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Modulation of sediment transport rates and hydraulic resistance by increasing mud-to-sand ratios

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Biologically-mediated muds and sand-mud sediment mixtures are prevalent in lowland rivers, coastal, marine, and estuarine environments. These systems are highly sensitive to ongoing sea-level rise and environmental change. Effective management of these environments and adaptation to future changes, including mitigation to flood risk, requires accurate prediction of how flow and bed morphology changes over time, which has recently been shown to strongly depend upon substrate composition and the mud-to-sand ratios.

Mud is cohesive and helps stick granular sediment together, potentially reducing sediment transport rates and bedform growth, which impacts hydraulic resistance and thus the fluid flow. We examined the co-evolution of bedform growth (morphodynamics) and hydraulic resistance (hydrodynamics) in muddy, shallow coastal environments subject to the simultaneous action of waves and currents (combined-flow) through controlled physical experiments in the Total Environment Simulator at the University of Hull.

We conducted experiments with combined flow (regular waves plus a steady current in 0.4 m water depth) over 1.5 m wide channels constructed within the experiment basin (11 m long). The channels were each filled with a homogeneous sediment mixture of kaolin clay (D_{50} = 8 microns) and medium sand (D_{50} = 390 microns) in mud-to-sand ratios ranging between 0% (clean sand, baseline) and 16% by mass, to a substrate depth of 0.10 m. We ran the experiments to equilibrium conditions whereby steady-state bedform dimensions were approached with respect to the flow conditions. As such, longer experimental run-times were required for beds with higher mud-to-sand ratios. We quantified bedform formation and evolution, and flow velocities with a suite of acoustic sensors. With the 3D flow velocity data, we quantified turbulent fluctuations to assess the flow dynamics and estimate shear characteristics of the flow. We used these data to quantify hydraulic resistance.

Our results show that there is a mud-content threshold of approximately 8-11% (depends on

hydrodynamic conditions) below which clean sand ripples form once the finer sediment is winnowed out, leading to similar ripple heights as those measured for clean sand conditions at equilibrium. This in turns results in comparable hydraulic resistance (friction) to the low mud or sand-only substrates. However, increasing clay content suppresses bedform dimensions (shorter and smaller ripples), and thus reduces hydraulic resistance. Above the mud-content threshold, ripples are inhibited and sand transport rates are insignificant, resulting in minimal form drag and subdued skin friction. Our results suggest that hydraulic resistance predictors for muddy-, shallow-coastal environments need to account for the presence of mud and its modulating effects in sediment transport and friction, which ultimately affects flow properties and associated flood risks.