Band width analysis morphological predictions Haringvliet Estuary

G. Dam & A. J. Bliek
Svašek Hydraulics, Rotterdam, the Netherlands

A. W. Bruens
National Institute for Marine and Coastal Management, The Hague, the Netherlands

ABSTRACT: Process based morphological models are used as a policy tool to predict the morphological changes due to (human) impacts. Due to computational time of these models sensitivity of the model results are often not considered. This paper presents a case study in the Haringvliet Estuary (the Netherlands) and shows that bandwidth in morphological predictions cannot be neglected. The questions to be answered in estuarine morphology should not only concentrate on the bathymetry after a period of (say) 10 years, but also on the accuracy ranges of the prediction.

1 INTRODUCTION

1.1 *General*

In recent years, different process based morphological models have been developed to predict seabed changes in tidal estuaries. Especially the models that dynamically predict seabed changes over periods of years are very attractive to be used as a tool in the prediction of the impact of human activities on the long term estuarine development. However, this type of models asks for heavy computer capacity to obtain the required spatial resolution in the area of concern. Budget and time frame constraints are the main reasons that the sensitivity of the forecast for model uncertainties and/or sediment properties are often not considered. This paper presents a case study in the Haringvliet Estuary (the Netherlands) that emphases on the uncertainties of the forecast. To determine the bandwidth of the morphological predictions was one of the key items of the scope.

1.2 *Haringvliet case study*

The Haringvliet case study is carried out with the morphodynamic model FINEL2D. The seabed changes over the last 30 years (after closure of part of the estuary and other human activities) were used to calibrate and validate the model. After calibration and validation the model was applied to forecast the long term development of the estuarine bathymetry for different development schemes, like re-opening of the inner part of the estuary and a further extension of the Rotterdam Port area.

The forecast model was not only used with the set of (calibrated and validated) model parameters and boundary conditions, but a range of calculations was done with varying input data. In this way also an accuracy range for the morphodynamic forecast was obtained. Accuracy ranges in terms of future seabed bathymetry have been determined for the following types of uncertainties:

- Uncertainties related to physical parameters like hydrodynamic factors and sediment properties;
- Uncertainties related to modelling principles and assumptions;
- Uncertainties related to climatological factors (like the occurrence of heavy storms or river floods).

2 THE HARINGVLIET ESTUARY IN PAST AND FUTURE

2.1 *General*

The Haringvliet estuary is located in the South West part of the Netherlands, see figure 1. In 1970 the major (inner) part of the estuary has been closed off from the sea to protect the hinterland against flooding. As a part of the closure dam, a fresh water discharge sluice was built to discharge the fresh water of the rivers Rhine and Meuse to the sea. During low tide at sea the sluices in the dam are opened and large quantities of river water are discharged into the sea. Due to the closure of the inner estuary by the dam the tidal volume of the remaining part has decreased by about 70%. This has caused a large accumulation of sand and silt in the area. See the figures 2, 3 and 4 where the seabed of the years 1970, 1986 and 2000 are shown. The main channels in the area are called ‘Slijkgat’ and ‘Rak van Scheelhoek’. The Slijkgat is the largest channel nowadays through which most of the tidal and rivervolume is transported. In the Rak van Scheelhoek a depth decrease of approximately 5m has occurred since 1970. Most of the sediment that settled in this channel is silt.

On the sea side, the shallow sand bar (called ‘Hinderplaat’) has moved eastwards and has grown above mean sea level due to the relative dominance of the wave action since the tidal currents have dropped significantly after the closure.
Also the river discharge plays a role in the morphology of the area. Due to the regular discharge of fresh water into the sea vertical salinity gradients occur, resulting in density currents and vertical exchange of sediments seaward of the Haringvliet sluices.

Just north of the estuary the Port of Rotterdam is located. The port has reclaimed large areas from the sea since 1973. The development started in 1973 by reclaiming the first seaward extension called Maasvlakte and the closure of a secondary channel in the north of the estuary. In 1986 another area is reclaimed called the Slufter.

