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HUMAN VERSUS NATURAL MUD FLUXES IN THE SCHELDT ESTUARY: ARE THEY SIGNIFICANT AND IF SO, HOW CAN THEY BEST BE OPTIMISED?

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ABSTRACT

The mud dynamics of the Scheldt estuary is governed by the interplay between tidal flow, freshwater discharge, marine and fluvial mud supply and local sources and sinks. A question is how large human impacts are on these mud dynamics. Using a process-based mud transport model of the Scheldt estuary, these impacts have been quantified by evaluating different scenarios representative for present or alternative maintenance dredging procedures.

The results show that although the 'human' fluxes caused by maintenance dredging are typically small compared to natural gross fluxes, they are very significant compared to natural residual fluxes, notably in the narrower section of the estuary near Antwerp. Here more than half of the available mud is 'second-hand', i.e. it has been dredged from and released back into the estuary at least once. This implies that an optimization of the dredging and release cycles, including the smart selection of release locations, offers the perspective of smaller human impacts, possibly even at lower costs.

A down-estuary shift of release locations would be favourable. Also, locations closer tidal flats may contribute to interrupting the vicious circle between dredged mud dispersion and maintenance dredging by enhancing the accretion rate of these flats. However, the surface area of these flats has to be substantial to provide more than just a short-term solution.

Keywords: Scheldt estuary, mud, human impacts

1. INTRODUCTION

The mud dynamics of the Scheldt estuary is governed, like other estuaries, by the interplay between tidal flow, freshwater discharge, marine and fluvial mud supply and local sources and sinks, notably mud flats. Human impacts on the mud dynamics can be either direct or indirect. Direct impacts are caused by harbour and fairway maintenance dredging (i.e. dredging vessels transporting mud from A to B), indirect impacts are caused by human modifications of the estuary such as increasing channel depth by capital dredging or reducing the area of tidal flats by land reclamation, thus modifying the natural flux. The question is whether these impacts are significant compared to the natural estuarine mud dynamics and if so, how they can best be optimised to reduce maintenance cost and to increase the ecological values of the estuary.

2. METHODS

The answer to this question is addressed by using a process-based 3D mud transport model of the Scheldt estuary. This model has been developed in the past few years within the framework of the Belgian-Dutch cooperation on the management of the Scheldt estuary. All technical reports containing details on the development of the Scheldt estuary mud model are publicly available at www.scheldemonitor.be. Also, some journal papers on its development and application have been published (van Kessel *et al.*, 2011a; van der Wal *et al.*, 2010 and Eleveld *et al.*, 2014). Recently, the same modelling approach has been applied to the Ems estuary bordering The Netherlands and Germany (van Maren *et al.*, 2015).

The adopted modelling approach originates from work on the impact of the construction of Maasvlakte-2 land reclamation for the benefit of Rotterdam harbour extension on the mud dynamics and turbidity in the Dutch coastal zone (van Kessel *et al.*, 2011b). Although it has a lot of elements in common with many other mud transport models, it is special in the sense that the model is not only aimed at reproducing the short-term suspended sediment dynamics of the Scheldt estuary, but also at reproducing the long-term mud balance and the evolution of the mud distribution in the bed. The advantage of this approach is that the mud distribution in the bed does not need to be prescribed by the modeller; instead, it is computed by the model. Only mud concentrations at the river and sea boundaries need to be prescribed. Therefore, the mud distribution in the bed is free to respond to changes in navigation channel depth, the construction or extension of tidal docks, a new strategy for maintenance dredging etcetera. Both the short-term and long-term effects of these changes can thus be evaluated. As the mud distribution in the bed only changes slowly (at a timescale of months to years), only direct effects on the suspended sediment concentration play a role on the short term. However, on the long term also the mud distribution may change. Therefore, short-term and long-term effects are not necessarily the same; they even may be opposite. For example, a deepening of a navigation channel may, on the short term, result in lower mud concentration in the water column if the channel velocity decreases. However, on the long term the mud concentration may increase caused by increased estuarine circulation and tidal asymmetry. Classical short-term mud models lack this distinction and can only predict short-term effects correctly.

However, to reduce the computational costs for long-term 3D model computations, the hydrodynamic model is decoupled from the sediment transport model. This makes it possible to re-use the hydrodynamics model results (for example available for a period of a month or a year) for a multi-year sediment transport computation. This advantage comes at a cost: the model is not a morphological model, so the bathymetry of the underlying hydrodynamics is fixed. Also, the effect of suspended sediments on hydrodynamics is neglected, so the approach is only valid for low concentrations (typically < few 100 mg/l). In most of the Scheldt estuary and at most times, the low-concentration requirement is met.

Human impacts are quantified by evaluating different scenarios representative for present and alternative maintenance dredging procedures. The focus of this extended abstract is on the dredging procedure, as this can more easily be modified on the short term than estuarine bathymetry. Both a reversion of land reclamation and channel depth would have large consequences for the economical function of the Scheldt estuary.

