CHAPTER 43

THE HISTORY OF THE DUTCH COAST IN THE LAST CENTURY

by W.T. Bakker[1] and D.Sj. Joustra[2]

ABSTRACT

The purpose of this paper is

1. Publishing some available coastal measurements and computations of more than local importance
2. Investigation on the influence of groynes in practice.
3. Investigation on the motion of the gullies in the outer deltas.

The following conclusions are drawn

1. The gross littoral drift along the dutch coast is in the order of 1.5 to 2 mln m^3/year, (computed with the CERC-formula) the resulting net drift is mostly within the order of accuracy of the computation.
2. The erosion of the areas with groynes was much less than the erosion of the adjacent areas, partially this effect is due to lee-side scour but mainly to decreased erosion in the protected area.
3. The gullies in the outer deltas of the Wadden mainly turned clockwise, which is probably the direction of the resultant transport there.

INTRODUCTION

The dutch coast consists of three parts (fig. 1)

1. The Rhine-Schelde Delta
2. The uninterrupted coast of Holland
3. The Wadden area

It is a sandy coast ($D_m \approx 200\mu$), the tidal difference varies between 4 m near the Belgium border, down to 1.5 m near Hook of Holland, to 1.3 m near den Helder and then up again to 1.8 m near the German Island Borkum. The gully systems in the Rhine-Schelde delta and that of the inlets between the Wadden Islands in the North have quite a different shape, since the tidal basins are quite different. In the South the basins are rectangular with an open short side towards the sea and in the North they are rectangular with the long side parallel with the coast-line, this side is bordered by the Wadden Islands with narrow inlets in between. Therefore the Wadden coast can be compared with lagoon coasts, as they occur in many parts of the world. The Wadden Sea is a tidal flat, which is submerged during every high tide. Most information will be given about the Holland coast and the Wadden area, as DRONKERS [1] stresses the research in the Delta-area.

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The main purpose of this paper is to supply data, which enables international comparison. This paper gives largely a summary of many reports of regional study-branches of Rijkswaterstaat, made over a period of about 50 years. From the former papers, covering the same subject, special attention is asked for WENTHOLT (1912)[2] who investigated especially the effect of groynes, van VEEN (1936) [3], who treated the origin of the Dutch coast and the shape of the gullies, van BENDEGOM [12], [22], [4], who investigated the hydraulic laws for the motion of the gullies, van STRAATEN [5], who considered the directional effects of winds, waves and currents and concluded that the sand drift must be strong (west to east) along the northern barrier islands and small between Katwijk and Texel, EDELMAN and EGGINK [6] who drew morphological conclusions from the curvature of the coast. PER BRUUN and GERRITSEN [7] treated the cross section of gullies and the stability of coastal inlets. BIJKER and SVAŠEK [8] give a treatise about IJmuiden harbour. The following paper gives more recent data than WENTHOLT, the conclusions of van VEEN, van STRAATEN, EDELMAN and EGGINK are reviewed in the light of modern theories about sand transport of CERC, BIJKER and SVAŠEK, making use of tidal computations.

BEACH MEASUREMENTS

Figure 2 and 3 show the erosion and accretion of the low-tide line, the high-tide line and the dune foot in periods of 10 year. First the 10-year average of each of these lines was determined, for instance 1856 - 1865, the distance between two successive 10-year averages is plotted in fig. 2 and 3. It is indicated where groynes, seawalls or harbour moles are present and when they are constructed.

The area of the Holland coast (fig. 2) is highly influenced very much by the building of the harbour moles of Hook of Holland and IJmuiden in 1870. The low-tide line shows the influence of climatologic changes [5], overall much erosion between 1860 and 1880 and accretion between 1880 to 1900. These periodical changes are attenuated very much in the line of the dune foot and here one finds the general trend as indicated by EDELMAN and EGGINK [6] a general accretion of ½ m/year, with erosion near Hook of Holland and den Helder (fig. 4). The Hondsbossche Seawall lies at the moment much further seaward than the adjacent dunes because of the erosion of the dunes.

The influence of the harbour moles (length 1400 m) of IJmuiden built in 1870 is shown in detail in fig. 5. Fig. 2 shows, that the low-tide line and high-tide line obtain stability about 1900, but that the dune foot changes up to 1930. Fig. 5 gives an upper view on the 5-years average of the low-tide and high-tide line (seaward scale exagerated with respect to the longshore scale). The total gain was 9.10^6 m^3 in the North and 6.10^3 m^3 in the South [8].

In 1965 the harbour moles were enlarged to 3000 m. Fig. 5 shows on the right hand side the change of the mean of the low-tide and high-tide line since 1965. Now the accretion on the South side is more than on the North side. Although a changing of the wave climate may have been of influence [5], [8], also the fact must be important, that at the moment an extensive area with only small currents prevents the entrainment of material from the surf zone around the head of the mole.

The changes of the Wadden Islands are shown in fig. 3. The changes at the ends are large compared to the changes in the middle of the islands, partly due to the changes in the gully-systems in the inlets, the silting up of a gully causes that a shoal grows together with the end of the island. After that, a sandwave along the coast is generated [9]. Obvious is the relatively large erosion on both ends of Texel. We shall return to this subject.

GROYNES

The Dutch groynes have a length of about 200 m, the distances between the successive groynes can be found from fig. 6 to 8 (about 200 m). In the considered area they are broad-crested stone structures, lying at about mean sea-level. In order to investigate the behaviour of groynes in practice three areas were considered, on which groynes were constructed during the period of the measurements South-Holland km 97 to 105 (fig. 6), North-Holland km 8 to 20 (fig. 7, derived from [11]) and Vlieland km 41 to 52 (fig. 8). Constructed is the 5-year average of the low-water line, (for instance 1858 to 1862 for 1860), the scale perpendicular to the reference-line is 10 times exagerated in fig. 8 and 20 times in fig. 6 and 7 with respect to the longshore direction. In each figure two successive lines are plotted together, the black fields show the erosion in 10 years, the grey fields the accretion.
The groynes built from 1853 - 1862 are plotted through the line of 1860, and so on. The hatched area gives the protected coastal area. Fig. 8 seems a striking proof of the benefit of groynes. The erosion near km 47 to 51 in 1860/70 can hardly be ascribed to the groynes 5 km away. The reduction of the erosion after the building of the groynes is quite clear. Of course, this does not mean that groynes are the most economic way of coastal protection.

The same kind of effect can be seen in fig. 6, 1860/70, although less convincingly. The influence of the lee-side scour plays here also a big role. A rough estimation of this lee-side scour (giving also a measure for the net littoral drift in this zone) about 100.000 m^3/year (erosion of about 2 m/year over 3 km). Less clear still is fig. 7. The Northern part of this area is subject to the movement of the Schulpengat, the Southern branch of the inlet of Texel. The lee-side scour on the Northern side can be observed clearly (km 20, 21, 1860 to 1880 etc.), and also the inverse the accretion near km 13, 14 between 1900 and 1910 on the luff-side.

