CHAPTER 232

Morphological modelling of Keta Lagoon case

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Abstract

DELFT HYDRAULICS' morphological model system is applied to the case of Keta
Lagoon, Ghana; the results are compared with a physical model test carried out
by DELFT HYDRAULICS in 1982.

1. Introduction

Predictions of morphological evolution in a coastal area are of importance in
many engineering applications. Such predictions have often been made by
carrying out physical model tests, which are usually very expensive and time-
consuming, and which may suffer from scale effects. Nowadays, mathematical
models offer a relatively cheap and efficient way for morphological predictions.
However, validation of such models requires much attention.

The objective of this study is to test the coastal area model developed at DELFT
HYDRAULICS against the measurements from physical model tests and to produce
results for comparison with other models.

The study is part of the "G8 Coastal Morphodynamics" research programme,
which is funded partly by the Commission of the European Communities in the
framework of the Marine Science and Technology Programme (MAST), under
contract no. MAS2-CT92-0027. For more background information see De Vriend
et al. 1992). Details of the present study are described in Walstra (1994).

2. Morphological model system

The morphological model system to be tested here is a subset of DELFT HYD-
RAULICS' system DELFT3D, which has recently been developed in order to allow a
flexible integration of the models for currents, waves, sediment transport, bottom

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changes, water quality and ecology. The morphological system contains the first four models and a control model. This control model allows the user to prescribe any combination of processes and arranges the time-progress of each model and possible iterations between models. The models relevant to morphological simulations are outlined below:

Waves
Stationary multi-directional (short-crested) wave model HISWA (Holthuijsen et al., 1989).

Hydrodynamics
2D or 3D flow model TRISULA based on the shallow water equations, including effects of tides, wind, density currents, waves, spiral motion and turbulence models up to k- ϵ ; for morphodynamic computations, a quasi-3D option to account for wave-driven cross-shore currents is available.

Sediment transport
New model TRANSP, including a sub-model TRSTOT, bed-load and suspended load transport according to several formulae, and TRSSUS, a quasi-three-dimensional advection-diffusion solver for suspended sediment, including temporal and spatial lag effects.

Bottom change
New model BOTTOM, which contains several explicit schemes of Lax-Wendroff type for updating the bathymetry based on the sediment transport field. Options for fixed or automatic time-stepping, fixed layers, various boundary conditions.

The first combination used in this study is similar to that used in the earlier MaST intercomparisons, viz. 2DH currents, multi-directional wave propagation and Bijker transport model.

The flow diagram for the combination of models applied in this study is given in Figure 1. Starting from an initial bathymetry, a number of wave computations covering a tidal cycle are carried out, followed by a run of the flow model which includes tidal and wave forcing. The wave and current computations can be iterated to account for full wave-current interaction. Sediment transport computations are carried out for a number of steps within the tide. The transports are averaged over the tidal cycle and the bathymetry is updated based on the residual tranport pattern. A very important branch in this scheme is denoted B. Here, the discharge pattern is kept constant and (small) bottom changes are assumed to affect the current velocity only locally: at a constnt discharge rate, the current velocity increases if the depth decreases. This is a reasonable assumption as long as the bottom changes are small and leads to an enormous reduction in computational cost. Typically, 20-40 so-called continuity correction steps can be taken in between full hydrodynamic runs (branch A).
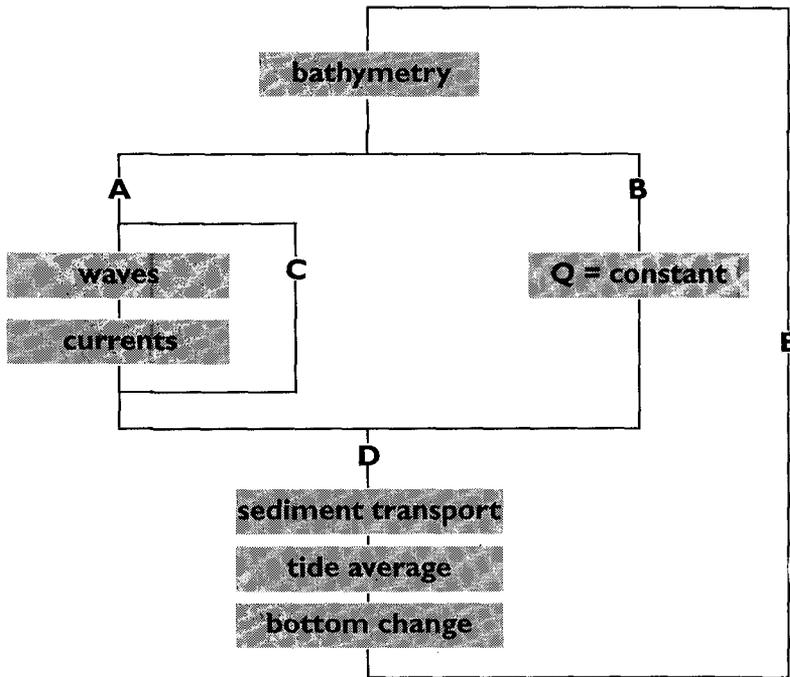
Figure 1. Flow diagram of morphological model system.

