NOURISHMENT OF THE SLOPE OF A TIDAL CHANNEL. FROM EXPERIMENT TO PRACTICE

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Abstract: This paper describes an experiment to stop the migration of the tidal channel "Oostgat" in the coastal zone of the Westerschelde, The Netherlands, by nourishing the landward slope of the channel. The goals of the experiment were to determine whether nourishing the steep slope of a channel is technically possible and to investigate morphological developments and sediment transport. In the experiment glauconitic sand was used as a tracer material. Surveys were conducted during one year, using multi beam soundings and the MEDUSA mapping system. Results show that nourishment of a steep slope (1:7) is possible. Sediment transport could be clearly observed and after one year a large percentage of nourished material was still present. Questions remain on the influence of the steepness of the slope and on the scale of the experiment. A full scale nourishments has been planned on the slope of the Oostgat, which will be closely monitored.

INTRODUCTION

In 1990 a coastal policy was introduced in the Netherlands to stop the structural erosion of the coastline. The adopted strategy contains three stages: 1) allow natural sediment transport processes, 2) prevent erosion by nourishments, 3) prevent erosion by coastal structures. Stage one allows natural processes to redistribute sediment along the coast. If this leads to unwanted coastal development (erosion) nourishments are performed. Only if these nourishments do not suffice, coastal structures, like groins an breakwaters, are build in the coastal zone. The last fifteen years al lot of effort has been put in preventing erosion by nourishments and up till now this has been successful.

The decision to perform a nourishment is based on the position of the coastline relative to the 1990 reference position. These positions are named Momentary Coastline (MCL) and Basal Coastline (BCL) respectively. The MCL represents the volume of sand in a cross shore profile. This is illustrated in Figure 1. The upper plane is located around +3m NAP, the lower plane around -5m NAP (NAP: Dutch ordinance level: ± mean sea level). When the MCL tends to exceed the BCL in landward direction, a nourishment is performed which moves the MCL seaward. A more complete description can be found in (TAW, 1995).

