coastal management in The Netherlands

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Introduction

After the storm surge disaster of 1953 (1855 death casualties and an damage of approx. 14 % of the National Product) all sea defense structures have been improved in the Netherlands. This did not only mean an improvement of the dikes, but also an improvement of the dune coast. The program is completed in 1990. All sea defense structures fulfill the requirements.
However, the 320 km long sandy coast along the North Sea is a dynamic coast. At some locations it is accreting, but at other places there is erosion. The location of the erosion varies during the years. The erosion endangers the strength of the dunes as a sea-defense. Behind the dunes are low lying polders (very often with a surface level even below the low water line), in which millions of people are living. Erosion of narrow dunes can therefore not be tolerated in the Netherlands. At 40 km of the coastline the dunes have no more than 10 m extra width available to cope with the erosion problem. A yearly erosion of approx. 1 m/year causes big problems within a few years.
But also at locations were the dunes are wide erosion causes problems. Of course at those points there is no danger for inundation of polders during storm surges. But were the dunes are wide, the dune area has important values. At a few places people live in the dunes. But the dunes are mainly natural reserves. In a densely populated country like the Netherlands the few natural reserves are of high importance. The dunes have also a high recreational value, not only for the 14 million Dutch inhabitants, but also for approx. an equal number of people living in the German Ruhr area. For them, the Dutch coast is the nearest coastal recreation area.
In the Netherlands the dunes are also used for the production of drinking water. Because ground water in large parts of the Netherlands is brackish, is cannot be used for drinking water. In the 19th century the public water works of the big Dutch towns started to pump drinking water from the fresh-water lenses in the dunes. At this moment the natural supply from these lenses is not enough any more, and the lenses are supplied with river water (mainly from the Rhine river), which is infiltrated in the dunes and recovered later.

history

In the past only the sea-defense aspect was very important. The authorities responsible for sea-defense therefore improved the dunes by placing more sand behind the dunes on the landward side, causing considerable damage to nature.
In order to control the erosion many groins have been build. In some cases the dunes became so narrow that is was necessary to construct a seawall or a sea dike. The consequences of the construction of seawalls and dikes was that the safety of the polders was guaranteed, but the beaches in front of the constructions disappeared. Also the effect of groins was not quite satisfactory. In cases were they were located near tidal gullies they were able to keep the

tidal current out of the coastline, and preventing extra erosion of the beach in that way. In those cases were the tidal current was not so strong, the effect of groins in controlling erosion was minimal.
Because of these problems and because of the improvements in the dredging industry the last decade erosion was mainly controlled by means of artificial beach nourishment. The nourishment projects were executed on a ad-hoc basis by the national government and not by the sea-defense authorities. This is caused by the fact that it are generally big projects and that sea-defense is only some aspect.
Because also the sea-level is rising (now 20 cm/century, because of the greenhouse-effect in future it will be more) it is to be expected that the erosion problems along the coast will increase. At the same moment the ecological and recreational pressure on the dune area will increase.
These points made it necessary to define a national policy on coastal defense and erosion management.

plan of action
In the new "Law on the Sea-defense and Flood-control" (operational in 1991) the responsibilities of the national government and the sea-defense authorities is described. The national government is responsible for erosion control along the coastline.
In order to have an adequate coastal policy in 1991, the Minister of Public Works asked for a policy analysis on coastal management. The study for this policy analysis was performed by Rijkswaterstaat, assisted by specialized institutes (like Delft Hydraulics) and universities. An inventory of all available knowledge regarding the Dutch coastline was made, forecast were made on the expected sealevel rise and on the development of the coastline for the next century. Maintenance methods and costs were analyzed. This study took approx. one year and resulted in a set of 20 technical reports. On the basis of the technical reports, a discussion memorandum was produced in which 4 different management strategies were presented. These strategies are presented to parliament and other groups for discussion. Public hearings will be held. After the discussion the minister will make a choice from the alternatives and present the decision to parliament for approval. When approval (and the budget) is granted by parliament, the national coastal management policy is effective.

alternative 1: withdrawal (terugtrekken)
If nothing is done, the coastline will erode. This is not acceptable on locations where the dunes have only marginal safety. Everywhere where the dunes are wider, erosion can be allowed until the minimal dune width is reached.
This alternative is the minimal alternative. The coastline of the Netherlands will be determined by the natural erosion. Only at those locations were the safety of the polders is in danger, action will be taken. Generally the action will be a beach nourishment, but also other solutions are possible (like the construction of a heavy sea-dike). After some years artificial headlands will be formed along the coast (the coast between the headlines continues to erode). The costs to defend these headlands will increase in due course.
If erosion continues, there is the possibility that villages in the dunes (not in the polder-area) have to be removed to a more inland location. This has happened often in the past centuries. Also damage will be caused to recreational areas, natural reserves and the drinking water production. The loss of land in the next decade will be in the order of 350 ha (800 acres) and 20 km of coastline has to be defended by beach nourishment or other means.
In a few cases also the dunes has to be improved on the landward side. This improvement will cost approx. 100 ha (220 acres). In this alternative all sea-

dikes and groins will be maintained in the same way as it was done until today. A landward reconstruction of these structures has proven to be more expensive than maintenance on the present location. This alternative will cost 35 million guilders per year (16 million US $/year).

alternative 2: selective erosion control (selectief handhaven)
The second alternative is control the erosion in a selective way. Here also safety is the primary aspect. But erosion is not only controlled in case of danger for inundation of polders, but also when important other functions are endangered. Because there are many functions in the dune area, some choices have to be made. What has to be protected, what is "important" ? In this alternative the following choices have been made:

- all villages in the dune area will be protected;
- natural reserves with an (international) high value will be protected;
- infiltration plants for drinking water production will be protected;
- investments for recreation will be protected (hotels, etc.).

The expected loss of land in the next decade will be approx. 100 ha (220 acres), 60 km of coastline has to be protected and the coast are 45 million guilders per year (20 million US $/year).
The details of this alternative have to be worked out on a regional level.

alternative 3: full erosion control (handhaven)
The coastline of 1990 will be maintained. Erosion will be compensated fully by beach nourishment. A small strip will be available for natural fluctuations of the beach. Nourishments will be performed on the beach, but probably also just in front of the beach, on the inshore zone. There will be no lost of land, 140 km of coastline has to be protected by nourishment. The costs are 60 million guilders per year (27 million US $/year).

alternative 4: seaward expansion (zeewaarts)
This alternative is a more active one than the other alternatives. In this alternative the dunes which have a marginal safety are improved by making more beach in front of them. This will be done by the construction of very long groins and other construction in the sea. This alternative has not yet worked out in such detail as the other ones, therefore the cost-indications are more tentative. The main purpose of this alternative is not the creation of extra land. Most of the constructed accretions are on locations were the do not have a high economic value. The purpose is improving the sea-defense. It is a more offensive policy than the other ones.
Also 140 km of coastline requires protection in this alternative. The costs are approx. 80 million guilders per year (35 million US $/year).

sealevel rise
In the above alternatives the present rate of sea-level rise (20 cm/century) is used. It is expected that this may be more. Two sea-level rise scenarios have been studied. One with a sea-level rise of 60 cm/century and one with a sea-level rise of 85 cm/century plus an additional change in the wind-climate (mainly a change in the wind direction).
This resulted in the following data:

	20 cm/cent	60 cm/cent	85 cm/cent+wind
1. withdrawal	100 %	110 %	155 %
2. selective control	100 %	110 %	160 %
3. full control	100 %	115 %	165 %

To:
The chairman of the Second Chamber
of the Parliament ("House of Commons")
1a Binnenhof
2513 AA The Hague

The Hague, May 9th, 1989

subject: Memorandum Sea Defense after 1990

Mr. Chairman,

The protection of our country against the sea is of greatest importance. This is especially so for the more specific field of protection of the North Sea Coast. Now it becomes more and more clear that the rate of sealevel rise will increase in the future years, it is to be expected that also the attack of the sea on our coastlines will increase. First of all the higher waterlevel causes a higher pressure on our sea defense along the coastline. Also follows from recent research that probably also the rate of erosion of the coastline will increase. This was one of the arguments of my conclusion that Water Authorities had to manage the sea defense structures along the coast, but that the care of the position of the coastline itself should be the responsibility of the National Government. I informed you on this subject in my letter of May 7th, 1985 (TK 18975, no.1). In the Commission Meeting of April 6th, 1987 Parliament supported this choice. The task of the National Government related to the care of the coastline will have a legal basis in the Law on the Sea Defense and Flood Control (Wet op de Waterkering), on which the High Council of State will advise in short terms.

It is necessary that, before the Law on Sea Defense takes effect, a long term policy has been developed for the management of the coastline. A strategic choice has to be made regarding the sea defense policy, also regarding the increased rate of sea level rise and the increased erosion rate caused by that fact. For that purpose in my department the memorandum "Sea Defense after 1990" (kustverdediging na 1990) has been prepared.
The preparation takes place in three phases:

a. Production of a discussion-memorandum, in which an analysis is presented of the problems of sea defense and on which basis four policy alternatives are presented.
b. Advise by the Advisory Council for Watermanagement and by the Technical Advisory Committee on Water defenses. Also there will be discussions with the representatives of the provinces and the Waterboards.
c. Making a choice by the government from the alternatives. This choice will be presented tot parliament in a policy-memorandum. This memorandum will be send to you at the end of this year.

Phase a is completed now. Today I have send questions for advise to the Advisory Council for Watermanagement and to the Technical Advisory Committee on Water Defenses. I have asked the Advisory Council to make arrangements for public hearings on this subject.

policy alternatives
The policy alternatives presented in the discussion-memorandum are roughly

worked out on a national level. This is done because after selecting one alternative by the government on a national level, further detailing has to be done on a regional level, using local know-how of provinces and water boards. This can be done by preparation of actual coastal plans by specialized regional (discussion) boards. The memorandum "The sea defense along the Dutch coast" (parliamentary year 1976-1977, no. 14481) did already describe these boards and the Law on Sea Defense will give them a legal basis.
The policy-alternatives give the boundaries within which the details have to be worked out. By making the alternatives attention has been focused on those parts of the coastline which are eroding. This has been done because the problems of eroding coastlines which possible threat to safety or loss of important dune areas is more important than the problems of accreting coastal sections. For the same reason reclamation is also not placed into the discussion. Reclamation projects require -if demands on a good coastal management are fulfilled- mainly a spatial planning process.

The alternatives can be characterized as follows:

I. WITHDRAWAL. Coastal erosion is principally accepted. Only in those coastal sections were erosion may cause inundation of low-lying polders behind the dunes, coastal erosion will be controlled.