Figure 1: The location of the Haringvliet Estuary (Bathymetry of the year 2000)

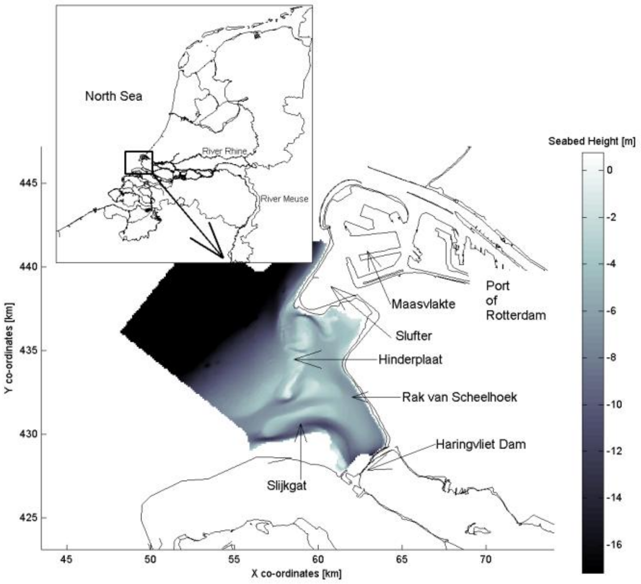


Table 1 shows the observed areas (in hectare) of different depth ranges for the years 1970, 1986 and 2000. All levels are expressed in NAP, which is approximately Mean Sea Level.

Figure 2: Depth contours in the years 1970, 1986 and 2000

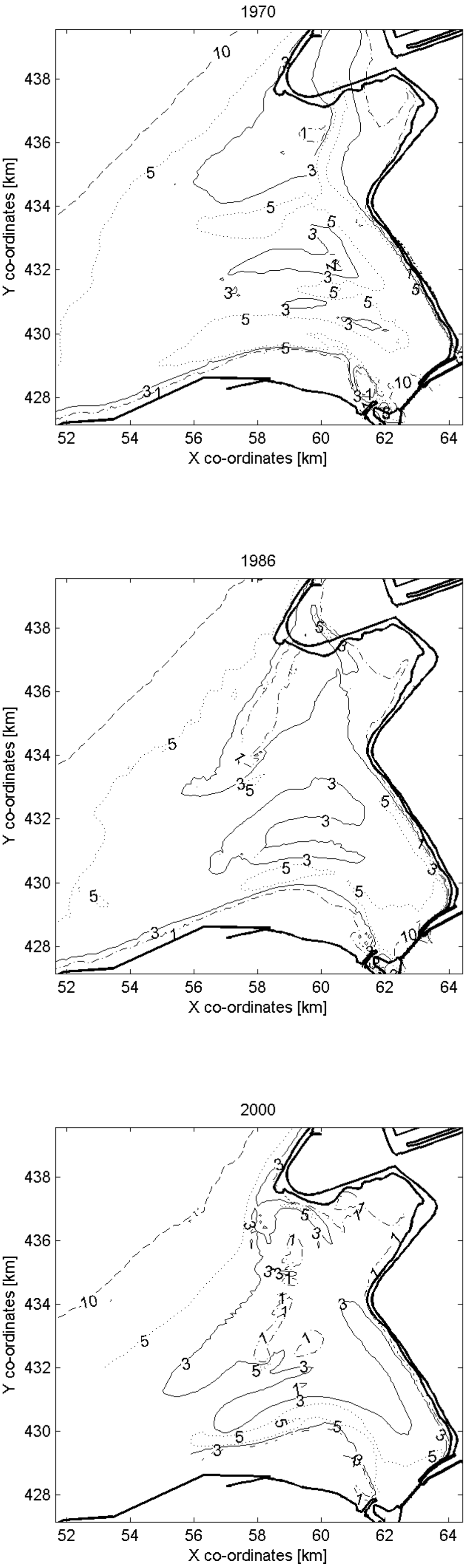


Table 1. Observed depth areas in 1970, 1986 and 2000

Area		Meas.	Meas.	Meas.
	year:	1970	1986	2000
	unit:	(ha)	(ha)	(ha)
< -10 m		514	582	911
-10m / -3m		10788	9965	7302
-3m / -1m		2131	2008	2871
–1m / +1m		547	853	1070
+1m / +2m		380	412	347
> +2m		194	308	641
Total		14554	13275	13142

The sedimentation of the channels can best be seen in the –10m/ -3m depth range, where a decrease of 3000 has occurred. Partly because of the growth of the Hinderplaat, the shallow zone and the intertidal area show a large increase since 1970.

The reduction of the total area in course of time is mainly caused by the reclamation works for the Port of Rotterdam.

The total sedimentation of the Haringvliet area from 1970 till 2000 is approximately 100 million m^3.