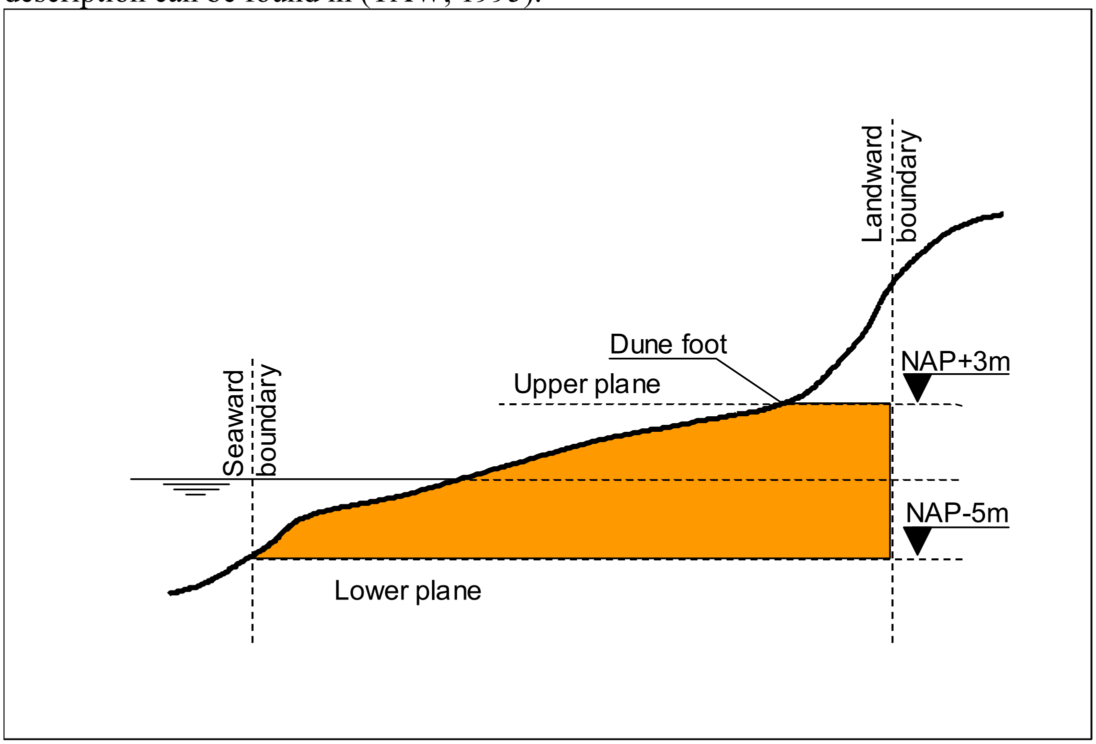

Fig. 1. Cross sectional area used to determine the position of the Momentary Coastline (MCL)

Figure 1 illustrates a typical cross shore profile that can be found along the central part of the Dutch coast. The shore face is generally characterized by gentle slopes. Hence the seaward boundary generally lies a few hundred meters offshore. At these locations beach and shore face nourishments are performed. However, at some locations in the outer deltas along the Wadden and Delta coasts steep slopes occur where tidal channels are present adjacent to the beach.

Figure 2 shows the development of a profile along the southwest coast of Walcheren, located in the coastal zone of the Westerschelde. The upper part of the profile is comparable to that in Figure 1. Around –4m NAP however the slope becomes dramatically steeper, due to the tidal channel "Oostgat". To stop erosion beach nourishment have been performed in the MCL-zone. In term of retreat of the MCL the problem has been fixed. In fact, as a result of these nourishments the upper part of the profile has accreted (indicated by the upper arrows in Figure 2). However, erosion of the lower part still occurs, due to the migration in landward direction (lower arrow in Figure 2). In the long term the combination of nourishing the beach and an even steeper slope in the lower part of the profile may lead to an unstable situation.

