CHAPTER 208

Experimental Shoreface Nourishment, Terschelling (NL)

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Abstract

An experimental shoreface nourishment was implemented at Terschelling, the Netherlands in 1993. The effectiveness of this nourishment will be evaluated in the framework of an EU sponsored project NOURTEC.

The design of the Terschelling nourishment including the objectives and alternatives, are described in detail. Preliminary monitoring results lead to a cautious optimism with regard to the performance of the nourishment.

NOURTEC: evaluation of innovative nourishment techniques

Full scale experiments with alternative coastal nourishment techniques, including shoreface nourishments, are being carried out in three countries around the North Sea: at the island Terschelling in the Netherlands, at the island Norderney in Germany and at the closed barrier coast near Torsminde Tange in Denmark (Fig. 1; Table 1). A comparative analysis of all these experiments is planned within the project NOURTEC.

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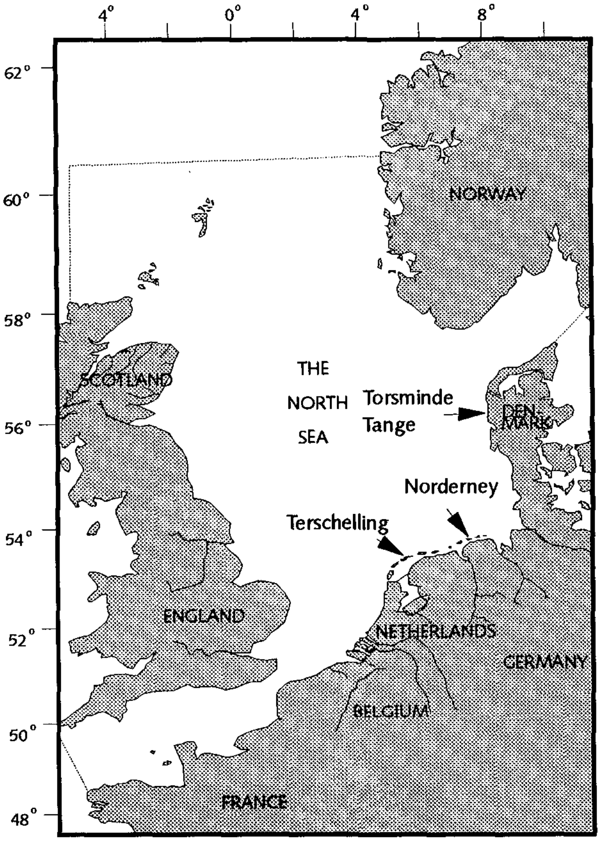


Fig. 1 Location of the three NOURTEC test sites

NOURTEC locations	nourishment type	total amount (Mm^3)	averaged volume (m^3/m)	year
Terschelling (Netherlands)	- shoreface	2	450	1993
Norderney (Germany)	- combined shoreface- and beach	0.45	250	1992
Torsminde Tange (Denmark)	- shoreface - beach	0.25 0.25	250 250	1993 1993

Table 1 Characteristics of nourishment experiments in the NOURTEC project

In particular, NOURTEC aims at generalized conclusions on the design, the effectiveness and the feasibility of shoreface nourishment techniques in different coastal environments.

In general, shoreface nourishments can be used to attain one, or a combination, of the following design objectives (i) coastline stabilization, (ii) coastal protection, (iii) creating or maintaining a recreational beach. Although each of the NOURTEC nourishment experiments has a specific design objective - i.e. coastal protection for Torsminde and Norderney and coastline stabilization for Terschelling - within the framework of NOURTEC each will be evaluated for all of the above design objectives. The final report is due in 1996.

Each nourishment experiment is accompanied by an extensive monitoring program including frequent bathymetric surveys and monitoring of the offshore wave climate and nearshore tidal current field. In addition to this special process-oriented field programs are carried out (Hoekstra et al.,1994; Kroon et al., 1995).

