CHAPTER 151

OFFSHORE SAND EXTRACTION AND NEARSHORE PROFILE NOURISHMENT

The Dutch Coast: Paper No. 12

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Abstract

Because of the increasing need of sand for use on land and coastal protection, offshore sand extraction has become commonplace. On the other hand, the practice of beach nourishment has become a common method to combat beach erosion. Here, economic and other interests may be served by dumping the sand not directly onto the beaches, but nearshore. Within the framework of the Coastal Defence Study for the Dutch coast and the preparation of a Marine Aggregate Extraction Plan model studies were performed in order to obtain indications and quantitative estimates of the morphological effects of offshore sand extraction and nearshore profile nourishment. The major results of the model computations are:

- offshore sand extraction landward of the 16 m isobath may affect the coastline within a century.
- nearshore nourishments landward of the 7 m isobath have positive effects on the coastline.

The model computations could not be validated in the field. Due to the relatively large margins of inaccuracy the political implication of this study is that sand extraction landward of the 20 m. isobath is not licensed.

Introduction

Within the framework of the Coastal Defence Study for the Dutch coast several methods to combat beach erosion have been investigated (Roelse, this volume). One of these methods, and maybe a very promising one, is nearshore profile nourishment. This method consists of the nearshore dumping of sand, say landward of the 10 m. isobath in the breaker zone, followed by onshore transport by the orbital wave motion.

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in the breaker zone, followed by onshore transport by the orbital wave motion. Encouraging field experience with this method has been gained in e.g. Australia (Jackson & Tomlinson, 1990).

For all kinds of nourishments the sand will be extracted offshore. From a coastal zone management point of view offshore sand extraction is an interesting problem. On the one hand sand extraction becomes more expensive with increasing distance offshore (in the Dutch situation several percents of the m3 price per kilometer). On the other hand sand extraction nearshore may induce coastal erosion, because extraction can be considered as withdrawal of sand from the sand budget of the shoreface and adjacent beaches and dunes. In the past the Dutch regulatory authority did not license sand extraction landward of the 20 m.isobath. This policy was based on the idea that wave induced onshore sand transport becomes increasingly important in shallow waters, especially landward of the 20 m. isobath. Results of foreign field studies indicated a similar value (Migniot & Viguier, 1980; C.E.R.C., 1984)

Within the framework of the Coastal Defence Study and the preparation of a Marine Aggregate Extraction Plan for the Dutch part of the North Sea model studies were performed to obtain better and more quantitative estimates of the morphological effects of offshore sand extraction and nearshore nourishments. Various existing modelling techniques for waves, currents, sediment transport and morphology were applied, combined with new knowledge, field data and surveys.

This paper will address the morphological impact of offshore sand extraction and nearshore nourishment, including nourishment with simultaneous extraction. The approach adopted and representative results are presented.

General background

The orientation of the Dutch coastal section considered changes from SW-NE in the southern part to S-N in the northern part (see Table 1). The 20 m. isobath, situated 5 to 15 km. offshore, separates the shelf from the sloping shoreface, on which wave action becomes increasingly important with decreasing waterdepth. Shoreface gradients vary from 1:1000 near the 20 m. isobath to 1:100 near the 10 m. isobath, which is situated about 1 km. offshore. Landward of the 10 m. isobath breaker bars are abundant. Shoreface sediments consist of non-cohesive sands with a median grain size of 0.150-0.300 mm.

Sediment transport on the upper shoreface (breaker or active zone, situated landward of about the 8 m. isobath) is wave dominated due to wave asymmetry, swell action, breaking waves and wave induced currents. On the lower shoreface sediment transport is dominated by tidal currents. They are mainly longshore directed and reach maximum surface velocities of about 1.0 m/s. Tidal action, wind, salinity gradients and waves induce relatively small residual currents. A persistent landward residual bottom current of about 0.03 m/s. exists on the Dutch shoreface (Van der Giessen et al., 1990).