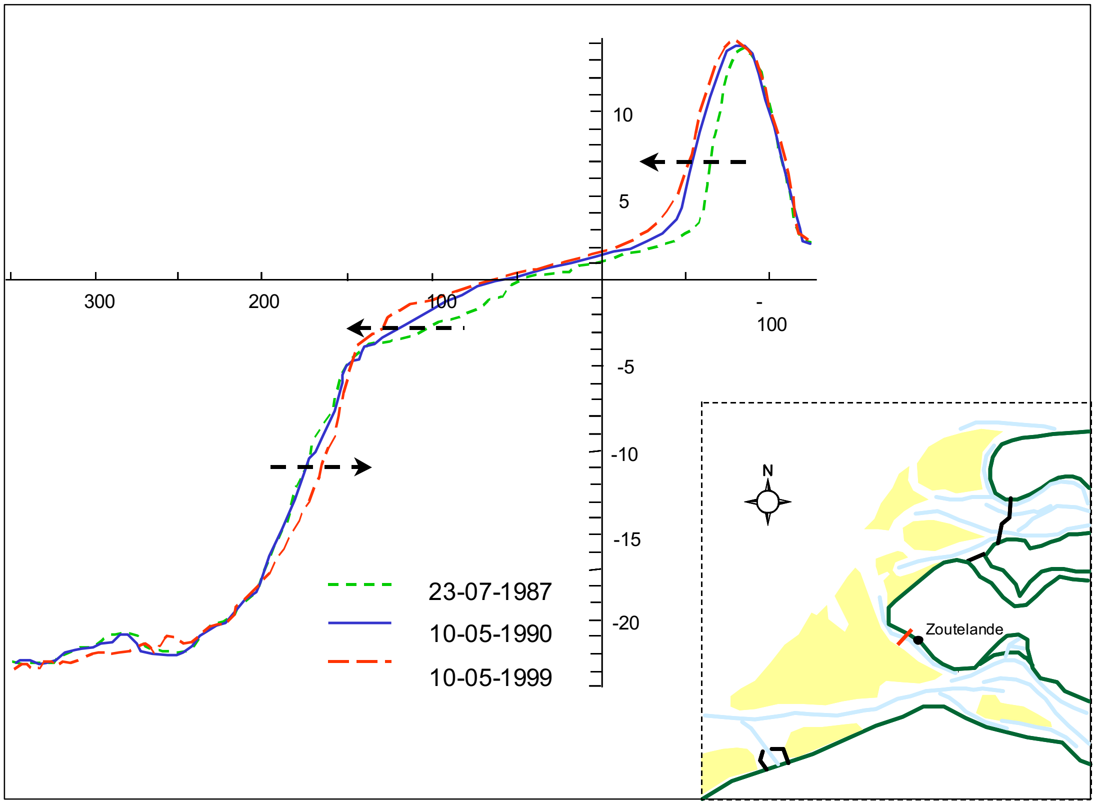

Fig. 2. Typical profile of the Oostgat and development of the profile over a 12 year period

Rijkswaterstaat investigates possibilities to stop the migration of the Oostgat. The traditional way in these cases has always been to protect the deeper part of the slope with a revetment. However, given the adopted coastal strategy, this is a last resort, which should only be done when the erosion can not be stopped with nourishments. Therefore the aim is to try and stop the migration of the Oostgat by not only nourishing the upper part of the profile, but also the lower part. Since such nourishments have not been performed before along the Dutch coast the feasibility has to be determined first. Therefore an experiment was set up.

The two main research questions for this experiment were:

- Is a nourishment on a steep slope possible, or will the dumped material wash away right after dumping?
- How does the nourishment behave and what are the sediment transport directions?

EXPERIMENT SET-UP

Rijkswaterstaat started an experiment, to find out if nourishing the steep slope of a channel is possible and to investigate what happens to the nourished material. The Oostgat was chosen to perform a small scale nourishment, using tracer material, which would be exposed to real time current and sediment transport conditions. Before, during and after the nourishment six surveys were conducted during one year, using multi beam soundings, to obtain detailed bathymetric data, and the MEDUSA technique to localize the tracer material.

Site Description

The Oostgat is a tidal channel, which runs parallel to the southwest coast of Walcheren and is located in the coastal zone of the Westerschelde. It is a part of the "Delta-region" in the southwest part of the Dutch Coast. The total length of the southwest Coast of Walcheren, which reaches from Westkapelle in the northwest to Vlissingen in the southeast, is about 13 km.

The slope at the Walcheren side of the channel varies between 1:2 and 1:30. The steepest slopes occur due to the out cropping of geological layers, containing peat and clay, which make the channel wall more resistant to erosion. Typical erosion rates in the Oostgat lay in the order of 1 m per year. In the past groins have been built along a major part of the Oostgat to prevent erosion. At Westkapelle, Zoutelande and Vlissingen dykes have been built. Along the rest of this coast dunes protect the hinterland from flooding.

The experiment was performed in 2001 as a small scale nourishment (10.000 m^3) on a predetermined dumpsite of 50*100 m^2 at the Walcheren side of the channel. Locally the channel slope has a steepness of 1:7. The water depth at the dump site varies from 7,5 m to 15 m. The maximum current velocity is 0,80 m/s (measured 1 m above bed level).