3. Test case

The town of Keta is situated in the south-east of Ghana, near the delta of the Volta River, and was built on a narrow sand ridge between the Gulf of Guinee and the Keta Lagoon. In past years Keta Town has suffered much from erosion, which attacked the heart of the town and destroyed a great number of houses.

Beside the great threat from the sea the main problem for the inhabitants of Keta is the lack of land at a sufficiently high level to enable them to construct their houses safe from the lagoon floods. The Keta Lagoon, with an area of 300 square kilometres, collects the run-off from a large catchment area. From the lagoon the excess water may find its way to the sea through a long winding channel towards the mouth of the Volta River. Most of it however evaporates during the dry season. In very wet years, the lagoon water level becomes so high that houses and crops on the lagoon side of the sand ridge are inundated. In the years 1963 and 1968 the situation was considered dangerous and a small cut was made in the

sand ridge. In both cases the excess water was discharged successfully into the sea, forming however, a tidal inlet of considerable capacity by scouring due to high lagoon levels (see Fig. 2). Consequently, traffic to and from Keta was interrupted.
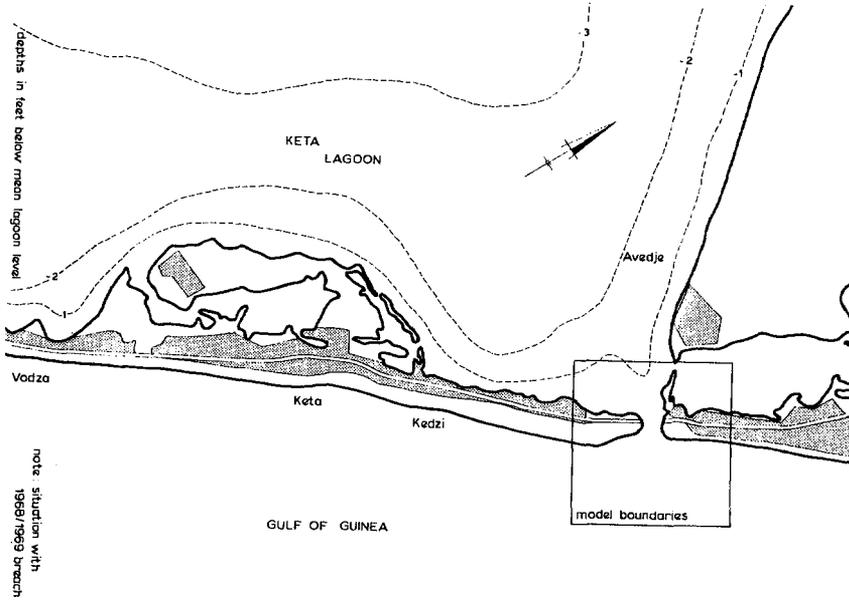

Figure 2. Situation at Keta (with 1968/1969 breach)

4. Physical model study

A physical (movable-bed) model study was carried out at DELFT HYDRAULICS in 1982 (Delft Hydraulics Laboratory, 1982). The aim of this physical model study was to investigate the possible stabilization of the lagoon outfall and to determine the most favourable layout of the outfall structure. The model has been calibrated by reproducing the conditions which occurred in 1963 and 1969.

In the model, a dyke was built separating the lagoon from the sea. At the seaside, a uniform beach profile was applied. The bottom of the lagoon was horizontal. The sea and the lagoon were connected by a straight channel.