2.2 *Future development schemes*

Future development schemes for the estuary refer to:

- partial re-opening the Haringvliet closure dam (MER Beheer Haringvlietsluizen, 1998). This should bring back the tidal influence in the inner part of the estuary as a part of an ecological restoration project;

- further extension of the Port of Rotterdam by 1000-1500ha (gross area), which is planned west of the existing Maasvlakte and Slufter (called ‘Maasvlakte2’).

Each of these schemes may have a significant impact on the development of the estuary. An expansion of the port reclamation could lead to a decrease of the wave action in the estuary, while the partial re-opening of the dam could stop the sedimentation trend and enhance the tidal motion again.

A good knowledge of the morphological impact of the different (combinations of) schemes is crucial for the authorities when applying for permits to implement the schemes. Estuarine environments and wetlands have been given international status as protected zones and sea reserves. In the Netherlands among others the Bird and Habitat Directive (issued by the European Union), are applicable. These directives give strict guidelines for any development scheme in wetlands. Mitigation and compensation of adverse impacts are key words in EIA and permit applications. Especially any expected loss of intertidal areas should be compensated. Creating new intertidal zones with the same habitats and biodiversity is an option then.

In other words: the knowledge of the morphological impact of the development schemes is directly related to the extent of compensation and mitigation that is required. Accuracy of morphological predictions and bandwidth of intertidal area forecasts are no longer items of scientific interest only, but have to do directly with obtaining development permits or not, and with the costs involved in compensation and mitigation works.

3 THE MORPHODYNAMIC MODEL FINEL2D

3.1 *General*

The morphological analysis of the Haringvliet estuary is carried out with the hydrodynamic and morphological model FINEL2D.

Under the FINEL2D umbrella a series of modules exists for different applications. In the Haringvliet case the following modules were applied:

- Hydrodynamic modules, focusing on tidal levels and currents, river discharge, wave action and wave induced currents;
- Sediment transport modules for the calculation of bed and suspended load of non-cohesive and cohesive sediments and for the interaction between cohesive and non-cohesive sediments at the seabed;
- Morphodynamic modules for online adaptation of the seabed level in the model grid points to the calculated sedimentation and erosion rates and for online restarting of the dynamic loop.

Each of the modules is discussed in more detail in the next sections.

3.2 *Hydrodynamic modules*

3.2.1 *FINEL2d*

FINEL2d is a 2DH numerical model, based on finite elements. This model is developed by Svašek Hydraulics. FINEL2D makes use of unstructured triangular grids. The advantages of such a unstructured triangular mesh in comparison to a finite difference grid are obvious: the major computational effort takes place in the area of interest, no nesting techniques are required and a triangular mesh can describe complicated coastlines very good.

3.2.2 *Wave model SWAN*

Waves can play an important part in morphological changes. For this reason the wave model SWAN is integrated in the model suite. See for a further description of SWAN Booij et al. (1999).

The wave model SWAN is used in the model in 3 ways:

- The spatial distribution of wave forces, is input for the hydrodynamic module to include the effect of wave driven currents in the total flow pattern. Because of the varying water level during the tide, the wave calculations are done for several water levels during the tidal cycle, for intermediate water levels the wave fields are interpolated.
- The spatial distribution of the orbital motion at the seabed (amplitude and direction), to be added to the current shear stresses (tide, wind or wave driven) to obtain the total shear stress as input for the sediment transport module. Here again, the results of the wave field calculations at varying water levels are used and interpolated if required during the calculation process.
- The cross shore distribution of the wave field in the coastal zone as input for the calculation of sediment transport according to Bailard (1981) and Nipius (1998). This option is applied in this study as an extra calibration parameter in the dynamic coastal section with breaking waves.

3.3 *Sediment transport modules*

3.3.1 *Sand module*

The transport formula for non-cohesive sediments (sand) in the Haringvliet study is the Bijker formula. We refer to Bijker (1967) for details. The formula is applied to make the results comparable with previous studies in the same estuary. Other transport formulae can easily be incorporated in the sand transport module.

3.3.2 *Silt module*

The basis of the silt module is the well known formula of Krone (1962) for deposition and of Partheniadis for erosion (1962, 1965). The module takes into account the availability of silt at the seabed.

3.3.3 *Sand-silt module*

The separate sand and silt modules as discussed above have the disadvantage that the transport processes of both sediments are treated completely independent of each other. In this approach the availability of sediment at the seabed is the only parameter that can prevent unrealistic erosion of one of both sediment types (for instance excessive erosion of silt at locations where no silt is present). To refine this approach a module is developed that takes into account the interaction between cohesive and non-cohesive sediments. This is the so-called sand-silt module.

