Threshold surface concentration of microplastics triggering higher mobility on gravel bed

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Abstract

Transport processes of sediments depend on three physical variables (grain dimensions, density and shape), and their interplay defines the transport behaviour (Waldschläger et al., 2022). With this contribution we aim at investigating yet another variable which plays a role in sediment transport, and even a bigger role in microplastics transport: bed sediment availability. The effects of surface concentration of microplastics on a gravel bed was investigated using two types of microplastics particles with mean diameter comparable to that of the used gravel (d_{50}=3 mm). The range of surface concentrations spanned between 0.04% - 4% of surface covered in MPs. It was observed that MPs bed cover influences the conditions at which near-bed motion starts, and this transport behaviour differs for light and heavy particles. A comparison with reference condition suggests that a “critical concentration” exists at the bed, causing higher apparent mobility for both types of MPs tested.

MP transport in rivers

Microplastics are assumed to undergo transport and sedimentary processes similarly to clastic sediments.
When does transport start?

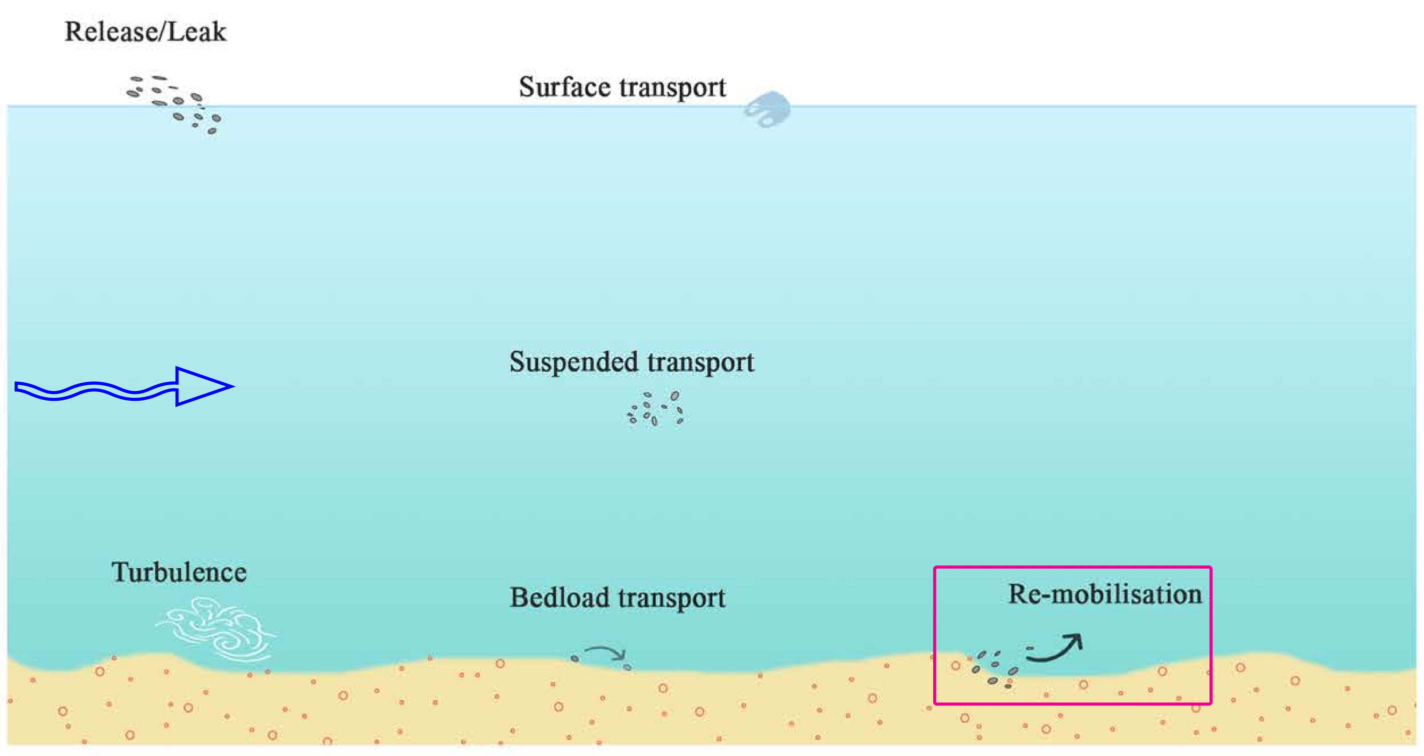


Figure 1. Different transport modes for different particles: for *clastic sediments* suspended and bedload transport are controlled by *grainsize*, for *microplastics* all modes occur depending also on the particles’ *density and shape*.

Experimental setup

Gravel bed experiments were carried out in a 5.2-m long, 0.25 m wide flume (Figure 2). The different concentrations were released at sub-threshold flow conditions, allowing both light (PA6) and heavy (POM) plastic particles to deposit within a length of 5 cm from the release section. By stepwise increments of the discharge, measurements of near-bed flow field with an UVP and of MPs movements on the bed via a camera were performed for each flow condition (see Figure 3).

Figure 2. Flume schematic plan view

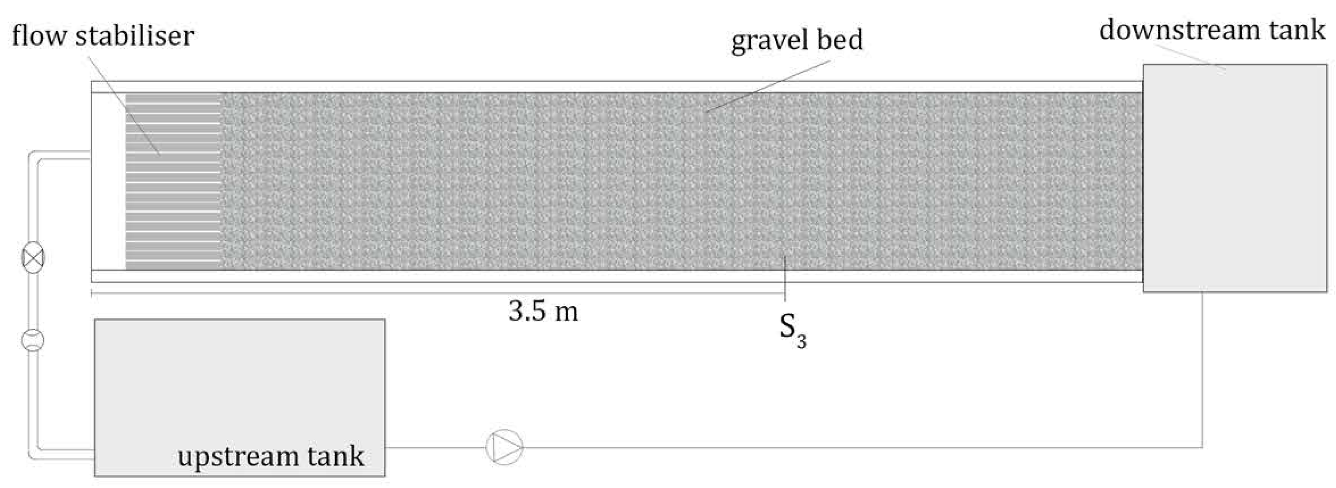
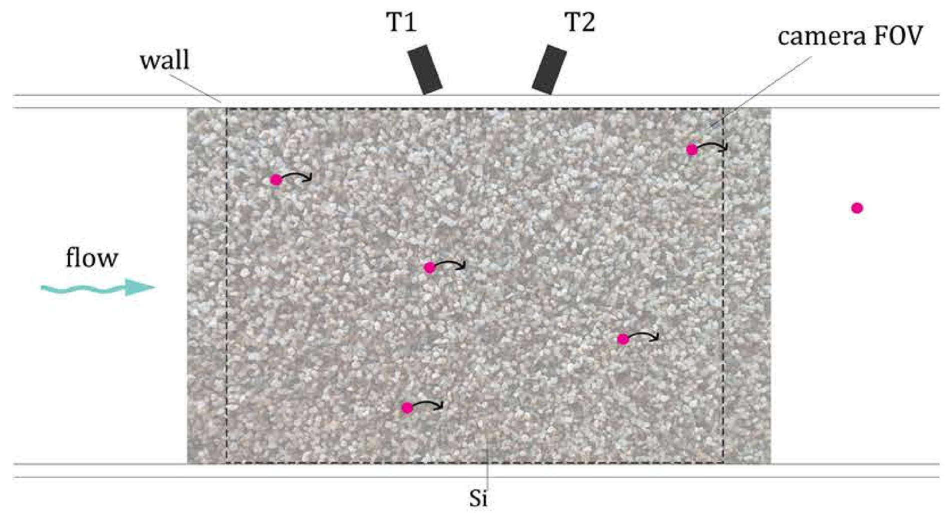