II. SELECTIVE EROSION CONTROL. Besides locations were the polders are threatened, erosion is also controlled at those locations where considerable values in the dune area or on the beach are threatened by coastal erosion.

III. EROSION CONTROL. Everywhere the coastline will be maintained at its present location.

IV. SEAWARD. On some very eroding areas and relatively weak spots constructions will be build in the sea, which change the eroding trend of the coast into a more accreting trend. Everywhere else the coastline will be maintained at its present location.

Consolidation of the reached level of safety -the purpose of the Bill on the Sea Defense- implies that withdrawal is the minimal alternative. The alternative Erosion Control is identical to erosion-stop-policy, sketched in my letter TK18975/3 of March 25th, 1988. The basic thoughts behind the fist three alternatives is that coastal erosion has to be decreased or stopped. De basic thoughts behind the last alternatives is that coastal erosion locally is changes in coastal accretion. This requires specific constructions to be built in front of highly attacked coastal sections. These constructions are also complementary to the other alternatives. These works have the only purpose to protect the coastline against erosion. They may have an interesting "by-product", such as some reclaimed area, like the areas on both sided of the harbor moles of IJmuiden. The constructions can be build adjacent to reclamation works, which are mainly situated on stable or accreting coastlines; there coastal defense is not the primary objective.

present policy

In the following the various alternatives are compared with the present policy. The present policy consists of the components:

1. By the construction of dune improvement works according to the Delta Law (Law which states that all sea defenses has to be reinforced in order to guarantee a certain level of safety) always a certain sand-buffer has been formed to cope with the erosion for a number of years. Implicitly the alternative Withdrawal was used in those cases.
2. Additionally on ad-hoc basis a number of beach replenishment projects were

executed on coastal sections with high values in the dune area or on the beach. As examples can be mentioned the nourishment works on Texel, near Westerschouwen and additional to the sea defense works near Cadzand.

Both components together form the "bottleneck-policy", sketched in my letter TK18975/3 of march 25th, 1988. The philosophy behind the present bottleneck-policy is equal to the alternative Selective Erosion Control. Executing this policy was limited by shortage of budgets, and had therefore a strongly ad-hoc character. Future policy should have a more structural basis.

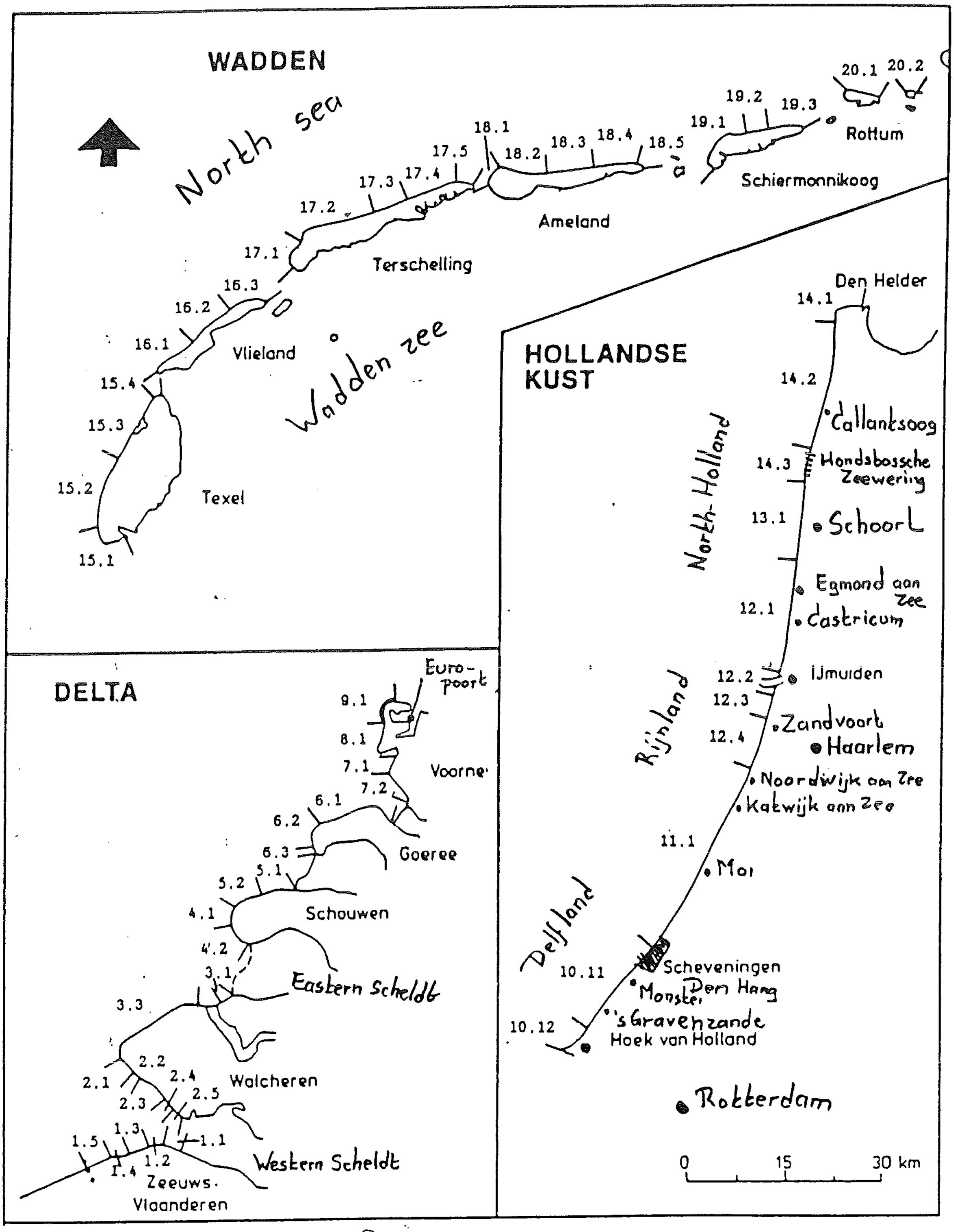
no policy choice yet

All social effects of the alternatives have to be considered. A choice has to be made between more effort for coastal defense and losing less dunes with high values for society, or making less effort and losing more dunes. Safety against inundation of polders is guaranteed in any case. I have not yet made a choice. To prepare a choice a period of consultation and discussion is foreseen. It is my intention that the council of ministers makes a choice at the end of this year, which choice will be presented to parliament in a policy-memorandum.

Sincerely,

The Minister of Transport and Public Works,

N. Smit-Kroes


WADDEN
North sea
Wadden zee
Texel
Vlieland
Terschelling
Ameland
Schiermonnikoog
Rottum
15.1
15.2
15.3
15.4
16.1
16.2
16.3
17.1
17.2
17.3
17.4
17.5
18.1
18.2
18.3
18.4
18.5
19.1
19.2
19.3
20.1
20.2
HOLLANDSE KUST
Den Helder
14.1
14.2
Callantsoog
14.3
Hondsbossche Zeewering
13.1
Schoorl
Egmond aan Zee
12.1
Castricum
12.2
IJmuiden
12.3
Zandvoort
12.4
Haarlem
Noordwijk aan Zee
Katwijk aan Zee
11.1
North-Holland
Rijnland
Delfland
10.11
Scheveningen
Den Haag
10.12
's Gravenzande
Hoek van Holland
Rotterdam
0
15
30 km
DELTA
Europoort
9.1
8.1
7.1
7.2
Voorne
6.1
6.2
6.3
Goeree
5.1
5.2
Schouwen
4.1
4.2
3.1
Eastern Scheldt
3.3
2.1
2.2
2.3
2.4
2.5
Walcheren
1.1
1.2
1.3
1.4
1.5
Western Scheldt
Zeeuws-Vlaanderen

Wadden sea
North sea
Amsterdam
Rotterdam
Antwerp
Belgium
Germany

kustgedeelte	sector	segment	celnummers	rijksstrandpalen
Zeeuws-Vlaanderen	1	1.5	1 - 4	11 - 15
		1.4	5 - 7	8 - 11
		1.3	8 - 10	5 - 8
		1.2	11 - 12	3 - 5
		1.1	13 - 15	0 - 3
Walcheren (zuid)	2	2.5	16 - 17	34 - 36
		2.4	18 - 19	32 - 34
		2.3	20 - 24	27 - 32
		2.2	25	26 - 27
		2.1	26 - 28	23 - 26
Walcheren (noord)	3	3.3	29 - 46	5 - 23
		3.1	47	1 - 2
Schouwen (zuid)	4	4.2	48 - 51	13 - 17
		4.1	52 - 54	10 - 13
Schouwen (noord)	5	5.2	55 - 59	5 - 10
		5.1	60 - 64	0 - 5
Goeree	6	6.3	65	18 - 19
		6.2	66 - 70	13 - 18
		6.1	71 - 81	2 - 13
Voorne	7	7.2	82 - 87	10 - 16
		7.1	88 - 91	6 - 10
Slufter	8	8.1	92 - 100	5 - >9
Europoort	9	9.1	101 - 108	<0 - 5
Delfland	10	10.12	109 - 113	114 - 119
		10.11	114 - 129	98 - 114
Rijnland (zuid)	11	11.1	130 - 159	68 - 98
IJmuiden	12	12.4	160 - 167	60 - 68
		12.3	168 - 170	57 - 60
		12.2	171 - 174	53 - 57
		12.1	175 - 189	38 - 53
Noord-Holland (midden)	13	13.1	190 - 201	26 - 38
Noord-Holland (noord)	14	14.3	202 - 206	21 - 26
		14.2	207 - 225	2 - 21
		14.1	226 - 232	<0 - 2
Texel	15	15.1	233 - 237	4 - 9
		15.2	238 - 248	9 - 20
		15.3	249 - 259	20 - 31
		15.4	260	31 - 32
Vlieland	16	16.1	261 - 267	35 - 42
		16.2	268 - 274	42 - 49
		16.3	275 - 280	49 - 55
Terschelling	17	17.1	281 - 284	0 - 4
		17.2	285 - 296	4 - 16
		17.3	297 - 301	16 - 21
		17.4	302 - 308	21 - 28
		17.5	309 - 310	28 - 30
Ameland	18	18.1	311 - 313	1 - 4
		18.2	314 - 320	4 - 11
		18.3	321 - 327	11 - 18
		18.4	328 - 333	18 - 24
		18.5	334	24 - 25
Schiermonnikoog	19	19.1	335 - 341	1 - 8
		19.2	342 - 344	8 - 11
		19.3	345 - 349	11 - 16
Rottum	20	20.1	350 - 352	3 - 6
		20.2	353	11 - 12

Boundaries of coastal segments

Technical reports prepared as a background to the Coastal Memorandum:

1. Sandsystem of the coast; a morphological characterization
2. Situation in 1990; type of coast and location of the coast
3. Coastal maintenance; costs of basic maintenance
4. Inventory of dune-functions
5. Coastal predictions; predicted coastlines 1990-2090
6. Sea level rise; hydro-meteo scenarios
7. Dunes as a sea defense; the impact of coastal changes on safety
8. Dune functions; impact of coastal dynamics
9. Inventory functions of the inshore area; interaction with sea defense
10. Mining sea sand; the influence of borrow-areas on the coast
11. Beach and dune nourishment; effectivity and costs
12. Groins and pile-groins; evaluation of their effect
13. Big civil works; influence on the coastline
14. Inshore nourishment; an alternative for coastal defense
15. Monitoring the coast; present situation and future
16. Hard sea defense; seadikes, harbor areas and beach walls
17. Policy-analysis model
18. Results of calculations with the policy-analysis model
19. Innovative coastal defense
20. Coastal defense seaward of the coastline

Sandsystem of the coast; a morphological characterization

Technical report nr. 1 for Coastal Memorandum
A. Stolk
University of Utrecht

Morphology

The Dutch coast is a part of the coastal plain between northern France and Denmark. The coastal plain is bordered at the seaside by a sandy barrier, on which dune developed. The coastal barrier is partly closed. On some places it is interrupted by inlets. This leads to a division of the Dutch coast into three sections:

a. The Delta area, with peninsulas separated by estuaries
b. The coast of Holland, with a closed row of dunes, without inlets and islands
c. The Wadden areas, with barrier-islands and wide intertidal areas behind the islands.