The sand-silt module in the Haringvliet study is based on Van Ledden (2003). The main elements of the ‘Haringvliet’ sand-silt module are:

- The formulae of Bijker for sand and Krone-Partheniadis for silt are applied (similar to the separate modules).
- The module administrates the history of the mix of sand and silt in the seabed on the basis of field data and/or morphodynamic calculation results in a number of layers.
- In course of time the sand-silt ratio of succeeding bottom layers is adapted related to physical processes like bioturbation (so even without seabed exposure the composition of the bottom layers is not constant).
- The erosion characteristics of the top layer at the seabed (being the layer that is directly exposed to the water forces) depend on the sand/silt ratio of the top layer at the moment of exposure.
- This dependency is based on the approach of Van Ledden (2003) that triggers on cohesive or non-cohesive behavior of the top layer only. A silt content below 30% declares the seabed to be non-cohesive and erosion is generally easily. In return, if the silt content at the seabed exceeds the 30% level, the seabed characteristics are defined as cohesive, which implies that the erosion of this layer is much harder. The availability of sand for erosion and transport is determined by the silt component.

This sand-silt approach has many entrances for refinement. But, in the Haringvliet case, this relatively straightforward approach has proven to be a suitable instrument to contribute to the assessment of reliability and bandwidth of morphological forecasts.

3.4 *Morphodynamic modules*

3.4.1 *General*

In the morphodynamic modules of the model no additional calculations of physical processes are done. The results of the hydrodynamic and sediment transport modules are used to come to a statistically representative mix of conditions and processes. Also the sequence of execution of the different calculations, the method to cope with daily conditions and extremes and with the co-incidence of different events are organised by the morphodynamic modules. Finally, this part of the model arranges for the gradual adaptation of the seabed level and composition in the model to the changing conditions and calculated sediment movements.

3.4.2 *Representative mix of conditions*

In an estuarine environment like the Haringvliet estuary often a series of statistical independent physical processes and phenomena are present. These phenomena are:

- The tidal motion; this phenomenon is well predictable by using the harmonic components of the astronomical tide. In this way (for instance) spring-neap cycles can be defined which are basically forecastable over a period of decades.
- The wave climate; the character of the wave climate is stochastic. On the long run a statistical distribution of wave conditions can be defined, but the occurrence of specific conditions (like a storm from a certain direction and with certain intensity) may coincide with any phase of the tide in the spring-neap cycle.
- The river discharge; this phenomenon is also stochastic. The occurrence is statistically independent from both the tide and the waves. The time scale of changes in river discharge is in the order of several days, compared to one or two days for the waves and to 12.5 or 25 hours for the well-defined tidal cycle.

The easiest way to deal with all of these conditions is to take a sufficiently long period and to run the model in real time mode. The historical joint occurrence of tide, wind, wave and river discharge will pass the computer then without further mixing problems. There is one constraint in this approach, and it is a showstopper. Its name is computer time. Depending on the statistical distribution of extreme waves and river discharges, the minimum calculation period should be in the order of several years to achieve a representative mix of conditions. This makes the real time mode as a standard solution to be not realistic.

A complete morphological calculation consists of several blocks. In each block a constant river discharge, wind and wave condition is applied. Each block calculates a certain hydrodynamic timeframe of 1 or more tides. A morphological acceleration factor (N) is applied to the calculated bottom change each timestep the morphological module is called. So for example when the hydrodynamic part of the model has calculated one timestep (dt) the morphological part has calculated N*dt timesteps. The reason for using an acceleration factor is computational time.

The choice for the number of tides which are calculated, the constant river discharge, wave conditions and wind is based on the long term observations. When combining all different parameters, for example northerly directed waves and high river discharge and southerly directed waves and low river discharge, the complete mix of these statistical variables are treated and should in theory approach realistic statistical conditions. All blocks are calculated after each other.

In this study two different approaches for the combination of are followed, called SET 1 and SET 2.

3.5 *Methodology SET 1*

Because of limitations of computational time the input of morphological calculations are often very schematised. The modeller often uses a morphological tide, schematised discharge and meteorological conditions. This approach is called ‘SET 1’ in this paper.

The assumptions used for SET 1 are derived from previous studies, which are carried out in this area (Roelvink et al., 1998; Steijn et al., 2001). These assumptions include:

- A morphological tide of 12 hr and 25 minutes. In this study the same morphological tide is used as the previous studies;
- Three wave conditions; Northern directed wave conditions; southern directed wave conditions; Conditions without waves. All three wave conditions are applied with a constant wind of that direction.
- Constant river discharge;

These assumptions are used to calculate the calibration period (1970-1986), the validation period (1986-2000) and the prediction period (2000-2010).

