Estuaries - Morphology - Inter tidal flats

Case: Inter tidal flats

Modelling steps

Intro

Case Study: Eastern Scheldt

The Eastern Scheldt estuary, in the southwest of the Netherlands, is a meso-tidal estuary with land boundaries that are mostly intertidal and bordered by dikes. As a result of the Delta Works, the estuarine dynamics changed considerably since the 1960’s. A storm-surge barrier was constructed at the estuary mouth and the Oesterdam and Philipsdam were placed upstream in the east. The cross-sectional area of the channels and the inlet mouth were reduced from 80,000m$^2$ in 1984 to approximately 17,900m$^2$ in 1987 (Louters et al., 1998). During the construction works the tidal volume, tidal current velocities and tidal range decreased. The subsequent closure of the Oesterdam (1986) and the Philipsdam (1987) led to a decrease of almost 30% of the tidal volume but an increase in tidal range. This led to a decrease in current velocities in the estuary by about 30% (Louters et al., 1998), which locally can be much higher, leading to a reduction in the sediment transport carrying capacity and resuspension forces.

In addition to a reduction in sediment transport, the tidal volume decrease also results in the need for the channels to accrete in order to adapt the channel cross-section to reach a new morphological equilibrium. Therefore, more sediment is required to keep the system in equilibrium. However, the sediment demand from the channels comes from the intertidal areas.

While the transport power of the currents has reduced, the erosive power of the short waves generated inside the estuary has not. Consequently, the intertidal flats in the Eastern Scheldt are decreasing in area and height, and research is needed to determine long-terms solutions. The importance of preserving the remaining tidal flats is for safety, as well as environmental, issues. A loss of more tidal-flat area will expose the dikes that protect the islands bordering the Eastern Scheldt to higher waves, thus reducing their effectiveness.

Conceptual

The processes occurring on the intertidal flats and their effects on the accretion and erosion are still not well understood due to its highly variable and dynamic nature. The tidal flats of the Eastern Scheldt are of high ecological importance as they function as feeding and resting grounds for birds.

One of the potential short-term solutions to tidal-flat degradation is nourishing them to compensate for the sediment lost to tidal channels. To test this innovative approach, the Galgeplaat was nourished with 150,000 m$^3$ of sand in 2009, dredged from adjacent channels as part of the Building with Nature project. This study is presented here with particular focus on the set-up of the model and a selection of sensitivity tests and results.

Due to the influence of many factors, the reworking of bed sediments and their suspension and redistribution under different conditions is complex (Gleizon et al., 2003) Difficulty lies in adequately calibrating spatially varying parameters such as bed roughness. Simulating the correct spatial variation in bed roughness is important to attain the correct levels of bed shear stress that will reproduce the observed sediment transport patterns. Inaccurate estimate of roughness is a major source of error in sediment transport predictions (Davies and Villaret, 2002).

Bed roughness can be influenced by many factors, both biotic and abiotic and is one of the most difficult parameters to quantify in morphological models. Roughness is usually divided into form-related and grain-related roughness. In sandy environments, bedforms influence the roughness whereas in muddy environments, where the surface is quite smooth, roughness values depend on the sediment particles (Van Ledden, 2004). Abiotic variations in roughness can be caused by ripples, differences in grain size, sand waves etc. Biological roughness effects also play a major role but are often neglected. Biotic variations in roughness can be caused by mussel bed, oyster reefs, diatoms, microphytobenthos etc.

Approach
In order to gain more understanding on these processes and how they affect the morphological development of the estuary, a Delft3D sediment transport model was set up and analysed for different scenarios.

A depth-averaged, two-dimensional horizontal (2DH) Delft3D hydrodynamic model was set up for the Galgeplaat shoal with a fine grid resolution of 25-45 m (Das, 2010). SWAN (Simulated Waves Nearshore) was used to simulate waves on the Galgeplaat grid (resolution of 80-130 m) which was nested in a larger wave domain.

This coupled model was in turn nested in the larger South Coast model. This model simulates the hydrodynamics (including waves) of the southern part of the North Sea, Western Scheldt and Eastern Scheldt estuaries (Fig 1). Around the Galgeplaat, the grid resolution of the South Coast model in the x-direction is 100-250 m and in the y-direction 200-400 m.

Model setup and Calibration

South Coast Model

The offshore boundary conditions for the South Coast model are astronomic water level constituents. A time-step of 0.5 minutes and bathymetry for the Eastern Scheldt from 2001 and 2004 was used. A Manning coefficient of 0.025 s/m$^{1/3}$ was applied with a uniform wind field and default SWAN settings.

The South Coast model was set-up for a spring/neap cycle and for a period of several months depending on the period being analysed. Wave and winds from the wave buoy Europlatform (51.9N 3.3E) were used to force the flow and wave models. Waves were predominantly from the south-west for both periods. These simulations were used to generate boundary conditions for the Galgeplaat nested (* see notes below on nesting) model.

Galgeplaat Model

The Galgeplaat grid has three open boundaries, to the northwest (NW), northeast (NO) and southeast (ZO). The northwest boundary is a mixture of current and water level boundary segments, the southeast and northeast are current boundaries (Fig 1).
A time step of 0.5 minutes was applied. The bathymetry of the model was taken from 2007 measurements. The nourishment was included in the model by adjusting the bathymetry around the nourishment site. The soundings taken at October 2008 (T1) were used to replace the bathymetry within the nourishment area (Fig 2).

