CHAPTER 198

A feasibility study of a perched beach concept in the Netherlands

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Abstract.

The present Dutch coastal defence policy is aimed at a full compensation of shoreline retreat, mostly by means of beach nourishment. For some parts of the coast with a small dune ridge attacked by severe erosion, a so-called 'seaward coastal defence strategy' might be more profitable. According to this stra-tegy, measures will be taken to influence the morphological system in such a way that erosion is prevented, which will result in a stable or even progressive coastline.

An analytical policy design was chosen at the onset of the study. A number of seaward coastal defence measures will be tested following a series of selected criteria, such as effects on morphological, financial and construction aspects as well as effects on recreation and ecology. The study works from 'coarse' (entire province of Zeeland, SW-Netherlands; different coastal defence alternatives) to 'fine' (selected location; preferred coastal defence alternative). This has resulted in conclusions and recommendations with regard to the feasibility of a pilot project with a perched beach in the 'Cadzand' area.

1. Introduction.

1.1 A new coastal defence policy for the Netherlands

Major parts of the Netherlands are situated below sea level and would be flooded if there was no protection by a coastal defence

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system. This system consists of dunes and dikes to protect the polders and dams to close off large (former) tidal inlets.
The dunes represent about 75% of this line of defence, varying in width from one hundred metres to several kilometres. They give the Netherlands its characteristic landscape and harbour unique natural values for the Northwest of Europe. They also represent an economic value: drinking water supply, recreation, industry and residential.

At present the Dutch coast is 'Delta safe'. It can withstand extreme storms and the associated water levels and waves with a frequency of 1/2000 to 1/10000 per year. This level of safety must be maintained. Constant effort is demanded, as ongoing coastal erosion causes almost half of the coastline to recede, slowly but relentlessly.
Past coastal defence was based on a problem solving policy. For large parts of the coastline, recession was tolerated: dunes underwent 'controlled retreat'. Interests and natural values in the dune area were affected to an increasing extent. Furthermore, sea dikes and other hard barriers came to protrude like bulwarks into the sea.

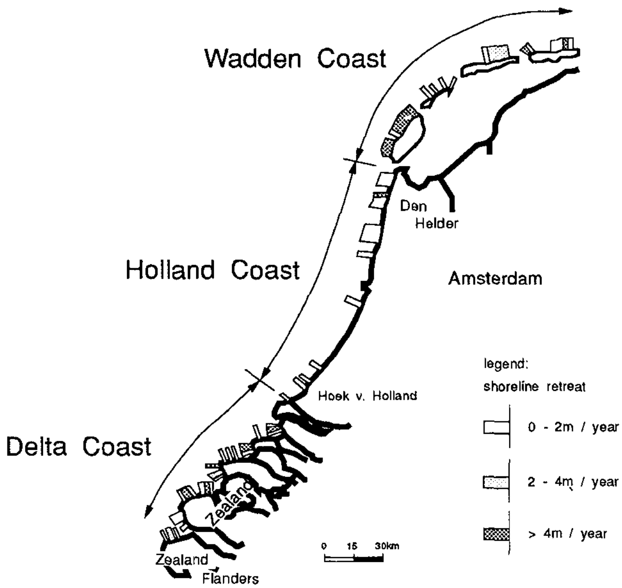

Figure 1. Pattern of erosion along the Dutch coast (Louisse & Kuik, 1990).

Coastal erosion is evident along the entire coastline: more than 50% of the dune coast suffers erosion (figure 1). A more rapid sea level rise will be felt everywhere, resulting in erosion along 80% of the sandy coastline. Not one function of the coast will be left untouched. This problem requires a reconsideration of the coastal policy. The options vary from no protection to full protection of all interests and values:

- Retreat: Coastal erosion is accepted unless polder safety is threatened;
- Selective Preservation: Special values and interests in the dune area are protected;
- Preservation: Coastal erosion is counteracted at all locations;
- Expansion Seaward: Preservation, but at some markedly eroding coastal sections with a relatively weak sea defence the coast will be reinforced by a seaward construction and natural sand sedimentation will be encouraged.

In 1990 the Dutch government made a choice for the 'preservation' alternative, which implies that the coastline will, at the least, be preserved at its 1990 position: all structural erosion will be counteracted (Ministry of Transport, Public Works and Water Management, 1990; Louisse & Kuik, 1990).