Analysis of the effect of the groynes is very difficult. Comparison with unprotected parts of the beach has no sense, since groynes are constructed only on eroding beaches. A before- and after-comparison will be obscured by climatological changes (cf fig. 3, low-waterline)
We chose the areas of fig. 6, 7 and 8 for comparison (all eroding beaches, gradually more and more protected with groynes) and computed for each area for each 10-year period the mean erosion/year of the protected part and of the unprotected part (fig. 9a, b, c). Thus the erosion on the same area could be compared, when this

area was protected (later on) or not (in the beginning)
In order to eliminate local influences all three areas were put together and again the mean erosion per year of the protected and of the unprotected area were computed (fig. 9d). An impression of the climatological changes gives fig. 9e, in which the mean regression and progression per 10-year period of the low-tide line of the uninterrupted coast of Holland is shown. Only the relative changes are of importance. In fig. 9f finally the erosion of the protected part of fig. 9d is plotted against the erosion of the unprotected part, from which a considerable reduction of the erosion can be concluded. Although nearly all the considered unprotected areas were subject to lee-side scour, fig. 8 shows that the reduction is not mainly caused by that, but that the building of groynes reduced the erosion.

SAND TRANSPORT BY WAVES AND TIDES

Van STRAATEN [5] and EDELMAN and EGGINK [6] both give qualitative considerations about the sand transport by waves. Since their publications so many data have been collected, about the relation between the longshore component of the wave energy and the sand transport, that it is worthwhile to apply such formulae to the dutch coast, in order to obtain more quantitative conclusions. However, these conclusions can be not better than the available data the visual wave observations on the dutch light-vessels. These measurements from 1949 to 1957 have been statistically treated by DORRESTEIN [10], giving for each wave condition, (characterized by height, period and direction of the waves) the probability of occurrence.
From [10], the longshore component of the wave energy flux P_1 has been computed, defined by

$$P_1 = \frac{1}{8} \rho g \, H_{br}^{\ 2} \, C_{br} \sin \varphi_{br} \cos \varphi_{br}$$

in which ρg = specific weight water, H = wave height, C = wave celerity, φ = angle of wave incidence and the index br refers to the breaker zone.
The exact way of computation is treated in [14].
The accuracy is very low, because it is impossible to get an accurate significant H, C and φ in the breaker zone from visual wave data from a distance of 10 km. It was necessary to make a lot of assumptions [14]. The results are given in the table above fig. 12, and fig. 10 shows a probability distribution.
It is easy to compute from this the mean energy flux and the mean littoral drift Q using the CERC-formula, which can be transferred [14] in

$$Q^* = 2300 \, P_1 \qquad (Q^* \text{ in m}^3\text{/year, } P_1 \text{ in W/m'})$$

However, the used data and formulae are not accurate enough to justify this computation, also because the probability distributions are about symmetrical. Only along the Vlieland coast the resultant drift is significant (about ½ mln m^3/year).
The gross littoral drift (sum of transport in both directions) is found to be of the order of 1.5 to 2 mln m^3/year (thus about 1 mln m^3 in each direction).

Assuming for instance no influence of tides, the distribution of the littoral drift over the surf zone has been computed by an adapted method proposed by SVAŠEK [8], the way of computation is pointed out in another paper of this conference [13]. The result for Scheveningen is shown in fig. 11.

Considering which one is most important, the influence of waves or tides, in [15] and [16] the driving forces of waves and currents are investigated.

In order to get an impression of the influence of the tide, a tidal computation has been carried out with the numerical tidal model of which fig. 12 gives the scheme [19]. We assumed a gully system parallel and perpendicular to the coast On the ends the vertical tide was given, in the knots the vertical tide was computed and in the gullies the horizontal tide. The computerprogram was developed by BOOY according to the explicite leap-frog method, non-linear terms were considered, but Coriolis was neglected. In each gully at every time was computed $\sum_t Bvh. \Delta t$, in which B is the width of the gully, v the current velocity, h the water depth at that moment and Δt the time step. From this, the resultant currents, indicated in the upper figure of fig. 12 were found, about 3 cm/sec in the shallow regions and 6 cm/sec in the deeper regions. A computation, taking the tidal currents into account, based on a simplified BIJKER-method (cf [8]) is in preparation.

THE OUTER DELTAS

The boundary conditions for the motion of the coast are given by the inlets. Therefore it is important to consider the motion of the gullies. Fig. 13 and 14 give the motion of the gullies in the inlets of Texel and Vlie respectively. The arrows give the motion of the gullies since the last recording. What is known about these deltas?

The cross-section of the gullies reasonably fit in with the theory PER BRUUN and GERRITSEN [7]. As a variation HARING[20] found, that the quotient of the tidal volume (ebb + flood) and the total profile area of the gully was about 55 cm/sec, except for the inlet of Texel and the inlet of the Vlie, where it was 75 cm/sec (cf DRONKERS [1]). This higher velocity might be some influence of littoral drift. Van VEEN [21] states, that the largest gullies are mainly orientated in the direction of the greatest water gradient, averaged per tide. If the tidal amplitude is everywhere the same (which is often not the case), this direction is perpendicular to the cotidal lines (fig. 17) the gradient between A and B is much larger than between A and C.

Two reasons can be given for erosion of the coast near these inlets As has been pointed out by van BENDEGOM [22], the submerging of the Wadden during flood tide takes place with larger velocities than the retreating of the water over the shoals during ebb-tide. Thus, the water looses here a part of its sediment, which makes, that the Wadden shoals reach an equilibrium at about the mean water level. Now the relative sea-level rising in the Netherlands during the last 20 centuries was about 6 cm/century, which would result in a "sand hunger" of the Wadden shoals of about 1 mln m^3/year (distributed over all inlets).

However, this will mostly be confined to finer sediments (D_m about 100-150 μ).

The second reason is that the water during the flood tide gets an acceleration, entering the inlet, but that during the ebb-tide it gets a retardation and this will give a jet-stream with vortexes on its side. Therefore in the gullies near the beaches, there is surplus of flood discharge and in the center gully a surplus of ebb discharge. The flood erodes the beaches and the ebb gives an outer delta, which can reach up to mean sealevel (Noorderhaaks in inlet of Texel. This delta gives a shelter against these waves, which would transport material away from the delta. As the waves come alternately from both directions, this process reinforces the erosion of the beaches near the inlets. Thus the erosion of Texel could be rather well explained [23]. After some time an equilibrium should be reached.

Two reasons can be given too for the motion of the gullies a meandering effect and a longshore sand drift. It will be clear, that the resulting sand drift perpendicular to the gully can not be derived from the velocity of the gully because of the meandering effect. The big sand transport in the gullies can be attributed to the high current velocities and this meandering.

The motion of the gullies and the effects of their orientation has been investigated (fig. 16). The line in the middle of each of the bars gives the orientation of the gully in course of time. The width of the bar gives the development of representative cross section. As far as they were known, the time-integrated slope of the water-surface as a function of the orientation have been mentioned (fig. 16[1]). It gives no evidence about the van Veen-theory.

In fig. 18, derived from fig. 16, the turning of the gullies in the dutch Wadden delta is shown. Mainly they turn clockwise, although very slowly and there is a slight indication (correlation coeff.,24), that the large gullies turn slower than the small ones.

