NATIONAL RIVERS AUTHORITY

SEPTEMBER 1991

VISIT TO DANISH COASTAL AUTHORITY

CONTENTS

APPENDICES

APPENDIX A

"Coastal Zone Planning and Coast Erosion Management in Denmark 1991 - Preliminary Draft"

APPENDIX B

"Shore Protection at Danish North Sea Coast"

APPENDIX C

"Copenhagen Metropolitan Region - Coast Erosion Management"

APPENDIX D

"Stabilisation of Coastal Dunes in Denmark"

APPENDIX E

"Master Plan for Coast Erosion Management in Sri Lanka"

APPENDIX F

"Erosion Control with Breakwaters and Beach Nourishment"

APPENDIX G

"DCA West Coast - General Information"

APPENDIX H

"A Coastal Study of the Skagen Spit, Denmark"

APPENDIX I

"SYLT - Germany"

APPENDIX J

"Block Revetment Design with Physical and Numerical Models"

APPENDIX K

"Coastal Protection along the Danish Wadden Sea"

APPENDIX L

"Ribe Dige Reinforcement 1978-80"

APPENDIX M

"Coastal Drain System"

VISIT TO DANISH COAST AUTHORITY

ROBERT RUNCIE

SEPTEMBER 1991

1. Introduction

The purpose of the visit was to exchange ideas and compare technical approaches to common flood defence problems. The visit took place on an exchange basis following the visit to NRA - Anglian Region by DCA Engineer Holger Toxvig - Madsen.

General

The Danish Coast Authority was founded in 1973 and given wide reaching powers for the co-ordination of coastal protection and development within the coastal Environment under the Danish Coast Protection Law 1988.

The Danish Coast Authority (DCA) is a Government Institution serving the Ministry of Transportation and Public Works in the following:

It is the technical advisory body to the Ministry on all coastal engineering matters, also dams, road bridges, tunnels, harbours and marinas for pleasure use, and beach landing stages for the inshore fishing industry.

It is responsible for constructing and maintaining coast protection works established by the Government, and the construction or supervision of any other coast protection works along the West Coast of Jutland which receive Government Grants.

It supervises and monitors navigation channels.

It regulates construction activities, pipeline installation and cable laying in Danish Territorial Waters. These regulatory activities are laid down in the Danish National Coast Protection Act. This Coast Protection Act would be the equivalent of the Flood Defence aspects of the Water Act 1989 and the Coast Protection Act 1949 in the United Kingdom.

It provides technical advice to other Danish Authorities, eg Local Authorities, on matters concerning coast protection and the abstraction of materials such as sands and gravels from the sea and inland waterways.

It is also responsible for the storm surge alert system for the West Coast and Wadden Sea areas of Jutland.

2. The Organisation

The DCA has its administrative headquarters in Lemvig and 5 local depots along the West Coast in Aggar, Thyborøn, Ferring, Blavand and the Rømo Causeway (Figure 1).

There are 120 full time staff:-

45 in administration which includes financial contract work, also the computer department.

20 in the technical department, ie the equivalent of our Engineering Department.

55 in the Construction and related areas including planning, and 12 in the survey section.

The 5 local depots are used to conduct construction and maintenance works along the 500km North Sea Coast.

The DCA uses contractors for channel dredging and coast protection work. This applies to its own projects and those where it acts in a consultative capacity for local councils operating on Government Grants.

The DCA operating expenses, including maintenance, are approximately £4m per annum. Capital Project expenditure is approximately £7m per annum. Typically, the Government grant aid capital schemes at 60%, the remaining 40% is raised locally through the local councils.

There is 7300km of coastline surrounding Denmark but it is the West Coast of Jutland which is most susceptible to the pressures of north sea storm surges. Thus the £11m total annual expenditure is almost entirely concentrated on 400km sandy west Jutland Coast.

Tidal ranges compared with ours and still water return periods for Denmark are given in Figures 2a and 2b. The DCA is developing its Coastal Zone Management policy and a "preliminary draft" is given in Appendix A.

The issues covered include Coastal Zone Planning and Coast Erosion Management.

Papers to illustrate the issues discussed in the policy paper are given in Appendices B to E. These include:-

B - Shore Protection at the Danish North Sea Coast

C - Copenhagen Metropolitan Region. Coast Erosion Management

D - Stabilisation of Coastal Dunes in Denmark

E - Master Plan for Coast Erosion Management in Sri Lanka.

General map

Figure 1

NORTH SEA TIDAL RANGES

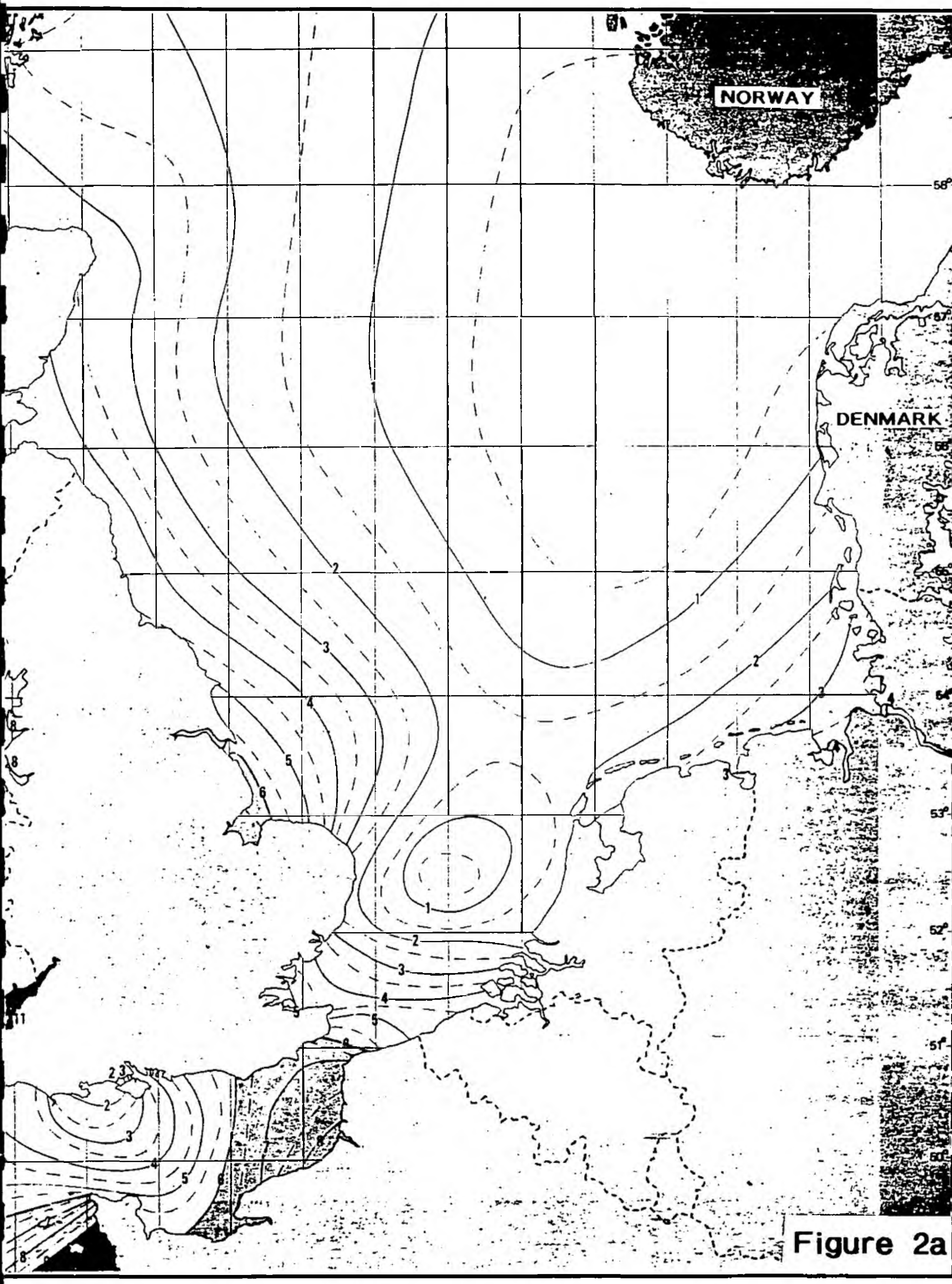


Figure 2a

WATER LEVEL - RETURN PERIOD 100 YEARS

IN DANISH COASTAL WATERS

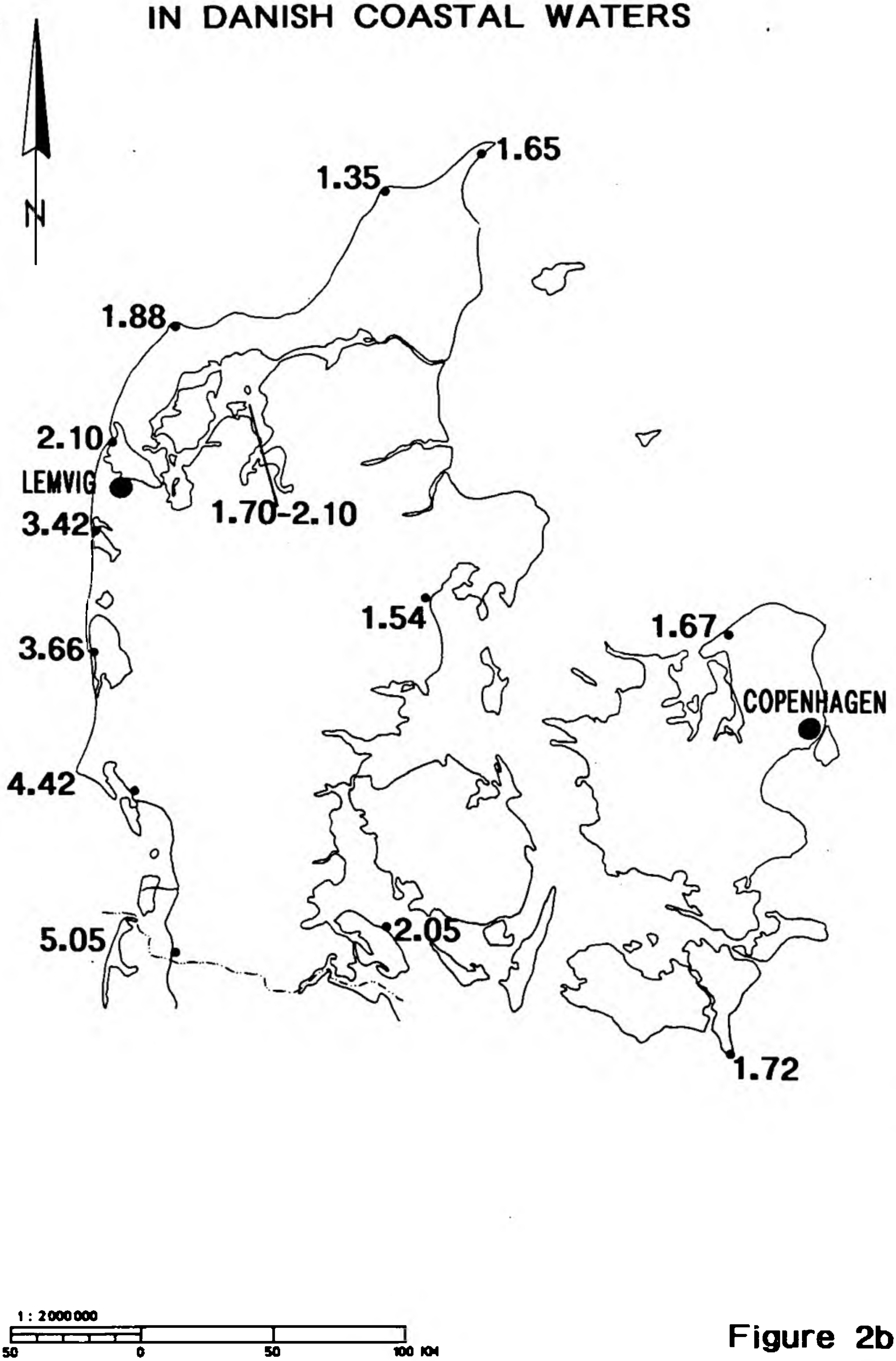


Figure 2b

3. <u>Project Promotion</u>

Projects are promoted in one of three ways:-

i) On the West Coast facing the North Sea the Government sponsors Coastal Defence in conjunction with the County Authorities. The Danish Coastal Authority monitors this coast, produces strategies and submits these for approval to local and government officials for financial approval to proceed. Not too different from our procedures with Local Flood Defence Committees.

ii) Also on the West Coast, owner stimulated concerns funded through the collective owners in the defended area, state and private, can instigate a scheme. The concerns are passed either from Government, or County Authorities, or direct to DCA who then conduct appraisals and make recommendations.

iii) For all other areas outside the West Coast grant aid cannot be sought from Government. County Authorities take responsibility - like District Councils in our system.

If there is a local collective consensus that there is a need for coast or tidal protection it is passed through the County Council to the DCA. The DCA will make an outline assessment including an agreed division of costs for all aspects of the scheme - including investigation and appraisal, eg if land is State owned the County Council will pay, but otherwise costs are shared by beneficiaries. Alternatives, options etc are then usually assessed by consultants with the DCA commitment rescinded after the 1st phase evaluation. This process of evaluation was brought about by the 1988 Coast Protection Law and since then the process has only been used four times.

4. Design Standards

The DCA determine their own design standards in most circumstances.

However, for the large embankment (or dyke) construction in the Wadden Sea Area, Committees were formed to set project constraints - see Appendix L "Ribe Dige Reinforcement 1978 - 80". The DCA propose risk levels for approval by funding Authorities. There are no target design levels approved, but levels of service of 1:100 standard for Rural Areas and 1:1000 standard for Urban Areas have been used and now form precedent.

German DIN standards are used for embankment designs.

Contract administration and supervision is done in-house for schemes on the West Coast from Esbjerg to Skagen. For more distant sites these responsibilities are often contracted out, with consultants acting as "Engineer".

5. Monitoring

Monitoring is the responsibility of the survey section within the DCA Construction Unit (which is equivalent in some respects to our Operations staff).

It has a staff of 12, two survey vessels and supporting 4 wheel drive vehicles.

Monitoring of the west coast of Jutland is conducted over a two year period on 430 fixed profiles at 1km intervals. Surveys are conducted topographically from the back of dune defences to merge with bathymetric surveys extending 2km, 5km and 10km out to sea. Land and bathymetric surveys are conducted on the same day to ensure qualitative data is being recorded. Sensitive sites are also surveyed after significant storm events to ensure coastal process history is reflected in their database. In project areas eg, Nourishment schemes, surveys are conducted every two weeks throughout the contract period and beyond. Digitised data is then transferred to the "MOSS" system which is used to analyse volumes, produce historic profiles, and plot sand movements as nourishment is dispersed.

Volume calculations are calculated using closed polygons from scatterpoints between defined breaklines. Accuracies of $\pm 20m^3$ in $20,000m^3$ have been achieved!

Tide gauges are maintained and data recorded every 15 minutes. This permits a tide prognosis which is essential to the survey work and flood warning system.

The survey section also investigate and monitor borrow sites for beach nourishment.

In addition to the west coast the DCA survey section monitor navigation channels in all Danish Territorial Waters. They let and supervise navigation dredging in these areas - annual budget for this work is approximately £230k with dredging @ £1.70/m^3 on small contracts. This work takes almost 30% of the departments resources in terms of finance and manpower.

The electrical engineers also provide a support service for all mobile radio communications equipment.

6. Consultation

In addition to the Consultation with County Council and Government funding agencies the DCA has a statutory obligation to advise 11 Conservation groups of its intentions, eg Greenpeace and other similar organisations. This is done in advance of EEC SI 1217 advertising by an automatic consultation procedure.

7. Maintenance

Dune maintenance is conducted by Dune Authorities (refer to Appendix D). Embankment maintenance is low on the tidal reach between Tøndor and Esbjerg. The 1:10 seaward slopes are grassed and grazed under the supervision of the Ministry of Agriculture. The Ballum summer flood embankment was constructed to a 1:5 year standard by the DCA but is the responsibility of the private land owners to maintain.

Reveted embankments and dunes, plus the Rømo causeway polders are maintained by DCA in-house staff and finance is raised through the appropriate County Council.

Beach nourishment is not considered as maintenance, and as this fronts many revetted natural and artificial dunes it keeps down the size of the operations budget.

8. Erosion Control on the West Coast of Jutland

The 384km west coast of Jutland from Skagen in the north to Blåvand is a dune coast subject to significant erosion.

Much of the dune is a developed as holiday housing with the hinterland used for mixed agriculture. A 100m strip was set aside from development in 1937. The ban on development in the coastal zone was increased to 3km in 1978 to prevent further pressures for new development of hotels and vacation housing. These measures were taken initially to protect the environmental qualities of the Danish coast, but also to allow for future potential set back in coast erosion management should this prove necessary.

There are no plans to implement a set back policy, in fact measures to actively arrest and stop erosion are being pursued.

Erosion rates vary from a peak of 11m/year to a more frequent rate of 1 to 2m/year. (Figure 3)

Three principal measures are being taken to control the rates of erosion:

The construction of breakwaters typically in water depths 1m below MSL.

Beach nourishment with annual recharge considered as a capital investment.

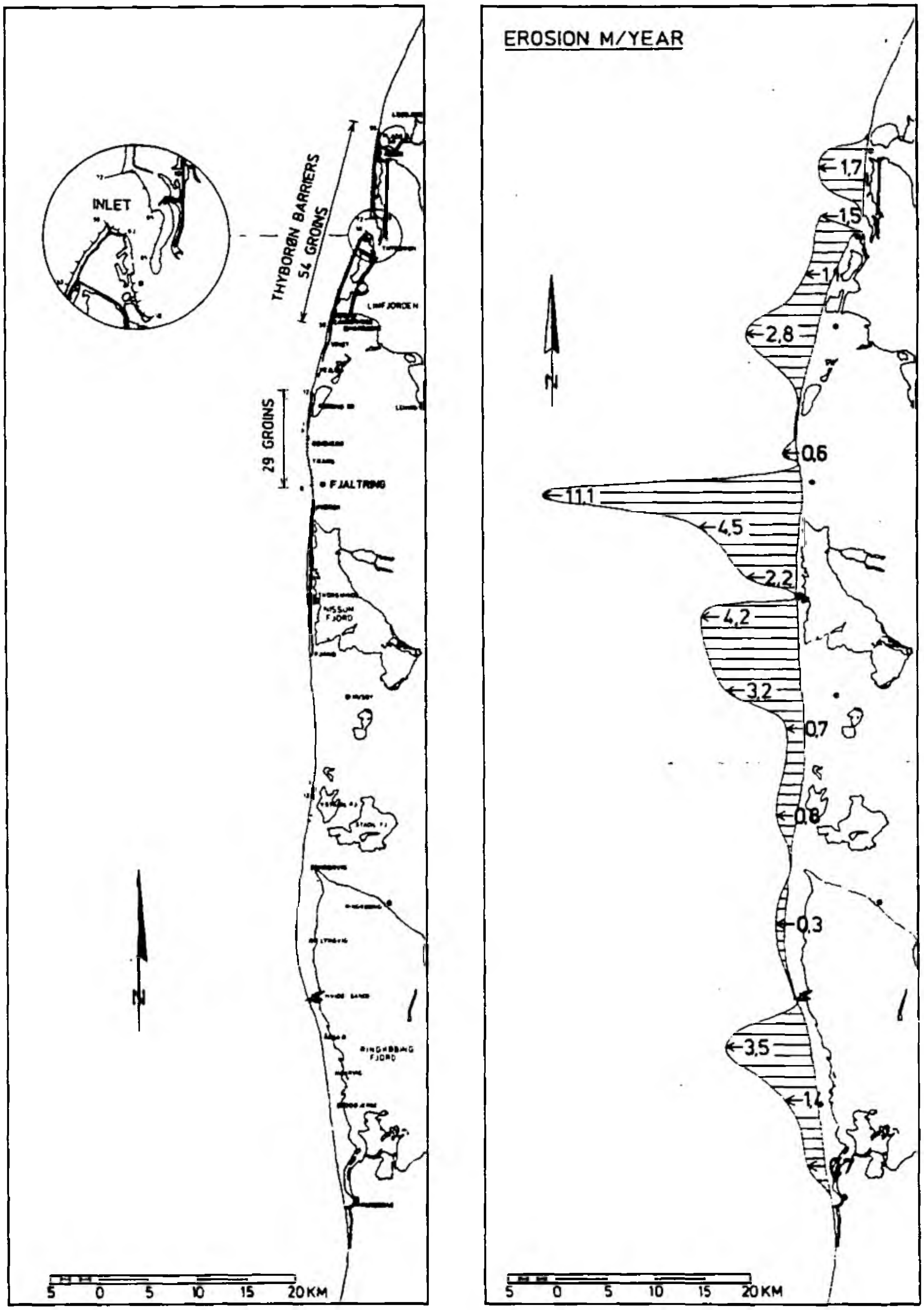
Revetment to front natural or artificial dunes. These are typically constructed using 2 tonne and 3 tonne concrete revetment blocks.

The design of these are given in Appendix F and shown diagrammatically in figure 4. Typical descriptions of past projects are given in Appendix G. Annual beach nourishment is considered to be ongoing capital expenditure, ie an indeterminate contract completion date. This "phasing" of work enables government grant aid to be paid and thus obviates the need for maintenance expenditure.

Two principal forms of measurement are used for dredging contracts:

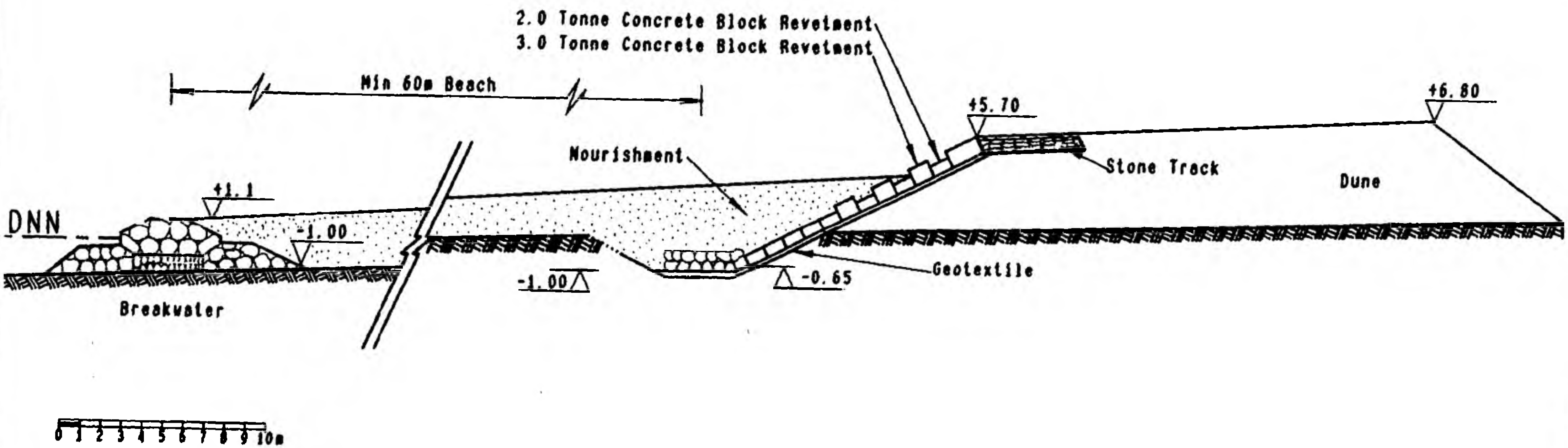
i) Payment to predetermined profile - this method is being phased out. It is considered that profiling produces an unnatural looking beach and this is of high concern where the beaches have high recreation value. Also nourishment contracts are let annually before the end of the surge season. If the winter storm period is quiet, and previous seasons profile undisturbed, contractual problems arise as the scope for placing material above due surf zone is diminished.

ii) Payment to hopper measure - this is the preferred method and the one used for schemes where material is pumped above using the "Rainbow Method" or piped to shore. No profiling is done as the sand is allowed to form its own shape. Monitoring is conducted to ensure specified quantities of nourishment reach the required beach margins. In both methods borrow areas are defined in the contract.



