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A comparison between process-based and idealized morphodynamic models for the Western Scheldt case

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1. Introduction

In the Western Scheldt, the marine part of the Scheldt estuary, a large dredging operation is needed to maintain the shipping channel to the harbour of Antwerp. This harbour is one of the major harbours in north-west Europe, but it is located about 60 km inland from the estuary mouth near Vlissingen in the Netherlands.

In addition to the maintenance dredging two deepening programs have been carried out since the seventies, for allowing larger ships entering the harbour. During the last deepening, carried out in 1997 and 1998, the minimal water depth was increased from 14,5 m to 16,0 m below N.A.P. (Dutch ordnance level ≈ mean sea level), and a new deepening program for the near future is readily proposed. The deepening and (thereby increased) maintenance of the navigation channel will inevitably impact the morphological development and the ecological system in the estuary. To reduce the possible negative effects it is necessary to understand this impact. For this purpose a research program is initiated.

The major question for the water management is the retention of the morphodynamical structure of the estuary in relation with the economic development and the protection of the ecological important habitats. By a combined action of the Dutch and Belgium authorities a long term development vision is build at the moment in which three policy questions are discussed: “safeguarding against flooding”, “accessibility for shipping” and “naturalness and resilience”. Detailed research of the morphological dynamics is taken as the basic study of this development vision, focusing on the multi-channel topography of the Western Scheldt.

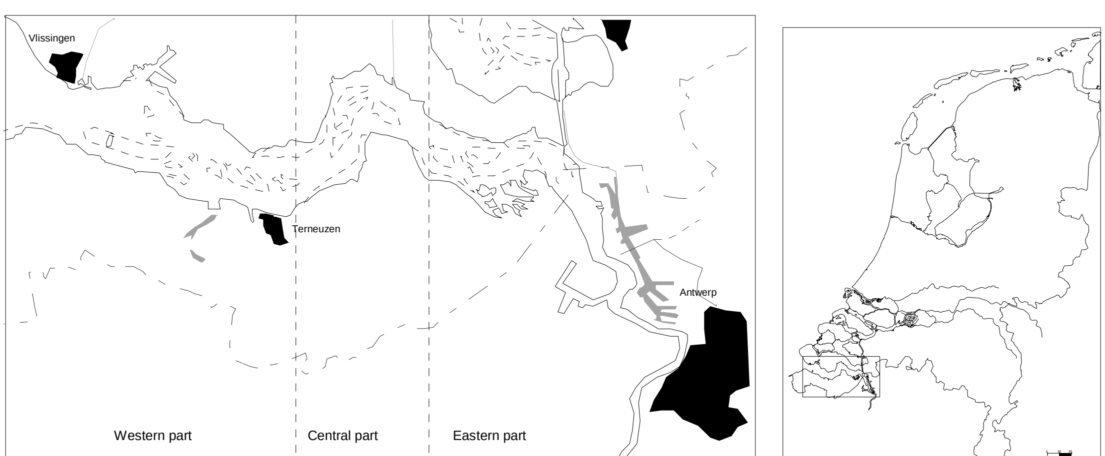

figure 1. The Western Scheldt is the marine part of the Scheldt Estuary and it is located in the southwest part of The Netherlands on the border with Belgium

2. Morphodynamic models used for the Western Scheldt case

2.1 process-based model

Various morphodynamic models have been set up for the Western Scheldt based on **DELFT3D**, a 2D/3D modelling system developed by WL | delft hydraulics. The Delft3D system contains a wave module, a flow module, a sediment transport module and a bottom development module. A main (steering) module makes it possible to apply the process modules in an integrated manner for simulating morphological development. In Verbeek et al. (1999) the application of this system to the eastern part of the Western Scheldt is presented. A study on the sill of Hansweert (Groenewoud et al, 1997) showed the importance of detailed modelling for the evaluation of the dredging operation. These model studies have been carried out using the existing 3D hydrodynamic model TRISCAL, operational at Rijkswaterstaat (Verbeek et al, 1998).