The morphology of the Dutch coast is described quite well by the yearly coastal measurements. Between a waterdepth of approx. 25 m and the landward border of the dunes four morphological units can be distinguished:

a. The flat sea-bottom
b. The inshore area
c. The beach
d. The dunes.

The boundary between the flat sea-bottom and the inshore area is defined by the point where the slope of the bottom becomes steeper than 1:1000. The average low water line is the boundary between the inshore area and the beach.

On the flat seabottom in front of the coast there are two areas with sand ridges. A southern complex near the Delta area and a northern complex from Katwijk aan Zee until the island of Schiermonnikoog. The length of the ridges varies from a few until several kilometers. They have a width of one to 10 km. The ridges of the southern complex are deeper (20-30 m below MSL) than the northern ridges (14-20 m below MSL). The southern ridges have a height of 4-20 m, the northern ridges are 3-6 m high. In both complexes ridges can be found with connections to the inshore area. This is very clear in the Central part of Holland (fig.1.1)

The flat sea-bottom changes near to the coast in a more sloping bottom. The boundary is generally near 20 m below MSL., except in the central part of Holland, where the boundary is at approx. 15 m depth. Near the inlets of the Delta and Wadden area the bottom is dominated by outer deltas with their channels and bars. The slope of the bottom increases if one comes nearer to the coastline, at the coast of Holland and the central part of the Wadden area. It is remarkable that the average slope is at maximum in the central part of Holland (1:136 near Egmond aan Zee). The section above the 10 m depth contour, however, is steeper in the southern and northern section than it is in the central section. In the upper section generally one or more breaker ridges can be observed. The most landward bank generally dries during low water, and forms small, shallow channels on the beach. The dry beach is bordered at the landward side by one or more rows of dunes.

The dune area varies in width form a narrow dune row, like it is near Monster, to a vast area of 4 km, like it is near Haarlem and Schoorl. In these last areas also the highest dunes can be found (up to 50 m). These "younger dunes" were formed between 1000 and 1400 A.D. The are significantly higher than the so called "older dunes". In total a quantity of $2*10^9$ cubic meter of sand has been transported from the beach towards the dunes in the period between 1000 and

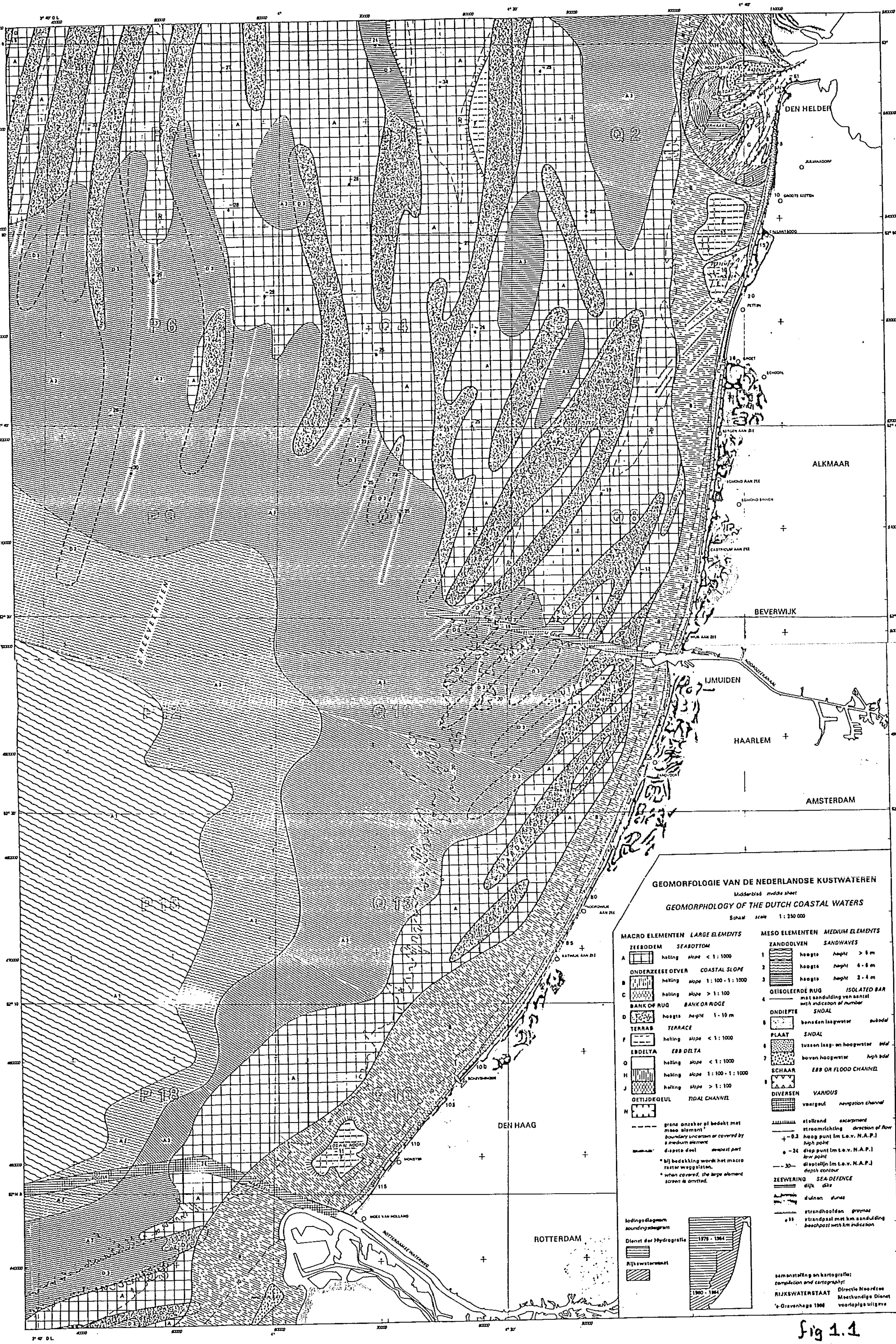
1850 A.D. in the western section of the Netherlands.
The morphology of the Dutch coast shows sudden changes. The width and the slope of the various zones vary very much, as well as the grain size and the composition of the beach sand. See table 1.1.
table captions:

1. Coastal sector
2. Segment number
3. Orientation of the LW-line (degrees)
4. average width of the beach (m)
5. average width of the dry beach (m)
6. average width of the intertidal beach (m)
7. level of the average low water (m above MSL)
8. level of the average high water (m above MSL)
9. average slope of the intertidal beach
10. average dune width (m)
11. grain-size in the inshore area (until 1000m from the coastline) (mu)
12. grain-size on the dry beach (mu)
13. grain-size on the intertidal beach (mu)
14. grain-size on the beach (mu)
15. grain-size in the dunes (near the seafront) (mu)

genesis

The coastal area of the Netherlands did develop in the last 6000 years behind a more or less closed beachwall. In periods with a strong marine influence a lagoon-environment (wetland environment) developed. In this environment in channels sand was deposited. Outside the channels clay was deposited, sometimes with sandy layers. In periods with less marine activity, the water in the coastal area was fresh and freshwater marshes were formed. This is the origin of the wide peat layers in the Netherlands.
In the west of the Netherlands a sandy coastal strip developed after approx. 3700 B.C. The developments stopped around 700 B.C. After that year coastal erosion started again. In the period between 1000 A.D. and 1400 A.D. a new dune strip developed along the west coast, the Young Dunes. At the same time in the north and in the southwest of the Netherlands there was an expansion of the marine influence via the inlets and estuaries.
From an analysis of historical maps follows that since 1600 the coast in the Delta area has eroded nearly everywhere with several hundreds of meters. De movements of the low water line vary from island to island. Generally the islands eroded at the westerly "heads" and accreted at the northern side.
The coast of Holland is characterized for centuries by erosion in the north and the south and by a stable situation in the central part. The erosion was strongest near 's-Gravenzande and near Den Helder, where since 1600 an erosion of 1400 m, respectively 1500 m was ascertained. From Zandvoort to Castricum the coastline is rather stable after 1600. This division in three sections is confirmed by the detailed coastal measurements of the last one and a half century. South of Scheveningen the erosion is 0.35 m/year. Between Scheveningen and Egmond aan Zee there is an accretion of 0.25 m/year and north of Egmond aan Zee there is an erosion of 0.92 m/year.
In the Wadden area the coast was eroded since 1600. The development of the tips of the islands was highly variable. In the last century especially Texel and Vlieland showed strong erosion rates. On Terschelling and Ameland there was erosion in the central part and accretion on the west side. Schiermonnikoog did accrete in the last century.

