

MANAGEMENT OF BEACH NOURISHMENT IN AN OPEN SAND SYSTEM

Hans H. Dette¹⁾

Abstract

The nourishment of beaches is an environmentally friendly method of shore protection but the annual sand requirement may lead to substantial expenditure. Therefore the annual sand demand should be minimized. Factors which affect the sand demand along a sandy coastline in order retain the shoreline at a given position will be discussed. A wide normally dry beach on which waves can dissipate their energy at raised water levels without substantial reshaping of the underwater profile is desirable. Where such a beach cannot be created measures have to be taken to minimize sand losses from dunes during extreme events into the everyday surf zone. Furthermore the sand requirement for an open sand system, like the Island Sylt/North Sea, can be obtained by a reduction of the amount of sand from longshore transport which is carried over the ends of the island and is lost from the system.

Introduction

The west coast of Sylt (Fig. 1) is fully exposed to the North Sea waves from westerly directions and subjected to ca. 2 m high tides. Due to the geometry of the German Bight the coast is also affected by storm tides which lead to a rise in MHW level of up to 3.5 m. A maximum wave height $H_{m0} = 6$ m in 13 m depth of water (approx. 5 km off the coast) has been recorded so far.

The nearshore area is characterized by a longshore bar which is located approximately 300 m seaward of the shoreline. There high waves break as plunging breakers. During storm surges with a water level rise of more than 2 m the protective effect of the bar (crest height approx. MSL - 3 m) is lost and the waves pass over the bar without breaking (Fig. 2).

According to geological estimates the west coast of Sylt has been receding approximately 13 km over a period of 7,000 years (1.8 m per year). During all these

¹⁾ Academ. Dir., Leichtweiss-Institute, Technical University of Braunschweig, P.O. Box 3329, 38023 Braunschweig, Germany

years the underwater profile has been translated eastward, probably without much change in shape. The eroded material established spits to north and south of the core of the island. These are now curtailed by major tidal channels. The tidal currents carry the sand that arrives at the ends of the spits away from the island. Thus, Sylt is a typical example of an open sand system, because eroded material is not returned to the island.