3. RESULTS

3.1 Present release locations

Figure 1 shows the computed near surface concentration around Vlissingen harbour in case of harbour sedimentation, maintenance and local release of dredged mud relative to the surface concentration in case of no harbour sedimentation (switched off in the model) and no mud release. The left hand panel is a snapshot during maintenance dredging, the right hand panel between maintenance dredging intervals. It is clear that during dredging the mud concentration increases with respect to the no-intervention case because of mud release, but afterwards it decreases because of harbour sedimentation. Figure 2 shows the time-average effect, which is limited. In seaward direction the presence of the harbour results in a slight decrease of the near-surface concentration (up to a few percent), in up-estuary direction it results in a slight increase of the concentration. According to the right-hand side of Figure 2 about 5% of the suspended mud originates from the harbour, but without the harbour most of this sediment would have remained in suspension. Because of this compensating effect, the net effect remains small.

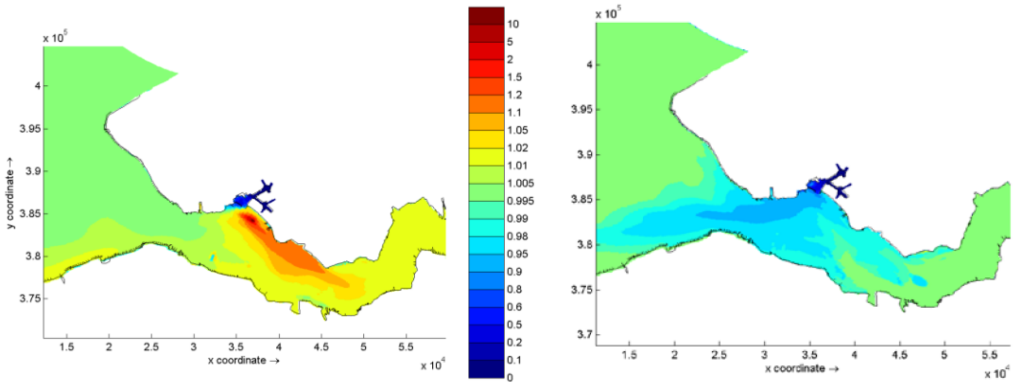

Figure 1. Relative change in near-surface mud concentration for a scenario with harbour with respect to a scenario without harbour. Left: during dredging and release. Right: outside maintenance time window. 1 = no change.

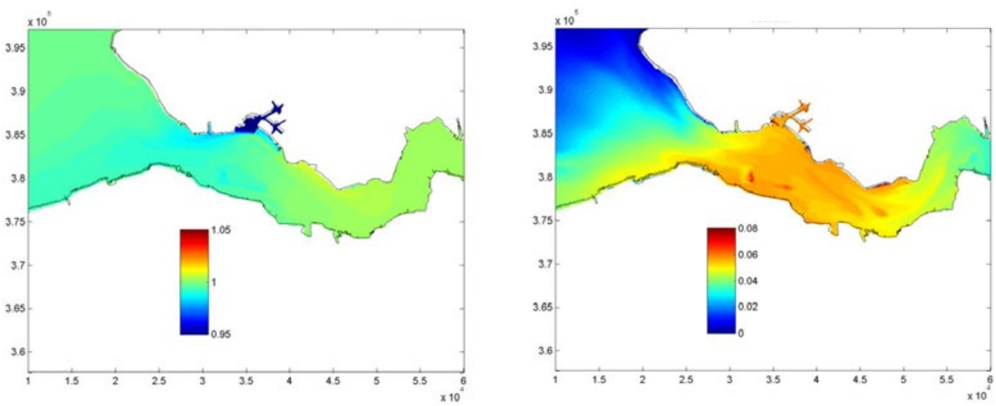

Figure 2. Left: time-average effect of harbour on near-surface concentration. Relative concentration difference with and without harbour. Right: fraction of sediment originating from Vlissingen harbour with respect to the total suspended sediment concentration.

At Antwerp, where the estuary narrows but were the natural suspended sediment concentration is 4-fold larger (about 200 mg/l) because of a local turbidity maximum, the effect of harbours is more distinct. Figure 3 shows a pie chart of the computed origins of the mud at Boei84 near Antwerp. Only about 30% of the mud is 'fresh', i.e. not originating from one of the harbours in the vicinity. About 65% of all mud originates from the harbours and access channels of Antwerp (Zandvliet, Deurganckdok and Kallo, of which DGD has by far the largest contribution). The Dutch harbours contribute only for about 5%. More than 2/3 of all sediments are 'second hand', i.e. have at least once been dredged and released. This suggests that there is a large potential for optimisation of the local dredging strategy.

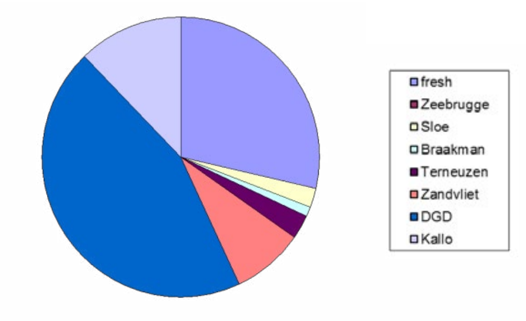

Figure 3. Computed mud origins at Boei84, close to Antwerp harbour. 'Fresh' represents mud not originating from one of the harbours.