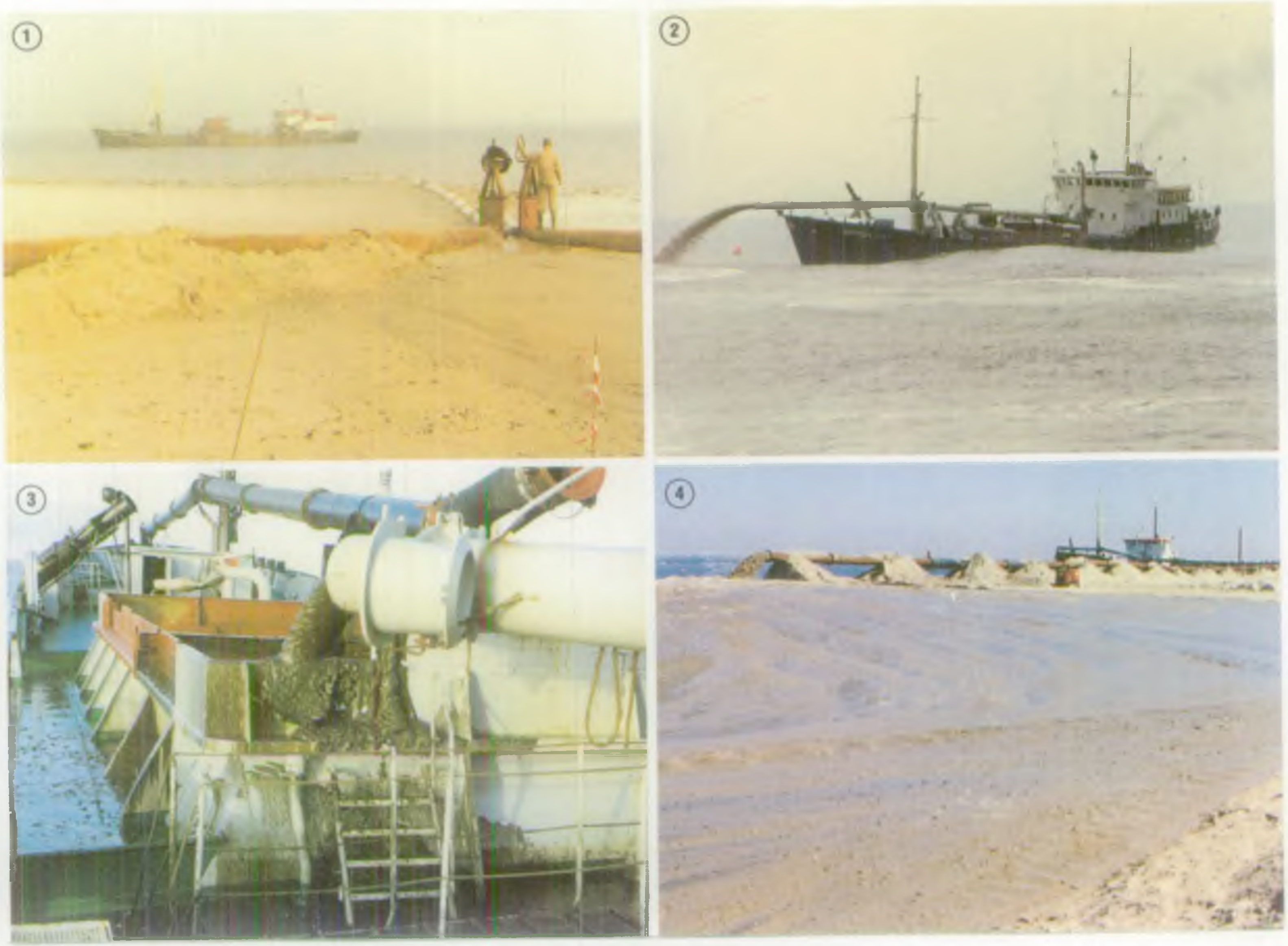
West Coast Erosion

Figure 3



TYPICAL WEST COAST PROFILE

Figure 4



"Rainbow Method"

8.1 Skagen

The Skagen Spit or Skaw Spit forms the most northern point of Jutland between the Skagerrak and the Kattegat seas. The morphology and calculating the coastal response is described in Appendix H - "A Coastal Study of Skagen Spit". Apart from the complex development of the spit it is of interest to note the change in engineering practice. Namely the construction of breakwaters in 1m of water to replace the original "T" groynes. The rock groynes are being taken down and rebuilt as breakwaters without links spans. The shore links were observed to be the cause of leeside erosion and thus detrimental to overall performance of the defence system.

All breakwaters are now designed after a period of monitoring the nearshore water level, wind and wave climates. The spacing, size, rock size and length of breakwater are then designed in accordance with the US Shore Protection Manual. Each site is designed for its site specific conditions but standard design profiles appear typical. Modules of 25m lengths of breakwater with 25m gaps in the Southern reaches of the west coast tending towards 50m modules in the northern areas. The beach is accreting south of the reef at a rate of 8 to 9m/year. This material is used to nourish the retreating coastline of both the Skagerrak and Kattegat coasts. The material is taken by road to sites at a cost of less than £3/m^3 (including profiling). The transfer of material by lorry meets with some opposition locally, and other measures of transfer are being investigated.

8.2 Lønstrup

The breakwater and nourishment scheme at Lønstrup was constructed following severe storm damage in November 1981. 10 detached breakwaters and 100,000m^3 of beach nourishment were put in place at a cost of £1.5m in 1983. The initial 100,000m^3 nourishment is topped up annually at a rate of 20,000m^3 to match erosion losses. The nourishment is brought 35km from Hirtshals by lorry at a total in place cost of £2.80/m^3. This is considered as capital expenditure with 50% of costs met by Government and 25% each from the Local Authority and County Council.

The cliff is revetted and adjacent dunes strengthened with brushwood faggots & fascines and planted up with marram grass to reduce wind blown sand problems.

9. <u>Sylt</u>

Sylt is an island situated off the North West Coast of Denmark (Figs. 5 & 6) The coastline is sandy with sand cliffs and dune systems protecting the hinterland. The rate of erosion has been recorded since 1870 and the rate of retreat observed to increase in the past 30 years from 0.9m to 1.5m per year.

The authority responsible for protection works on Sylt is the office for Land and Water Economy (Husum). This section is part of the official Department of Agriculture and Hydraulic Economics, Husum, Schleswig - Holstein, AWL (Husum).

In 1985 following an evaluation of past experience a decision was made to continually nourish the coastline on an annual basis. This is considered to be technically and economically the best way forward.

A general description of the "Protection of the West Coast of Sylt" is given in Appendix I. Annual nourishments of 2 million cubic metres are conducted with contractors bidding for 2 year contract periods.

This year's contracts were for a 1500m frontage requiring 800,000m^3 at Wenningstedt, and 1,200,000 m^3 on a 2,200m frontage at Hörnum. The contract value is DM 12,100,000 ie £2.15/m^3 including land based operations.

Contracts are written to commence in April and completion is for the Contractor to determine. Note: contractor has to make risk assessment for weather conditions. The contract specifies the borrow area(s) to be used and the type of plant method that must be used.

Borrow areas are typically 8 to 10km from discharge anchor points and contracts allow provision for additional payments for every 2km of extra distance the contractor may have to travel if specified borrow areas are changed during the contract period. Water depths average 14 to 20m in borrow areas. Two methods of lifting the sand are used:-

i) Trailer suction dredging

ii) Trailer suction dredger in static position with jet pipes used when hard spots are encountered.

Measurement is made against material raised to hopper and is verified by inspectors employed by the client. Payment is made when the material raised is placed to profile and gives a minimum of 60m deep beach at +5m. Measurement for Danish contracts is similar to the German method, ie, it is made against the material in the hopper. However, options to gauge material in the discharge pipeline have been investigated but not considered accurate enough for measurement purposes.

By contrast the DCA, albeit on smaller volume contracts, have the contractor conduct its own measure. This is done by recording hopper take, and photographing the hopper laden and following discharge. The photographs are date and time marked and used to validate volumes calculated after the material has been discharged and profiled. Typically, bathymetric and land surveys to check volumes on Danish Schemes are conducted once every two weeks with a contractors representative present.

SANDVORSPÜLUNGEN
Hörnum - Wenningstedt/Kampen
auf der Nordseeinsel Sylt

Auftraggeber: Die betroffenen Gemeinden

Planung und technische Bearbeitung: Amt für Land- und Wasserwirtschaft, Husum

HAM 309 liefert Sand beim Ankerponton zum Abtransportieren Richtung Küste

Figure 5

BREWABA Wasserbau-Gesellschaft Bremen mbH - Bennigsenstraße 2-6 - 2800 Bremen 1 - Telefon: (0421) 49 20 81-84 - Telex: 2 46 134 brewa d - Telefax: 49 44 90

Spülfeld Kampen/Wenningstedt

Schleppkopfsauger HAM 309 beim Ankerponton

Figure 6

Payment based on a specified and sourced material obviously lessens the Contractors risk and reflects the low cost of nourishment schemes in Denmark and Germany.

Sand grading is not specified as the client has defined acceptable material and borrow area. Typical sand grain size is 300 to 700 per µm. Contractor prefers finer material, client Husum prefers the coarser material. Note:- claims arise if material raised becomes coarser than the 700 µm, eg additional wear and tear, increased material transport times etc.

10. Vestkysten 90

Vestkysten 90 is a strategy for investment along a 125km stretch of the Jutland west coast from Agger Tange in the North to Holmsland Tange in the south (see figures NR1.1 and NR1.2). The land levels in the hinterland are generally +1 to +2m above mean sea level with sparse population, many holiday homes and agriculture dominates the landscape.

The coastal response along this length is shown in Figure 3 and described in Appendix F. The proposal is to control erosion along this length of coastline to a maximum of 1m/year. A beach nourishment strategy commencing at the edge of the dune system and extending to the -6m DNN contour is being recommended. Ideally the lower limit should extend to the -15m contour but costs become prohibitive at this level.

Current expenditure along this length of coast is 60 million DKK/year (£5.45m/year). 60% is met by government aid and the remaining 40% raised locally through the Danish equivalents of our District and County Councils. The proposal if accepted will raise this expenditure to 100 million DKK/year (£9.09m/year). The ideal would cost in excess of 130 million DKK/year (£11.8m/year) and would not attract sufficient political support to be approved.

If accepted the proposal will provide a holding situation so that a review can be conducted and conditions reappraised in 10 to 20 years time. The principal costs will be attributed to the beach nourishment programme but new dune revetment and some breakwater construction may be required at vulnerable locations. The majority of the recharge material will come from offshore borrow areas but some material will come from accretion points and channel/harbour maintenance dredging. 500,000m^3 from harbour and channel dredging, 1,300,000m^3 from harbour areas, to give an annual total 1.8 million m^3 over approximately 110km of beaches. Typical dredging rates (1988) and quantities are given in Table 1. Note the rate has remained stable, ie reduced in real terms to date.


N
LEMVIG
COPENHAGEN
1 : 2000 000
50
0
50
100 KM
NR1.1

Beach nourishment projects on the Danish North Sea in 1988.

Location	Quantities solid measure (m^3)	Total costs (DKK)	Unit costs (£/m^3) *
Skagen: Damsted.	8,780	321,000	3.32
Skagen: The harbour - Klitgården.	2,400	310,830	11.77
Skagen: Parking place, Grenen.	6,800	99,600	1.33
Lønstrup	25,000	802,000	2.91
Agger Tange.	96,470	3,048,920	2.87
Thyborøn	39,590	1,015,750	2.33
Harboøre Tange.	91,792	2,616,990	2.59
Vrist.	125,832	1,777,375	1.28
Fjaltring/Mærsk - Ndr. Thorsmindetange.	254,964	8,724,000	3.11
Thorsminde - Fjand.	50,293	718,563	1.30
Hvide Sande - Årgab.	173,684	3,678,645	1.93

* 11 DKK = £1

Table 1

10.1 Agger and Thyborøn

The northern limit of this scheme known as the Agger Tange consists of groynes with nourishment in front of a revetted dune system. The groynes are considered to be redundant, the nourishment is lost to the winter storms and the revetment exposed.

The revetment is mainly concrete block 2 to 4 tonne elements but there are some gabion mattresses. The gabions installed in the 1970's have not performed well in the aggressive coastal environment.

At Thyborøn south of the inlet to the Nissum Bredning lake the defences are being nourished to the landward side. A defence width of between 30 and 60m is being established to permit a roll back of the dune system whilst maintaining the overall defence security to the town of Thyborøn.

The nourishment material for Thyborøn is being won from the inland lake. Sand is dredged at a rate varying from 200,000 to 300,000 m^3/year. It is recognised that this is a diminishing resource and future borrow areas out to sea are being investigated. Dredging is carried out by contractor who stockpiles in a DCA depot. The DCA has a permanent transfer pipe system to facilitate the planning of material for use either north or south of the inlet.

Agger and Thyborøn are defended to a 1:1000 year standard.

10.2 Ferring Strand

The narrow coastal strip keeping the North Sea from entering the lake - Ferring Sø is to be revetted and nourished as part of the Vestkysten 90 work. The Ferring Sø is environmentally important and is the justification for the work in this section.

South of Ferring at Fjaltring open stone asphalt revetment was installed in 1979. This has performed well to sustained wave attack but the 250mm thick revetment now requires refurbishment. It is proposed to resurface the revetment with a new 100mm thick open stone asphalt overlayer on a bitumin emulsion binding layer. However, this method is considered to be aesthetically unattractive for use in areas frequented by the public for recreation and not thought to stand as well with sand beaches as does the concrete revetment.

10.3 Torsminde

Water levels are controlled by a sluice structure to the Nissum Fjord and salinity levels monitored in this environmentally sensitive brackish lake.

Sand accumulates at its inlet and maintenance dredging of 250,000m^3 contribute to Bøvling Klit nourishment.

Typically the maintenance sand is transferred to site by dumper and tipped in location. No profiling takes place - storm surge action models the beach over the winter period.

Dredged material is currently pumped ashore into settling bunds and dozed to profile. From 1992 it will be pumped ashore but natural profiles will be developed between the dunes and breakwaters, ie no dozing to shape.

It is interesting to note that the land defended at Bøvling is owned by the state, purchased with the original intention that retreat could take place. Pressure from two state sponsored cultural institutions, and subsequent agricultural development have since reversed the decision, hence the commitment to maintain the defence.

10.4 Husby Klit

This length is subject to the construction of new revetment to 750m of existing dunes. The revetment construction using 2 and 3 tonne blocks laid at 1.62 over a geotextile are typical for the west coast. Refer to Appendix J - "Block Revetment Design with Physical and Numerical Models".

2 tonne blocks towards the toe and 3 tonne blocks where wave energy is greatest at the upper end of the revetment.

The block revetment can be constructed at a rate of 14 linear metres per day at a cost of £750 to £900 per linear metre (slope lengths of 10m are common). The rock toe and blockwork are then covered with sand to give the required standard of protections for the area. Sand for this length is currently won from the land side and a scheme to create trout ponds is under construction to mitigate the borrow pit impact. Artificial dykes are being constructed to secure lengths where there are gaps in the natural dune system. Consideration to landscape these geometric structures is taking place. Both natural and artificial dunes are planted with marram grass to improve their stability. Brushwood wind breaks also help arrest sand movement through the dunes.

10.5 Hvide Sande

Hvide Sande is situated on the inlet to the Ringkøbing Fjord and has a small fishing port and commercial harbour. Similarly to Torsminde the inlet suffers from the sanding up of the navigation channel. Maintenance dredging produces 250,000m^3 of sand a year. This is purchased for nourishment at a cost of 11 DKK/m^3 (£1/m^3). However, DCA has an arrangement whereby additional material over and above the quantity raised for maintenance purposes can be purchased. An additional premium of 12 DKK/m^3 is paid to give a total of 23 DKK/m^3 (£2/m^3) for this material.

Maintenance dredging is conducted throughout the year by the Port Authority and the DCA have commissioned the construction of a permanent pipeline and booster station.

Without a booster the dredger at Hvide Sande can pump sand approximately 250m. The booster station is designed to pump material up to 3km with a capacity equal to the dredger discharge of 400m^3/hour.

Takeoffs from the delivery pipe have been installed at 100m intervals along the 700mm diameter pipe.

The total cost of the installation is approaching 10 million DKK (£0.9m) which compares with 11.5 million DKK (£1.05m) for conventional trucking with dumpers. The new booster and pipeline will have the advantage of being capable of operation at any time the dredger can discharge. The booster will be operated remotely from the dredger. The booster station has to be fitted in a container module so that it may shore sites, eg with Torsminde of trials prove successful.

There have been a few problems with the pumping plant and costs have escalated by almost 100% since conception of the project. The scheme is still economically viable with an internal rate of return for capital investment of 7 years. 60% of costs are met by government and 40% from Local Authority and County Council equivalents.

11. Jutland Wadden Sea

South of Esjberg is the Danish Wadden Sea. The lowland area of approximately 30,000 ha below +5m DNN is defended by 80km of embankments fronted by managed saltings. This area is administrated along the same lines as IDB's in the UK. The embankments were designed and construction supervised by the DCA. The saltings are managed, and saltings development through polder field construction by the Danish Ministry of Agriculture. (Figure 7)

The Wadden Sea Tidal Embankments are described in Appendix K and the Ribe Dige in Appendix L. This discussion will concentrate on the polders and saltmarsh as parts of this area.

The embankments and saltmarshes are part of and integrated international policy for flood and coastal protection in the Wadden Sea of Denmark, Germany and Holland. In Danish waters £500k/year is invested in polder construction and maintenance. All of the money comes from central government sources. Engineers from the Ministry of Agriculture in Tøndor supervise the work which is let to contracts paid on a piecework basis.

Polder fields have been constructed, maintained and monitored in the area for up to 50 years. Each year new polders are developed on state owned land. The Government is gradually purchasing all foreshore interests in order that it can implement a common management policy along all of the foreshore. Polder fields have been optimised at 200m wide and extending 250m from the embankment toe. However, the constraint on the seaward edge is that it is established in depths not exceeding 0.6m below DNN. The tidal range is ± 1m in this area. Stoned access road/groynes are formed at 1km spacings and help stabilise the polder fields between them. Brushwood groynes are used to construct the polder margins and these undergo annual maintenance commencing in the spring.

The brushwood construction suffers badly in years when ice sheets form.

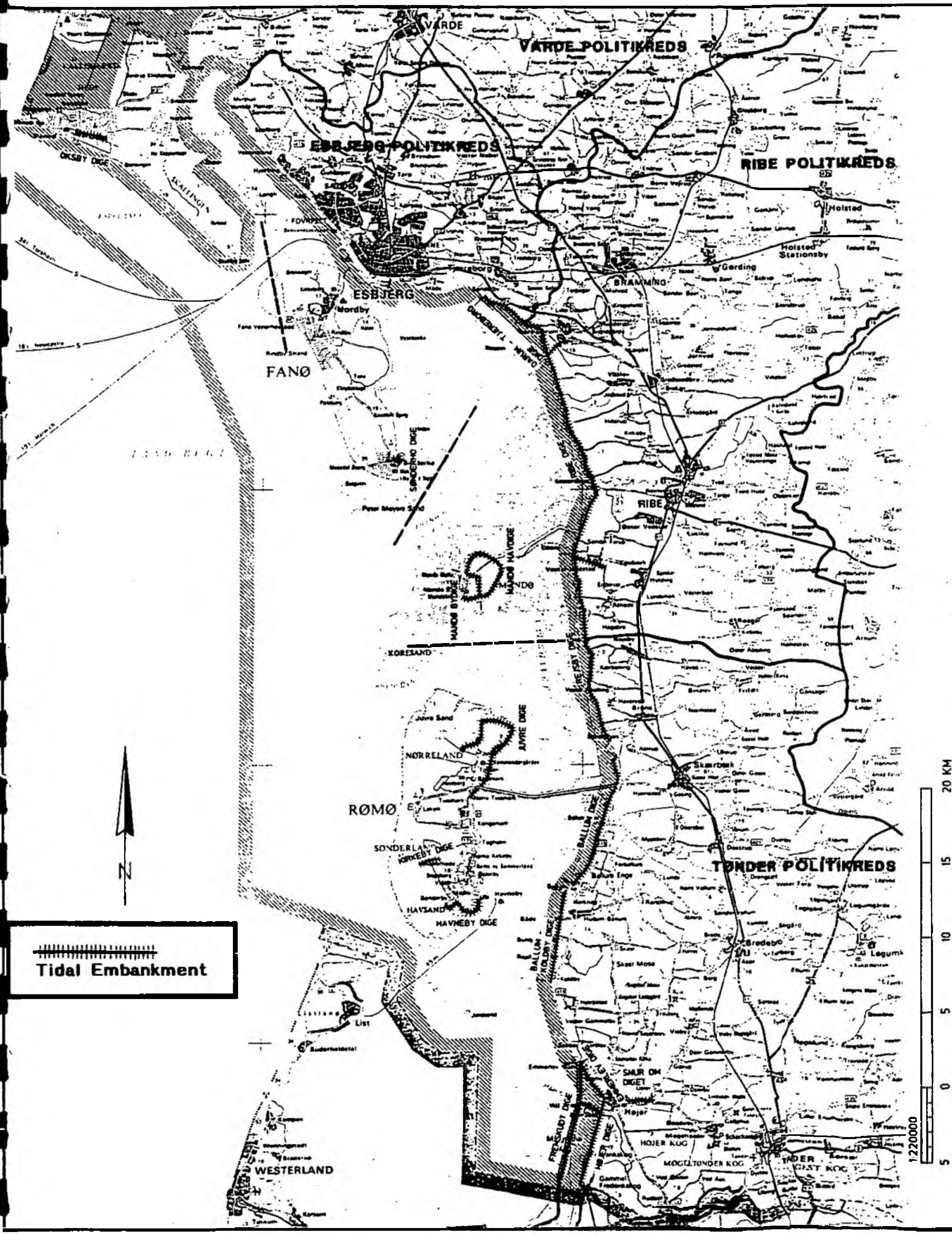
Accretion of 2cm/year is the average rate and it takes up to 40 years for a stable salting to be established.

Once silt layers begin forming over the sand foreshore in the polders, drainage management commences.

A drainage channel is formed 6m back from the seaward edge to reduce pressures on the brushwood. As the salting develops, drainage furrows are formed at angles normal to the embankment toe. These are recreated annually, they help to encourage accretion and natural colonization by salting plants. Spartina and salicornia stricta grasses in the first instance. Puccinellia Maritima is introduced to the more mature areas. Where stable well vegetated saltmarsh exist they are grazed by sheep. Grazing density, ie sheep/ha, and grazing seasons are controlled by the Agricultural Ministry.

In one area stable saltmarsh has encouraged natural salting development and over 400m separates the embankment toe from the edge of the sea.

The reclamation of land in the form of summer grazed saltings as a form of foreshore protection is a well planned and monitored system of flood defence in the Wadden sea.

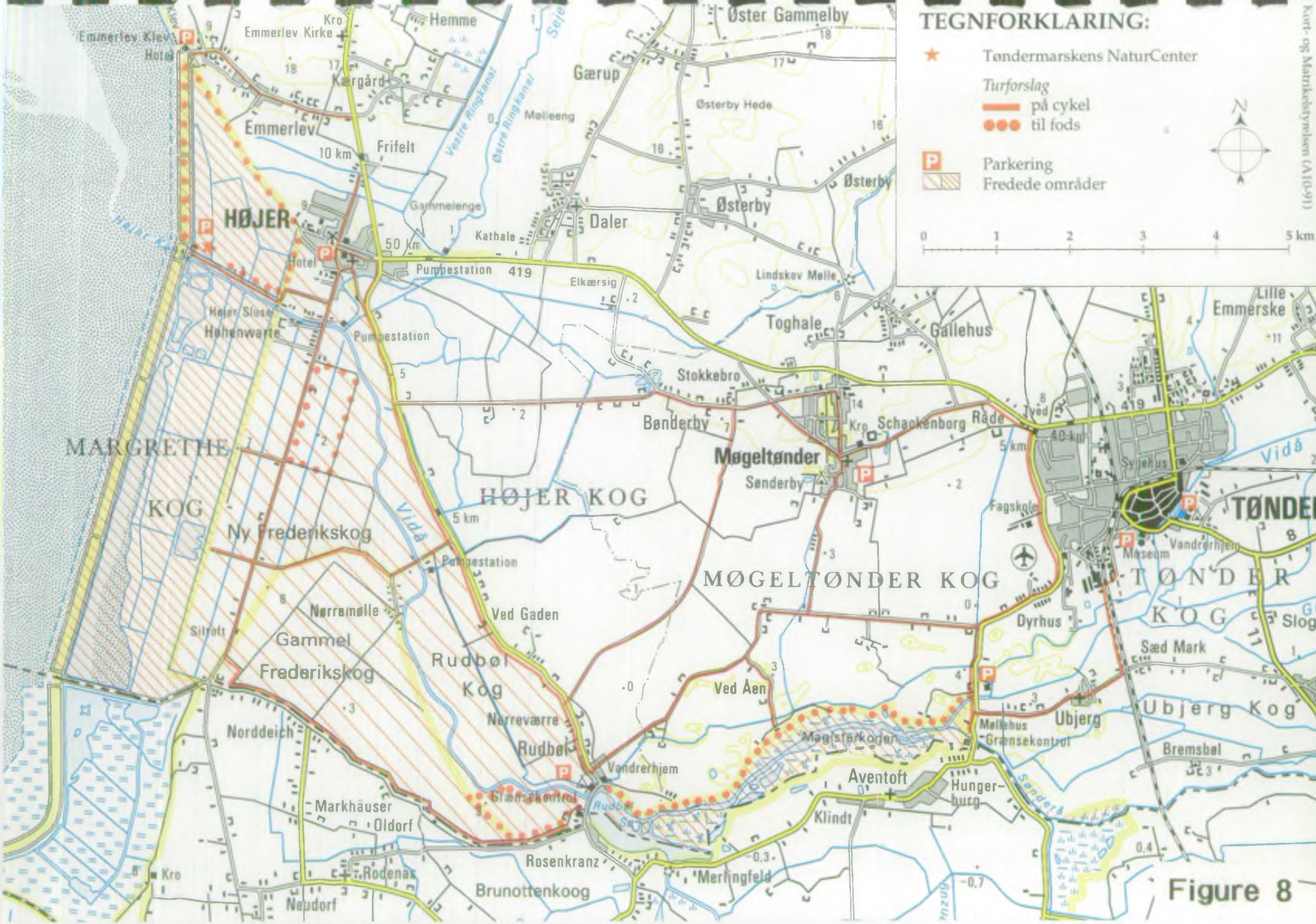


Wadden Sea Embankments **Figure 7**

Not all of the salting is grazed. Areas are set aside and allowed to develop unhindered. However, drainage is kept throughout the polder system: new polders < 20 years old on an annual basis; mature polders every fifth year.