Monitoring Sediment Transport

Successive measurements of water depth with a multi beam system have been used to determine changes in morphology. The uncertainty in these determinations (typically 15-30 cm in depth) prohibits the monitoring of the distribution of sediments from an underwater nourishment at larger areas. The recent development of the MEDUSA detector system is a result of a long-standing research program that aims at developing geophysical methods that provide quantitative information on sediment composition. With the MEDUSA system it has become possible to measure small changes in composition of the top layer of the sediment (Van Wijngaarden et al., 2002a). MEDUSA is a detector system that utilizes variations in the content of natural radio nuclides (background levels) between sediments (`fingerprint´). The system is towed over the sediment behind a vessel (Figure 3) and determines the sediment composition (e.g. median grain size, mud concentration) each second (Van Wijngaarden et al., 2002b). The system has been operated on various types of vessels in water depths ranging from 0.5 m to 5 km. The system can been used simultaneous with other monitoring devices as echo sounder or multi beam. The towing speed is up to 6 knots.

The combination of this MEDUSA data with detailed images of morphology obtained with a multi beam system gives high-quality 3D visualizations of the underwater environment. Successive measurements of sediment composition show the behavior of the sediment bed and reveal sediment transport patterns.

Tracer Material

The small-scale underwater nourishment in the Oostgat was designed as a tracer experiment. To that end, sediment with a fingerprint that differed strongly from the fingerprint of naturally occurring sediment in the Oostgat was used for the nourishment. We used glauconitic sand, that can be found in deeper geological layers under the Westerschelde, which became available by the constructing the "Westerschelde tunnel". The physical properties of the nourished glauconitic sand is comparable to the physical properties of the native sediment. Effects of selective sediment transport by its grain size or density (Koomans and De Meijer, 2004) will therefore be negligible. The chemical properties (expressed as the concentration of the natural occurring radio nuclides) of the sediments are however different. The concentrations of the radio nuclides ^{40}K, ^{238}U and ^{232}Th can be measured in the field with the MEDUSA system. From these measurements and the `fingerprint´ in Table 1, the concentration of the glauconitic sand can be determined.

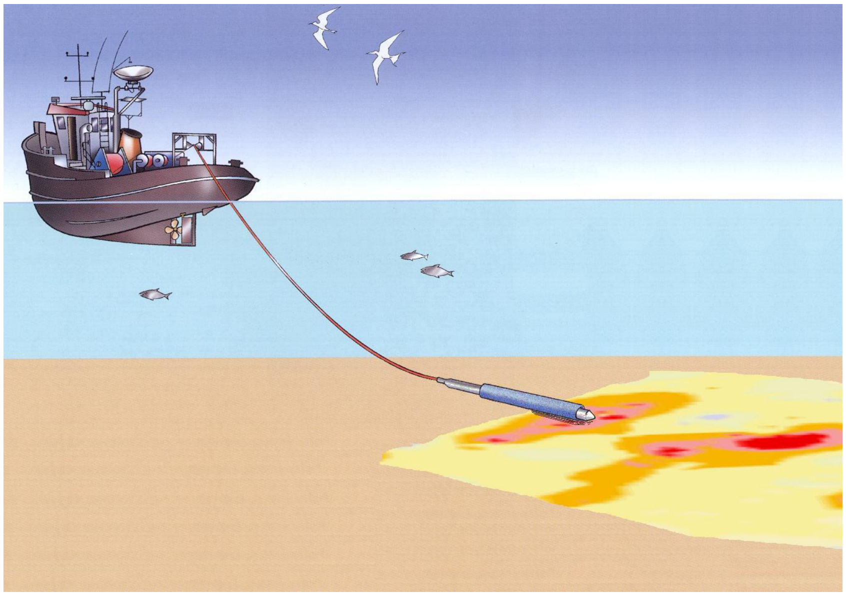

Fig. 3. The MEDUSA system towed behind a vessel

Table 1. Physical and chemical properties of the glauconitic sand and original Oostgat sediment

	Physical properties		Chemical properties		
	D50 (μm)	ρ (kg/l)	^{40}K (Bq/kg)	^{238}U (Bq/kg)	^{232}Th (Bq/kg)
Glauconitic sand	245	2.65	644	27	11
Oostgat sediment	280	2.65	212	6	5

RESULTS

Six surveys were conducted using multi beam and the MEDUSA tracer: one before dumping, one during dumping and three after dumping (Oosterhoff et al., 2003). Figure 4 shows the morphological development of the site during the monitoring program. At t_0 different morphologic features are visible in the study site. At the toe of the bank, ripple structures are absent, whilst ripple structures are present in the axis of the channel.