This paper will focus on the design of the Terschelling nourishment (NOURTEC, 1994) and some initial results of the monitoring program.

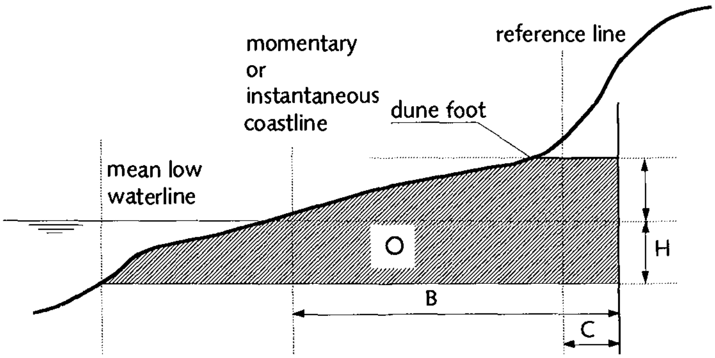
Coastal defense policy in the Netherlands

About three-quarters of the Dutch coast consists of dunes and beaches. Together they offer a natural, sandy defence to the North Sea. Under the influence of nature, this barrier is constantly changing; advancing at one location, receding at another. In 1990 the Government and Parliament of the Netherlands instituted a new national coastal defence policy: dynamic preservation of the 1990 coastline. This policy is based on the concept of a standard or reference coastline, the so-called basal coastline (BKL). Whenever the actual coast line tends to move to a position landward of the basal coastline, the beaches will be restored.

The main method in the Netherlands, to preserve the 1990 coastline is beach nourishment. On a yearly basis 5 to 7 million m^3 of sand is added to the (dry) beaches.

Definition of coastline

To arrive at a uniform measure for the overall change in a cross- shore profile, a critical region O - indicated by the hatched area in Fig. 2 - is defined. In the vertical direction the critical region extends between the elevation of the dune foot and a depth corresponding to twice the vertical distance between Mean



H = height between dune foot and mean low water [m]
O = BKL-zone [m^2]
B = O / 2 H [m]
B - C = distance momentary coastline - reference line [m]

Fig. 2 Definition sketch of the BKL zone and the Momentary Coastline

Low Water (MLW) and the elevation of the dune foot. In the landward direction the critical region is bounded by a vertical line. The location of this line is sufficiently landward so that erosion is not encountered. This critical region is called the BKL - zone.

Making use of the concept of the BKL - zone, the momentary coast line is defined as a line located at a horizontal distance B seaward of the dune foot. The magnitude of B follows from B = O / (2H). Note that in general the momentary coast line does not coincide with MLW. To document the position of the coastline, once a year cross- shore profiles spaced 200 - 250 m apart are measured along the entire Dutch coast. For each cross - shore profile, the values of O and B are calculated and the position of the coast line is referenced to fixed survey monuments.

To account for yearly fluctuations, a transient coastline (TKL) is defined. The TKL for a given year follows from the linear trend of the momentary coastline during the preceding ten years. As an example, in Fig. 4 the TKL for 1992 is indicated, based on coast line data over the period 1982 - 1991.
The TKL for 1990 was defined as the basal coastline.

Coastline retreat at Terschelling

The project site is located on the central part of the island of Terschelling; see Fig. 3. As an example of