Causeways to the islands of Rømo and Mandø have polder fields established to safeguard the accessway embankments. The Rømo polders are managed by the DCA in-house workforce using the same techniques as the Ministry of Agriculture.

The embankment line was brought forward in the Tøndor marsh adjacent to the German border. An area behind the flood embankment (a 1:200 standard for Tøndor and Ribe) was issued for a flood storage reservoir. The agricultural land behind the defences is part of the pumped drainage system established on repatriation of the land to Denmark in 1920. However, this 380 ha area of which saltmarsh covers 300 ha is kept saline by pumping seawater in on every high tide. The saltmarsh is separated from the river by a broadcrested stone weir and sluice structure. Environmentally the scheme is highly successful with a permanent nature centre established for study groups and open to the general public. (Figure 8)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10 km
Vestre Ringkanal
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Daler
Østerby
HØJER
Gammelenge
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Pumpestation
419
Elkærsig
Lindskov Mølle
Højer Sluse
Hohenwarte
Toghale
Gallehus
Lille Emmerske
Stokkebro
Bønderby
Kro
Schackenborg
Råde
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Sønderby
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TØNDER
MARGRETHE
KOG
HØJER KOG
Ny Frederikskog
Vidå
Fagskole
Museum
Vandrerhjem
MØGELTØNDER KOG
TØNDER KOG
Pumpestation
Nørremølle
Ved Gaden
Dyrhus
Sæd Mark
Siltoft
Gammel Frederikskog
Rudbøl Kog
Ved Åen
Ubjerg Kog
Nørreværre
Ubjerg
Møllehus
Grænsekontrol
Norddeich
Rudbøl
Magisterkogen
Bremsbøl
Vandrerhjem
Aventoft
Hungerburg
Grænsekontrol
Markhäuser
Oldorf
Klindt
Sønderå
Rosenkranz
Kro
Rodenäs
Merlingfeld
Brunottenkoog
Neudorf

Figure 8

12. Coastal Drain System

The coastal drain system currently being promoted by MMG in the UK has been monitored on sites in Denmark for 7 years.

The initial conclusions are given in Appendix M - DHI paper, "Coastal Drain System".

Research has not quantified the volumes and costs. However, current nourishment scheme costs are less than running and maintaining a coastal drain.

The DCA has made available monitoring data for control sites North and South of the drain, and for the drain system. This should permit realistic unit rates to be calculated for the system. The Danish Hydraulic Institute is also going to forward further information in due course.

In areas where nourishment costs are not so attractive, eg West Coast of USA and Queensland Australia the scheme has been tried with successful results. On the Thorsminde prototype site in Denmark the coastal drain has held the beachline in an area where it is known to vary by ±15m.

It must be noted that the method does depend on an adequate depth of permeable medium for drainage to create an unsaturated zone above the drain. Typical drain depths are 2 to 2.5m below beach level. The design of the system enquires knowledge of tidal range, wave climate, storm frequency and direction, beach and nearshore profile, sediment load and drift direction.

The system may prove viable along our limited sand/dune coast and must be worth a trial - perhaps in conjunction with a coastal erosion length on the R & D programme. The implications of creating a sand groyne by intercepting a quantity of the net drift could then be assessed.

Robert Runcie
Senior Engineer
Engineering Department

4 October 1991

WP-1/BD/RR12

LIST OF USEFUL CONTACTS

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KYSTINSPEKTORATET DANISH COAST AUTHORITY MINISTRY OF PUBLIC WORKS	Højbovej 1 7620 LEMVIG	TEL 010 45 9782 1544 FAX 010 45 9782 2943	Christian Laustrup Chief Engineer
KYSTINSPEKTORATET DANISH COAST AUTHORITY MINISTRY OF PUBLIC WORKS	Højbovej 1 7620 LEMVIG	TEL 010 45 9782 1544 FAX 010 45 9782 2943	Holger Toxvig Madsen Head of Section, Coastal Eng. Div.
KYSTINSPEKTORATET DANISH COAST AUTHORITY MINISTRY OF PUBLIC WORKS	Højbovej 1 7620 LEMVIG	TEL 010 45 9782 1544 FAX 010 45 9782 2943	Per Lykke Larsen Senior Surveyor
LANDBRUGSMINISTERIET JORDBRUGSDIREKTORATET DANISH DIRECTORATE OF AGRICULTURE	Allégade 24 Postboks 109 6270 Tønder	TEL 010 45 7472 1380 FAX 010 45 7472 1980	Karsten Jensen Agronomist
GEOTEKNISK INSTITUT DANISH GEOTECHNICAL INSTITUTE	1 Maglebjergvej DK-2800 Lyngby COPENHAGEN	TEL 010 45 288 4444 FAX 010 45 288 1240 TELEX 37230 GEOTEC DK	Jørgen Chrøis Schuldt Senior Hydrogeologist, Cand.Scient.

PHOTO REVIEW:

List of photos showing the individual nourishment projects.

Location	Photo number
Skagen: Damsted.	1
Skagen: The harbour - Klitgården.	2 and 3
Skagen: Parking place, Grenen.	4
Reclamation at Nordstrand.	5
Lønstrup.	6
Vrist.	7 and 8
Fjaltring/Mærsk - Ndr. Thorsmindetange.	9
Thorsminde - Fjand.	10


9


10
'88 4 26


5


6


7

8

APPENDICES

APPENDIX A

"Coastal Zone Planning and Coast Erosion Management in Denmark 1991 - Preliminary Draft"

APPENDIX B

"Shore Protection at Danish North Sea Coast"

APPENDIX C

"Copenhagen Metropolitan Region - Coast Erosion Management"

APPENDIX D

"Stabilisation of Coastal Dunes in Denmark"

APPENDIX E

"Master Plan for Coast Erosion Management in Sri Lanka"

APPENDIX F

"Erosion Control with Breakwaters and Beach Nourishment"

APPENDIX G

"DCA West Coast - General Information"

APPENDIX H

"A Coastal Study of the Skagen Spit, Denmark"

APPENDIX I

"SYLT - Germany"

APPENDIX J

"Block Revetment Design with Physical and Numerical Models"

APPENDIX K

"Coastal Protection along the Danish Wadden Sea"

APPENDIX L

"Ribe Dige Reinforcement 1978-80"

APPENDIX M

"Coastal Drain System"

APPENDIX A

APPENDIX A

"Coastal Zone Planning and Coast Erosion Management in Denmark 1991 - Preliminary Draft"

Preliminary

COASTAL ZONE PLANNING

AND

COAST EROSION MANAGEMENT

IN DENMARK

1991

Manuscript

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ABSTRACT

The universal objective of Coastal Zone Management (CZM) is to ensure orderly and balanced utilization of resources in the coastal zone and to maintain and where possible restore and enhance the environmental quality of the coastal zone.

The issues at stake are numerous for which reason the present presentation will concentrate on:

- Physical planning aspects in the coastal zone
- Coast Erosion Management
- Dune Management

Other vital issues have been left out such as:

- Fisheries
- Environmental Management
- Traffic Issues
- Exploition of offshore resources

It has not been an easy choice to by pass these issues, especially because Denmark has strong and fine traditions in the fields.

Management of the coastal zone has been in existence in Denmark as in many other developed countries for many decades even through centuries.

The discipline has always been considered an integral part of physical planning and has as such especially matured and developed since the second world war.

The interactive geographical, physical and demographic conditions in Denmark vary with orders of magnitude and give

rise to unique erosion/demographic scenarios. The Danish Sandy North Sea Coast thus takes maybe the hardest beat on a soft coast in Europe.

Coast Erosion Management undertaken by the Ministry of Transportation and Works hence becomes a critical issue which requires a flexible and modern approach.

A well developed technical background provides, together with a new legislation backed by area specific arrangements, a sound basis for present and future activities.

The Danish Coast Authority (DCA) is a Government institution serving the Ministry of Transportation and Works:

- It is the technical advisory body to the ministry in all coastal engineering issues.

- It administrates state owned coast protection works.

- It is in charge of regulatory activities under the national Coast Protection Act.

- DCA was established in 1973, but is rooted in a more than 100 year tradition.

- During the years its activities have gradually increased and DCA is today one of the hubs in the Danish Coastal Zone Management System.

1. BACKGROUND

Denmark is a maritime and offshore nation with old traditions for study, management and exploitation of the sea.

It is also a coastal country, with more than 7,000 km of coast corresponding to 1,5 m per inhabitant and no Dane being more than 50 km away from the coast.

Historically, management traditions are strong. Our ancestors, the stone age man, settled along the coasts of which "køkkenmøddinger" bear withness. Much later the vikings started their raids from coastal ring forts. Despite their reputation the vikings represented in many respects a high level of civilisation and founded so to say CZM in Denmark.

The right of way for the public to the beaches was thus already given in the Jyske Law of King Valdemar Sejr in the year of 1241 based on earlier traditions. In 1683 the beaches were privatised, a situation which continued for almost 250 years when rights finally were given back to the public with the Nature Preservation Law of 1937, which at the same time imposed a 100 m set-back zone along all coasts for new buildings and similar activities.

The Jyske Law also confirmed the long established sovereignty of the King over all territorial waters. This sovereignty is in Denmark not directly based on a law or found in the Constitution, but is considered a given thing as far as remembered - a very old regulation, which sometimes makes it difficult to manage.

Right of way, general set back lines and governmental sovereignty over the sea territory are pillars in Danish coastal policy.

In pace with the increasing complexity of society and growing environmental, concerns sectoral legislation and planning has grown to a high level of sophistications over decades. Similar trends are found in other European countries.

What appears to have been lagging behind - at least in Denmark - has been an up-dated legislation on erosion management, which at the same time takes into account the increasing erosion pressure and the modern demographic/ recreational coastal encroachment.

Furthermore new erosion combatting techniques, especially large beach nourishment schemes, set other requirements to legislation in terms of ownership of artificial beaches, acceptance of the dynamic nature of the schemes and potential adverse ecological effects.

A paramount step forward has hence been the new law for "Coast Protection" which has been passed by the Danish Parliament in spring 1988.

It opens up for improved coordination of coastal protection and development schemes within a coastal environmental perspective.

It subsequently appears that coastal studies and plans and physical planning and legislation now are harmonized to a level, which allows for pragmatic handling of coastal issues.

This integrated process has been named Coast Erosion Management (CEM) to highlight:

- The level of planning which is coordination,

- The multidisciplinary process to be physical planning and coastal engineering,

- The focal point for many use conflicts to be erosion.

It is on that basis that the themes for the present contribution have been identified.

2. GEOGRAPHY AND DEMOGRAPHY

The geology of Denmark is predominantly of glacial origin. Coastlines are therefore generally formed in sandy glacial plains or moraine cliffs. Erosion of the latter represent virtually loss of a non-renewable ressource.

Occasionally tertiary chalk formations protrude the glacial landscape, whereby fairly impressive headlands are formed, between which sandy beaches of gentle curvature are suspended.

Denmark is situated in the temperate climatic zone, which favours windy conditions, wave formation and coastal attack.

The area of Denmark is 44,000 km^2. It consists of 500 islands of which approximately 200 are inhabited, notably the two largest Funen and Sealand, where the capital Copenhagen is located. Fig. 1. The peninsula of Jutland connects Denmark with the continent and is coastwise extremely exposed towards the rugged North Sea.

It follows that Denmark by nature is in the sea and surrounded by the seas, such as the Baltic Sea, the Kattegat, the Skagerrak and the North Sea. Denmark is thus a coastal country having a coastline of 7,300 km.

Physical coastal environments in Denmark are set by the interaction between the glacial geology and respective seas.

- The North Sea Coast of Denmark (the West Coast) is sandy and particularly vulnerable to erosion. Mean erosion for eroded reaches is up to 2 m and littoral drift is in the order of 100,000 - 1,000,000 m^3/yr.

- The Kattegat and Baltic Sea Coasts are medium exposed. Mean erosion is 0.3 - 0.5 m/year and littoral drift is up to 75,000 m^3/yr.

- Belt and fjord coasts are less exposed. Mean erosion is less than 0.25 m/yr, littoral drift less than 10,000 m^3/yr.

Denmark's interesting coastal and marine setting is furthermore highlighted by the fact, that it is the transition area between the brackish Baltic Sea and the more saline waters of Kattegat and the North Sea.

470 km^3/yr of discharge flows from the Baltic through the three straits of The Sound, The Storebælt, and The Lillebælt. The effect of this situation is that for many practical purposes, i.e. engineering and environment, the inner Danish waters have to be considered as one large estuary.

Denmark has a somewhat unusual demographic distribution. The Metropolitan Region of Copenhagen thus comprises 6% of the country's area and coastline, while its population is 1.7 mio., i.e. 34% of the country's total.

In the following table these figures are compared with figures for two selected West Coast counties, Ringkjøbing and Ribe.

	Area*		Population		Vacation** Housing		Coast
	1000 km²	%	1000	%	1000 ha	%	km
Denmark	43.1	100	5.1	100	42	100	7.314
West Coast: Ringkjøbing & Ribe counties	8	18	0.5	9	5	12	804
Copenhagen: Metropolitan Region	2.8	7	1.7	34	7	17	539

*) Denmark Statistical Yearbook
**) Arealundersøgelsen 1982

Table 1 Key Figures: Denmark - the Region

It is seen that a population of about 1.5 mio. in the metropolitan region "consumes" 7,000 ha vacation housing, while 0.5 mio. on the west coast consume 5,000 ha. The latter reflects the situation, that the West Coast Serves as a recreational area not only for domestic purposes, but even more so for our European neighbours.

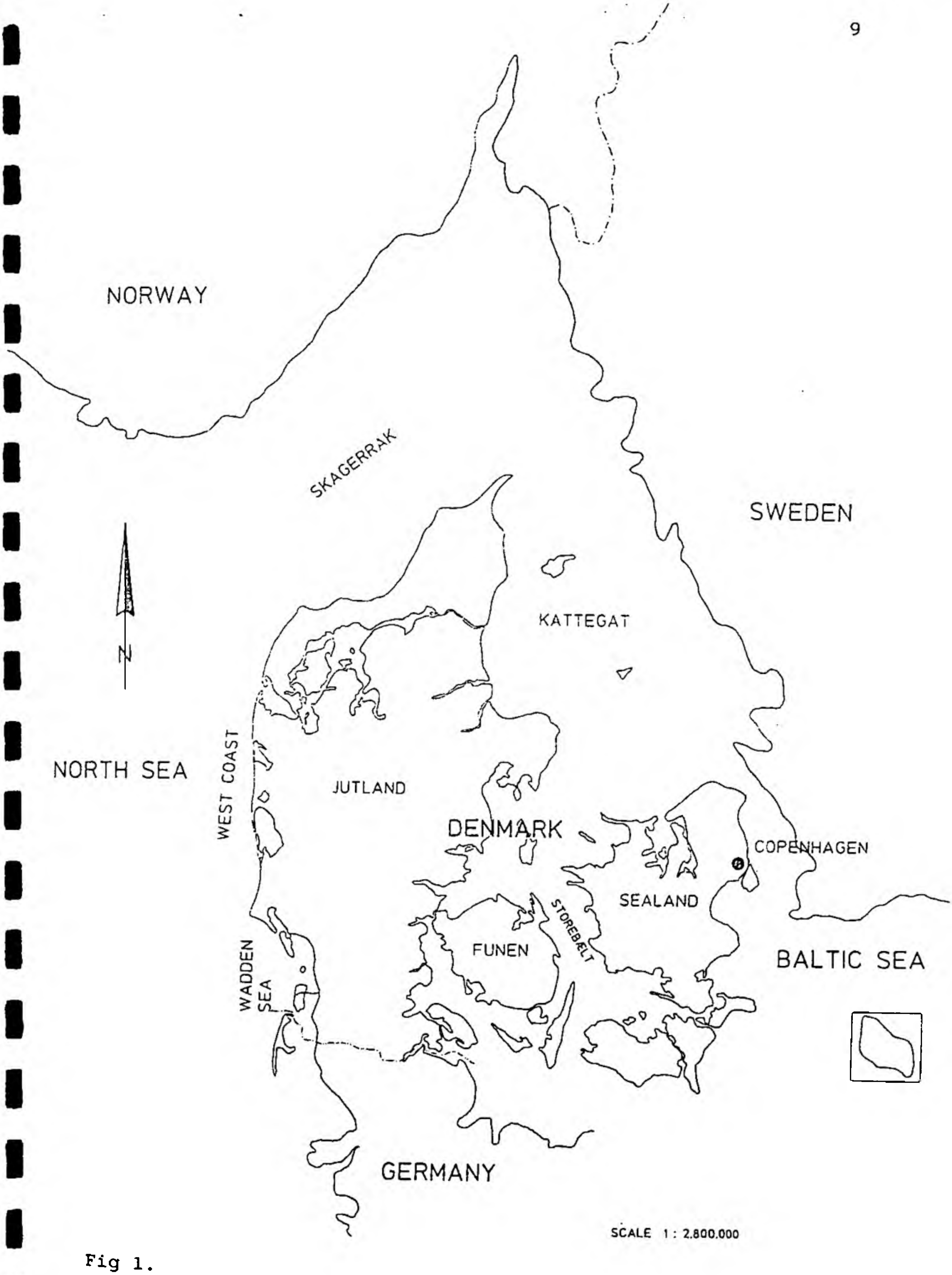
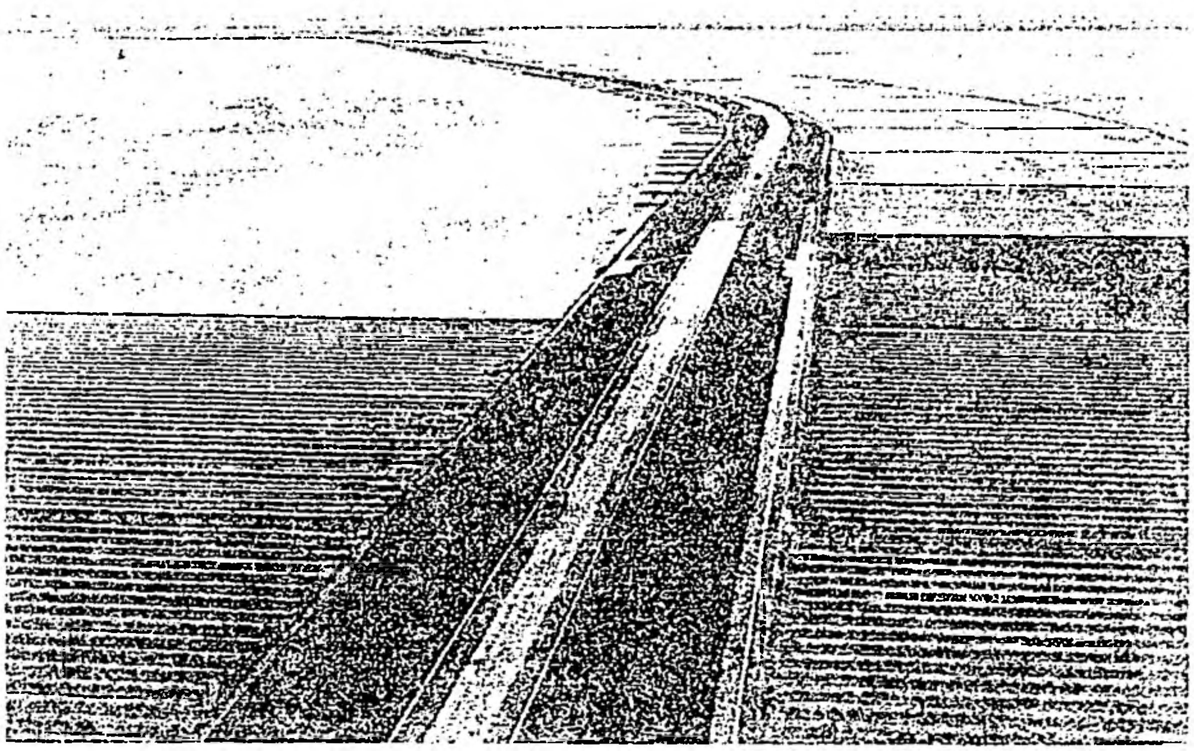

NORWAY
SKAGERRAK
SWEDEN
KATTEGAT
N
NORTH SEA
WEST COAST
JUTLAND
DENMARK
COPENHAGEN
SEALAND
STOREBÆLT
FUNEN
WADDEN SEA
BALTIC SEA
GERMANY
SCALE 1 : 2.800.000

Fig 1.

The climatic conditions as we know them today with sustained severe westerly winds appear to have commenced in or just after the Viking Age about 1000 years ago. Prior to that easterly and milder climatic conditions were prevailing. Historic and cartographic evidence, however, shows barrier spit growth and similar phenomena 1100 - 1600.

But around 1600 - 1700 conditions got worse, erosion increased and barrier breaches occurred.

However, apart from dike protection in low lying marshy areas coastal protection on a large scale was not considered till about 100 years ago.



Rømø Dam, 1970

3. COASTAL ZONE MANAGEMENT FRAMEWORK

The planning and administrative systems in Denmark have been subject to a thorough modernization and reform since about 1970. Reference is made to the pampleth enclosed, prepared by the "Danish National Agency for Physical Planning".

Strategies

The universal objective of Coastal Zone Management is to ensure orderly and balanced utilization of resources in the coastal zone and to maintain and where possible restore and enhance the environmental quality of the coastal zone.

The national approaches taken towards the fullfilment of this overall objective are related to the historical development within the country, its geographical and demographical characteristics and contemporary trends in resource exploitation.

It is evident that a developed country has better opportunities for a gradual and harmonized approach towards CZM than developing countries, where the turmoil and intensity of evolution processes make it very hard for the administration to catch up with actual course of events.

The dynamic conditions and open administrative and legal structures of many developing countries may, however, have the advantage that a relatively clear - by the book - CZM can be implemented.

In Denmark, where formal physical planning as such has been in existence for about 100 years, CZM has never been defined as a separate issue, but has implicitely matured through gradual harmonisation and coordination of administrative and legislative frameworks.

An example of an early CZM initiative provoked by necessity, but now in reality an integral part of CZM, was the legislative and administrative consequences of the problems caused by migrating dunes in coastal zones, which aggravated in the 16th century and continued to modern times. (Appendix C).

The problems is today under control and has had the favourable spinoff, that out of 384 km of the Jutland west coast 372 km are now under the jurisdiction of the Dune Preservation Law. The legislation has thereby functioned as an early set-back line, which has prevented much undesirable development in this century.

The challenges faced today, caused by the growth of society, especially since the second world war, have been met by implementation of reforms of the planning and administration system of which modern Danish CZM is an integral part.

Administration and Plan References

In the 1970ies a reform of the Danish overall administrative framework was carried out. Taking account of modern demographical, infrastructural and industrial structure, new geographical boundaries were delineated for 13 counties (the regional authority) and the number of local authorities reduced from 1360 to 277. Fig. 2. The new division opened up for and was followed by new definitions of rights and responsibilities shared between state -, regional -, and local authorities.

This development was followed by a reform of the planning legislation in three steps:

1) 1970 the Urban-Rural Zone Act. It is especially aimed at controlling unwanted development in the open rural land.

2) 1974 the Country and Regional Plan Act. The country planning is executed by the Ministry of Environment in collaboration with the planning council of the government. On behalf of the government the Minister of Environment will yearly prepare a statement on planning.

The regional authority shall prepare regional plans based on plans prepared by the local authorities.

3) 1977 the Local Authority Act. According to this the authority shall prepare a common plan for all sectors of the local administration. The said plan can be broken down in further area specific plans as required. A typical example in the present connection could be a plan for a beach park.

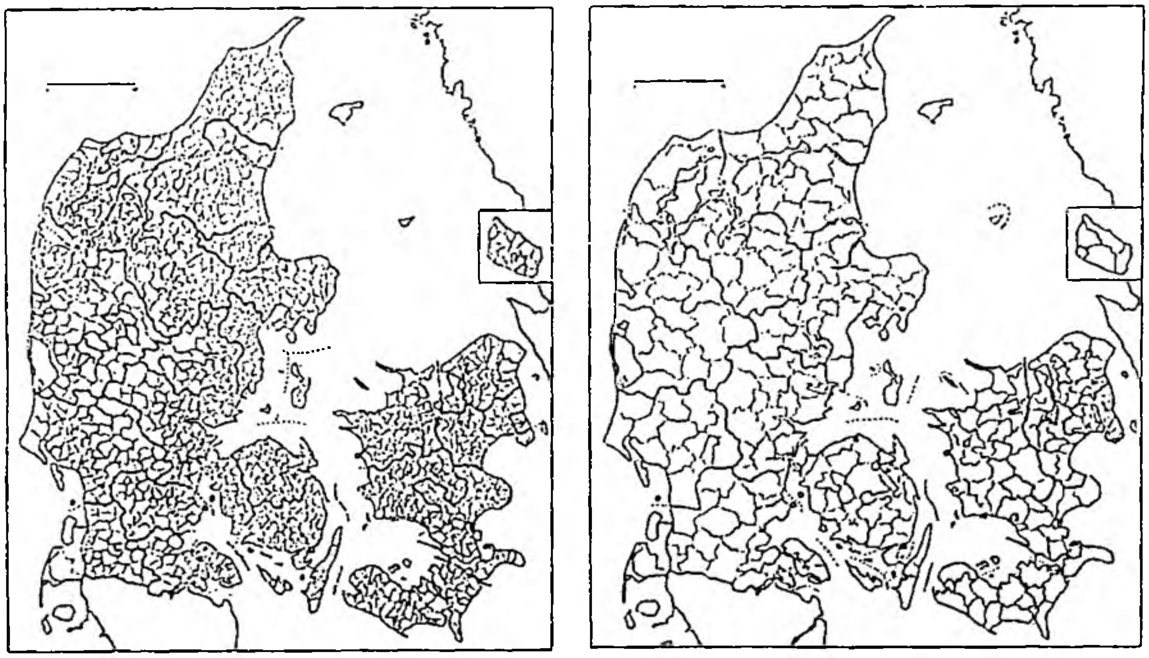


Fig. 2.

