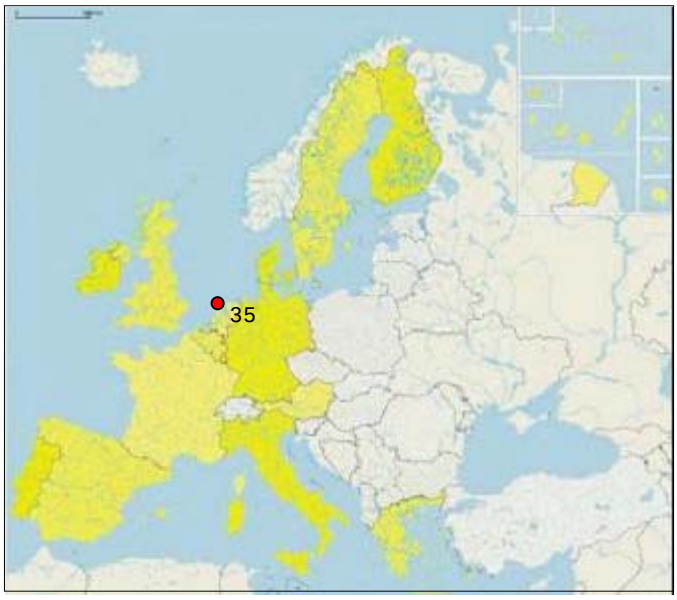
WADDEN SEA ISLANDS
(THE NETHERLANDS)



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1. GENERAL DESCRIPTION OF THE AREA

The Wadden Sea is the sea between the Wadden islands north of the Netherlands and the Dutch main land. The area of interest in this case is the Dutch part of the Wadden Sea area, especially the islands 1.Rottumeroog en Rottumerplaat, 2.Schiermonnikoog, 3.Ameland, 4.Terschelling, 5.Vlieland and 6.Texel.

1.1 Physical process level

1.1.1 Classification

General: barrier island coast
CORINE: beaches
Coastal Guide: coastal plain

The Wadden Islands are a chain of barrier islands in front of the Dutch coast. The sea between the barrier islands and the main land is called the Wadden Sea. The islands are made of sand beaches with sand dunes at the North Sea side and protected for flooding by dikes at the Wadden Sea side. Total length of the coastline of the Wadden islands is 94 km.

1.1.2 Geology

Barriers have evolved during the Holocene. Subsurface deposits typically consist of unconsolidated sand, clay and peat. Subsurface sediments in the Wadden Sea range from fine sand to mud. Erosion resistent layers are restricted to local outcrops of tillites.

Sediment characteristics of the beaches are fine sand, typically about D_{50}=180μm.(Biegel and Spanhoff, 1996)

1.1.3 Morphology of the coast

The inhabited parts of the islands are protected by dikes. The uninhabited parts of the islands are not artificially protected and therefore subject to natural processes.

In the Wadden Sea the spring tidal range is about 2 m and this keeps a complex system of tidal channel and flats intact, see Figure 1. Along the main land in some areas salt marshes are present.