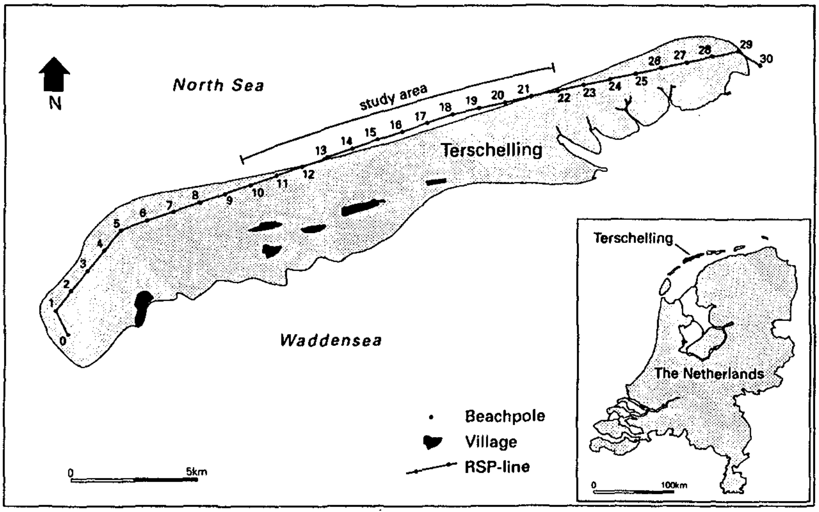


Fig. 3 Location of nourishment at Terschelling; the numbers correspond with km-positions of the cross-sectional profiles along the coast

coastline retreat the position of the coastline over the period 1965 to 1991 at km 16.00 is plotted in Figure 4. In the same figure the position of the basal coastline (BKL) and the transient coast line (TKL) for 1992 are presented. The transient coast line suggests that at km 16.00, the TKL 92 will soon retreat to a position landward of the BKL. Calculations showed that for 68 % of the profiles between km 13.70 and 17.80 the TKL 92 had already crossed the BKL. On this basis it was decided that for this stretch of the Terschelling coast the coast line had to be restored by means of a nourishment. Because of the west to east direction of the littoral drift, the project area was extended to km 18.20.

To calculate the amount of sand required to assure that the TKL for the next ten years remains landward of the BKL, the erosion rates were determined from the trend lines of the various profiles. Erosion rates for the project area range between 1- 5 m /year. This corresponds to a loss of approximately 110 thousand cubic meters per year. If this trends continues, 1.10 million cubic meters of sand will have been removed out of the BKL-zone in the next ten years.

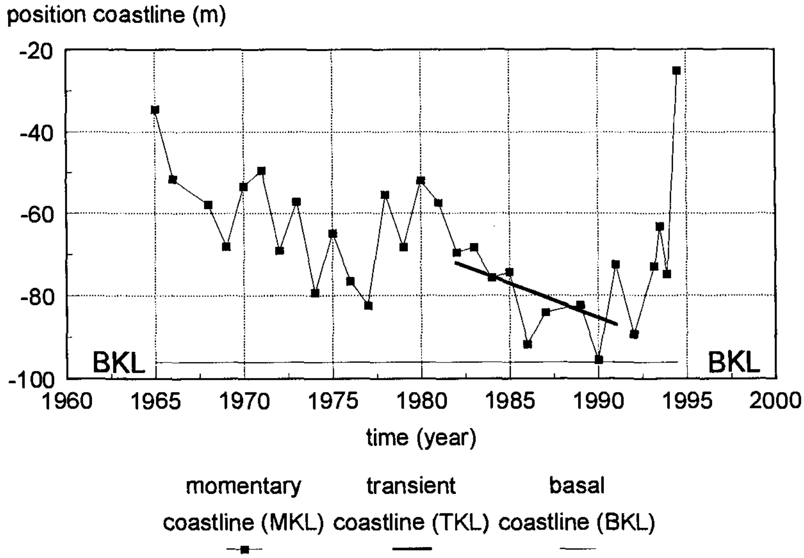


Fig. 4 Coast line development at km 16.00; indicated are the Transient Coastline (TKL) for 1992 derived from the period 1982 - 1991, and the Basal Coastline (BKL). Note the remarkable positive trend after the nourishment (Nov 1993 - June 1994).

Design objectives

The design objectives are to return the TKL to a position seaward of the BKL and to assure that the TKL will not retreat landward of the BKL during the next ten years. Maintaining a sufficiently wide recreational beach and protecting the low-lying polderland landward of the dunes from storm surge are not acute problems and therefore are not part of the design objectives.