These process-based models are meant to reproduce the reality by describing the relevant processes as good as possible. They are based on detailed schematisations of the situation in the field (geometry, driving forces like tide, sediment characteristics, etc.). The values of this type of models for the Western Scheldt have been proven by the mentioned studies. However, there are still a number of fundamental problems inhibiting full use of the potentials of such models. Long-term simulations (longer than about 5 year) is still not possible, not only due to reasons of computational efforts, but also because the results have the tendency to become chaotic on the long-term. The fundamental problem here concerns the morphological equilibrium. It is not even known if a morphological equilibrium exists according to formulations in the morphodynamic models, whereas field observations suggest that some kind of equilibrium like to exist indicated by the empirical relations derived from data. Fundamental analysis on the behaviour of morphodynamic models is therefore very important. Such analysis is one of the applications of the idealized models, which keep the essence of the process-based models but ignore the complicated details of them.

2.2 idealized model

Because of this uncertainty the morphodynamic development of the Western Scheldt is analysed also using idealized models. These models can give a better understanding of the existence of morphodynamic equilibria on the basis of the external tides and the global geometry of the estuary. The occurrence of rhythmic features like the movements of banks in estuaries can be shown also. Model runs are made on a continuation of the L/L_g - parameter, which is the scaled length of the estuary.

The idealized model that is used for the Western Scheldt is an extension of the case of a short embayment (Schuttelaars & De Swart, 1996) used for the Dutch Wadden Sea. In that case a morphodynamic equilibrium can be defined on the basis of the external tides. In Schuttelaars en De Swart (in press) the application to the Western Scheldt is presented, showing the existing of multiple equilibria depending on the characteristics of external tides and other model parameters. The presented model is an one-dimensional model, which will be the basis for 2D non-linear instability analysis in the near future.

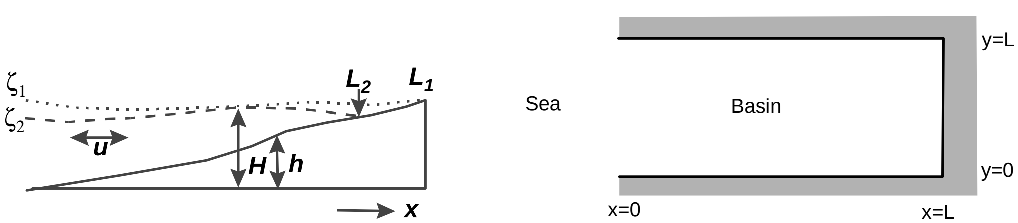

figure 2. Topview and side view of an idealized embayment (for explanation see the text)

The embayments under study are rectangular and the water motion is forced at the seaward entrance by a prescribed sea surface variation of tidal origin (see figure 2). The boundary on the landward side is assumed to be closed. The water motions are described by the cross-sectionally averaged shallow water equations for a homogeneous fluid and the sediment transport is described by a depth-integrated concentration equation. The bottom evolution is derived from continuity of mass in the sediment layer.

3. Comparison of the models

3.1 description of the compared cases

In order to compare the results of both models a simplified version of the process-based model is made using a straight channel with a reduced number of cells in the transversal direction, creating a almost 1D-solution possible. The process formulations are taken from the idealized model as far as could be build into the process-based model. The sediment transport formulation in the idealized model uses the quadratic formulation for erosion and sedimentation instead of the higher order formulation that is normally used in the process-based model. For the comparison the first approach is taken. But the idealized model uses a integrated suspended sediment concentration and the process-based model a depth averaged sediment concentration.

For both models the upstream boundary is closed (river outflow is not incorporated at the moment) and at the downstream boundary (the sea) a waterlevel consisting of a M_2 and a M_4 component is supplied. The idealized model uses a weak upper boundary condition, while in the process-based model a wetting and drying procedure is installed. The difference in the upper boundary leads to a singularity in the process-based model, because the friction does not decreasing with decreasing depth. For the lower boundary the process-based model uses a internal determined concentration at outflow and by doing so blocking the diffusion over the seaward boundary. In the idealized model the concentration at the lower boundary is fixed.

A few point of difference are not bridged and the influences of these differences will be subject of the presented study. The idealized model uses a linearized friction term according to the energy dissipation condition discussed by Zimmerman (1992). The process-based model uses a quadratic approach using the Chezy formulation.

