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A short review of the Dutch coast

Dutch contribution to the report of the project CORINE 'coastal erosion' of the Commission of the European Communities

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PREFACE

This report about the Dutch coast was written in the context of the experimental phase of the programme CORINE of the Commission of the European Communities. The programme CORINE (COoRdination of INformation on the Environment) is a programme for the gathering, coordinating and ensuring of the environment and natural sources in the Community.

The objective of the project 'coastal erosion', as part of the CORINE-programme, is to provide a cartography and a database of the risks of coastal erosion in the Community.

This report has grown out of the objectives of the project and the activities and agreements of the working group involved. However, some parts of the contents may be interesting to a wider group.

In the text you will often find the notation NUTS followed by a number. The NUTS (Nomenclature of Territorial Units for Statistics) is an interlocking system of territorial units at three levels. The used level III is the finest one.

1 COLLECTION OF INFORMATION

1.1 Working method

1.1.1 Introduction

A large part of the Netherlands lies below mean sea level. For that reason the struggle against the sea is a matter of survival, especially when North Sea water is driven against our coast by heavy northwesterly gales. In the course of our history the low lands have been inundated several times by such storm surges. These storms have left a good many traces in the shape of our coast and our landscape. The most recent inundation by a storm surge happened in February 1953, which mainly affected the southwestern part of our country. Nearly 2000 people were killed. This disaster led to reconsideration of the safety of our country against the sea.

In addition to storm surges our country is threatened by creeping erosion. In the past the only answer to that was to withdraw with the eroding coast. Besides the direct loss of territory, erosion poses a threat to the strength of small dune rows as a water defence. Where the dunes became too small they were defended by the construction of a revetment or sea wall, and more recently by artificial beach nourishment. In the light of the above-mentioned threats it is not surprising that the Netherlands has a long tradition of monitoring coastal behaviour.

The information has been derived from two main sources : 1. measurements, and 2. an investigation of maintenance measures and the maintenance condition of the North Sea coast.

1.1.2 Measurements

Since the middle of the last century measurements have been made of the position of the dune foot (point of intersection of the steep outer slope of the dune and the flat slope of the beach), the mean high-water line and the mean low-water line.

To obtain a good understanding of the development of the sandy North Sea coast and to be able to predict coastal behaviour in the future, a system of (about 3000) fixed measuring lines perpendicular to the coastline has been defined along the Dutch North Sea coast. The distance between the lines is 200-250 m. Each year the coastal profiles are measured and stored in the JARKUS database. The measurements of the underwater part of the coast extend to about 800 m seaward and are carried out by echo sounding from a ship. The measurements of the dry part of the coast are carried out by stereo photography from an aeroplane, as far as about 200 m inland from the most seaward dune front. The data set contains the annual coastal measurements since 1963. For this project use could be made of a study of the behaviour of the coast based on the JARKUS data set (Kohsiek, 1988a). The measurements per location could also be used.

1.1.3. Investigation of maintenance measures and condition

The primary purpose of this study was to asses the effectiveness and efficiency of the maintenance measures employed, based on an inventory of the maintenance measures, the maintenance condition and the maintenance costs (Burger, 1987). To get all the necessary information all the coastal managers have been visited, and extensive questionnaires have been filled in and discussed by means of interviews. Each coastal manager has divided his territory into uniform segments, especially with regard to uniform in maintenance measures. Since maintenance is logically determined by the structures that are built in the coastal zone and the rate of erosion or accretion, this subdivision is also suitable for the description of morphological behaviour.

The segmentation of the Dutch sandy coast for the CORINE project is mainly derived from the above-mentioned investigation. Wherever the segmentation was too detailed or too rough it was adapted. The degree of erosion of a coastal segment is very well known by those who are responsible for maintenance: the coastal managers. The rates of erosion mentioned in this report are mainly derived from the above-mentioned investigation. They refer to the period from 1975 up to and including 1984.

Calculated erosion rates depend on the period under consideration. At the beginning of 1988 calculations of trends in the position of the low-water line over the period 1965-1985 were available, based on the JARKUS data set. Because of the different period these rates differ slightly, but not so much that the rates mentioned in the maintenance study had to be distrusted.

The segmentation of the coast of the Wadden Sea (Waddenzee) is derived from the topographical map of the Netherlands, scale 1:50,000. Figure 1 shows the location of the topographical names mentioned in this report.

The practical work for the CORINE "coastal erosion" working group was carried out by D. Dillingh, Tidal Waters Division of the Rijkswaterstaat (Public Works Department), Ministry of Transport and Public Works. This report was written by D. Dillingh and A. Stolk, Department of Physical Geography, University of Utrecht.

1.2 Representativeness of the encoded data

The data presented are derived from information provided by those people who work daily on the coast, and were checked with the aid of a multi-year data set of measurements. Amelioration of the results is hardly possible in view of the attention given to the coast in the Netherlands.

Very recently an extensive policy analysis is being carried out on how to deal with the Dutch coast in the future, in the framework of a governmental memorandum on coastal policy. The studies that support this analysis provide more insight into the behaviour of our coast and more detailed information than this collection, but it does not affect its validity.

1.3 Recommendations

1. Erosion has been considered in this project as the retreat of the coastline. It is however possible for the coastline to be stable while the nearshore becomes steeper due to erosion, or a tidal channel moves to the coast. The definition of erosion used is rather limited in space perpendicular to the coast and does not give complete insight into the erosion problem.

   Another complication is the phenomenon noted in the Netherlands of the horizontal sand waves that disturb the long-term picture. On the Wadden and Delta islands they are a familiar phenomenon. They develop because sandbanks in the outer deltas periodically grow as far as the islands. The periodicity varies between 40 and 130 years. They move from west to east at a rate that varies from 30 to 450 m per year. They may cause the coast to grow for several decades, while in the long term the coast retreats. The opposite is also possible. Rates of erosion may be misleading without this extra information. The definition of erosion used is also limited in time. So this definition needs improvement.

2. Erosion is not a phenomenon which is constant in time. Coastal segments which currently are stable, may erode in the future. The reverse may also occur, by natural causes or by human actions. To keep its value in the future the CORINE database needs to be updated at regular intervals.

3. The pure measure of erosion does not say enough about the risks involved. Besides an inventory of the erosion rate also an inventory of the <u>use</u> of the hinterland and the <u>consequences</u> of continuing erosion needs to be drawn up. The consequences for the Netherlands are very large, since about half of the country may be inundated. Moreover in the case of a wide dune area high erosion rates may be tolerated for a long time, while in the case of a small protective dune row very low erosion rates may cause big problems.The present database does not discriminate on this points.