Pertinent physical parameters

At the location of the project, the width of the surf zone ranges between 1600 m and 2000 m. The morphology is characterised by three long-shore bars. Typically, the distance between the bar crests, measured in the cross-shore direction, varies between 100 m and 400 m. The vertical distance between trough and landward crest can be as large as 4 m. Using bathymetric data of the past 26 years, Ruessink (1992) showed that bars tend to originate between the high water and low water line, migrate in an offshore direction and fade out at a depth of 8-11 m below MSL or about 2000 m offshore; see Fig. 5.

The total sequence takes approximately 10-15 years. Although less pronounced than the offshore directed movement, there is also a long-shore movement of the bars. The area is in general very dynamic with a considerable transport of sediment.

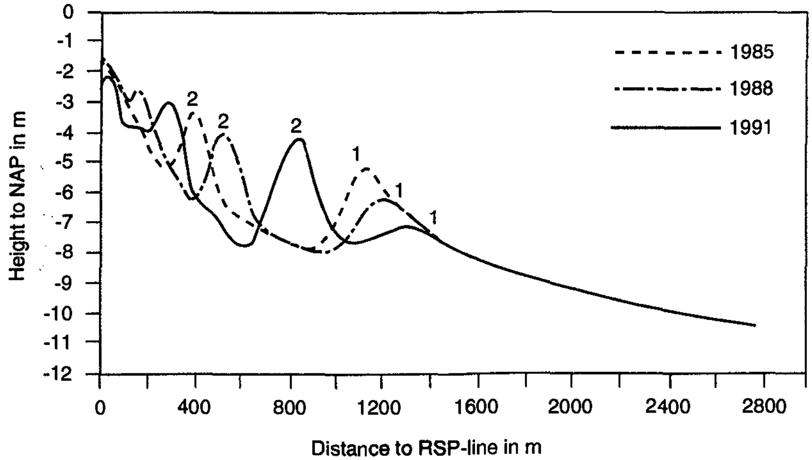


Fig. 5 Typical example of migration of longshore bars

The wave climate at the project site is characterised by an annual average significant wave height of 1.2 to 1.5 m. Tides are semi-diurnal with neap tidal range of 1.5 m and a spring tidal range of 2.1 m. The amplitude of the tidal current at the nourishment site is estimated at 0.4 m/sec. There are indications that the residual current is from west to east. The sand present in the nourishment area has a median grainsize of 155 - 165 μm.

Principles of shoreface nourishment

Shoreface nourishment involves placement of sand on the shoreface rather than on the beach. The principle of the shoreface nourishment is based on the observation that erosion of the shoreface leads eventually to erosion of the beach and the dunes. Conversely, it is expected that nourishment of the shoreface might stop or retard the erosion of the beach.

There are two types of shoreface nourishments: a stable berm and a feeder berm. A stable berm is constructed in deeper water. It's function is to attenuate storm waves and to reduce the wave energy expanded on the beach. For Terschelling this is not a viable design alternative because there is no initial contribution of sand to the BKL-zone, implying that the TKL will remain landward of the BKL, and subsequent transport of sand to the BKL-zone is, by definition, not expected. A feeder or nearshore berm is constructed in relatively shallow water and therefore part of it could be in the BKL - zone. It serves as a dissipator of incident wave energy and is expected to gradually provide additional sand to the BKL-zone.

Both types of shoreface nourishments have been constructed since 1935. Only the more recent projects were accompanied by monitoring programs. With regard to the feeder berm projects the monitoring results showed a gradual movement of sand in the landward direction and consequently a movement of the coastline in the seaward direction. In addition, the following general conclusions can be reached:

- the estimated cost of a shoreface nourishment is half of that of a beach nourishment;
- sand should be placed as high as possible in the profile to assure landward transport, a depth of less than 10 m is recommended;
- the length of the nourishment in the along-shore direction should be several times the average local wavelength to minimize the potential for wave focusing.

