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Seaward coastal defence: limitations and possibilities

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Abstract. In The Netherlands shoreline retreat is actively counteracted, mostly by means of beach nourishment in which some allowance is made for natural fluctuations.

For some parts of the coast, however, a more active so-called 'seaward coastal defence strategy' might be more profitable. This applies to coasts with a small dune ridge subject to severe erosion. According to this strategy the morphological system is influenced in such a way that erosion is prevented, which will result in a stable or even an accretion coastline.

The effectiveness of the seaward coastal defence strategy has to be compared with maintenance by beach nourishment. The effects on the morphological system, the environment and other interests must also be analysed. Several seaward solutions are possible. In order to gain more insight into the behaviour of these solutions, comparative pilot studies have been executed for the most vulnerable locations.

This paper gives an overview of the main conclusions of the pilot studies in comparison with sand nourishment, the main coastal defence measure.

Keywords: Dynamic preservation; Feasibility study; Management; Nourishment.

Introduction

Dynamic preservation: the Dutch coastal defence policy

The coastal defence system in The Netherlands consists of dunes and dikes to protect the polders and dams to close off large (former) tidal inlets (e.g. van der Meulen & van der Maarel 1989).

The dunes cover ca. 75 % of this defence line, varying in width from 100 m to 5 km. They give The Netherlands its characteristic landscape (Doing 1995). They harbour unique natural values for Northwest Europe and they also represent an economic value including supply of drinking water, recreation, industry and residential usage (van der Maarel 1979).

Coastline retreat is evident along the entire coastline: more than 50 % of the dune coast suffers long-term (structural) erosion. An accelerated sea level rise will be felt everywhere, resulting in erosion along 80% of the sandy coastline. Important nature reserves might be lost and other interests on the beach and the dunes would be endangered.

In 1990 the Dutch government decided to stop any further long-term coastal recession. The choice for this 'preservation' alternative implies that the coastline will be preserved at its 1990 position: all structural erosion will be counteracted (Anon.1990; Louisse & Kuik 1990; Hillen & Roelse 1995; de Ruig & Hillen 1997). By nature, however, the coastline of a dune coast is not fixed at one single position. Choosing for the 'preservation strategy', allowances should be made for movements of the coastline. At some locations more aeolian dynamics (sand drifts, blowouts, mobile dunes) will be permitted and so-called 'slufters' (dune valleys influenced by the tides) can be formed.

When allowances are made for a certain degree of dynamics in the 'preservation' alternative, the charm and quality of the natural coasts will be safeguarded: 'preservation' changes into ' dynamic preservation'.

Seaward coastal defence strategy

In line with the dynamic preservation philosophy, the Government and Parliament have chosen sand nourishment as the principal approach towards coastal protection. This does not mean that other forms of coastal protection are excluded. Some parts of the Dutch coast are facing extreme erosion as well as very poor safety margins. For these locations a reinforcement by a seaward structure can be more profitable or (in time) even necessary, for instance with respect to sea level rise.

This approach, which is known as the 'seaward coastal defence strategy' has been roughly investigated. According to this strategy, additional measures will be taken to influence the morphological system in such a way that the coastline will not erode any further, but will be kept in place or even move in a seaward direction. The effectiveness of this approach has to be compared with maintenance by beach nourishment, together with the effects it will have elsewhere on the morphological system, nature and other interests (Pluijm 1990).

Possibilities for seaward coastal defence in The Netherlands

Comparative study: working from 'coarse' to 'fine'

The differences between the several morphological systems along the Dutch coast make it impossible to adopt only one seaward defence option. In order to gain more insight into the possibilities for a more differentiated approach, different plans have been elaborated for the most vulnerable locations along the Dutch coast.

All plans have been evaluated by means of a comparative study. A stepwise approach is used in these studies and a refinement is achieved from 'coarse' (large-scale: entire region or province; different coastal defence alternatives) to 'fine' (small-scale: selected location; preferred seaward structure).