Especially during storm conditions waves act as a stirring mechanism, bringing sand into suspension and ready for transport by currents. Waves approach the coastline predominantly from directions varying from 240 to 360. Year averaged wave height and period are about 1 m. and 5 s. respectively.

Set-up of the study

Although a reasonable qualitative knowledge exists of the dominant physical processes

of sediment transport in the Dutch coastal zone, there is still a considerable lack of:
- quantitative descriptions of these processes
- knowledge of the representative input conditions
- verification and calibration of the existing mathematical models in the field.

Moreover, no general two-dimensional morphodynamic modelling system is available yet in which the sub-models for hydrodynamics and sediment transport are applied in direct interaction with computed changes in sea bed level. Nevertheless, in the present study an attempt was made to estimate and compare morphological effects of different sand extraction and/or near-shore nourishment schemes with relativelty simple existing mathematical modelling techniques.

The study focussed on different locations along the Dutch coast (Table 1).

	EXTRACTION	NOURISHMENT	EXTRACTION + NOURISHMENT
LOCATION	S B	D N E	D
ISOBATH (m)	10, 16, 20	3, 5, 7, 10	10+ 5
VOLUME*(10^6m^3)	0,2 1 10		
(m^3/m)	100, 500, 2000, 5000	100 , 200	100

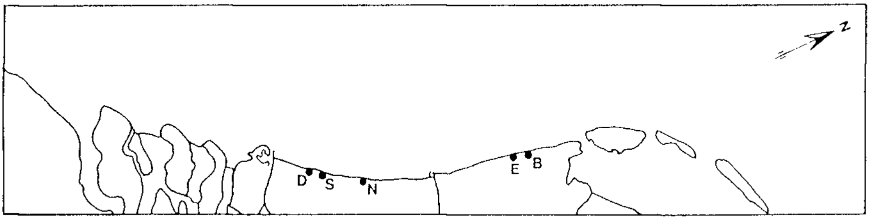

Table 1: extraction and nourishment schemes: locations and variants. S = Scheveningen, D = Delfland, N = Noordwijk, E = Egmond, B = Bergen. *: different volumes of extraction are obtained by different combinations of extraction length (2000 and 5000 m.), width (100, 500 and 1000 m.) and depth (1, 2 and 5 m.).

Different sand extraction schemes between the 10 and 20 m. isobath were analyzed, varying in length, width and extraction depth and, accordingly, in volume (Table 1). Nourishment schemes were assumed between the 3 and 10 m. isobath, varying in width and height. One combined extraction (10 m.) and nourishment (5 m.) simulation was performed.

The morphological processes, as distinguished in the present approach, are outlined in Figure 1.