At the sea boundary, irregular waves were generated by means of a paddle-type wave generator at an angle of 15° to the coastline. In addition to the waves, two phases of steady current were generated with a water circulating system, representing an ebb and a flood respectively.

In the tests. measurements were made of the initial and final bed topography.
A summary of the parameters used in the physical model is given below.

Physical model description	
Model scales	horizontal 36 vertical 28
Model size	30 m by 30 m

Bathymetry	beach profile: 1:15, depth 0 m to 0.125 m
	                        1:45, depth .125 m to .28 m
	inlet channel: depth 0.19 m, width 2.4 m,
	                        1:4 slopes
	lagoon: flat, depth 0.07 m

Waves	irregular wave height $Hs=0.07$ m, $Tp=1.5$ s, $15°$ to coastline
Currents	ebb/flood, cycle time 2 hr 30 min. additional littoral drift (magnitude unknown)
Sediment	$D50=0.21$ mm, $D35=0.19$ mm
Test duration	75 hr
Measurements	bottom topography with intervals 1 m by 0.25 m no wave measurements no current measurements
Programs	Two sets of tests with different tidal discharges through the channel. Test case used here T0-3

5. Set-up of the numerical model

Since it is difficult to exactly reconstruct the physical model in the numerical
model, a different approach was chosen: given the same prototype data that were
used to schematise the physical model, a new schematisation was made for the
numerical model. Prototype scale was used for the numerical model. It covers an
area of 1500 m longshore by 1100 m cross-shore. A rectangular grid was used,
initially with a uniform grid size of 15 m by 15 m and approximately 6500 active
points. The first computations showed that the resolution at the channel entrance
was rather poor with this grid, and consequently a variable grid size was applied,
with cell widths ranging from 30 m in the lagoon and deep water to 5 m near the
entrance. The bathymetry was obtained by scaling the physical model back to

prototype scale. Prototype scale significant wave height is 1.96 m, peak period is 8 s.

A tidal movement was assumed at the sea boundary, which is perpendicular to the coastline with a tidal range of 0.98 m. The tidal movement was described with the water level variation at the sea boundary. For simplicity, a sinusoidal variation was assumed with a period of 12 hr 30 min. The tidal data are primarily based on the field observations (mean tide). In the physical model, the tidal movement was schematized into an ebb and a flood phase each lasting for 1 hr. Inside the lagoon, the water level variations are very small (0.03 to 0.06 m) according to the field observations. Thus at the lagoon boundary (western, northern and eastern sides), the water level is assumed to be constant. i.e. at Mean Sea Level. Both lateral boundaries are prescribed as current boundaries. The current is the computed longshore current on a uniform beach, with a varying water level. All boundary conditions

The bed material chosen for the model has a uniform size distribution at all locations in the model. The characteristics of the material are: $D_{50} = 0.54$ mm (with fall velocity of 0.0785 m/s), $D_{35} = 0.30$ mm. A uniform roughness height of 0.1 m is assumed; the enhancement of bottom friction by waves is modelled using the Bijker approach.

Other characteristics are: $g = 9.81$ m/s², density of sea water 1030 kg/m3, turbulent viscosity 2 m²/s and no Coriolis force.

6. Results

Figure 2 shows the initial bathymetry. The beach has a bed slope of 2% and connects the sea side area with an area of uniform water depth of 8 meter. The channel has a width of approximately 130 meters, the length of the channel is 250 meter and its depth is 5.4 meters below MSL. The sand ridge has a maximum height of 3.60 m above MSL.