1.2 Dynamic preservation

By nature, the coastline of a dune coast is not fixed at one single position. Choosing for 'preservation', some allowance should be made for movements of the coastline. At some locations more aeolian dynamics (sand drifts, blow-outs, mobile dunes) will be permitted and so-called 'slufters' (wet dune valleys influenced by the tides) can be formed.
By lending the 'preservation' alternative a certain degree of dynamics, the charm and quality of the natural coasts will be safeguarded: 'preservation' changes into 'dynamic preservation'. The choice for sand nourishments, a 'soft' coastal defence method, as the major means to defend the coast is in line with this philosophy.

1.3 Seaward coastal defence strategy

Some parts of the Dutch coast are facing extreme erosion as well as very poor safety reserves. For these locations the application of the 'expansion seaward' alternative can be more profitable or (in time) even necessary, for instance with respect to sea level rise.
This approach is roughly investigated as the 'seaward coastal defence strategy'. 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 longer, but be kept in

place or even grow in a seaward direction. The effectiveness of this approach has to be compared with maintenance by beach nourishment, as well as the effects it will have elsewhere on the morpholgical system, nature and other interests (Pluijm, 1990).

1.4 Feasibility study: working from 'coarse' to 'fine'

The difference between the several morphological systems along the Dutch coast makes it impossible to suffice with one seaward solution. In order to gain more insight into these possibilities, plans have been worked out for the most vulnerable locations.

There are two main reasons to realize these plans within the framework of a feasibility study:

- the choice for beach nourishment as the general way to keep the coast-line in its place; along each kilometre of the coast this will be the reference for other coastal defence measures;
- in principle, the effects of seaward constructions on the morphological system, nature and other interests are unknown.

The aim of the feasibility study is to select locations in Zealand (province in the southwest of the Netherlands) where:

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

A stepwise working method is used in this feasibility study. That is, we work from 'coarse' (large scale: entire province of Zealand; different coastal defence alternatives) to 'fine' (small scale: selected location; preferred seaward construction). This intention is reflected in the headings of the following chapters.

2. Possibilities for seaward coastal defence in Zealand.

2.1 The Zealand coast: an introduction

The Dutch coast is composed of three major units. In the south the Delta coast, consisting of (former) deltas and islands; between Hoek van Holland and Den Helder a stretch of coast not interrupted by tidal inlets (the Holland coast); and in the north the Wadden coast, consisting of series of coastal barrier islands with tidal inlets in between (see figure 1).
The province of Zealand lies entirely within the Delta area. Its defence system is composed of dunes and dikes, which protect the

polders and dams which close off large estuaries and basins and which have been constructed during the last decades ('the Delta works'). The implementation of these works has induced major changes in hydraulic conditions and the geomorphology of the former ebb tidal deltas (Mulder et al., 1990). Although the shoals in the ebb deltas protect the coast against severe wave attack, the shifting of deep tidal channels causes much erosion. Along these channels very steep shorefaces and small beaches occur, with only little space available for nourishment. Most of the coastal sections with narrow dune ridges are protected with groynes to reduce the coastline withdrawal.
One of the estuaries in the Delta area, the Western Scheldt, is still open, being the shipping entrance to Antwerp. The estuary mouth is an active system of bars and gullies, with important impacts in the form of coastline undulations on the adjacent coastal stretches of Walcheren en Zealand Flanders (figure 2).

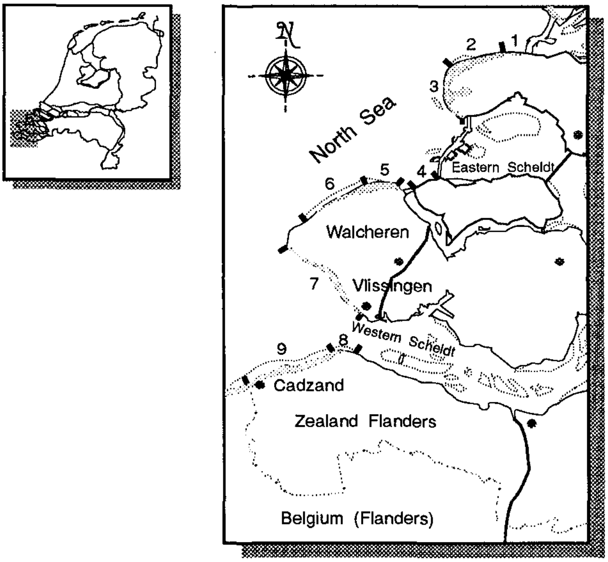

Figure 2. Division of the Zealand coast used in the feasibility study.