processes



DEN HELDER
ALKMAAR
BEVERWIJK
IJMUIDEN
HAARLEM
AMSTERDAM
DEN HAAG
ROTTERDAM
Q 2
Q 4
Q 5
Q 8
P 6
P 15
Q 13
P 18
GEOMORFOLOGIE VAN DE NEDERLANDSE KUSTWATEREN
Middenblad middle sheet
GEOMORPHOLOGY OF THE DUTCH COASTAL WATERS
Schaal scale 1 : 250 000
MACRO ELEMENTEN LARGE ELEMENTS
ZEEBODEM SEABOTTOM
A helling slope < 1 : 1000
ONDERZEESE OEVER COASTAL SLOPE
B helling slope 1 : 100 - 1 : 1000
C helling slope > 1 : 100
BANK OF RUG BANK OR RIDGE
D hoogte height 1 - 10 m
TERRAS TERRACE
F helling slope < 1 : 1000
EBDELTA EBB DELTA
G helling slope < 1 : 1000
H helling slope 1 : 100 - 1 : 1000
J helling slope > 1 : 100
GETIJDEGEUL TIDAL CHANNEL
grens onzeker of bedekt met meso element*
boundary uncertain or covered by a medium element
diepste deel deepest part
* bij bedekking wordt het macro raster weggelaten.
* when covered, the large element screen is omitted.
MESO ELEMENTEN MEDIUM ELEMENTS
ZANDGOLVEN SANDWAVES
1 hoogte height > 6 m
2 hoogte height 4 - 6 m
3 hoogte height 2 - 4 m
GEÏSOLEERDE RUG ISOLATED BAR
4 met aanduiding van aantal with indication of number
ONDIEPTE SHOAL
5 beneden laagwater subtidal
PLAAT SHOAL
6 tussen laag- en hoogwater tidal
7 boven hoogwater high tidal
SCHAAR EBB OR FLOOD CHANNEL
DIVERSEN VARIOUS
vaargeul navigation channel
stellrand escarpment
stroomrichting direction of flow
hoog punt (m t.o.v. N.A.P.) high point
diep punt (m t.o.v. N.A.P.) low point
dieptelijn (m t.o.v. N.A.P.) depth contour
ZEEWERING SEA-DEFENCE
dijk dike
duinen dunes
strandhoofden groynes
strandpaal met km aanduiding beachpost with km indication
lodingsdiagram sounding diagram
Dienst der Hydrografie
Rijkswaterstaat
samenstelling en kartografie: compilation and cartography:
RIJKSWATERSTAAT Directie Noordzee Meetkundige Dienst
's-Gravenhage 1986 voorlopige uitgave

fig 1.1

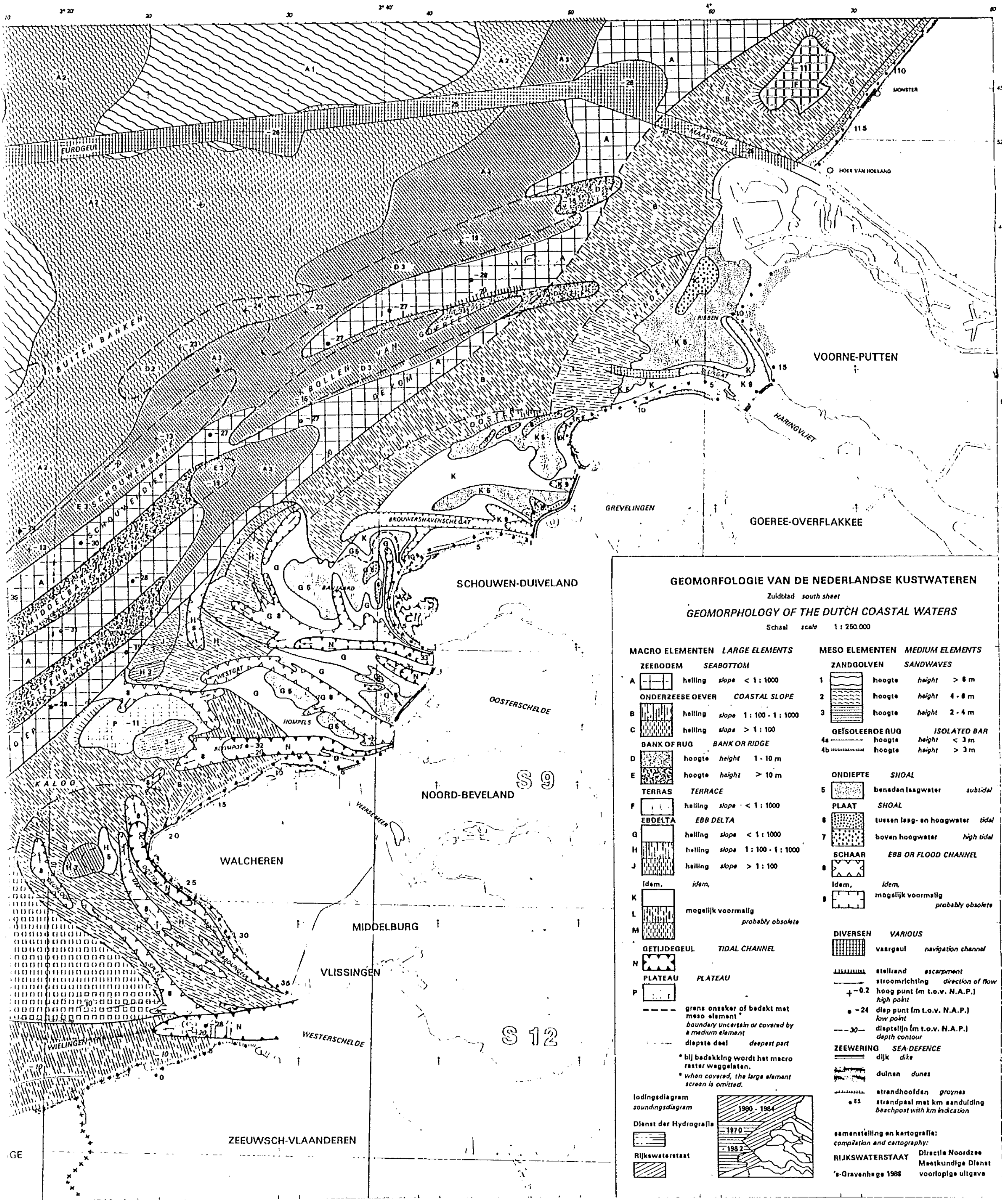

GEOMORFOLOGIE VAN DE NEDERLANDSE KUSTWATEREN
Zuidblad south sheet
GEOMORPHOLOGY OF THE DUTCH COASTAL WATERS
Schaal scale 1 : 250.000
MACRO ELEMENTEN LARGE ELEMENTS
ZEEBODEM SEABOTTOM
A helling slope < 1 : 1000
ONDERZEESE OEVER COASTAL SLOPE
B helling slope 1 : 100 - 1 : 1000
C helling slope > 1 : 100
BANK OF RUG BANK OR RIDGE
D hoogte height 1 - 10 m
E hoogte height > 10 m
TERRAS TERRACE
F helling slope < 1 : 1000
EBDELTA EBB DELTA
G helling slope < 1 : 1000
H helling slope 1 : 100 - 1 : 1000
J helling slope > 1 : 100
Idem, idem,
K
L mogelijk voormalig probably obsolete
M
GETIJDEGEUL TIDAL CHANNEL
N
PLATEAU PLATEAU
P
grens onzeker of bedekt met meso element *
boundary uncertain or covered by a medium element
diepste deel deepest part
* bij bedekking wordt het macro raster weggelaten.
* when covered, the large element screen is omitted.
MESO ELEMENTEN MEDIUM ELEMENTS
ZANDGOLVEN SANDWAVES
1 hoogte height > 6 m
2 hoogte height 4 - 6 m
3 hoogte height 2 - 4 m
GEÏSOLEERDE RUG ISOLATED BAR
4a hoogte height < 3 m
4b hoogte height > 3 m
ONDIEPTE SHOAL
5 beneden laagwater subtidal
PLAAT SHOAL
6 tussen laag- en hoogwater tidal
7 boven hoogwater high tidal
SCHAAR EBB OR FLOOD CHANNEL
8
Idem, idem,
9 mogelijk voormalig probably obsolete
DIVERSEN VARIOUS
vaargeul navigation channel
steilrand escarpment
stroomrichting direction of flow
hoog punt (m t.o.v. N.A.P.) high point
diep punt (m t.o.v. N.A.P.) low point
diepteliin (m t.o.v. N.A.P.) depth contour
ZEEWERING SEA-DEFENCE
dijk dike
duinen dunes
strandhoofden groynes
strandpaal met km aanduiding beachpost with km indication
lodingsdiagram soundingsdiagram
Dienst der Hydrografie
Rijkswaterstaat
1980 - 1984
1970
1982
samenstelling en kartografie: compilation and cartography:
RIJKSWATERSTAAT Directie Noordzee Meetkundige Dienst
's-Gravenhage 1986 voorlopige uitgave
EUROGEUL
MAASGEUL
BUITENBANKEN
BOLLEN VAN DE GOEREE
SCHOUWENBANK
MIDDELBANK
KALOO
WESTGAT
HOMPELS
ROOMPOT
BROUWERSHAVENSCHE GAT
SLIJKGAT
HARINGVLIET
RIBBEN
MONSTER
HOEK VAN HOLLAND
VOORNE-PUTTEN
GREVELINGEN
GOEREE-OVERFLAKKEE
SCHOUWEN-DUIVELAND
OOSTERSCHELDE
NOORD-BEVELAND
WALCHEREN
MIDDELBURG
VLISSINGEN
WESTERSCHELDE
ZEEUWSCH-VLAANDEREN
S 9
S 12