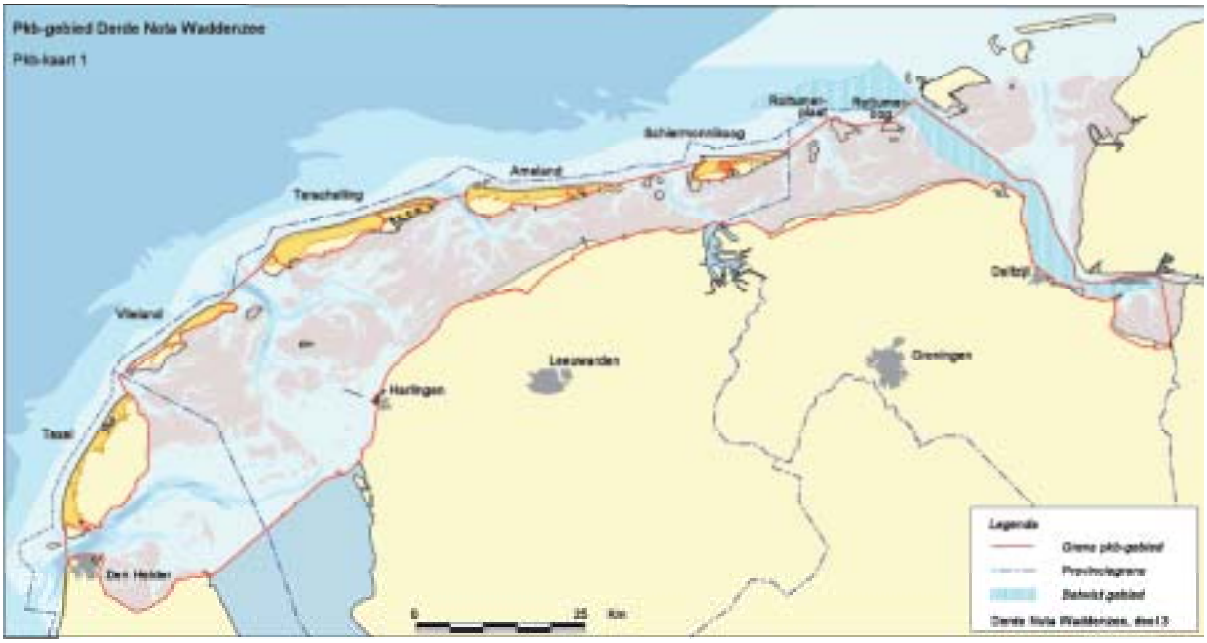

Fig. 1: Map of the Wadden Sea and islands (VROM, 2001).

1.1.4 Physical processes

Along the North Sea side of the islands the near shore currents are influenced by tide and waves, see Figure 2.

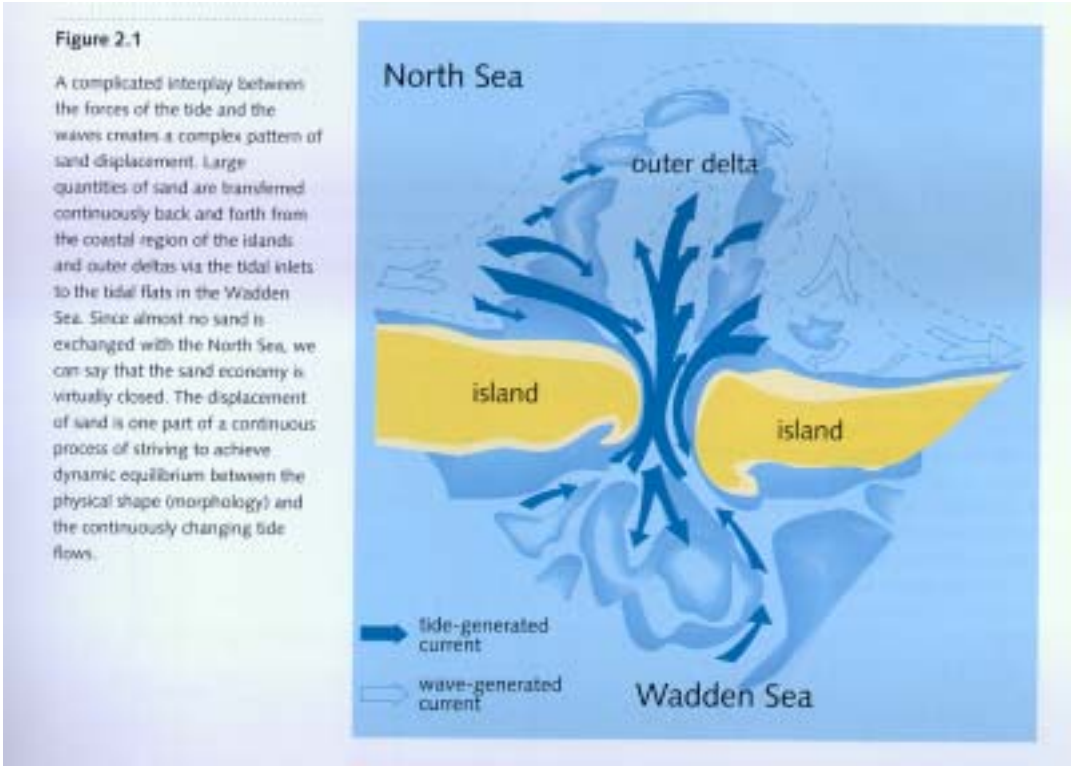

Fig. 2: System explanation (Louters and Gerritsen, 1994).