There are two main reasons why seaward defence plans should be realized within the framework of a comparative study (de Ruig & Roelse 1992):

- beach nourishment, as the general way to keep the coastline in its place, will be the reference for other coastal defence measures;
- basically, the effects of seaward structures on the morphological system, nature and other interests are unknown.

The aim of the comparative study is then to select locations where:

- in practice beach nourishment cannot stop the structural erosion, or:
- the costs of combatting erosion for a seaward approach are less than for beach nourishment, and if so:
- the possible construction of a seaward structure will not have any severe negative effects elsewhere.

Locations, coastal defence alternatives and criteria

The Dutch coast is composed of three major units (Fig. 1, see also van der Maarel 1979): (1) the 'Delta coast' in the southwest, consisting of (former) deltas and islands; (2) the 'Holland coast' between Hoek van Holland and Den Helder, a stretch of coast not interrupted by tidal inlets; (3); the 'Wadden coast' in the north, consisting of a series of coastal barrier islands and tidal inlets in-between.

Coastal sections bordered by tidal inlets are vulnerable for erosion. Although the shoals in the ebb deltas protect the coast against severe wave attacks, shifting tidal channels cause much erosion. Along these channels very steep shore-faces and narrow beaches occur, where only little space is available for sand nourishment. More frequent nourishments with larger volumes could become an expensive solution here.

Alternatives for sand nourishment have been studied for eight locations (Fig. 1): Zeeuws-Vlaanderen, the southwest and northwest coast of Walcheren and Schouwen (Delta coast), Scheveningen (Holland coast) and the Wadden islands Texel, Vlieland and Ameland.

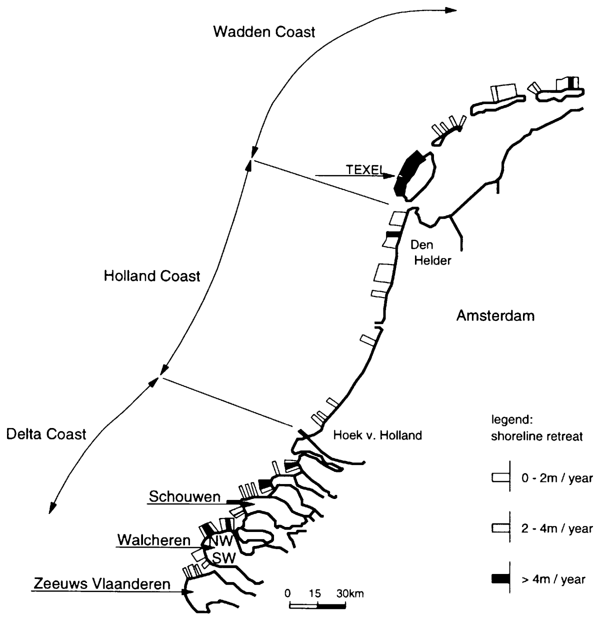

Fig. 1. Erosion pattern along the Dutch coast (Louisse & Kuik 1990).

Both 'hard' and ' soft' coastal protection measures have been investigated. The selected alternatives range from large dams – both perpendicular and parallel to the coastline– (enlarged) groynes and breakwaters to sand dams, perched beaches and relocation of tidal channels.

Coastal erosion is the result of forcing by waves and tide, and the resistance of the coast to these forces. Some of the selected measures, for instance breakwaters, will act like a screen which reduces the incoming wave height. Sand will be deposited. In the problem area these structures give good results. Usually, this induces a shortage of sand somewhere else, which will diminish the overall gain. Other measures will increase the resistance temporarily (beach nourishment) or permanently (shore-face protection). A perched beach combines both principles (de Ruig & Roelse 1992).

Different coastal defence alternatives will have different effects. The impact of these effects will vary with the selected locations. So, for each coastal section measures were evaluated as to different criteria, as for instance:

- effectiveness;
- effects on other functions and values in the coastal zone;
- cost (initial and maintenance); nullification of capital;
- flexibility and stability;
- consequences for coastal management;
- risk.

In the first step of a comparative study each judgement is based on a rough estimation of the consequences of a given alternative, in terms of the criteria concerned.