Regional and Local Authorities before 1970

Regional and Local Authorities after 1970

Finally, a sector planning system has been established which is coordinated with the physical planning in the Regional and Local Authority Plans, respecting the goals for regional development prepared by the Minister of Environment.

Management Framework

The reforms have improved the exchange of information between all authorities involved and have de facto led to a true management framework system, where planning and management on a given level is a free process as long as coherence with the frames given by superior authorities is maintained.

It can be concluded that the process has improved management tools, and has provided an improved clarity of the planning system, but admittedly also introduced some time consuming procedures. Furthermore, two other objectives of the system have been obtained, namely a decentralization of the decision making process and more active participation by the citizens.

Sector Planning

The principal objectives for sector planning is to provide an improved basis for the society's use of resources. It may take place on all levels in the planning hierarchy and shall be coordinated with the physical planning.

The regional authorities are responsible for the preparation of a number of sector plans (fig. 3) for resource areas such as:

- Guidelines for preservation of nature related interests.

- Guidelines for the water quality in rivers, lakes and coastal waters.

- Guidelines for the use of areas for sand and shingle mining at land and to some extent at sea.
- Guidelines for areas reserved for agriculture.
- Guidelines for water supply and waste water treatment and disposal.

These and similar sector plans shall be integrated in the regional plans. In addition the planning shall consider the integrated aspects of history of civilization, scientific interests, the landscape characteristics and recreational interests.

In other words it is the aim to provide a planning based on a holistic ecological view, in order to provide a preparedness against the increasing pressure on the utilization of natural resources. In this connection preservation plans are being prepared.

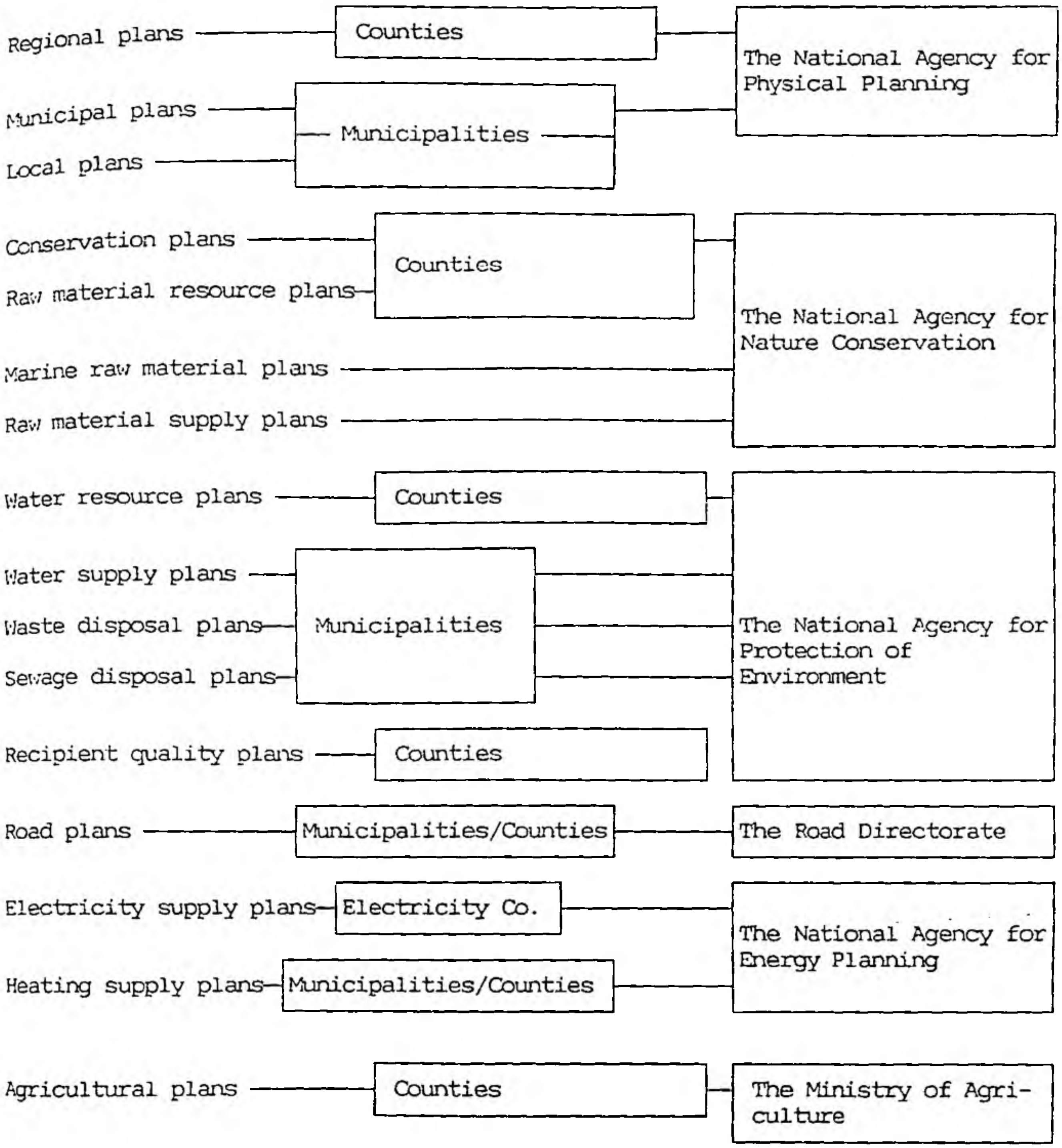


Fig. 3.

Overview of physical planning and the authorities, wich prepare and/or approve plans.

4. COAST EROSION MANAGEMENT

Coastal erosion has apparent and immediate consequences to society and is often an overriding concern in coastal countries. This explains why coastal engineers often are called at an early state to plan the Coast Erosion Management CEM as an integral part of the overall Coastal Zone Management.

CEM plans have to be tailored to suit site specific conditions, such specific arrangements prepared for areas of the Danish West Coast, nevertheless there is a number of fundamental prerequisities over which solutions are modelled:

- Coherence with the planning system.
- Set back and no-build regulations.
- The Coast Protection Act 1988.

The regional plans can provide guidelines for the rational use of coastal areas of the region including planning of recreational activities and similar. The new Danish Coast Protection Act has given regional authorities significant influence in the decision process related to coast erosion management issues. It follows from the discussion of the overall planning framework, that the best possible tool thereby has been established for an early coordination of all CZM interests at the appropriate planning and administration level.

Set-Back and No-Build Zones

The Nature Preservation Act 1917 formalised the right of public access to all Danish beaches. The Act was revised in 1937, whereafter a definitive stop for all construction and building activity on the beach proper and the adjacent 100 m of the hinterland was brought into force. A directive issued by the Minister of Environment 1978 has provided a general stop for the outlay of new vacation housing and hotel areas in a 3 km wide coastal zone.

These measures have been taken primarily to protect the environmental qualities of the Danish beach areas and coastscapes, however, they function at the same time as important set-back lines for the CEM.

In general, considerable efforts are devoted to preservation of access from the hinterland to beaches and several public funds are available for the acquisition of areas which can form green wedges through the coastal zones.

The Coast Protection Act 1988, The Ministry of Traffic & Works.

Since 1874 and 1927 Denmark had a Dike Protection and Coast Protection Law, respectively, based on owners responsibility for the coastal activity.

During this century the use of coastal resources has changed considerably, notably towards increased use of coasts for vacation housing and other recreational activities.

The demographic pressure has changed the issue of coastal erosion from being, in principle, a quite natural phenomenon to a "problem" for society. Similarly, activities of man, such as harbour constructions and dune stabilisation programs interfere with the dynamics of the coasts in "unnatural" ways.

The erosion and coast protection issues have thereby changed dimensions from being directed primarily towards property protection to a more holistic approach, which emphasizes the environmental values of the coastal zone and the changed use patterns, which especially arise from modern needs for recreation in coastal zones.

This change in view on the erosion problem can be illustrated by the change of nomenclature for the activities undertaken, i.e. from Coastal Defence to Coastal Protection and now Coast Erosion Management.

The new dimensions in the coastal situation include changed economical relations. The property protection affected economically in principle only front property owners, while coast erosion management relates to property areas in considerable depth of the hinterland, local as well as regional, private or public enterprises, which all derive considerable income from tourism and recreational related activities.

Finally; the new beach protection techniques, especially beach nourishment schemes, require thinking, planning and financing on a larger scale than previously thought of.

It appears then, that there has been a considerably well founded justification for a completely new legislation.

The principles of the new law adhere to three main themes:

- Project appraisal,
- Project preparation,
- Regulatory procedures.

The Coast Protection Act states in its first paragraph that "The Regional Authority can decide, that on a given coastal reach, constructions or similar measures can be executed for the protection against flooding or the erosive effect from the sea, fjords or other parts of the sea territory (coast protection measures)".

The Regional Authority is thereby given the leading managerial role in the appraisal process. It may respond to requests for protection brought forward by local citizens or authorities or may take its own initiatives.

Its role in the general planning process makes the Regional Authority well suited to combine a good understanding of the local values at stake, with a properly balanced problem assessment taking account of the general planning in force in the area/region.

However, it may be short of the expertise which is required for a proper technical evaluation of proposed actions. The law therefore makes it possible, at an early state, to involve directly the Danish Coast Administration DCA for assistance in the further examination of the project request.

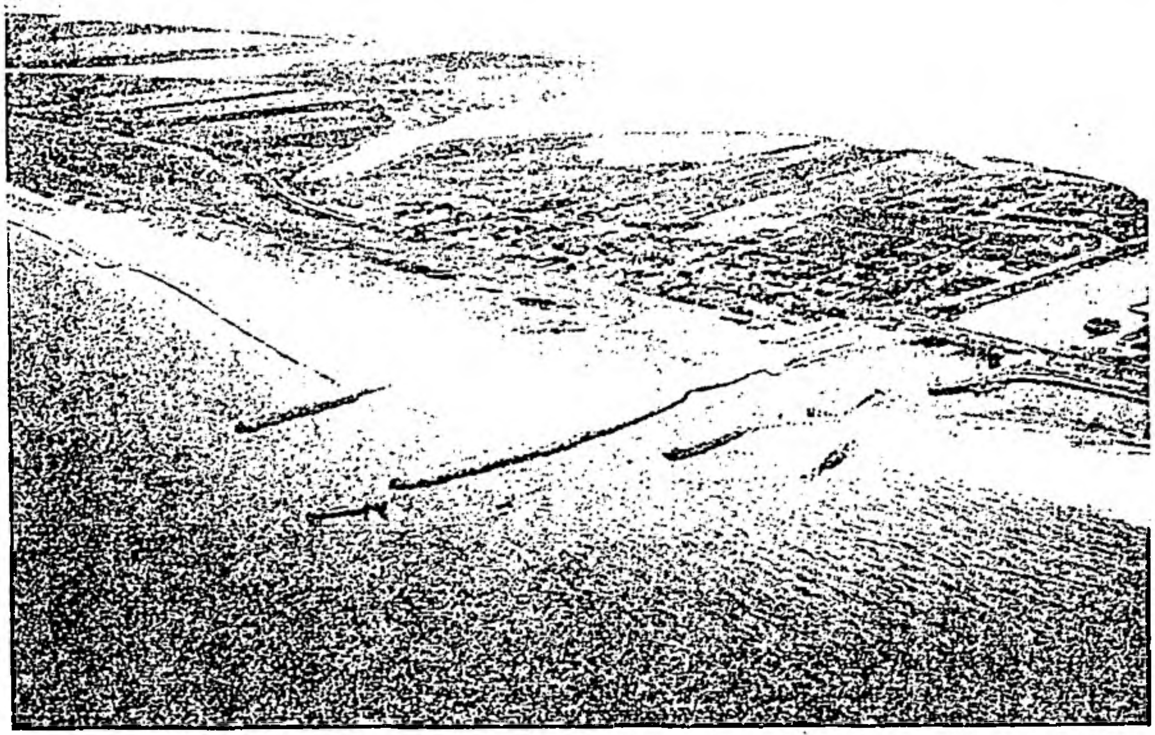
It is a new thing of great benefit, that key authorities thereby immediately and directly take part in the project appraisal at no cost for the applicants, and moreover that they can prevent unnecessary cost spending if feasibility for the project cannot be established.

If the project appraisal is positive, the regional authority can proceed with project preparation and decide the terms of reference for studies and designs to be executed, cost and finance schedules, selection of consultants, future ownership and maintenance responsibilities and whether compulsory acquisition of property is required. In this phase there will generally also be a close interaction between the regional authority and the DCA.

The regulatory procedures still require final permission from the Minister of Transportation & Works to establish coast protection works and other man-made changes in a zone 100 m landward and including territorial waters.

The regulations on the landward side were previously part of preservation and planning laws. As will be understood the new laws place the responsibility over the land/sea interface under one authority, which complies with modern requirements to coastal zone management.

DCA administrates, on behalf of the Minister of Transportation & Works, the regulatory procedures. In this capacity it will normally be responsible for an enquiry procedure which comprises the Water Inspection Board (Ministry of Defence), the Ministry of Industry (responsible for shipping and trading), the Fishery Inspection (Ministry of Fisheries). Historically, the concerned local and regional authorities and owners of neighbouring estates would also be heard, but with the procedures introduced with the new law, such needs will often be analysed as an integral part of the preparatory process.



Thorsminde City

5. THE DANISH COAST AUTHORITY

General

The Danish Coast Authority (DCA) is a government institution under the Ministry for Transportation & Works and is as such the technical expert adviser for the Ministry on coastal protection and similar works. The DCA is in charge of establishing, maintaining and operating state owned coastal protection works along the Danish North Sea Coast. Further the DCA supervises dikes, embankments and other coastal protection works, which are cofinanced by State, regional and local authorities, maintains a number of navigation channels and is main body in the administration of the Coast Protection Laws.

The domicile of the DCA is Lemvig in West Jutland.

For the Ministry the DCA also controls and manages the sovereignty of the sea territory regarding permissions for establishing cables, pipelines, groins and coastal protection works and participates in the regulatory activities regarding permissions for yacht harbours, bridges, dams, dikes, embankments, reclamations, etc.

The above mentioned functions are distributed over four major sectors.

Survey and Monitoring

This sector is in charge of collection of technical data for evaluation of the coastal evolution, site investigations for coastal protection projects, maintenance of navigation channels and storm surge warning.

The sector disposes of 2 fully fledged survey vessels.

On the Danish North Sea Coast some 500 fixed survey lines have been established. These are surveyed by annually and in addition to these measurements surveys are performed in a finer grid in areas where coastal protection works are being undertaken or where coastal scientific experiments are taking place. Further a number of navigation channels and routes are surveyed for checking of navigational depths. All in all some 2500 km survey lines are measured every year. The survey include further annual levelling of beaches and dunes in connection with the sea surveys, aerial terrestrial surveys are also applied.

Water level measurements from more than 10 tide gangs along the North Sea Coast are transmitted automatically on line to DCA´s computer where they are stored for use in the DCA´s storm surge warning systems.

Wave recorders are deployed for collection of wave data which are analysed together with wind measurements collected by the Danish Meteorological Institute.

ANALYSIS AND DESIGN

In this sector the evolution of the coast is analyzed on the basis of collected survey data, accordingly projects for coastal protection are defined, i.e. beach nourishment, dune protection, revetments of concrete or cobbles, breakwaters, groins, etc.

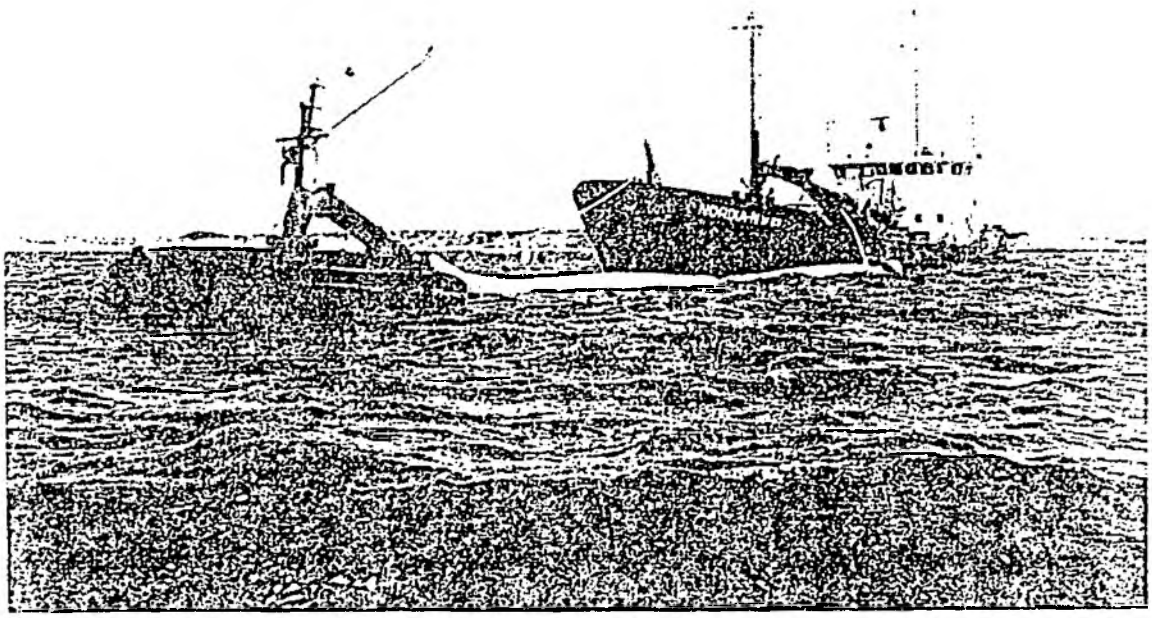
The sector prepares reports for political decisions for initiating coastal protection works.

For actual projects are prepared necessary preliminary investigations, prepare conceptual and detailed project documents, manages tender documents and contract negotiations and preparations, and follow-up on possible effects of the structures.

The project department prepares guidance lines for maintenance and development of the DCA´s own dike and groin works and plans and participates in experiments with new materials and methods in coastal protection. Activities involving artificial beach nourishment with both dredged sea material and material from gravel pits are large.

The department has managed the extensive coastal protection works in connection with reinforcing and extending the dikes in the wades.

The department also takes care of preparing EDP programmes and running these for analyses of wave measurements and of coastal surveys on the DCA´s own computer system (HP).



Sanddredging, Tuskær

Contracting.

This sector is in charge of five working sites along the Danish North Sea Coast for the maintenance of state-owned coastal protection works, including schemes which are subject to Government cofinancing.

The sites are equipped with fully modern equipment as required for the handling of concrete blocks or quarry-stones for groins and breakwaters or beach nourishment.

The contracting department is in charge of beach nourishment whether being brought from gravel pits or directly by hydraulic pumping.

The department is also in charge of the prourement of material for the works, which on an annual basis amount to 50,000 t of concrete and 100,000 t of quarry material plus sand for nourishment, all present more than 1.5 mio. m^3/ year.

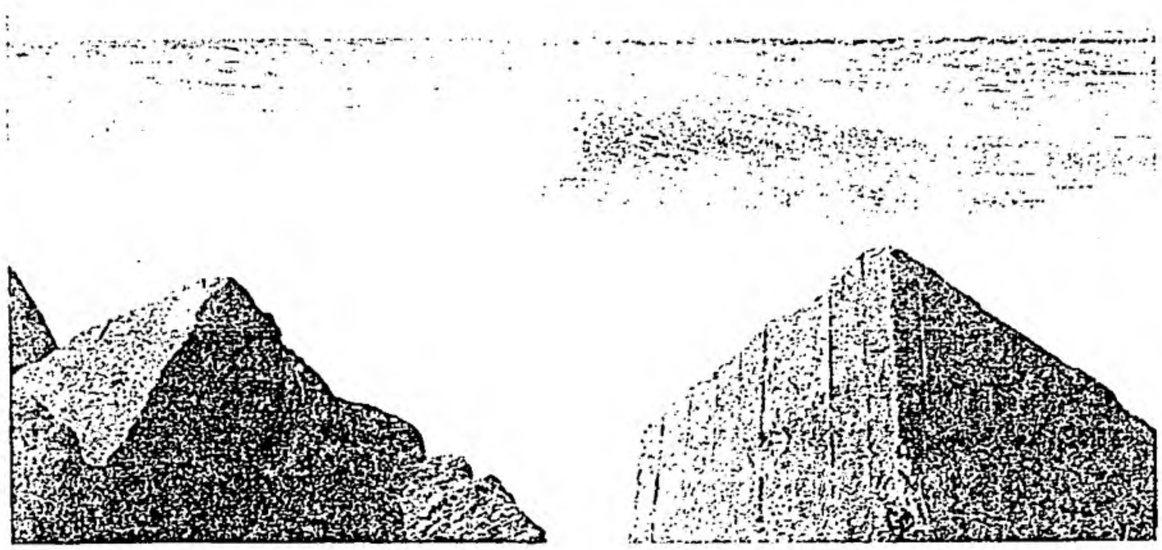
Legal and Regulatory Activities.

As technical advisor to ministry in technical affairs relating to constructions in territorial waters DCA has a special department dealing with applications and permissions related hereto. Thus DCA carry out hearings and issue permissions for all coastal protection works and marine pipeline in territorial waters. Likewise DCA participates in evaluation of applications regarding pleasure boat harbours, large bridge buildings, dams and reclamations. On behalf of the state DCA are supervising dikes and other coastal protection works contracts with state-participation.

DCA give their advise on coastal engineering conditions related to marine pipeline installations and cable under the administration of the Ministry of Energy and is further a member of the Commission dealing with special matters related to natural gas and oil deposits. Finnally DCA pronounces on coast protection conditions in case of sand or gravel mining in the coast protection zone.

DCA has a total staff of 130, of which 45 are in the Head Office in Lemvig. The remaining staff is dealing with survey work on five local places of sites. At the Head Office the staff consists of 17 engineers, 11 technicians and 16 within administration.

In 1990 the annual operating costs are app. 40 mio. Dkr. In addition to this come construction for dikes and coast protection works for a total of 80 mio. Dkr., of which 20 mio. Dkr. are state subsidy.



6. MAJOR COASTAL SCHEMES IN DENMARK

In order to illustrate in a more direct manner how the current problems in Denmark are handled, four papers have been included as appendix to this presentation:

- "Shore Protection at the Danish North Sea Coast".

  The paper prepared by DCA describes the planning of projects which have been and will be carried out on the exposed coast of western Denmark. It describes the decission process, provision of databases, further analysis and finally important design aspects.

- "Copenhagen Metropolitan Region. Coastal Erosion Management".

  The paper describes the approach to the problem in this region, where medium exposure of coast combined with a high concentrated demographic pressure, leads to a set of coastal situations which are significant on a national level. As well planning background as actual activities are illustrated in the paper.

- "Stabilisation of Coastal Dunes in Denmark".

  The Coastal Dune Management is undertaken by The National Forest and Nature Agency.

  Coastal Dune Management plays a significant role in the coastal zone. Denmark has probably suffered propertionally more from drifting sand originating from coastal dunes, than any other country in Europe. The level of legislation and expertise related to this specific issue is therefore very high within the country. Over the years this has formed the basis for a considerable export of know how to other countries.

- "MASTER PLAN FOR COAST EROSION MANAGEMENT IN SRI LANKA".

In order to illustrate how Danish know how has been transferred abroad the case of the Sri Lanka Master Plan provides an excellent example.

The preparation of a National Zone Management Plan is a mandatory requirement of the Coast Conservation Act and a major policy goal of the Coast Conservation Department (CCD), Sri Lanka. Sri Lanka has adopted an incremental problem approach towards the preparation of the said plan. As an integral part of this Coastal Zone Management effort, highest priority has been given to the preparation and implementation of a Master Plan for Coast Erosion Management. Thus in 1984 it was decided to commence the preparation of the Plan in relation to which the Danish International Development Agency, DANIDA, granted assistance during 1984-1986.

The document defines the problem of coastal erosion in Sri Lanka within the constraints of available information and sets out the best possible technical approach towards mitigation and the capital investment necessary for such action.

7. COASTAL RESEARCH AND DEVELOPMENT

The coastal zone is dynamic, and not all processes and developments are fully understood.

Coastal problems all over the world have some features in common. After all, wave and tide physics are universal and sandy beaches also show similarities in their response to wave action. Still, the variations in local meteorology, geology, use pattern, etc. call for tailor-made approaches, based upon intimate familiarity with local coastal problems. It is therefore important to develop the local expertise within these fields concurrently with possible consultancy, also with a view to ensuring continuity, since coastal processes have to be studied over a considerable span of time.

