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TURNING THE TIDE: LIVE-BED SCALE EXPERIMENTS OF BAR-DOMINATED ESTUARIES AND EFFECTS OF DREDGING ON INTERTIDAL HABITAT

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1 INTRODUCTION

Many large sand-dominated estuaries and tidal basins have complex channel and bar patterns, wherein a continuous deep channel suitable for shipping is rarely naturally present, which requires dredging. The intertidal area has important, often protected habitats for macro-benthic species, wader birds and other species. The question is to what degree channel and shoal dimensions and the amount of intertidal area are affected by dredging and disposal for access to ports.

While numerical modelling is conducted for these systems with some success, complementary scale experiments with live beds have challenged the fields of coastal engineering and coastal morphodynamics for over a century. Compared to scale models for rivers, the scale issues in tidal experiments are more complicated and very few attempts have been pursued. For example, Reynolds (1889) conducted the first scale experiments of an estuary by a periodic sea level fluctuation, but found that even fine sand was hard to mobilize, while the bed surface was dominated by ripples rather than bars. Similarly, Tambroni *et al*. (2005) carefully scaled sediment mobility in a converging channel and obtained large-scale morphological patterns with gentle bars nearly overwhelmed by ripples. Stefanon *et al*. (2010) present a careful attempt at erosive tidal channel network development in a scale model with low-density sediment, which showed unexplained, over-large scour holes at channel junctions. The key issues for tidal experiments are to obtain sufficient sediment mobility (expressed as Shields or Rouse number) and to avoid over-large ripples and scours, and to this end classic river scale modelling is inadequate. Here we assess whether our recent innovation solves these scale issues. The objective of this abstract is to elucidate the scaling of experiments that enable study of morphodynamic estuaries in many aspects including effects of sediment management by dredging.

2 METHODS

We designed and built a periodically tilting flume of 20 m long and 3 m wide, called the Metronome. The tilting drives sufficiently high sediment mobility along the estuary, which is not accomplished by periodic sea level fluctuation as also evidenced by one-dimensional modelling with the shallow water equations (Kleinhans *et al*., 2017). Without tilting, the shallow water depth (a few cm) in a typically sized laboratory setting causes rapid damping of the tidal wave, transition to laminar flow, limited sand transport in the ebb direction and none in the flood direction. By tilting, the inadequate Reynolds approach of mainly horizontal tidal current generation by mainly vertical water level control is avoided. Instead, periodic tilting at slopes less than 0.001 m/m directly generate periodically reversing currents. The coastal sea is kept at near-constant depth and horizontal water level is set by a weir that moves periodically at a 180º phase shift to keep the sea surface approximately horizontal. Regular waves are generated by a horizontal paddle. On the landward boundary, river discharge is supplied. The tilting period controls the degree of flooding and was empirically set at 40 s, and overtides can be applied to simulate the M4 tidal component as found in the North Sea offshore of the Western Scheldt estuary.

As an example we present a control experiment without dredging, and an experiment with dredging. Experiments with bank protection are presented in Nota and Kleinhans (this conference). The initial sand bed had a central, convergent but narrow channel carved into a 0.07 m thick sand layer. The sand is poorly sorted and has a median diameter of 0.52 mm and a 90^{th} size percentile of 1.2 mm, which, combined with the roughness caused by saltation, avoids that the viscous sublayer is thicker than the particles. This has proven essential to avoid the scour holes and ripples (Kleinhans *et al*. 2017a) found in numerous previous experiments. In a second experiment, the dredging and disposal protocol followed that of the Western Scheldt (Cox *et al*. 2022) for initial channel deepening and fairway maintenance by removal of sediment from shallow areas and disposal primarily on bar margins. Photogrammetry was used to create bathymetric maps and a two-dimensional flow model was used after verification on particle imaging velocimetry for flow fields and tidal prism calculation (Weisscher *et al*. 2020). Using these and other experiments, a synthesis of possible scale effects of Metronome experiments will be presented.

3 RESULTS AND DISCUSSION

The flow velocity amplitude was 0.2-0.5 m/s depending on location and showed flood-dominance on the bars and ebb-dominance in the channels. The flow was turbulent for most of the tidal cycle, remained subcritical, and caused general sediment mobility with Shields numbers up to 0.5. Local tidal prism reduced nearly linearly from the inlet to the upstream boundary. Over 11,000 tilting 'tidal' cycles, the experiments developed channels and bars and eroded the unprotected banks to develop a natural estuarine shape with wider and narrower reaches, as also found in earlier experiments (Leuven *et al*., 2018). After initial development (3000 tidal cycles), deepening and dredging commenced. Compared to the control, dredging resulted in a deep single channel that migrated less than the multi-channel system. In the dredged case there was more landward tidal penetration in the main channel, a reduction of intertidal area and a greater tendency to develop meanders, scour outer banks and erode the banks (see Leuven *et al*. (2018) and Cox *et al*. (2022) for details). This is in general agreement in many respects with observations in the Western Scheldt. Tidal bar length, width and height show the same proportionality to local estuary width as natural estuaries worldwide, meaning that the self-formed morphology is not distorted.

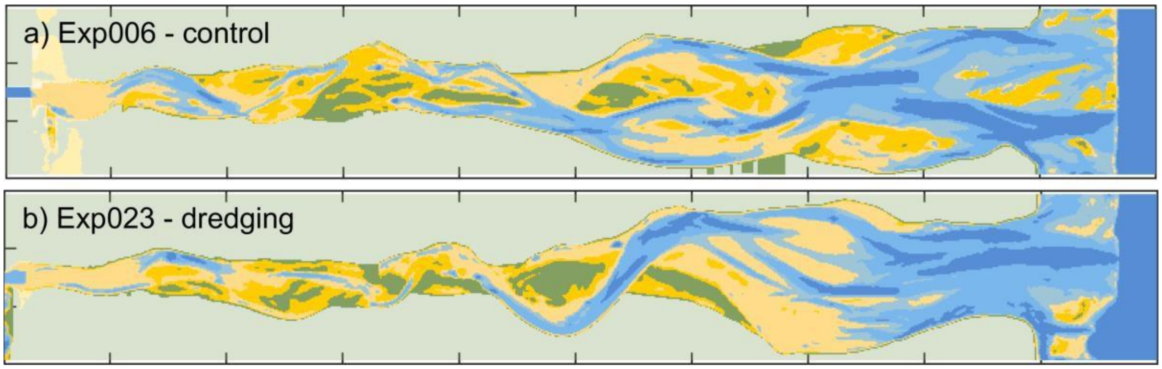

Figure 1. Bathymetry classified by depth from the flow model of the experiment without (top) and with (bottom) dredging.

4 CONCLUSIONS

Tidal systems with live beds can now experimentally be created at a length scale of order 1:1000 with subcritical, turbulent flow and appropriate sediment mobility, and without distortion, problematic ripples or scour holes. Experiments show self-formed channel-bar patterns quantitatively similar to those in natural estuaries. Dredging fixes and deepens the main channel at the cost of reduced intertidal habitat area, increased flood risk and the need for perpetual maintenance.

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