Obviously, more monitoring is needed to verify performance and to quantify the physical benefits of shoreface nourishments.

Roelvink (1989) carried out a desk study to determine the effect of a shoreface nourishment on the coast. In particular he focused on

- depth of placement
- volume of the nourishment
- influence of sea level rise.

He defined the effectiveness of the shoreface nourishment as the increase in volume of a specified part of the cross - shore profile, for example the BKL - zone, expressed as a percentage of the nourished volume. The autonomous development of the profile is not taken into account.

The main conclusions of Roelvink's study are that

- shoreface nourishments become more effective when placed close to shore; for the Dutch coast nourishments placed landward of MSL -7 m have a definitely favourable effect on the beaches; the nourishment has little or no effect when placed seaward of MSL - 10 m;
- the volume of a specific part of the beach profile and therefore the effectiveness increases linear with the volume of the nourishment;
- the effectiveness is little influenced by an

increase in the rate of sea level rise.
Parameter values used in the calculations by Roelvink pertain to the Dutch coast. Conclusions are valid within this parameter range and should not be extended beyond this range.

Partly in response to Roelvink's study, Hillen et al. (1991) carried out a feasibility study for shoreface nourishment including methods of construction and cost. One of their conclusions was that for nourished volumes of 1-10 million cubic meter, distances to the borrow area of 15-20 km and a nourishment depth of less than MSL -7 m, only nourishments carried out by small to medium size split barge hopper dredges lead to a price per cubic meter of sand that is substantial lower (50 %) than that of a beach nourishment. Furthermore, using the results of Roelvink they calculated how much sand is expected to be in the BKL-zone as a function of time and depth of placement. The results showed that a shoreface nourishment placed between MSL -5 m and MSL -7 m has an effectiveness of 35% to 60 % after 5 years. It was concluded that, compared to a beach nourishment (effectiveness estimated at 90 %), twice the volume of sand is needed for a shoreface nourishment to arrive at the same volume of sand in the BKL-zone after 5 years. In view of the 50 % reduction in the price of a cubic meter of sand in place, it follows that the total cost of a beach nourishment and a shoreface nourishment, which would guarantee the same volume of sand in the BKL - zone after 5 years, are about the same.

Hillen et al. (1992) emphasize that estimates of cost and effectiveness of the shoreface nourishments used in their study are conservative; this to not create false expectations. However it seems clear that the method has potential, and ultimately could lead to substantial savings considering the annual budget of 60 million Dutch guilders (28 million Ecu) spent in The Netherlands to combat erosion. In view of this
it was decided for Terschelling to select the option of a shoreface (feeder berm) nourishment.

Design of the shoreface nourishment

Further specification of the feeder berm design was largely based on experience with earlier nourishments and on theoretical results. Unfortunately, state-of-the-art models turned out to be of limited use as a design tool. For the shoreface nourishment to meet the design objectives stated above, a total of (2 * 1.10 million =) 2.20 million cubic meter of sand is required. Sand should be placed as high as possible in the profile. However an upper limit of MSL - 5 m was imposed by the smallest available hopper dredge. This depth is still available within the BKL - zone which extends to NAP - 5.24 m at the project site. This allowed at least a fraction of the sand to be placed initially in the BKL - zone.