Per hydrodynamic run, three wave computations were carried out to represent the tidal variation (LW, MSL and HW). after which the current model was run for 1.5 tidal cycle. Here, the wave forces were obtained by linear interpolation. Comparison with results for more wave runs per tide showed no significant differences.
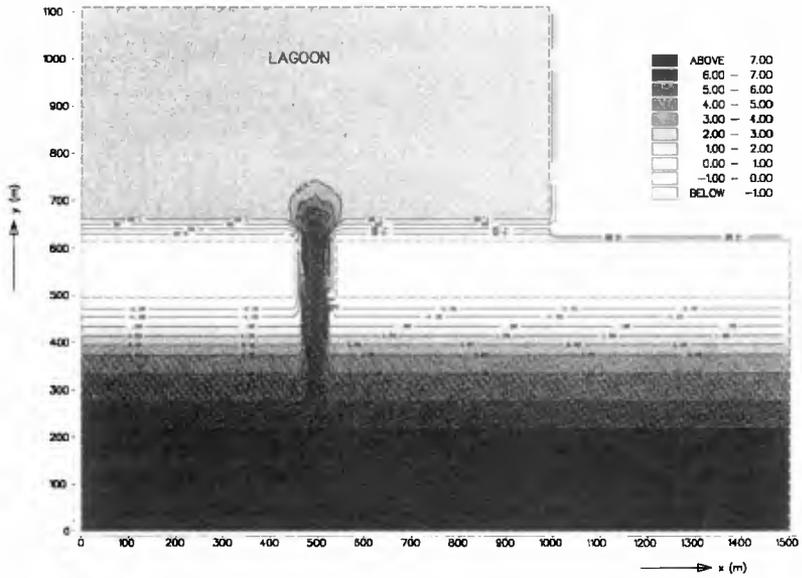
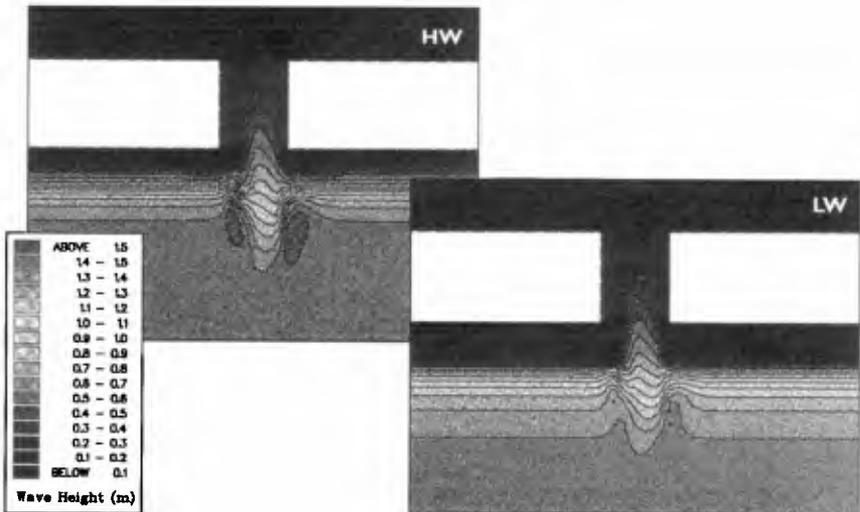*Figure 3. Initial bathymetry in numerical model.*

Figure 4. Wave height patterns near the entrance, High Water and Low Water.

In Figure 4, the initial Hrms wave height patterns for high water (HW) and low water (LW) are shown. The main effect of the water level variation is a horizontal shifting of the pattern. The effect of the current on the wave height pattern was investigated in trial runs and found to be significant. However, in order to reduce the complexity of the morphodynamic problem, this aspect was not taken into account further.
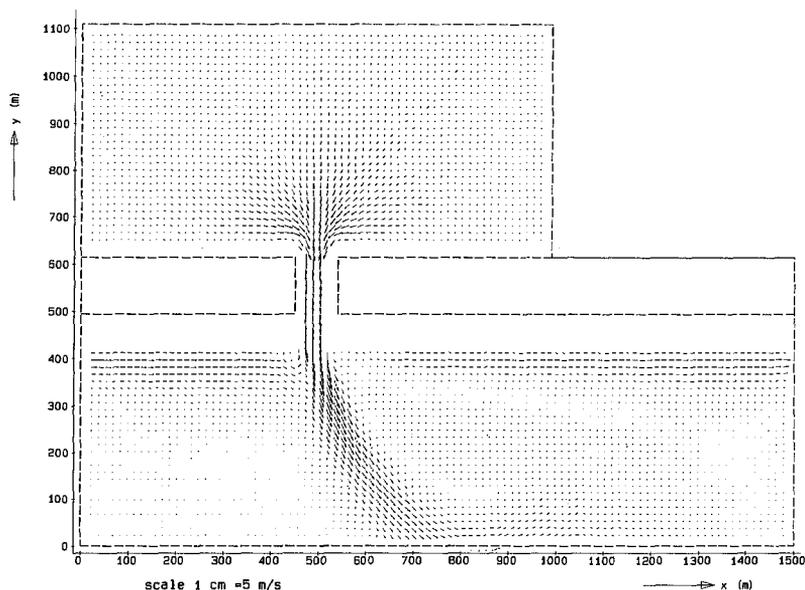
Figure 5. Current pattern at LW.