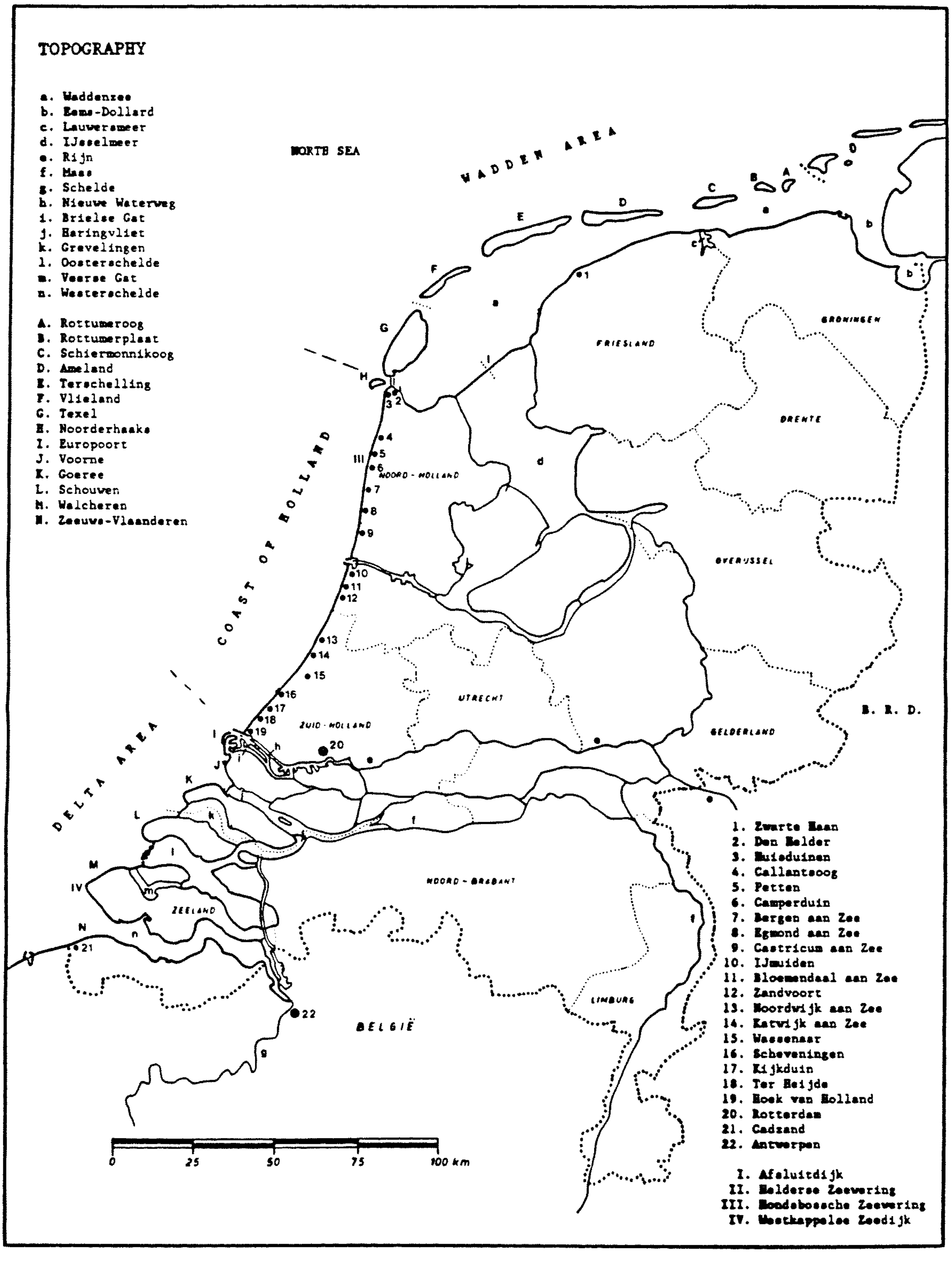

Fig.1 Topography of the Dutch coastal area

2 THE CHARACTERISTIC FEATURES OF THE SHORE

2.1 Introduction

The Dutch coastal plain has developed over the last 6000 years behind a more or less closed coastal barrier. The sedimentation of the coastal plain has been characterised by an alternation of transgressions and regressions. In periods of significant marine influence the barriers were encroached upon by the sea at many points. In the coastal plain a lagoon or tidal-flat environment was formed, in which channels with sandy deposits developed. Outside the channels marine and brackish clays were deposited, sometimes alternating with sandier layers. In the periods when the sea's influence was slight, the barrier had a more closed character. In large parts of the coastal plain the water became fresh and warping took place. This give rise to extensive peat areas.

Two great transgression phases can be distinguished. The Calais phase and the Dunkirk phase. They are separated by a regression phase, in which a thick peat layer was formed. This peat layer still has a thickness of 2.5 m in places. It appears from the presence of the thin peat layers within the Calais and Dunkirk sediments that both transgressions were locally and temporally interrupted.

Due to the fact that the rivers Rijn (Rhine), Maas (Meuse) and Schelde (Scheldt) discharged into the sea via the coastal plain, the barrier has never been completely closed. In the west of the Netherlands, a westward extension of the sandy coastal belt took place from 5000 BP onwards. A succession of barriers with a total width of 8 to 10 km was formed. On top of the barriers dunes were formed with a maximum altitude of 10 m. This extension terminated c. 2500 BP.

After a few centuries coastal erosion occurred moving the coastline a few kilometres eastwards. After c. 1000 AD an extensive dune formation took place, presumably accompanied by a steepening of the shoreface. Between 1000 and 1400 AD, a new coastal belt was formed along the west coast of the Netherlands. Later on, it was partly eroded, mainly in the south and the north. This dune complex currently has a variable width from a small foredune, e.g. near Hoek van Holland and Den Helder, to an extensive dune complex 4 km wide near Zandvoort and Bergen aan Zee. At the same time, in the north and southwest of the Dutch coastal area, marine influence is steadily growing due to enlargement of the tidal basins.

In the Dutch coastal region, three areas can therefore be distinguished:

(a) The Delta Area in the southwest
This area is characterised by peninsulas separated by estuaries and (former) tidal basins.

(b) The Coast of Holland in the west
This area is characterised by an almost uninterrupted dune row and a lack of islands and tidal inlets.

(c) The Wadden Area in the north
This area is characterised by a chain of barrier islands, separated from the mainland by extensive tidal flats.

The Dutch coast is a mixed-energy coast. Both the waves and the tide have an influence on coastal behaviour. At the Coast of Holland the influence of the waves is greater than that of the tide. In the Delta Area and the Wadden Area the tide is more important, because of the larger tidal range and the presence of tidal inlets. The wave height ranges from 60 cm under quiet conditions to 5 m during a storm. The tidal current along the coast may reach values of 1-1.5 m/s. The vertical tide may vary from one location to another. The mean tidal range is at its largest near Cadzand (435 cm) and decreases towards the north, with minimum values of 137 cm near Den Helder. From Den Helder it increases and is 209 cm near Rottumerplaat (state 1981).

The gradient of the Dutch beaches varies from 1 to 4%. The gradient of strand plains is less than 1%. The morphology of the beach largely coincides with meteorological conditions. During stormy weather erosive processes prevail and the beach flattens. In quiet weather the beach builds up and is characterised by a ridge and runnel morphology. At low tide the runnel is exposed. Where the slope of the upper shoreface is relatively small, there may exist two more longshore bars seaward of the ridge, e.g. between Katwijk aan Zee and Egmond aan Zee. The system of ridge and runnel is interrupted by rip channels, through which the water from the runnel discharges into the sea. The distance between them was found to vary between 400 and 1850 metres (photo 7).

The beach sands in the northern and southern parts of the Dutch coast indicate differences which for largely coincide with the provenance of the sand and also depend on the processes which these sands have been subject to. The provenance of the northern and southern sands can be seen from the size and the composition of the heavy mineral fraction. The beach sand is mainly composed of quartz. To the south of Bergen aan Zee the content of heavy minerals is less than to the north. Worthy of note is the difference between saussurite and garnet. In the south the heavy fraction of the grains with a size of 200-250 μm contains mainly saussurite (50%) and garnet (10%). In the north the figures are 20 and 30% respectively. The sands from the southern part of the coast consist almost completely of sand originating from the Rijn. Most of the northern sand is (about 60%) was transported by the continental ice sheet during the Saalian glaciation. This glacial sand contains a large amount of garnet and less saussurite.

Concentrations of heavy minerals caused by sorting processes occur locally at various places along the coast. This is the case on Goeree, near Bergen aan Zee and Camperduin, and on Texel and Ameland. The difference in iron content is so striking that in the north of Bergen aan Zee, one speaks of "white" sands and in the south of "blond" sands, but even in the "blond" sand the iron content is not higher than 1%. The differences in calcium carbonate content are also remarkable. North of Bergen aan Zee the calcium content is low (0.2%). The same applies to the Wadden Islands. (< 2%). From Castricum aan Zee to Hoek van Holland it gradually increases from 2 to 6% . In the Delta Area it is variable (2-8%). The calcium content depends largely on the supply of fresh marine sand with shell particles.

In recent times practically no sand supply from the rivers has occurred. All of the beach sand is reworked older sand. To the south of IJmuiden the beach sand still has the characteristics of river sand. This is evident from the lower degree of sorting. North of

IJmuiden the sorting is better. Here the sand looks like reworked sand from tidal flats. The beach sand becomes finer from Bergen aan Zee northwards and eastwards to Schiermonnikoog. This can also been seen as an indication of an increased amount of former tidal flat sands in this direction. The average grain size gradually decreases from about 300 µm near Bergen aan Zee to about 170 µm at Schiermonnikoog. South of Bergen aan Zee no trend is noticeable. Here the average grain size varies a great deal. Relatively coarse sand (200-350 µm) occurs from Bergen aan Zee to Hoek van Holland and on Walcheren. In the rest of the Delta Area fine beach sand is present (150-250 µm).

2.2 The Delta Area (NUTS 4735, 4741, 4742)

Although the rivers Rijn, Maas and Schelde discharge into the sea in the Delta Area, there is no river delta. The region is characterised by peninsulas separated by estuaries and tidal basins. In recent decades the Veerse Gat, the Grevelingen, the Haringvliet and the Brielse Gat have been closed by dams (Y). In the Oosterschelde a storm-surge barrier was built (photo 2). The estuaries of the Nieuwe Waterweg and Westerschelde remained open to provide entrance to the ports of Rotterdam and Antwerpen.

The North Sea beach in Zeeuws-Vlaanderen and on the southwestern side of the peninsulas Walcheren, Schouwen, Goeree and Voorne is relatively small. This is also the case on the northwestern side of Walcheren. At the northwestern side (on Walcheren the north side) the beach is much wider and in some places has been enlarged to form a strand plain, as is the case in Voorne.

On Zeeuws-Vlaanderen the coast is partly defended by dikes (Y) or groynes (E_1). The southwestern side of Walcheren is reinforced with groynes and pile rows (E_1). On the northwestern side only pile rows have been constructed (E_1). The westpoint is defended by the Westkappelse Zeedijk (Sea Dike) (Y) (photo 1). On Schouwen the southwestern and western sides are reinforced with pile rows and the northern part with groynes (E_1). Goeree and Voorne have no groynes or pile rows (E) (except for a single kilometre on Goeree). The former island of Rozenburg has been completely buried by the construction of the harbour and industrial areas of the Europoort and does not have a natural coast any more (J).

The morpho-sedimentological units mentioned here and in the next sections are according to the classification of the CORINE project (Quélennec et al., 1987). Figure 2 shows their location along the coast.

2.3 The Coast of Holland (NUTS 4721, 4722, 4723, 4724, 4731, 4732, 4733, 4735)

This part of the coast is called the uninterrupted coast because of the lack of tidal inlets, shoals and islands (photo 4 and 5). It extends from Hoek van Holland to Den Helder and is only interrupted by the ports of Scheveningen and IJmuiden (J) (photo 6), a small sea wall at Scheveningen (Y) and a large, 4.5 km long, sea dike, the Hondsbossche Zeewering (Sea Dike), between Groet and Petten (Y) (photo 8), and the Helderse Zeewering (Sea Dike) near Den Helder (Y).

The coast of Holland is mostly classified as E (from Scheveningen to Bergen aan Zee) and E_1 (from Hoek van Holland to Scheveningen and from Bergen aan Zee) to Den Helder).