Figure 1. Open sand system: Island Sylt/North Sea

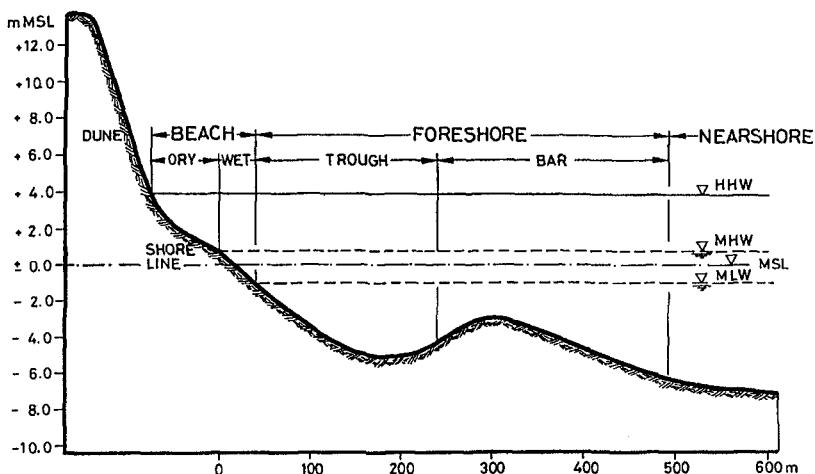


Figure 2. Typical beach, foreshore and nearshore profile of the Sylt west coast

The 36 km long west coast consists mainly of unprotected dunes and an up to 25 m high cliff (Fig. 1). Only 10 % of the coastline are protected by heavy coastal structures (city of Westerland). Since 1950 the mean yearly recession has increased from 0.9 m/year (1870 - 1950) to 1.5 m/year (1950 - 1985) due to an increased storm surge frequency (Dette, 1997). This is equivalent to an annual sand loss of $1.5 \times 10^6 \text{ m}^3$ (1/3 to the south and 2/3 to the north). As a consequence of this accelerated recession a coastal protection concept for a period of 35 years (1985 - 2020) was initiated. This was done on the supposition that the increased storm surge frequency would continue and with it the erosion, which would endanger the island if no counter-measures were undertaken. The consideration of all possible alternatives of future coastal protection, their technical, economic and environmental aspects indicated that repeated beach replenishments appeared to be the most favourable solution. These repeated nourishments aim to replace the mean yearly loss of sand off the coast. A Sylt-specific masterplan based on the above considerations was introduced in 1985. It includes the task of monitoring, especially land and sea surveys before, during and after the individual nourishment schemes.

The first experiences gained from monitoring led to modifications of the initial profile of the berm nourishment to a lower and broader shape in 1988 (Fig. 3). Fig. 4 shows that the initial fill geometry (1992) has been altered considerably by a single storm surge within one year after the fill. The storm surge established an equilibrium profile for its raised water level (1993), which remained fairly stable even during a following storm surge of comparable strength (1994). Attempts to optimize the current design practice have been made since the beginning of the 90's.

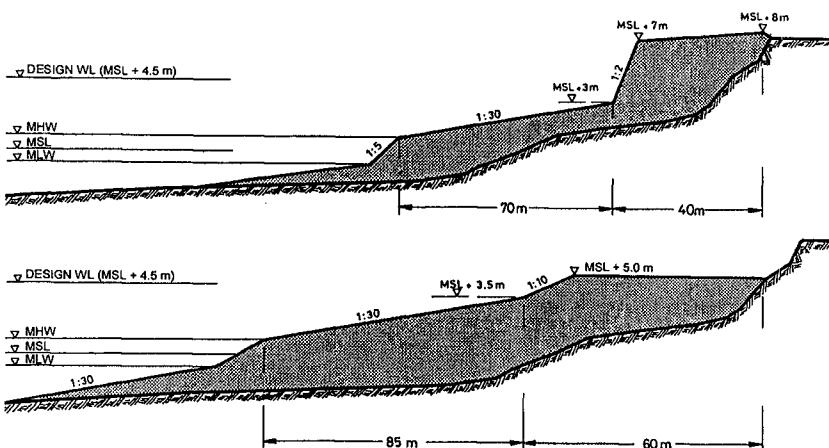


Figure 3. Change of intial berm nourishment profile (above) to a lower and broader shape (below)

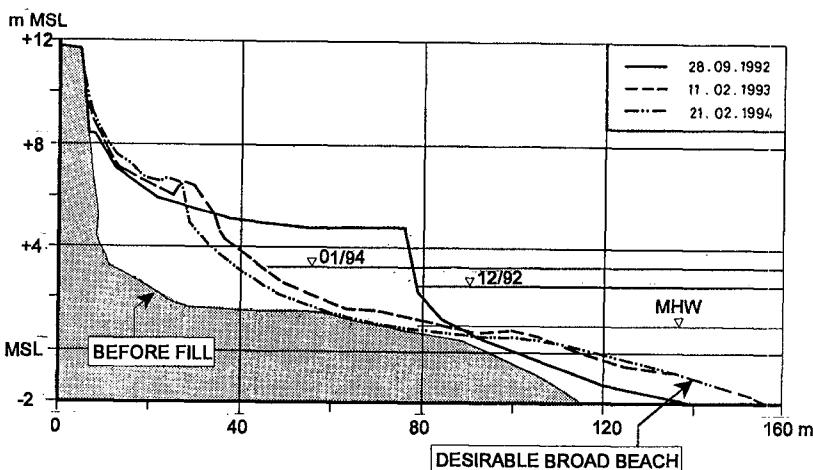


Figure 4. Changes of beach fill geometry (Sylt) during major storm surges in two consecutive years

Boundary Conditions on Nourishment Optimization

Having beautiful beaches and sea ambience Sylt developed into the primary recreational area in the North Sea since the middle of the last century. Any method of optimizing the coastal protection has to take into account the following boundary conditions:

- retention of the shoreline and the surf zone in its present form
- prevention of negative impacts on the near- and farfield coastline and islands
- minimization of any environmental impacts
- retention of a sandy beach
- acceptability for tourism

In addition protection has to meet the policy decision by the government that: "As a general principle hard structures should be avoided on sandy beaches."