From trial runs without tidal variation it was clear that the wave-induced set-up forces a nett discharge into the lagoon. Though this may happen initially, in reality the lagoon will fill up until an equilibrium is reached. Through iteration the correct water level increase in the lagoon was found to be 0.091 m; with this mean level inside, the nett discharge through the channel was very close to zero. The boundary conditions in the lagoon were adjusted accordingly.

In Figures 5, 6 and 7 the current pattern is shown at LW, MSL and HW respectively. In all three cases the wave-driven longshore current is evident. During LW there is a strong ebb current which is forced sideways by the longshore current. The MSL phase shows mainly the longshore current and local effects of the channel. During flood, the longshore current accelerates towards the channel on the upstream side, whereas it is suppressed on the downstream side.
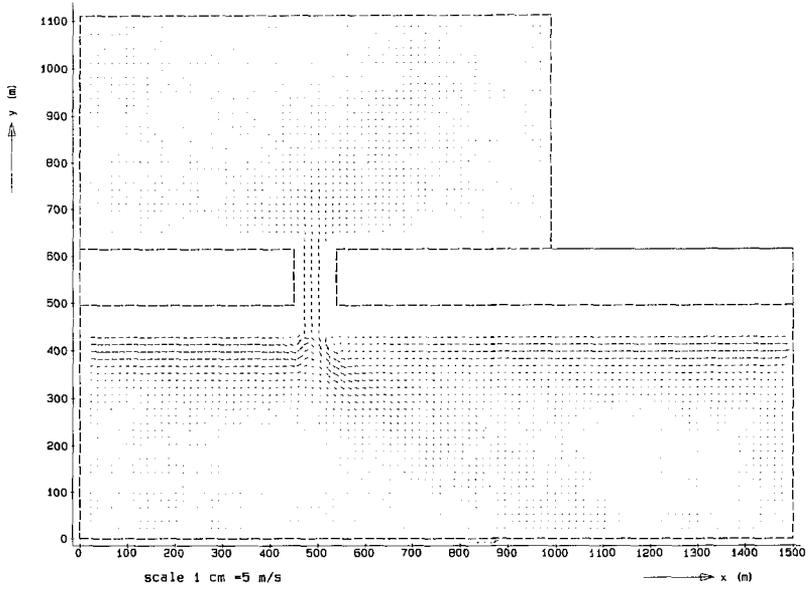
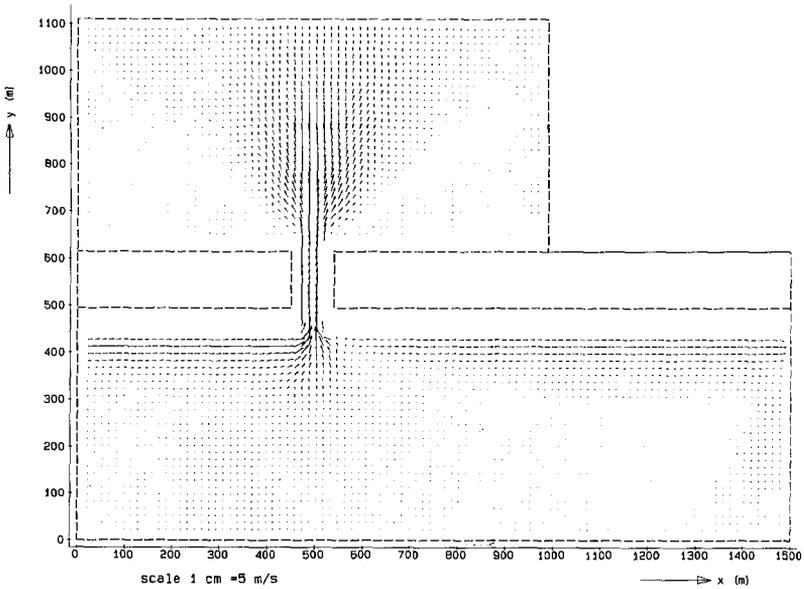*Figure 6. Current pattern at MSL.*

Figure 7. Current pattern at HW.