A significant number of Danish research institution in all desciplines of coastal research are ready to render services as and when required.

In this content it is pertinent to pay special attention to the Danish Hydraulic Institute (DHI) which since 1964 has undertaken projects in more than 75 countries.

DHI is prepared for the future tasks by supplementing well-earned experience with continuous development of more refined, sophisticated and specialized techniques, of which the most important and powerful undoubtedly is computerized hydraulic numerical models for detailed and reliable simulations of water movements and sediment transport. Still, a thorough examination of the site conditions, and a scrutinizing of the overall physical processes should precede the choice of more refined methods to be used for the further zooming on the problems considered.

A copy of the DHI phamleth is included as Appendix.

APPENDIX B

APPENDIX B

"Shore Protection at Danish North Sea Coast"

SHORE PROTECTION AT DANISH NORTH SEA COAST

By

Christian Laustrup, Head of Project Department
Danish Coast Authority, Lemvig
Danmark

ABSTRACT

The paper describes the planning and the projects which have been and are carried out concerning shore protection at the Danish North Sea coast. The paper relates these activities to the data which have been used.

1. INTRODUCTION

The Danish North Sea coast is partly a tidal coast (appr. 7o km) and partly a sandy coast (appr. 33o km). To give an idea of how

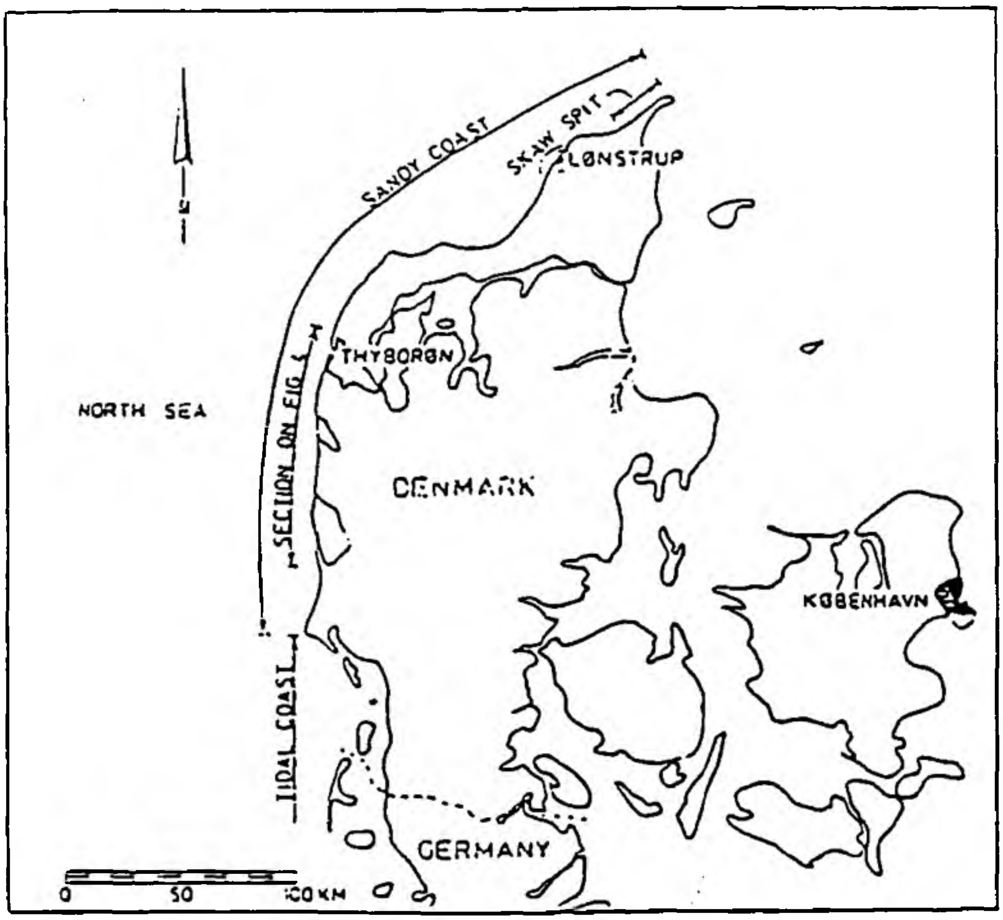


Fig. 1. Area map.

exposed this coast is to storms from W-directions a few data from a storm surge which occurred on November 24, 1982 can be useful. On that occasion the waterlevel at the tidal coast where the normal HW is about 1 m raised to appr. 5 m and the erosion at the sandy coast was in many places appr. 10 m and up to 30 m.

The paper will give a general view of the process of decision-making, planning and design of shore protection measures. It will focus on certain parts of this process namely the analysis which was the basis of the political decisions, examples of the following study of coastal processes and of the design of the coast protection. Also a forecast model for storm surge at the tidal coast will be mentioned.

2. FLOWCHART OF ANALYSIS AND PROJECTS

The cronology of decision-making, studying of coastal processes and constructing the protection are shown on fig. 2 together with the data used. The basis for the political decisions were cost-benefit analysis.

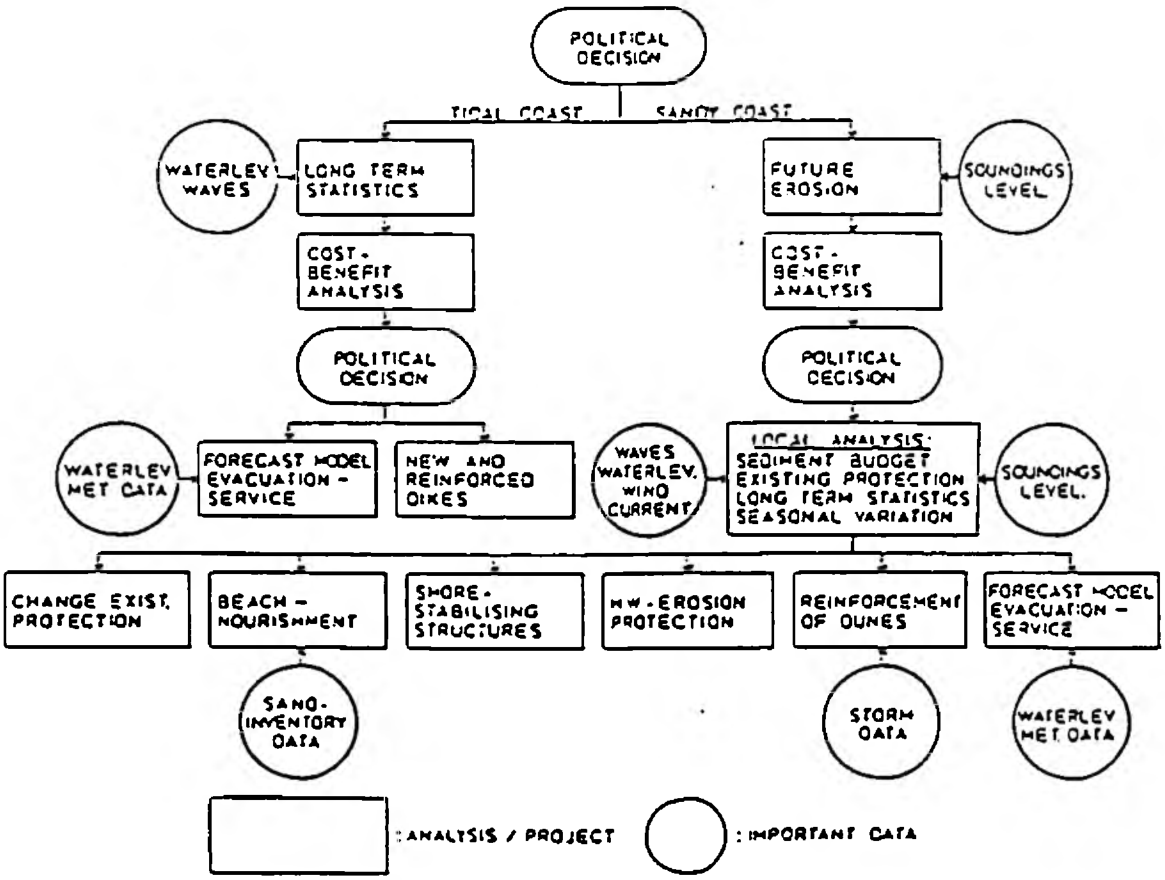


Fig. 2. Flowchart, analysis and projects.

After that, the sandy coast was devided into smaller parts where each part only affected the other parts in a simple manner and the different parts were studied. Finally, for the tidal and the sandy coast the protection measures which have been and are going to be carried out are shown on fig. 2.

3. DATABASE

The most important data which have been used are stated on fig. 2. In short they are as follows:

Soundings and levellings: For the sandy shore they date back to 1874 for certain parts. Since 1970 they are carried out yearly to a depth of appr. 15 m and with a distance between lines of appr. 1000 m. On parts of the coast which are especially interesting the lines are surveyed with 50 or 100 m intervals. The results are recorded on papertape and stored in a computer-database.

Waterlevels: Since 1970 waterlevel has been recorded at 8 locations along the tidal and sandy coast. The data are recorded and transmitted to a central computer by the hour.

Waverecordings: Since 1975 waves have been recorded at different locations along the coast in periods of ½ - 5 years with Waverider-bouys. The data are A/D-transformed and stored in a computer-database.

Sandinventory data: Since 1979 a series of test-dredgings and vibracore-drillings have been performed along the sandy coast to map the sandressources available for beach nourishment.

4. TIDAL COAST

The polders in the tidal area were until recently only protected by weak earthdikes. In the period from 1970 till 1981 a number of measures were carried out with the purpose to increase safety of the population.

Because of the area being rather sparsely populated and because there are only a few buildings just behind the dikes it was not found appropriate to increase the dike protection for all polders. It was therefore decided to base the solution on 3 principles a) to establish the best possible safety against the loss of human lives b) to improve dikeprotection for the more densely populated polders and c) to establish a possibility for quick repair of smaller damages in the dikes.

The measures that should be carried out according to this were a) to establish a warning and evacuation organization b) to reinforce or to renew the dikeprotection of the important polders and c) to construct new or to extend existing roads to and along all the dikes and to establish a repair organization for immediate repair of stormsurge damages.

4.1. Forecast model

To establish a reasonable good safety in all polders against the loss of human lives by floodings a warning and evacuation organization was established in 1970. As a basis for decisions about evacuation a forecast model was developed.

The model was developed by regression analysis of data from 600 stormsurges (1).

By the regression analysis two considerations were taken, namely a) to explain as much as possible of the residuum-variance and b) to minimize the number of variables. The regression analysis was carried out as a socalled reverse regression, i.e. That a number of "good" variables were selected by means of qualitative estimation. By F-test successively the variables which did not contribute significantly to the explanation of the variance were illiminated.

The estimated residuum at a certain time for a certain locality is then calculated as follows:

$$R = a_o + a_1x_1 + a_2x_2 + \text{---------------} \; a_kx_k$$

where the a's are the coefficients found by regression analysis and the x's are the variables, which contributed significantly to the explanation on the variance.

It can be noted, that the model is guite simple and that the actual calculation of the forecasts do not require a computer. On the other hand the calculation of confidence intervals and the achievement of sufficient speed and security in the datahandling requires the use of a smaller computer.

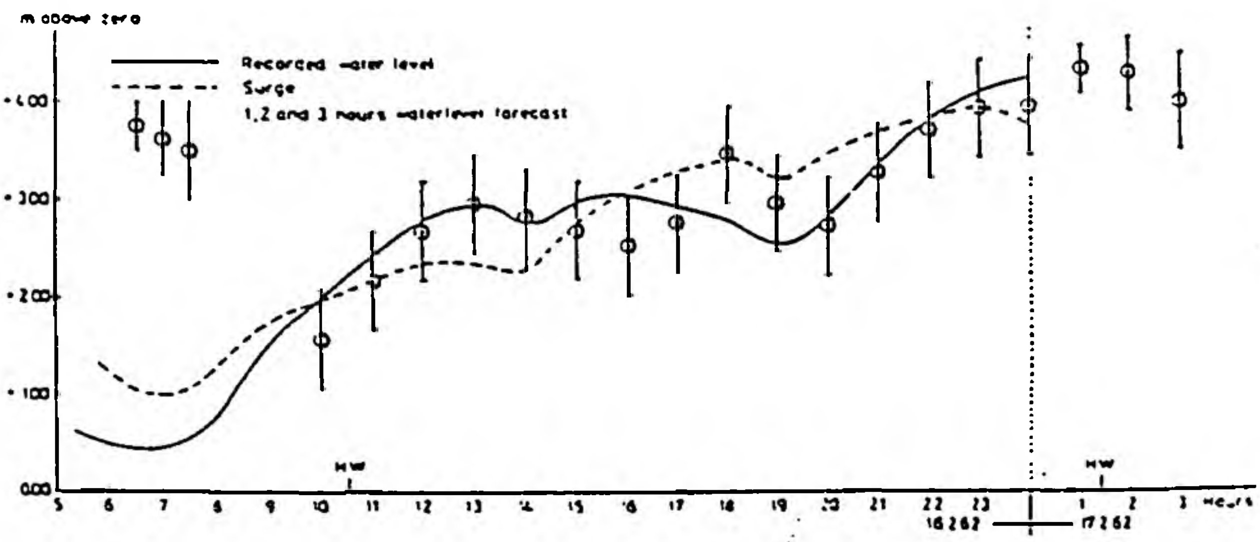


Fig. 3. Stormsurge at Hojer 16. - 17. Feb 1962.

The 95 % confidence intervals of the forecastings vary very little. The approximate range is ± 20 cm, ± 35 cm and ± 45 cm for respectively 1, 2 and 3 hours forecasts. On fig. 3 an example of the forecasts is shown.

To improve the model i.e. to explain more of the variance of the data we are now analysing the model-errors by a socalled autoregressive, mooving average model (ARMA):

$$Z_1 = C_1 \cdot Z_{t-1} + C_2 \cdot Z_{t-2} + \text{--} \; C_p \cdot Z_{t-p} - D_1 A_{t-1} - D_2 A_{t-2} - \text{---}$$

$$D_q A_{t-q} + A_t$$

where Z_t = the regression model-error at time t

A_t = ARMA model-error at time t

C and D are constants.

We find this type of model very useful in forecasting surge and we are probably also going to use it on the sandy coast.

5. SANDY COAST

5.1. Cost-benefit analysis

The beaches of this coast are partly with dunes partly with clay-clifs. The main problem is the big erosion which takes place along most of this coast.

On the basis of regression analysis of the soundings and levellings we tried to estimate the future average erosion along the coast for equilibrium profiles. The result is shown on fig. 4. The erosionrates are drawn perpendicular to the coastline.

The big erosions which occur at certain sections can in general be explained as leaside effects from harbours and groingroups. Besides that, variation of geology along the coast f.x. lack of sand in the eroded layers can be the reason for a weak longshore bar.

The future erosion estimates were used to estimate the costs of reducing erosion to different levels. Generally the costs of reducing erosion to 0 and to max. 2 m/year was estimated.

Since it is difficult to quantify the effect on erosion rates of different structures we based the cost-estimate on the assumption that erosion can be reduced by A m3 pr linear m by nourishing the coast with A m3 pr linear m of sand of the same quality as is eroded, provided the sand is not dredged in the littoral zone. Since this method is not necessairily the optimal method to use for the protection, the design should involve further studies.

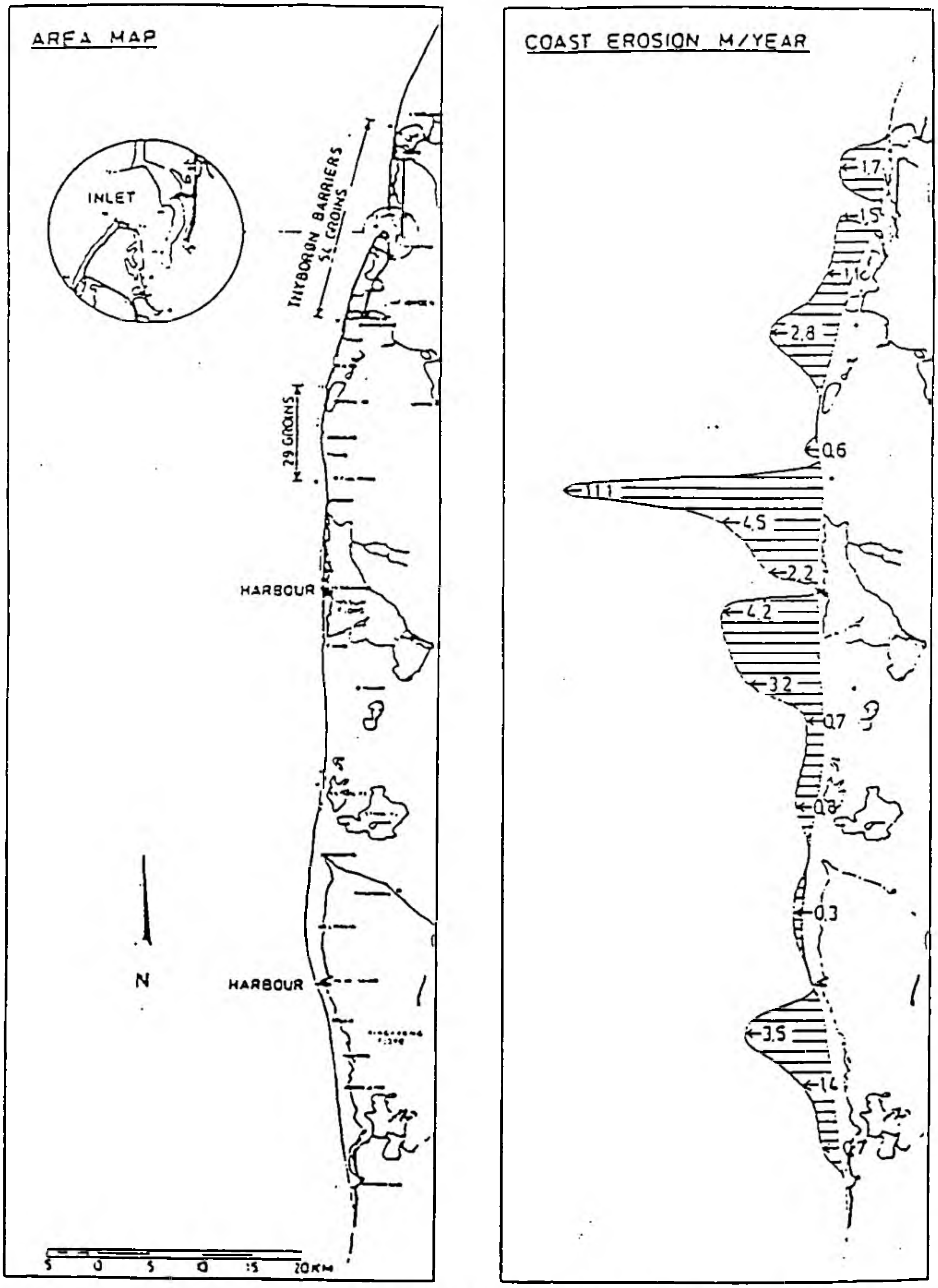


Fig. 4. Estimated future erosion in m/year on part of sandy coast (see fig. 1).

In 1982 is was decided that the yearly costs should be at a level by which erosion could be reduced to max. 2 m/year.

5.2. Study of shore processes

As examples of the studies which were undertaken after the decision-making, a sediment budget estimation at the Skaw Spit and an analysis of the function of existing groingroups at the Thyboron barriers is reportet (see fig. 1).

5.2.1. Sediment budget

The Skaw Spit has developed during the latest 5ooo years to its present length of appr. 3o km and is still growing. Fig. 5 shows the estimated sediment budget which explains the development. The growth of the spit is also shown on fig. 6 which shows the development of the coastline since 1787. It can be noted that the spit grows to the NE while the N-coast preserves its equilibrium form (2).

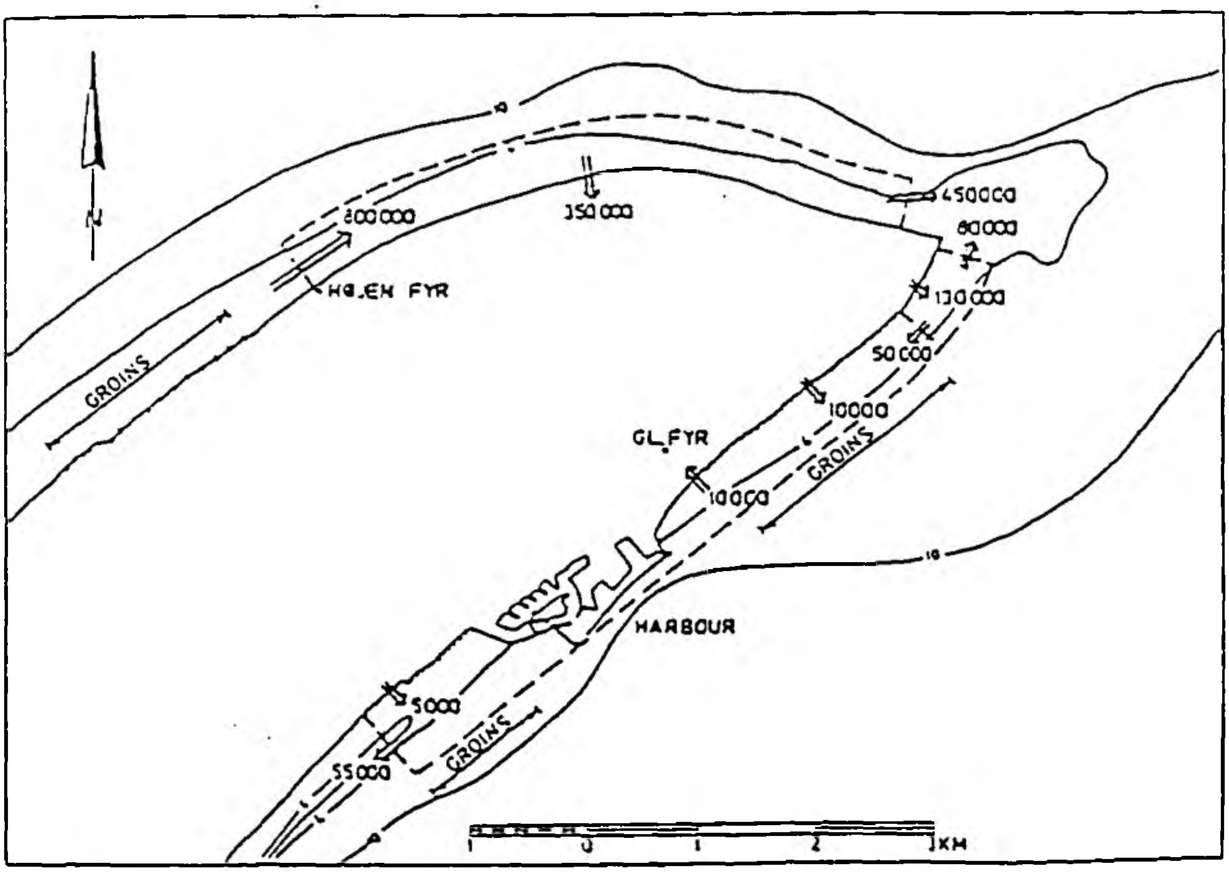


Fig. 5. Skaw Spit. Sediment budget in m3/year.

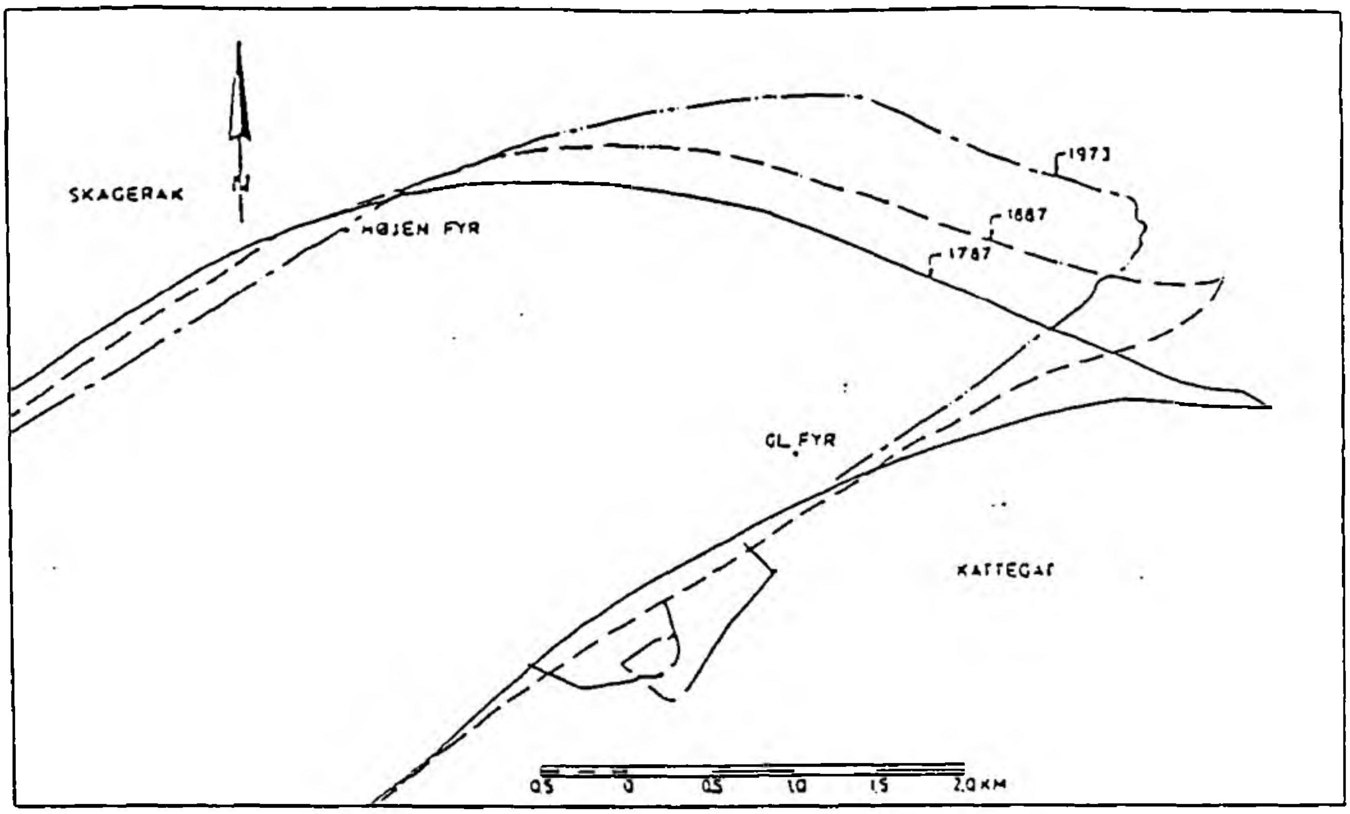


Fig. 6. Growth of the Skaw Spit 1787-1973.