3.2 Alternative release locations

Figure 4 shows the results of a sensitivity computation on the effect of a down-estuary shift of the release location for mud originating from maintenance of tidal docks and access channels at Antwerp. The left-hand panel shows the computed time-average suspended mud concentration near the surface for the present maintenance strategy. Note that the observed estuarine turbidity maximum (ETM) near Antwerp is reproduced by the model. When the release location is shifted in down-estuary direction as indicated in the left-hand panel, the time-average concentration increases in down-estuary direction but decreases in up-estuary direction. However, the computed local increase of about 5 to 10% is much smaller than the local decrease (more than 20%), so the overall effect is positive, i.e. on average the mud concentration decreases. This can be explained by two effects: 1) towards the sea the estuary is wide, so the same mud release rate results in a smaller concentration effect and 2) as the concentration at DGD decreases (with about 7% according to Figure 4), also the sedimentation rate decreases, resulting in a smaller dredging effort and mud release rate. Therefore both effects reinforce each other.

With the mud model, a third mechanism that may further reduce mud concentration levels and the return flow of mud towards the harbour basins has not yet been studied. This mechanism is the release of dredged material at a location near low-dynamic tidal mud flats. It may contribute to interrupting the vicious circle between dredged mud release and maintenance dredging by enhancing the accretion rate of these flats. However, the surface area of these flats has to be substantial to provide more than only a short-term solution.

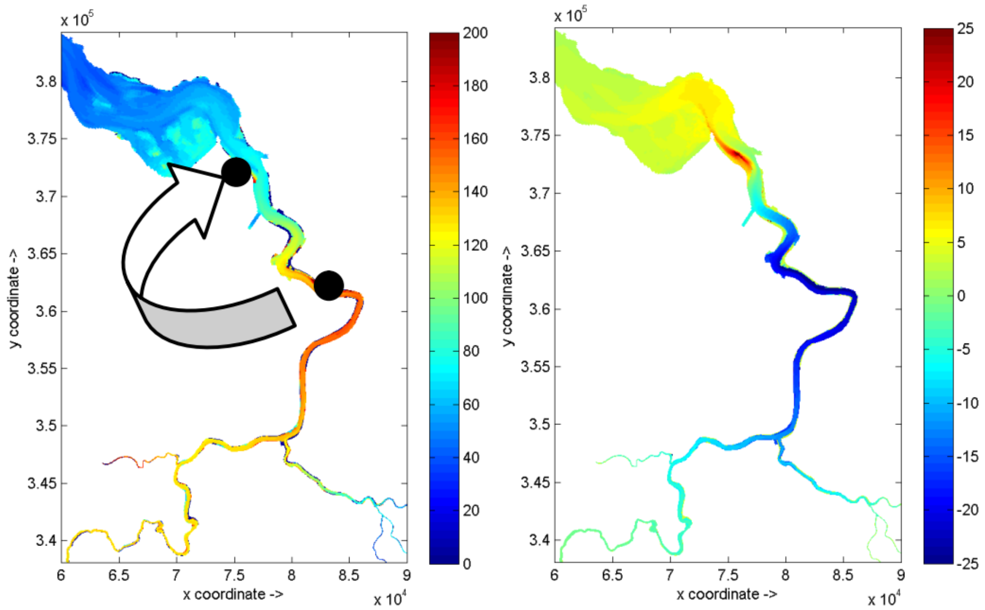

Figure 4. Left: time-average near-surface mud concentration near Antwerp harbour. Right: % change resulting from a down-estuary shift of the release location.

4. CONCLUSIONS

The results show that although the 'human' fluxes caused by maintenance dredging are typically small compared to natural gross fluxes, they are very significant compared to natural residual fluxes, notably in the narrower section of the estuary near Antwerp. Here more than half of the available mud is 'second-hand', i.e. it has been dredged from and released back into the estuary at least once. This implies that an optimisation of the dredging and release cycles, including the smart selection of release locations, offers the perspective of smaller human impacts, possibly even at lower costs. In the Western Scheldt human impacts are smaller, as the estuary is much wider and natural gross fluxes are much larger because of the much larger tidal volume, whereas the volume of maintenance dredging at Vlissingen or Terneuzen is smaller than at Antwerp.

Computations with the mud model show that a down-estuary shift of release locations would be favourable, whereas the present practice is that dredged mud is most often released up-estuary of the harbour or access channel from which it has been dredged. Two mechanisms are responsible for this favourable effect, i.e. 1) a wider estuary results in a smaller concentration effect and 2) a smaller concentration effect results in a lower harbour sedimentation rate and therefore mud release rate. A third mechanism to reduce mud concentration levels would be the selection of release locations close to tidal flats, as the vicious circle between dredged mud dispersion and maintenance dredging may be interrupted by enhancing the accretion rate of these flats.

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