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Idealised modelling of estuarine development affected by human interventions and climate change

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ABSTRACT

Estuaries worldwide are facing the challenge of coping with changing climates. Insufficient supply of sediment to overcome sea-level rise can increase flood risk and saltwater intrusion and drowning of ecosystems. To explore how estuarine eco-morphology is affected by large-scale human interventions and climate change, an idealised eco-morphological model is developed and validated. The model represents the Nieuwe Waterweg estuary in the Rhine-Meuse Delta. Short-term simulations (1 year) are performed after human-induced changes and projected climate changes are implemented in the model.

The model is able to represent annual morphological trends. Results show the sensitivity of the system towards channel depth and the presence and size of wetlands. Simulations will be repeated with projected future climate forcings, enabling assessment of estuarine development after large-scale changes for the present and the future.

1. Introduction

Estuarine regions connect our rivers with the ocean, and are important socio-economic zones, being densely populated and hosting many major ports worldwide. They are highly susceptible to changes in climate, from the sea-side (sea level rise, changes in wave climate) and from rivers (changing river discharge and sediment supply). To cope with sea-level rise (SLR), estuaries need sufficient sedimentation (Giosan et al., 2014). Lack hereof can increase flood risk and intrusion of salt water, and can cause drowning of valuable wetland ecosystems. To optimise estuarine functions and prepare for these future threats, improved understanding of estuarine development after potential changes in its climate and/or system configuration is desired. To this end, this study explores the annual behaviour of the 'Nieuwe Waterweg' estuary, in the Rhine-Meuse Delta, after human interventions in the contemporary climate and in projected climate changes.

2. Methods

2.1. Study area

The Nieuwe Waterweg estuary, the Netherlands (Figure 1), typically has an average discharge of $1600m^3/s$, with a relatively high discharge in winter and low discharges during summer. The estuary has a mean tidal range of 1.6m and typical average wave heights of 1.1m, which varies over the seasons. It flows out into the wave-dominated coasts of the North-Sea. While historically wetlands were abundantly present, extensive human interventions to this estuary resulted in an embanked and channelized estuarine channel which is annually dredged to maintain its artificial depth, allowing large ships to enter the ports.

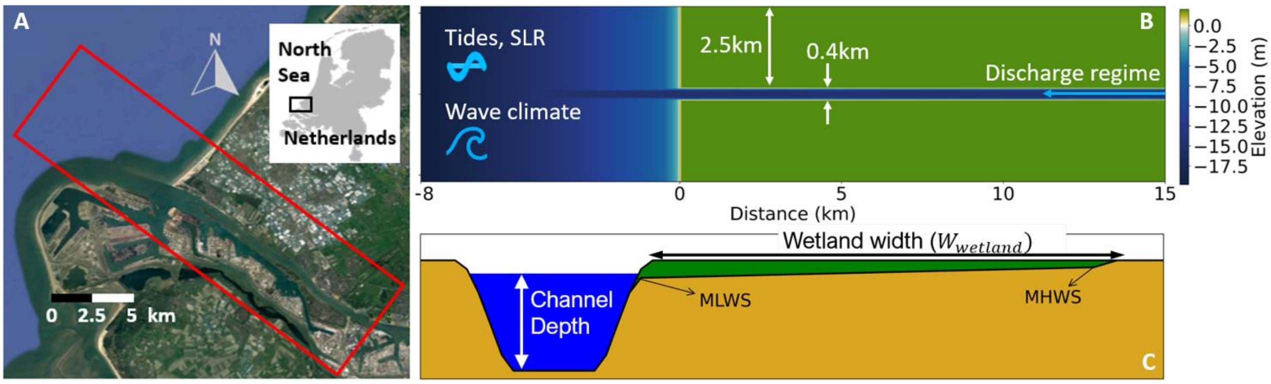

Fig. 1. A) Top view of the study area. **B)** The schematised model domain. It is forced by tides and a monthly averaged wave climate on the sea-side side, and by a monthly averaged discharge regime from the river. Future scenarios are implemented by changing system forcings: the wave climate and the discharge regime. **C)** Schematic overview of large-scale interventions implemented within the estuary.