These requirements basically predetermine beach nourishment as the best method of coastal protection. The normal longshore transport along the west coast of Sylt which is necessary to maintain the present appearance of the surf zone should not be influenced. The minimization of transport along the coast into the tidal channels can only be focussed on surplus sand masses exceeding the normal demand of sand in the surf zone. That is the uncontrolled transfer of sand from unprotected dunes or fills in front of dunes into the everyday surf zone at raised water level.

Under these premisses the following alternatives will be discussed:

- reduction of sand losses into the surf zone by design of nourishment techniques
- reduction of sand losses into the surf zone by measures that reduce the losses by storm surges
- reduction of sand losses from the island into the tidal channel by structural means

Protection by Exclusive Nourishment

Since 1972 repeated beach nourishments have been carried out for the protection of a seawall and revetment (length: 3 km) at Westerland (Fig. 1) against underscouring of the structures (Fürhröter, 1974 and Dette, 1977). On the basis of the masterplan the nourishments were extended to the so far unprotected dune and cliff sites (length: 33 km) in order to maintain the shoreline in its natural appearance. The nourishments are nowadays aimed at the retention of the 1992-position which was legally introduced as the reference. Up to 1996 the total volume of beach fills amounted to $25 \times 10^6 \text{ m}^3$ of sand from offshore borrow areas (Fig.5). Practical experiences with the placement of beach fill, its effectiveness and life span have been gathered over a period of more than 25 years (Dette et al., 1994).

In the case of exclusive nourishment an optimization of the necessary amount of sand for the everyday surf zone is not possible because the longshore transport potential remains unaltered by an ordinary fill. As mentioned before in case of an exclusive nourishment, that is without any additional constructive measures, the supply of the surf zone from the high beach is uncontrolled (Newe and Dette, 1995).

