Modelling of the sediment transport at the Belgian coast
Dries Van den Eynde
Management Unit of the North Sea Mathematical Models, Gulledelle 100, B-1200 Brussels, Belgium
EMail: D.VandenEynde@mumm.ac.be

Abstract

A vertically integrated and a three dimensional sediment transport model are used to simulate the dispersion of dredged material at the Belgian coast. Both models are Lagrangian models, based on the Second Moment Method. Different sediment types can be taken into account. The bottom stress is calculated under the influence of prevailing currents and waves. The results of radioactive tracers, executed by HAECON NV, are used for the validation of the models. For the time being, the most satisfying results are obtained with the two-dimensional sediment transport model. Therefore, only this model and its results will be presented. By a careful interpretation of the results of the experimental and model results, a better insight can be gained on the transport of the dredged material at the Belgian coast.

1 Introduction

Between 1980 and 1989 each year around 33 million m³ dry material was dredged to maintain and to deepen the fair channels and the harbours in the Belgian coastal waters (BMM & AWZ²). Most of this material is dumped back into sea (Malherbe⁹). The selection of dumping sites with a high efficiency is essential. Firstly the dumped material should return as little as possible to the place where it was dredged. Further the chemical and biological effects, caused by these dumping activities, should stay as localised as possible. Since the efficiency of the current dumping sites varies between 25 % and 0 % (BMM & AWZ²) an investigation to select dumping sites with a higher efficiency was necessary.
Different numerical models are developed to study the transport and dispersion of the dredging material at the Belgian coast. Since the dispersion of cohesive material is a complex phenomenon, of which not all essential relations are yet well understood, the models can provide qualitative results only. The validation of these models therefore is of great importance. The models can be used in many different simulations and in sensitivity studies to evaluate the importance of different factors on the sediment dispersion. By careful interpretation of the model and experimental results, a better insight can be gained on the transport of the sediments in the area of interest.

In the present paper, some results of the sediment transport models are presented. In a first section, the numerical models are shortly introduced. In a second section, the validation of the models will be presented. Some conclusions are formulated in the last section.

2 Description of the numerical models

2.1 Introduction

Since the water at the Belgian coast is well-mixed during the entire year a two-dimensional vertical integrated model was developed in a first stage. Later a full three-dimensional (layer-)model was developed to account for the vertical structure of the water velocities and the suspended matter. The results of the latter model obtained so far are less satisfying then that provided by the former. Therefore, only the two-dimensional model and its results will be presented and discussed further.

In a first section, a short description is given of the hydrodynamic model. The wave model is discussed in section 2.3, while the sediment transport model is presented in section 2.4. A more complete description of the models can be found in Van den Eynde.

2.2 The hydrodynamic model

The two-dimensional hydrodynamic model MU-BCZ calculates the depth-integrated current velocity and the mean water level over the model grid under the influence of the tides and the meteorological effects. The bottom stress is computed using a quadratic friction law. The equations are solved using a fully explicit finite difference method on a staggered Arakawa-C grid.

The model is implemented on a grid, covering the Belgian coastal area and the Flemish Banks, with a resolution of 25” x 40”
(approximately 750 x 750 m²). The model bathymetry is presented in Figure 1. At the open sea boundaries, the model is coupled with a larger hydrodynamic model of the North Sea and the Channel. At the outflow of the Scheldt river, the model is coupled with a one-dimensional model for the Scheldt estuary.

2.3 The wave model

For the calculation of the wave environment in the Belgian coastal area, the MU-WAVE model (Van den Eynde) is used. The core of the model is formed by the HYPAS wave model (Günther & Rosenthal), which is a second generation wave model, which combines the independent calculation of swell energy for each frequency and direction through a ray technique, with a parametrical wind sea model, using the JONSWAP parameters and the mean wind sea direction as prognostic variables. For the current application, the model is implemented on two nested grids. In the Southern North Sea a grid resolution of 5 x 5 km² is used.

2.4 Sediment transport model

The sediment transport model MU-STM is based on the Second Moment Method (de Kok), which introduces less numerical diffusion than classical Eulerian methods. Using this Lagrangian method, the dumped material directly can be followed through the model grid and the return to the fair channels and the sea harbours can be calculated easily.

The model can account for different sediment classes and calculates for each of them the advection and diffusion of the material in suspension under the influence of the tidal currents and of the currents generated by the waves (Stokes drift). The bottom stress is calculated under
the combined effect of currents and waves (Bijker\textsuperscript{1}). The erosion and the deposition are modelled according to Partheniades\textsuperscript{10} and Krone\textsuperscript{8}.