The above results were obtained for the original coarse grid and showed a rather poor resolution at the entrance of the channel. For further computations, a much finer grid was applied, as is shown in Figure 8 for the velocity at MSL.
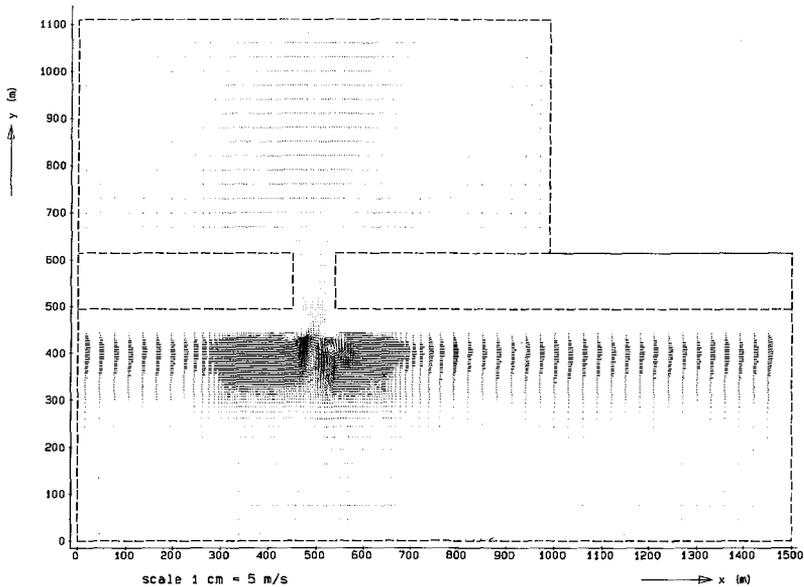

Figure 8. Current pattern at MSL, locally refined grid.

Sediment transport computations were carried out at 15 min. intervals; the sediment transports were averaged over a tidal cycle.