2.4 The Wadden Area (NUTS 4111, 4112, 4113, 4121, 4122, 4721)

The Wadden Area consists of a series of seven barrier islands (F) and extensive tidal flats, which separate these islands from the mainland. The tidal inlets are deeply (11-50 m) eroded by the strong tidal currents.

Ebb-tidal deltas have been formed on the sea side of the inlets, and in some cases bars have permanently emerged, e.g. the Noorderhaaks near Texel. Migrating bars of these deltas may be joined to the North Sea beach of the islands, developing into strand plains (E) (photo 10). This is the case on the south side of Texel, the western, northwestern and eastern sides of Terschelling and the northwestern side of Ameland.

The coastal plain on the west side of Vlieland is the remains of the former western part of the island. Strand plains have also been formed along the east side of Ameland and Schiermonnikoog. At the west side of Schiermonnikoog a spit with a lagoon is developing.

Reinforced natural beaches (E_1) occur on the southern part of Texel, in central and eastern Vlieland, western Ameland and the nucleus of Rottumerplaat and Rottumeroog. The rest of the North Sea beaches consist of a natural sandy beach (E).

The Wadden Sea consist of six tidal basins which are connected with the North Sea via tidal inlets. In the east of the Dutch Wadden Sea lies the Eems-Dollard estuary (H). The western Wadden Sea is about 25 km wide. At low water 1/5 to 1/3 of the surface becomes dry. The eastern part is narrower (10 km). In this area 2/3 to 4/5 belongs to the intertidal area. The coast of this inland sea has been formed by salt marshes; these are vegetated and dissected by meandering channels, and are only inundated during storm surges (G and G_1).

On the sea side these salt marshes are bordered by an erosion cliff or, in the more sheltered areas, by a strip with significant deposition. On the land side the salt marshes are bordered by dikes, with the exception of the west side of Vlieland, the east side of Terschelling, the west and east sides of Schiermonnikoog and Rottumerplaat and Rottumeroog.

The natural discharge system of the salt marshes along the coast of Friesland and Groningen has been replaced by a system of ditches and trenches, which are part of land reclamation projects (M). These extend from Zwarte Haan to the Eems-Dollard estuary, and are interrupted only by a dike which closed the Lauwersmeer.

The Wadden Sea is separated by the 30 km long Afsluitdijk (Y) from the former Zuiderzee, an inland sea which is now called the IJsselmeer.

(Eisma,1968; Depuydt,1972; Van den Berg,1977; Ten Hoopen & Van Driel,-1979; Klijn,1981; Eisma & Fey,1982; Roep,1984; Zagwijn,1986; Van Alphen,1987; Anonymus,1987; Meijer et al.,1987; Bakker & De Vroeg,1988; Van Bemmelen,1988; Rijkswaterstaat,1987)

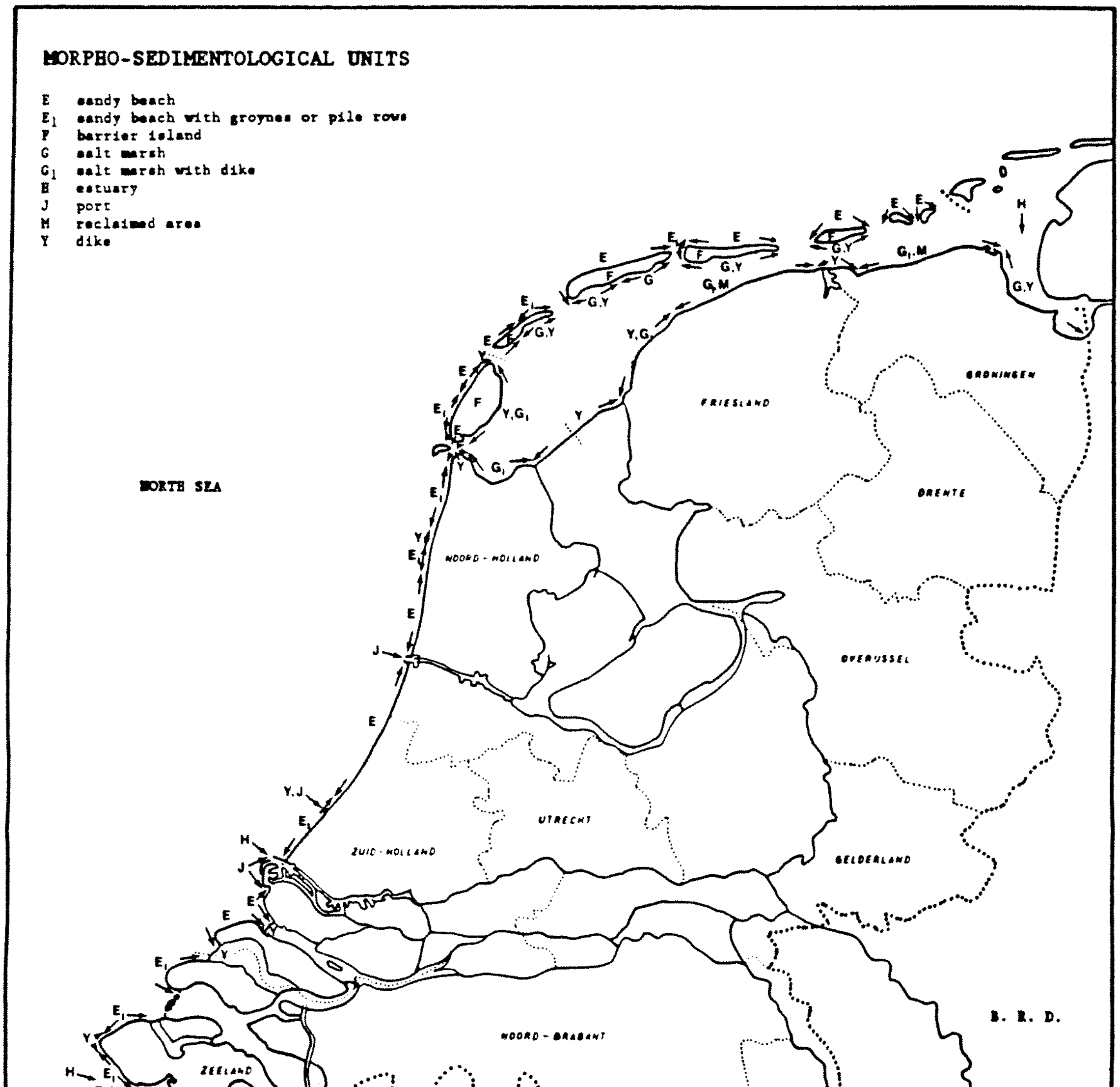

Fig.2 Morpho-sedimentological units along the Dutch coast

3 COASTAL EVOLUTION

3.1 Historical evolution

3.1.1 Introduction

Since 1843, annual measurements have been taken every 1000 m on Dutch beaches of the mean high-tide line, the mean low-tide line and the dune foot. This has resulted in series of measurements which elucidate the development of the Dutch coast during the last century. From these data, Kohsiek (1988a) established a trend for the erosion and accretion of the Dutch coast for the period 1885-1985. Ligtendag (1987) has reconstructed the coastline for the years 1600 and 1750 AD, on the basis of historical maps. At present, there is a reasonably good understanding of the development of the entire Dutch coastline during the last 350 years and a detailed picture of its development during the last 100 to 140 years.

3.1.2 The Delta Area

In the Early Middle Ages (500-700 AD) the northern part of the Delta region was more or less covered with peat. In the southern part the marine influence has increased since the Roman Period (c. 100 AD). The influence of the sea steadily increased and in the Late Middle Ages the Delta Area consisted of small islands. Land was reclaimed by embankment, but between 1350 and 1650 a great deal of land was lost along the tidal inlets and estuaries. Since 1600 the coast of the entire delta area has deteriorated with the exception of the northern coast of Goeree, where accretion of 900 m had occurred, and the coast near the harbour and industrial complexes of the Europoort, northwest of Voorne.

In Zeeuws-Vlaanderen (NUTS 4741) the coastline had migrated land wards by an average of 400 m since 1600. On Walcheren and Schouwen (NUTS 4742) a pronounced retreat, up to 1 km, had taken place locally in this period. Due to the disappearance of a sand flat connected with the land on the west side of Goeree (NUTS 4735), the present location of the coastline is 4 km to the east of where it was in 1600. The coast has retreated 500 m at Voorne (NUTS 4735).

The development of the position of the mean low-tide line over the last hundred years differs per peninsula. At Zeeuws-Vlaanderen slight erosion or accretion (less than 0.5 m/year) has taken place depending on the location. On Walcheren erosion has taken place nearly everywhere, with a maximum of 2.5 m/year on the northwestern side. During this period Schouwen suffered erosion on the southwestern side (up to about 3 m/year). On the western and northern sides accretion took place (about 3 and 4 m/year respectively). On Schouwen erosion of approx. 4 m/year occurs on the southern side, changing to accretion of approx. 7 m/year on the northern side. In the last century Voorne was subject to erosion, varying from approx. 1 m/year on the southwestern side to more than 5 m/year on the western side.

3.1.3 The Coast of Holland

From the 10th century onwards erosion has occurred. It is assumed that this erosion was accompanied by the steepening of the coastal profile. Along the coast the Younger Dunes were formed. The main changes took place in the north of Noord-Holland. In the 11th century there was still a coastal arch which ran from Egmond aan Zee to the northwest of Texel and Vlieland. The coastline in this area was extended 5-10 km from the present coast. Between the 11th and 14th centuries, the coastal arch disappeared and the land behind it was inundated. Here the western Wadden Sea was formed. North of Petten the coast was formed by the islands of Callantsoog, Huisduinen and Texel. In 1610, Callantsoog and Huisduinen were connected by an artificial sand dike. At the end of the century both islands became part of the mainland again.