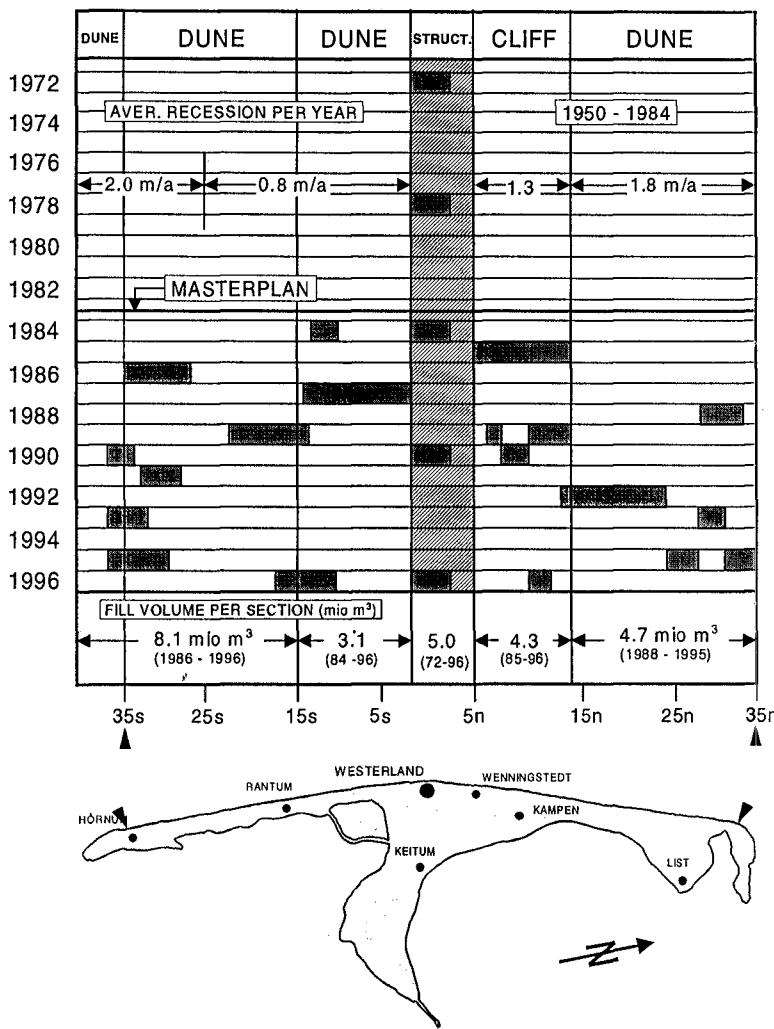


Figure. 5 Overview over beach fills at the west coast of Sylt in the Period 1972 to 1996

It depends on the occurrence of storm tides. An optimization of sand requirement is restricted to the following alternatives:

- shaping of the fill geometry on the dry beach
- control of replenishment frequency

Shaping of Beach Fill Geometry

The day-to-day processes occur in the surf zone. The erosion during storm surges affects the normally dry beach and dune. The material is carried cross-shore into the everyday surf zone. On the basis of detailed profile surveys before and after a storm tide it was calculated that two major storm tides in 1990 caused a loss of $1.8 \times 10^6 \text{ m}^3$ of sand from the 36 km long west coast of Sylt. This is equivalent to 60 m^3/m shoreline. This large volume of sand in the everyday surf zone leads to a profile which is out of equilibrium with the everyday wave conditions. During the following normal weather conditions waves start to reshape the profile left after the storm into an equilibrium profile. This is associated with an increased mobilization of sediment and an increased longshore transport. Consequently, increased sediment volumes are transported by superimposed wave and tide-induced currents to the ends of the island during the reestablishment of the equilibrium profile. That means increased losses of sand. Only a minor part of the sand dumped into the surf zone by the storm will be returned to the beach, because the wave climate off Sylt contains only a small portion of long and swell waves. However, at times appreciable accretion of the beach does occur, as illustrated in Fig. 6 (12/73 - 12/74).

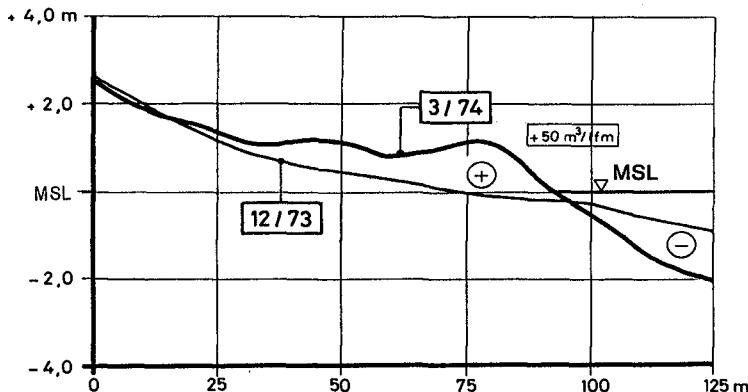


Figure 6. Appreciable accretion of the beach (Sylt) during occasional environmental conditions (seaward winds)

The shaping of beach fill geometry should be focussed on the creation of an as broad as possible dry beach with a flat slope which would suffer minimal sand losses during minor storm surges.

In case of raised water levels the flat slope of the usually dry beach (ca. 1:15) will lead to wave runup without creating an erosion escarpment. The amount of sand required for the reestablishment of an equilibrium profile, corresponding to the raised water level, is small (Fig. 7). The initial establishment of a broad beach along the west coast of Sylt would, however, require a very substantial amount of sand (Fig. 4, similar to 2/93 profile).