For each coastal section this multi criteria analysis selects the most promising measures which in some cases might be more effective than beach nourishment.

The most promising alternatives for seaward coastal defence

The comparative studies have been executed within an integral framework; a common strategy and time scheme, however, was missing. In all cases sand nourishment, as the main coastal defence measure in the present policy, was used as a reference. It was assumed, that for every location nourishment could indeed counteract the erosion.

The following preferred alternatives were chosen (Fig. 2):

Zeeuws-Vlaanderen: Perched beach concept (de Ruig & Roelse 1992);
SW-Walcheren: Perched beach concept (Maranus et al. 1993);
W-Walcheren: Sand dam/stockpile (Kevelam & Besselink 1992);
Schouwen: Channel shifting (Kevelam & Besselink 1992);
Scheveningen: Large dam perpendicular to the coastline;
Texel: Large dam(s) perpendicular to the coastline, or: Groyne system (Rakhorst & Pwa 1993);
Vlieland: Small dam and groin perpendicular to the coastline (Steijaert 1994);
Ameland: Perched beach/shoreface protection (Prakken 1993).

All options include integration with sand nourishment. The results of the comparative studies will be discussed in the following paragraphs. The solutions for Zeeuws-Vlaanderen and Texel will be considered in more detail.

Zeeuws-Vlaanderen

For Zeeuws-Vlaanderen, the first step in the comparative approach was to select a perched beach concept for further study. In general, a perched beach construction consists of a dam parallel to the coast (breakwater) with sand nourishment at its landward side. Sometimes the nourished beach has been closed off at its extremities by groynes or large dams. The dam and the nourished beach gradually absorb the wave energy, giving the beach a more stable equilibrium profile, resulting in less erosion. The coastal defence system is strengthened

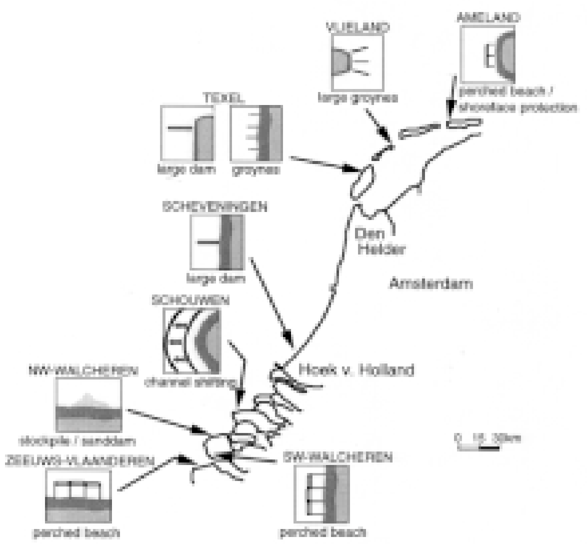

Fig. 2. Preferred coastal defence structures as used in the comparative studies.

and the beach is widened, which gives opportunities for recreation.

Different perched beach alternatives have been considered. As discussed above, each alternative has been evaluated as to several criteria. In fact, these criteria are about the same, but the evaluation is done more detailed. Important aspects are the effectiveness of the structure and the future erosion rate.

Evaluation of the different aspects as mentioned above resulted in a preferred perched beach concept as shown in Fig. 3. In fact, the strong points of a perched beach, sand nourishment and shoreface protection are combined here.

The comparative study reveals that the structure will act as an effective coastal defence structure. Shore-face and beach protection can be achieved for a reasonable price and without harming the charm of the natural sandy coast. Attention should be focused on the development of scour holes at the landward side of the dam. Sand nourishment, although in much reduced quantities, will remain necessary until about the year 2030.

The total costs appear to be the most important distinctive element in the evaluation. Estimations of these costs (including direct investments and (capitalized) costs for repeated beach nourishment for a period of 30 - 40 yr) indicate that a perched beach is roughly as expensive as repeated beach nourishments alone.