Over the last three hundred years, the Coast of Holland has been characterised by erosion in the north and south and by stability in the central part.

At the beginning of the 17th century a sand flat was formed at the northern bank of the Maas. This caused a southwards extension of the coast of 4.5 km between 1600 and 1750. To the north of this sand flat, near Ter Heijde, the coast retreated 1100 m between 1600 and 1750, and 300 m from 1750 to the present. Near Scheveningen the figures are 250 m and 50 m respectively. In this coastal part (NUTS 4733) groynes have been constructed from the end of the 18th century, known as the Delflandse Hoofden (Delfland Groynes) (photo 3).

The coastal part from Scheveningen to Zandvoort (NUTS 4731, 4732) has retreated to a minor extent (50-150 m) since 1600. An exception is the coast near Noordwijk aan Zee, which in this period was eroded by 300 m. It has been noted that since 1750 accretion of 100 m has occurred near Katwijk aan Zee. This accretion coincides with the construction of a drainage canal. From Zandvoort to Castricum aan Zee (NUTS 4723, 4724) the coast has been stable since 1600. Near Egmond aan Zee, 160 metre coastal erosion occurred between 1600 and 1750 and 130 metre after 1750.

To the north of Egmond aan Zee (NUTS 4722, 4721) there was considerable erosion in the period between 1600 and 1750. Near the Hondsbossche Zeewering, 700 m has been eroded, and near Den Helder about 1500 metres. At the Hondsbossche Zeewering 375 m has been lost since 1750. This sea dike had to be shifted more than once, for the last time in 1823. The coast near Den Helder remained stable due to the construction of the Helderse Zeewering in 1774.

As far as the development of the position of the mean low-tide line of the Coast of Holland is concerned, three coastal parts can be distinguished on the last hundred years (Van Vessem, 1989). To the south of Scheveningen the coast retreated by 0.35 m/year, with the exception of the coastal part directly to the north of the harbour mole of Hoek van Holland, which has undergone artificial accretion in this period. Between Scheveningen and Egmond aan Zee accretion of 0.25 m/year has taken place. There is significant accretion in the immediate vicinity of the harbour moles of IJmuiden. North of Egmond the coast retreated by 0.92 m/year.

3.1.4 The Wadden Area

The development of the western Wadden Area is closely related to that of the northern part of Noord-Holland. The western Wadden Sea and the Zuiderzee originated in the 12th century. A few islands were formed e.g. Texel and Vlieland. The area east of Vlieland was already a tidal-flat area with barrier islands.

Since 1600, the North Sea coast has retreated on all the islands. The amount of retreat of these coastal sections differs from one island to another: e.g. on Texel approx. 400 m; on Vlieland 600 to 1900 m; on Terschelling less than 300 m. On Ameland the North Sea coast has retreated up to 1200 m locally since 1600. In 1750, however, the island was almost divided into three parts. At present, these parts are connected again (photo 11).

The extremities of the islands do not show uniform behaviour. The net progradation on Texel (NUTS 4721) on the south side has been approx. 2800 m since 1600. In this area sand flats repeatedly join the island. Erosion on the north side amounts to 1600 m over the same period. The progradation at the southwestern end of Vlieland (NUTS 4121) was approx. 900 m, and the erosion at the northeastern end approx. 500 m. Terschelling (NUTS 4121) exhibits pronounced progradation at both the west end (approx. 3 km) and the east end (approx. 11 km) during this period. At Ameland and Schiermonnikoog (NUTS 4121) there is erosion at the west end and progradation at the east end. This eastward extension is most pronounced on Schiermonnikoog (approx. 2 km). Further towards the east the islands display a dynamic behaviour. Throughout the ages, islands originate, migrate and disappear. At present the islands Rottumerplaat and Rottumeroog are situated in the area (NUTS 4113).

In the last hundred years (1885-1985) the North Sea coasts of Texel and Vlieland have retreated everywhere (2-11 m/year). The retreat varies depending on the location and is most pronounced on the southwestern side of Texel. The western parts of Terschelling and Ameland experienced progradation (5-10 m/year), except for the westernmost end of Ameland. Erosion occurs especially in the middle of the islands (approx. 4 m/year). In this period, Schiermonnikoog has undergone progradation of an average of 3-7 m/year along the entire North Sea coast.

(Bakker & Joustra,1970; Schoorl,1973; Eisma & Fey,1982; Zagwijn, 1986; Ligtendag,1987; Kohsiek,1988a; Van Vessem,1989)

3.2 Current trends

3.2.1 Introduction

Since 1965 the coastal profile has been measured annually every 250 m along the coast, as far as 800 m seaward and 200 m landward of the coastline. Every 5 years a 2500 m long coastal profile was measured every kilometre along the coast. These data, together with the annual measurements of the positions of the mean low and high-tide line and the dune base, give a clear insight into coastal behaviour.

The trend in the position of the mean low-tide line was calculated over the period 1965-1985 (Kohsiek, 1988a). At the same time an investigation was carried out into the retreat and progradation of the coast in the period 1975-1984 (Burger, 1987). This investigation was based not only on the measurements of one aspect of the coast, e.g. the low water line, but also on the impression of the coastal managers responsible.

The entire coastline will be discussed on the basis of the abovementioned data. There is an important difference between coastal behaviour in the last hundred years and that of the last few decades due to the fact that there are factors influencing coastal development that act on a small time scale and to the fact that the human influence on the coastal behaviour has increased in recent decades.

3.2.2 The Delta Area

The coastal development of the Delta Area over the last 10-20 years has been markedly influenced by local effects, e.g. sand waves, tidal currents and dams. The coast of Zeeuws-Vlaanderen is strongly defended. In the southern parts erosion occurs (approx. 2 m/year), and in the central part progradation (approx. 1 m/year). On Walcheren erosion occurs generally (0.5-1.5 m/year), and progradation only in the very north of the coast (1 m/year). The southern coast of Schouwen is subject to erosion (approx. 3 m/year). In the northwest and north accretion takes place (up to 4 m/year). The coast of Goeree is subject to effective erosion, especially along the west point. Beach nourishment has been used at various places in the area. This has contributed to the movement of the low-tide line in a seaward direction (approx. 4 m/year). The west point of Voorne has been vigorously eroded (up to 5 m/year).

3.2.3 The Coast of Holland

This part of the Dutch coast is fairly stable from Hoek van Holland to Wassenaar. Locally some erosion or accretion takes place (< 1 m/year). Erosion is concentrated near Hoek van Holland, Kijkduin and Scheveningen. From Wassenaar to Egmond aan Zee the coast is stable or progrades (up to 1 m/year). Directly to the north and south of IJmuiden progradation occurs (2-4.5 m/year). Five kilometres south of IJmuiden significant erosion occurs locally. Five kilometres to the north the same effect occurs, but less pronounced. The Coast of Holland to the north of Egmond aan Zee is eroding. Erosion is more pronounced near Den Helder than it is near Egmond aan Zee (0.5-1.5 m/year).

3.2.4 The Wadden Area

The dynamic coastal behaviour of the Wadden Islands can clearly be seen from the results of the measurement series during the years 1965-1985 and the investigation over the period 1975-1984. Both investigations have shown that the west coast of Texel is subject to vigorous erosion: up to 10 m/year in the southwest, 1.5 m/year in the central part and 5 m/year in the north.

For the other islands there is a marked deviation in the results of the two investigations. This is possibly due to the difference in the length of the period in which the investigation took place. According to both investigations erosion occurs in the central part of the coast of Vlieland (0.5 m/year), in the central part of Terschelling (1-2 m/year) and in the central part and the east of Ameland (3-5 m/year). The west point of Ameland also shows pronounced erosion (up to 5 m/year).

3.3 Erosion

The Delta Area and the Wadden Area suffer most from erosion. In the Delta Area the western ends of the peninsulas Schouwen, Goeree en Voorne are subject to severe erosion. In all three cases there is an impact on nature reserves. Besides on Schouwen, the dunes are in use as a water conservation area. Safety problems in the Delta Area will occur at several coastal sections in the near future.

Along the Coast of Holland erosion is most severe at Scheveningen, Bloemendaal aan Zee and Callantsoog. The coastal defence at Scheveningen consist of a sea wall (boulevard) and dike. The beach in front of the sea wall is important for recreational purposes. This can only be guaranteed by periodic beach nourishment. At Bloemendaal aan Zee there is a large natural reserve in the coastal zone (large dune area). To the north of Egmond aan Zee erosion occurs along the whole coast as far as the Helderse Zeewering which is flanked by a tidal channel with a depth of 50 metres in places. Near Callantsoog the dune row is small, with the result that the safety of the hinterland is threatened. Just south of Callantsoog there is an important nature reserve with dune lakes.

In the Wadden Area, Texel and Ameland in particular, are subjected to erosion. At Texel erosion causes loss of important nature areas in the southwestern and northwestern parts and recreational areas in the central part. On Ameland recreational areas are threatened in the central part and at the western end of the island, where the dunes are also partly used as water conservation area. In the eastern part erosion threatens natural reserves and a terminal for the exploitation of natural gas. The island of Vlieland suffers relatively little from erosion, but the protective dune row is very small. The east point of Terschelling is subject to significant erosion, which threatens a nature area.