The growth process is caused by the accretion of the N-coast by 350.000 m3/year and the reef by 530.000 m3/year and the erosion of the SE-coast by 140.000 m3/year.

The general picture of the growth process is that it is maintained by a sediment transport of 800.000 m3/year along the NW-coast and the direction of the growth of the spit probably is maintained by a current which flows in situations with strong winds from westerly directions. Current measurements show that in those situations an eddy is formed on the SE-side of the tip of the spit giving a nearshore current to the NE of 1.5 m/s or more. The analysis of shore profiles support the assumption that the nearshore current and waves in combination erode the SE-coast of the tip of the spit and thereby maintains its direction.

The conclusion with regard to shore protection is in short as follows:

1. Avoid constructions in the growth-section if possible. The moovements of the coast in this section are too big for constructions to be maintained. On the SE-coast there is a group of T-groins of which the northern section has to be nourished since it is placed in the erosion part of the growth section where the erosion is up to 30 m/year.

2. An existing groingroup at the NW-coast can be extended to the NE with a good result until it reaches the growth section.

3. An existing groingroup on the SW-side (leaside) of the harbour does not function because of lack of natural sand supply. The beach should be nourished and the groins will stabilize it.

5.2.2. Function of groingroup

At the Thyboron barriers (see fig. 1 and fig. 4) the erosion is 1.1 - 1.7 m/year. The big groingroup was built around 19oo. The total length of the group is appr. 2o km and the space between groins is 38o m. The length of each groin is about 2oo m from the dune. The littoral drift is towards the inlet on both barriers and the inlet therefore drains the coast of about 7oo.ooo m3/year. This means that there is no negative leaside-effect and the groups function well.

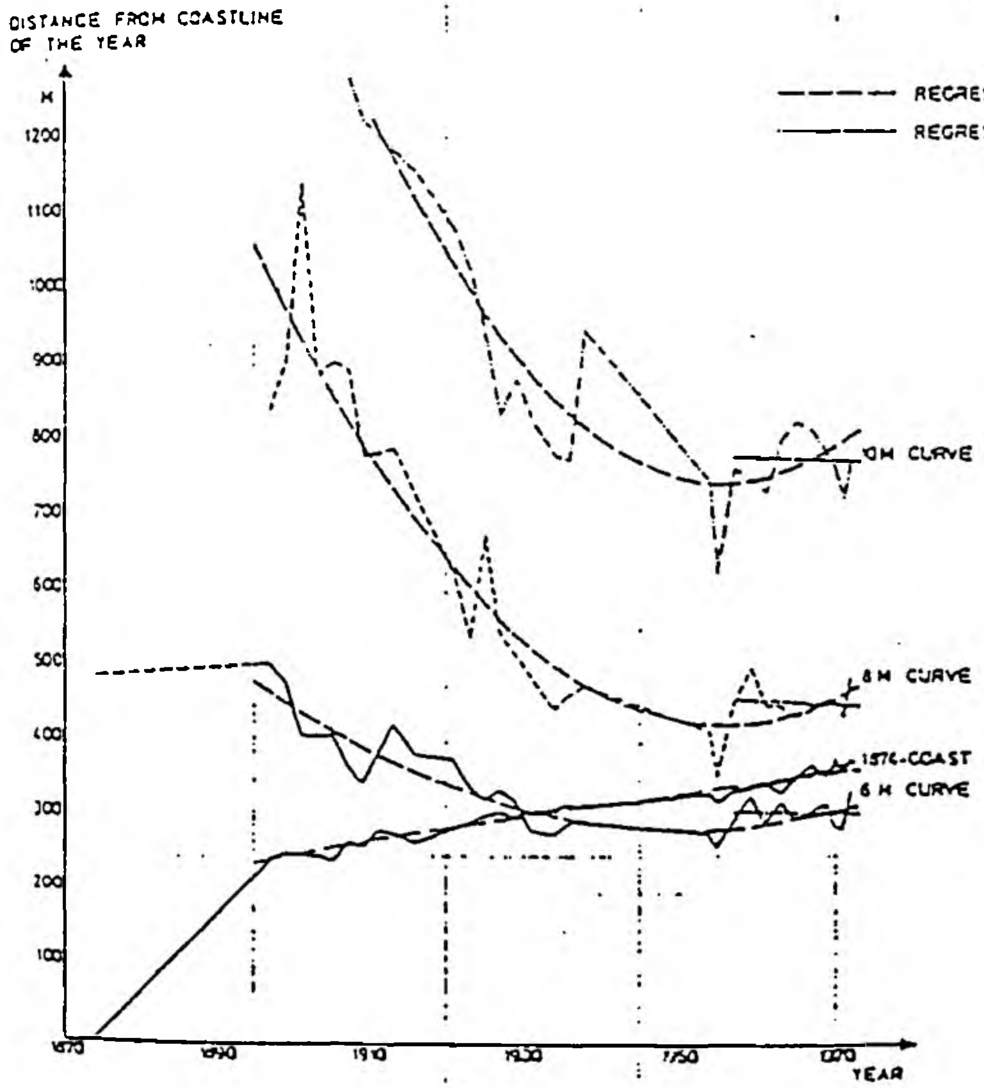


Fig. 7. Development of profile on Thyboron Barrier since building of groins around 19oo.

On fig. 7 the development of a profile on one of the barriers during 70 years from the groins were built around 1900 till 1970 is shown. On the vertical axis the distance from each years coastline to the depth contours is marked. Also the distance from each years coastline to a fixed point, the 1874-coastline, is marked. This distance represents the setback of the coastline since 1874.

The erosion of the equilibrium-profile which existed before the building of the groins (steepnes 1:140) was appr. 10 m/y. It can be noted that the coastline immedeately responds to the building of the groins, since the erosion now is reduced to 1.6 m/y. The depth contours need about 50 years to adapt to the new situation by forming a steeper (1:60) equilibrium profile.

5.3. Shore protection measures

The shore protection measures at the sandy coast are now being carried out. They can roughly be divided into protection against surge and reduction of erosion.

5.3.1. Surge protection

The surge protection consists of a) reinforcement of dunes where they protect low areas, b) building of revetments and c) development of a forecast model and establishing of an evacuation service.

Planning of surge protection must be coordinated with the planning of the reduction of coast erosion. Building of a revetment is not sensible if it will be destroyed in a few years because of continuing erosion of the coast. In the long run it will also be very expensive to maintain a dune-system as a protection against flooding if the coast erosion is not stopped, since the natural process of windblowing by which the dunes mooved with the same speed as the coast is stopped by the planting of dune grasses. This means that the dune system is becoming still narrower.

5.3.2. Reduction of coast erosion

As fig. 4 shows the reduction of erosion to max. 2 m/year involves reduction at sections with big leaside erosion. It is therefore an important problem to reduce erosion on one section of the coast without damaging other sections.

An example of how we try to solve this problem is given on fig. 8 which shows a section of the protection of the small town of Lonstrup (see fig. 1). The protection is carried out in 1982-83. The protection consists of a) 60 m long breakwaters at 0.5-1 m of depth, b) revetment and c) beach nourishment. Besides that, two small groins are built to protect a beach for small boats.

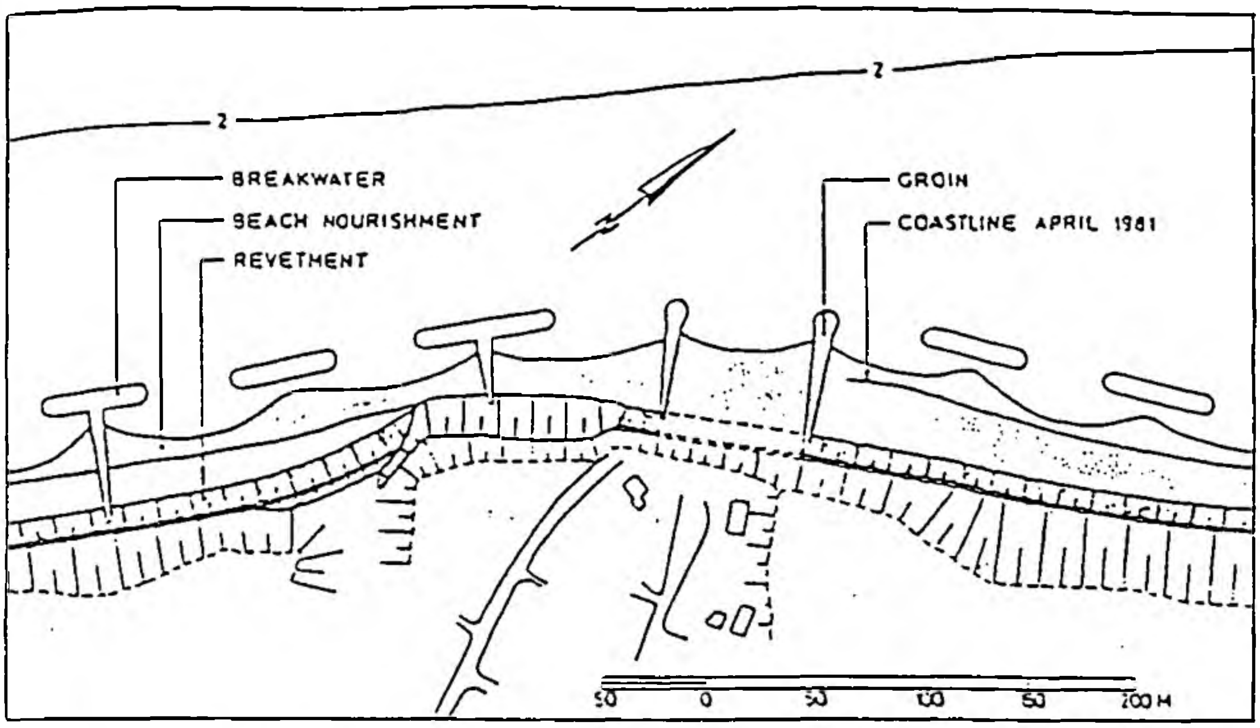


Fig. 8. Section of coast protection at Lonstrup.

We have tried to optimize the total costs, being construction costs and kapitalized maintenance cost of beach and constructions. It can be assumed that higher breakwaters with less space means less nourishment and vice versa. It was assumed that erosion of the beach behind the breakwaters is proportional to the component of waveenergy flux normal to the shore and that erosion of the beach behind breakwaters therefore would be reduced with the same percentage as the breakwaters reduced the waveflux.

Fig 9 shows that the optimal hight of breakwaters over seabed in this situation was 1-1.5 m and that the optimal waterdepth where the breakwaters should be built is o.5 m. The method which was used for the estimation is probably very rough and the performance of the protection will therefore be surveyed carefully.

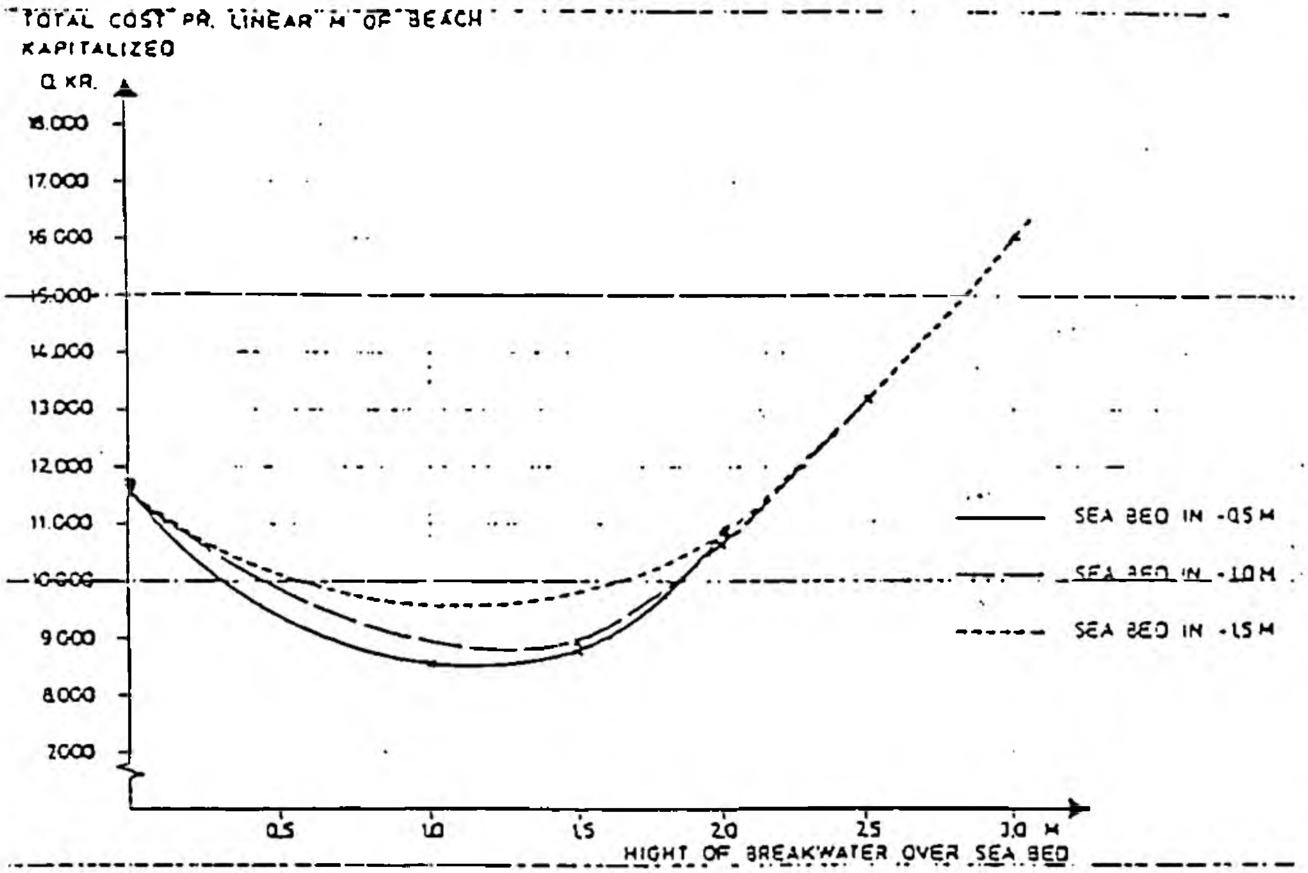


Fig. 9. Examples of design curves for breakwaters.

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APPENDIX C

"Copenhagen Metropolitan Region - Coast Erosion Management"

COPENHAGEN METROPOLITAN REGION
COAST EROSION MANAGEMENT

by

Jakobsen, Per Roed*, and Tougaard, Niels **, and

Larsen, Knud ***

Abstract

Denmark is a coastal country having a coastline of 7.300 km and a population of 5 million, corresponding to 1.5 m coast per inhabitant, Fig. 1. Unfortunately this impressive coastal ressource, which also internationally is considerable, is unevenly distributed over the country. The Metropolitan Region thus comprises 6% of the country's area and coastline, while its population is 1.7 million, i.e. 34%, and the outlay for vacation housing 17%. This combination of concentrated demographic pressure and medium exposure of the sea coasts leads to a set of coastal situations which are significant on a national level. Denmark has a strong tradition within physical planning, and coastal works remain fairly well controlled through the established legislation, notably the Dike Protection Law of 1874 and the Coastal Protection Law of 1922.

Hence it appears that the modern requirements for control and development of the coastal zone are best fulfilled through ad hoc initiatives towards coordination between authorities and professionals, based on truly manifested involvement and tailored to the specific objectives. At the same time it is also recognised that modern approaches to coastal protection and planning i.e. large scale beach nourishment projects may necessitate certain adjustments in existing legislation.

The integrated activities have been named Coast Erosion Management to indicate the level of planning which is coordination, the multidisciplinary process to be physical planning/engineering and the focal point for many use conflicts to be erosion, although the Copenhagen Beach Park situation serves to present an interesting case of accretion.

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Copenhagen Metropolitan Region

Environment

The region covers the north eastern part of Sealand. With an area of 2,850 km^2 it covers 7% of Denmark, while the population is 34%.

	Area		Population		Vacation Housing		Coastline	
	1000 km^2	%	1000	%	1000 Ha	%	km	%
Denmark	43.1	100	5,112	100	42	100	7,314	100
Copenhagen Metropolitan Region	28	6	1,727	34	7	17	539	7

Table 1. Key Figures: Denmark - the Region.

The Region covers three counties and the cities of Copenhagen and Frederiksberg, all comprising 50 municipalities. The first Copenhagen Metropolitan Council Election took place in 1974. Regional planning is a primary objective of the Council, which furthermore is responsible for all public bus/train transport systems within the region. Urban areas in the region radiate from central Copenhagen 'The finger plan', Fig. 3 and forms a brim of predominantly urbanised coast of 70 km flanked by sea coasts used for vacation houses and other recreational activities.

Physical coastal environments in Denmark are set by the interaction between the glacial geology and respective sea.

- The North Sea Coast of Denmark (The West Coast) is particularly vulnerable to erosion. Mean erosion for eroded reaches is up to 2 m and littoral drift is in the order of 100,000-1,000,000 m^3/yr.

- The Kattegat Baltic Sea Coasts are medium exposed. Mean erosion is 0.3-0.5 m/yr and littoral drift up to 75,000 m^3/yr.

Belt and fjord coasts are less exposed. Mean erosion is less than 0.25 m/year, littoral drift less than 10,000 m^3/year.

The overall coastal environment in the Copenhagen Region and the set of coastal situations discussed are thus determined by a high demographic pressure for recreation and vacation and a medium coastal exposure - Kattegat/Baltic Coasts -, alternating with less exposed urbanised coasts with high demand for recreational facilities. The combinations lead to a set of coastal situations, the handling of which is important on a national level, only exceeded by the problems encountered along the North Sea Coast, which is characterised by the high erosion level, storm flood hazards and intensive fishing and tourist activities.

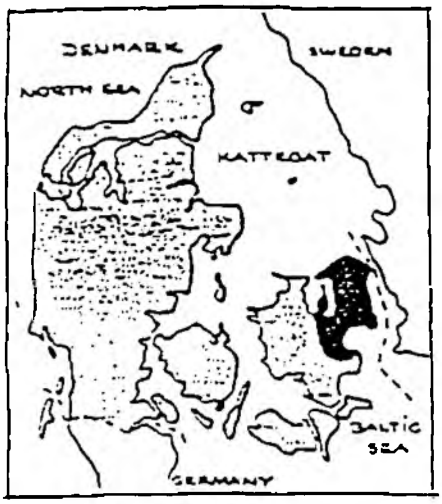

Figure 1. General Setting

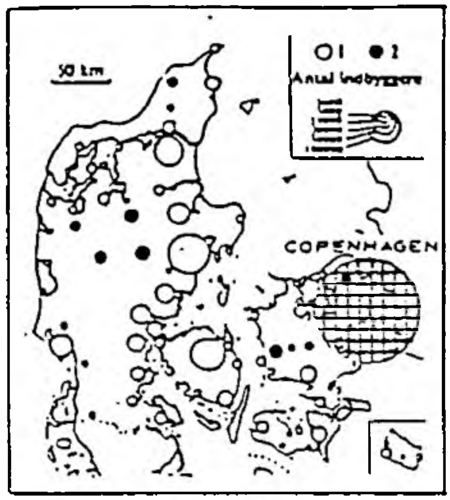

Figure 2. Danish Towns' Relative Sizes

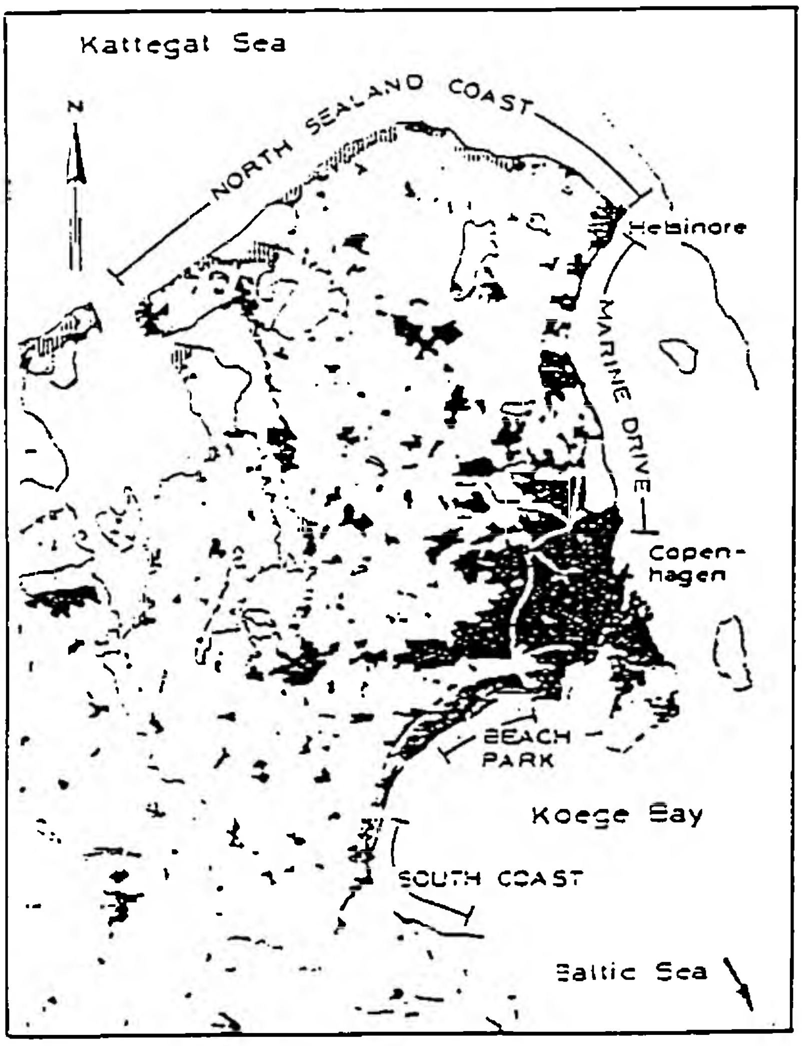

Figure 3.
Black: Urban
|||||: Vacation

National Planning Guidelines

The right of way for public to the beaches was already given in the Jyske Law of Valdemar Sejr in the year of 1241. In 1683 the beaches were privatised, a situation which continued for almost 250 years when rights finally were given back to the public with the Nature Preservation Law of 1937, which at the same time imposed a 100 m set-back zone for new buildings and similar activities to be constructed.

The Jyske Law also confirmed the long established sovereignty of the King over all territorial waters. This sovereignty is in Denmark not directly based on a law or in the constitution, but is considered a given thing as far as remembered - a very old regulation.

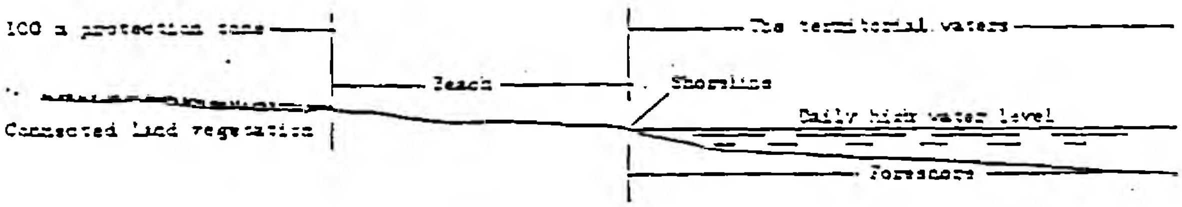

Figure 4. Definition of Terminology in Coastal Regions

	Length km	Coast	Use	Investments US$
North Sealand	60	Medium Erosion 40-60% Accretion 20-30%	Vacation/ Recreation	Planning and Pilot Scheme 1 million for erosion management
Helsinore/Copenhagen	45	Erosion small	Urban/ Marine Drive	Large. 10 major marinas and small craft harbours
Koge Bay North	10	Predominantly Accretion	Urban/ Recreation	Copenhagen Beach Park 20 million
Koge Bay South	16	Erosion minor 20% Accretion 13%	Recreation/ Urban	Planning 0.5 million

Table 2. Coastal Environments

During the 1970'ies a comprehensive planning legislation was established in Denmark. A distinction was made between the State, the region and the local municipality. The planning system may be characterised as a framework control system, consisting of national planning at the State level, regional planning at county level and municipal planning and local planning. Various forms of sector planning on all the three political levels supplement the system.