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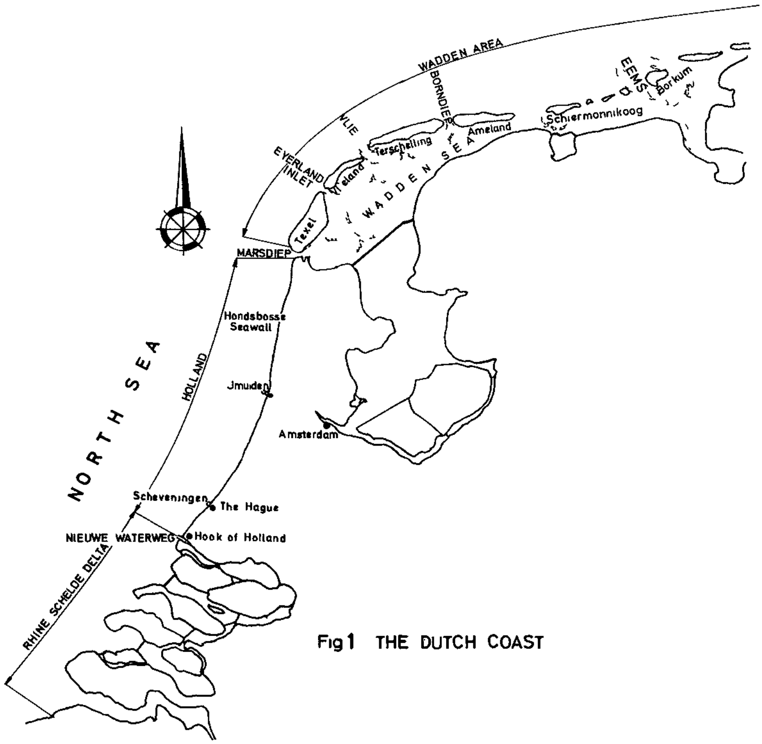