3.6 *Methodology SET 2*

On the other hand when taking into account a complete neap-spring cycle, varying discharge and varying meteorological conditions should give better results. This approach is called ‘SET 2’. Besides these boundary conditions the calculations are carried out with the sand-silt module instead of the seperate sand and silt module.

The basic principle of SET 2 is to take into account as many relevant aspects as possible in comparison to SET 1 to get a maximum band width between these two sets.

The difference between SET 1 and SET 2 are:

- The basic difference between these two sets is that SET 2 uses a complete neap-spring tidal cycle instead of a schematised morphological tide
- SET 2 takes into account the influence of variable meteorological conditions instead of averaged meteorological conditions (SET 1). Storms are calculated separately in SET 2, while SET 1 is averaging the storms in the wave conditions. The wave conditions in the past decades show that the averaged number of storms in one year is 2.
- SET 2 takes into account the influence of variable river discharge, while SET 1 calculates an average river discharge. The observed river discharge is used as the boundary condition. For the prediction in the future the average discharge of the last 3 decades is taken, since the discharge of the future is unknown.

- SET 2 uses a sand-silt interaction model, while SET 1 uses a different model for sand and silt.

Since SET 2 uses different way of modelling than SET 1 the calibration and validation has to be carried out again with this model. The calibrated model is then used to carry out a prediction. The difference between SET 1 and SET 2 gives a band width due to different boundary conditions and physical processes.

3.7 *Methodology SET 2 meteo*

Future meteorological conditions are not known. This causes a natural band width of morphological predictions. The prediction of SET 2 uses an averaged number of storms each year and an averaged river discharge. Therefore three more predictions are carried out:

1. SET $2_{extreme}$: This prediction uses the settings of SET 2, but with 3 storms each year, instead of 2 storms;
2. SET 2_{mild}: This prediction uses the settings of SET 2, but with 1 storms each year, instead of 2;
3. SET 2_{river}: This prediction uses the settings of SET 2, but with a higher river discharge and 0 storms.

The difference between these predictions gives a band width in meteorological conditions.

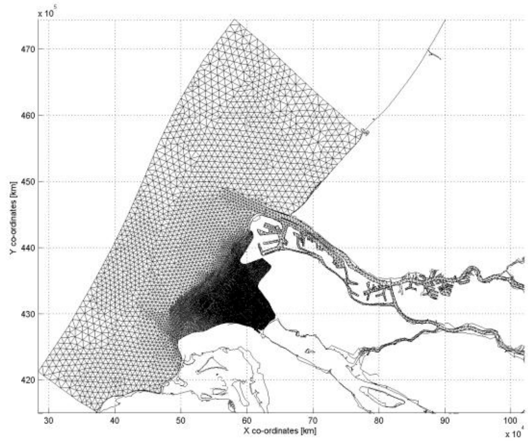
4 BUILDING, CALIBRATION AND VALIDATION OF THE MORPHODYNAMIC MODEL

4.1 *Building of the grids*

The sea boundaries of the computational grid were chosen such that the results of existing models could be used as boundary condition for this model. The overall grid is shown in figure 3. At the sea boundaries the grid is coarse. Near the area of interest the grid becomes finer, until a maximum resolution of approximately 100m is reached.

Please note that 3 different grids are build for this study: the first for the calibration phase (1970-1986) in which the Maasvlakte is being build, the second for the validation phase (1986-2000) in which the Slufter is completed and the third for the future layout of Maasvlakte 2 (2000-2010).

Figure 3: Overall grid of the FINEL2d model



4.2 *Calibration of the watermovement*

The first and important step in the calibration of a morphological model is the calibration of the watermovement. In this case the model is calibrated on observed waterlevels during a spring tide and neap tide and observed discharges of channels in the Haringvliet during a neap tide. The boundary conditions of the calibration periods of the watermovement are obtained from a hydrodynamic model of the complete coast of the Netherlands.

The shape and magnitude of the calculated waterlevels match the observed waterlevels well. The waterlevels are usually calculated within an accuracy of 10 cm. The observed discharges in the Haringvliet channels correspond very good to the FINEL2d discharges. The quality of the calculated waterlevels and discharges are good enough to begin the calibration of the morphology.