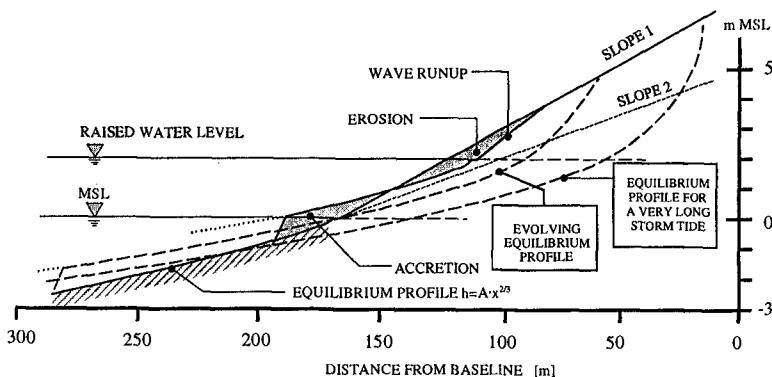


Figure 7. Development of a new equilibrium profile at raised water level (schematic)

Even with this solution losses from the fill geometry at all storm tides would occur, and by these means nourish the everyday surf zone. This process is an uncontrolled one and associated with occurrence of storm surge tides.

Controlled Beach Nourishment

Controlled beach nourishment is considered under the aspect of the establishment of a flat and as broad a beach as possible without attempting to "relocate" the surf zone seaward. This can be achieved by protecting the dune with a built-in membrane (Fig. 8). The membrane limits the amount of sand lost from the dune during a storm tide to the volume of sand cover on the membrane, i.e. the membrane serves damage as limitation measure (Dette and Raudkivi, 1994). The membrane does not affect the appearance of the beach. If the membrane is exposed during a storm tide the sand cover has to be restored.

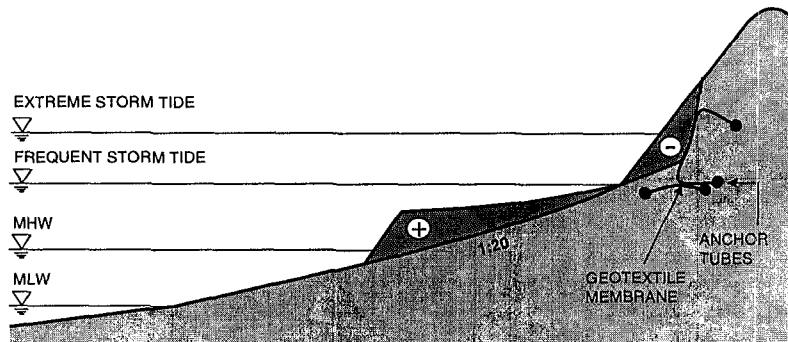


Figure 8. Barrier to limit dunes erosion by extreme storm tides (schematic) showing the erosion at extreme water level

If the dry beach is very narrow the frequency of the membrane being exposed can be reduced by installing a stone wall at its toe. It limits the frequency of storm tides which overtop the wall to ten or more year intervals (Fig.9). The maintenance of the surf zone by means of sufficient longshore transport in this case is from the beach which has to be replenished at required intervals.

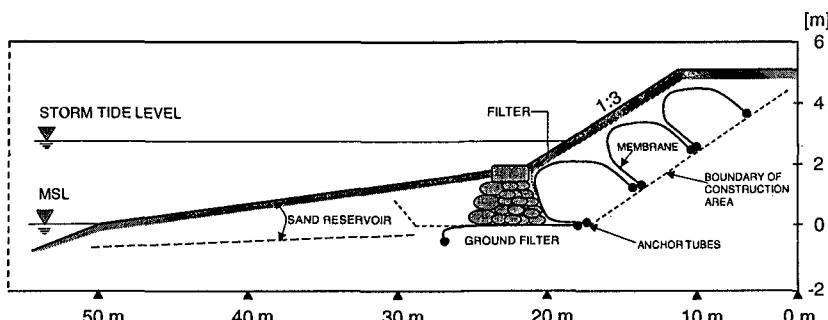


Figure 9. Dune and flood protection on a narrow beach (schematic)

Reduction of Sand Requirements

The sand requirement can only be reduced by reduction of the sand loss from the western shoreline. That is the reduction of the amount of sand carried into the main tidal channels at the ends of the island. The installation of underwater sills at the ends of the island will counteract the concentration of the longshore currents at the island's ends and the development of deep channels. The sills will spread and slow down the longshore current and lead to accretion of sand. This will reduce the slope of the underwater beach and induce it to assume more the plan shape of a half moon bay. The reduction of the slope leads to wave energy conversion over a broader surf zone and reduce the energy loading per unit area.