fig 1.2

BIJLAGE 2a : Kustsegmenten ; morfometrie

kustgedeelte (sector)	segment	strand (GLW:gemiddeld laagwaterlijn; GHW:gemiddeld hoogwaterlijn)							gem. duin-breedte (m)
		expositie GLW (kompas-richting)	gem. breedte strand (m)	gem. breedte droge strand (m)	gem. breedte natte strand (m)	gem. hoogte GLW (m NAP)	gem. hoogte GHW (m NAP)	gem. helling natte strand	
Zeeuws-Vlaanderen (1)	1.5	327 - 341	177	19	157	-1,75	1,96	1:42	165
	1.4	338 - 21	244	33	211	-1,77	2,00	1:56	-
	1.3	327 - 349	175	13	163	-1,77	2,04	1:43	-
	1.2	350 - 10	182	25	157	-1,78	2,07	1:40	-
	1.1	9 - 27	-	-	-	-	-	-	-
Walcheren (zuid) (2)	2.5	224	-	-	-	-	-	-	-
	2.4	214	100	6	95	-1,76	1,97	1:26	-
	2.3	225 - 241	167	24	142	-1,70	1,90	1:40	170
	2.2	209	90	2	90	-1,66	1,85	1:26	-
	2.1	217 - 236	133	17	116	-1,63	1,80	1:33	90
Walcheren (noord) (3)	3.3	323 - 64	174	74	135	-1,43	1,59	1:45	376
	3.1	340	-	-	-	-	-	-	-
Schouwen (zuid) (4)	4.2	216 - 270	125	30	96	-1,23	1,42	1:36	1917
	4.1	270 - 303	144	48	95	-1,19	1,38	1:37	468
Schouwen (noord) (5)	5.2	307 - 4	418	203	214	-1,14	1,34	1:83	660
	5.1	343 - 15	138	39	98	-1,17	1,30	1:40	161
Goeree (6)	6.3	251	145	53	93	-1,01	1,34	1:40	400
	6.2	251 - 10	218	83	134	-1,00	1,33	1:59	424
	6.1	338 - 37	412	251	160	-0,95	1,30	1:83	479
Voorne (7)	7.2	237 - 270	162	81	81	-0,72	1,20	1:42	972
	7.1	290 - 298	452	294	158	-0,66	1,15	1:91	1510
Slufter (8)	8.1	-	-	-	-	-	-	-	-
Europoort (9)	9.1	-	-	-	-	-	-	-	-
Delfland (10)	10.12	305 - 324	137	65	74	-0,65	1,04	1:43	490
	10.11	310 - 319	96	35	61	-0,69	1,02	1:36	540
Rijnland (zuid) (11)	11.1	293 - 312	105	69	67	-0,73	0,96	1:40	2102
IJmuiden (12)	12.4	292	97	36	63	-0,74	0,92	1:38	4943
	12.3	270 - 287	281	189	92	-0,74	0,92	1:56	4802
	12.2	231 - 306	188	93	95	-0,75	0,90	1:59	-
	12.1	277 - 291	114	45	70	-0,78	0,85	1:43	2298
Noord-Holland (midden)(13)	13.1	276 - 282	114	42	71	-0,81	0,77	1:45	2704
Noord-Holland (noord) (14)	14.3	282 - 299	-	-	-	-	-	-	-
	14.2	273 - 290	103	46	57	-0,84	0,63	1:38	587
	14.1	274 - 290	-	-	-	-	-	-	-
Texel (15)	15.1	138 - 256	-	-	-	-	-	-	-
	15.2	269 - 303	148	59	87	-0,91	0,67	1:55	1388
	15.3	301 - 321	133	53	81	-1,01	0,74	1:45	1396
	15.4	340 - 25	128	39	84	-1,07	0,78	1:45	-
Vlieland (16)	16.1	258 - 328	-	-	-	-	-	-	-
	16.2	312 - 326	148	57	91	-1,08	0,78	1:50	-
	16.3	338 - 126	159	83	76	-1,08	0,78	1:42	1149
Terschelling (17)	17.1	221 - 317	-	-	-	-	-	-	-
	17.2	280 - 350	455	297	156	-1,11	0,82	1:83	2167
	17.3	338 - 348	224	98	126	-1,15	0,86	1:63	1889
	17.4	357 - 57	625	480	145	-1,17	0,89	1:71	-
	17.5	-	-	-	-	-	-	-	-
Ameland (18)	18.1	262 - 24	537	321	223	-1,08	0,79	1:125	807
	18.2	356 - 24	564	329	233	-1,10	0,81	1:125	1004
	18.3	352 - 356	218	72	146	-1,13	0,85	1:71	1363
	18.4	354 - 2	290	123	170	-1,16	0,88	1:83	-
	18.5	10 - 45	-	-	-	-	-	-	-
Schiermonnikoog (19)	19.1	274 - 0	-	-	-	-	-	-	1646
	19.2	350	614	422	194	-1,26	0,98	1:83	-
	19.3	350 - 25	-	-	-	-	-	-	-
Rottum (20)	20.1	-	-	-	-	-	-	-	-
	20.2	-	-	-	-	-	-	-	-

BIJLAGE 2b : kustsegmenten ; korrelgrootte

kustgedeelte (sector)	segment	klassen gemiddelde korrelgrootte onderwateroever (tot 1 km uit de kustlijn) (μm)	gemiddelde korrelgrootte droge strand (μm)	gemiddelde korrelgrootte natte strand (μm)	gemiddelde korrelgrootte strand (μm)	gemiddelde korrelgrootte zeereep (μm)
Zeeuws-Vlaanderen (1)	1.5	250-500	258	208	233	236
	1.4	250-500	225	210	218	212
	1.3	250-500	200	183	192	-
	1.2	250-500	-	-	-	188
	1.1	250-500	165	120	143	218
Walcheren (zuid) (2)	2.5	250-500	-	-	-	-
	2.4	250-500	325	275	300	-
	2.3	250-500	280	245	263	254
	2.2	125-250	295	225	260	-
	2.1	250-500	290	235	263	248
Walcheren (noord) (3)	3.3	125-250	323	304	314	294
	3.1	125-250	-	-	-	-
Schouwen (zuid) (4)	4.2	125-250	220	210	215	214
	4.1	125-250	205	200	203	211
Schouwen (noord) (5)	5.2	125-250	213	222	218	210
	5.1	125-250	208	215	212	209
Goeree (6)	6.3	125-250	-	-	-	248
	6.2	250-500	245	252	249	240
	6.1	125-250	218	198	208	201
Voorne (7)	7.2	125-250	223	162	193	194
	7.1	-	203	132	168	169
Slufter (8)	8.1	-	-	-	-	-
Europoort (9)	9.1	-	-	-	-	-
Delfland (10)	10.12	125-250	268	260	264	234
	10.11	63-125;125-250	273	266	270	214
Rijnland (zuid) (11)	11.1	125-250	252	269	261	218
IJmuiden (12)	12.4	125-250	207	354	281	201
	12.3	125-250	240	305	273	238
	12.2	-	-	-	-	192
	12.1	125-250	269	261	265	229
Noord-Holland (midden) (13)	13.1	125-250;250-500	275	315	295	246
Noord-Holland (noord) (14)	14.3	250-500	-	-	-	-
	14.2	125-250;250-500;500-2000	292	289	291	243
	14.1	250-500	-	-	-	-
Texel (15)	15.1	125-250	-	-	-	-
	15.2	125-250	199	232	216	197
	15.3	125-250;250-500	221	255	238	202
	15.4	125-250	-	-	-	-
Vlieland (16)	16.1	125-250	180	245	213	197
	16.2	125-250	200	274	237	199
	16.3	125-250	215	193	204	194
Terschelling (17)	17.1	125-250;250-500	205	220	213	206
	17.2	125-250	191	209	200	187
	17.3	125-250	185	248	217	188
	17.4	125-250	180	229	205	190
	17.5	125-250	-	-	-	192
Ameland (18)	18.1	125-250	165	190	178	-
	18.2	125-250	178	193	186	178
	18.3	125-250	178	187	183	165
	18.4	125-250	178	185	182	168
	18.5	125-250	-	-	-	170
Schiermonnikoog (19)	19.1	125-250	173	182	178	162
	19.2	125-250	168	173	171	164
	19.3	125-250	160	168	164	161
Rottum (20)	20.1	125-250	-	-	-	-
	20.2	-	-	-	-	-

On the Dutch coast both tidal currents as wave induced currents have an influence on the coastline. Generally the influence of the tide is most important on deep water, and decreases towards the coastline, while the influence of the wave action increases near to the coastline. In the inlets in the Delta and Wadden area the tidal influence is also significant near to the coastline.
Wind is also an important parameter for coastal development. Wind causes currents and waves and also directly influences the formation of dunes. The coastal processes are highly connected with the waterdepth. Because of the morphological differences and the hydro-dynamic distribution of energy along the coastline there is a variation in the effect of the various processes on sediment transport. A gradient in sediment transport may occur, causing differences in erosion and accretion.

dynamics

The coastline as a border between sea and land is continuously changing. These changes happen on various scales, both in time and space. Besides natural causes, along the Dutch coast there is also a significant antropogene influence.
On a scale of several centuries the whole coast is influenced by the relative sea level rise (0.20 m/century in the last decades), climatic changes and the availability of sediment. In the period between 3700 B.C. to 700 B.C. the sea level rose with approx. 3 meters. Because there was sufficient supply of sand the coast accreted in this period.
On the scale of 10 - 100 years the natural coastal development is, besides the natural trend, determined by temporary minor climatic changes and by more or less cyclic processes, like the movement of horizontal sand waves along the coast and the movements of the tidal channels in the estuaries. Examples are the sandwaves along the coast of Walcheren. They cause coastline changes up to 300 m and move northward with a celerity of approx. 45 m per year.
The human influence on this time scale is caused by dune management, construction of dikes and big civil works, like the closure of the estuaries in the Delta area (Deltaplan). Because of the Deltaplan significant changes did occur in the southwest of the Netherlands. Because of the decreased tidal influence and consequently the (relatively)increased influence of the waves on the former outer delta sandbanks parallel to the coast were formed, which partly dry during low water.
Also other civil works have big influences, like the harbor moles of IJmuiden. There influence can be observed on a wide part of the central coast of Holland. Changes on the short term (a few years) are caused by small variations in hydraulic an meteorologic conditions and minor human actions, like beach nourishments.

Situation in 1990; type of coast and location of the coast

Technical report nr. 2 for Coastal Memorandum

F.M.J. Hoozemans and P. van Vessum
Rijkswaterstaat (DGW), Den Haag

Summary and Conclusions

Coastal maintenance; costs of basic maintenance

Technical report nr. 3 for Coastal Memorandum

M.M. Schoor
Rijkswaterstaat (DGW), Den Haag

approach

This Technical Report is a summary of an investigation commissioned by Rijkswaterstaat and the Union of Waterboards to the coastal maintenance costs in the Netherlands. The original investigation was done by mr. A. Burger of the Delft Hydraulics Laboratory. The whole Dutch sandy coast was divided in 82 units with a length varying from 1 to 16 km. The inventory was made in this units. Within a unit it is assumed that the costs are homogeneous. The inventory covered the years 1975-1984. All coast are corrected for inflations. The base year for the presented data is 1984. For the dune coast (47 units) is has been investigated if there was initial erosion and the type of protection. Initial erosion is the average erosion of the dune foot in the period 1964-1984. The type of protection can be natural dunes, dunes with groins, dunes with dunefoot protection or dunes with pile-groins. If in one unit several types of protection were present, only the most important one was used.