2.2 Method

Due to the differences in morphology of the coastal zone and shoreface, the Zealand coast has been divided into nine sections (figure 2). In this way, the necessity of a seaward defence could be determined for each section .

Ten coastal defence constructions where selected, including large dams perpendicular as well as parallel to the coastline, artifi-

cial channel shifting and perched beaches. Seven of these constructions are illustrated in figure 3.
Coastal erosion is the result of the boundary conditions of waves and tide and the resistance of the coast to these conditions. Some of the selected measures, for instance breakwaters, will act like a screen and diminish the incoming wave height. In the problem area these constructions give rise to good results. Usually, this induces a shortage of sand somewhere else, which will diminish the overall gain. Other measures will raise the resistance temporarily (beach nourishment) or permanently (shoreface protection). A perched beach shows both principles.

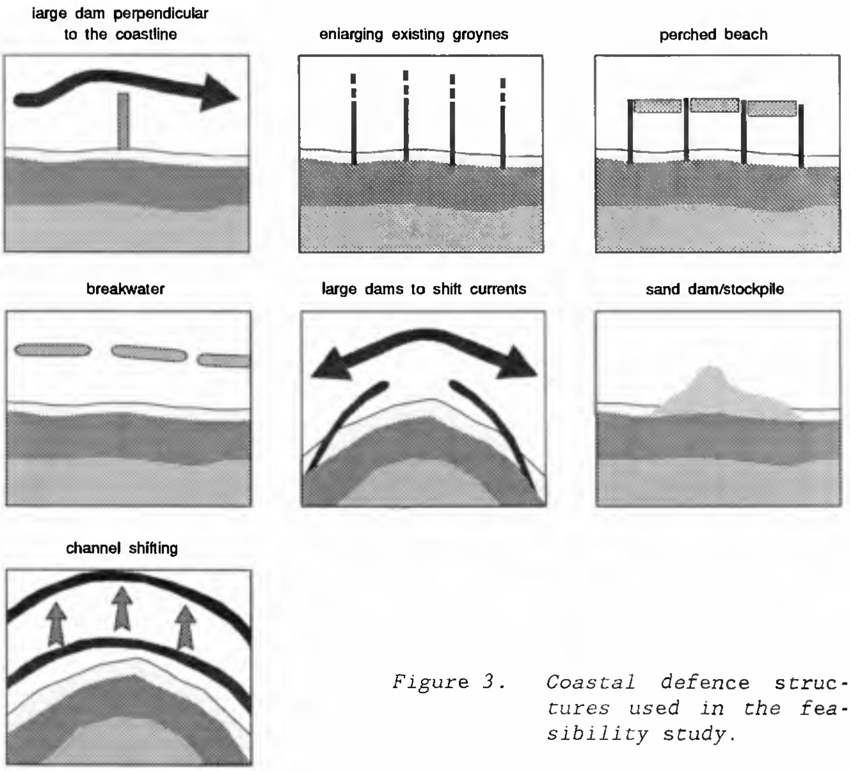

Figure 3. Coastal defence structures used in the feasibility study.

For each coastal section these measures where tested for different criteria and scored within a matrix (Maranus et al., 1990):
- effectiveness;
- effects on other functions and values in the coastal zone;
- costs (initial and maintenance); nullification of capital;
- flexibility and stability;
- consequences for coastal management;
- risk.

Each judgement was based on a rough estimation of the consequences a measure should have for a concerned criterion. For the purpose of the first step in a feasibility study, this seems sufficient.

2.3 Results

The method used selects the most promising measures for each coastal section. The necessity to intervene, however, varies and depends on the erosion rate. Both elements combined resulted in three coastal defence measures which could be more effective than beach nourishment. Among them, a perched beach concept for the coasts of SW-Walcheren and Zealand Flanders was considered for further study.