However, problems in coastal areas are caused not only by erosion. The strong sedimentation in the former tidal inlet of the Haringvliet may become a problem for the use of the sluices in the dam. The parts of the coast that are threatened most by erosion are shown in figure 3. The choice of the levels 1.5 m/year and 5 m/year in this figure is a rather arbitrary one, but it gives some idea of the seriousness of erosion.

Parts of the coast with less erosion, however, may cause more problems, for example when the protecting dune row is small. Those parts of the coast are also very sensitive to the present erosion rate.

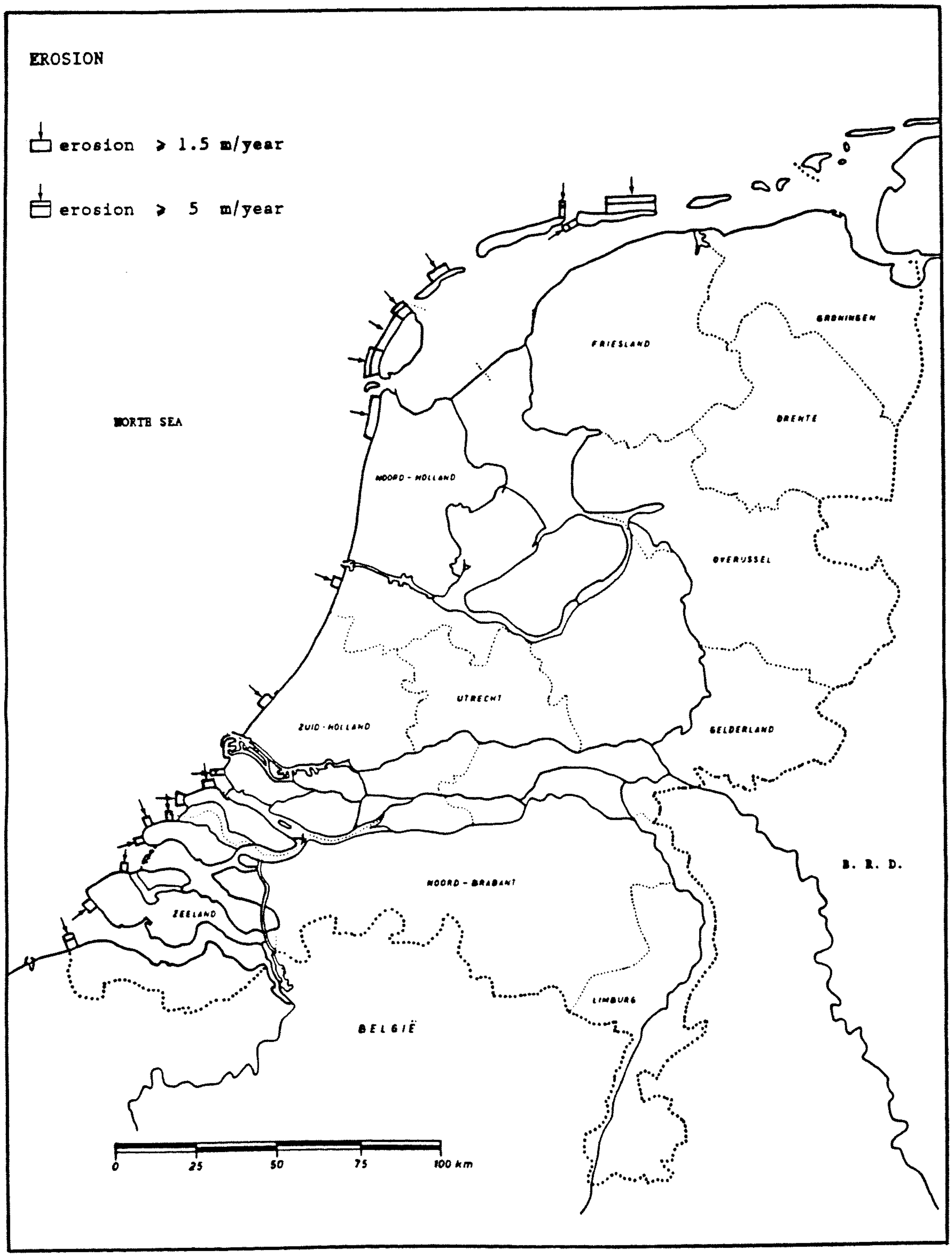

Fig.3 Erosion rates at the Dutch coast

4 CAUSES OF COASTAL EVOLUTION

4.1 Natural causes

The natural causes of coastal development are connected with the time scale on which the processes in question operate.

Over long periods of time (centuries) the fluctuations in the relative sea level, climatic changes and the availability of sediments have an effect on coastal processes and trends in coastal development.

Relative sea level is determined by various factors, e.g. eustatic changes in sea level and tectonic activities. In the Netherlands the subsidence of the North Sea basin is an important factor (4-8 cm/century). There are indications of small differential tectonic movements along the Dutch coast, which could cause spatial differences in the changes in relative sea level. The average rise in sea level over the last 2000 years is approximately 5 cm/century. However, in the last hundred years the sea level has risen 15-20 cm. It is expected that in the next century, there will be an extraordinary rise in sea level, as a result of the "greenhouse effect", which will prove to be a threat to the Dutch coast. The extent of this danger will also depend on the morphology of the shoreface which shows spatial variations along the coast.

The morphology/palaeomorphology of the coastal zone may, over a long period of time, have an effect on the development of the coastline. The morphology of the shoreface influences the hydrodynamic processes, resistant layers can slow down the erosion rate and sandy topographical heights may act as sediment sources.

Climatic changes also have an effect on the development of the coast over a long period of time. Changes in wind and wave direction and storm frequencies could change the hydraulic conditions of a coastal zone. It will change the relationships between the various coastal processes, such as alongshore and diabathic transport. The same applies to the sediment budget.

In relatively shorter periods (decades) natural coastal development is mainly determined by small, sometimes temporary climatic changes that influence the hydraulic and eolian processes.

Coastal changes on this time scale are also caused by the occurrence of horizontal sand waves along a larger part of the Dutch coast. With the movements of these sand waves, the coast has a cyclic behaviour, which is indicated by the variation in the position of the high and low-tide line. The sand waves migrate along the west coast of the Netherlands towards the north, and along the north coast towards the east.

These sand waves have been studied in the Delta Area, especially, along the coasts of Walcheren and Schouwen. There they have a period of approx. 130 years, and a wavelength along the coastline of approx. 6 km, causing coastline changes of up to 400 m. They migrate with a velocity of approx. 30-300 m/year. They have approximately the same wavelength along the coast of Holland, a period of 50-150 years and cause coastline changes of approx. 50 m. The migration rate is about 65 m/year. Their occurrence on this part of the coast is not so clear as in the Delta Area. The process of sand wave migration is more dynamic along the Wadden Islands. The period is 40-100 years in this area and the migration velocity is 220-450 m/year. The sand waves cause coastal changes especially along the west side of the islands (up to 2500 m). However, towards the east of the islands they decrease to 20-50 m.

It will be necessary to take the effect of these sand waves into account, when interpreting the erosion data for coastal management purposes.

Coastal erosion is also promoted by tidal channels when they are close to the coastline and remove sediments.

Natural short-term changes (years) in the position of the coastline are usually related to continuous small changes in hydraulic and meteorological conditions. Heavy storms could effect the position of the coastline locally for some years. The effect of the storm of February 1953 could still be observed locally approximately 10 years afterwards in the position of the dune foot.

(Van Straaten,1961; Maranus,1986; Vellinga,1986; Zagwijn,1986; Van Alphen & Damoiseaux,1987; Maranus & Verhagen,1987; Stolk et al.,1987; Kohsiek,1988a; Kohsiek,1988b; Verhagen,1988; Wiersma & Van Alphen, 1988; De Ronde & Vogel,1989)

4.2 Anthropogenic causes

Man has had a considerable effect on the development of the Dutch coastal area. The oldest dikes date from the second half of the 11th century. From the 11th century onwards there has been continuous management of the coastal and inland waters in the Netherlands. The influence of man in the coastal areas may be negative, by lowering the country, causing erosion of the land; or it may be positive, by protecting the land against the sea and by reclamation. These effects occurred mainly in two different periods. The negative influences took place from the 10th-11th centuries until the 16th century. The positive influence occurred mainly from the 16th century until the present.

The most significant cause for the increasing influence of the sea in the western Netherlands during the Middle Ages, was human activity in the peat area. Peat was cut for salt extraction and peat exploitation purposes, but even more important was the arable farming in the peat areas. The encroachment of the sea on the land facilitated the drainage of a part of the high moor peat area. Man reinforced this process by improving the drainage systems. Dehydration and oxidation of the peat not only occurs as a result of the activities of man and the sea, but may also take place due to climatic changes. In the 10th century, dry periods contributed to the lowering of the surface of peat areas.

The necessity of building dikes became evident after the subsidence of the land. The danger of floods and the loss of land increased. Periods of land loss during the Middle Ages, were followed after 1500 by periods of land reclamation and the construction of coastal defences. With the use of windmills, reclamation of lakes became possible. Parts of the tidal basins and estuaries were also reclaimed, causing a decrease in tidal prism and the silting up of tidal inlets. These measures require well-organised management. In times of war, this may lead to the neglect of dike maintenance and the failure to do repairs after encroachment, or to wilful inundation. Three large sea dikes were built: the Westkappelse Zeedijk, the Hondsbossche Zeewering and the Helderse Zeewering (photo 1, 8).