present management

The Dutch coast is managed by 16 different authorities. Some of them ar part of Rijkswaterstaat (65 % of the coastline), others managing-authorities are waterboards (35 % of the coastline). In the next years the whole management of the coast will be done by waterboards, except the management of the Wadden islands, which will remain a management area of Rijkswaterstaat.
Generally the management was directed to follow the coastal dynamics. The aim of coastal maintenance work was to decrease the negative effects of natural changes in the coastline. Mainly the purpose of maintenance was to decrease the amount of future maintenance.
The management philosophy in the last years was, trying to maintain the most seaward row of dunes, and trying to keep as much as possible sand in this row. A movement of this row of dunes in a landward direction was generally accepted.
The following kind of maintenance were distinguished:

bottom protection	replacement and expansion of existing bottom protection works (mattresses and other stone filters)
groins	penetration of stones with asphalt, repair and reconstruction of the groins
pile-groins	replacement of piles, placing piles deeper in the sand, extend the length of the groin (landward, because of erosion)
beach	cleaning up the beach, maintenance of monuments
dune foot	placing fences and screens (reed, brushwood) for trapping eolian sand transport
dunefoot protection	repair of stones, penetration of stones with asphalt
dune	planting beach grass, fencing, placing screens for trapping eolian transport, maintenance of paths
seadike	repair of stone protection, maintenance of grass cover
beach wall	repair of masonry work

basic maintenance costs

The basic costs (including taxes, technical overhead, but excluding beach nourishment) were 13 million US $ per year. The main part (10 million US $) is spent on the dune coast. Following table gives the distribution:

	length (km)	Delta 108	Holland 124	Wadden 121	Total 353
dunes	254	1.8	4.1	4.4	10.3
beach-plains	38	-	-	0.6	0.6
dikes	34	0.7	1.4	-	2.1
others	27	0.3	0.2	0.1	0.6
total	353	2.8	5.6	5.1	13.4

table 3.1: Total yearly maintenance costs of the sandy coast in million US $.
Beach-plains are at the end of islands, without any land behind them
Dikes along estuaries, etc. are not included

The basic cost can also expressed as average cost per meter of coastline. This allows comparison of coasts. However one has to take into account that there is a wide deviation in the costs. The standard deviation is of the same order as the average. The costs per meter are given in the next table:

	length (km)	Delta 108	Holland 124	Wadden 121	Total 353
dunes	254	27	39	54	40
beach-plains	38	-	-	16	16
dikes	34	33	111	-	60
others	27	15	22	43	18
total	353	26	45	42	38

table 3.2: Yearly maintenance costs of the sandy coast in US $/meter

From table 3.1 and 3.2 one may conclude that:

* The basic maintenance costs in the Delta area are lower than in the rest of the Netherlands
* Also the total maintenance costs of seadikes is low, they are relatively very expensive
* The basic maintenance costs of beach-plains are very low.

the dune coast

A part of the deviation in the costs of basic maintenance of the dune coast can be explained by the presence of protection works, like groins. Especially the costs of groins are considerably. This is mainly caused by the fact that in eroding coastal sections groins have to be enlarged in a landward direction, and also need protection at both sides when the beach lowers. Maintenance of pile-groins is considerably cheaper, but more expensive than a beach without groins. From table 3.3 one may conclude that:

* The basic maintenance costs of dunes with groins is three times as high as undefended dunes
* The basic maintenance costs of dunes with pile-groins is 1.5 times as high as undefended dunes

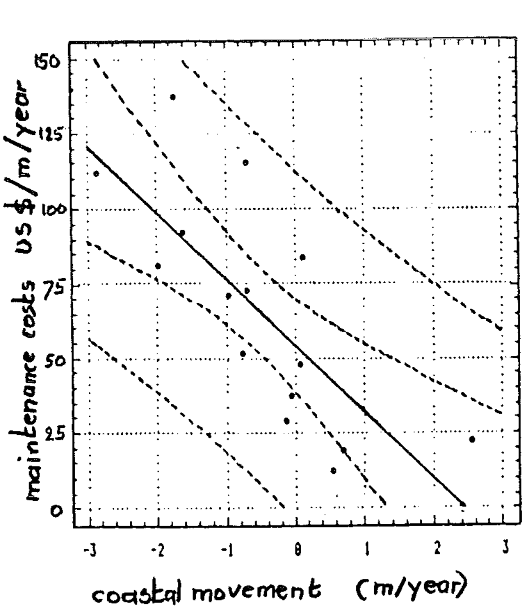
	Delta cost	Delta km	Holland cost	Holland km	Wadden cost	Wadden km	Total cost	Total km
undefended dunes	17	30	21	33	34	61	25	157
dunes with groins	38	20	69	38	112	21	72	79
dunes with pile-groins	32	17	23	1	-	-	32	18
whole coast	17	67	39	105	54	82	40	254

table 3.3: average basic maintenance cost of the dune coast in US $/meter/year

From a statistical analysis the differences between defended and undefended dunes are significant. The differences between dunes with groins and dunes with pile-groins are statistically not significant. This is probably caused by the fact that only a small part of the coast is defended with pile-groins.

Because the maintenance cost are mainly caused by the type of defense, it is investigated if there is a relation between the erosion rate and the costs of maintenance.
From a regression analysis follows that for dunes with groins the maintenance cost increase with 23 US$ per meter coastline per year for an increase of the erosion rate with 1 m/year. These costs are mainly caused by the fact that high cost are necessary for lengthening the groins in a landward direction at an eroding beach.
Regression analysis of undefended dunes gives a fully different figure. Here the maintenance costs do not depend on the erosion rate. However one should consider that nearly all the highly eroding beaches in the Netherlands are in one way or another protected. For undefended dunes 30 - 90 % of the costs are caused by placing fences and screens, as well as planting grass. This is done both on accreting and eroding beaches.

The increase of erosion on the maintenance costs of pile rows could not be investigated, because not enough data are available to make a statistical analysis.



The relation between erosion and maintenance costs for dunes with groins

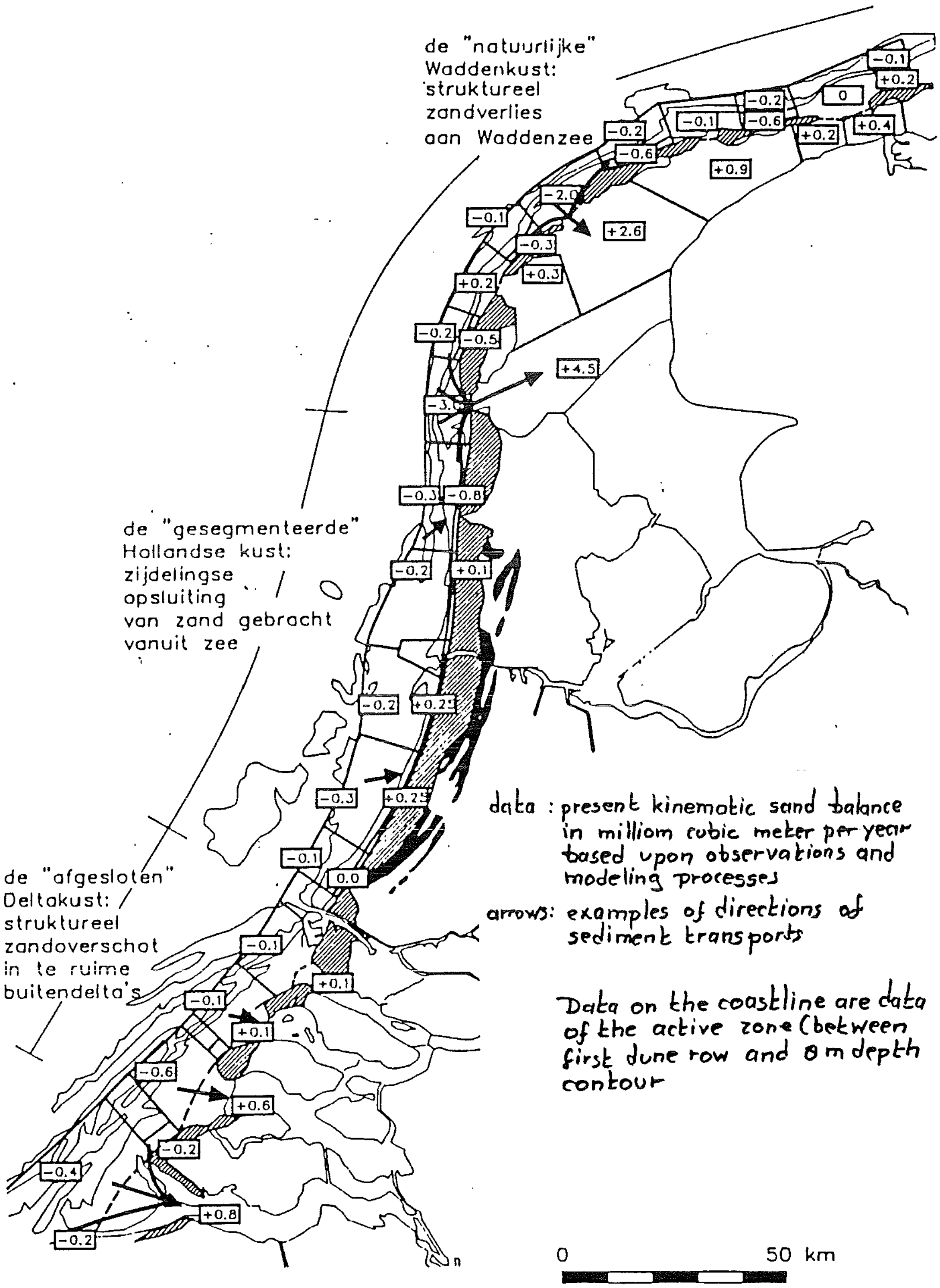
regression equation: $y = 55 + 22x$

$r = -0.76$

Coastal predictions; predicted coastlines 1990-2090

Technical report nr. 5 for Coastal Memorandum
M.J.F. Stive
Delft Hydraulics Laboratory