3. A perched beach: theory, effects and experiences.

In general, a perched beach construction consists of a coast parallel dam (breakwater) with a sand nourishment at the landward side of it. Sometimes the nourished beach has been closed off at its extremities by groyns or large dams. In Japan and the U.S.A. it is considered as a new phase in coastal defence systems. It is based on the concept that a 'plane', rather than a 'linear structure', is able to protect the shore effectively (figure 4; Arai & Tamura, 1987; Sawaragi, 1988). 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 and the beach is widened, which gives opportunities for recreation.

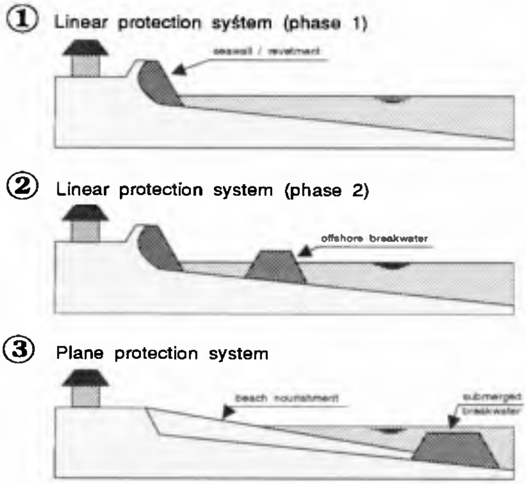

Figure 4. Evolving coastal defence: from 'linear protection system' to 'plane protection system' (after Arai & Tamura, 1987).

During the last decades some experience has been acquired with perched beaches, especially in the United States and Japan. The construction was applied with varying success. Besides the metioned benefits, some disadvantages became clear:

- development of scour holes on either side of the dam (Sawaragi et al., 1988; Delft Hydraulics, 1990; Franco, 1990);
- blocking of natural beach nourishment during fair weather periods (Douglass & Weggel, 1987);
- possible danger for swimmers and small boats;
- high investments (with respect to beach nourishemnt).

4. Seaward coastal defence in Zealand Flanders.

4.1 Defence alternatives

The coast of Zealand Flanders is bordered by the main tidal channel of the Western Scheldt estuary, the Wielingen (figure 5). During the last centuries, widening and southward displacement of the channel induced a great loss of land.
Today, the 15 km long coastline and adjacent dikes and small dune ridges are defended by 85 groyns, each with a length of about 200 to 300 m. and a spacing of 100 to 300 m.
The shoals in the ebb delta protect the coast against severe wave attack; the maximum yearly significant wave height is about 3 m. The mean tidal difference reaches 3.7 m. Close to the shore, the maximum flood and ebb current amounts to 1.0 - 1.2 m/s.

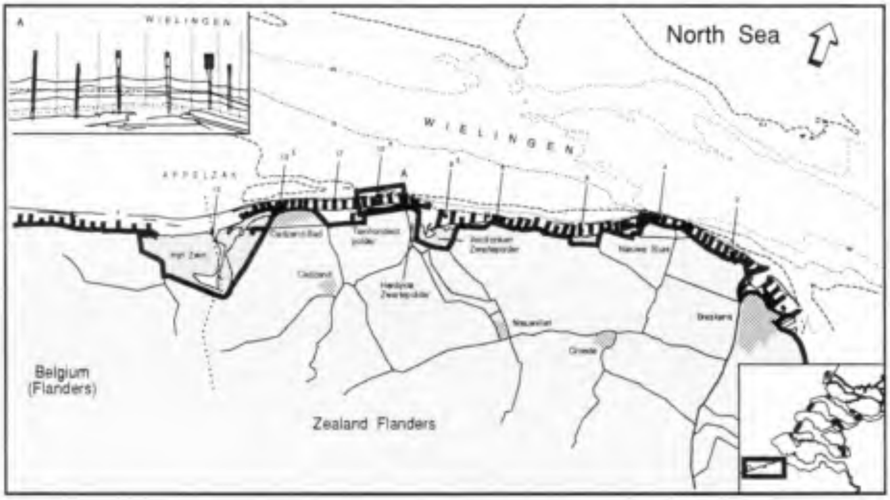

Figure 5. Zealand Flanders.