The retreat of the Dutch coast is retarded in various places. This might be the result of continuous small-scale coastal management. The maintenance of the dunes by sand replacement and planting during the last few centuries has been significant. Weak sections in the coastal barrier have been reinforced by drift sand dikes, and the dunes have been consolidated with beach grass. Measures to regulate sand drift such as the planting of beach grass and the construction of sand drift screens, remain important aspects of daily coastal management.

The coastal management which has been carried for centuries is most discernible in the coastal area between the Hoek van Holland and Scheveningen. As early as in the first half of the 16th century, a dune foot defence of timber was constructed to protect the villages of Ter Heyde and Scheveningen. In 1776 the first groynes (Delflandse Hoofden) were built. They consisted of poles, osiers and brick. The last groyne dates from 1930. These works have made a major contribution to hydraulic knowledge in the Netherlands.

In recent years preference has been given to more flexible types of coastal defence, such as beach and dune nourishment (photo 9). Since 1971, 58 million cubic metres of sand has been deposited on beaches, e.g. on Goeree, Texel and Ameland and at Hoek van Holland, Scheveningen and Callantsoog. Large nourishments e.g. those on Goeree (about 6.5 million cubic metres in 17 years), have an effect for years on coastal development.

The entire or partial closure of the tidal inlets in the Delta Area causes great changes in the tidal current patterns. Longshore sand bars develop on outside edges of the former ebb-tidal deltas, approximately 3 to 8 km offshore. These sand bars have a positive effect on coastal development. However, it is not known how long it will take before the coast in its new situation will reach a state of equilibrium. In the vicinity of the closure dams accretion of the beaches occurs.

Construction works which are not directed to coastal management may also have an effect on coastal processes. After the construction of the harbour moles near IJmuiden (c. 1870) progradation of 450 m took place locally. The new position of the low-tide line was reached after 30 years. In 1966 the moles were extended, and this had a similar effect (photo 6). The Nieuwe Waterweg was constructed through the coastal barrier to the south of Hoek van Holland in 1866-1872. It is an artificial estuary of the Rijn. The construction of the harbour and industrial complex of Europoort has produced a completely artificial coastal section.

Human influence on the coastal zone was extensive until the beginning of this century, but had its limitations. The measures taken remained subject to natural forces. Man could only direct certain developments to his own advantage, but not determine coastal changes.

Since the first half of this century the changes along large parts of the coast have been directly determined by man with the aid of eleborate hydraulic works, e.g. the Afsluitdijk to separate the IJsselmeer from the Wadden Sea in 1932 and the Delta Works in recent decades. In the near future other forms of human influence will take place. Gas exploitation on Ameland will result in a lowering of the surface by a maximum of 26 cm. Future coastal management will be determined largely by the rise in sea level caused by an increase of the content of CO_2 and other trace gases in the atmosphere.

(Eisma & De Wolff,1980; Klijn,1981; Eisma & Fey,1982; Vellinga, 1986; Stolk et al.,1987; Terwindt et al.,1988; Rijkswaterstaat,1988).

5 POLITICAL ORGANISATION AND COASTAL PROTECTION

5.1 Laws and regulations

5.1.1 Introduction

The organisation of the management of the Dutch coast is rather complicated. In principle three layers of public authorities can be distinguished: 1. the state, 2. the province and 3. the polder board. Polder boards are in principle financially independent lower authorities, under supervision of the province, which impose taxes and receive subsidies from higher authorities for the execution of certain tasks. The management of the North Sea coast is in principle in the hands of the polder boards. For the execution of their tasks they receive a contribution from the government. However if polder boards do not have sufficient resources (for example the Wadden Islands) or the situation demands state management (for example closure dams in estuaries) the state also performs management duties with respect to the coast (subdivisions of Rijkswaterstaat). In the present situation the responsibilities of the different authorities are laid down in the act known as "Waterstaatswet 1900".

In accordance with the terms of the "Deltawet", an act that came into force in 1958 as a result of the storm disaster in 1953, many reinforcement works along the North Sea coast have been constructed, almost completely at the expense of the central government. These works will be completed in 1990. The situation known as a "delta safe" coast will then be obtained. This guarantees a given level of safety, as is indicated in the final report of the Delta Committee (Deltacommissie, 1960).

To guarantee safety in the future in relation to the erosion problem and the big chance of an accelerated rise in sea level, the teamwork between the different authorities will be reorganised in the act known as "Wet op de waterkering", which is expected to become effective in 1990. The decision to construct works will remain the responsibility of the central government. Keeping water defences in a good condition according to the safety standards also laid down in this act, will be the primary responsibility of the relevant polder boards, under the supervision of the provinces concerned. In the special cases mentioned above the central government will take care of the condition of the water defences, also under the supervision of the provinces concerned. The provinces will report to the central government on the condition of the primary water defence structures every five years.

The central government will be held responsible under this act for the fight against erosion. The works which the minister concerned deems necessary to prevent or counter an inland movement of the coastline will be carried out by and at the expense of the state, in order to maintain the degree of safety according to the law or to protect the interests other users of the beach or the dunes if this is reasonable.

Present and future policy regarding the erosion problem can be summerised as follows: the coastline will be kept in its place, but not everywhere and not at any price. This means that:

- If the safety of the hinterland is endangered, action will always be taken;
- If ts safety is not in danger, the local interests which are threatened will be assessed against the costs of intervention.

5.1.2 The level of safety

As regards the level of safety mentioned above, the following text has been taken from the English summary of the final report of the Delta Committee (Deltacommissie, 1960).

"The Committee came to the conclusion that for the entire coast of the country the protection provided by the present defences is inadequate and that an immediate strengthening of a large proportion of the main sea-defence structures which protect the Netherlands against the storm surges was necessary and warranted.

Because the strengthening of the sea-defences should be related not to the locally-recorded highest storm-surge level but to a level which will ensure acceptable and economically sound protection for the future, the Committee's first task was to determine basic and design levels along the coast, in the southwestern estuaries, and for the Wadden Sea.

The studies which were carried out convinced the Committee that it was impossible to determine the highest storm-surge level which could occur. The Committee came to the conclusion that along the whole coast the levels with the same chance of excess as the ordnance level N.A.P. + 5.0 m at Hook of Holland should be taken as the general standard for setting the requirements for the main coastal defence-structures taking into account the importance of the region lying behind them. These levels are called basic levels. Using the results of studies concerning the extrapolation of the frequency curve for the storm-surge levels at Hook of Holland, the frequency of excess of the ordnance level N.A.P. + 5.0 m at Hook of Holland was taken to be 10^{-4}. This level lies more than a metre above the exceptional storm-surge level which occurred in 1953. The basic level was determined for a great number of stations along the coast, whose frequency of excess is by definition 10^{-4}.

Together with the basic level, those levels were determined which were needed to serve as criteria for the improvement of the coastal defences. In determining these levels, which are called design levels, the importance of the area to the rear was taken into consideration. For the coast between Hook of Holland and Den Helder, design levels were taken which have the same frequency of excess as the basic levels. For the south-west and north of the country and for the Wadden region, however, levels were chosen with a greater frequency of excess than that of the basic level because there the defence works must protect less important interests. In determining the design levels for the south-west, account was taken of the effect of the closure of the estuaries on the storm-surge levels in the neighbouring areas."

5.2 Coastal protection works

5.2.1 Protection works

The following protection works can be distinguished:
- sand drift screens or beach grass near the dune foot (photo 12);
- rubble mound on a mattress (nearshore) in the case of pushing tidal channels;
- groynes and pile rows (photo 1, 3, 13);
- dune revetments (photo 14);
- sea walls;
- artificial beach or dune nourishment (photo 9).

The construction of new solid defences will be avoided as much as possible. The existing structures, if effective, will be maintained as well as possible. At present the erosion problem will be tackled mainly by artificial beach nourishment.

5.2.2 Some statistics

As a result of the classification used which is made for the description of the coastline in this project and the subdivision of the coastline into uniform segments in the sense of morphological behaviour, the following tables can be drawn up. Table 1 is derived from the cartography and the database.

Tab.1 Total lenght (km) of the segments of the coastline with the same classification.

		morpho-sedimentological units							
		E	E_1	G	G_1	H	J	Y	tot
rates of	-	-	-	-	-	61.6	48.7	-	110.3
change	2	-	-	-	-	-	-	121.2	121.2
of the	3	84.9	19.6	32.9	112.3	-	-	-	249.7
coast-	51	68.4	113.4	-	-	-	-	-	181.8
line	71	78.3	42.3	-	76.6	-	-	-	197.2
	tot	231.6	175.3	32.9	188.9	61.6	48.7	121.2	860.2

In this table the codes used mean:

E, E_1 : developed beaches with sandy strands
G, G_1 : strands made of muddy sediments: waddens and inter-tidal marshes with slikkes and schorres
H : estuary
J : harbour area
Y : artificial coastal segment, longitudinal coastal protection without presence of beach

The code 1 after E and G indicates the existence of artificial structures for the protection of the coast.

2 : evolution almost not perceptible at human scale
3 : small occasional variations around a stable position: if evolutionary trend uncertain
51 : erosion with recession of the coastline generalized to the whole of the segment
71 : aggradation with advance of the coastline generalized to the whole of the segment

The length of the North Sea coastline, so the Wadden Sea excluded, from Cadzand to Rottumeroog amounts to 353 km, tidal inlets and estuaries, open and closed, excluded. Of this North Sea coastline 254 km consist of a dune coast, 34 km dikes, 38 km strand plains and 17 km rest (harbours, industrial areas and such). Of the dune coast about 40% comprises extra defence structures like groynes, pile rows and dune revetments (Rijkswaterstaat, 1989).

