Self-organisation of morphology and sediment transport in alluvial rivers

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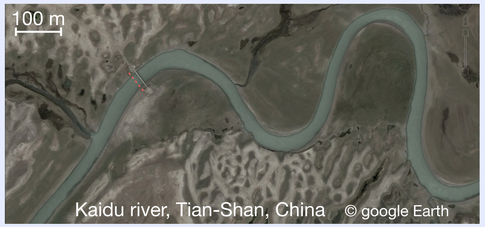
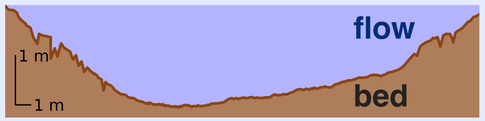
1. Introduction

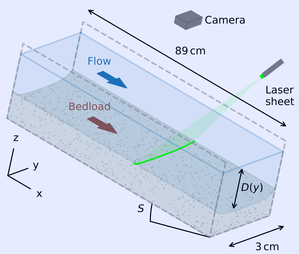




Alluvial rivers dig their bed in the sediment they carry: the flow entrains sediment grains and deposit them downstream, thus deforming the channel that confines it [Leopold & Maddock,1953]. This fluid-structure coupling selects the shape an alluvial channel: gravity pulls the traveling grains toward the center of the stream. To maintain its banks, a river thus needs to balance this transverse flux of sediment [Parker, 1978].

We investigate this process in simplified laboratory experiments.

2. Experimental setup



A viscous mixture of water and glycerol entrains a bed of plastic sediment (size = 830 μm).

Viscous fluid → **laminar flow** (Re < 250).

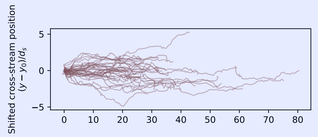
After a few hours, the sediment bed reaches an equilibrium shape.

Camera's field of view with superimposed grains trajectories (red lines).

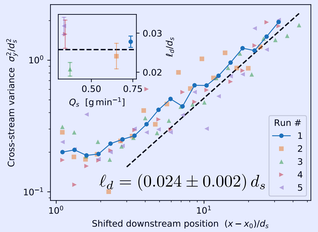
Measurements:

- particle trajectories,
- local sediment flux,
- laser deviation → bed elevation.

3. Particle trajectories : bedload diffusion



Deviations induced by bed roughness turn the trajectories into a random walk across the stream [Samson *et al.*, 1998].



Cross-stream variance increases linearly with the travel distance.

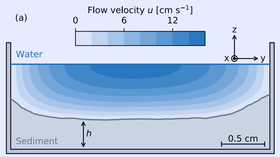
→ random walk [Seizilles *et al.*, 2014].

Random walk induces diffusion in the cross-stream direction:

$$q_d = -\ell_d \frac{\partial q_s}{\partial y}$$

diffusion length; streamwise sediment flux; cross-stream diffusive flux; cross-stream coordinate

4. Profiles of bed topography and sediment flux

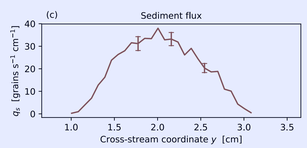


Blue colormap: downstream flow velocity calculated with finite elements.

- Sediment bed is convex, confining particles in its center.

Flow-induced shear stress on the bed.

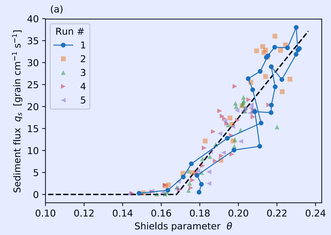
- Viscous stress is maximum at the center of the channel. It vanishes where the bed's surface joins the walls.



Sediment flux measured by grain tracking.

- Sediment transport concentrates around the center of the flume.

5. Transport law

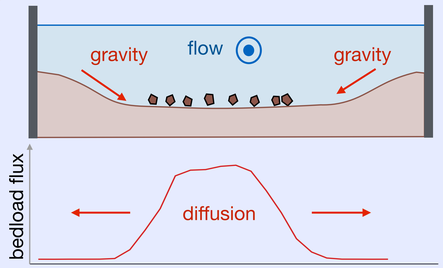


Local sediment flux vs local shear stress obeys the transport law :

$$q_s = q_0\,(\theta - \theta_t)$$

streamwise sediment flux; Shields stress

6. Equilibrium condition



At equilibrium, two cross-stream fluxes balance each-other:

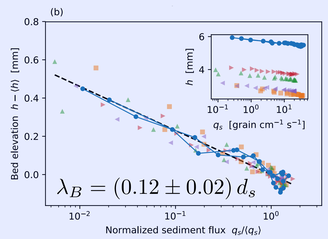
$$\ell_d \frac{\partial q_d}{\partial y} = -\alpha\, q_s \frac{\partial h}{\partial y} \qquad (1)$$

diffusive flux: pushes the traveling grains away from the flume's center.

gravity-induced flux: pulls the travelling grains towards the flume's center.

7. Boltzmann distribution

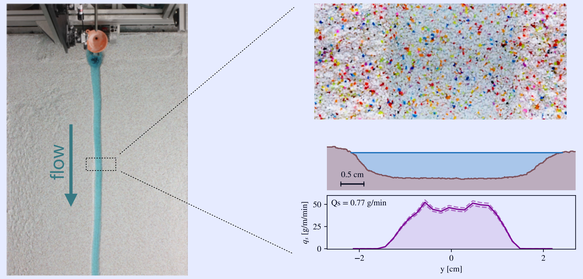
Equilibrium condition (1) → $$q_s(y) = q_0 \exp\left[-\frac{h(y)}{\lambda_B}\right] \qquad (2)$$



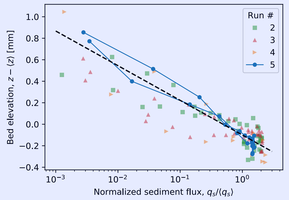
Sediment flux vs bed elevation.

- Experimental data accord to equation (2).
- Equation (2) is analog to the Boltzmann distribution in statical physics [Abramian *et al.*, Sub.].
- Cross-stream deviations of grains' trajectories play the role of thermal fluctuations.

8. Laboratory river



- A laboratory river not only selects its shape, but also its size.
- Sediment flux and bed elevation follow the same Boltzmann distribution as in the flume.



9. Conclusion

- Bedload particles wander randomly across the bed's surface, inducing a cross-stream diffusive flux [Seizilles *et al.*, 2014].
- The sediment bed adjust its shape so that the diffusive flux, which pushes the traveling grains away from the flume's center, balances the gravity-induced flux, which pulls them towards the lowest point of the bed's surface.
- The balance of diffusion and gravity results in a peculiar Boltzmann distribution, in which the bed's roughness plays the role of thermal fluctuations, while its surface forms the potential well that confines the sediment flux [Abramian *et al.*, Sub.].

References

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