Longshore transport is dominant along the island and is mainly wave induced. Cross-shore transport is dominant through tidal inlets and is tide induced. Aeolian transport is of the same order of magnitude as longshore transport.

The sediment moves through the tidal inlets into the Wadden system. For the long term development of the Wadden Sea it is of utmost importance to know how big a portion of the inflow of sediment is retained in the Wadden Sea. These net quantities are relatively small compared to the total quantities transported.

1.1.5 Erosion

The shores of the islands show erosion and accretion in different places. Also, there are a lot of different trends in time in erosion and sedimentation. Changing erosion and sedimentation of the island Ameland is illustrated in Figure 3.

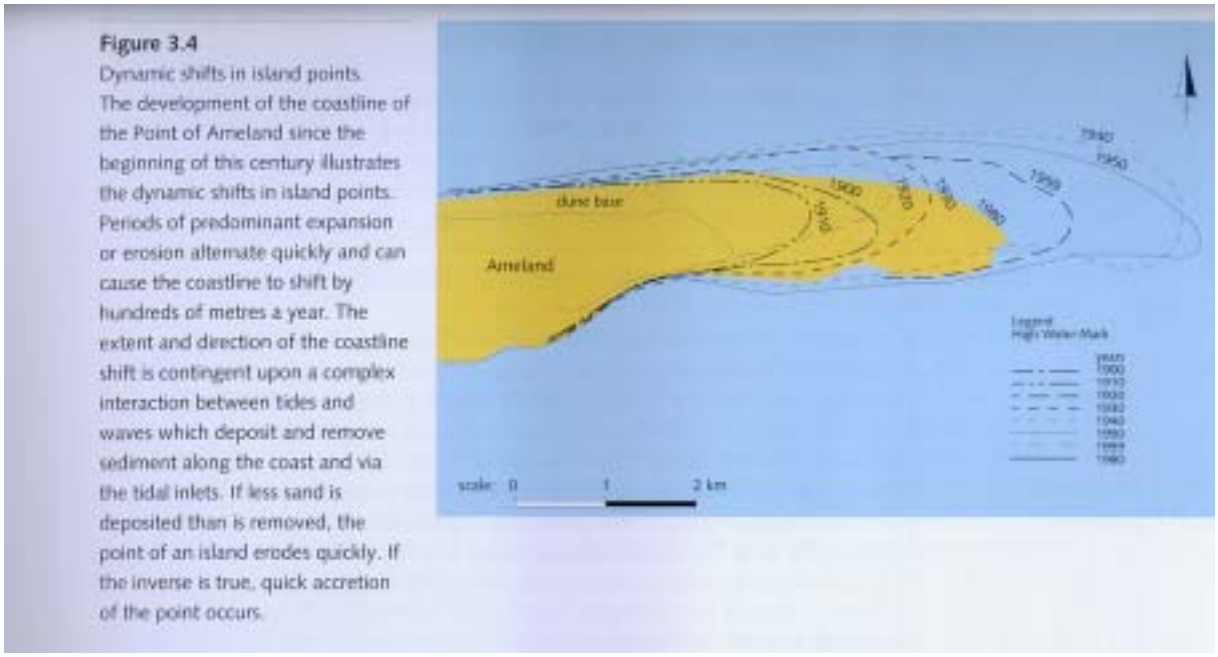

Fig. 3: Shifting of island head (Louters and Gerritsen, 1994).

Erosion Type

From measured data over the period between 1965 and 1992 Figure 4 could be made showing both erosion and sedimentation in the area. The outer deltas and some parts of the beaches are eroding. The erosion is structural because the sediments import into the Wadden sea is an ongoing process. Cause of the erosion is that the import into the Wadden Sea is larger than export. Sea level rise has a big impact on the structural erosion, the tidal flats grow with sea level, and import into the Wadden Sea increases. This might happen at the cost of the North Sea side beaches. Sea level rise is in this period in the order of 20cm/century.