The non-erodible sills will reduce the sand loss into the main tidal channels but will not stop it. That means that a supply to the adjacent areas will continue. Such a sill existed as a natural ridge at the northern end some 50 years ago, linking the end of the island to the larger offshore sand bank. Today the ridge is been eroded down to a 6 m deep channel with concentrated high velocities. At the northern end the installation of the sill means restoration of the ridge which was there before. It is schematically shown in Fig. 10.

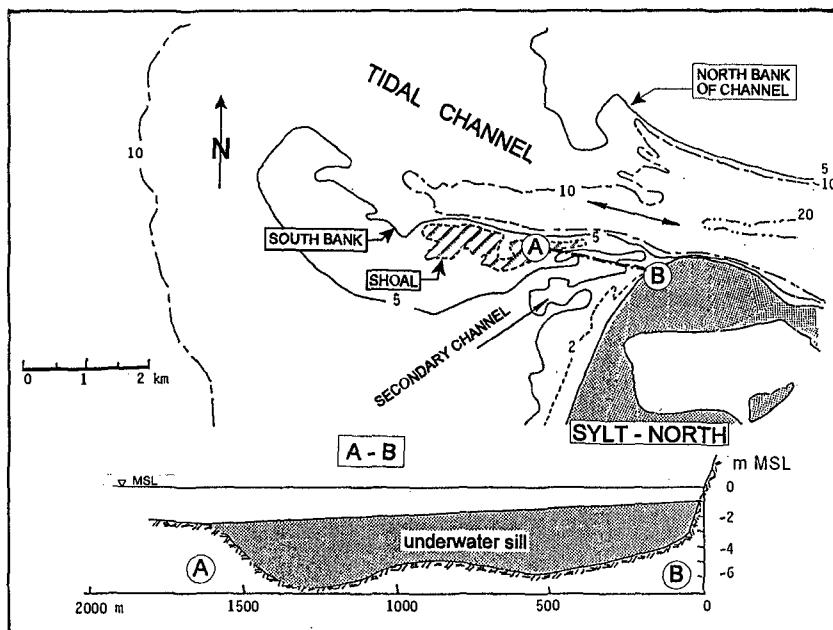


Figure 10. Layout of an underwater sill at the northern end of sylt to reduce longshore transport into the tidal channel (schematic)

At the southern end the installation of a sill involves a substantial effort. The dynamic equilibrium of the southern end of the island was disturbed by the construction of the large tetrapod groyne at Hörnum in the 70's. It deflected seaward the southerly longshore transport and it continued offshore to the main tidal channel (Fig. 11). The shoreline south of the groyne suffered by lee erosion and the southern end has retreated nearly 1 km. The ridge along the tidal channel to the offshore sand bar has increased in length from 800 m to 1750 m and the depth over it by 2 m (Fig. 12).

