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A MORPHOLOGICAL ASSESSMENT ON THE EFFECTS OF EMBANKMENTS ON SEDIMENT TRANSPORT IN SANDY ESTUARIES

EISE W. NOTA[1], MAARTEN G. KLEINHANS[2]

1 Utrecht University, Department of Physical Geography, Netherlands, e.w.nota@uu.nl

2 Utrecht University, Department of Physical Geography, Netherlands, m.g.kleinhans@uu.nl

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1 INTRODUCTION

Many large estuaries around the world are engineered to some degree for both flood protection of coastal communities and maintenance of economically vital shipping routes. Engineering challenges arise due to the highly dynamic morphological nature of estuaries, where the complex processes of sediment transport are driven by an interplay between the turbulent flows of rivers and tides. Naturally, the planforms of sandy estuaries have the tendency to converge landwards exponentially, where deviations from this shape provide alternating space and constrictions where tidal sandbars and channels form (Leuven et al., 2018-a; 2018-b). In the case of embankment by bank protection and dikes, such topographically forced channels can develop deep scour holes that endanger bank stability. Our objective is to study effects of channel and planform dynamics on scour depth variation near protected banks. To this end, we conducted scale experiments of estuaries with completely fixed banks in the tilting tidal flume the Metronome (Kleinhans et al., 2017). We study the effects of these fixed banks on the morphological behaviour of the channel pattern through one experiment, two repeat experiments, and a control without fixed banks. By collection of much longer timeseries than available in nature, we use the experiments to shed light on the topographic forcing and channel dynamics of these systems, and on the repeatability of Metronome experiments.

2 METHODS

Scaled estuaries with a self-formed channel-bar pattern were created in mobile sand bed experiments with imposed, turbulent tidal flows. The principle of the Metronome facility is to impose reversing shallow flow over a sand-bed by periodic tilting of the flume with a tidal cycle period of 40 seconds. This solves several scale problems that arise by imposing tidal water level fluctuations on the seaward boundary. The flume is 20 by 3 m and has water depths of a few centimeters over a mobile sand bed. Earlier work demonstrated that tidal bar and channel dimensions normalized by local width scale the same as in natural systems. The functioning and scaling of the Metronome are addressed in Kleinhans et al. (2017 and abstract submitted to this conference). Before starting the initial experiment of this study, a control experiment was conducted with the same setup, but without fixed banks. The initial experiment started with a straight channel of 54 cm wide and 4 cm deep with a smooth bed extending for 18 m from the river inlet to the mouth, where tidal currents from the seaward boundary enter the channel. The straight channel was allowed to develop natural morphology for 2000 tidal cycles, after which the banks were fixed with industrial sandpaper of high roughness (grade 24; Figure 1). For the first and second repeat experiment, this configuration of the sandpaper banks was maintained, and re-initiation commenced after smoothening the bed between the banks, which kept the total amount of sand in the system constant. All experiments were continued for about 22,000 cycles. After runs of 500-1000 cycles, orthophotos and Digital Elevation Models (DEMs; Figure 2) from a line laser scanner were acquired at a horizontal resolution of 3 mm. Triggered at each tidal cycle, 7 overhead cameras collected time-lapse imagery, visualizing blue-dyed water and morphological development. Finally, at specific stages we conducted Particle Image Velocimetry (PIV) and water surface elevation measurements from 3 acoustic distance meters to characterize hydrodynamics and enable shallow water equations modelling.

3 RESULTS AND DISCUSSION

Figure 2 gives an example of a shaded DEM derived from the laser scanning equipment. Channels and bars developed early within 1000 tidal cycles. Especially at the downstream half of the Metronome, we observe the establishment of topographically forced scour holes and sandbars for all three experiments, where most scours tend to form directly along the embankments and erode much deeper than the control run without embankment. In contrast, the control run shows bank erosion and free channel migration instead of topographically forced scours and sandbars. Surprisingly, the initial and repeat experiments exhibit cyclic behaviour in the development and disappearance of specific sandbar and channel patterns. Moreover, observed cyclic behaviour of cross-cut channels in the lower reach appeared to be linked, suggesting that aspects of the complex morphological behaviour may be described by coupled oscillators. While the general time-averaged pattern is similar between estuaries, notable variation and differences between the experiments occur in periodicity of scour depth and bank failure locations. This shows that the general pattern in relation to topographic forcing is repeatable, but superimposed natural variations in scour depth and channel location due to complex system dynamics are not repeatable. This has ramifications for observation and numerical modelling of natural estuaries.

4 CONCLUSIONS

Fixing the banks of laboratory estuaries cause repeatable patterns of topographic forcing and surprising quasi-cyclic behaviour in channel position and scour depth. Notable variations within and between repeat experiments result from a degree of chaos in the system.

Figure 1. Seaside view of the Metronome. The estuary banks are fixed by blue sandpaper.

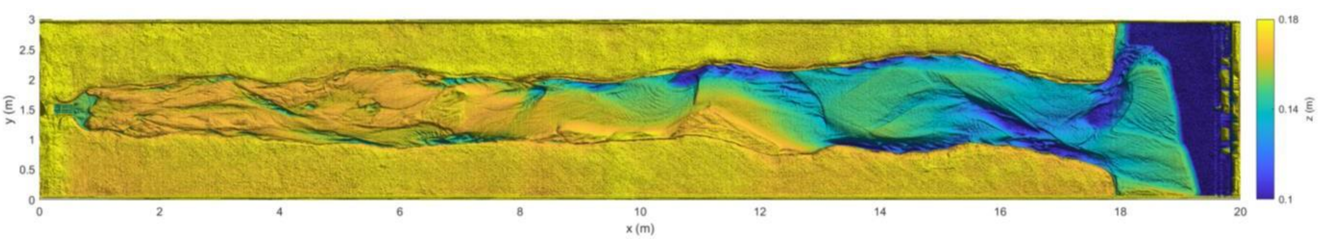

Figure 2. Digital elevation model (DEM) from line laser scanning of the first repeat experiment at 13000 tidal cycles. Mean sea-level is at 0.16 m.

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