Fig 1 THE DUTCH COAST

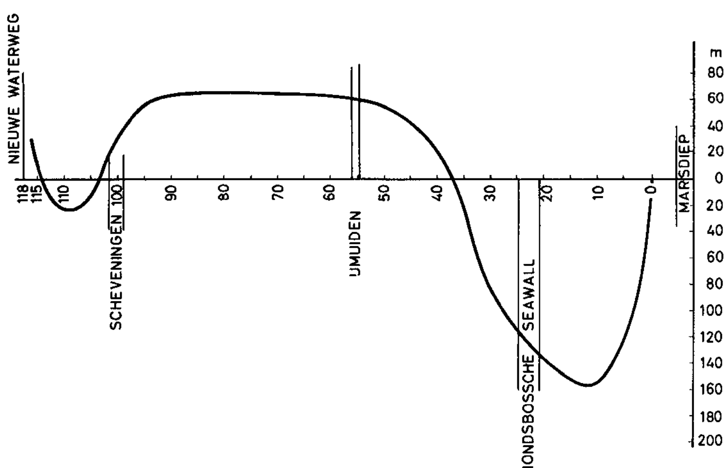


Fig 4 MEAN DUNE-FOOT MOVEMENTS FROM 1860 TILL 1960 BETWEEN NIEUWE WATERWEG AND MARSDIEP

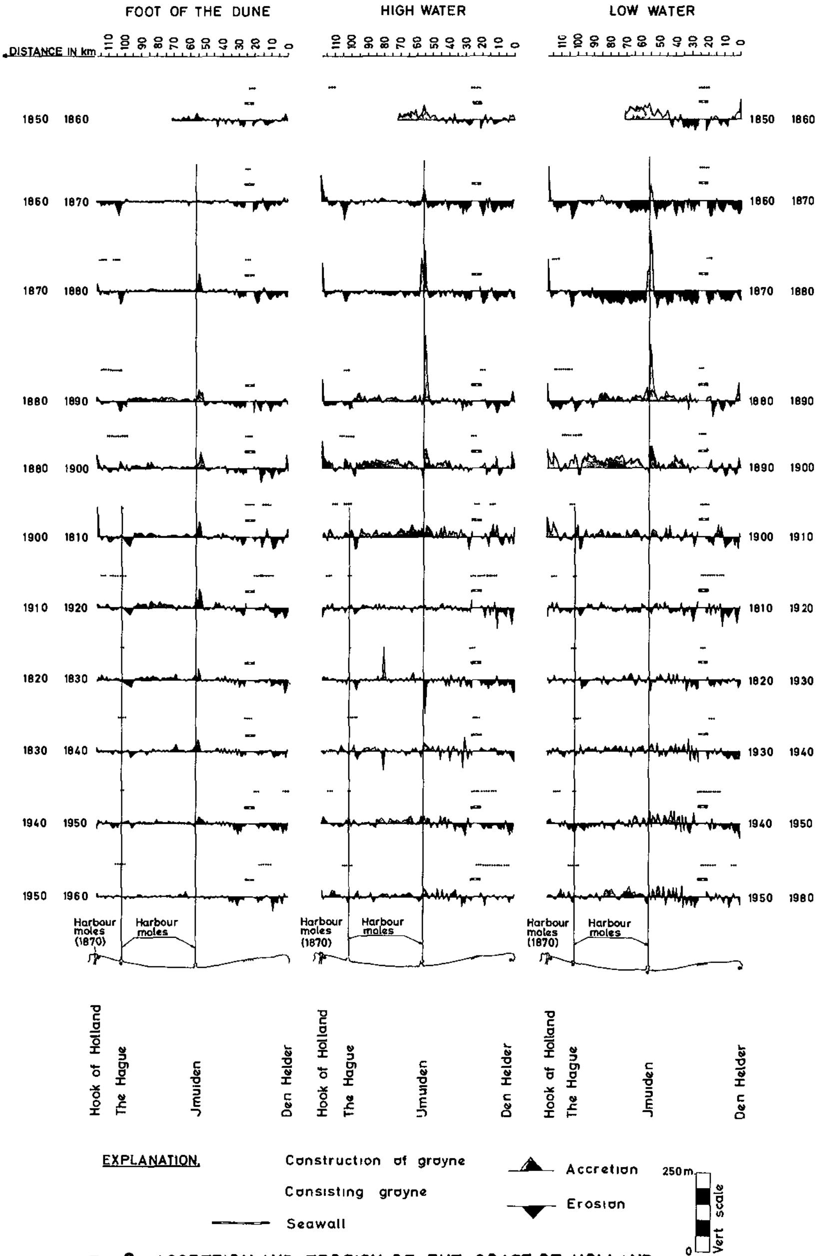


Fig 2 ACCRETION AND EROSION OF THE COAST OF HOLLAND

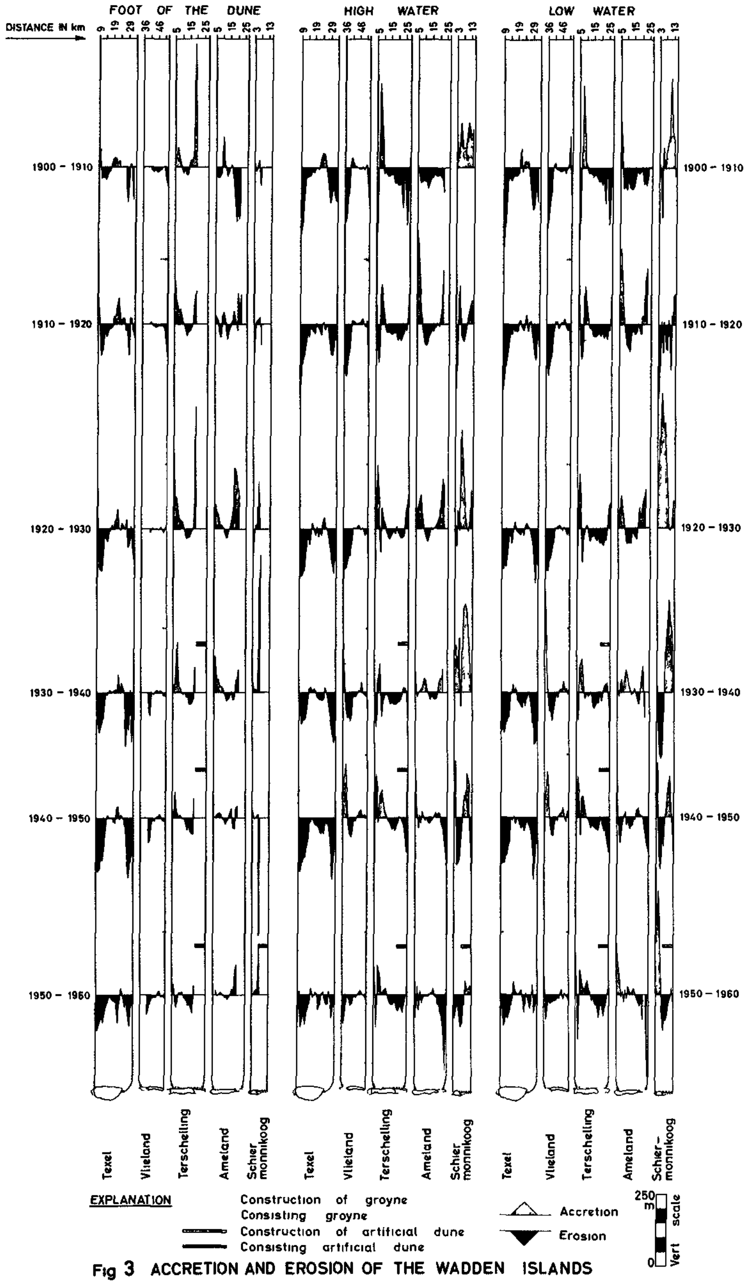


Fig 3 ACCRETION AND EROSION OF THE WADDEN ISLANDS