Figure 2. Inclusion of the nourishment in the model bathymetry

A uniform sediment fraction with a grain size diameter of 200µm (median grain size on the flats) was used. In the morphological parameterisation, bed updating was switched on with an initial spin-up period of 12 hours before bed-updating began. Parameters, such as the Chezy coefficient and the morphological factor were adjusted for different simulations. In these simulations a Chezy coefficient was applied for bed roughness. The 2D Chezy coefficient ($C_{2D}^2$) can be determined according to the Chezy formula, Manning formula or White-Colebrook’s formula. These formulae are described in the Delft3D-FLOW User Manual, (2010). The bottom roughness may be uniform or spatially varying. A Chezy coefficient of 65 m$^{1/2}$/s was used for the reference run after calibration of the value and comparison with current velocity measurements.

When the morphological factor is 6, results of the morphological simulations represent six spring-neap tides. The sediment transport formula of van Rijn, (1993) is used by default.
Sensitivity runs

Wind and wave forcing

Both winter and a spring simulations were carried out to assess the affect of different wind and wave conditions. The winter scenario was characterised by higher wind speeds, with strong winds towards the end of the simulation. Winds and waves were prominently from the south-west. During the spring scenario wind speeds are lower, and from multiple directions but a large proportion from the north-east. Waves are predominantly from the east, with a large proportion also from the south-west.

Nourishment Scenarios

Three simulations were set up. A winter, spring and longer simulation (several months) with the nourishment in its current location to assess the behaviour of the nourishment in the model and its effect on the local sedimentation and erosion patterns. Simulations were also set up with nourishments of different dimensions in different locations.

Biological roughness effects

The influence of biology on sediment transport on the intertidal flats was examined by simulating the effect (separately) of oyster reefs and diatoms on the Galgeplaat. The amount of sediment transport that takes place depends on the amount of turbulence, the force of the current and on the nature and roughness of the bed. Resisting stresses such adhesive physico-chemical forces, biological stabilisation or particle-particle interlocking and armouring effects all play a role (Cancino and Neves, 1999a; Barros, 1996).

The bed roughness of the Galgeplaat varies spatially and temporally. Five sources of bed roughness were identified based on field observations: sand ripples, diatom mats, mussel- and oysterbeds, lugworm fields and tube building worm fields (Borsje, 2010). Roughness will vary over the nourishment as recolonisation of the benthos occurs over time. Many biological processes show a seasonal variation. For example, the biomass of lugworms is much higher in autumn and microphytobenthos show a peak in April and July (Borsje, 2010). Mussel and oyster beds effect the flow as they can be up to 0.5 m above the surrounding sediment and cover a significant area. They act as a physical barrier and therefore the flow in front and behind these beds can slow down, with increased flow velocities along the sides of the bed as the flow moves around, depending on the orientation of the bed and the main current velocity. The flow over the bed is also reduced. These reduced flow velocities will affect sediment transport around the biological feature.

Biological roughness effects of oyster beds and diatom mats were included in the model by taking into account their effective roughness height. Therefore the White-Colebrook formula (Equation 1) was used to estimate the Chezy coefficient in locations where there are oyster beds (Fig 1).

![Figure 1. Oyster bed distribution](image-url)
In order to simulate sediment transport correctly, the hydrodynamics (currents and waves) need to be well represented in the model. Therefore, current velocities and waves predicted by the reference run were compared with field measurements at different locations.

Waves

A comparison was made between waves at Keeten and an observation point in the Brabantse Vaarwater to the north east of the Galgeplaat, for the winter simulation. Significant wave height was predicted well for most of the simulation period. Lower wave heights were overestimated at certain times. Significant wave heights are also well simulated for the longer simulation. It was observed in the model that both wind and current direction play a role in the correct simulation of significant wave heights for different locations around the Galgeplaat.

Current Velocities

Current velocities were compared with current velocity measurements done on the flats. Velocity magnitudes compare well at some stations over the intertidal flats and are slightly underestimated in others. Measurements were also compared to simulations with a different bed roughness to see how it improved or deteriorated the simulation of current speed.

The direction of the flow velocities over the flats vary throughout the tidal cycle. Kohsiek et al., (1988) found during field measurements in the adjacent western tidal channel of the Galgeplaat that the current direction near the bottom is along the edge of the shoal, but that the current direction near the surface is shifted 20 degrees and is directed onto the shoal. This occurs around the maximum flood velocities. Although the model is 2D the vectors do appear to curve inwards towards the flats mid-way through the flood and around high water on the western side (Figs 1). During ebb, large current velocities are directed off the flats.

Figure 1. Current velocities at different points in time

Additional peaks in current velocity during drying and flooding are also observed. These occur just after and just before low water. These extra velocity peaks are not observed in the current velocity measurements, but there is evidence of such additional flood peaks in the ADCP data of 2010. These additional peaks are documented in the literature (Friedrichs et al. Quaresma et al., 2007). Velocities and stresses due to tides are greatest near the tidal front i.e. just after the tidal flat is submerged during flood and just before it is exposed at the end of ebb (Friedrichs et al). Where water depths are small, such velocity spikes may be reinforced by momentum-induced bores associated with strong frictional nonlinearities in the vicinity. A corresponding double peak in sediment transport is also observed and as sediment transport is the product of velocity and concentration, the peaks tend to be even greater.

Sediment Transport and Morphology

For the different scenarios, mean total sediment transport vectors (Fig. 2) and cumulative sedimentation erosion (Fig 3) were plotted and analysed. Calculations of volume change under different forcing conditions were also assessed. These plots were created in MUPPET.
Figure 1. Mean transport vectors  

Figure 2. Cumulative sedimentation (red) and erosion (blue) plots