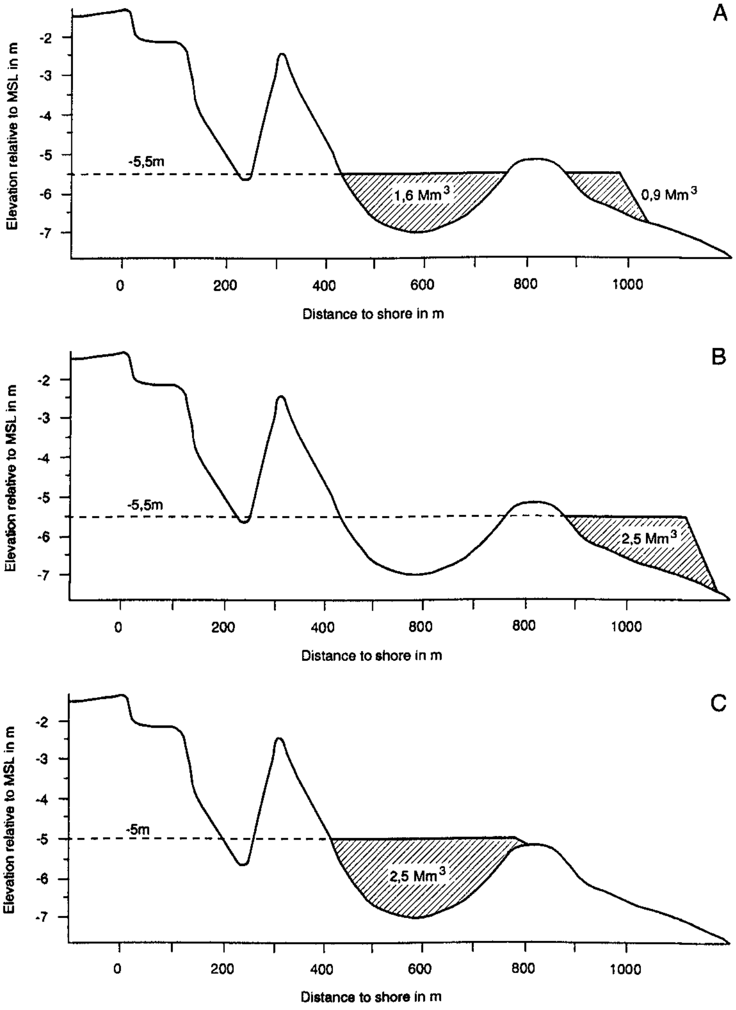


Fig. 6 Design alternatives for a shoreface nourishment at Terschelling

Three possible designs for a shoreface (feeder berm) nourishment were considered; see Fig. 6. To reiterate, the design objectives or functional requirements to be met by each of the designs were

- After placement of the sand the TKL should be seaward of the BKL everywhere at the project site;
- The TKL should not retreat landward of the BKL during the next ten years.

Furthermore the design should allow adequate monitoring (this in view of the experimental character of the nourishment). The optimum design is the one that meets the functional requirements at a minimum total cost.

Calculations with a 3-LINE model (Bakker, 1995), which included the actual geometry with the three bars, suggested that nourishment seaward of the outer bar, as in designs A and B, could not sufficiently compensate for the landward movement of the coastline of about 1-5 m per year during the next ten years. The nourished volume seaward of the outer bar would act as a breakwater, however, with little effect on the natural erosion of the coast. For design C, the model indicated that the nourishment would prevent the TKL from retreating behind the BKL in the next ten years. It should be emphasized however, that the calculations were of an exploratory nature.

For designs A and B sand loss during dumping could be substantial due to the relatively large depth and tidal current speed. For design C, losses during construction were expected to be minor due to the placement of the sand between two bars. Consequently, the cost per cubic meter sand in the profile was expected to be lowest for design C. In design C a substantial fraction of the sediment is initially placed in the BKL-zone. From a monitoring point of view both designs B and C were acceptable. Design A was less attractive because it consists essentially of two parts.

It follows that design C is the only design that meets all design criteria and it has the lowest cost. Therefore, this design was selected as the final design. Because of financial constraints the total volume of sand was somewhat reduced to 2 million cubic meters. The nourishment stretched between km 13.6 and km 18.2; see Fig. 3. Originally a volume of 0.3 million cubic meter was placed in the BKL zone.

The <u>type of sand</u> to be selected for the nourishment should closely resemble the native sand to avoid additional complications and to facilitate interpretation of the behaviour of the shoreface nourishment. If it is different, the sand should preferably be coarser than the native sand. This will lead to less loss of sediment during and immediately after placement and will lead to an extended life span of the nourishment. Borrowing of sand in the Dutch territorial waters is limited to the zone offshore of the 20 m isobath. A good source of sand resembling the native sand was found 10 km of the project site at the 22 m depth contour with a median grain size in the range of 183 - 212 μm.