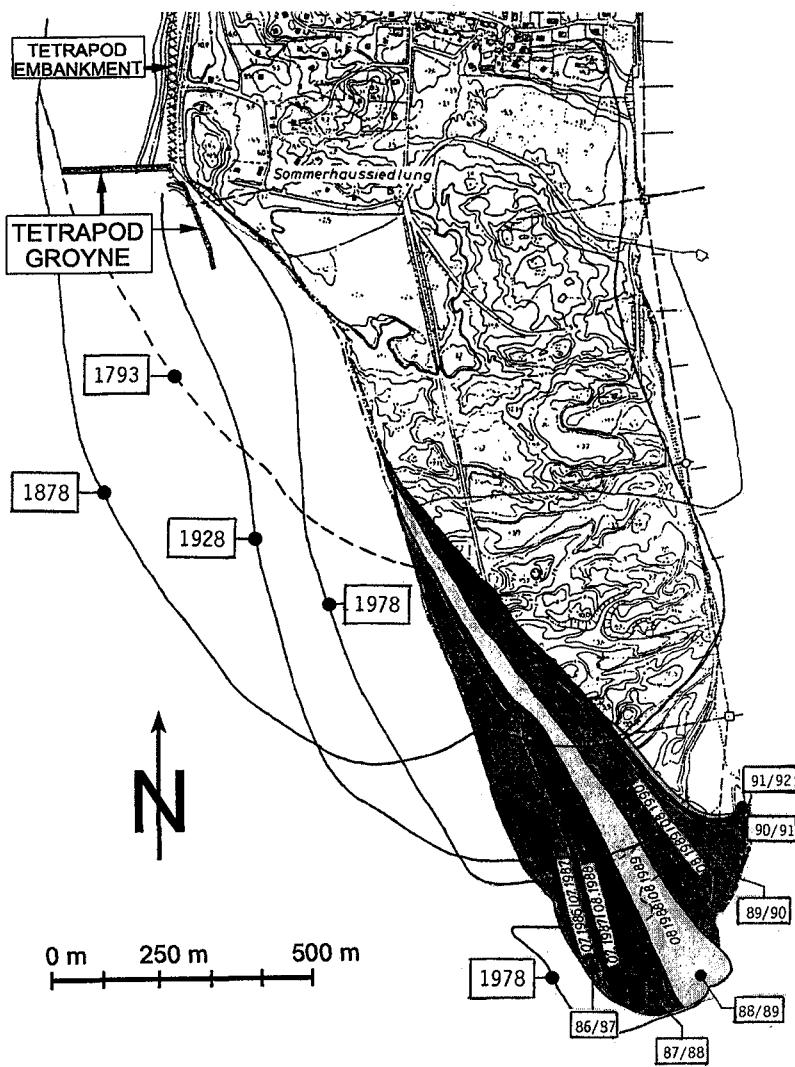


Figure 11. Accelerated shoreline recession after construction of a Tetrapod groyne in the 70-ties (ALR Husum)