4.3 *Calibration SET 1 & SET 2 (1970 – 1986)*

Starting point of the calibration of SET 1 and SET 2 is the geometry of 1970. This observed bathymetry is used as input. The calculated bathymetry in 1986 is used for calibration against the observed bathymetry. Assumed is that no silt is present at the initial sea bed.

For more information about the calibration we refer to Dam (2004).

The overall morphology could be reproduced well for SET 1. Most of the relevant morphological phenomena could be reproduced by the model such as the sedimentation of the channels, the eastward movement and growing of the Hinderplaat. The total sedimentation in the period 1970 – 1986 is 75 M m^3 in the area. SET 1 calculates a sedimentation of 67 Mm^3.

The calibration of SET 2 was performed on the first 2 years because of a lack of time. After 2 years the morphological changes could be reproduced well, however when calculating the complete 16 years of the calibration period the calibration effort was less successful as SET 1. Too much sediment settles in the estuary. A further calibration effort can substantially improve the results, because the overall processes. SET 2 calculates a sedimentation of 158 Mm^3, instead of the observed 75 Mm^3. Because of the overestimation of the sediment volume the inter tidal area is overestimated about 5 times.

4.4 *Validation SET 1 & SET 2 (1986 - 2000)*

The validation period was chosen for the period 1986 – 2000 and is used to verify if the calibration still applies for this period. In this period the sedimentation of the estuary still going on. SET 1 is calculation a sedimentation of 40 Mm^3, while the observation shows a measurement of 43 Mm^3, so the overall sedimentation is calculated good. When looking at different patterns like the morphologic change of the Hinderplaat the validation of SET 1 shows less good results than the calibration of SET 1. This also applies for the results of SET 2. A total sedimentation of 122 Mm^3 is calculated using SET 2.

5 PREDICTION OF GETEMD GETIJ (2000-2010)

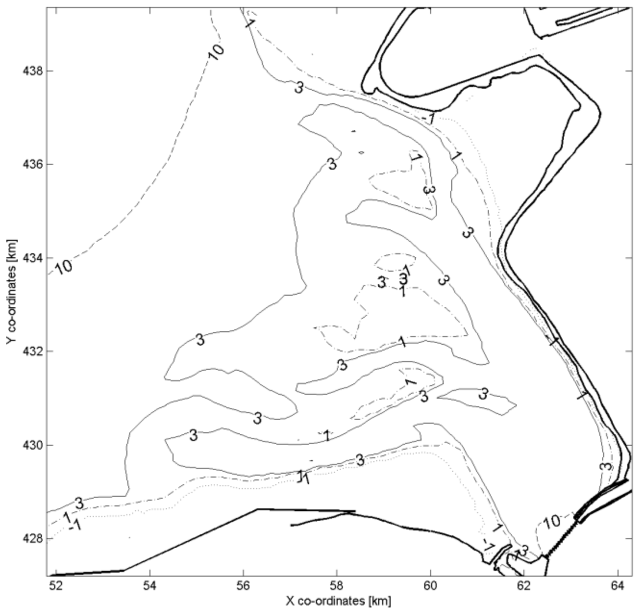
5.1 *Bandwidth SET 1 & SET 2*

Both SET 1 and SET 2 are used to calculate a ten year prediction including the partly opening of the Haringvliet dam (getemd getij) and a Maasvlakte 2 variant. When the sluices of the dam are opened a lot more water is transported through the channels each tide. It is therefore expected that erosion of the channels might occur.

It is known that the sedimentation in the last 30 year of the Rak van Scheelhoek is silt. This silt layer of approximately 5m thickness is used as input in SET 1 and SET 2. The major difference for this channel between SET 1 and SET 2 is the use of the sand-silt interaction module, which is used in SET 2, while SET 1 uses a 'normal' silt model. Because the silt percentage of this channel is very high the sand - silt interaction module assumes cohesive behaviour of the channel. The other major channel called 'Slijkgat' is a sandy channel.