5.2.3 Maintenance costs

In Burger (1987) and Schoor (1989) an inventory has been drawn up of the basic maintenance costs of the North Sea coast, price level 1984. The basic maintenance costs are the average annual costs of normal (annual) and extraordinary (multi-year) maintanance, BTW and technical overhead included, the costs of artificial nourishments excluded. They amount to about 27 million Dutch florins (Fl) per year. Table 2 gives a review of the total costs for the three areas of the Dutch North Sea coast and the different coastal types.

Tab.2 Total costs of basic maintenance in million Fl/year (Schoor, 1989)

		Delta	Holland	Wadden	NL
coastal type	coastal length	108 km	124 km	121 km	353 km
dunes	254 km	3.6	8.1	8.8	20.5
strand plains	38 km	-	-	1.2	1.2
dikes	34 km	1.4	2.7	-	4.1
rest	27 km	0.6	0.3	0.1	1.0
total	353 km	5.6	11.1	10.1	26.8

Expressed in average costs per kilometre coastline per year with gives a better mutual comparison the table changes as follows :

Tab.3 Average costs of basic maintenance in 1000 Fl/km/year (Schoor, 1989)

		Delta	Holland	Wadden	NL
coastal type	coastal length	108 km	124 km	121 km	353 km
dunes	254 km	54	77	107	80
strand plains	38 km	-	-	31	31
dikes	34 km	65	221	-	120
rest	27 km	30	43	85	36
total	353 km	52	90	83	76

remark : the standard deviation has the same order of magnitude as the average value itself

Part of the spreading in the costs of the basic maintenaance of the dune coast can be explained by the presence of coastal defence structures. Subdivided to the kind of defence (not defended, defended by groynes, defended by pile rows) table 4 has been derived.

Tab.4 Average costs of the basic maintenance of the dune coast in 1000 Fl/km/year (Schoor, 1989)

	Delta		Holland		Wadden		Nederland	
	Fl	km	Fl	km	Fl	km	Fl	km
not defended	33	30	42	66	67	61	50	157
def. by groynes	76	20	137	38	224	21	144	79
def. by pile rows	64	17	46	1	-	-	63	18
whole dune coast	54	67	77	105	107	82	80	254

Over the period 1975-1984 the total costs of the artificial beach nourishments for maintenance purposes amount to 58 million guilders for 31 km of coastline. With an average lifetime per nourishment of 5-10 years, this is an average of 250 kFl/year/km (Burger, 1987).

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ANNEX 1

The number of segments per NUTS unit (level III)

NUTS number	name of the area	number of segments	number of islands
4111	Oost-Groningen	1	
4112	Delfzijl e.o.	2	
4113	Overig Groningen	4	2
4121	Noord-Friesland	25	4
4721	Kop van Noord-Holland	13	1
4722	Alkmaar e.o.	3	
4723	IJmond	6	
4724	Agglom. Haarlem	1	
4731	Agglom. Leiden	3	
4732	Agglom. 's-Gravenhage	5	
4733	Delft en Westland	2	
4735	Groot-Rijnmond	11	
4742	Overig Zeeland	14	
4741	Zeeuws-Vlaanderen	3	

ANNEX 2

Reference maps

The maps that are used are the following numbers of the Topographic Map of the Netherlands, scale 1:100,000. These maps have been derived from the topographic map on the scale 1:50,000 by direct reduction.

no. 1 Leeuwarden
no. 2 Groningen
no. 3 Amsterdam
no. 5 Rotterdam
no. 7 Middelburg

ANNEX 3

Some representative photo's of the Dutch coast

photo 1 : Walcheren, Westkappelse Zeedijk, NUTS 4742,
Sea dike with groynes.

photo 2 : Oosterschelde, NUTS 4742,
Storm surge barrier in the Oosterschelde.

photo 3 : Delflandse Hoofden, Ter Heijde, NUTS 4733,
Groynes of Delfland (between Hoek van Holland and Scheveningen); small dune row, "sleeping" dike behind the dunes, greenhouses of the Westland (of economic importance).

photo 4 : uninterrupted coast, south of Zandvoort, limit between NUTS 4731 and NUTS 4724; Infiltration area for the supply of drinking water.

photo 5 : Zandvoort, NUTS 4724,
uninterrupted coast, recreation, construction, artificially thrown up banks on the beach for beach pavilions.

photo 6 : IJmuiden harbour, NUTS 4723,
Influence of the moles of the harbour of IJmuiden,

photo 7 : Bergen aan Zee, NUTS 4722,
eroding coast, shows clearly ridge, runnel, rip currents and dune erosion.

photo 8 : Hondsbossche Zeewering, NUTS 4721, sea dike with groynes.

photo 9 : Callantsoog, NUTS 4721, eroding coast, beach nourishment works south of Callantsoog, small dune row near Callants oog.

photo 10 : De Hors (strand plain), south-west corner of the Island of Texel, NUTS 4721; ridge and runnel, rip currents and sand drift screens.

photo 11 : The Island of Ameland, NUTS 4121
eroding North Sea coast, ridge and runnel, sand drift screens, drift sand dike behind the dune row, nature area connected with the Wadden Sea behind the sand dike.