3 Application to Belgian coastal zone

3.1 Introduction

Six radioactive tracer experiments, executed in the Belgian coastal zone between 1992 and 1993 by HAECON NV\textsuperscript{5,6,7}, are used for the validation of the model (Van den Eynde\textsuperscript{13}). In a first section, the tracer experiments will be shortly described. Further, the model simulations will be discussed. The most important results are formulated.

3.2 Tracer experiments

Six radioactive tracer experiments were executed by HAECON NV, to investigate the recirculation of the dumped material to the Belgian coast. The position of the six sites are given in Figure 1. Note that five sites are within a range of 21 km of the coastline, while the last site (sx3b) is about 30 km from the coastline.

After the dumping of the radioactive mud, bottom samples were taken at different stations and over a period of several months to trace the dispersion of the dumped material. The main findings of these experiments can be summarised as follows.

The material dumped at the five stations within 21 km of the coast, clearly recirculates very rapidly to the coast. In some cases, material is found back in the harbours after two or three days already. The material spreads out over the entire Belgian coast and even migrates into the Western Scheldt. During storm periods, the material can disappear for a shorter or longer period, but after time, material is found back at the coast. In strong contrast with this, the material dumped at site sx3b does not recirculate to the coast. During the entire sampling period, no tracer is detected on the Belgian continental shelf.

Although it is clear that these tracer experiments are a very valuable source of data for the validation of the model, due to several reasons, the results can only give some first indications. First of all, during the sampling of the bottom, no attention was made to the tidal cycle. Measurements and model results clearly indicate that the mud comes into suspension during periods of high currents and settles down during slack water periods. Material thus can be present in the water column at a certain station while no radioactivity will be found in the bottom samples.
Further most of the bottom samples were taken near the coast and consequently not much information on the dispersion of the material in the open sea is available. Furthermore, many of the samples were taken in the harbours themselves, where local effects, e.g. of harbour dams, can play an important role, which can not be represented in the numerical models. At last, from the calculation of activity balances, which are probably questionable, it appears that in some cases only a very small amount of the material is found back during the detection campaigns. This implies that the complete dispersion of the material can not be derived from these results. The results from the tracer experiments therefore must be interpreted with the necessary precautions.

3.3 Model simulations

For each of the tracer experiments the dumping of 5500 ton of mud is simulated. The critical stress for erosion and for deposition are both set to 0.5 Pa, the erosion constant is taken as 0.12 g/nfs and the fall velocity has a value of 0.01 m/s. These parameters were selected after a literature study and some sensitivity tests. A period of 14 days after the dumping is simulated. For four tracer experiments a longer simulation was executed.

3.4 Results

3.4.1 Tracer experiments sx1a and sx1b (22/4/1992)
During the first fourteen days after the dumping of the radioactive material, the meteorological conditions were relatively quiet. As well in the results of the tracer experiments as in the model results the sediments returned to the Belgian coast quite rapidly, although the recirculation and the spreading over the entire Belgian coast are in the model results not as fast as observed in the experiments. In the model results, the material is dispersed over a large area. The lack of bottom samples taken in the open sea prevents to confirm this by the experiments.

Note that, as shown in Figure 2, the moment in the tidal cycle has a large effect on the material that can be found at the bottom. Once again, the experimental results must be interpreted with the necessary precautions.

3.4.2 Tracer experiments sx2a and sx2b (18/1/1993)
The first week after the dumping of the radioactive material at sites sx2a and sx2b, the weather conditions were relatively rough. Wind speeds up to almost 20 m/s and wave heights up to 2.5 m were observed
in front of Zeebrugge on 24-25/1/1993. Both wind and waves were directed to the north to northeast.

Figure 2: Results of MU-STM for the dispersion of mud for tracer experiment sx1b: mud at the bottom at (a) 6/5/1992 12h24 and at (b) 6/5/1992 14h24 (14 days after the dumping).

In the few bottom samples, taken during this first week, some radioactivity could be detected in the sea harbours. After the storm, material has been detected at different coastal stations only after a much later date (24 of more days after the beginning of the experiment). During different campaigns material has been detected at the open sea stations.

In the model results the dumped material mainly is transported in the direction of the wind and wave fields. A considerable amount of the mud (especially for the material dumped at site sx2b) leaves the model area towards the Netherlands and the Eastern Scheldt. A certain fraction enters the Western Scheldt. As showed in Van den Eynde\textsuperscript{14} the residual currents and transports indeed are strongly influenced by the meteorological conditions. Therefore, it is reasonable to assume that the mud will be transported mainly in the direction of the strong wind fields and that only a minor part of the mud will be transported, due to the dispersion, towards the coast. This also agrees with the fact that material is only detected at a much later date and that material is found in open sea stations. The material that shows up again at the Belgian coast a later date could be migrated into the Western Scheldt and washed out later, a process that can not be represented in the model.