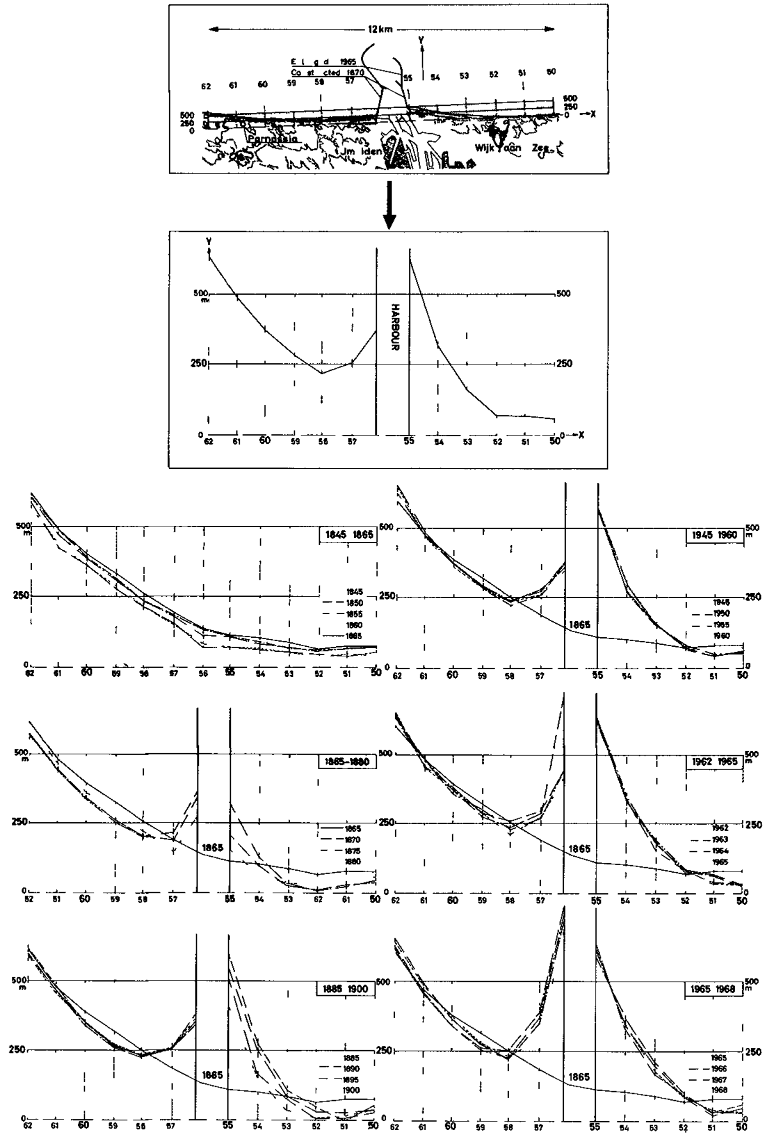


Fig 5 DEVELOPMENT OF THE WATERLINE NEAR IJMUIDEN

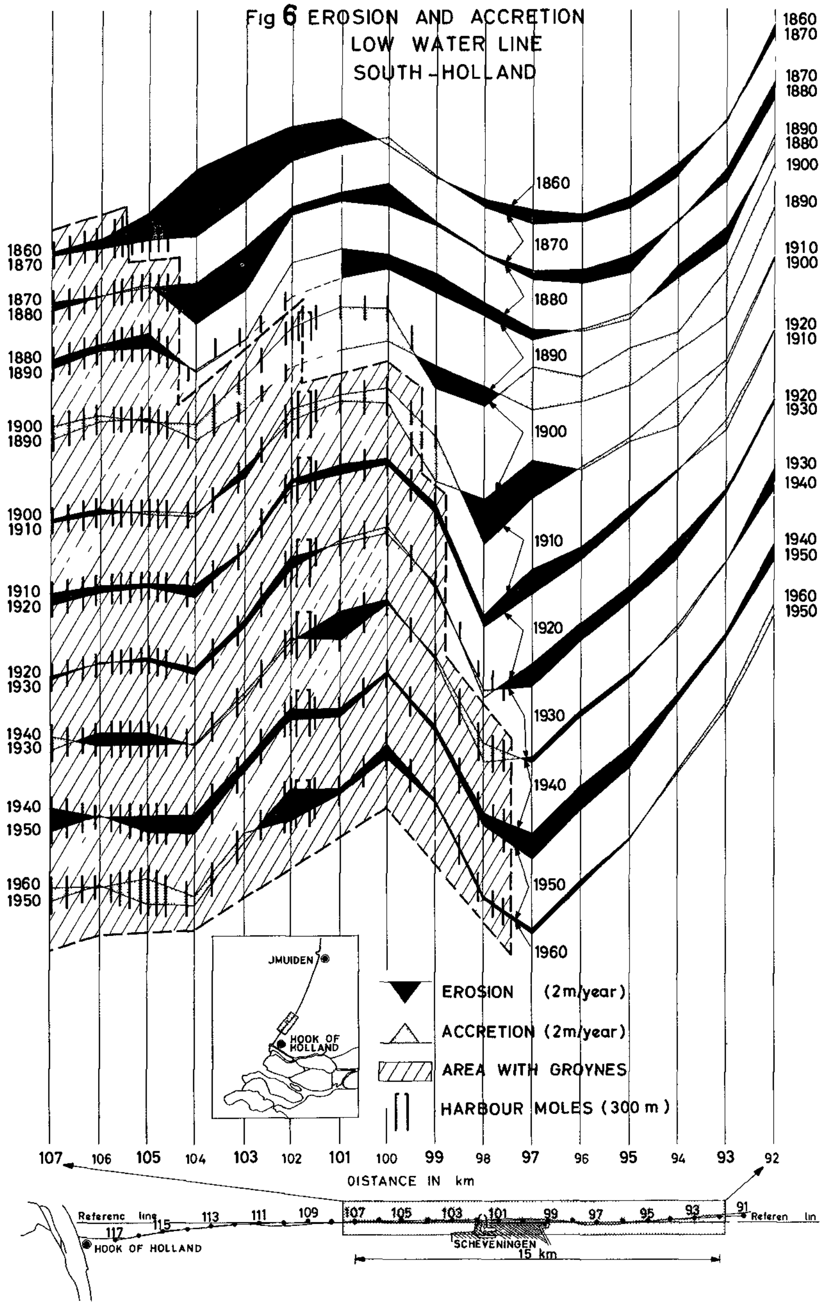


Fig 6 EROSION AND ACCRETION
LOW WATER LINE
SOUTH-HOLLAND
EROSION (2m/year)
ACCRETION (2m/year)
AREA WITH GROYNES
HARBOUR MOLES (300 m)
JMUIDEN
HOOK OF HOLLAND
DISTANCE IN km
SCHEVENINGEN
15 km