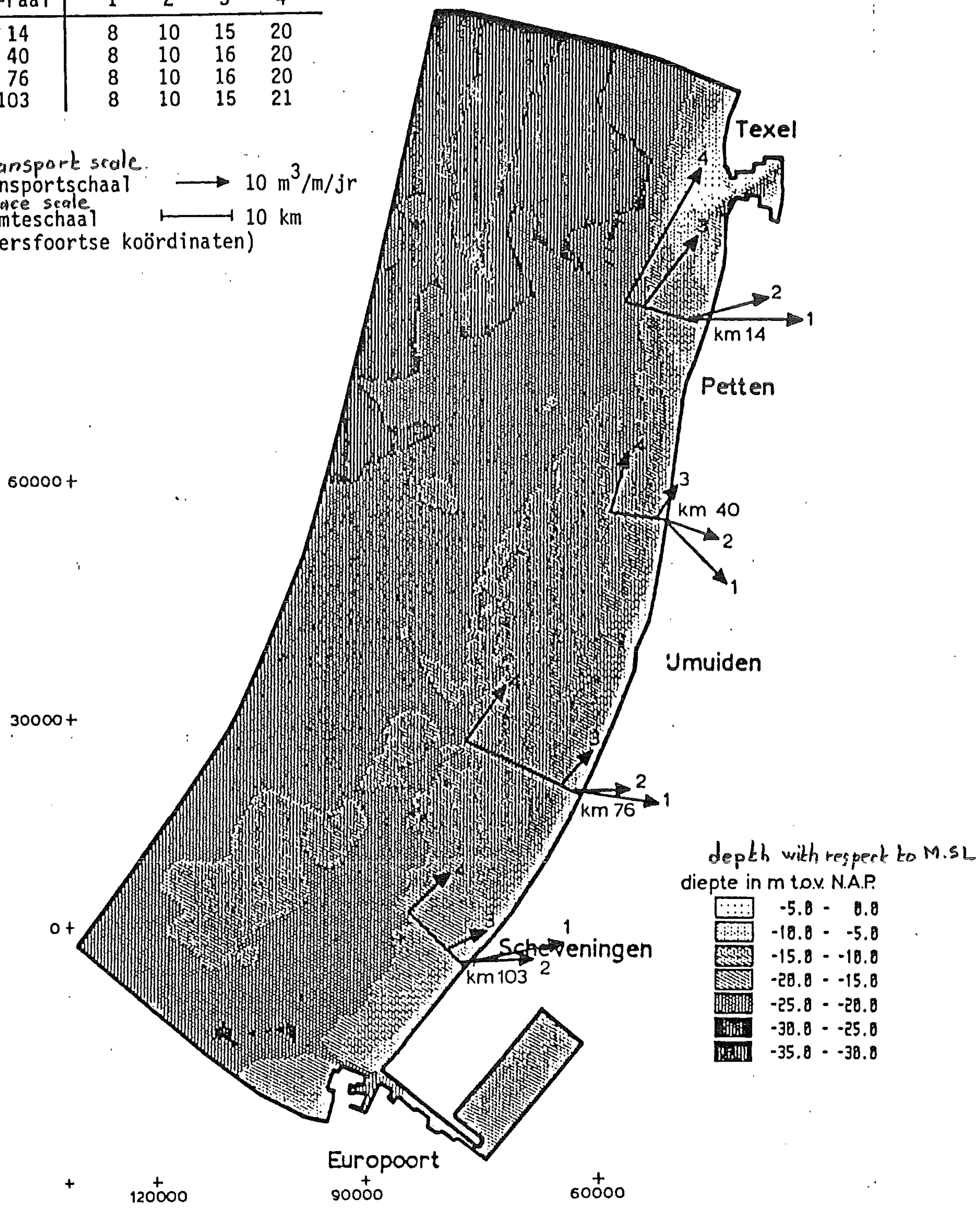
Summary and Conclusions



Figuur 1 Huidige zandbalans van het Nederlandse kustsysteem
sand balance of the Dutch coast

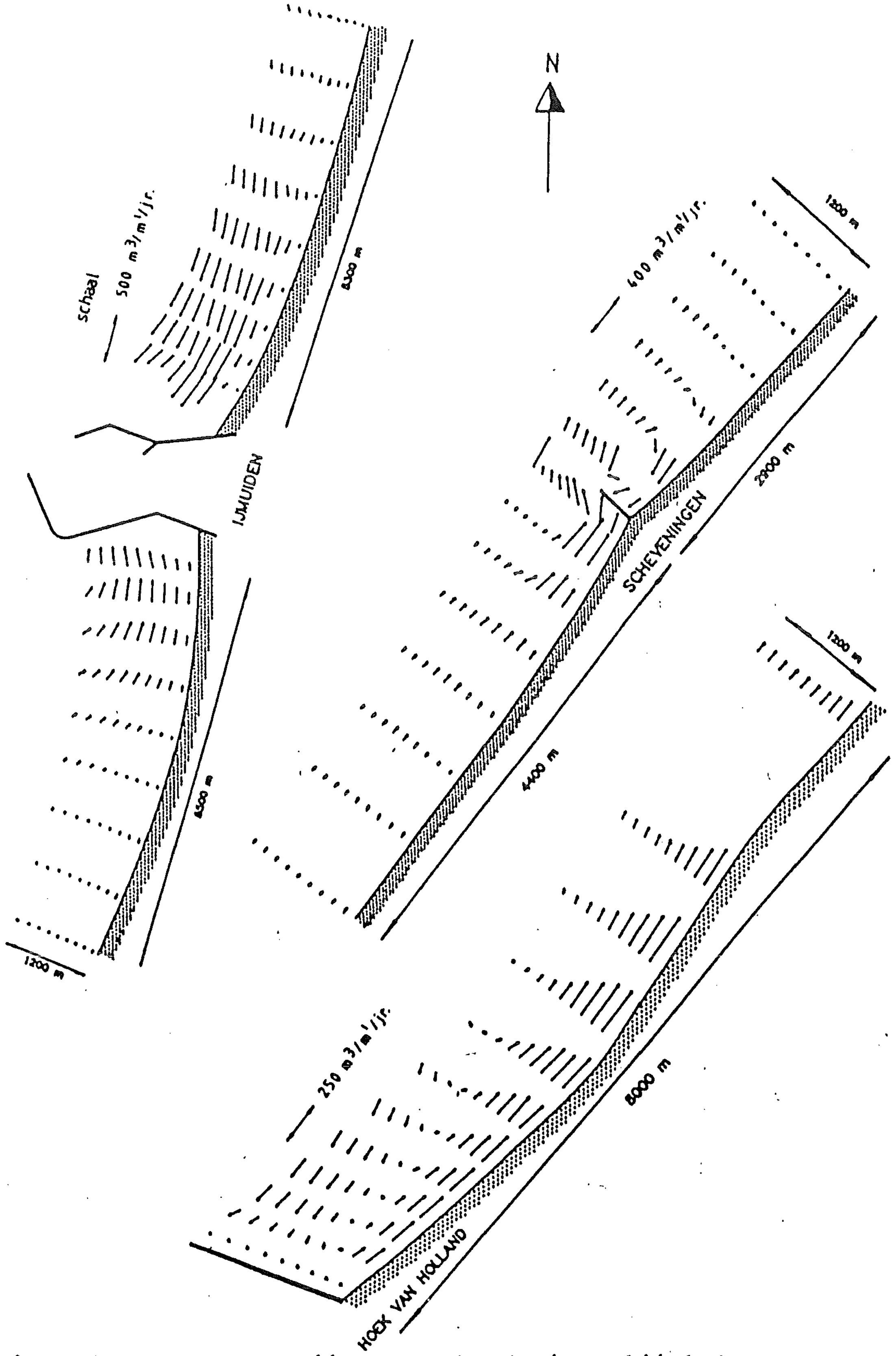
RSP-raai	vektor waterdiepte (m) 1	2	3	4
km 14	8	10	15	20
km 40	8	10	16	20
km 76	8	10	16	20
km 103	8	10	15	21

transport scale
transportschaal ⟶ 10 m^3/m/jr
space scale
ruimteschaal ⊢—⊣ 10 km
(Amersfoortse koördinaten)



Netto sedimenttransport on the inshore zone of the coast of Holland

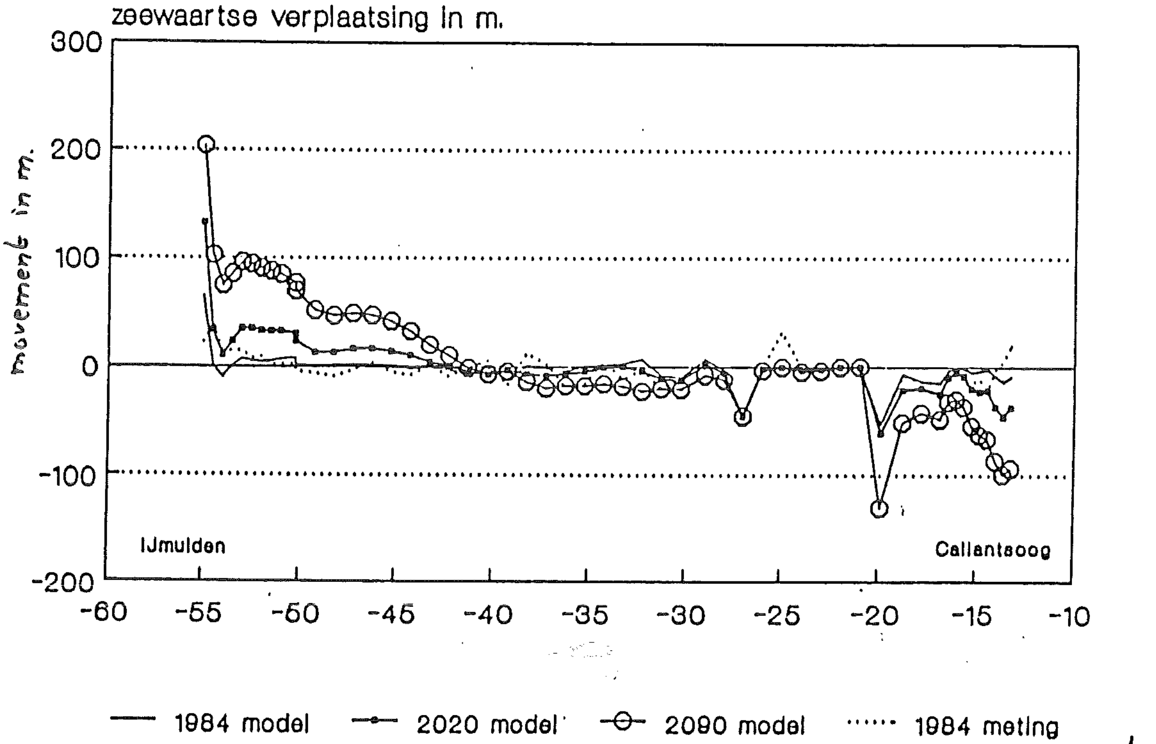
Figuur 7 Netto sedimenttransporten op de onderzeese oever van de Hollandse kust