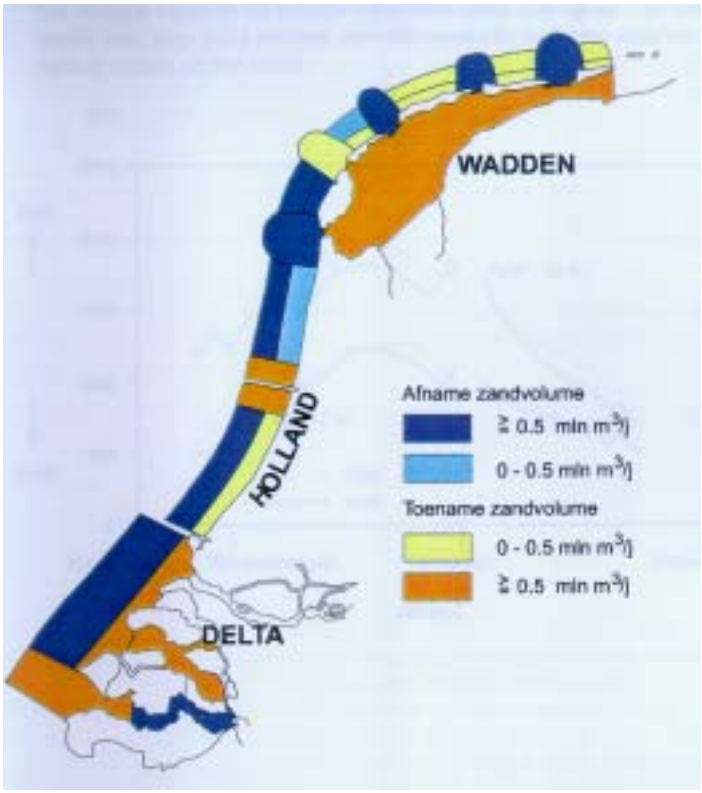

Fig. 4: Sand balance the Netherlands between 1965-1992 (corrected for nourishments). In front of the shoreline a near shore and a deep zone are defined. For the Wadden area near shore is until 6m below MSL and deep is from 6m to 20m below MSL (Stam, 1999).

Measurements on the island shores show a loss of about 10Mm^3 over the last decade(corrected for nourishments).

Acute erosion can also occur in a case of a severe storm. Then, the sand in the dune will first relocate to the beach where it can stay, but may be transported in a longshore direction.

Erosion Cause

The cause of the structural erosion is mainly due to sea level rise. Sediment extraction for sand mining (until 1990) and subsidence due to gas mining play a role as well (little influence). Major engineering works as closure of the adjacent Zuiderzee in 1932 and Lauwerszee in 1969 (now IJsselmeer and Lauwersmeer) have resulted in volume changes of channels and tidal flats.

Another important driving force is the existence of sand waves. These are sand volumes moving alongshore. It is important to know the behaviour of these waves in order to distinguish chronic erosion and the passing of a sand wave trough. Sand waves originate from cyclic behaviour of the outer delta. Time scales are typically in the order of 20-100 years.

Storms can relocate sand from the dune to the foot. Storm is a cause of acute erosion of the dune. This doesn't necessarily mean erosion of the coastal system, because the deposited sand under water might gradually move landwards again.

1.2 Socio-economic aspects

1.2.1 Population rate

Table 1: Population rate.

Islands	surface (km^2 land)	population rate (inhabitants/km^2)
Rottumeroog and Rottumerplaat	±12	0
Schiermonnikoog	39	26
Ameland	59	60
Terschelling	88	54
Vlieland	41	30
Texel	160	84

Source: CBS, except for Rottumeroog en Rottumerplaat.

1.2.2 Major functions of the coastal zone

- **Tourism and recreation:** A primary indicator of the extent of tourism in the Wadden Sea region (here islands and mainland municipalities) is the number of overnight stays in commercial enterprises (nine beds or more). For 1996 this is 12 million overnight stays. (De Jong et al., 1999).

- **Urbanisation (safety of people and investments):** The safety for flooding of urban areas on the Wadden Sea islands is maintained at a probability of once per 2000 years. However, some recently built urbanisations are located at the seaward sides the dikes. The risk for flooding is higher there.

- **Nature conservation:** On all the islands nature conservation plays an important role. The dunes of Texel and Schiermonnikoof are national parks. By means of regulations the Dutch government aims at the protection and development of the Wadden area as nature area and preservation of the open landscape. Except for shipping channels, the Wadden Sea and large parts of the islands are designated as Habitat regulations areas.