The yearly review of the planning system can result in actions taken for specific problems which are considered becoming critical. As an example it can be mentioned that a stop for any further building of hotels and vacation housing has been declared for a 3 km deep zone along the coast.

Regional Planning Guidelines

The regional plan shall give guidelines for identification and preservation of areas of special interest. Furthermore it gives directions for layout and reservation of areas for vacation housing or similar recreational activities. The Regional Council can offer loan or financing directly to the municipalities for the implementation of these goals. The interaction and coordination between the municipality and the region planning levels is hence a major factor in the planning of the regions' coastal zones. This is coupled with the general physical planning of the hinterland and future use of coastal area foreseen, closely coordinated with the coast protection and or management programmes which are being prepared in this decade.

North Sealand Coast (The Vacation Coast)

Environment

The 60 km long attractive North Sealand Coast is the largest and most extensively used recreational area in the region. Vacation houses have been built since the turn of the century and this mode of coastal use virtually exploded in the sixties. 80% of the regions outlay for vacation houses is found in this county, where vacation houses now fringe large tracts of the coast in a 1-2 km deep belt. Fig. 5.

Attractive coastscapes have thus been taken over and access to beaches obstructed; furthermore the erosion/use conflict is escalating. Erosion - caused by onshore storms with significant wave heights up to 3.5 m and the associated setup - predominates. Large moraine bluffs are being eroded/protected, whereby natural supply of sand to the sediment household diminishes, leading to decline in beaches and coastal quality.

Planning Approach

Dense areas exploited for vacation housing give rise to a number of problems to the municipal physical planning. Based on the regional guidelines the Copenhagen Metropolitan Council has in cooperation with the 5 affected municipalities identified the overall objectives for improving public access to the coast. A number of plans have been worked out which give guidelines and recommendations for action to be taken, which concurrently meet regional as well as municipality objectives.

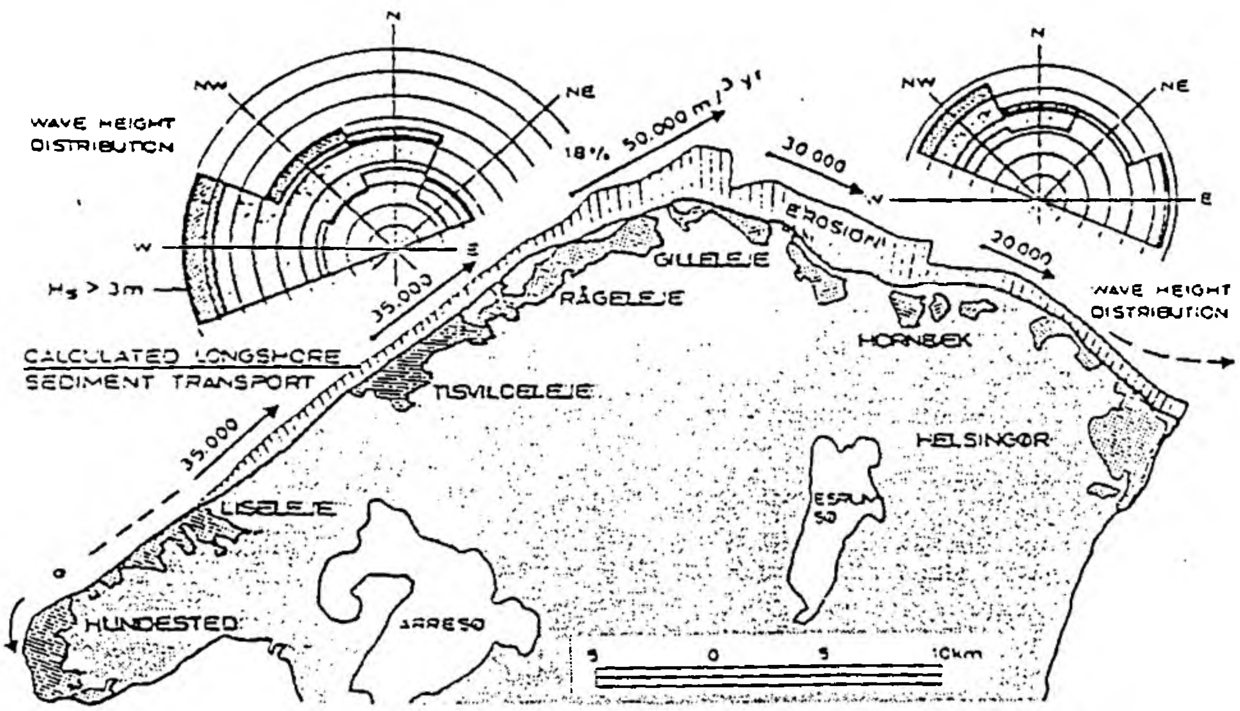

Figure 5. The North Sealand Coast

The guidelines comprise identification of valuable landscapes and their preservation. Improvement of access in form of layout of parking areas, establishment of public patch systems between hinterland and beach and proposed aquisitions of land.

This work has been coordinated with the work undertaken by the "Committee for Coast Erosion Management":

In 1971 the five concerned municipalities joined forces with the county for the coordination of the coast protection, while at the same time preserving coastal environment quality along the coasts of the region, the Copenhagen Metropolitan Council participates in the regular meetings. In 1976 the Danish Hydraulic Institute and the consulting engineers, Portconsult A/S, were asked to provide consultancy for the committee.

This work has resulted in baseline investigation of the coast, preparation of recommended approach for construction or restoration of coast protection works. During the present work period the consultants have been asked to prepare a Master Plan for Coast Erosion Management.

Two programmes will be prepared for political decision:

- A Protection Programme

  This takes off from the present level of protection and is primarily directed towards the improvement of the quality of erosion control schemes.

- A Management Programme

  This programme is directed towards improvement of beach qualities in symbiosis with the beach erosion control and therefore addresses the regional community. It will technically contain a significant element of beach nourishment.

Finally a third group is active in the area, viz. "The association of privately owned coast & dike groups". This group has been very active in pushing all authorities at different levels towards a more active coast protection policy.

The sum of initiatives taken along the North Sealand coast has thus been one of the significant factors which has led to the preparation of a new draft legislation for Coast Protection. Details cannot be given at the moment since the law now is due for presentation in Parliament 1987/88. However, apparently it will open up for improved coordination and financially and environmentally more acceptable coastal schemes, matured by the appropriate authorities in the planning pyramid.

It then appears that coastal studies and plans, physical planning and legislation now are harmonised to an extent where pragmatic handling of key issues can be undertaken.

Erosion Management

The recommendations prepared by the Committee are presently being used by private frontline lot owners in their protection efforts, corresponding to yearly spending of 0.5 million US$.

It is now widely accepted, that substantial improvements or restoration of the lost beach quality will only be possibly through larger coordinated beach nourishment schemes.

The Committee has therefore initiated and financed a pilot beach nourishment scheme in order to introduce the concept in the coastal environment and to improve the basis for design.

During the summer of 1984, 25,000 m^3 sand (with a median diameter of 0.25 to 0.40 mm) was hydraulically placed on the selected beach. At that time, the beach was almost entirely stripped of sand, the natural grain size of which was about 0.15 mm.

The triangular shape of the beach fill was evened out during the first three months. Since then, the erosion became moderate with an average monthly coastline recession of 0.6 to 0.8 m. The corresponding loss of sand volume can be derived from Fig. 6. The predominant part of the loss of sand took place during the winter. From March to August

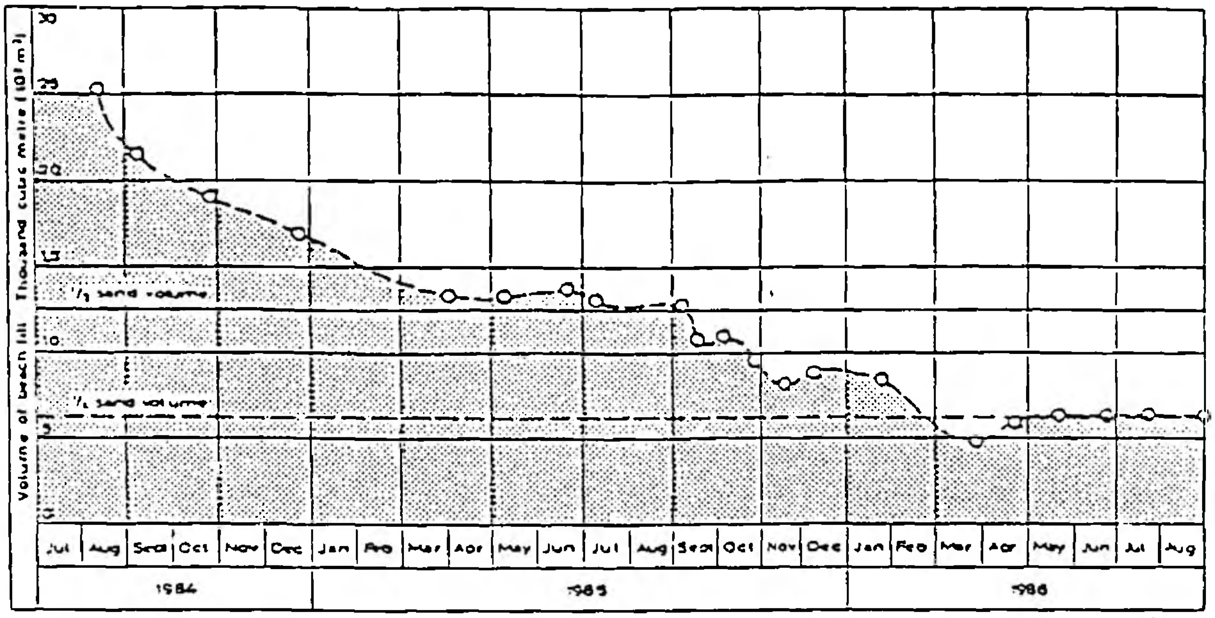

Figure 6. Development of Beach Fill

1985, only a negligible volume of sand was lost and the loss was mainly confined to a few one-day weather events during which the coast was exposed to high waves in the order of 1.5 to 2.0 m.

The nourishment may be considered a feeder beach which lost 50 per cent of sand during the first year of testing.

However, the major part of the sand has nourished a downstream coastal reach of 1,500 m, and it appears that the offshore loss of sand feared for has been very small, i.e. 10 to 20 per cent at the most. The monitoring has continued through August 1986 and the derived information will be used for the preparation of conceptual schemes for large-scale nourishments.

Elsinore-Copenhagen (The Marina Drive)

Environment

The 45 km coastal road between the cities of Elsinore and Copenhagen winds its way along the sheltered Sound coast between residential areas and lush vegetation alternating it follows sea defensed coast utilising as base the old marine foreland which fronts the fossile coastal bluffs in the hinterland. Minor fishing harbours characterised the earlier environment. The increased urban settlement and structural changes in society have turned most of these into marinas which subsequently have expanded and modernised. The about 11 major marinas have a boat capacity which - before the Copenhagen Beach Park - corresponded to 75% of the total sea coast pleasure boat harbour capacity.

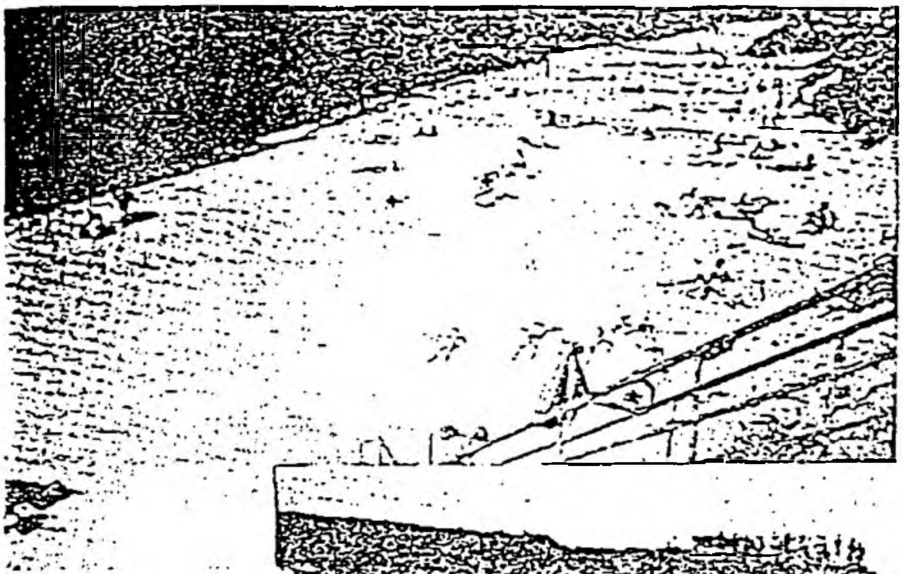

Figure 7.
AFTER

Figure 8.
PRIOR

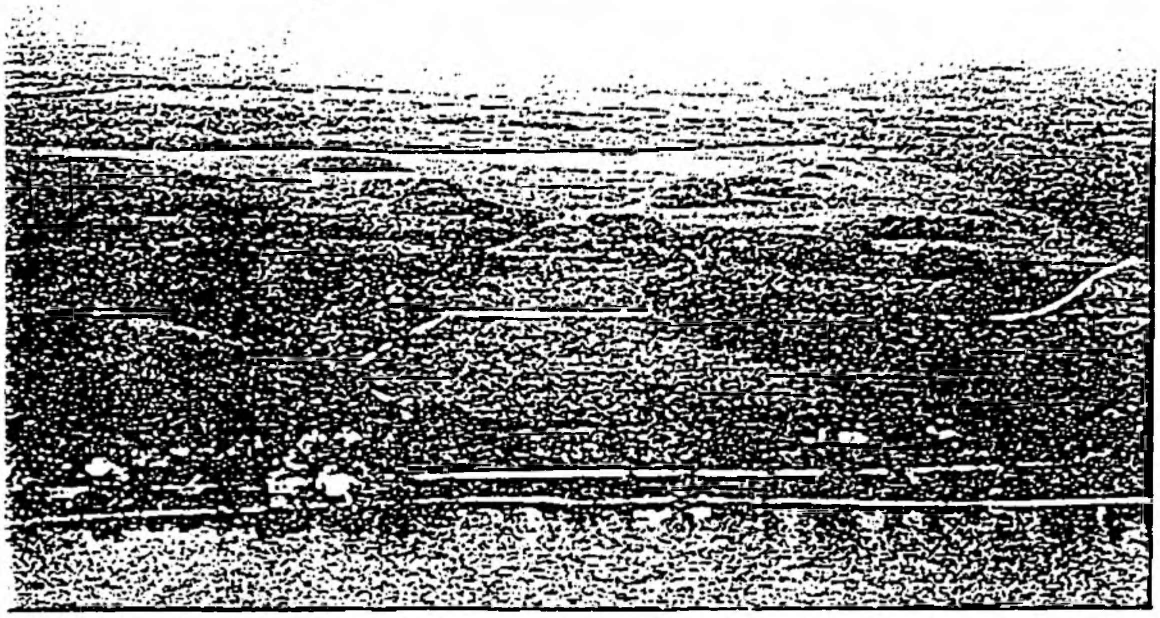

Figure 9. THE MARINE DRIVE

Planning Approach

The goal for the planning has been laid down in the Coastal Road Report 1960 and is to: "Preserve and enrich the unique combination of man and nature developed coast". County as well as municipality funds are available for the acquisition of important landscapes and buildings, the latter are often demolished in order to improve scenic values. The policy for acquisition is long-term in the sense that land and property usually will be acquired only when offered for sale, in which case though the authorities have first priority for bid. Through this incremental policy about 80% of the entire reach shown on the photo has been brought back to the public since 1930 corresponding to an increase of 100% in publicly owned beaches. Today's value of investments in this scheme is roughly 15 million US$.

The former Danish kings have also contributed to the still relaxed environment by skirming the roads from the hinterland traffic pressure through the preservation of their hunting forests.

Coastal Engineering

A number of minor coastal problems are linked to the presence of the marinas. In several cases it has been possible to optimise the layout through combined layouts of marinas and bathing and surf beaches.

Køge Bay North (The Copenhagen Beach Park)

Environment

The initial landforms of Køge Bay were created during the last glaciation. The bay can be characterised as a central depression reflecting a large glacier lobe, which advanced in a NW direction during the last stages of the Pleistocene era in Denmark. When the ice melted away, a smoothed-out till plain was left, sloping gently towards the central part of the bay. 6-9000 years ago, the base level was about 18 m below present-day sea level. The development of the actual coastal zone is due to the transgression during the Litorina Sea (5-6000 B.P.). The maximum sea level reached 2.5-3.0 m above present-day sea level in this area. During the transgression, a very wide and shallow offshore zone was formed. Onshore net transport of material predominated. Therefore several barrier systems at different levels can be detected along most of the coastline of Køge Bay.

Planning Approach

Over the last decades the landscape west and south-west of Copenhagen has been urbanised. The most spectacular changes apply to the Køge Bay coastal reaches, where a number of new urban communities have been established. During the period 1965-1980 altogether 42.000 new dwellings - existing 4000 permanent and 5000 vacation dwellings - have been built together with the infrastructure required.

The unique not yet exploited coastal conditions in the area had been in the searchlight since 1936, but it took 25 years before site investigations and design preparation were commissioned to Portconsult and Danish Hydraulic Institute 1972. In 1975 the Ministry of environment decided to sponsor the project and requested the Metropolitan Council to undertake responsibility for implementation. The final goal for planning and design was: to establish a beach park facility, which at the same time preserved inherent environmental values and expanded the nature given recreational ressource for the benefit of the growing population. A joint venture was establish between all concerned municipalities, counties and cities, which carried the project forward to execution and today manages and maintains this large project.

The creation of the Køge Bay Beach Park has provided within a distance of less than 15 km from the center of Copenhagen

- o 5000 ha-1200 acres recreational beach park area
- o 8 km - 5 miles - of virgin beach
- o 4 new harbours with an altogether capacity of up to 5000 pleasure crafts.

On a good hot summerday 100.000 visitors have been counted on the beaches.

Coastal Engineering

Site investigations 1964, 67 and 74 proved that the barrier island system was subject to slow but continuous growth. The project concept was therefore to benefit from and accelerate this natural trend of evolution. The plan layout for the beach park was modelled over the main morphological features. The existing lagoon was thus turned into three recreational harbours and six lakescapes for use of man and wild life.

The project thereby meet three major objectives: Recreational - Storm Flood Protection - Pleasure Boating.

It appeared that especially requirements to the dunes were a determining factor for sand parameters, since aeolean transport had to be kept down. Mean grain size for exposed sand was 0.4 mm. Seismic investigations showed that such valuable beach material could be localised within the bay proper on depths of 6 m. The predominant construction material was thus 5 million m^3 of hydraulic fill/sand of which 2 million was provided from the bay.

The storm flood protection was designed on basis of elaborate analysis of simultaneous occurrance of waves and high water level. It was shown, that frequent high waters of 1.5-1.8 m and associated wave attack were as dangerous as the historical singular value of high water level of 3 m which occurred in 1872, but which was not followed by onshore wave attack. An automatic operated operated sluice system prevents high water level from penetrating through lakes etc. to threaten the low laying hinterland.

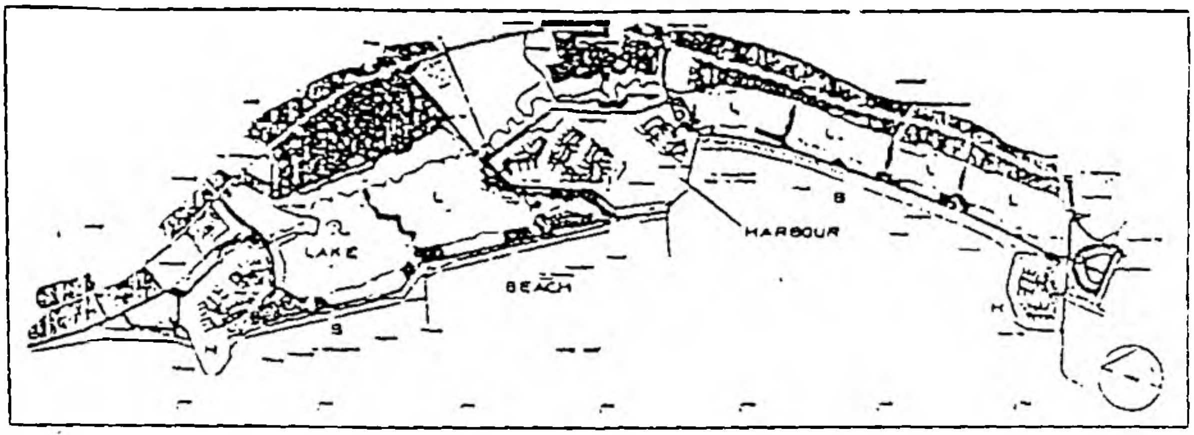

Figure 10. 6 Lakes, 3 Harbour Clusters, 4 Beaches

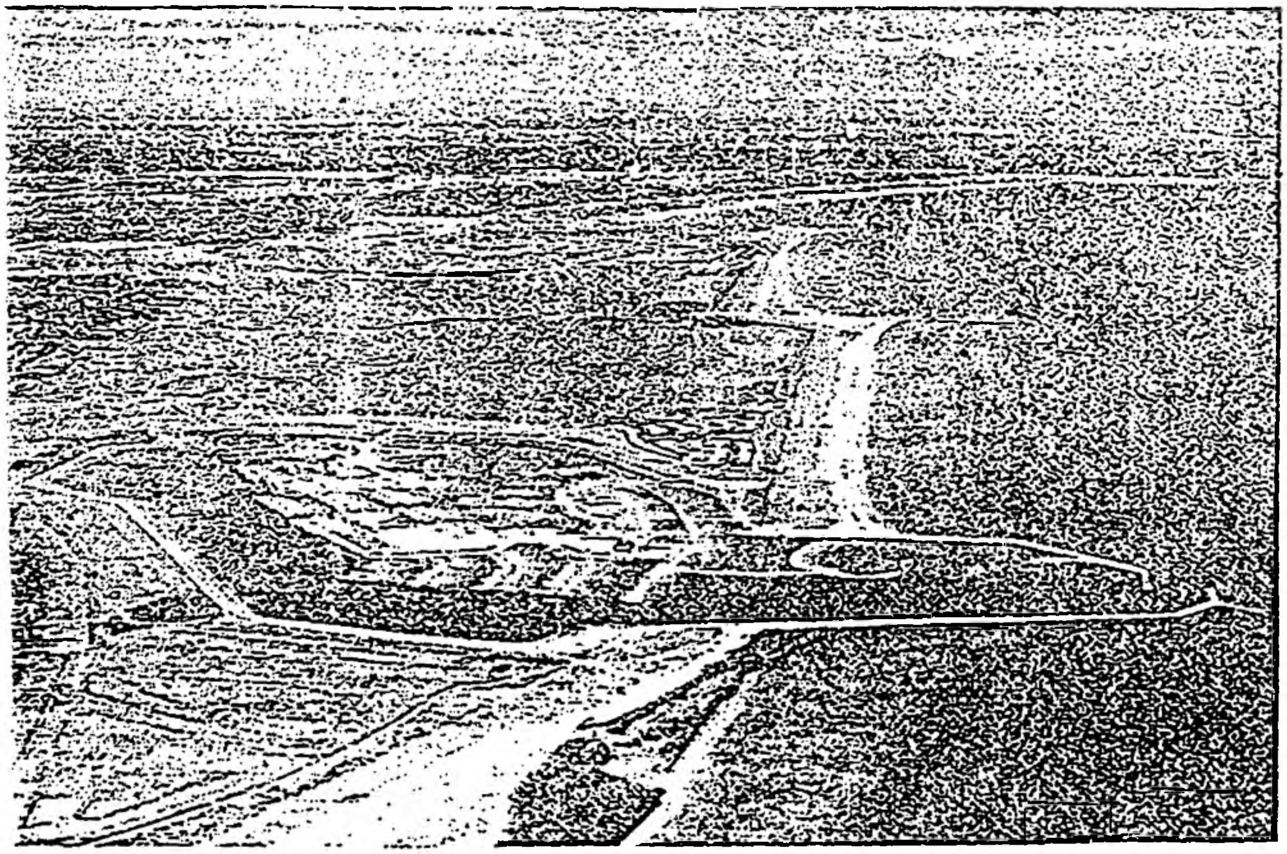

Figure 11. Beach alignments were shaped over existing coastlines and optimised through wave refraction analyses and the incorporation of three large 175 m groynes.

The coastal cross-section was determined with equal consideration to: Coast Stability - Stability of Dunes - Storm Flood Hazard.

The project was implemented in 1978-1979 and the technical performance has been satisfactory as no major project modifications have been required as yet. The reactions from the users have been enthusiastic.

It is unusual that the coastal engineer is allowed to "build in sand" to the extent here demonstrated, but it remains a prime objective for him to encourage coastal planners and clients to use such methodologies in increasing measure.