3.2 results of the comparison

The comparison is made for different estuary length scales: 10 km, 50 km and 110 km. The idealized model uses a continuous 1D representation and the process-based model uses a 2Dh representation of 50 by 7 cells. There are 3 cases compared: for an estuary of 10 km, 50 km and 110 km. These cases are specific defined in the process-based model. In the idealized model a continuous 1D representation is used. The 10 km case gave problems for the process-based model because it was not stable. It showed severe oscillations due to the wetting and drying routine, yielding to an unrealistic current speed. Due to the oscillations and unrealistic current speed the results show negative sediment fluxes.

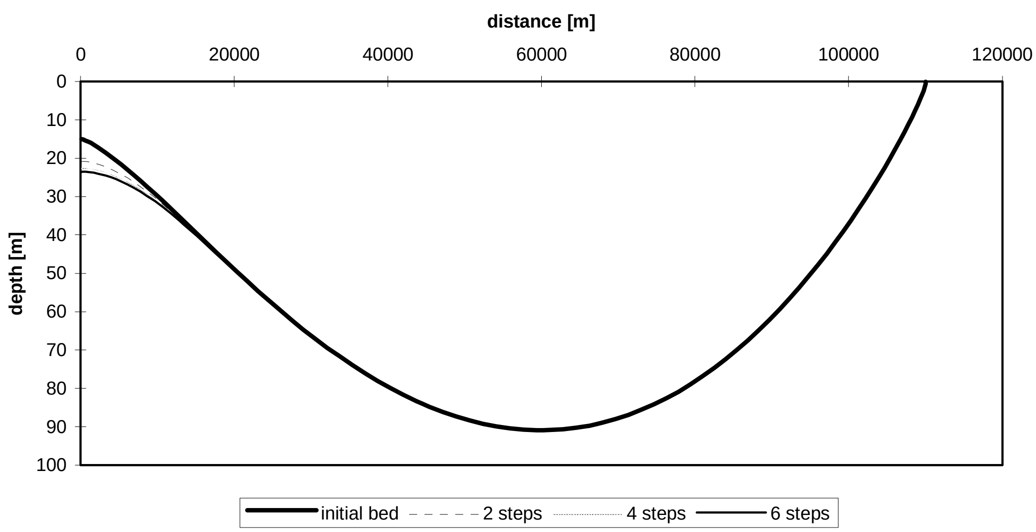

figure 3. The results for the 110 km case with the process-based model starting with an initial bed and showing 2,4 and 6 morphological timesteps

The 50 km case still shows oscillations at the upstream boundary, but now it does not lead to unrealistic current speed or sediment transport fluxes. The problems now arises at the downstream end for the model is closed of after two morphological time steps. Changing the parameters for the sediment transport rate the results are stable. The initial equilibrium bed is changed in the process-based model first leading to a constant erosion, but afterwards changing into lesser bed change. In the 110 km case (shown in figure 3) the same features as in the 50 km case arises. After changing the sediment properties the resulting bed development yields to a deviation from the initial equilibrium bed towards a new equilibrium. This equilibrium is not yet achieved after 30 morphological time steps of 1 month but the bed change is diminishing.

4. Discussion

Although the presented models are in the physical basics comparable model systems the outcome is different. Both models are based on the shallow water equations and on sediment transport formulations that could yield to comparable systems. But due to differences in the approximations of the external forcings and the internal boundary conditions the results are not alike.

The different approximations are:

- a linearized versus a quadratic friction term
- a depth integrated versus a depth averaged suspended sediment concentration
- differences in the upper boundary definition for waterlevels and friction
- differences in the lower boundary definition for suspended sediment concentration.

These differences showed to be of great importance to the morphodynamic stability of the represented estuary. Beforehand it was discussed that the first point was not essential for the results. Therefor it was not altered in the process-based model. The other differences are essential, but due to pragmatic reasons it was not changed to be alike. The investigation was to see how sincere these differences are. This is shown to be of great importance.

The results show that the differences are important and it must be discussed which approximation is most valid. As both models have been reviewed in literature the question focuses on the time scales on which these models are valid. The idealized model is developed for the long-term prediction and the process-based model is applied for the short-term prediction. The gap between this is not bridged yet.

There is more research needed to see if the morphodynamic equilibria as found by the idealized model can be used as a stable solution for the process-based models. In the present case their is not yet an intermediate model found, that can be de basis of a systematic comparison. The next step will be to use the results of another idealized model, based on a more local model domain with a 3D expansion (Schramkowski, 1999). When the intermediate model is found the analysis can be done more sincere.

5. References

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