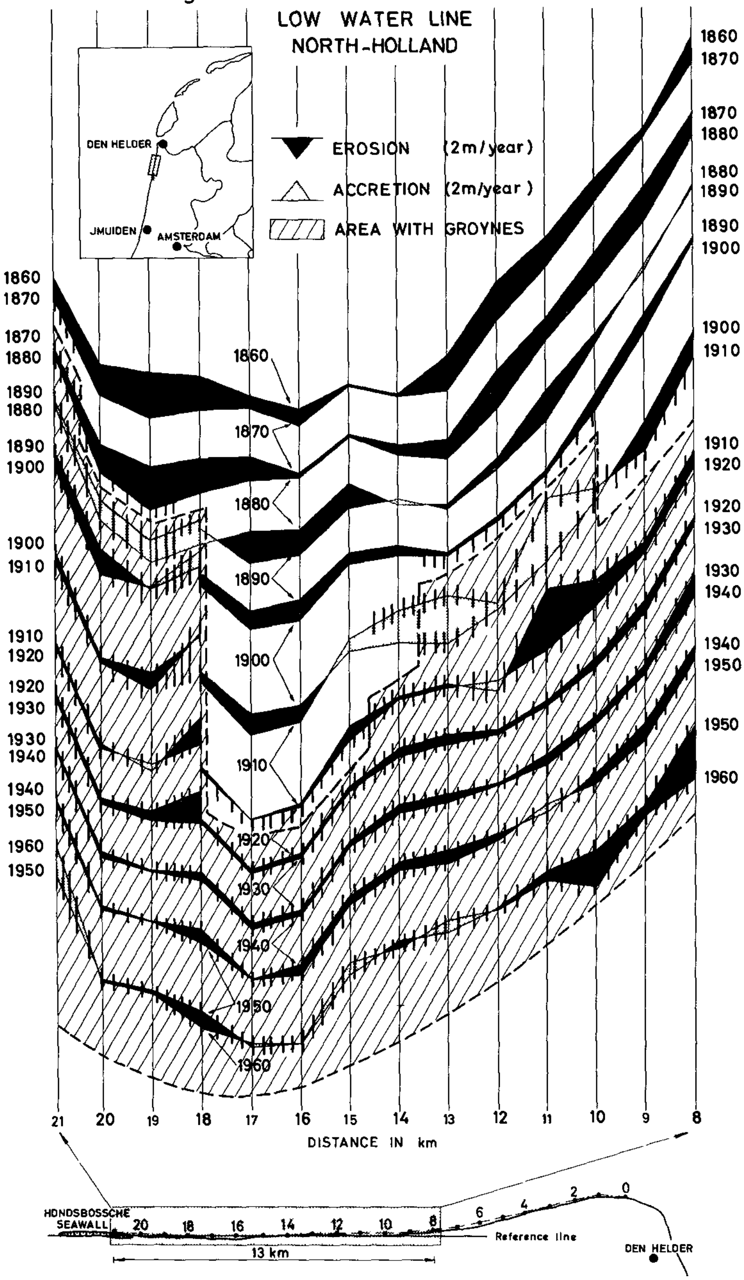


Fig 7 EROSION AND ACCRETION LOW WATER LINE NORTH-HOLLAND

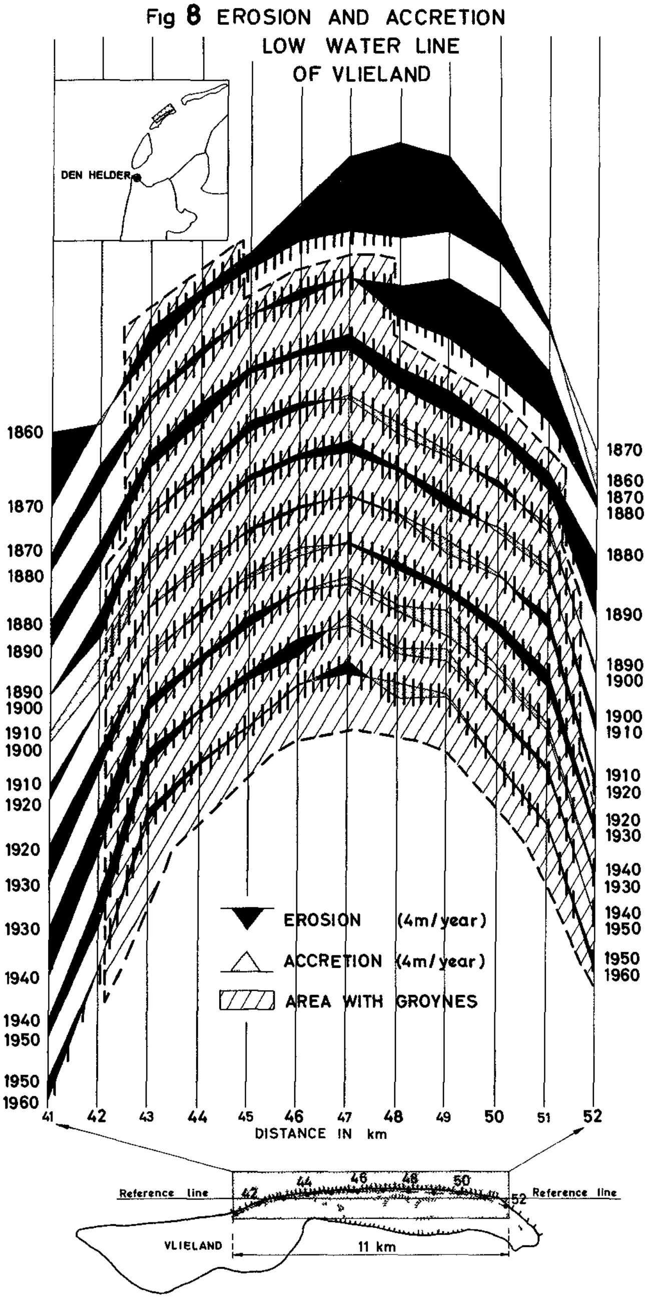


Fig 8 EROSION AND ACCRETION LOW WATER LINE OF VLIELAND

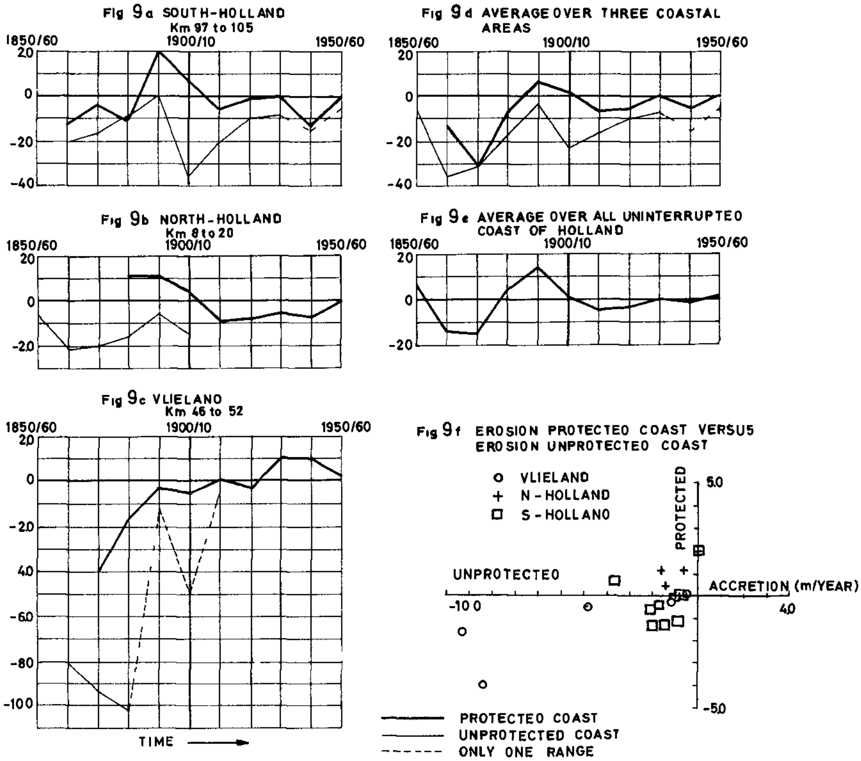


Fig 9 COMPARISON OF EROSION IN m/YEAR OF PROTECTED AND UNPROTECTED AREAS

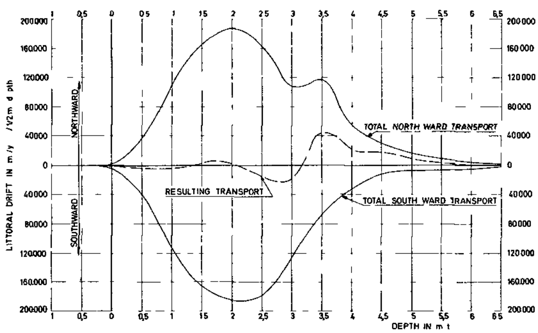


Fig 11 Littoral drift near The Hague in m / year between two successive depth contours with 1/2 m difference in depth

Site	Orientation of the coast with respect to the North
Vlieland	060° - 240°
Texel	030° - 210°
IJmuiden	015° - 215°
Scheveningen	045° - 225°

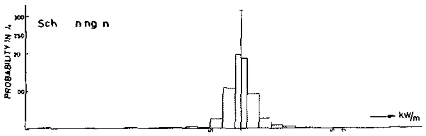


Fig 10 THE PROBABILITY DISTRIBUTION OF THE LONGSHORE COMPONENT OF THE WAVE ENERGY FLUX NEAR SCHEVENINGEN

Probability in ‰ of P_1 (from North to South)

Min. 1)	-33	-31	-25	-23	-19	-17	-15	-13	-11	- 9	- 7	- 5	- 3	- 1	-
Max. 1)	-31	-29	-23	-21	-17	-15	-13	-11	- 9	- 7	- 5	- 3	- 1	0	0
Vlieland	-	-	-	-	-	-	.03	.27	.25	1.2	.82	8.9	32	166	210
Texel	-	-	-	.13	-	.13	.25	.50	.76	2.4	4.3	19	56	203	287
IJmuiden	-	.52	.17	.24	.42	.70	-	1.1	3.1	8.7	3.4	26	120	159	323
Scheveningen	.13	-	-	-	.27	-	.92	1.6	.35	5.6	2.0	26	119	200	355

Probability in ‰ of P_1 (from South to North)

Min. 1)		0	1	3	5	7	9	11	13	15	17	21	23	29	0
Max. 1)	0	1	3	5	7	9	11	13	15	17	19	23	25	31	
Vlieland	529	155	53	29	11	5.4	1.4	1.0	1.1	.84	.81	.34	.42	.12	261
Texel	401	196	70	31	6.1	4.2	2.1	.61	.84	.47	.24	.23	-	-	312
IJmuiden	299	272	86	15	4.0	.88	1.3	.15	-	-	-	-	-	-	379
Scheveningen	316	188	92	28	10	6.0	.56	2.9	-	.56	.22	.44	-	-	329

1) Lower limit (min.) and Upper limit (max.) of P_1 expressed in KW/m'