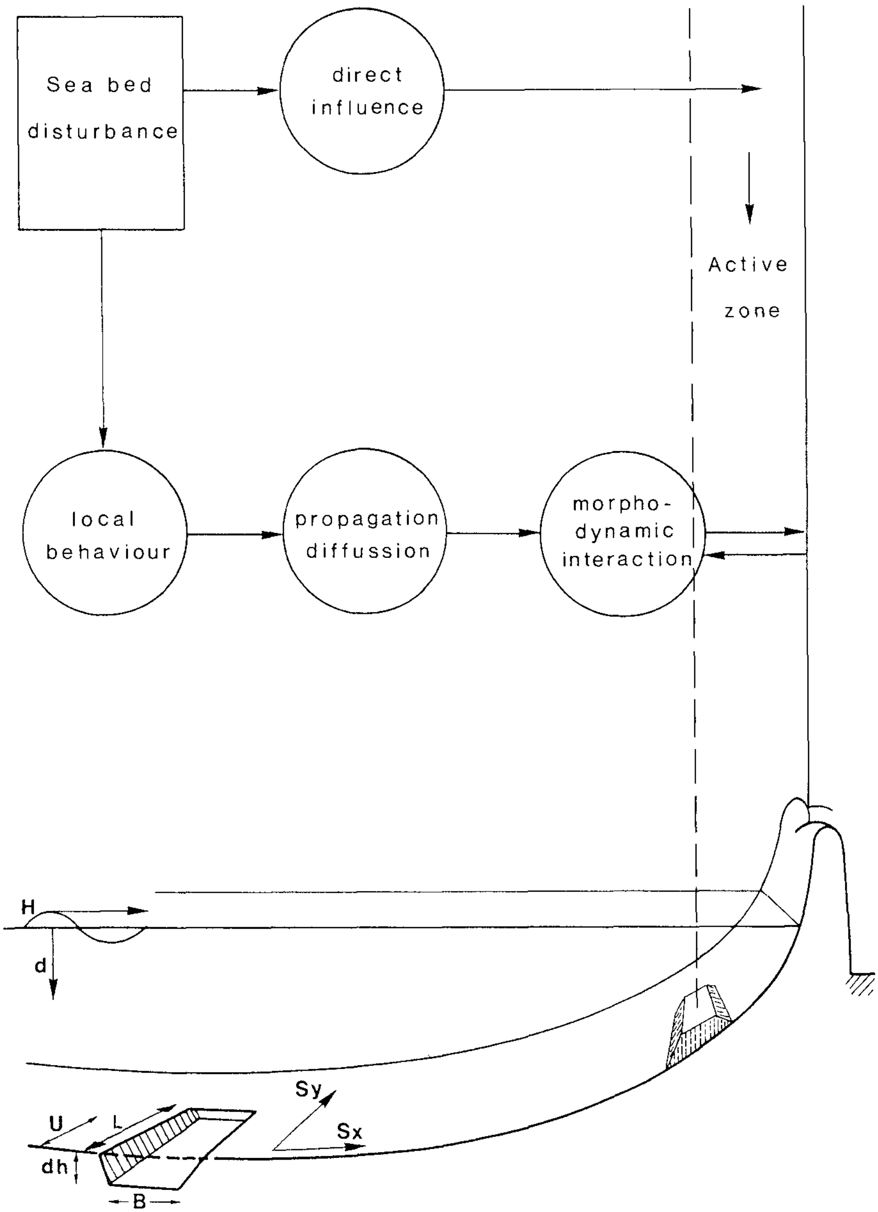

Figure 1: schematization of relevant processes, symbol definition (H = wave height (m), d = water depth (m), dh = depth of extraction (m), B = width of extraction (m), L = length of extraction (m), U = tidal current (m/s), Sx, Sy = cross-shore and along-shore component of sediment transport.

Sand extraction in relatively deep water leads to a local disturbance of the sea bed topography which, under the combined action of waves and currents, can directly affect the hydrodynamics, sediment transport and morphology of the near-shore zone. Moreover, the local sea bed disturbance may lead to erosion of the near-shore zone at a larger time-scale, for example by onshore propagation/diffusion of the extraction pit and/or by acting as a sink for sediment that is eroded from the near-shore zone.
The direct hydrodynamic effects of the different extraction schemes were analyzed by studying:

- the disturbance of the tidal current pattern around the extraction pit (streamline convergence/ divergence), using a two-dimensional (2DH) flow model for depth-averaged currents and water levels.
- the disturbance of the waves (refraction), using a wave field model to obtain the 2DH propagation, refraction and energy dissipation.

The direct and long term morphodynamics of the extraction pits were estimated in longshore and cross-shore direction separately, assuming that this is allowed within certain time limits.
The cross-shore development of the different extraction schemes was computed with a one-dimensional morphodynamic model (CROSTRAN, see Roelvink and Stive, 1988), in which the sediment transport model of Bailard (1981) is adopted. The hydrodynamic input of the transport model is derived from a one-dimensional wave energy decay model in combination with:

- non-linear wave theory for the computation of near-bed velocities (wave asymmetry),
- wave induced net bottom currents (drift currents)
- a persistent onshore directed residual bottom current of 0.03 m/s.