The presence of the Wielingen dominates the coastal evolution. Up till now it caused a continuous regression of the coastline, in spite of the intense coastal defence. Superimposed, we find a second order long-term fluctuation caused by so-called 'sand waves' (Verhagen, 1989;), resulting in a pattern of periods with sedimentation and erosion (figure 6).
Nowadays, the most vulnerable section of the coast lies in the neighbourhood of the Tienhonderd Polder (figure 5). The small beach is bounded by a steep shoreface and is influenced by continous erosion since 1960. The narrow dune ridge shows poor safety reserves. Further study on seaward coastal defence structures is focused on this part of Zealand Flanders.

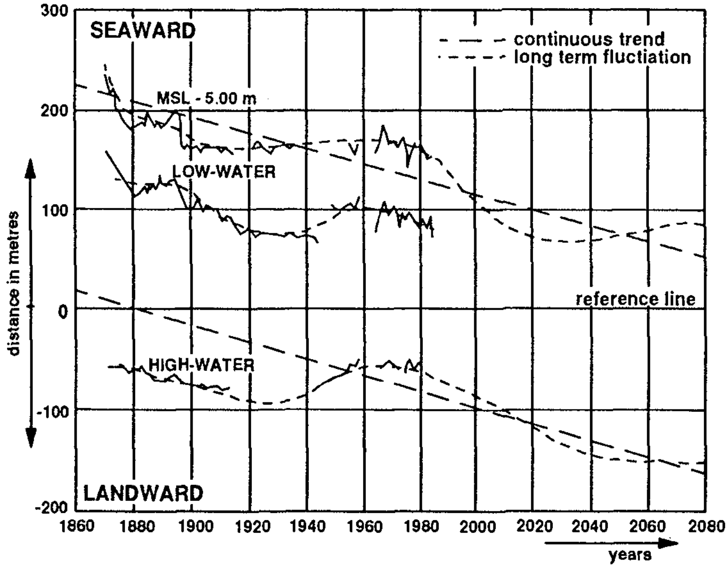

Figure 6. Tienhonderd polder, Zealand Flanders: Patterns of sedimentation and erosion.

For Zealand Flanders, the first step in the feasibility approach selected a perched beach concept for further study (2.1). This concept is at the centre of the next step of this strategy. Two perched beach variants are considered. Beach nourishment, as the main coastal defence measure in the present policy, is the reference. For the present, it is assumed that nourishment can indeed counteract the erosion. Other well tried or far reaching possibilities have also been taken into account, which results in the following list of measures (figure 7):

- perched beach (small);
- perched beach (medium);
- large coast parallel dam/breakwater;
- large dam perpendicular to the coast;

- shoreface protection;
- beach nourishment.

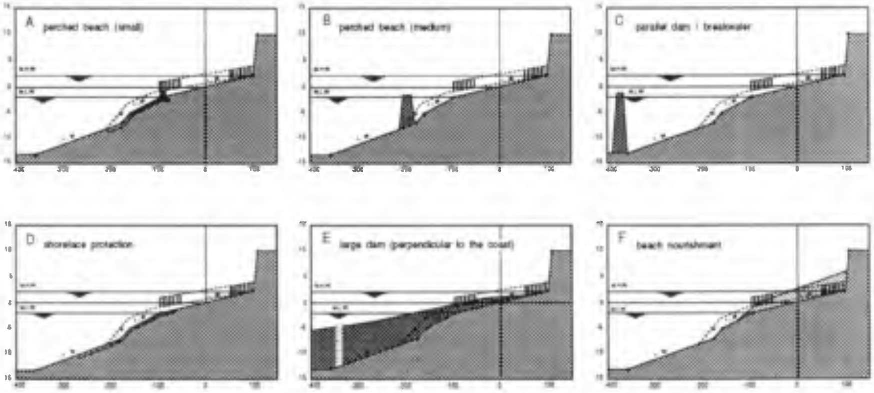

Figure 7. Tienhonderd polder, Zealand Flanders: Possible coastal defence measures.

4.2 Criteria

As in chapter 2.1, each measure has been tested for several criteria. In fact they are about the same, but testing is done with more detail. Important conditions were the effectiveness of the construction and the future erosion rate. The effectiveness was defined as the percentage of the overall erosion stopped by the construction in question. Every measure except the large dam perpendicular to the coast needs additional sand nourishments to fully counteract the structural erosion.
Indirectly, the initiation of scour holes and lee side erosion also determines the effectiveness to a high degree. Far reaching constructions such as large dams score negatively from this point of view.