The nourishment was built in two phases: the southern half of the dump site was filled ($t_{0,5}$) before the northern half (t_1). Inside the study site, the glauconitic sand is dumped in two `bumps´. During the year after the nourishment, the multi beam soundings show how the shape of these bumps becomes asymmetric and start behaving as large ripple structures. These ripple structures are perpendicular to the coastline and have a flood oriented shape.

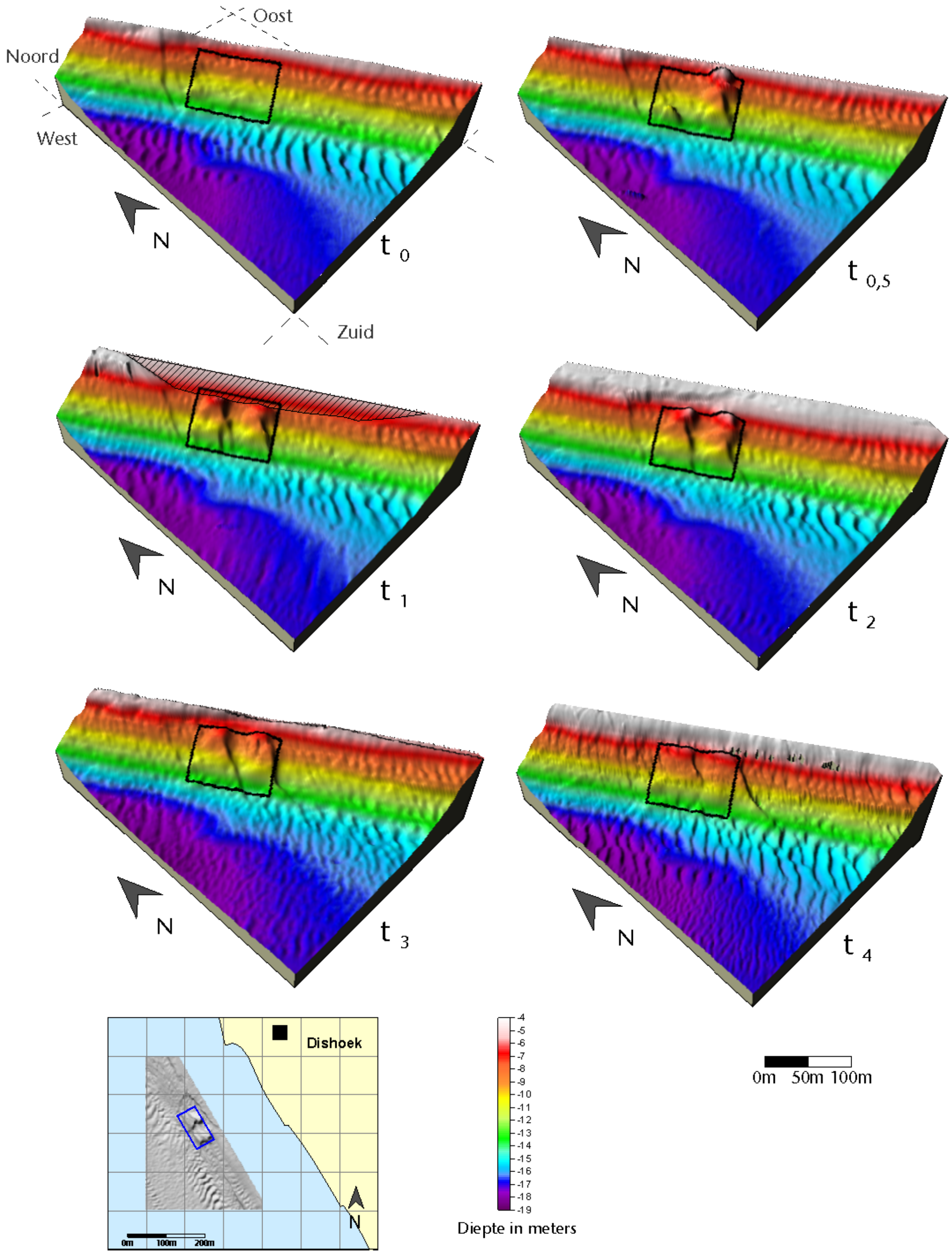

Fig. 4. 3D image of the bathymetry of the nourished site, during six surveys. The rectangle represents the predetermined dump site. t_0 = September 18, 2001; $t_{0,5}$ = October 24, 2001; t_1 = November 10, 2001; t_2 = December 3, 2001; t_3 = February 18, 2002; t_4 = October 7, 2002