The result of a comparison of the costs of beach and shoreface nourishment depends on the future erosion, the costs of sand mining and the effectiveness of both alternatives. The uncertainty of these elements plays a major role which is illustrated in Fig. 4. The following example is indicated: Assuming a neutral-pessimistic shoreline retreat scenario, a m^3-price of 10NLG (ca. 6 USD) and an effectiveness of beach nourishment of 80% (80% reduced erosion rate), a perched beach has to be at least 50% effective to be cheaper than beach nourishment only. In case the coastline development is favourable (optimistic scenario) the perched beach application would only be effective if m^3-prices rise exorbitantly.

The construction method and the location of the proposed perched beach considerably reduce the risks of loss of functions and valuable interests within adjacent coastal sections. In general, the appearance of a 'hard' structure within a sandy coast will result in a negative score from a recreational point of view because it can give rise to dangerous bathing conditions. The wider beach gets a positive score.

The ecological effects are small. In general, the application of stonelike materials strengthens the biodiversity. Organisms attach to the stones and others will find shelter. The total biomass on hard structures can exceed that of sandy substrates by about 10 to 100 times. On the other hand, the existence of a(nother) stony breakwater within a sandy coast is not in line with preservation of the charm and quality of natural coasts.

The seaward extension of the perched beach is limited: the main existing current and sediment patterns will almost remain the same. Neighbouring coastal sections (a dyke section and a 'slufter') will hardly be affected. Nevertheless, if the construction produces unacceptable effects, a minor and easy operation can remove the breakwater, after which the material can be added to the shoreface protection (de Ruig & Roelse 1992). The construction of a perched beach is still in discussion.

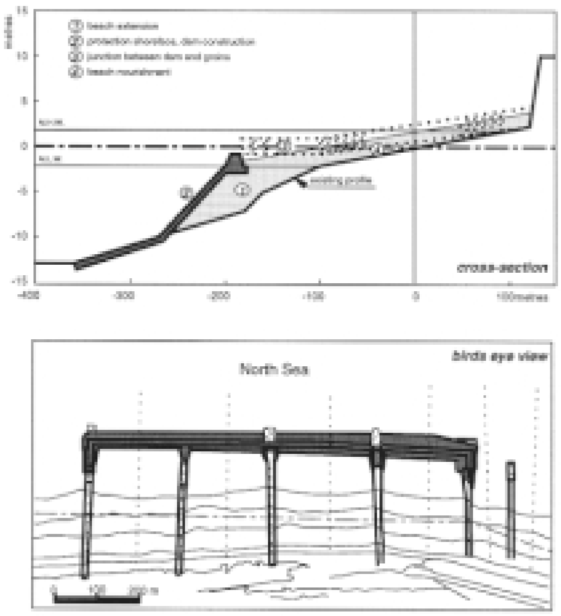

Fig. 3. Zeeuws-Vlaanderen: Preferred perched beach concept (de Ruig & Roelse 1992).

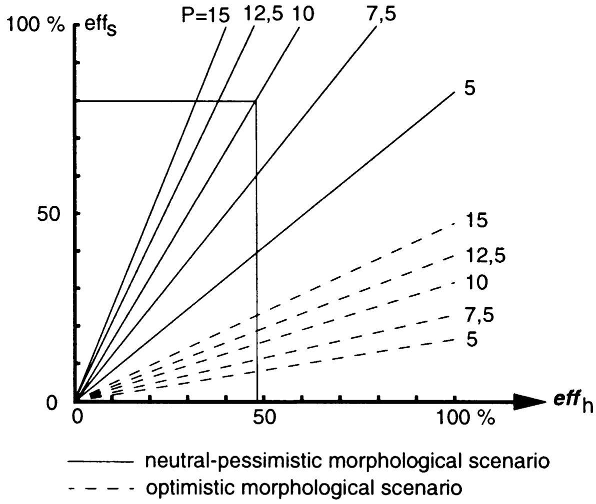

Fig. 4. Effectiveness of beach nourishment (eff_s) and perched beach (eff_h) related to m^3 sand price (P) (de Ruig & Roelse 1992).