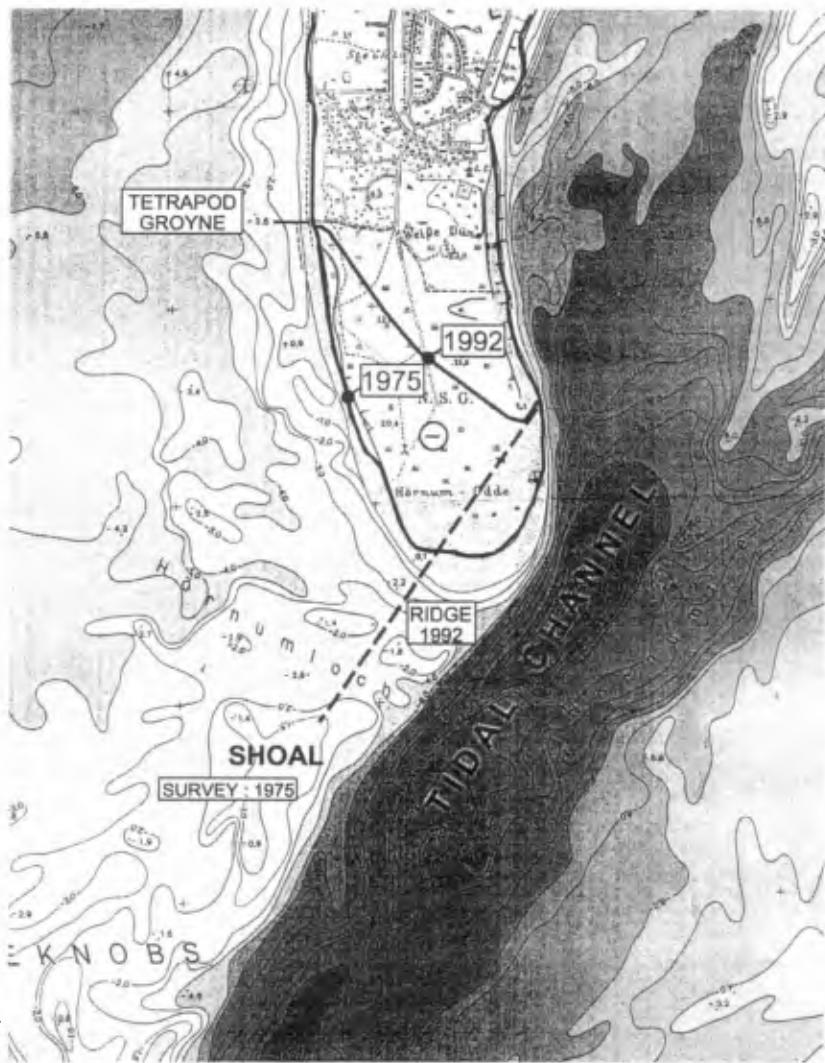


Figure 12. Extension of the ridge along the tidal channel from the shoreline to the offshore shoal and lowering of the depth contour by 2 m in the average

A sill at the southern end would stabilize that end. It would involve some "reconstruction" of the end and a sill as illustrated schematically in Fig. 13.

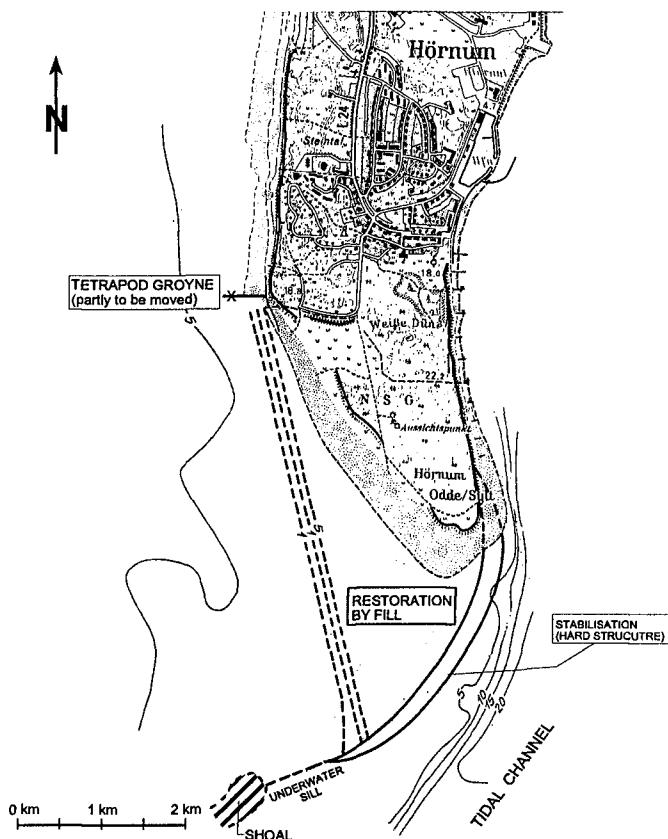


Figure 13. Restoration of former island's shape and its fixing at the southern end of Sylt (schematic)

Conclusions and Recommendations

In order to protect an open sand system the entire coastline should be considered as one single unit, i.e. it should not be splitted into sectors with different protection standards. The most favorable solution for the management of an open sand system like the westcoast of Sylt would be the minimization of the everyday longshore transport to that magnitude which just is necessary to preserve the present appearance of a wide beach and surf zone.

The required minimization of sand loss can be achieved by a barrier inside the dune or inside a berm nourishment profile that limits uncontrolled erosion by extreme storm tides. In case of a narrow beach the barrier, e.g. a geotextile membrane, can be protected by an additional stone wall at its toe. Sand deficits to the everyday longshore transport due to this measure could be compensated by additional sand supply (nourishment) to the beach in the middle of the island, from where the sand will be moved alongshore to the ends of the island.

Underwater sills at the ends of the island will reduce the concentrated longshore flux into the tidal channels and by these means extend the residence time of sand in the open system.

The realisation of such an overall solution, with the aspect of changing philosophy from shortterm, mostly remedial measures to a longterm preventive strategy, necessitates persuasive power and last not least the availability of substantial funds.

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