Input conditions were derived from a schematized measured deep water wave climate.
The longshore development of the different extraction schemes was estimated with a quasi-2DH morphodynamic model (LOMOR). The sediment transport in longshore direction is dominated by tidal currents. The behaviour of the tidal current along the extraction pit is computed with a simplified steady 2DH flow model. It is assumed that the longshore axis of the pit coincides with the (undisturbed) tidal flow direction and can be considered as symmetry-axis. This model is applied in a quasi-steady way at 10 moments during a characteristic tidal cycle (12h 30 min), using boundary conditions from a calibrated overall 2DH flow model of the area (without seabed disturbance). To be consistent with the cross-shore model the same sediment transport (capacity) formulation, based on the same Bailard model, is used. The sediment stirring effect of waves is incorporated for a selected characteristic wave height-wave period combination ($H_s = 1.5$ m., $T = 6$ s.).
The adjustment of suspended load transport to the changing hydraulic conditions is modelled with a depth-averaged suspended load model, based on Galappatti (1983).
Computed local erosion and sedimentation rates are integrated over the tidal cycle. Bed level changes are computed after selecting an appropriate morphological time step. The adjusted sea bed topography is then fed back into the flow model and the computation with the morphological model is repeated. With this technique the long term morphodynamics of the different extraction schemes were estimated for periods up to 40 years.

As a result of the process-schematization and modelling techniques time estimates have an inaccuracy in the order of a factor 3 to 5.

The nourishment schemes are situated inside the active zone. Here sediment transport is more intense and morphological changes take place on shorter time-scales than on the lower shoreface.
The sediment transport and morphodynamics of the nourishment schemes and nearshore profile were also studied with the above mentioned CROSTRAN model. This model proved to be able to simulate some overall characteristics of the natural nearshore behaviour of e.g. breaker bars (Roelvink and Stive, this volume). Input for this nearshore application were daily averaged values of wave height, wave period and swell characteristics derived from a deep water wave record of 1983. In the computations this time sequence of wave conditions was used as input for 6 consecutive years. The same model was also applied for the combined extraction-nourishment scheme.

Results
The direct effects of extraction on the cross shore
distribution of the near bed maximum tidal current velocity is shown in Figure 2a. Only an extreme extraction of 5 m. at a waterdepth of 14 m. (L = 2000 m., W = 1000 m.) gives a small decrease (about 10 %). On both sides of the extraction pit the width of the affected area is about two times the extraction width. There are no immediate effects landward of the 10 m. isobath.

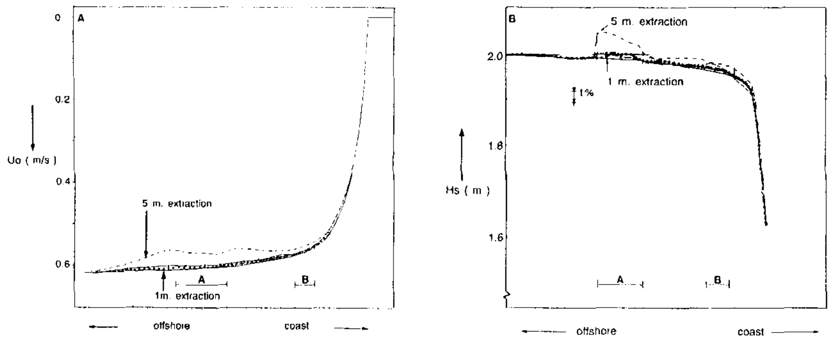

Figure 2a: predicted cross-shore distribution of near bed tidal current velocity and (b) significant wave height. Sand extraction at d = 14 m. (A: W = 1000 m., dh = 1 m. and 5 m.) and at d = 10 m. (B: W = 500 m., dh = 1 m.).

The immediate effect of extraction on the wave climate is local and minor as well. Figure 2b shows that in case of incoming waves (H = 2 m., T = 6 s.) only an extreme extraction of 5 m. on the 14 m. isobath results in a 1 % increase of the wave height which has disappeared before the 10 m. isobath.
Because of these minor direct changes in hydrodynamics, instantaneous morphological adaptation is negligible as well. Computations on initial transport show that within the affected area vertical sea bed movements are within the order of 0.001 to 0.01 m. per year, which is insignificant compared to the inaccuracy of sounding.