The Wadden Islands are not of national importance to food, water and energy supply. Most basic needs are imported from the main land by ship and gas and water are transported to the islands by pipeline. Farms on the islands are of minor economical importance, but valueale for landscape preservation. Much of the natural system has been preserved on the islands, only some small villages can be found with low buildings. The islands are far less densely populated than the city areas in the Netherlands.

For the Wadden Sea fishery (fish, shrimp, mussels and cockles) plays a role. This is a source of conflicts between income and nature conservation.

Actual housing is important and is therefore protected by dikes and the spatial planning of the islands is organised by the Spatial Planning Act of 1965 and the spatial planning policy document of 2000. A lot of the houses on the island are built for recreational and tourism purposes. For the local people, tourism and recreation is the main source of income.

The islands do not have an important transport function. Transport by ship is only for the islands and there are no harbours for ongoing transport. On the islands there are roads to distribute the goods coming by ship.

1.2.3 Assessment of capital at risk

See section 1.2.2. for general description. No detailed information available is given here.

2. PROBLEM DESCRIPTION

2.1 Description of eroding sites

The figures used in this part are taken from Roelse (2002). The Hold the Line zones are the stretches along which no structural erosion is allowed. The coastline will be maintained there at a minimum position.

Legend:

- Sedimentation from 1990
- Erosion from 1990
- Hold the Line zone
- Recreation

- **Texel**

North Sea side coast is eroding with a peak in erosion velocity at de Koog (at NW side).

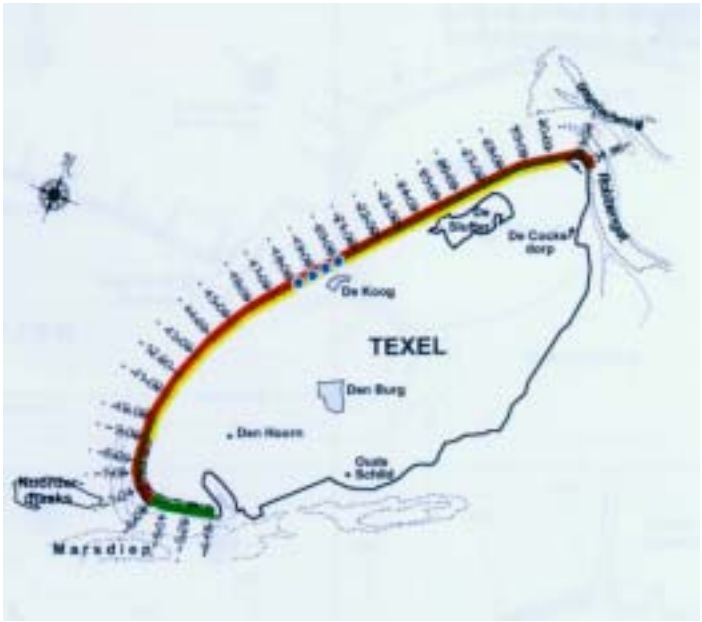

Fig. 5: Texel erosion and sedimentation.

- **Vlieland**

The NE upper one third of the North Sea side is eroding. The tidal channel at the East side of the island is moving landwards.

Fig. 6: Vlieland erosion and sedimentation.

- **Terschelling**

The middle part of the North Sea side beach is eroding and the East side head of the island shows rapidly cyclic behaviour.

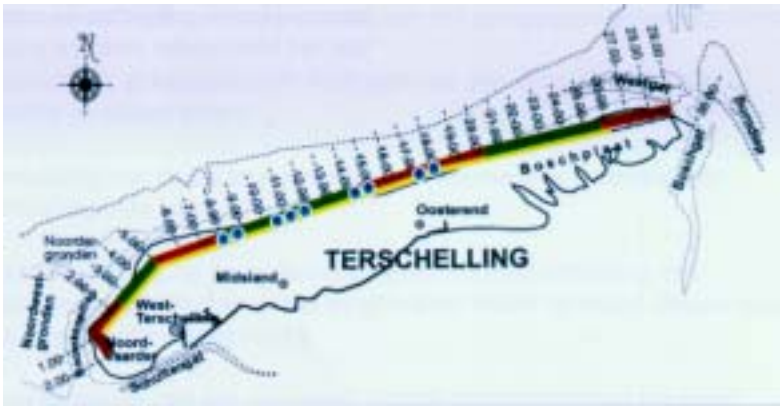

Fig. 7: Terschelling erosion and sedimentation.