Remark at last that, although the site sx2a is further located from the coastline then the site sx2b, more material is detected in the bottom samples that originated from the former station. This is also the case in the model results.

As an example, in Figure 3 the results of the tracer experiments and the model results are presented 10 days after the dumping of the radioactive material at site sx2a. In the tracer experiments no material is
detected in the bottom samples, except in Heist en Blankenberge, in station Breskens in the Western Scheldt and in the station in open sea Wandelaar. Due to the rough weather conditions also in the model results no material can be found at the bottom. The core of the material in suspension, however, is located near station Wandelaar.

![Figure 3: Results for the simulations for tracer experiment sx2a: (a) measured radioactivity in the bottom samples on 28/1/1993 (10 days after the dumping); (b) distribution of mud (in suspension and at the bottom) at 28/1/1993 14h00, calculated with the MUSTM model.](image)

### 3.4.3 Tracer experiments sx3a en sx3b (29/9/1993)

The first fourteen days after the dumping at the sites sx3a and sx3b, calm weather conditions occurred. During these tracer experiments, the radioactive material, which was dumped at both sites, behave very differently. While the material, dumped at site sx3a, recirculates to the coast rapidly, the material, dumped at site sx3b, is not detected anymore at the Belgian coast. Only in the Western Scheldt, some low values of radioactivity were sometimes detected. These results are well reproduced in the model. This is illustrated in Figure 4 where for both simulations, the mud in suspension and at the bottom is presented at the end of the simulation. While for the material dumped at site sx3a 5258 ton is still located on the model grid, almost all material dumped at site sx3b disappeared. Only 8 ton is still on the model grid located. Remark that a part of this material is located near the Western Scheldt, which agrees with the measurements.

### 3.4.4 Long term simulations

For the tracer experiments sx1a and sx1b and for experiments sx3a en sx3b, the simulations were continued over a longer period (69 and 80 days). During the simulations, the mud patch is displaced under the influence of the prevailing meteorological conditions. When the meteoro-
logical conditions remain quiet for a sufficiently long period, however, the material returns back to the coast and a tendency for the formation of a turbidity maximum located between Ostend and Zeebrugge can be noted (see Figure 5). The presence of such a turbidity maximum in the area is well-known and is e.g. described by Malherbe. Also in satellite images, such a turbidity maximum is often observed. An example of an AVHRR satellite images with a clear turbidity maximum in the area is given in Figure 5 (from Ruddick et al.).

4 Conclusions and further work

In the paper, a vertically integrated sediment transport model, developed to simulate the dispersion of dredged material at the Belgian coast, is presented. First the hydrodynamic and wave model are discussed, whereafter some specifications of the sediment transport model are given.

The model is used to calculate the dispersion of radioactive traced mud. The main features of the behaviour of the mud are well reproduced by the model. In five experiments, the material can recirculate and spread out over the entire Belgian coast quite rapidly, although the recirculation in the model is not as fast as that observed. The exact reason for this very rapid return to the coast is not yet well identified. The model further indicates that the material is spread out over a wider area and that it will be displaced under the influence of the prevailing meteorological conditions. It will be eventually transported to the northeast. This seems to be confirmed by some of the experimental data. The model results may therefore provide added value for the interpretation of the results of the tracer experiments.
Figure 5: (a) Sub-surface irradiance reflectance for AVHRR channel 1 from NOAA-14 taken on 11/7/1997 at 13h24 (from Ruddick et al.\textsuperscript{11}); (b) distribution of mud (in suspension and at the bottom) at 28/1/1993 14h00 calculated with the MU-STM model.

In the last experiment, no recirculation of material to the Belgian coast was observed, either in the measurements or in the model results. Also these results thus agree very well with observations.

It has to be mentioned that so far, the results of the two-dimensional model were superior to those of a three-dimensional model. Clearly some further work has to be executed for the calibration and the fine tuning of the sediment parameters and the parametrisation of the vertical diffusion coefficient in the three-dimensional model, to improve its results.

**Acknowledgements**

José Ozer is thanked for useful discussion of the model results and for his constructive criticism on this paper. Kevin Ruddick is thanked for providing the AVHRR satellite image. The CAMME team is acknowledged of computing support. This study was supported by the Flemish government under the “STM-II” and “VESTRAM” contracts.

**References**


Environmental Coastal Regions