2.2. Eco-morphological model setup

A morphological model is developed in Delft3D-FM (depth-averaged), the successor of Delft3D which is extensively applied for morphological modelling of estuaries. A schematized bathymetry is developed for the contemporary 'Nieuwe waterweg' estuary (Figure 1). The domain is forced by tides, and an annual monthly averaged wave climate from the coast, and by an annual monthly average discharge regime from the river with suspended mud concentrations of 20mg/L. The model representing the contemporary system is validated to gain confidence in its ability to represent the study area.

2.3. Scenarios

Next, simulations are performed after implementation of two large-scale interventions in the system: 1) Wetland restoration, a nature-based solution increasingly recognized for its potential for flood safety, sediment trapping (by vegetation) and additional ecosystem services and; 2) Channel deepening, an intervention often applied to allow larger ships to enter the ports. Wetlands are only implemented along the northern bank of the estuary, due to spatial limitations.

Moreover, using snap-shot simulations, the annual behaviour of the estuary after climate change is assessed. The model is adjusted to represent a future climate, using projected climate changes for the year 2100 (following the 6th IPCC report). System forcings are adjusted for SLR, projected wave climate and discharge regimes. Also, adjustments for the future bathymetry by way of basin infilling are included, (see Duong et al., 2016). Snap-shot simulations are performed with and without human-interventions, in the contemporary and future climate.

3. Results & Discussion

The model is validated with observed hydrodynamic timeseries (water levels and waves) and derived average annual morphological trends (Cox et al., 2021) and showed good resemblance. Simulations with the contemporary climate showed that channel deepening increased sedimentation in the estuary. While wetlands showed net accretion in all scenarios, presence of wetlands, and increasing their size, reduced net annual sediment budget in the estuary (Figure 2). These morphological trends were accentuated by the presence of vegetation. Increased channel depth slightly increased wetland accretion.

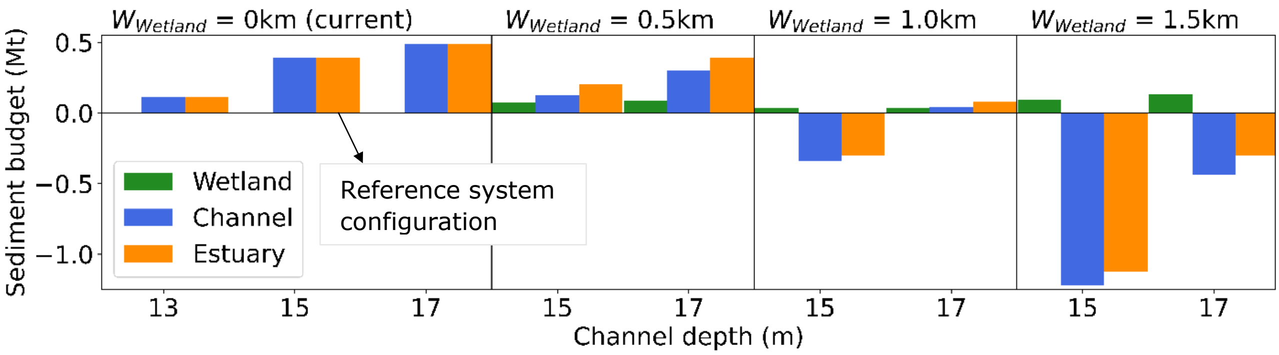

Fig. 2. Annual sediment budget for the wetland, channel and the entire estuary (both areas combined), under various configurations of the estuarine system.

Morover, results indicate that lateral location of the wetland substantially affects channel morphology. Strategic placement could aid in steering estuarine morphology. Simulations will be repeated under future forcings, which will give insights in estuarine development under potential climate- and human-induced changes.

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