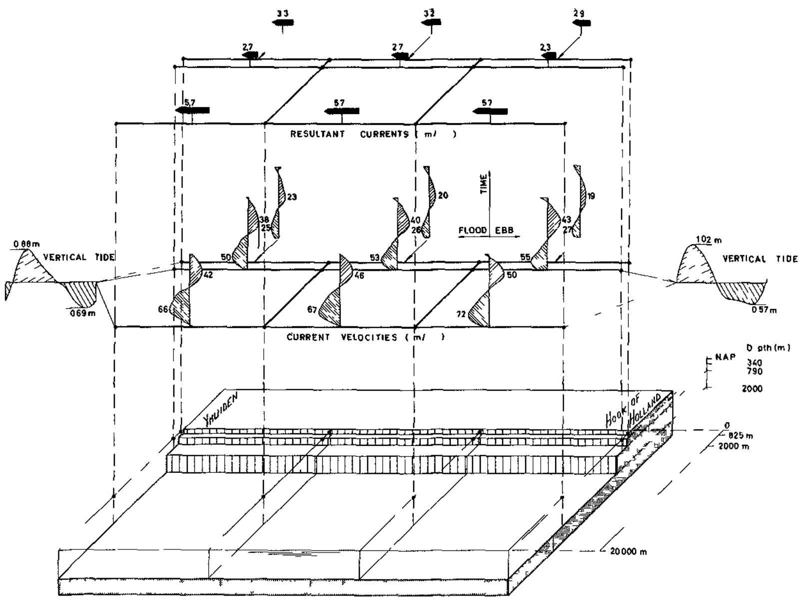


Fig 12 TIDAL MODEL

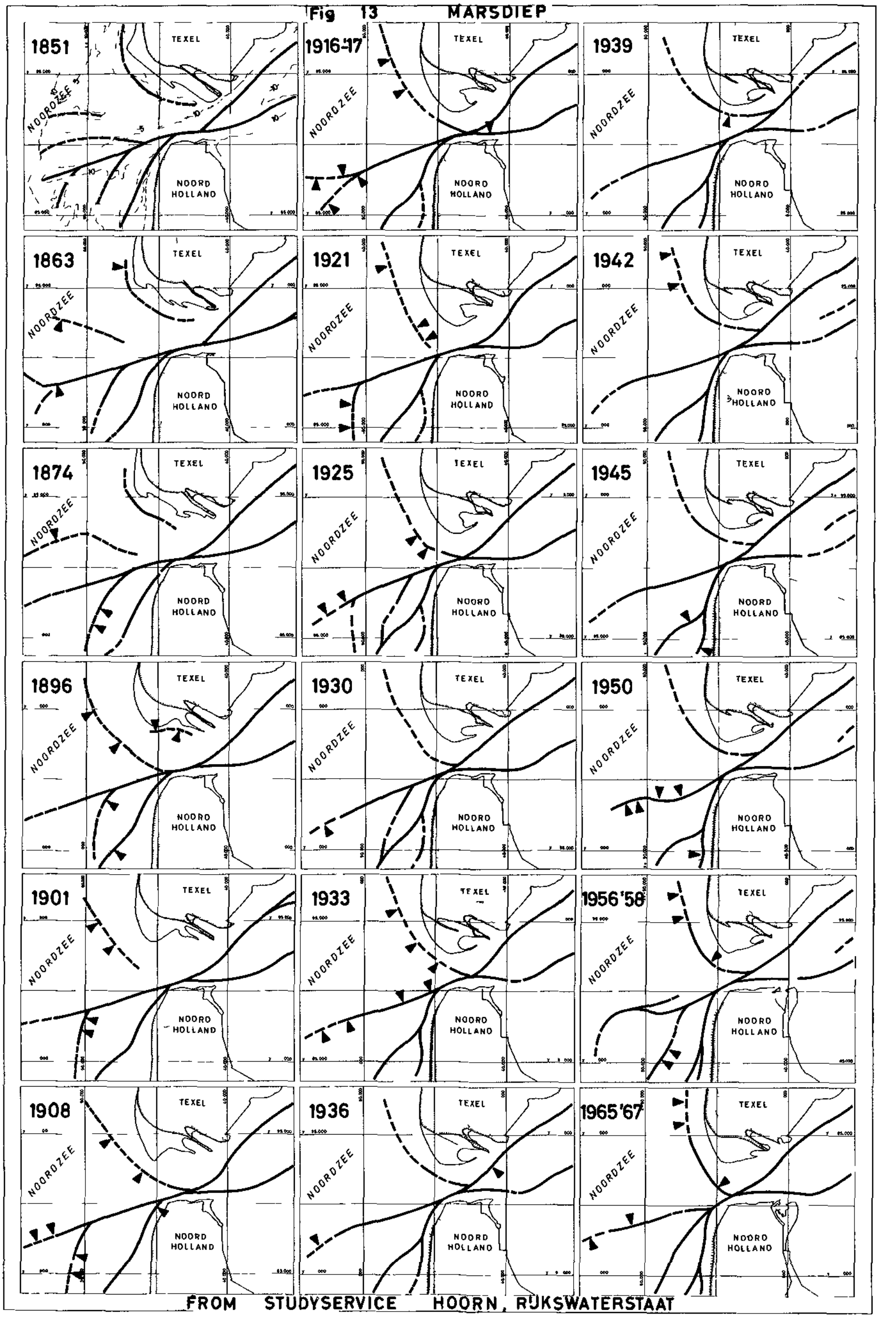
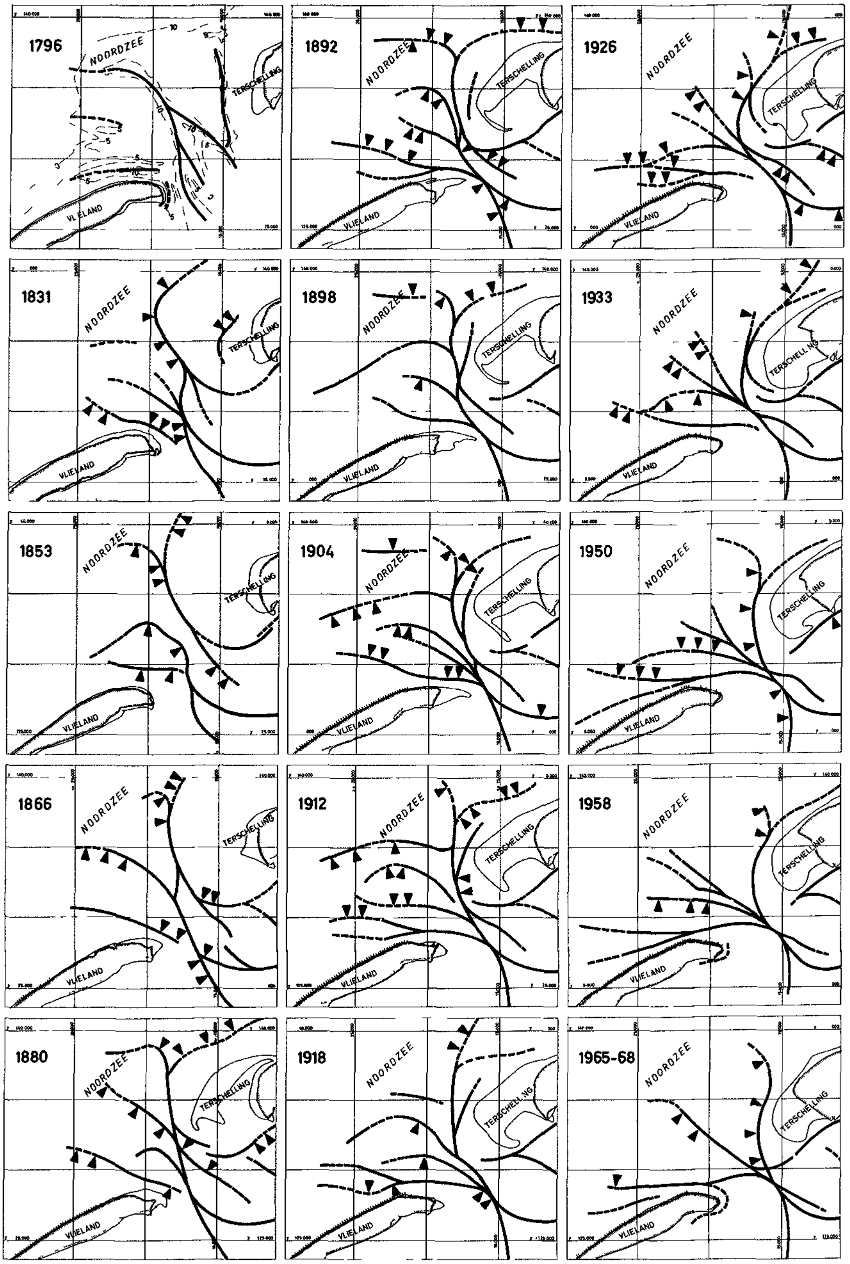