The predicted longterm longshore behaviour of the extraction pit and near bed current

velocity is shown in Figure 3.
In this case the extraction pit is situated on the 16 m. isobath (L = 2000 m., W = 300 m., dh = 1 m., t = 15 years). Initially there are gradients in current speed near the head and tail of the pit, but because of the interaction between currents and morphology the steep sea bed slopes become smaller and the gradients in velocity decrease in time. Apart from this diffusive kind of behaviour the pit is relatively stable in time under the given input conditions. Similar results were obtained for other locations and extraction volumes.

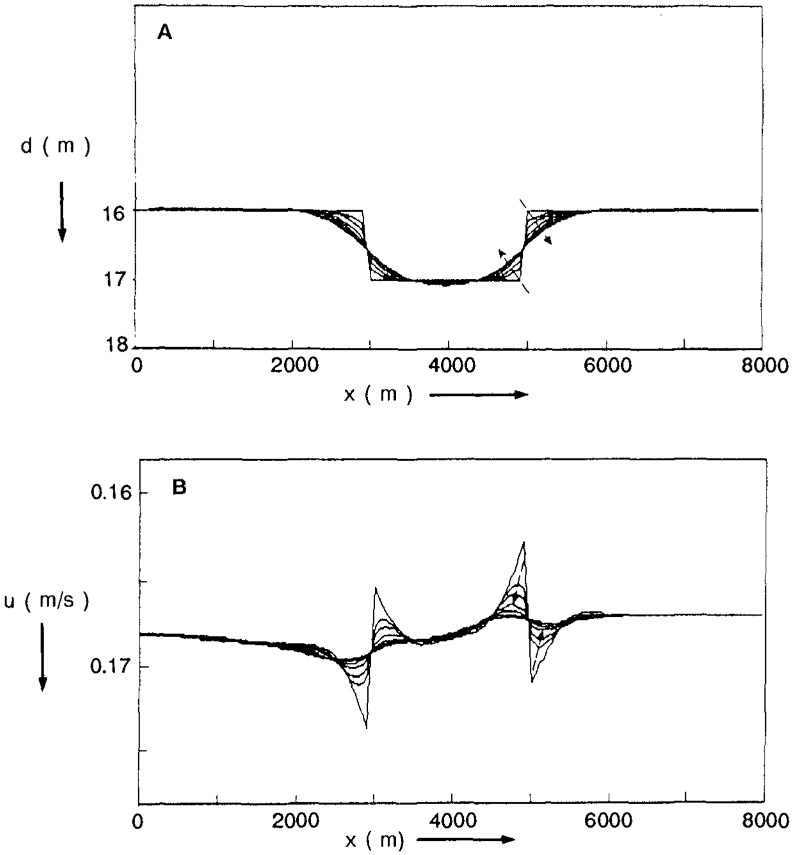

Figure 3a: predicted longshore behaviour of extraction pit and (b) near bed tidal current velocity. d = 16 m., L = 2000 m., W = 300 m., dh = 1 m., t = 15 years.

The predicted longterm effects in cross-shore direction are shown in Figure 4a and 4b. for extractions on the 20 m. and 16 m. isobath respectively. Extraction on the 20 m. isobath shows almost no cross shore effects, the pit remains stable for at least 40 years.

Extraction on the 16 m. isobath results in a minor change in depth of the pit. In addition, as a result of a small net onshore sediment transport, deposition on the offshore margin and erosion of the landward boundary leads to a onshore migration of the pit with a rate of 1 to 2 m. per year. The gradients in the profile smooth in time.