The nourishment was implemented using three suction split hull hopper dredges with hopper capacities ranging between 1200 and 2100 cubm. The draft of the vessels ranged between 4.50 to 5.30 m. To provide access to the project site, an entrance channel was dredged through the most seaward bar at km 16.30. The channel depth was 6.50 m below NAP. The nourishment area was divided into 9 dump sections each with a width of approximately 500 m. The dumping started simultaneously at the west and east side of the project area. Depending on the direction of the tidal current, the dredges placed the sand in the outermost east or west section. At the end of the construction the entrance channel was closed. For execution of the project an accurate electronic positioning system was used. Total construction time was 6 months (May - November 1993). Due to an unexpectedly high frequency of unfavourable swell conditions hindering manoeuvering of the dredges between the bars, the total operation took 65 instead of the planned 36 weeks of shipping time.

The contractor was reimbursed based on results of bathymetric surveys rather than volumes of sand transported by the hopper dredges. It appeared that the transported volumes were about 30% larger than the bathymetrically observed volumes.

Monitoring results

Since the completion of the nourishment in November 1993, bathymetric surveys have been carried out at regular intervals. Based on these surveys the position of the coastline was calculated for various cross-sections. As an example, for km 16.00 the positions of the coastline since the nourishment have been added to Fig. 4. Between the nourishment and the last survey during June 1994 the coastline has advanced by 50 m. In Fig.7, the change in volume of the BKL-zone since the start of the nourishment in May 1993 is indicated. As per June 1994, the volume in the project area (between km 13.60 and km 18.20) has increased by 0.9 million cubic meter. Originally only 0.3 million cubic meter of sand was placed in the BKL zone. The additional 0.6 million cubic meter was transported landward by wave action, leading to cautious optimism with regard to the performance of the shoreface nourishment.

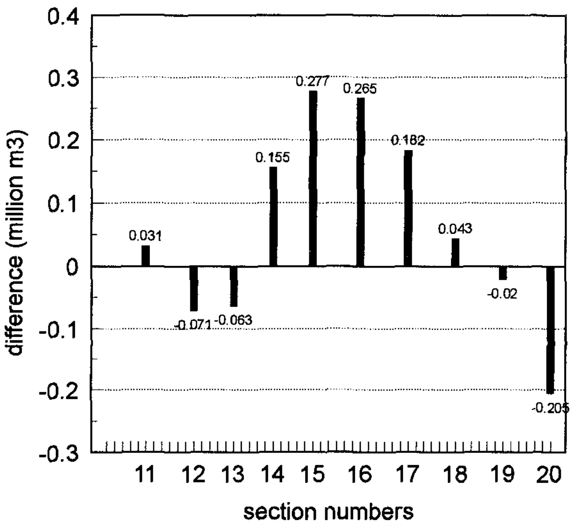


Fig. 7 Volume changes in the BKL zone after implementation of the shoreface nourishment over the period May 19, 1993 to June 20, 1994.

Acknowledgements

NOURTEC is a joint Dutch-German-Danish effort co-sponsored by the Commission of the European Communities under the Marine Science and Technology Programme (MAST-II), contract number MAS2-CT93-0049. Partners on the Dutch side are Rijkswaterstaat - National Institute for Coastal and Marine Management (RIKZ) and Utrecht University - Institute for Marine and Atmospheric Sciences (IMAU), on the German side the Coastal Research Station Norderney and on the Danish side the Danish Coastal Authority.

In the Netherlands the fruitful co-operation is acknowledged with the Rijkswaterstaat Directorates Noord Nederland and Noord Holland. Special thanks are due to mr. Edwin Biegel who was largely responsible for the analysis of the bathymetric monitoring data and for illustrating this contribution.

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