Figure 3. Top view of the experimental setup: dashed the field of view of the camera, T1 and T2 are the transducers of the UVP installed outside of the flume.



The flow-field was measured in the lower 25% of the flow depth, where the assumption of logarithmic law for the velocity profile is valid (Figure 4).
Velocity measurements in the near bed region provide data for the estimation of the threshold velocity u*, by using:

$$u = \frac{u^*}{\kappa}\ln z - \frac{u^*}{\kappa}\ln z_0$$

light-MPs

Threshold velocity can be used to estimate the bed shear stress, e.g the hydrodynamic forcing, just sufficient to trigger grain motion.

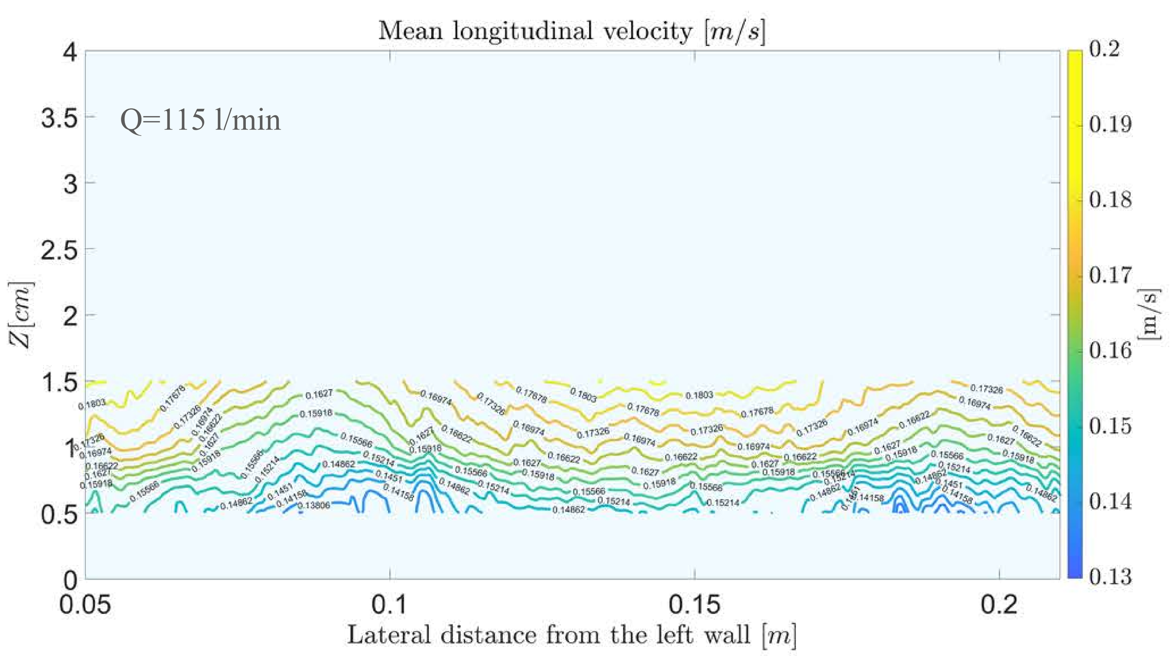


Figure 4. Near-bed measured, time-averaged flow field

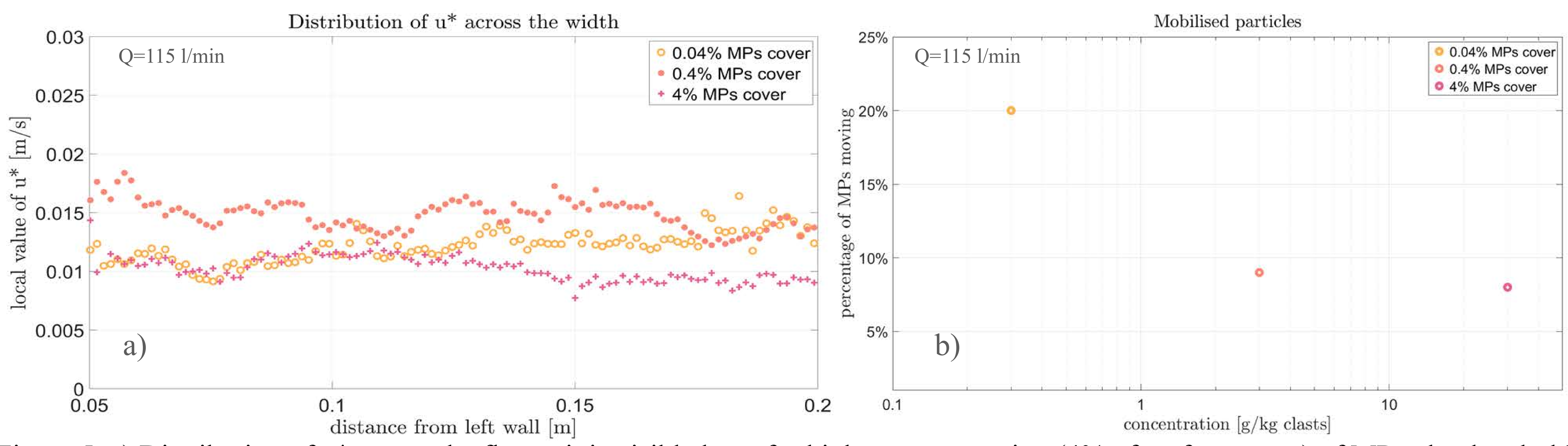


Figure 5. a) Distribution of u* across the flume, it is visible how, for higher concentration (4% of surface cover) of MPs, the threshold velocity is lower; b) percentage of moving grains versus concentration at threshold reference conditions.

Low bed surface concentration (i.e. 0.04% of surface cover) of light-MPs shew a behaviour similar to the one observed by the authors for MPs detaching from a loose bed composed of microplastics (reference conditions). As the MPs bed surface concentration increased, remobilisation of MPs occurred at mean flow velocities up to 15% lower than those at reference conditions.
Low bed surface concentrations of heavy-MPs, instead, were very stable on the gravelbed even with discharges 20% higher than the reference threshold flow, and remobilisation was observed only as their surface concentration surpassed 0.4% of the bed cover.

Conclusions

Bed surface concentrations of both light and heavy MPs were investigated, and two behaviours were observed. Heavy MPs, at concentration higher than 0.4% cover, react to varying discharges showing a threshold flow that is apparently not much affected by their availability at the bed surface, while for 0.04% cover, their stability at the bed is apparently uneffected by variations of discharge exceeding the reference threshold flow. On the contrary, light MPs show an apparent higher mobility, increasing with their availability on the bed. This apparent higher mobility depends on the concentration of MPs at the bed, in that the number of detachments is scaled upon the total number of MPs exposed to the flow. Further investigation is being carried out in this regard, to unfold the dependency on the definition of solid MPs flux, its relation to the MPs density and the bed-surface MPs concentration.

References

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