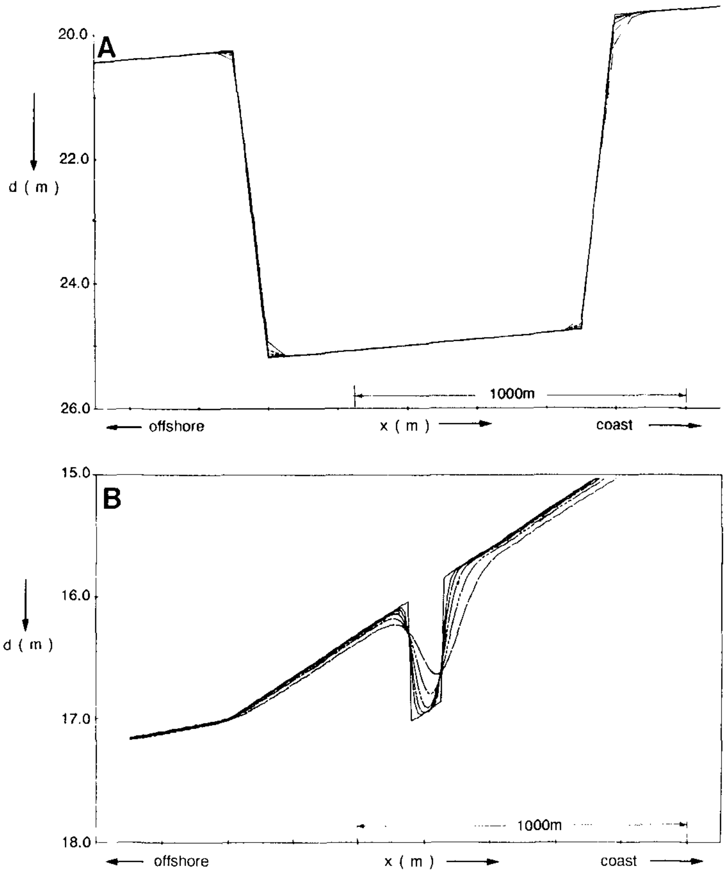

Figure 4a: predicted cross-shore behaviour of extraction pit at d = 20 m. (W = 1000 m., dh = 5 m.) and (b) d = 16 m. (W = 100 m., dh = 1 m.) over a period of 40 years.

According to the CROSTRAN and LOMOR computations the morphological development of the pit mainly occurs at the boundaries of the pit and take place in similar time scales in long and cross-shore direction. This indicates that the separate treatment in long and cross-shore dynamics is justified within the time limits considered (40 years).

By comparing Figure 4a with 4b the increasing importance of wave action with decreasing waterdepth and distance offshore is illustrated. As a consequence of this phenomenon predicted migration rates of sea bed disturbances speed up rapidly landward of the 16 m. isobath (Figure 5a). Based on these migration rates the necessary time for the head of a given extraction to reach a given isobath was estimated. Figure 5b shows that at Scheveningen the head of an extraction landward of the 14 m. isobath may reach the active zone within a century. It was found that with steeper shoreface slopes the time scale for a sea bed disturbance to reach the active zone decreases. E.g. at Bergen this time scale is twice as small (shoreface slopes between the 10 and 14 m isobath are 0.0016 and 0.0040 for Scheveningen and Bergen respectively).