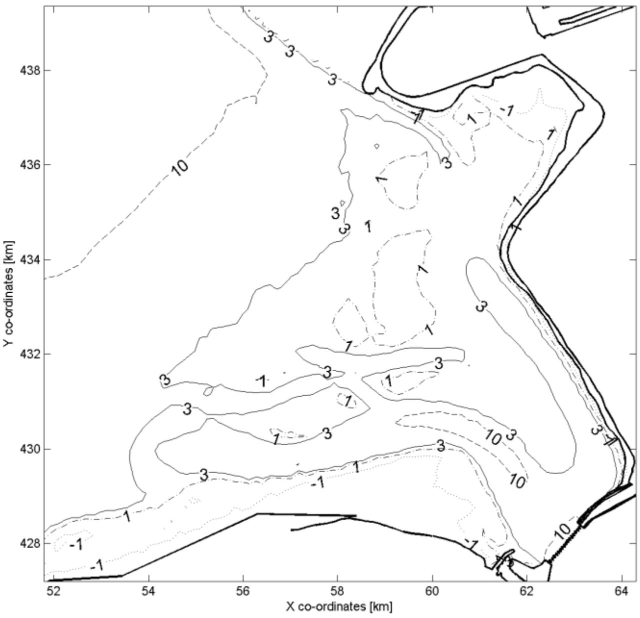
The calculated bathymetry in 2010 for SET 1 is shown in figure 4. The initial bathymetry of 2000 can be seen in figure 2. The most important change is that the silt layer in the Rak van Scheelhoek has completely eroded. Since the Rak van Scheelhoek has eroded the northern part of the area shows a strong morphologic change.

Figure 4: Predicted bathymetry of SET 1 in 2010



The prediction of SET 2 shows a complete different behaviour as can be seen in figure 5. Instead of the Rak van Scheelhoek the Slijkgat has eroded. This is explained by the fact that cohesive behaviour of the silt layer is assumed in the Rak van Scheelhoek, which makes it harder to erode. The Slijkgat becomes the main channel in the area.

Figure 5: Predicted bathymetry of SET 2 in 2010



The difference between SET 1 and SET 2 shows a transition in channel development; In SET 1 the Rak van Scheelhoek is eroded, in SET 2 the Slijkgat is eroded.

To calculate the influence of the sand-silt module (which takes into account the cohesive behaviour of the Rak van Scheelhoek) alone versus the rest of the differences between SET 1 and SET 2, like the boundary conditions (neap-spring cycle, storms etcetera) a separate run was carried out. The results showed that the sand-silt module was responsible for the major difference between SET 1 and SET 2. The other differences are of a second order.

The erosion parameters of the silt layer in the Rak van Scheelhoek are not known, since the channel has shown a sedimentating trend since 1970 and therefore calibration of the erosion parameters are almost impossible. The erosion of silt is high in SET 1, while the erosion is slow in SET 2. In this way the possible outcomes are covered.

A possible solution for the calibration of the silt erosion constants lies in the periods with high discharge. A high discharge might give the same morphologic response as the opening of the sluices, since a lot of water is transported through the sluices in both cases. In the 1990's a severe high water occurred in the Dutch rivers. The difference in bathymetry before and after the high water period showed an erosion in the Slijkgat, while the Rak van Scheelhoek remained stable. This gives an indication that the erosion parameters of SET 2 are more realistic, although this cannot be said for certain. A high level of uncertainty remains. It is clear that future research for this area should concentrate on the silt parameters of the Rak van Scheelhoek.

Table 2 shows the differences of the depth areas of the two sets.

Table 2. Comparison area of SET 1 and SET 2 prediction period (2000 – 2010) for Getemd Getij

Area		Meas.	SET 1	SET2	Diff.*	Diff.*
	year:	2000	2010	2010	2010	2010
	unit:	(ha)	(ha)	(ha)	(ha)	(%)
< -10 m		911	689	1008	+319	46%
-10m / -3m		7302	7244	6710	-534	-7%
-3m / -1m		2871	2429	2940	+511	21%
–1m / +1m		1170	924	1494	+570	+62%
+1m / +2m		347	1315	449	-866	-66%
> +2m		641	641	643	+2	0%

* Difference is defined as SET 2 - SET 1 in the year 2010

5.2 *SET 2 meteo*

Future meteorological forcing are unknown. This causes a natural band width in the morphological predictions. Three calculations were carried out using different meteorological forcings:

1. SET 2 extreme: As SET 2, but instead of 2 storms each year, 3 storms are forced.
2. SET 2 mild: As SET 2, but instead of 2 storms each year, 1 storm is forced.
3. SET 2 river: As SET 2, but no storms and a higher river discharge is forced.

The results in depth areas are shown in table 3. The columns shows a difference in % in relation to the normal SET 2 run. The difference is not high, a maximum difference of 11% can be seen. This is not high in comparison to the differences between SET 1 and SET 2.