Southwest-Walcheren

As in the Zeeuws-Vlaanderen case, the first step in the comparative approach for Southwest-Walcheren was to select a perched beach concept for further study. This research resulted in similar conclusions (Maranus et al. 1993):

- The construction will stop the shoreface erosion;
- The proposed limited dam height [top level MSL – 3 m (Anon. 1992)] will hardly have any effect on recreational activities, but at the same time it will not diminish the beach and dune erosion either;
- Neighbouring coastal sections will hardly be affected;
  - experiences from 1984 onwards show that sand nourishment is able to combat long-term erosion successfully, even when the shoreface is very steep (up to 1:3);
- In general, the perched beach will be more expensive than nourishment.

Northwest-Walcheren and Schouwen

Both solutions for NW-Walcheren and Schouwen (Fig. 2) show that optimal seaward defence structures will not always be hard constructions.

At first sight, the more gently sloping coast of NW-Walcheren seems a good location for a sand dam or stockpile nourishment. When a strategic location is selected, the sand mass shifts the erosive tidal current in seaward direction and can act as a continuous 'sand pump', redistributing the sand along the coastline through coastal processes. This will compensate the erosion downstream.

However, Kevelam & Besselink (1992) found that the orientation of the NW coast of Walcheren (with regard to the dominant long-shore sand transport path) prevents a rapid spread of sand to the eroding sections. Depending on the shape of the sand mass, even partly blocking of the long-shore transport will cause lee side erosion. Additional nourishment remains necessary, especially during the first 10 yr. Total capitalized costs will be more than 50% higher than 'normal' repeated nourishments.

Ca. 75-90% of the present coastal erosion at Schouwen is caused by landward movement of a tidal channel. An obvious alternative for nourishments seems to be a shifting of the channel in seaward direction (Figs. 2 and 5). A parallel working method can be achieved: hopper dredgers ' dig' a new channel and dump the sand in the old one. A channel shifting of ca. 500m will ensure a considerable reduction of coastal erosion for a period of ca. 30 yr. Depending on different aspects, this alternative can be as economical as repeated nourishments (Kevelam & Besselink 1992).

For Schouwen, the channel shifting option requires an artificial sand displacement of about 14-20 million m^3 within the ebb tidal delta of the Eastern Scheldt River, an area with a high ecological value. Especially the shoals and shallow waters are important habitats for seals, fish (nursery grounds), stilt-birds/waders and wintering scoters. In any case, the channel shifting will cause disturbance during the working period and the (temporary?) destruction of some shoals. On the other hand, choosing for repeated nourishments will bring about (smaller) disturbances every five years.

Scheveningen

Scheveningen is the most popular holiday resort along the Dutch coast. Several beach nourishments have been carried out here, the first one in 1969. The existence of harbour moles, groins and a beach wall results in a complex morphological situation in which the effectiveness of the nourishments largely depends on the frequency of storm surges. The preferred seaward solution, a large dam perpendicular to the coast, is still under study. In general, this alternative seems to be more expensive than nourishment.

Texel

The Northern part of the island of Texel is situated along a tidal inlet of the Wadden Sea. Each year almost 500000 m^3 of sand (ca. 75m^3 per m coastline) is eroded and rapidly carried away via tidal channels into the Wadden Sea. This is a net amount. Because of the complex morphological system, the overall sand fluxes might be much higher.

A major effort is made to understand this system. Several mathematical models have been used to describe the motions of waves, tides and corresponding erosion/accretion patterns. A conclusive description of the transport paths, however, has not yet been achieved. The quintessence is the existence of a sand supply, resulting from wave induced onshore transport along the edge of the ebb tidal delta (Fig. 6). Both solutions, with, or without this sand source, have been used in the comparative study (Rakhorst & Pwa 1993).