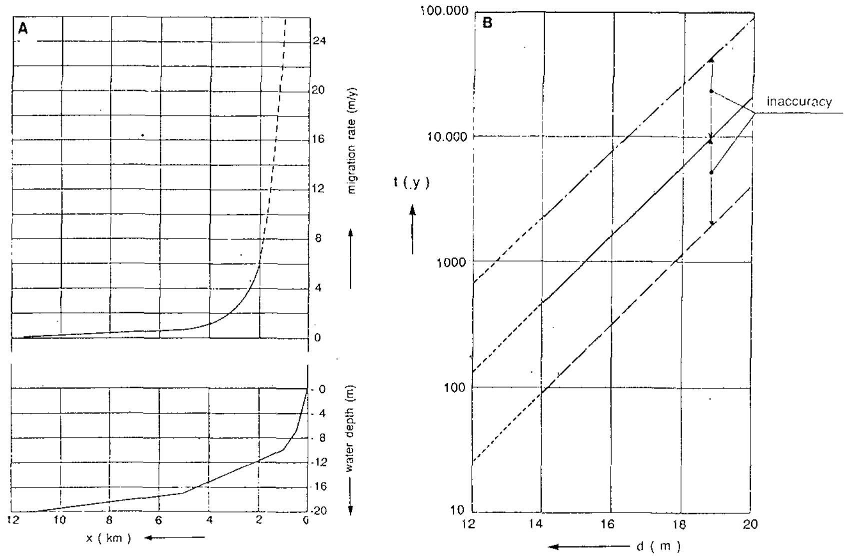

Figure 5a: predicted cross-shore migration rate (m/y) of sea bed disturbance at Scheveningen (S in Table 1) and (b) time necessary to reach the active zone. The dashed lines indicate the margins of inaccuracy.

It should be noted that the time needed for the head of the pit to reach the breaker zone is dependent on the cross shore sand transport rates rather than on the amount of extraction. However when the pit approaches the shore, the amount extracted represents the lack in the sand budget. Then it determines the rate of erosion and the period erosion prevails.

Figure 6 shows the behaviour of a nearshore nourishment of 100 m^3 per m. on the 3, 5 and 7 m. isobath. The thickness of the nourishment is 1 m. As a result of wave induced onshore transport in the landward part and a seaward directed undertow the nourishment volume is divided into an onshore and offshore directed transport in all cases. However when deposited on the 7 m. isobath only a small part of the original volume reaches the beach within 6 years.

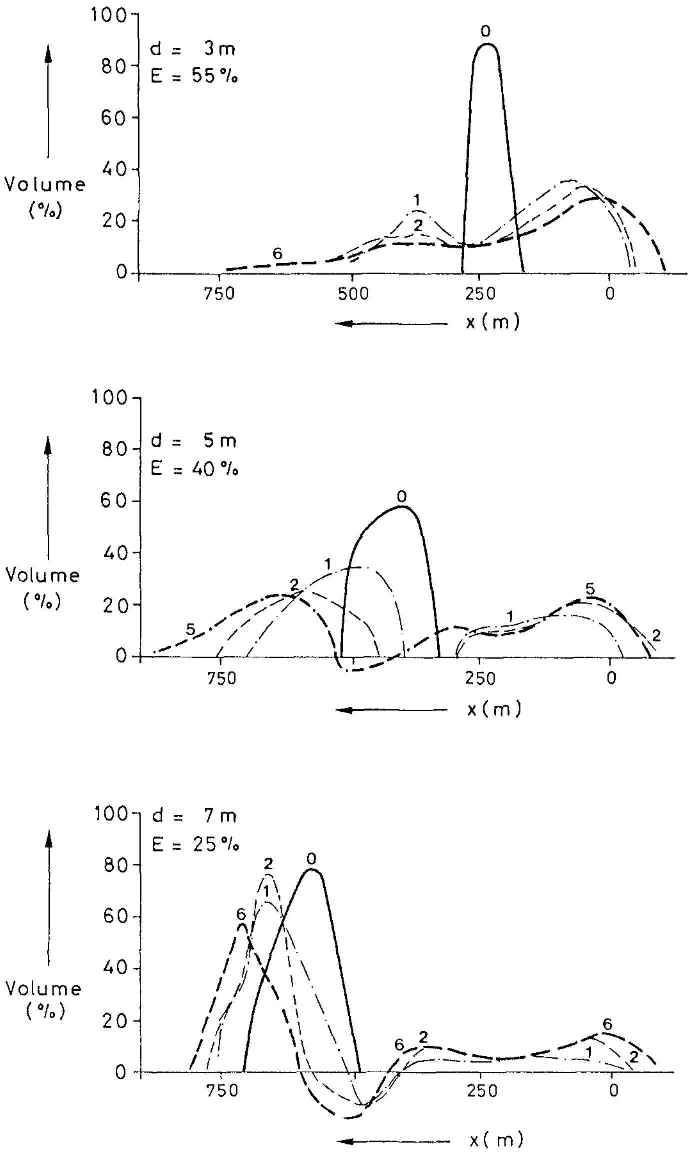

Figure 6: relative volumetric distribution of 100 m3/m. profile nourishments at waterdepths of 3, 5 and 7 m. in time. E = Effectivity (see text).