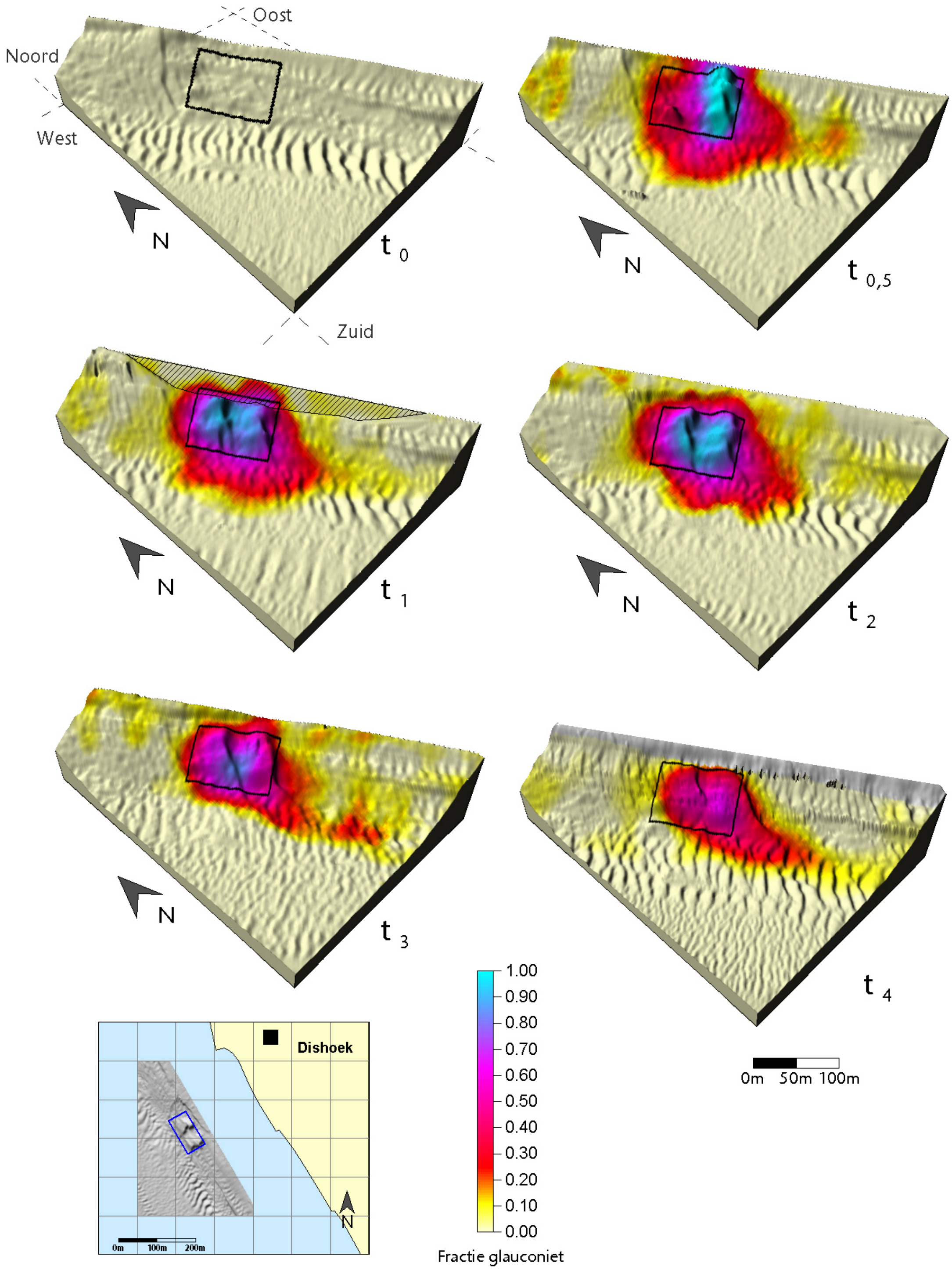

Fig. 5. Distribution (in color) of the fraction of glauconitic sand, projected on the 3D bathymetry images. t_0 = September 18, 2001; $t_{0,5}$ = October 24, 2001; t_1 = November 10, 2001; t_2 = December 3, 2001; t_3 = February 18, 2002; t_4 = October 7, 2002

Figure 5 shows some images that combine the morphologic measurement (as 3 dimensional plots) with the dispersion of the glauconitic sand, measured with the MEDUSA system, in color. This figure show how glauconitic sand is absent in the t_0 survey. During dumping, parts of the tracer material has dispersed within a range of 50 m from the nourishment. During the t_1 and t_2 surveys, the dispersion of glauconitic sand is most pronounced in southeastern and southern direction. During the t_3 mapping, the concentration of glauconitic sand in the dumping site is decreased, parts of the glauconitic sand are dispersed on southeastern direction. The t_4 mapping shows a decrease of the glauconitic sand at the dump site mainly at the northern side of the nourishment, whilst the dispersed sediments at the southeastern side of the nourishment clearly coincide with a ripple-shaped morphology. Detailed coring at various locations on the nourishment revealed how in the northern part of the nourishment, the glauconitic sand is covered by autochthonous material. In the southeastern direction from the nourishment, a mixture of glauconitic sand and original sediment covers the sediment bed.