Morphodynamic computations were made using the tide-averaged transport patterns, since the morphological time scale of interest was much larger than the tidal period. However, for numerical reasons, a morphological time step in the order of 0.5-1.0 hour was used in the run presented here. The time step was computed automatically based on a Courant number criterion. Twenty steps using continuity correction were taken before each full hydrodynamic update. Results indicate that the number of intermediate steps may be increased further, since no shocks are evident in the time-evolution of the bottom.
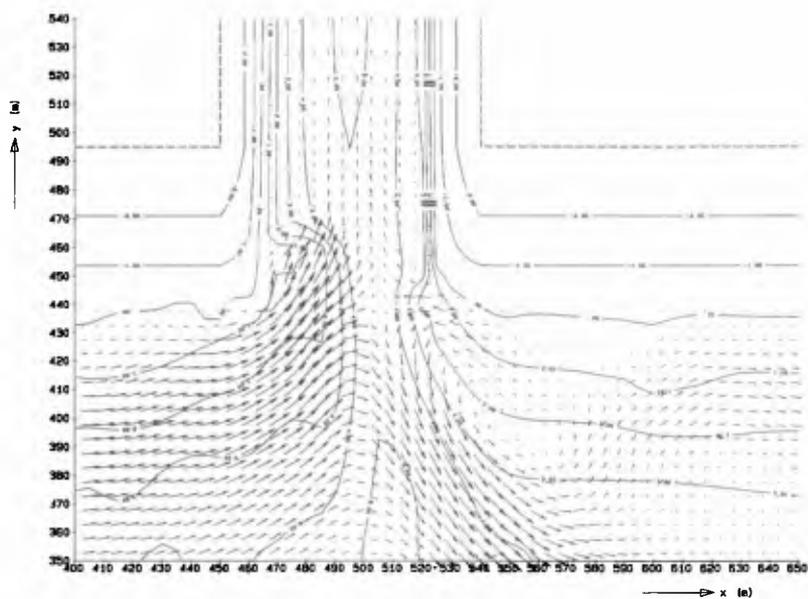
Figure 9. Tide-averaged sediment transport on updated bathymetry after 5 tides. Detail near entrance.
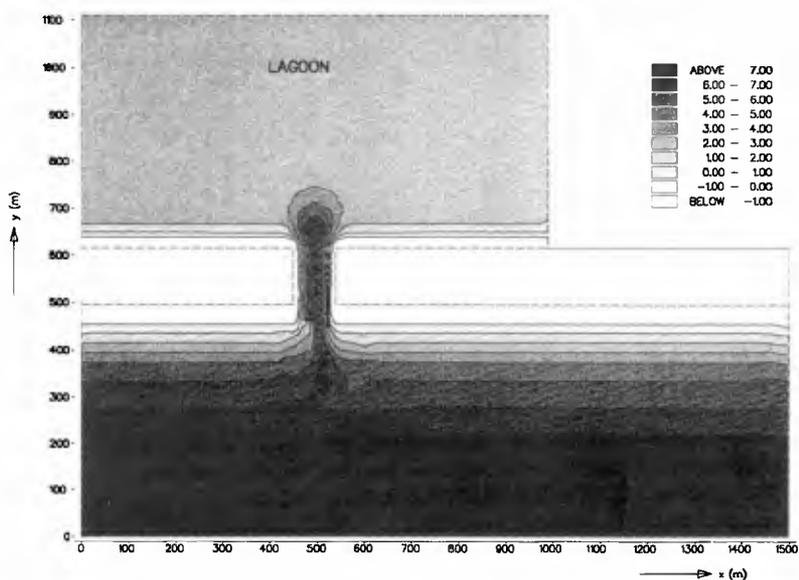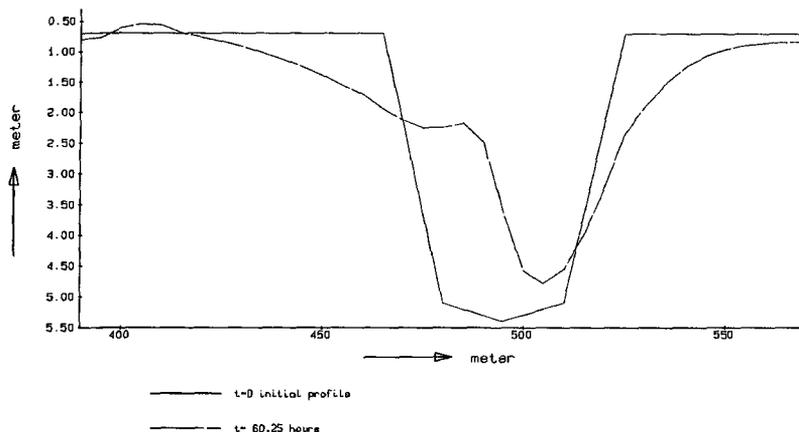

Figure 10. Computed bathymetry after 5 tides.

Figure 11. Development of longshore profile at Y = 420 m

In Figure 10, the computed bathymetry after 5 tides is shown. Clearly, the channel moves sideways due to the longshore current. The upstream part of the channel is accreting, whereas the downstream part erodes. This is further illustrated by Figure 11, which shows the evolution of the longshore profile at Y = 420 m.

In Figure 12, the computed bed level changes are shown. For comparison, the bed level changes obtained in the physical model test are shown in Figure 13. In view of many uncertainties related to the actual conditions in the physical model and in view of scale effects, a quantitative comparison is not possible. However, a qualitative assessment can be made.

The accretion on the upstream (left-hand) part of the channel is reproduced in the numerical model. Also, the erosion on the downstream (right-hand) side and the deposition due to the ebb current are represented in the model.