Fig 13 MARSDIEP
1851
1916-17
1939
1863
1921
1942
1874
1925
1945
1896
1930
1950
1901
1933
1956'58
1908
1936
1965'67
TEXEL
NOORDZEE
NOORD HOLLAND
FROM STUDYSERVICE HOORN, RIJKSWATERSTAAT

Fig 14 VLIE



FROM STUDYSERVICE HOORN RIJKSWATERSTAAT

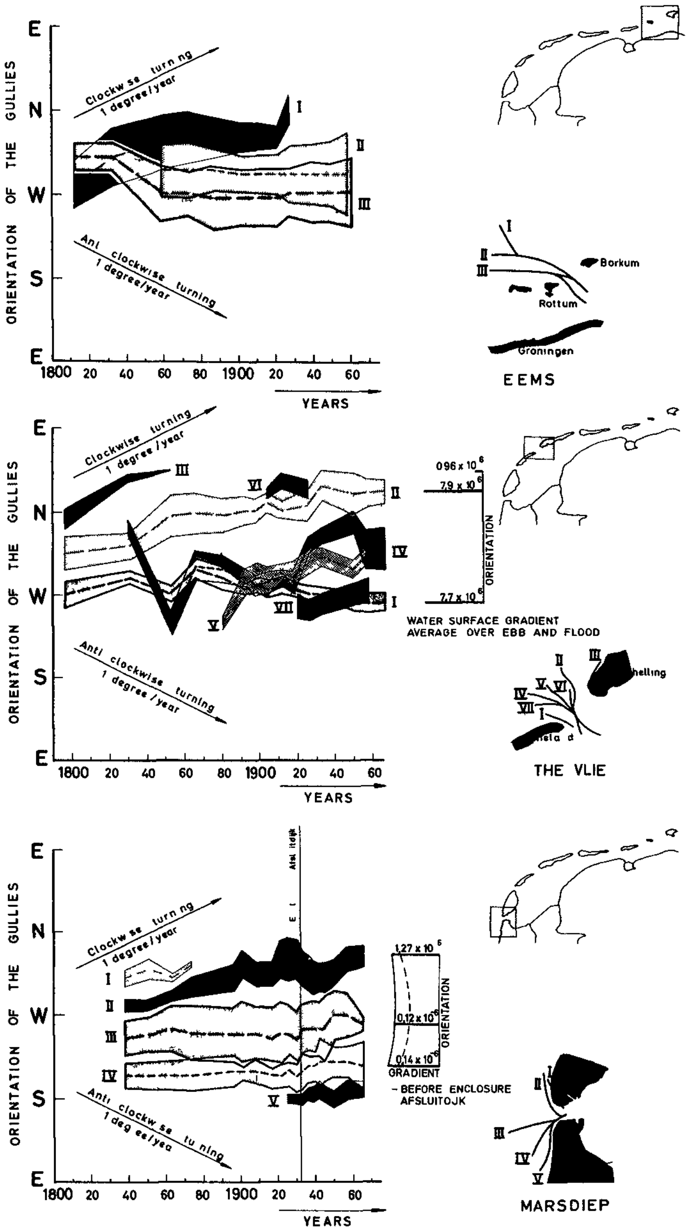


Fig 16 THE DIRECTION AND THE WET SURFACE OF THE GULLIES

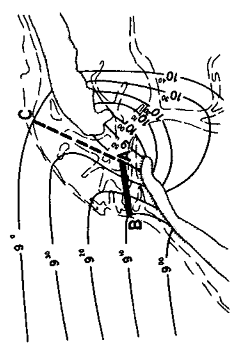


Fig 17 Orientation of gullies according to VAN VEEN theory

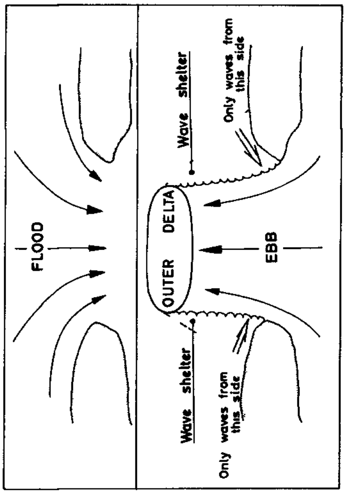


Fig 19 Erosion of the coast by tides and waves near on inlet

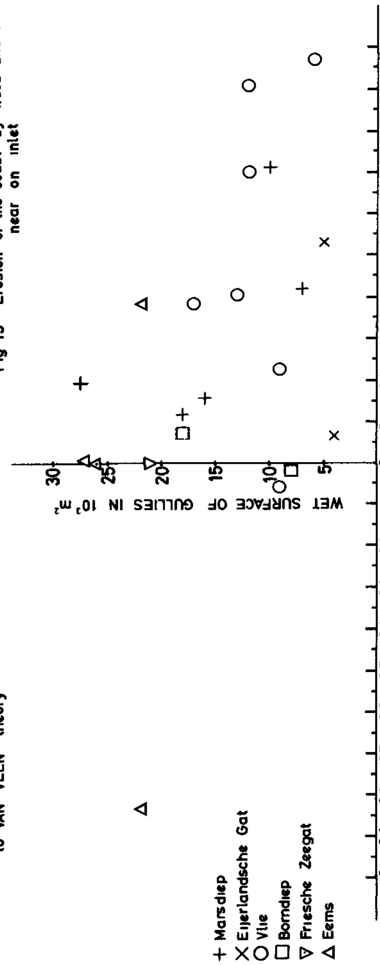


Fig 18 The correlation between the wet surface and the moving of the gullies