- **Ameland**

The channel is moving towards the East which causes erosion of the West side head of the island. The tidal flat at Norht Sea side at the West side of the island is gradually moving towards the island. This means erosion of the most seaward coastline, but can also be seen as a movement of a sand volume. The middle part of the North Sea side beach is eroding.

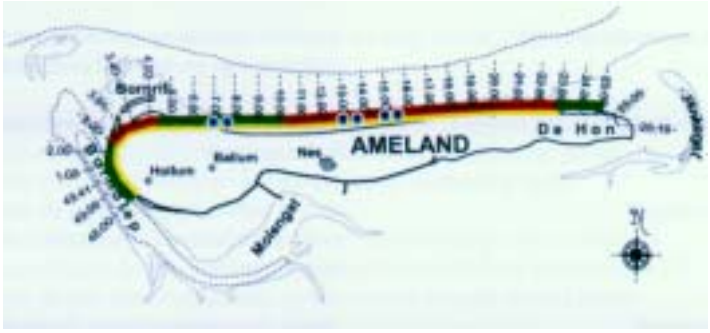

Fig. 8: Ameland erosion and sedimentation.

- **Schiermonnikoog**

This island is stable. Erosion not significant.

Fig. 9: Schiermonnikoog erosion and sedimentation.

- **Rottumeroog and Rottumerplaat**

These islands are probably eroding.

2.2 Impacts

Erosion along the North Sea side coast causes a higher risk for flooding. First, erosion is a threat for nature areas: dunes and salt marshes. At Texel this is the 'Slufter', this is a tidal inlet, see Figure 10a. Also, a salt marsh is eroding at Texel. At Ameland at the SW side a salt marsh is eroding, see Figure 10b. Generally seen as more important, if dunes disappear, urban areas are being threat.

At Vlieland, the erosion at the East side of the island caused a narrow beach and was threatening the dunes as well.

A B

Fig. 10: Photos of Slufter at Texel (A) and salt marsh at Ameland (B) (source: Archive, RIKZ).

3. SOLUTIONS / MEASURES

3.1 Policy options

The adopted policy option in 1990 is Hold the line, a summary brochure of the Coastal Policy Document "Tradition, Trends and Tomorrow" is available.

There are some exceptions to be mentioned: for the East side heads of Ameland and Schiermonnikoog, the SW side head of Vlieland and the South side head of Texel and for Rottumeroog and Rottumerplaat the policy is Do Nothing.

The policy option is called dynamic preservation in the Netherlands, because where possible (from a safety point of view) maximum freedom is offered for natural processes. See policy agenda of 2002 for actual discussions on coastal policy:

3.2 Strategy

The tools and methods used are described in *"Coastline management, from coastal monitoring to sand nourishment"* (RIKZ, 1996).

The engineering options are both soft and hard. The strategy is to work as much as possible with natural processes.

For the NE side head of the island Texel a soft solution only was not effective enough and therefore a mixed (in terms of soft and hard) option was chosen. At the West side of Ameland and the East side of Texel hard solutions are applied to prevent local erosion of the island.

3.3 Measures

At the islands a lot of manmade structures can be found that were built to stop or decrease erosion. These are listed here with the period in which they were built and/or maintained.

Table 2: Historic measures.

Texel	groynes	1950-1986
	cross-shore dam "Eijerlandse gat dam"	1990
	2 places at channels: revetments	before 1940
Vlieland	groynes, see Figure 11a	1870-2000
Ameland	revetments at channel	1948-1990

For many years dune maintenance has been carried out existing of leveling of dunes and maram grass planting, see Figure 11b.

A. Groynes at Vlieland

B. Planting of maram grass

Fig. 11: Photos of hard(A) and soft(B) measures.

For the NW side of the island Texel a combined measure was chosen of hard and soft solutions. The dam has a total length of 800m with 550m seawards from the coastline. First in 1994, a volume of 2Mm^3 was nourished on the beach. Then in 1995, the dam was constructed in 4 months. Building costs of the dam were eventually 8M€.

For Vlieland, a mixed option was chosen. Research of local coastal dynamics resulted in removal of existing groynes and construction of two new ones together with a beach nourishment of 200.000m^3. Dams have a length of 200m and 180m. Building cost of the two dams were eventually 2.6M€.