The morphological development in the physical model has progressed much further than that in the numerical model. The time span modelled in the physical model is meant to represent approx. half a year, whereas the numerical model has not progressed beyond some days. The reasons for this will be discussed in the next Section.
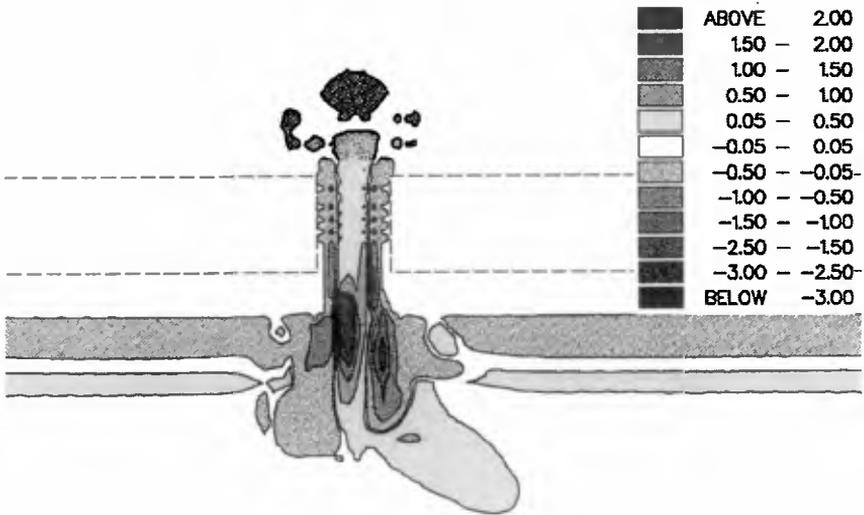
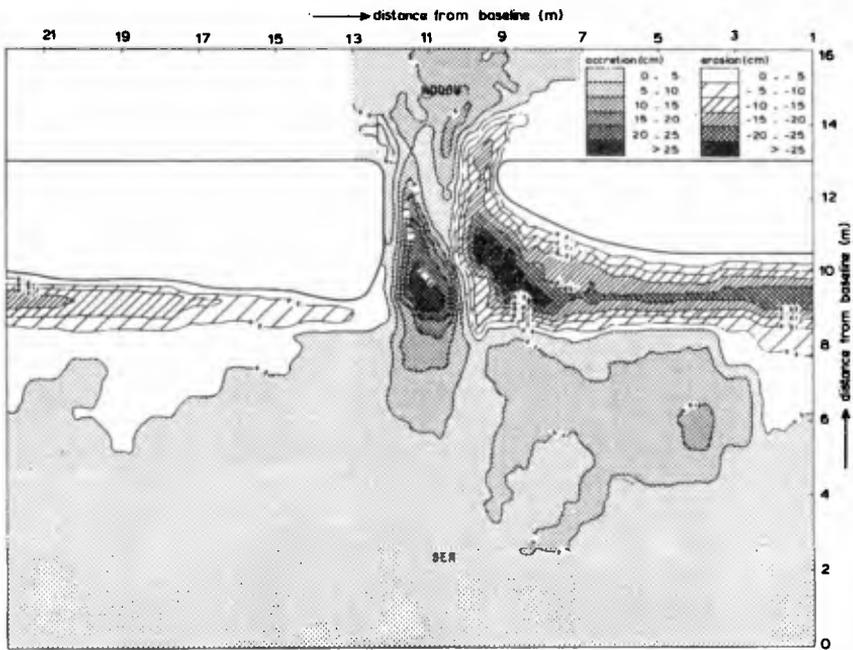*Figure 12. Computed bed level changes after 5 tides.*

Figure 13. Bed level changes measured in physical model.

7. Discussion

The results presented so far are encouraging in the sense that important aspects of a complex morphodynamic system can be represented in a computer model. Problems of informatics and numerical stability have been dealt with to the point where we can again focus on the physical aspects.

An important phenomenon which has to be represented is the erosion of the dry beach. The model has to be able to deal with this in order to be able to describe the actual migration of the inlet. To achieve this, an "avalanching" mechanism must be included in some way. Here a problem to be solved is the fact that the very steep slopes that occur in reality cannot be modelled even in a very fine grid such as was applied here. A more general "slope term" may be the solution. Experiments using such a slope term have not yet yielded the desired effect in this case.

Another important aspect is wave-current interaction. Up till now, we have only applied the wave effect on the current in these computations; the current refraction effect is important in this case and will be further investigated.

The effect of waves on the current profile (undertow) and on the bed load transport (wave asymmetry effects) is significant, since a considerable part of the erosion in the physical model is due to cross-shore transport. A quasi-3D approach has been implemented and is currently under investigation.

Once a workable mechanism for eroding the dry beach has been established, the problems of running the model over longer time-scales will be reduced, and making predictions on a time-scale of interest to engineers will be quite feasible.

References

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