The maintenance costs are directly deduced from the future erosion rate. In fact, this rate is unknown. The prediction, consisting of several variants, was based on extrapolation of the first order coastline regression and the superimposed sand waves. In general, it is expected that erosion will continue for another 30 to 40 years (figure 6). Rates of sea level rise higher than the present will lengthen this period.

The resulting costs, including additional nourishments based on the assumed future erosion rate, are brought together in table 1. It can be concluded that a large dam parallel to the coast and a medium sized perched beach cannot compete with the other coastal defence alternatives.

Table 1. Prediction of the total costs for each coastal defence alternative (Tienhonderd Polder, Zealand).

measure	costs (million dutch guilders)
beach nourishment	11 - 16
perched beach (small)	10 - 14
perched beach (medium)	16 - 19
large coast parallel dam / breakwater	48 - 58
shoreface protection	10 - 13
large dam perpendicular to the coast	14 - 15

Especially the greater constructions will influence the recreational and ecological values of the coastal area. Both threats and possibilities will develop. It is not always clear which will dominate.

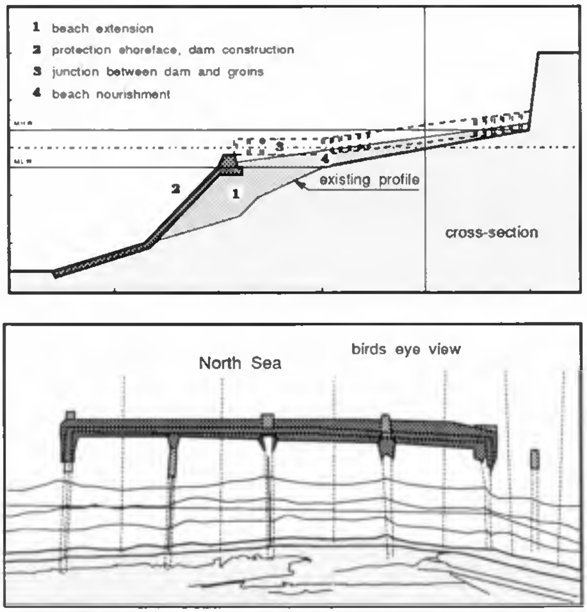

Figure 8. Tienhonderd polder, Zealand Flanders: Preferred perched beach concept.

4.3 Preferred coastal defence construction

Considerations of the different aspects as mentioned above culminated in a preferred perched beach concept as shown in figure 8. In fact, the strong points of a perched beach, sand nourishment and shoreface protection are combined. First, the beach is extended in a seaward direction by means of a nou-rishment and will approximate his (stable) equilibrium profile. Protection of the shoreface and the construction of a small breakwater connected with the already existing groynes will conserve this situation. Erosion of the shore-face will be prevented and the landward migration of the tidal channel blocked. Finally, a complementary beach nourishment will create a perched beach.
Most of this special perched beach construction is made out of sand. This yields profits from the point of view of costs and flexibility.

5. Perched beach concept for Zealand Flanders.

5.1 Location and dimensions

The presence of the Wielingen dominates the coastal evolution. Sand losses (about 20 m^3/m.jaar) from the coastal section of the Tienhonderd Polder are caused by seaward cross shore transport. Rip currents play an important role in this process. The sand drops into the tidal channel and is transported into the the Western Scheldt estuary.
It is expected that the perched beach construction will diminish the cross shore loss of sand and stop the landward migration of the Wielingen. The most suitable location for the breakwater and additional shoreface protection, therefore, seems to be the edge of the tidal channel. A more landward location of the breakwater will have less effect in reducing the erosion rate.

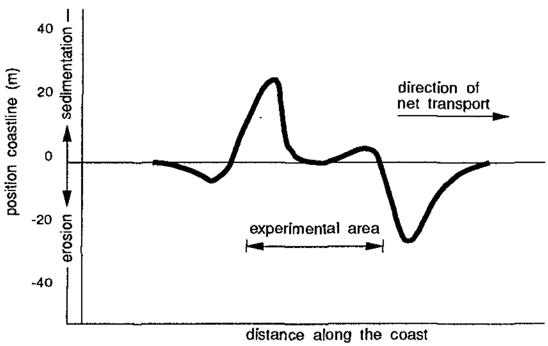

Figure 9. Effect of the perched beach construction (without additional sand nourishment) on the position of the coastline after 3 years (Delft Hydraulics, 1991).

