{-2})$	P and h_c
Manning with constant n	$f(h) = 8g\, n^2 / h^{1/3}$	n
Manning with variable n(h)	$f(h) = 8g\, (n(h))^2 / h^{1/3}$ with $n(h) = n_0\times(h/h_0)^{-\varepsilon}$ with limit $n\geq n_0$	n_0, h_0, ε



Friction factor as a function of water depth

Tracer transport :

- Depth-averaged advective-dispersive equation (Weill *et al*., 2009)

$$\frac{\partial hc}{\partial t}+\vec{\nabla}.\left(h\vec{u}c-\overline{\overline{D}}\overrightarrow{\nabla c}\right)=q_c$$

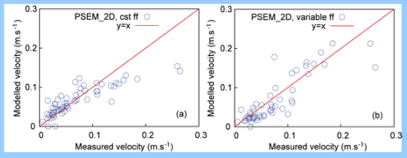
with: *c*, the depth-averaged concentration, *u* the runoff velocity, *D*, the diffusion-dispersion tensor, q_c a source or sink of concentration

Numerical scheme :

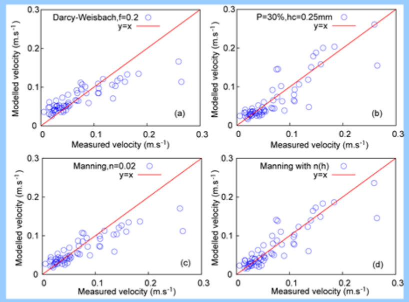
- Mixed-Hybrid Finite Element formulation (Dabbene, 1998) (Bernard-Michel *et al*., 2009)
- Cast3m code (www-cast3m.cea.fr)

4 - Simulation results

Surface runoff experiment :

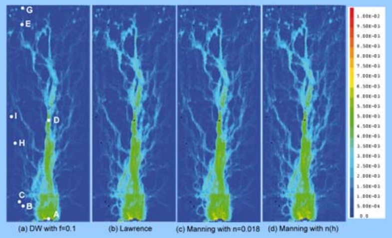


Modelled versus measured velocities obtained from PSEM_2D with:
(a) a constant friction factor *f*,
(b) a varying friction factor *f* (Tatard *et al.*, 2008).

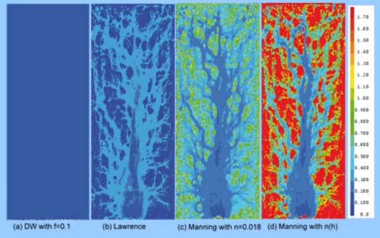


Modelled versus measured velocities obtained from Cast3M for four different friction laws (Mügler *et al.*, 2011):
(a) Darcy-Weisbach's model with a constant friction factor *f* equal to 0.2;
(b) Lawrence's model with *P*=30% and h_c=0.25 mm;
(c) Manning's model with a constant *n* equal to 0.02;
(d) Manning's model with *n(h)* with n_0=0.013, h_0=3 mm and ε=1/3.

Models with a constant friction factor largely underestimate high velocities. Moreover, they are not able to simulate tracer travel-times. Lawrence's model correctly simulates low and high velocities as well as tracer breakthrough curves. However, a specific set of parameters are required for each breakthrough curve from the same experiment. The best results are obtained with the Manning's model with a water-depth dependent roughness coefficient: simulated velocities are consistent with measurements, and a single set of parameters captures the entire set of breakthrough curves, as well as tracer mass recovery.

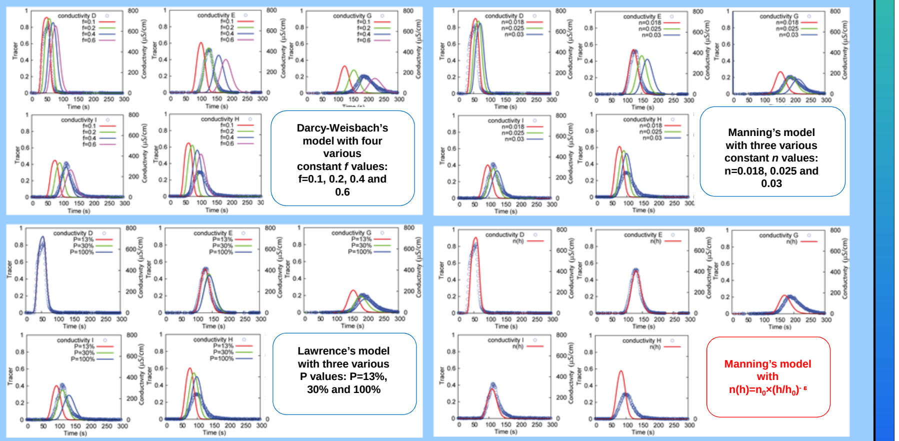


Water depth calculated with the various models



Friction coefficient for the various models

Transport experiment :



Darcy-Weisbach's model with four various constant *f* values: f=0.1, 0.2, 0.4 and 0.6

Manning's model with three various constant *n* values: n=0.018, 0.025 and 0.03

Lawrence's model with three various P values: P=13%, 30% and 100%

Manning's model with $n(h)=n_0\times(h/h_0)^{-\varepsilon}$

Breakthrough curves of tracer injected at points D, E, G, I, H (blue dots: conductivity data, full lines: models).

5 - Conclusion

Four roughness models have been tested to simulate surface runoff and tracer transport experiments under simulated rainfall at plot scale. This work brought the following findings:

➢ **Faithful simulation of the velocity fields does not imply a good prediction of travel time and mass recovery.**

➢**A Manning's model with a flow-dependent roughness coefficient gives the best results.**

The full dataset used in this work is available on request. It can be used as benchmark for overland flow and transport models.

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***Mügler** C., Planchon O., Patin J., Weill S., Silvera N., Richard P., Mouche E., 2011. Comparison of roughness models to simulate overland flow and tracer transport experiments under simulated rainfall at plot scale, to be published in J. Hydrol.*
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