photo 12 : example of coastal defence by beach grass

photo 13 : example of coastal defence by pile rows

photo 14 : example of coastal defence by dune revetment

Photo 1

Photo 2


Photo 3


Photo 4

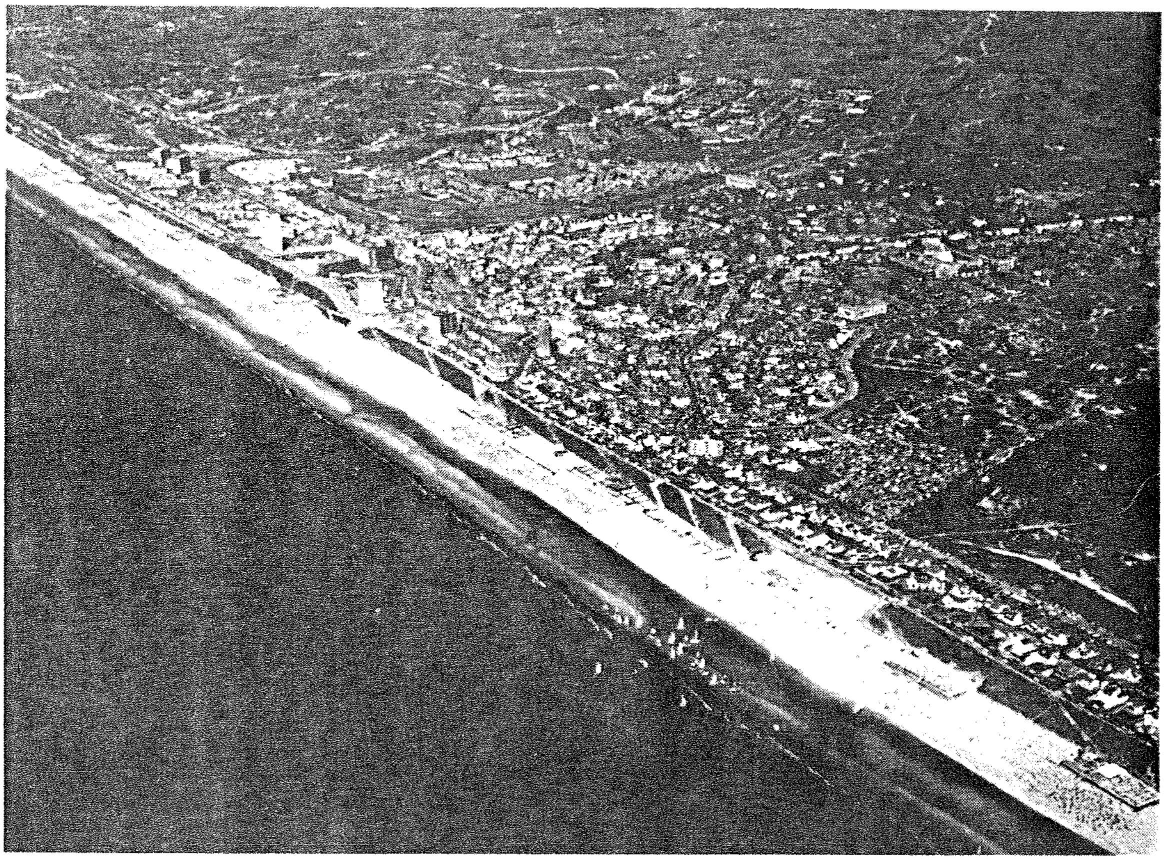
Photo 5


Photo 6

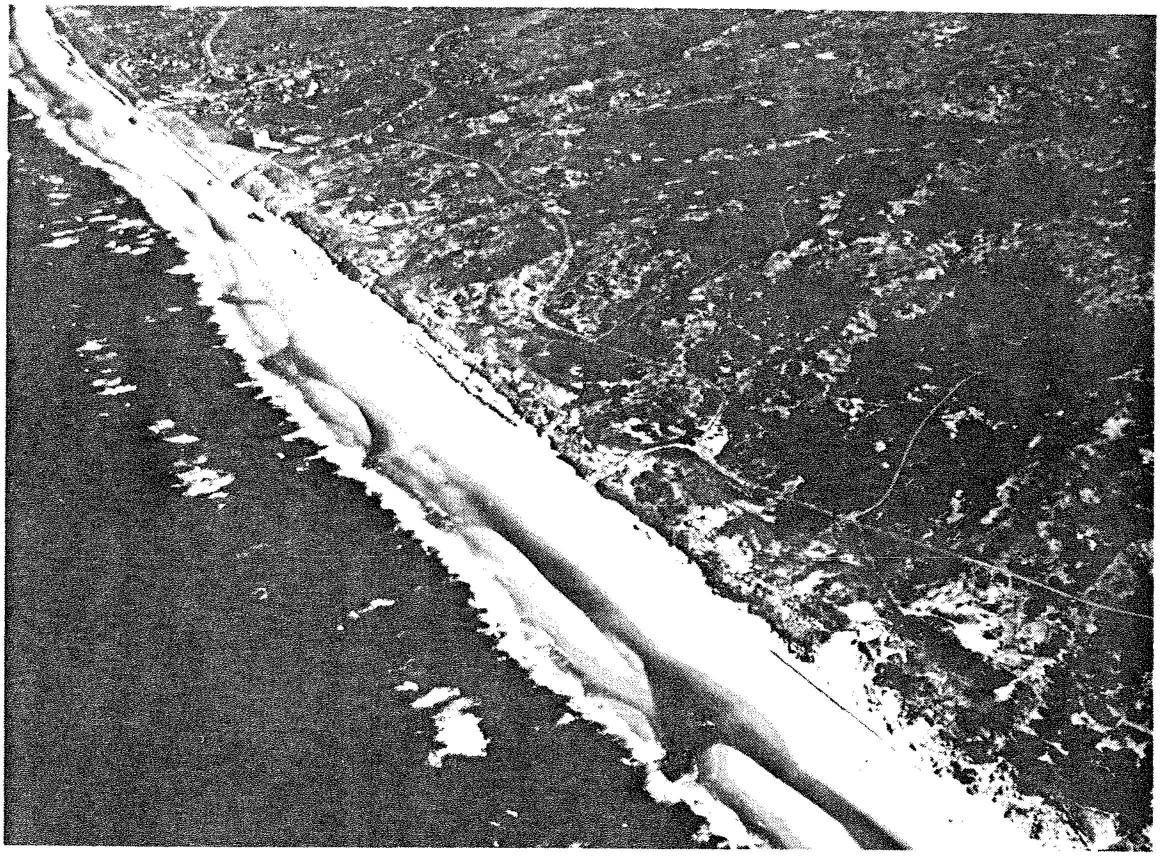

Photo 7

Photo 8

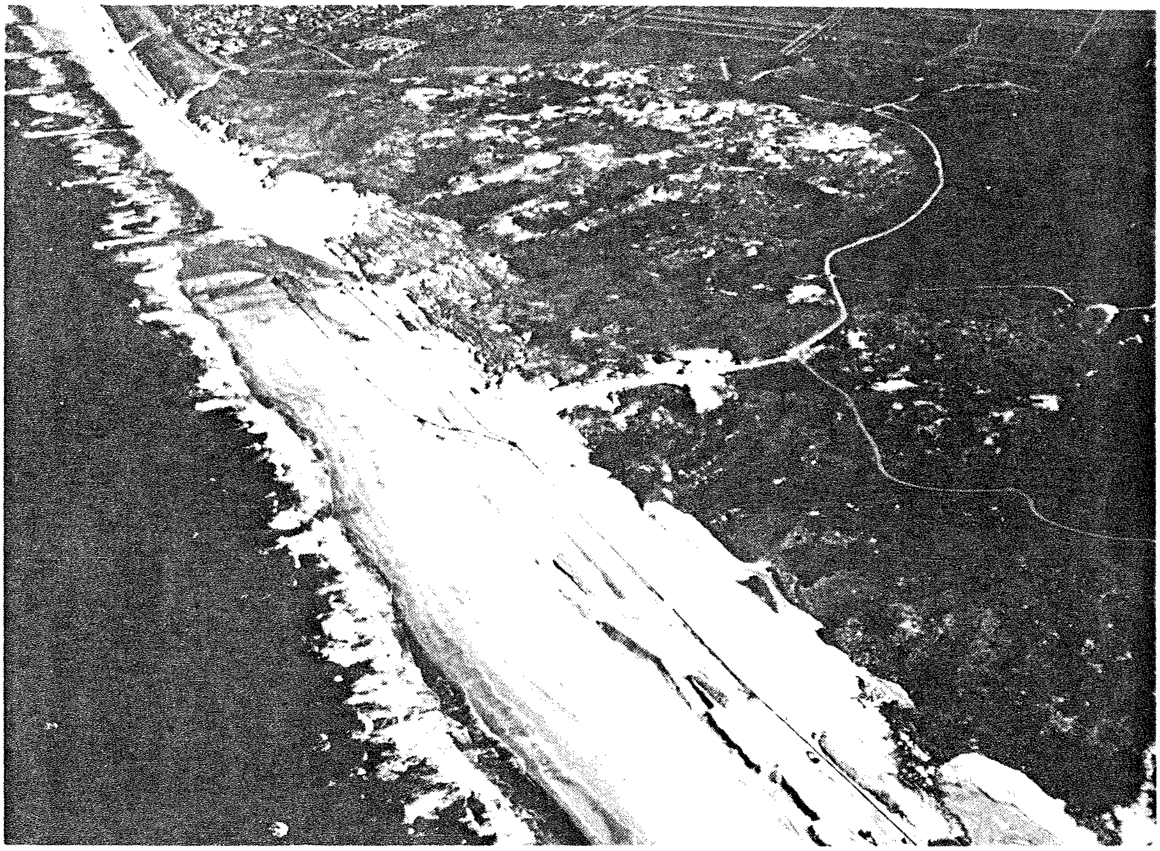

Photo 9

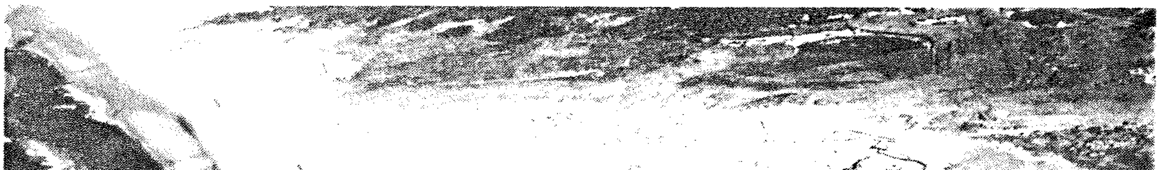

Photo 10

Photo 11

Photo 12

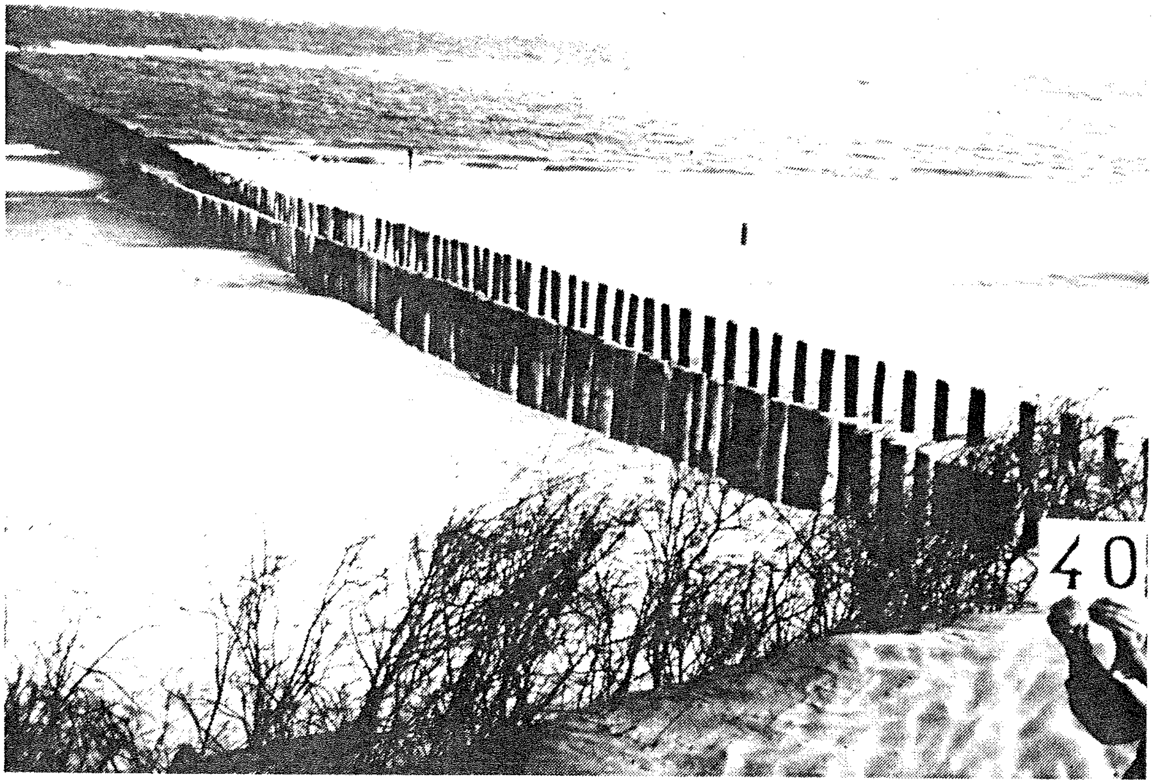

Photo 13

Photo 14