These data show that material is transported downhill and in southwestern direction. This indicates flood dominated net sediment transport. Especially the strip of ripples (with a high in the order of 1 m) seems to work as a conveyor belt: when the nourished sediments are transported downhill, these sediments are incorporated in the ripples, which have a flood dominated sediment transport direction.

Sediment budgets were determined from the multi beam data for the dump site and five areas around the dump site (indicated in Figure 6). Results are shown in Table 2. This sediment budget analysis indicates that only 4500 m^3 (of the 10.000 dumped sediment) was found at the dump site directly after dumping (t_1 measurement). Around the dump site another 1100 m^3 was found. The rest of the material is unaccounted for. We do not know whether this loss of sediment is the result of compaction, miscalculation by the dredging company or other causes. After one year 70% of the dumped material (measured at t_1) was still present at the dump site, 85% was found in and around the dump site. The largest sedimentation occurred in area b, which corresponds to the earlier observation of downhill transport in southwestern direction.

Table 2. Sediment volume changes relative to t_0 at and around the dumpsite*

Survey	Weeks after dumping	Dump site (m^3)	Area a (m^3)	Area b (m^3)	Area c (m^3)	Area d (m^3)	Area e (m^3)	Total (m^3)
$T_{0,5}$	-1	2573	-45	-56	393	35	-41	2859
T_1	1,5	4445	175	1	780	105	112	5618
T_2	4,5	4103	26	256	865	147	31	5428
T_3	15,5	3787	118	424	894	61	3	5287
T_4	49	3173	204	1218	463	82	-352	4788

* The different areas are indicated in Figure 6.