Table 3. Comparison area of prediction SET 2 meteo (2000 – 2010) for Getemd Getij

Area		Meas.	SET2	Diff.* extreme	Diff.* mild	Diff.* river
	year:	2000	2010	2010	2010	2010
	unit:	(ha)	(ha)	(%)	(%)	(%)
< -10 m		911	1008	2%	0%	6%
-10m / -3m		7302	6710	-1%	1%	2%
-3m / -1m		2871	2940	0%	0%	-5%
–1m / +1m		1170	1494	-1%	-2%	-1%
+1m / +2m		347	449	11%	-3%	-8%
> +2m		641	643	0%	0%	0%

* Difference is defined as this run minus SET 2

The cumulative sediment volume changes of all the runs of the prediction 2000 – 2010 are presented in table 4.

Table 4. Cumulative sediment volume changes prediction period (2000-2010) in Mm^3

	Volume change
SET 1	35
SET 2	5
SET 2 $_{extreme}$	7
SET 2 $_{mild}$	4
SET 2 $_{river}$	0

The difference between SET 1 and SET 2 is large. The difference is mainly caused by the large erosion of the Rak van Scheelhoek and a large sedimentation in the rest of the area. SET 2 shows a much calmer development in volume, mainly because the erosion of the Rak van Scheelhoek is slower. The runs using different meteorological forcings show that storms are transporting the sediment inside the system, resulting in a positive sedimentation. A higher river discharge on the other hand results in less sedimentation. A higher river discharge is transporting the sediment out of the estuary. The differences after ten years are in the order of a few million m^3.

6 DISCUSSION

6.1 *Bed roughness inter tidal areas*

The water movement is the basis of process based morphological models. The water movement is usually calibrated on observed water levels and some current/ discharge observations in the main channels. The main parameter which is used to calibrate hydraulic models is the bed roughness. The global water movement is calibrated in this way. The inter tidal areas are usually not taken into account when calibrating the hydraulic model, since no data is available and these areas are not important for the global water movement. It was found that the velocities of the model in inter tidal areas are very sensitive of the hydraulic bed roughness. Since no data is available to calibrate the model in the inter tidal areas the same roughness as found in the channel is applied to this areas. Since sediment transport formulas often use a higher order power (3- 5) of the current a small error in the velocity has big consequences for the resulting morphology. In SET 1 and SET 2 a constant bed roughness is applied, since this could not be calibrated, but a few sensitivity runs with a hydraulic bed roughness which was varied within realistic ranges showed that this could dominate the complete morphologic solution of the inter tidal areas.

It is a paradox that these models are developed and calibrated for global hydrodynamic results (modeller), while the area of interest is shifting more and more to the inter tidal zone (manager).

6.2 *Calibration of SET 1 and SET 2*

Table 5 contains the difference in depth area between SET 1 and SET 2 for the calibration/ validation and prediction.

The calibration and validation shows more or less the same differences between SET 1 and SET 2, while the prediction is completely different. It can be concluded that the calibration in another regime like the opening of the sluices cannot be applied by definition.

Table 5. Comparison* area between SET 1 and SET 2

Area		Calibration	Validation	Prediction
	year:	1986	2000	2010
	unit:	(%)	(%)	(%)
< -10 m		-53%	-42%	46%
-10m / -3m		-18%	-20%	-7%
-3m / -1m		45%	51%	21%
–1m / +1m		86%	73%	62%
+1m / +2m		-2%	4%	-66%
> +2m		6%	4%	0%

* Difference is defined as SET 2 - SET 1

The results also show that although the calibration of SET 2 is not good, the results of the prediction are in this case still valuable, since the solution is dominated by another effect, which could not be calibrated, namely the cohesive erosion behaviour of the Rak van Scheelhoek.

7 CONCLUSION

Two sets of model assumptions / boundary conditions and processes have been calibrated, validated and used for a prediction. The results show a large band width in the prediction of the development of the Haringvliet estuary for getemd getij situation. This is mainly caused by taking into account the cohesive erosion behaviour of the silt in the Rak van Scheelhoek. This is almost impossible to calibrate since the estuary is a sedimentating since 1970.

The calibration and validation effort of the model from 1970 till 2000, in which the system is sedimentating, is no longer valid when predicting the morphology of the opening of the sluices (getemd getij situation), in which the system is eroding. It is better to also calibrate on a period with a high river discharge, which has probably the same morphological result as the getemd getij situation.

Meteorological effects are of minor importance for the band width than the difference between SET 1 and SET 2.

The results clearly show the necessity to take band width into account when predicting morphological developments. The management of the area needs to deal with this band width and use it properly. At the same time the analysis of the results gives a good insight in the path for model development.

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