The effectivity of the nearshore nourishment (E) is expressed as the volumetric change of a 300 m. wide zone along a line of reference on the beach, compared to the original volume of the nourishment. It can be seen that the effectivity of nourishments increases in a landward direction: from 25 % of nourishments on the 7 m. isobath towards 55 % of those on the 3 m. isobath. With other words, the seaward loss of the nourishment volume decreases with nourishments in shallower water.
These results hold for the Delfland location but are similar on other locations. It was also found that the relative distribution of the initial volume over the profile is independent on the volume of the nourishment.

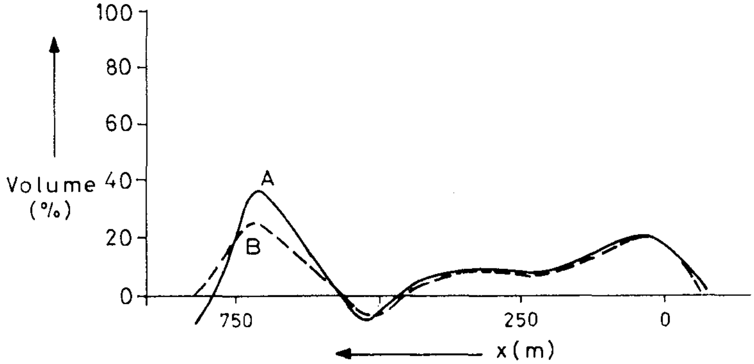

Figure 7: relative volumetric distribution of 100 m3/m. profile nourishment at d = 5 m. after 6 years, with (A) and without (B) simultaneous extraction of 100 m3/m. at d = 10 m.

The effect of extraction during nourishment was studied in a model run with a 100 m^3/m. nourishment on the 5 m. isobath and simultaneous extraction of the same amount on the 10 m. isobath. The distribution of the nourishment volume after 6 years with (A) and without (B) extraction is very similar (Figure 7). Only in the most seaward part of the profile with extraction the sea bed is a little lower. It looks as if the sand extraction nearby has no negative effects on the nourishment itself within this period of 6 years. However ,the long term studies presented in the former section suggest that on a timescale of decades to centuries detrimental effects may show up in this zone due to the approach of the extraction pit. The lowering of the seabed in the seaward part of the profile may be a signal of this already.

Conclusions

The computations performed showed the following results:

- the direct effects of the studied sand extraction schemes on hydrodynamics (current and wave climate) are very local. On both sides of the extraction pit the affected area has a width that is two times the extraction width.
- on the long term sandextraction landward of the 16 m. isobath may affect the coastline within a
- century by landward migration of the extraction pit, leading to a deficit in the nearshore sand budget.

- nourishments landward of the 7 m. isobath have positive effects on the coastline.
- simultaneous extraction has no significant effects on the nourishment within a period of 6 years, but may have on a larger time scale.

It should be emphasized that the results presented could not be verified in the field. A large scale field experiment like the one reported in Jackson & Tomlinson (this volume) is urgently needed to validate the models and assumptions on which the results are based, and to reduce the margins of inaccuracy.
The political implication of this study is that, from a precautionary point of view, the Dutch regulatory authority will refrain from licensing sand extraction landward of the 20 m. isobath, even if this sand extraction is meant for nourishments (an exception is made for extraction in navigation channels). In addition the Environmental Impact Assesment, prepared for the Dutch Marine Aggregate Extraction Plan, showed that this zone landward of the 20 m. isobath coincides with a area that is very valuable from an environmental point of view (i.e. relatively rich in benthic life and nursery area for several species of commercial fish).

APPENDIX I. References

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