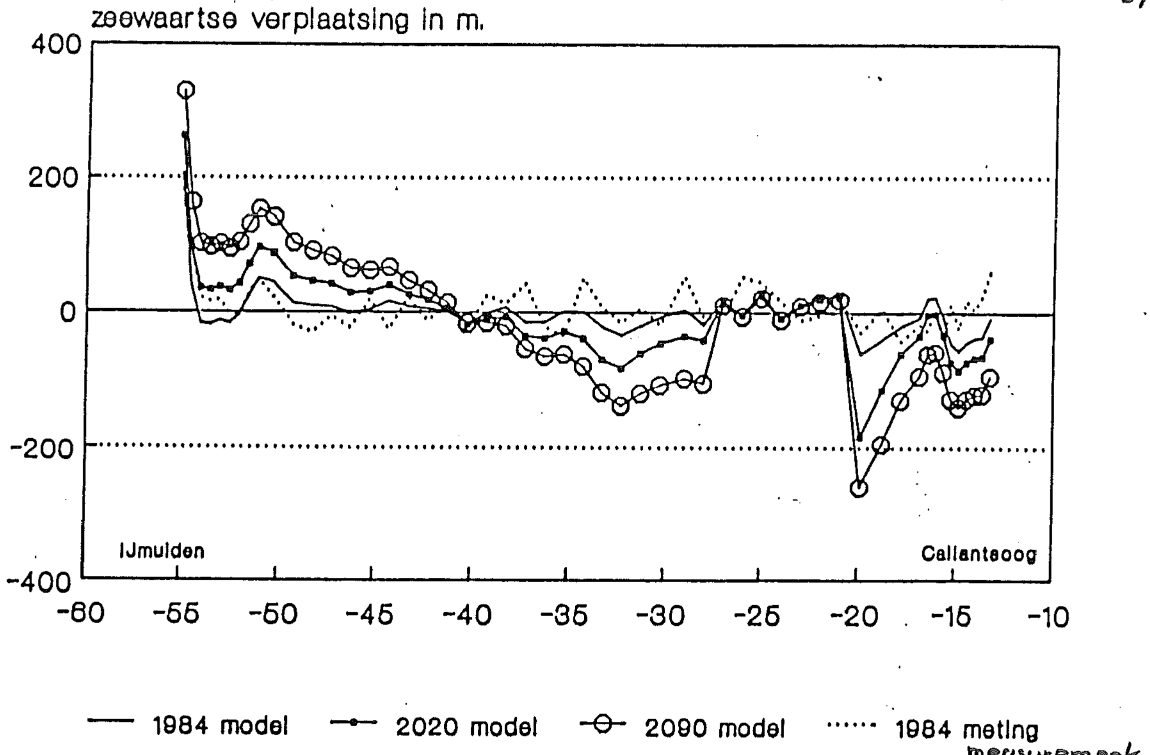
Figuur 8 Resultaten getijtransportberekeningen bij de havens langs de Hollandse kust

computed sediment transport caused by tidal currents

CALLANTSOOG - IJMUIDEN
STRANDLIJN -Beach line
verplaatsingen tov de situatie in 1973 movement relative to 1973



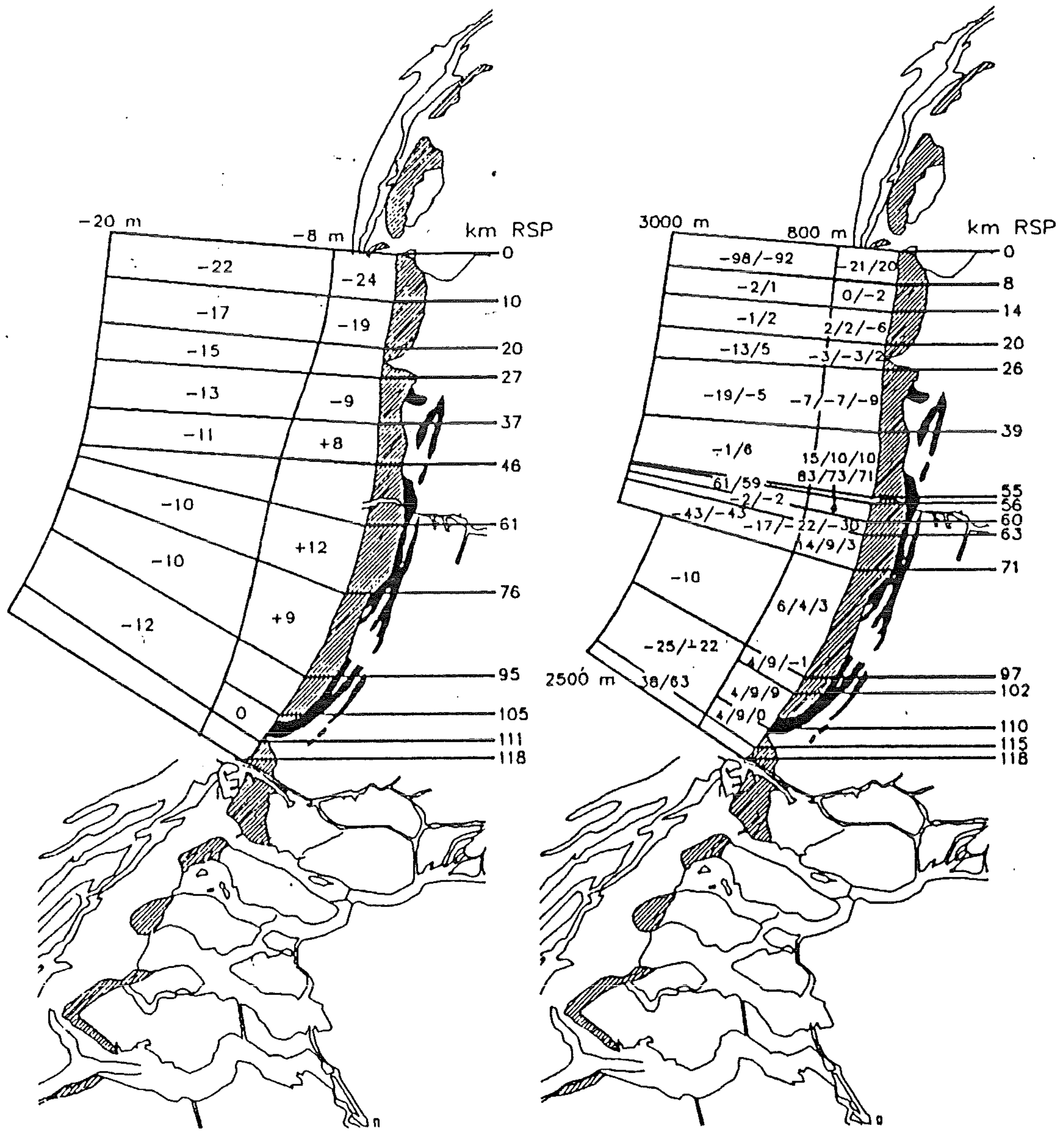
CALLANTSOOG - IJMUIDEN
VOOROEVERLIJN Inshore line
verplaatsingen tov de situatie in 1973 movements relative to 1973



Figuur 9 Resultaten "twee-lijn"-kustontwikkelingsberekeningen Callantsoog-IJmuiden

calculation of coastal development calculations with the 2-lines model volumetric changes in $m^3/m/yr$

inhoudsveranderingen in $m^3/m/jr$



kombinatie van voorspelling en rekonstruktie met het konceptuele model voor uniforme kustsekties

computed data

observations from yearly data

x/y/z:

waarnemingen volgens Jarkus- en doorlodingenbestand van 1965–1985;

x: verschil 1965–1985 - difference 1965-1985

y: lineaire trend '65–'70–'75–'80–'85 - linear trend

z: geschatte trend '70–'75–'80–'85 - estimated trend

comparison computed data and observations

Figuur 11 Vergelijking van waargenomen en gemodelleerde sedimentbalans van de Hollandse kust

Groins and pile-groins

Technical report nr. 12 for Coastal Memorandum

Hendrik J. Verhagen
Rijkswaterstaat (DWW), Delft

Evaluation of their influence of morphology

Along the Dutch coast in the last centuries a great number of groins and (after 1965) a minor number of pile-groins were built. Pile-groins are groins which consist of a row of piles only, with a spacing of approx. 30 cm between the piles. In the south of the Netherlands also stone groins with piles on top are present. In the Technical Reports these groins are not called pile groins, because there morphological effect is equal to normal groins. The purpose of the groins was to decrease the coastal erosion. Besides the construction of sea-dikes groins were during many years the only possibility to act against coastal erosion. many groins were planned and built based upon experience and evaluation of coastal behavior over a relatively short period of time.

The theoretical concepts developed in the last 20 years were not able to give good quantitative descriptions of the behavior of a coastline with groins over a long period.

By analyzing the behavior of groins along the Dutch coast, in this report it is tried to say something on the effectiveness of the existing groin fields and on the question if it is useful to build new groins.

It has been ascertained that groins are influencing the coastline in the different ways, by influencing the wave-induced longshore current and by influencing the attack of the tidal current on the coast. In the last case the working of a beach groin is comparable to a river groin.

From the analysis followed that on those locations were groins kept the tidal current away from the coastline (thus acting like a river groin), they functioned generally very well. These groins are quite costly, because deep scouring holes are formed in front of the groin, which require on their turn a heavy stone protection of the head of the groin. Maintaining these groins is compulsory. Removal of the groins will automatically cause withdrawal of the coastline.

On locations where groins act as resistance elements to the longshore current, there effectiveness is less clear. In those cases were the <u>resulting</u> longshore current is small (e.g. because of wave impact from various directions) groins were not able to influence the coastal erosion. Perhaps the coastal profile became somewhat more steep. Removal of these groins will therefore causing a somewhat more gentle coastal profile, causing some temporary erosion. At most coastal sections where these kind of groins exists this temporary erosion cannot be allowed, because the dune-row is already very narrow. Removal of the groins is therefore only possible after a thorough and detailed study of the local coastal morphology.

In those cases were a clearly dominant wave direction occurs, groins decrease the erosion, especially above the low-water line. Generally this causes lee-erosion. Lee-erosion can be combated by building more groins. The object of decreasing the erosion-rate is attained, but the costs are quite high, because of the necessity to construct more "lee-groins". Removal of these groins is dissuaded, because the coastline has been adapted to the new situation (is more steep). Removal will always lead to increased erosion.

Hardly any new groins will have to be constructed in The Netherlands. Construction of new groins can be considered along coastal sections with heavy attack by tidal currents. But all coastlines in The Netherlands with such an attack are already protected by groin-fields.

In case of surf-induced longshore currents the construction of new groins should only be considered if a clearly dominant wave direction exists. However in those cases periodically beach nourishments might be economically more attractive, especially along longer (straight) coastal sections.
In those cases where no dominant wave direction exists (waves enter the coast more or less perpendicular) groins should not be considered.

A general problem of groins is that they are quite static, and cannot follow the dynamic movement of the coastline, especially in case of moving longshore sand waves.

The effectiveness of pile-groins proved to be minimal. Only in those cases with a clearly dominant wave direction, the had some influence on the erosion, mainly by decreasing the effects of lee-erosion. The effects of the field are distributed over a longer distance. The general conclusion is that pile-groins should hardly be considered as a means to prevent erosion.

More research to the behavior of groins is not recommended. Research is only advised on the interaction between existing groins and beach nourishment works. It is expected that the life-time of a nourishment may be somewhat longer in an existing groin field. No quantitative data on this subject are available yet.