Model computations reveal that the concept will act as an effective coastal defence measure. However, scour holes could develop at the landward side of the dam, which can reduce the effectiveness of the construction. Further study can quantify this problem. The feasibility study shows that after the construction of the perched beach sand nourishment, albeit much less in quantity, will remain necessary until about the year 2030.

The length of the coastal section with severe erosion determines the length of the construction, e.g. almost 900 metres.
As stated, the main purpose of the perched beach is to reduce the sand losses in cross shore direction. This does not mean that the long shore transport of sand remains untouched. Model computations show a distinct lee side erosion at the eastern end of the construction (figure 9; Delft Hydraulics, 1991). In practice the consequences are small. The coastline here consists of a small dike and is therefore rigid. Eastward, the dike is bordered by a nature re-serve (the 'slufter' (chapter 1.2) of the Verdronken Zwarte polder; figure 5) that is in danger of being buried by sand.

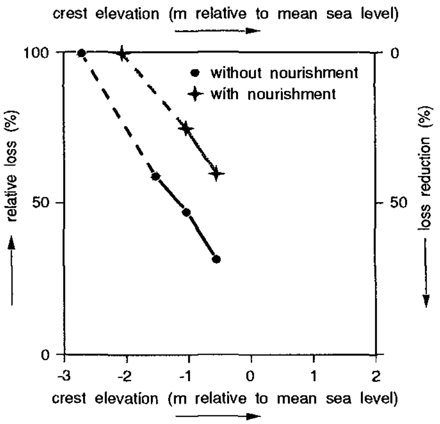

Figure 10. Relation between the crest elevation of the breakwater and the cross shore sand transport losses (Delft Hydraulics, 1991).

The level of the breakwater crest determines the loss of sand from the beach into the Wielingen tidal channel. In general, blocking this transport needs a crest height which is close to the seawater level (Lamberti et al., 1985). The tidal difference (3.7 m) complicates this thesis. Delft Hydraulics (1991) computed a 25% to 50% (with or without additional beach nourishment, respectively) reduced initial sand loss in case of a crest level of about 1 metre below MSL. The long term profits with a raised beach level are uncertain.

Roughly, each metre crest elevation means an extra 15% reduction (figure 10). However, the other side of the picture shows a more pronounced development of scour holes and higher costs and will score negatively from a recreational point of view. A breakwater crest level between 0.5 and I.0 metre below MSL seems to be a reasonable compromise and offers good opportunities for connection with the already existing groynes.

The width of the breakwater crest is of the utmost importance in reducing the risk of a landward scour holes. Several theories calculate the most effective width under different conditions (Sawaragi, 1988; Delft Hydraulics, 1989). Especially in consideration of costs and recreation, a decision in favour of a limited width seems to be reasonable. After that a wait-and-see policy can be followed.

5.2 Estimate of the cost

A comparison of different construction methods showed the cheapest way of execution:

1. extend the shoreface by means of sand fill;
2. defend the exposed new shoreface by a layer of stones;
3. construct the breakwater;
4. fill up the beach and
5. connect the old groynes with the breakwater.

In case of a construction length of about 900 metres, the costs of this operation are estimated at Hfl 7,700,000 (Dutch guilders (± US$ 4,500,000)). To find out if such an investment can be cost effective, the costs of construction, maintenance and additional sand nourishment are capitalized for a period of 40 years, the expected erosion period. These costs are compared with the capitalized costs of periodical beach nourishment. In fact, the effects on adjacent coastal sections must also be capitalized (policy of dynamic preservation: no structural coastline regression is allowed). However, long term effects are difficult to calculate and are therefore only qualitatively implicated in the comparison. Besides, the effects of lee side erosion within the dike section and neighbouring nature reserve will be small.

