Experimental Exploration of Sediment Density Interactions

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Abstract

Sediment is typically modeled using a single density for the entire system, often silica. However, some systems contain a mixture of materials with densities that range from organic particles to heavy metals. If models do account for density, they treat the density-classes independently. This paper describes initial results from flume experiments with variable-density mixtures to explore interactions between density classes. We ran a series of tests in a 0.9 m wide by 22.9 m long flume with a light-colored silica (specific gravity ~2.65) and a red garnet (specific gravity ~3.6). The selected silica and garnet materials have similar angularity and gradation curves with a d50 of ~0.45 mm (medium sand). We thoroughly mixed the materials in the bed and fed the same mixture into the upstream end of the flume during each run. We collected lidar scans to estimate final bed slope and bedform geometry. The stoss slope was covered by the denser particles while the lighter sand collected in the troughs. This paper presents the qualitative results of early experiments and the testable hypotheses about density-class interdependence that the rest of the study explored.

Introduction

Riverine sediments are composed of a wide variety of materials, with variation in size, shape, and density. Current numerical models typically account for different grain sizes but ignore other types of variability. In cases where models do allow particles to have different densities, the models assume that density classes can be treated independently (e.g., van Niekerk et al., 1992; Gibson, 2006; Brown, 2014), but this has not been validated.

Early sediment transport equations assumed uniform gradations and a single density (e.g., Meyer-Peter and Muller, 1948; van Rijn, 1984). More recent sediment transport work has shown that there can be significant interactions between particle size classes (Parker and Toro-Escobar, 2002; Wilcock and Crowe, 2003). Parker (2007) demonstrates that including these interactions in models results in better performance. There has not been an equivalent effort to look at potential interactions between different particle density classes.

In this paper, we present the results from an initial flume run conducted using a mix of 50% light (silica) and 50% dense (garnet) materials. We discuss both our qualitative observations and the results of a post-run lidar survey of the bed.

Methods

Medium sands (d50 ~0.45 mm) composed of silica (specific gravity ~2.65) and garnet (specific gravity ~3.6) were carefully sourced to match both the particle size distribution and angularity. We mixed 50% silica and 50% garnet, by weight, in batches using an electric cement mixer to ensure an even mixture. We filled the bed of the flume to a depth of 8.9 cm and tilted it to a slope of 0.00154 m/m.

At the start of the flume run, we carefully backfilled the flume with water to minimize disturbance of the bed. We then ran 0.07 m^3/s of water through the flume for 3.25 hrs. During the run, we used a vibratory hopper to feed 1.5 kg/min of the 50% silica/50% garnet mixture into the upstream end of the flume. At the conclusion of the run, we gradually allowed the water to drain out of the flume.

Once the flume was drained, we used lidar to collect detailed surface elevations of the final bed. In order to capture as much of the bed topography as possible, we set up a local reference system within the flume building and collected lidar data from multiple positions. We then used the local reference system to integrate the multiple lidar data sets into a single point cloud. We manually removed points that were clearly spurious (e.g., those not near other surface points) and then created a 5 mm-resolution raster from the data, using the median value of the points in each raster pixel.

We used the generated raster to extract 50 longitudinal profiles parallel to the flume and spaced 1 cm apart. We ignored the outer 20 cm on each side of the flume, to minimize sidewall effects. The extracted longitudinal profiles were then used to estimate the final bed slope by calculating a regression line. To limit the effect of boundary conditions, we did not include the upstream and downstream 1 m of bed data.

We also collected cores, both along the length of the flume and in the downstream catch basin. Finally, we developed a bedform slicer (Dahl et al., 2021) to sample selected bedforms in order to examine their internal structure and effects of sorting.

Discussion

Bed Mixing and Sorting

The pre-experiment bed was uniformly flat with both garnet and silica particles evenly distributed across the surface (Figure 1, left). After the flume run, the bed was dominated by complex bedforms and there was clear evidence of material sorting (Figure 1, right). The surface of the bedforms was primarily garnet while concentrations of silica material were observed in the lee of the bedforms. This may indicate that the sediment transport conditions on the stoss side of the bedforms were sufficient to keep the silica moving, but the flow separation on the lee side of the bedform allowed the silica to settle. Li and Komar (1992) observed a similar concentration of dense material on the stoss side of ripples in a flume experiment with low concentrations of dense material. This may be evidence of differing rates or even modes (e.g., rolling vs. saltation or suspended) of transport and supports our hypothesis that there are important interaction effects between the sediment types.

Figure 1. Photos of the flume bed, looking upstream before (left) and after (right) the experiment.

Lidar Data and Bed Slope

The complexity of the bedforms and the confines of the flume made collection of post-run lidar challenging, but we were able to construct a complete digital elevation raster of the flume (Figure 2).