The above mentioned models are applied to study the effects of different coastal defence alternatives. The most important effects for three defence measures are

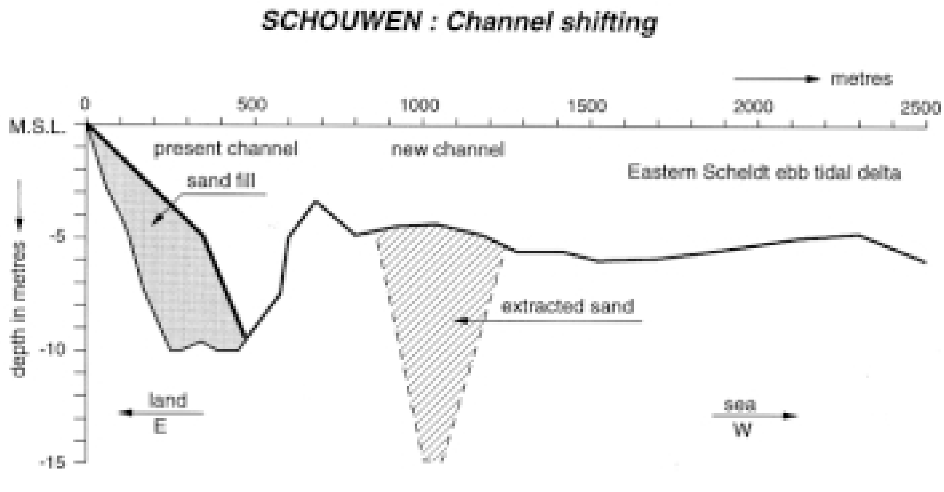

Fig. 5. Channel shifting: Simplified cross-section of the new (artificial) and present (natural) tidal channel at Schouwen (after Kevelam & Besselink 1992).

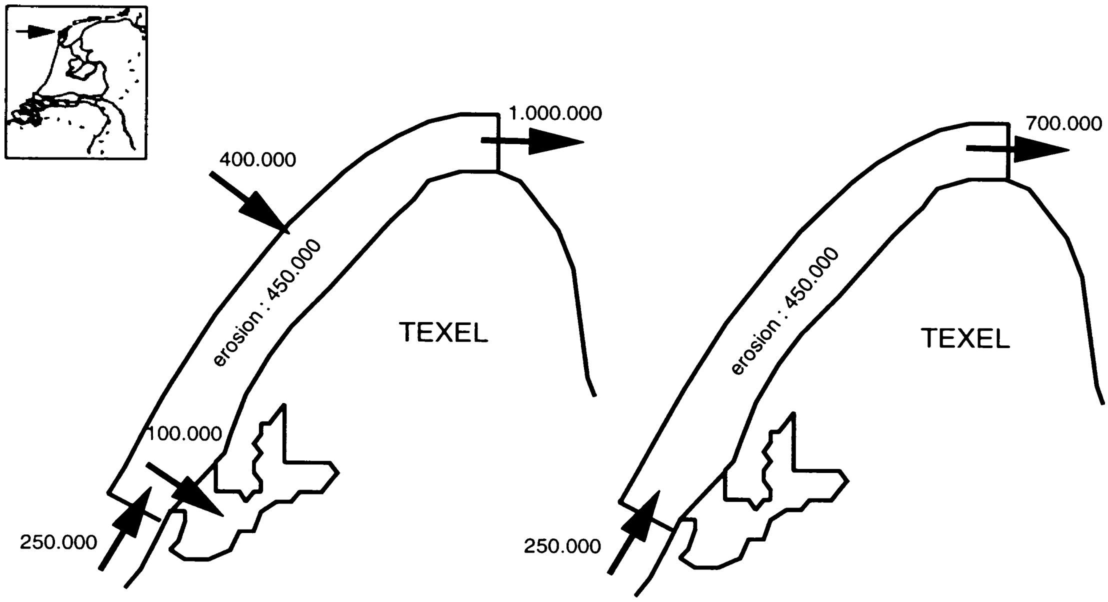

Fig. 6. The morphological system of the northern part of Texel Island with (left) or without (right) existence of a sand source along the ebb tidal delta (calculated with mathematical models in m^3 / year) after Rakhorst & Pwa (1993).

summarized in Table 1.