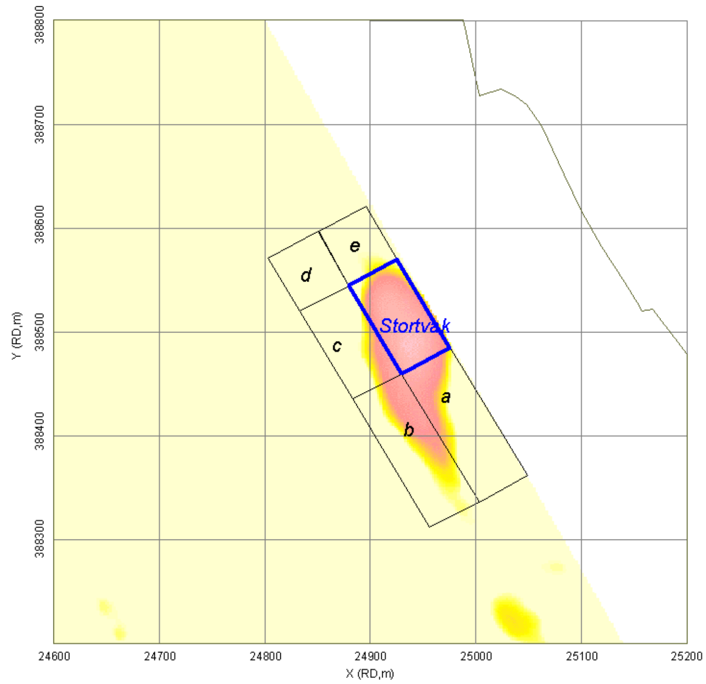

Fig. 6. Areas for which the sediment budget was determined, projected on the top view of the distribution of the glauconitic sand of the last survey

DISCUSSION AND CONCLUSIONS

The experiment shows that it is technically feasible to place a small scale nourishment on the slope of a tidal channel. It was also possible to monitor the morphological development. The combination of multi beam and MEDUSA has revealed sediment transport patterns: using detailed bathymetrical mapping and natural sediment as a tracer we were able to produce both qualitative and quantitative information on the morphological development of the nourishment. The study suggests that sediment transport by tides is most important, while wave driven sediment transport is not of importance. After a year a 85% of the recovered material was found to be present.

A few remarks have to be made considering the feasibility of this type of nourishment. Not all dumped material was found after dumping. There was a loss of some 40%, while with shore face nourishments along the Dutch coast generally a 15% loss is observed. This high rate observed in this experiment needs to be better understood. On a larger scale two considerations have to be taken into account. The first concerns the slope of the channel, which was 1:7 in the experiment. However, steeper slopes occur in the Oostgat and the question can be raised what the behavior of a nourishment on a steeper slope would be. The second concerns the scale of the experiment. A large scale nourishment might cause contraction of the cross-sectional area of the channel, with subsequent reaction of the flow. This might cause a different morphological behavior in terms of erosion rate and sediment transport rate then observed during the experiment.

IMPLEMENTATION OF THIS TYPE OF NOURISHMENT

Based on these results a nourishment of a tidal channel in one of the outer deltas of the Wadden Sea has taken place in 2003 and plans for a nourishment in 2005 in the Oostgat have been made. These are still nourishments that will be closely monitored to be able to establish whether this nourishment technique is an adequate tool in fighting coastal erosion in the Netherlands. If it is we have found a way to stop erosion of the coast caused by the migration of tidal which fits perfectly in the adopted three stage strategy.

The nourishment planned in the Oostgat in 2005 will be about 1,5 million m^3, which is 100 times bigger than the experiment described in this paper. For the entire Oostgat the estimated total amount needed is 12 million m^3. This shows we have merely begun going from experiment to practice.

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