To stop the structural erosion the main measure is nourishing. Both shoreface and beach nourishments are used. For an evaluation of shoreface nourishments, see the NOURTEC program (NOURTEC, 1996).

Nourishing has been carried out on the Wadden islands since 1979.

Table 3: Nourishment operations since 1979 in Wadden Sea Islands.

location	year	Volume (Mm^3)	Volume (m^3/m^1)	type
Texel, NE side	1979	3.05	510	beach
Texel, NE side	1985	2.85	480	beach
Texel, de Koog	1984	3.02	500	beach
Ameland	1980	2.2	365	dune front

After 1990, the nourishments have been intensified because of the adopted policy Hold the Line for most parts of the beaches at the North Sea side.

Table 4: Nourishment operations for the 1990-2000 decade.

location	year	number of nourishments	total Volume (Mm^3)	type
Texel	1991-2000	8	13.88	beach
Vlieland	1991-2000	2	0.47	beach
Terschelling	1991-2000	1	2.0	shoreface
Ameland	1991-2000	6	6.82	beach(5), shoreface(1)

3.4 Costs

The cost of nourishments in the Netherlands is relatively low. See comparison between different EU countries from Roelse(2002).

Table 5: Comparison between northern European countries regarding nourishment costs.

Land	costs beach nourishments (€/m^3)	costs foreshore nourishments (€/m^3)
Belgium	5 – 10	
Denmark	4,2	2,6
Germany	4,4	
UK	10 - 18	
Netherlands	3,2 – 4,5	0,9 - 1,5

Cross-shore dam of 800m: 8M€
2 Groynes of 180m and 200m: 2.6M€

4. EFFECTS AND LESSONS LEARNT

4.1 Effects related to erosion

Structural erosion did not stop. Negative effects of erosion of the islands has been almost nullified by nourishments and local erosion resistant structures.

The shores of the islands show erosion and sedimentation in different places. For the evaluation, first sedimentation and erosion areas have been defined. Most of the sedimentation areas are not nourished. After choosing the policy option 'Hold the Line' in 1990 for most parts of the beaches, the sand volume in the eroding areas parts has decreased with 5 Mm^3. This happened despite of the nourishments. It can be clarified almost entirely by the changes in the West head of Ameland. There the coastal dynamics are accepted, because it does not cause any increase in danger. The net erosion is accepted there. Actually, the policy there is not purely 'Hold the Line' anymore.

Since 1990 the coastline has been maintained at the same location. The difference with 1990 is small. In eroding areas a trend of 2m/year erosion has turned into 0.4m/year accretion. This is mainly due to the intensive nourishment effort on Texel. In sedimentation areas the trend of 8m/year accretion has turned into 4m/year accretion.

At Texel between 1979 and 1995 14.8Mm^3 has been nourished. This is less than the total erosion of 15.8 Mm^3. The effect of the cross-shore dam is currently (2002) still under discussion. It is very clear that since contruction strong accretion took place. The striking result is that the accretion takes place at both sides of the dam. The original purpose was accretion at the SW side of it, see Figure 12.

Originally, the cost of the dam was estimated much lower and needed future nourishments were expected to decrease more than happened. The chosen solution is possibly still the cheapest. See the comparison by Heuvel (1999):

Table 6: Comparison between nourishment costs and nourishment+dam costs.

Alternative	Initial costs	additional costs in plan period(50 years)	total costs
continue nourishments	-	sand: 25-30Mm3,	48-55M€
continue nourishments in combination with dam	Sand: 9M€ Dam: 5M€	maintenance costs dam + 9Mm3 sand	25M€
Evaluation in 1999	Sand: 9M€ Dam: 8M€	maintenance costs dam+ 9Mm3 sand+ 0,8Mm3 erosion to be compensated	unknown

New morphological developments in the area and new ways of nourishments make it impossible to estimate the additional costs in the plan period. It is therefore not sure if there will eventually be an economical benefit. The erosion of this part of the coast has decreased with 30% and will decrease more until 45%. As expected, erosion still has to be compensated with nourishments.

Situation 1994

situation 1999

Fig. 12: Effect cross-shore dam at island Texel.

At some places at the Wadden Sea side, channel migration towards the coast was stopped with revetments. The coastline was preserved, but erosion did not stop and in the end the construction was damaged. Over the last decades several works have been carried out at the channel and some failed due to scouring. The lesson learned is that structural erosion cannot be stopped with hard constructions.