In spite of intensive model computations, the effects on neighbouring coastal areas and the ebb tidal delta (Vlieland!) remain uncertain. The flexibility of sand nourishments seems to be an advantage; just nourish sand on the coast in quantities where and when it is needed. On the other hand, a hard structure offers enduring protection against erosion in the problem area, with only minor future costs for additional nourishments and maintenance. Estimates of the total costs show that the large dams alternative is probably cheaper than repeated nourishments (Rakhorst & Pwa 1993).

Table 1. Effects of the three most promising coastal defence measures for the island of Texel (after Rakhorst & Pwa 1993; van Haren et al. 1993). + = a positive, – = a negative and o = a neutral effect.

Aspect	Coastal defence alternative Sand nourishment	Large *	Groynes **
Enduring protection against coastal erosion	o	+	+
Certainty about effectiveness	o	o	–
Absence of lee side erosion effects	o	o/–	–
Absence of influence on morphological system of ebb tidal delta	o	–	o/–
Effects on ecosystem	o	–	o/+
Total costs (million NLG)	100 - 125	65 - 75	95 - 110

* Two dams of 1000 (S) and 700 (N) m perpendicular to the coast with a distance of 1000 m in between

** Four groynes with a length of 200 (S) to 550 (N) m and a spacing of about 1000 m

*** Planning period is 50 yr; rate of discount 5%; 1 NLG = ca. 0.5 USD; costs for the hard structures include supplementary sand nourishments to combat lee erosion.

The evaluation of effects on other functions focuses on environmental aspects. Van Haren et al. (1993) distinguish several effects; the influence on the groundwater level in the ecologically valuable dune area is the most dominant. This level will rise when the coastline shifts in seaward direction due to sand accretion behind the large dams or (to a lesser extent) groynes. The overall effect is the integration of negative (e.g. decline of characteristic wet dune valley vegetation) and positive (e.g. increase of gradients in drier dune areas) consequences. Van Haren et al. (1993) score this effect for the groynes slightly positive and for the large dams negative (Table 1). Referring to the discussions on dunes drying out and the high ecological value of dune lakes, especially this last result is questionable.

A phased execution of each of the structures gives the opportunity to evaluate effects and to diminish the financial risk.

Finally, it was decided to construct a 550 meter long dam perpendicular to the coast, combined with a large beach nourishment. The work was finished in the second half of 1995. The first results show that the dam offers protection against erosion without severe effects elsewhere.

Vlieland and Ameland

The eastern tip of the island of Vlieland and the western part of Ameland are facing severe erosion. On both islands small seaward coastal defence structures have been made; on Vlieland: a small dam and groin perpendicular to the coastline (1995); on Ameland: a perched beach with a shoreface protection (1994). Both solutions seem to have positive effects on coastline maintanance.

Conclusions

The success of seaward coastal defence structures largely depends on the local conditions (e.g. morphology, erosion rate, involved interests) in combination with the type of defence alternative. However, some general conclusions can be drawn:

1. A certain amount of investment is necessary to realize seaward coastal defence constructions. An alternative for sand nourishment can only be effective if the coastline can be maintained after construction with a minimum of means and efforts. In most cases, however, repeated nourishment is at least as economical as seaward structures with the exception of the northern part of Texel. Here, the erosion is severe to such an extent that a 'hard' solution is more profitable.

2. A seaward coastal structure might have some unexpected effects on the natural system and other functions. Apart from thorough preliminary examination, flexibility within the construction (easy removal, adjustment or phased construction) is an advantage. Again, nourishment is an important competitor: it can be utilised virtually everywhere, is easy to adapt with regard to sand volumes applied and it allows spreading of costs of coastal protection. It is a paradox, but on larger temporal and spatial scales successive nourishment of sand is the only structural solution to fill up the sand deficiency in the coastal zone (de Ruig 1995).

3. An effective seaward (hard) structure gives the certainty that for the problem area in question long-term erosion is stopped. Regular maintenance of the coastline and big expenses in the future are not necessary. On the other hand, the natural processes along the coast are usually disturbed, which will induce a shortage of sand in neighbouring coastal sectors, which in turn will diminish the overall gain ('problem shifting').

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