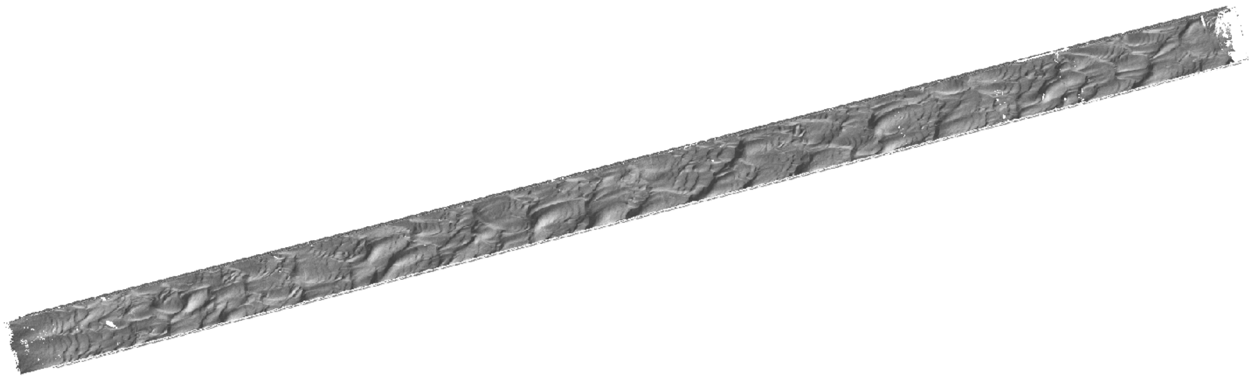

Figure 2. Post-experiment lidar of the flume bed shown with hillshading. Flow was from lower left to upper right.

The variation of the bedforms, both laterally and longitudinally, meant that any single longitudinal profile might not accurately represent the final bed slope of the experiment (see Figure 3 for representative variability). Our methodology allowed us to calculate that the final bed had a mean slope of 0.00224 m/m with a standard deviation of 0.00016. This was significantly steeper than the slope at the start of the run.

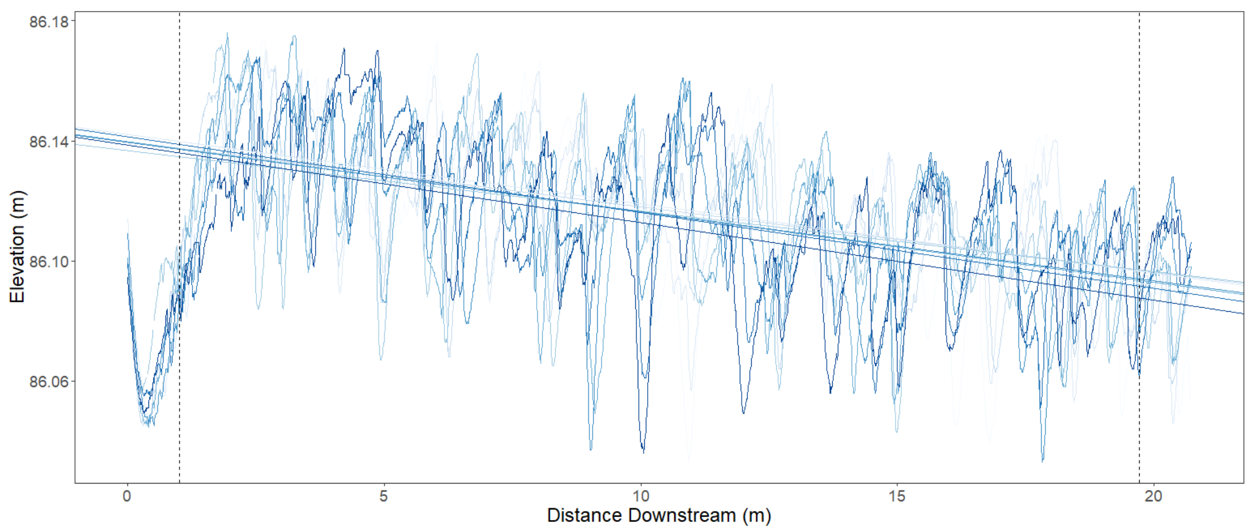

Figure 3. A selection of longitudinal profiles and corresponding regression lines. The dashed, vertical lines indicate the upstream and downstream extents of data used to create the regression lines.

Conclusions

This experiment demonstrated that mixtures of different density sediments can result in complex sorting and mixing during transport. Our methods were able to capture both the resulting mean behavior and variability of the longitudinal profile. Future experiments and analyses will expand on this to look at the difference in behavior across a range of light to dense particle ratios, allowing a quantitative examination of the density interaction effects.

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