For Vlieland, a comparison can be made between nourishments only and nourishments in combination with constructions over a period of 25 years. by Heuvel(1999).

Table 7: Comparison between nourishment costs and nourishment+groynes costs.

Alternative	Initial costs	additional costs in plan period(25 years)	total costs
continue nourishments 300'000m^3/5y	-	5*1.6M€/5y	8.2M€
continue nourishments in combination with 2 groynes 200'00m^3/10y	2.6M€	0.07M€/y + 0.11M€/y=4.42M€/25y	7.1M€

A conclusion in 1999 is that more research is needed for the erosion at the South side of one groyne and also for the erosion of the channel (became deeper).

The effect of the groynes is generally temporary. In most beaches of the Wadden islands groynes can only slow down and not stop structural erosion. Groynes have shown to be very effective where a tidal channel has to be kept away from the shore. This is the case in Vlieland.

The channel and tidal flats between Ameland and Terschelling show a cyclic behaviour with a period of about 60 years. The channel is gradually moving Eastwards. In 1994 it was decided to reinforce the existing channel slope with revetments together with a beach nourishment of 225'000m3. A comparison was made between nourishments only and nourishment together with construction. by Heuvel(1999).

Table 8: Comparison between nourishment costs and nourishment+revetment costs.

Alternative	Initial costs	additional costs in plan period(25 years)	total costs
continue nourishments 100'000m^3/5y	-	5*0.68M€/5y	3.4M€
continue nourishments(100.00m^3/10y) in combination with revetments and beach nourishment of 200'000m^3	0.9M€+ 0.9M€	0.05M€/y*25=1.13M€/25y	3.0M€

The conclusion in 1999 is that after construction a period of sedimentation took place. This was because of normal cyclic behaviour. When sedimentation changes into erosion again the construction will have a function (construction is under sand now). Timing was not right, it would have been better to wait for a time when from erosion was going to change into sedimentation.

4.2 Effects related to socio-economic aspects

The chosen coastal protection meets the main purpose of the Wadden Sea ("protection and development of the Wadden area as nature area and preservation of the open landscape"). Other coastal defence measures than nourishments would not meet this purpose. The Wadden Sea is and will be preserved because it can fill in with sand.

All the functions in the region present in 1990 did not experience any negative effect of the structural erosion.

It is known that marine bottomlife does not survive a sand layer from a underwater nourishment. It is not known in what way this affects the habitat and the birds. It is also known that bottom life recovers in about two years. It is strongly recommended to make a proper evaluation because it is obligatory to report the effects of works in assignated areas. For a consideration of effects it should be mentioned that ecology in the dunes benefit from nourishments as well.

4.3 Effects in neigbouring countries

The total Wadden Sea stretches along the German and Danish coast as well. The sand movement is not blocked in any way by the nourishments. Effects of the constructions is only local. The international cooperation of the Wadden Sea promotes increase of natural dynamics; the adopted policy meets this purpose.

4.4 Relation with ICZM

Safety still has highest priority. By law, a minimum safety for flooding must be guaranteed. As much as possible, other functions are regarded as well. The coastal maintenance is carried out by the national department of Public Works. There are several meetings held in order to combine functions as safety and natural dynamics in dunes.

It is undesirable that there should be any strict segregation of functions in the dune area. Subdivision into different zones would lead to abrupt and unnatural transitions in the dune landscape. The demarcation of a broad sea defence zone permits closer integration of functions in the dune area and in particular offers opportunities for encouraging the play of natural dynamic forces. In broad dune areas, for example, the decision to adopt a broad sea defence zone means that the aeolian transport of sand out of the foredune need not present a problem from the point of view of flood protection. In narrow dune areas, of course, such tolerances do not exist.

4.5 Conclusions

Effectiveness

Nourishments have shown to be effective.

Constructions have stopped local erosion of the coastline, but constructions always need maintenance.

Profound knowledge of the system is absolutely necessary to succesfully apply hard constructions

Possible undesirable effects

The impact on ecological functions of shoreface and beach nourishments.

Gaps in information

The filling in of the Wadden Sea can only be evaluated after a long period of some 50 years. The effectiveness of the “Eierlandse gat dam” is not clear.

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