In the estimate of costs, the uncertainty of some elements play a major role:

future erosion rate:
Two realistic morphological scenarios are worked out:

S1 (neutral to pessimistic):	coastline withdrawal by continuous regression and long term fluctuations ('sand waves');
S2 (optimistic):	long term coastline fluctuations only.

effectiveness of the measure:
The effectiveness of a perched beach in Dutch conditions is part of the feasibility study. In the Netherlands some experience with beach nourishment exists for tide dominated coasts. Based on that experience, in the design practice an effectiveness of 50% to 80% is applied (Roelse, 1990).

cubic metre price of sand nourishment:
In the Delta area the sand can be borrowed relatively cheap from shoals near to the shore. Based on projects in the past years prices per m^3 were taken into account varying from Hfl 10 (± US$ 6) for 0.5 million m^3 to Hfl 14 (± US$ 8) for 0.02 million m^3.

The sensitivity of the cost comparison for those variables is illustrated in figure 11. The following example is indicated: Assuming the neutral-pessimistic scenario, a m^3 price of Hfl 10 and an effectiveness of beach nourishment of 80%, a perched beach has to be at least 50% effective (50% reduced erosion rate) to be cheaper than beach nourishment only. In case the coastline development is favourable (optimistic scenario) the perched beach application can only be effective if m^3-prices rise extremely.

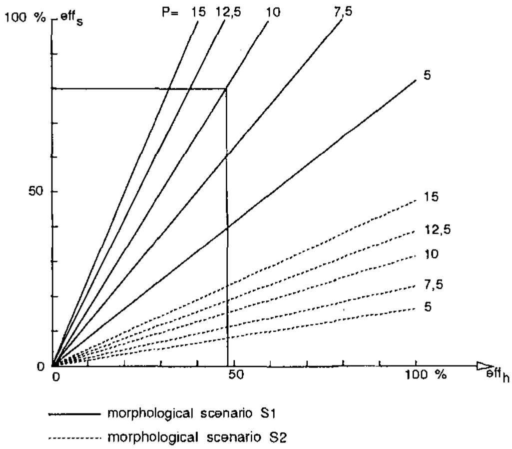

Figure 11. Effectiveness of beach nourishment (eff_s) and perched beach (eff_h) related to m^3 sand price (P).

5.3 Effects

The main effects on other interests focus on ecological aspects and recreation.

Recreation is of major importance to the region: Each year about 2 million overnight stays are registered.
The perched beach will initiate a wider beach, which is profita-

ble from a recreational point of view. However, the breakwater itself forms an obstacle for swimmers, surfers and small boats.
During some phases of the tidal cycle, dangerous bathing conditions can exist, due to undesirable currents and scour holes.
Avoiding any hindrance results in a far seaward (and hence capital) position of the breakwater.
If there is an overall negative effect on recreation, the project will fit in the provincial planning. In that case, the perched beach is expected to act as a buffer between the crowdy seaside resort of Cadzand in the southwest and the nature reserve in the northeast (see 5.1).

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

5.4 Surplus value and risks.

A decision in favour of a perched beach construction will initiate research results which, in principle, can be translated to other Dutch coasts bounded by tidal channels. Secondly, perched beach experiences are of great use in planning large seaward coastal constructions.

The seaward extension of the perched beach is limited: the main existing hydraulics and sediment transport paths will almost remain the same. Neighbouring coastal sections will hardly be affected.

The dike and the 'slufter' nature reserve downstream of the perched beach confine the risk for neighbouring coasts.
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.

6. Conclusions.

The feasibility study selects a perched beach construction as the most promising seaward coastal defence measure for the vulnerable section of the Tienhonderd Polder in Zealand, the Netherlands. The construction will act as an effective coastal defence structure. Shoreface and beach protection can be achieved for a reasonable price and without harming the charm of the natural sandy coast. Attention should be focussed 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 costs appear to be the most important element and determines the success of the preferred perched beach. The result of a price comparison with beach and shoreface nourishment depends on the future erosion, the costs of sand mining and the effectiveness of both alternatives. Calculations of the total costs (including direct investments and repeated (capitalized) costs for beach nourishments for a period of 30 to 40 years) indicate that a perched beach is roughly as expensive as repeated beach nourishments alone.

The construction method and the location of the proposed perched beach considerably confine 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 score negatively from a recreational point of view because it can give rise to dangerous bathing conditions. On the other hand, the beach is widened and the use of stones will encourage the settlement of several aquatic species.

A final decision on the perched beach alternative is not expected before the summer of 1993. A 'yes' will make a more detailed research (especially of crest width and elevation) necessary.

7. Acknowledgements.

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