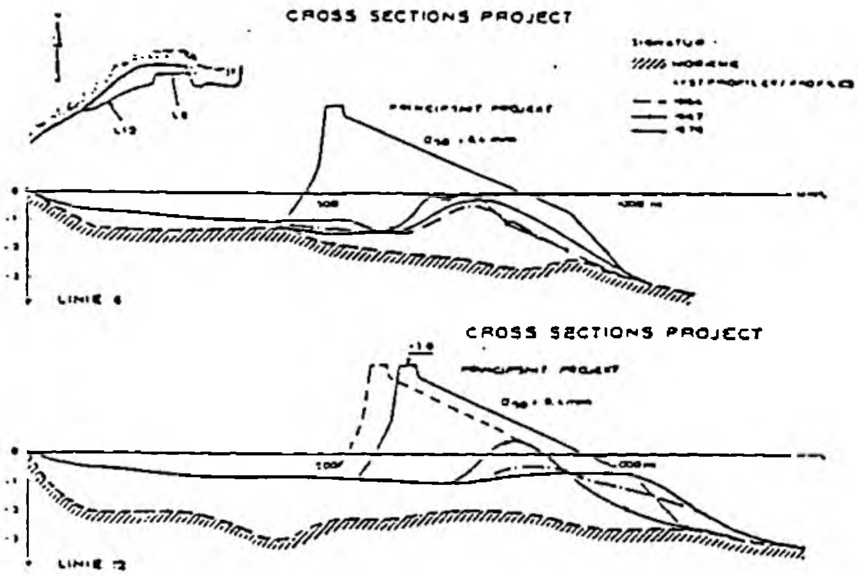

Figure 12.

Køge Bay South (The Vacation Recreation, Urban Coast)

Environment

The southern part of Køge Bay is to a large extent a man-made coast and the quality of constructions is low. Erosion is also low 2000 m^3/yr. The dwelling pattern is a mix of permanent and vacational dwellings.

Planning Approach

Following the development of the Køge Bay Beach Park the recreational planning of this reach has gained importance. The Copenhagen Metropolitan Council therefore commissioned Portconsult and Danish Hydraulic Institute to undertake a coastal study, the objectives of which was a) to provide the background for the recreational planning of the coast b) to suggest measures to improve coastal quality, and c) to improve the system of coastal protection.

A regional centre for outdoor activities is being prepared including a marina.

It has been experienced that the baseline report well substantiates the ongoing physical planning.

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Other backup information will be in Danish. Please contact authors.

Jan. 1987
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APPENDIX D

"Stabilisation of Coastal Dunes in Denmark"

STABILISATION OF COASTAL DUNES IN DENMARK

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Keywords: dunes, history, Denmark, sand fixation, afforestation, plant species

Abstract

A brief history of sanddrift and measures to reduce it in Denmark is given. Techniques of sand fixation are mentioned as well as the effect of plantations with evergreen trees.

The history of dune management

Coastal dunes are found first and foremost along the west coast of Jutland from Skagen in the north to Rømø in the south, a distance of approximately 400 km. The dunes and dune plains in this area cover some 80,000 ha. There are also coastal dunes on Læsø, Anholt, along the north coast of Zealand and on Bornholm (Fig. 1).

The map on Figure 2 shows a random stretch of dune landscape on the west coast of Jutland. Here there are beaches between 50-100 m wide where small embryonic dunes can be found which have developed in places where there are plants or stones. Occasionally a small barchan may be seen. The prevailing wind is westerly and because of this sand is blown from the beach and gathers in fore dunes where marram grass (*Ammophila arenaria*) grows. These dunes are commonly called white dunes as the fresh sand can be seen beneath the vegetation. Fore dunes can range in height from a few to 20-25 m, they are usually stable, but breaks and channels caused by the wind are not uncommon. Behind the fore dunes lies a Litorina plain and the lines of altitude on the map show that dunes have moved over the plain and have formed a typical parabolic dune. Along the west coast of Jutland many parabolic dunes can be found. A little further to the east the map shows an old coastal slope from the Litorina Sea period, and the many lines of altitude indicate that sand has drifted over the old moraine land, in a number of places 8-9 km inland.

Dunes have probably existed in Jutland as long as the country has had its present configuration, but from a geological point of view the present-day dune position is of a recent date.

The movement of the sand from the coast is likely to have started at approximately 1100-1200 AD, but not until the 16th century do we have historical information on damage caused by sand drift. From the 17th century the examples are more numerous.

The dunes gradually conquered more and more land. Houses, farms and even whole villages were buried and churches are known to have been moved eastward. People were forced to leave their homes and great hardships were experienced in the western part of Jutland. Economic losses on account of sand drift were considerable.

The inhabitants made various efforts to fight the sand drift but they were not aware of the right procedure. The farmers owned the dune areas in common and

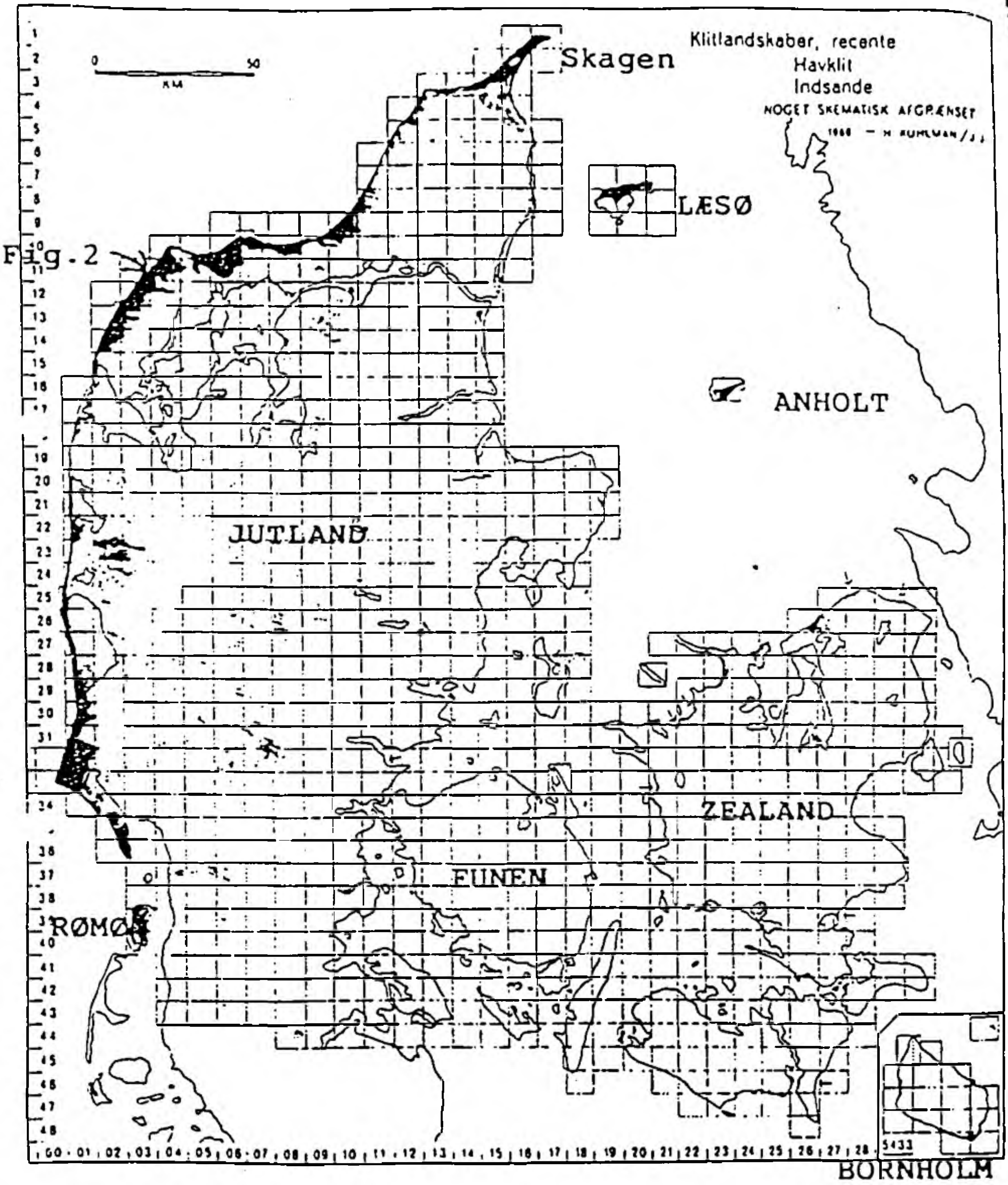
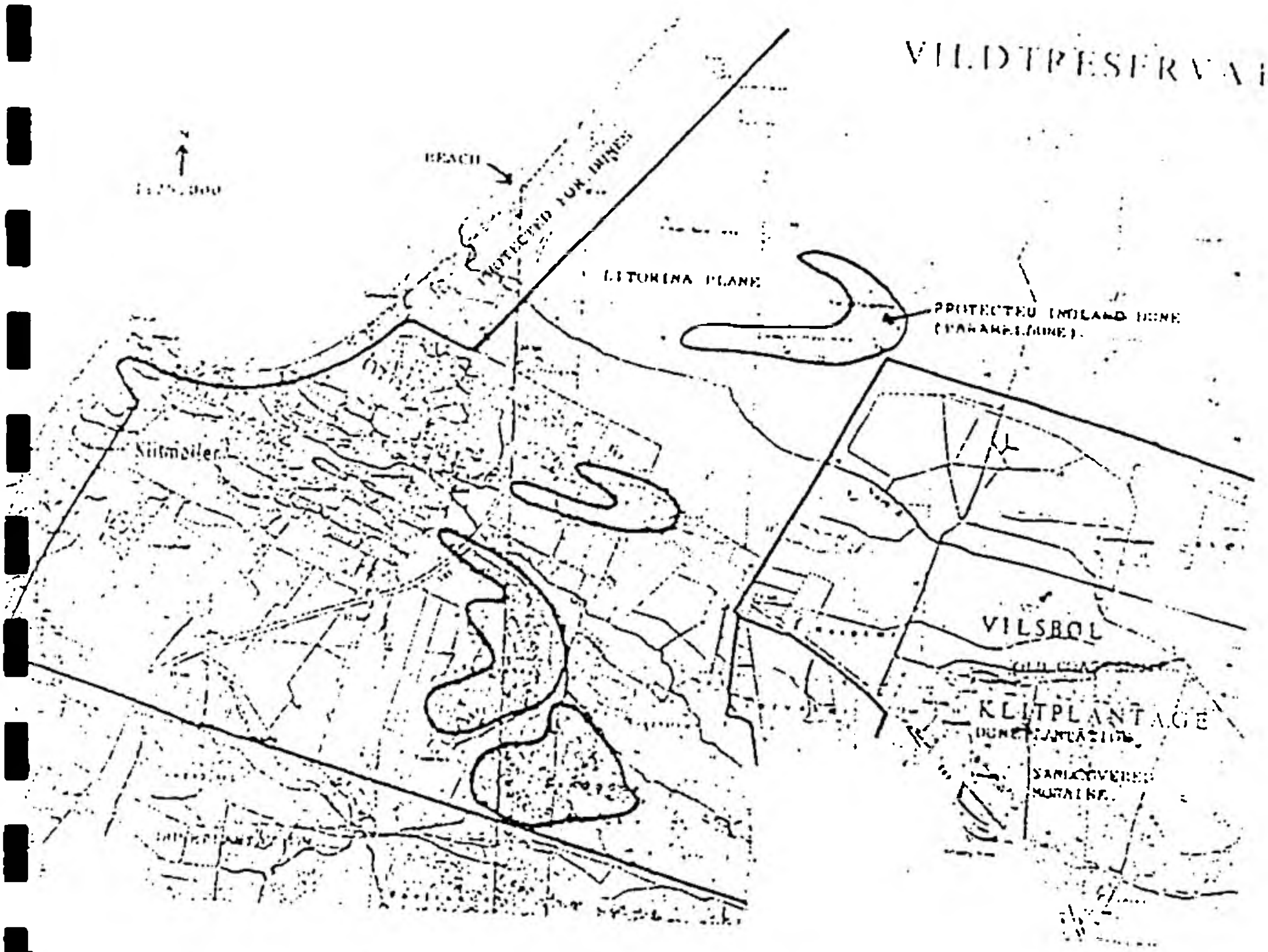


Fig. 1. Coastal dunes are mainly found along the west coast of Jutland. (H. Kuhlman, 1969.)

could not come to an agreement upon the work of stabilisation. The government rendered no economic aid to the farmers, and they were unable to fight the shifting sand dunes alone. Dikes and fences were made in order to stop the sand, but when these filled up, the sand again drifted over the fields behind them.

Denmark has probably suffered proportionally more from drifting sands from coastal dunes than any other country in Europe, and this is the reason why we have a special law concerning sand drift. The first provision in the fight against drifting sand is the royal decree of the year 1539 which prohibited the removal of any vegetation. Further ordinances followed, but the people were too poor to live without the



2. A random place on the west coast of Jutland with beach, fore dunes. Litorina plane, parabolic
ies and sandcovered moraine.

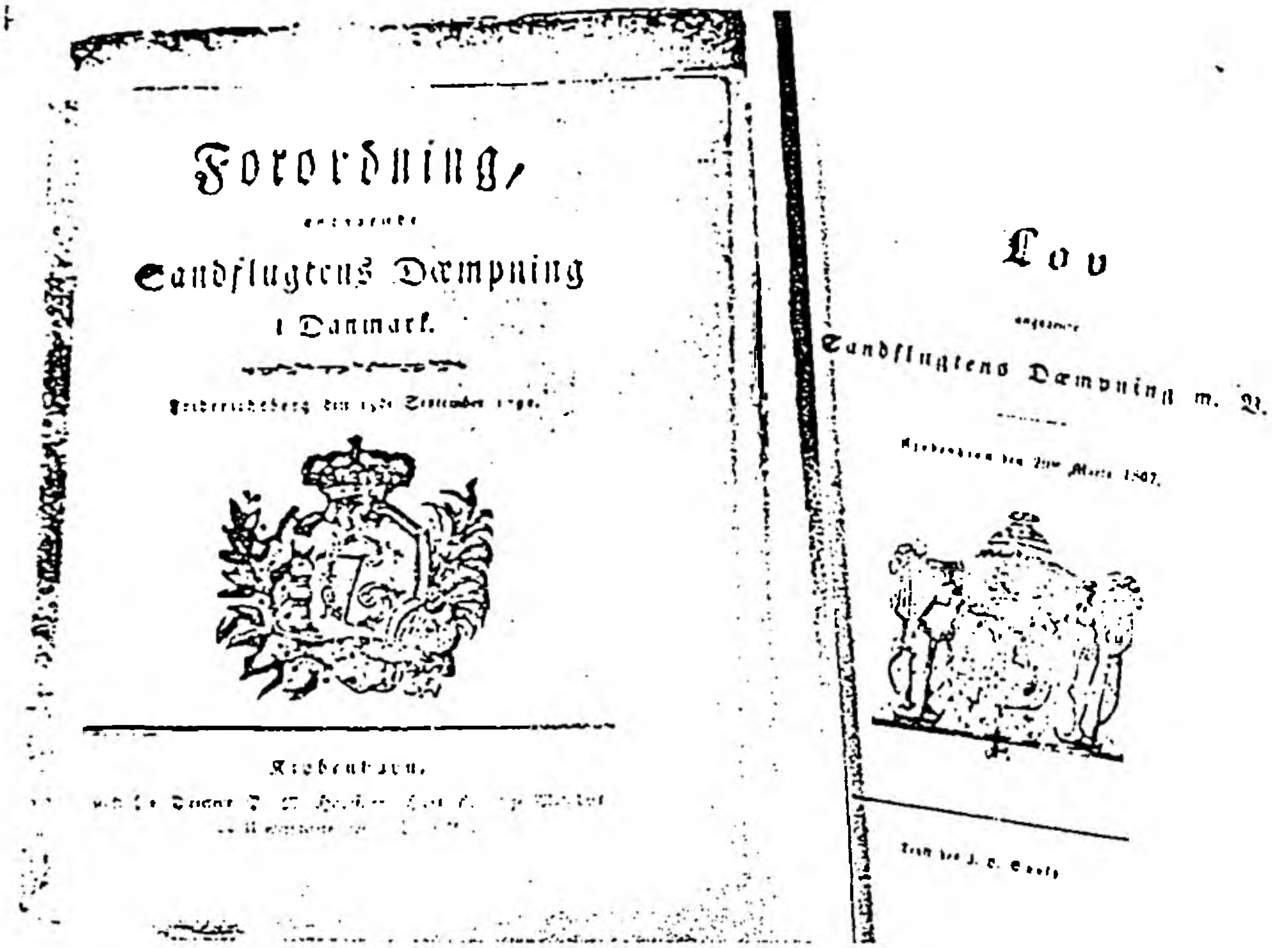

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Fig. 4. The important law from 1792 and a later law from 1867.

grazing and fuel that the dunes provided. Owing to the lack of wood the roots of marram grass and willows (*Salix*) were used for fuel and the marram grass was also used for thatching houses.

After 2-3 centuries the moving sand had almost changed large areas into deserts. The government at last took the initiative and as an experiment issued a provisio in the year 1779, but only in connection with the most damaged part of the coast. The experiment was a success, and in 1792 the law was extended to the whole coast. This most important law was worked out on the basis of a paper written by the botanist Viborg, a professor living in Copenhagen (Fig. 4).

The law made provisions for protecting the dunes and the employment of inspectors and suggested methods for fixing the sand. It was further decided how the dune areas were to be divided among the farmers, so that everyone now was given his ow part of the dunes. Grazing cattle and sheep and (again) removing vegetation were prohibited. Each year a commission was to determine what could be done about fixing the sand dunes.

There was now severe punishment for breaking the law. The dunes were fixed by planting and sowing marram grass as recommended by Viborg, who was aware of the necessity of using the vegetation of the dunes for successful fixation. Among the plants in the dunes marram grass was the most valuable for fixing. Other plants were also used, but without great success. Rows of small bushes which grew naturally i the dunes were set as well as willow (*Salix*). Marram grass was sown between the ows. It soon appeared that planting marram grass was better than sowing it, and fixation began to have an effect only when planting became general.

Work in the dunes was the responsibility of the inhabitants who were not paid and people living up to 24 km (15 miles) from the coast had to take a hand in planting. Fixation of the sand was thus a great burden for the inhabitants of coastal areas, a burden that they were to bear for 60 years. Only after this period did the state, counties and municipalities begin to make significant contributions to the cost of the work.

Sanddrift was first brought under control when the fixation of 1792 was organised, after 50 years of work in developing the correct procedures, but it was still an expensive procedure. The success of fixation was first of all brought about by protecting the dunes and organising the work to be done. In the years 1724-38 an extensive sand drift in North Zealand was fixed but similar work was not done to save the western coast of Jutland.

Although sanddrift can now be controlled, it is still necessary to build containing outworks for fixing the sand along the whole coastline. The dunes are continuously exposed to wind and a new sand supply from the beach. Large numbers of holiday-makers visiting beaches also have their share in damaging the dunes. Annual inspections of the dunes is an absolute requirement in planning the work of fixation.

Sand fixation in the coastal dunes today

How do we fix the dunes today? Procedures differ according to local conditions for sanddrift and the situation of the dunes. Marram grass is especially well-adapted to living in the dunes and enduring conditions of moving sand and strong winds.

We plant marram grass at a distance of 25 cm or 16 plants per m^2. Planting takes place in the autumn when the sand is moist and loose. The plants are set in a small slit made with the help of a small spade with a long, narrow blade.

The plants are taken from the natural vegetation of the dunes by cutting them with a sharp spade diagonally from the side. If the stalk has a knee, the plant is suitable - growth from the knees will begin soon after planting. Plants will grow even if partly covered with sand but new plants cannot survive when completely covered and few plants will be able to live under such conditions.

However, an established marram grass colony is able to survive when completely covered. A suitable supply of sand stimulates a vigorous growth with a density similar to that of a good field of corn.

Controlling sanddrift by the fore dune planting of marram grass is not sufficient everywhere. Often sanddrift is so violent and the erosion so advanced that it is necessary to use rows of brushwood to trap the sand. The brushwood (twigs and stems of small mountain pine (*Pinus mugo* var. *mughus*) is set in a furrow 40-50 cm in depth and the brush raised to a height of approximately 40-50 centimetres above the sand. Intended to form a good fore dune, the rows are set along the coast near the base of the dunes. The wind is able to pass through the brush but its velocity behind it is decreased, and sand will accumulate, thus forming the beginning of a new dune. Finally the whole row is covered with sand and a well-formed new fore dune is created. It now has to be planted with marram grass, capable of vigorous growth on account of a suitable sand supply. If a fore dune of greater height is required, a n... row of brushwood can be set on top of the first accumulation of sand.

In the very irregular coastal dunes with high dune crests, blow-outs and wind chan-nels are created by natural forces, and the use of brush rows is necessary to stop ero-sion. The rows are set transversely to the wind in large windchannels often 2-3 ro... wide. Here also the accumulated sandbank is planted with marram grass.

Besides planting marram grass and setting brush rows in strongly eroded dunes, it is often necessary to cut off the dunecrests with spades to level sharp edges, whe... the wind is especially violent. In large blow-outs the sharp edges are cut down and the bottom planted with marram grass. The aim of cutting down and planting is to level the dune to a certain degree in order to decrease wind influence.

Further inland than about 400-500 m (typical grey dunes) planting of marram grass to fix the sand is not suitable as the grass will not grow. Formerly heather was taken from the plains between the dunes to stabilize the areas with sanddrift. Other materi-als such as branches, tree tops and straw are mostly used now.

Today and the future

Today and in the future the problems in our dunes are associated with populatio... growth, longer holidays and a better standard of living. As greater numbers of holiday-makers spend more time on and around beaches, the dunes are exposed to more 'wear and tear'. This is particularly true of coastal dunes which, in contrast to grey dunes further inland, bear the greatest part of this traffic.

Due to the great damage caused by sanddrift, Denmark has had special laws ... connection with this problem for over 200 years, as mentioned earlier. The law was modernised in 1961. We shall briefly mention the most important provisions. Th... privately-owned protected dunes are supervised by a special sanddrift commission of three members, one from the state (the state forest service), one from the county ar... one from the municipality. The sanddrift commission decides what should be do... to fix the sand in each municipality. The state and the municipality pay. In the pro-tected dunes the owners cannot build houses, erect fences, use the dune areas f... grazing, or use the dunes for other purposes. The law is kept very strictly.

In general, people have the right to walk and sojourn in coastal dune areas, b... the sand drift commission has the power to prohibit all traffic if sanddrift is cause...

Protecting the dunes by law and the annual fixing work carried out by the sanddrift commission are the most important provisions in preventing sanddrift in the priva... ly owned areas along the western coast of Jutland today.

Afforestation

Afforestation was proposed by professor Viborg. The idea of afforestation was to bind the sand permanently, to provide fuel and to utilize areas otherwise wasted a... not used for economic purposes. However some small-scale experiments between 1820 and 1853 failed, and tree-planting was given up as impossible. In 1851 a memb... of parliament, professor Bjerring, proposed that a new attempt be made, and in 18...

the state gave the first approval of funds for dune planting and afforestation has since been continued.

In general the population appreciate the dune plantations and farmers have usually been willing to sell their dunes and heath areas to the state for afforestation.

Conditions for forestry in dunes vary greatly. In the dunes near to the coast planting is impossible on account of sand drift, salt spray and the strong wind. As a result plantations are never established closer than 1-2 km from the sea. Further inland where the sand is fixed, tree planting is possible, and here the dune plantations are situated both in the dunes and on the plains.

Conditions for tree growth are of course unfavourable in sand dunes owing to the poor soil. The nutrient content is so poor that it is surprising trees are able to thrive at all. The sand consists mainly of quartz. The average grain size is barely 0,2 mm, and the annual rainfall 600-700 mm.

It would appear that lack of moisture in the ground would prevent tree growth in high dunes, yet even though the water supply is small, it is greater than expected. Even at quite low depths the sand is always moist, probably because the dry upper layer of sand prevents evaporation.

The nutrient content of dune sand depends upon the distance the dunes have drifted, and the fertility of the ground the dunes have drifted over. The sand is especially infertile where the dunes have drifted a long way over the Litorina plain. Dunes which have drifted over more fertile ground, for instance fields of clay, have absorbed some of the clay and provide a relatively good soil for forestry. This fact has a great effect on trees growing in dunes with poor soil. On lee slopes frugal trees may grow tolerably, but on slopes exposed to the wind, the conditions for growth are very bad, because of the drying effect of the wind. Even windform trees develop only to brushwood.

The plains between the different dune systems are overgrown with heather, with grass in places. In most of the plains the ground water is close to the surface, and drainage is absolutely necessary, if the tree planting is to succeed. Drainage is only possible to a short depth, and growth conditions in the plains are characterised by ample water supply, little room for roots and a cold soil, where trees requiring a warm soil cannot thrive. The plants on the flats are also subjected to frost damage in the late spring and early autumn.

The best lands for tree planting in dune districts are areas where fertile soil, especially clay, has been covered by a layer of drift sand that is not so thick as to prevent roots from penetrating to the original ground. Such a situation constitutes a very good opportunity for forestry. The better the soil, the better trees can survive an unfavourable climate.

Tree species

As already mentioned, afforestation began in 1853. All beginnings are difficult. After some years of experiments a forestor developed a method by which the sand was covered with a layer of cut heather before planting. This kept the sand stable until the young trees had taken root. After about 10 years it became clear that only a few species were able to grow, namely Austrian pine (*Pinus nigra*), mountain pine (*Pinus*

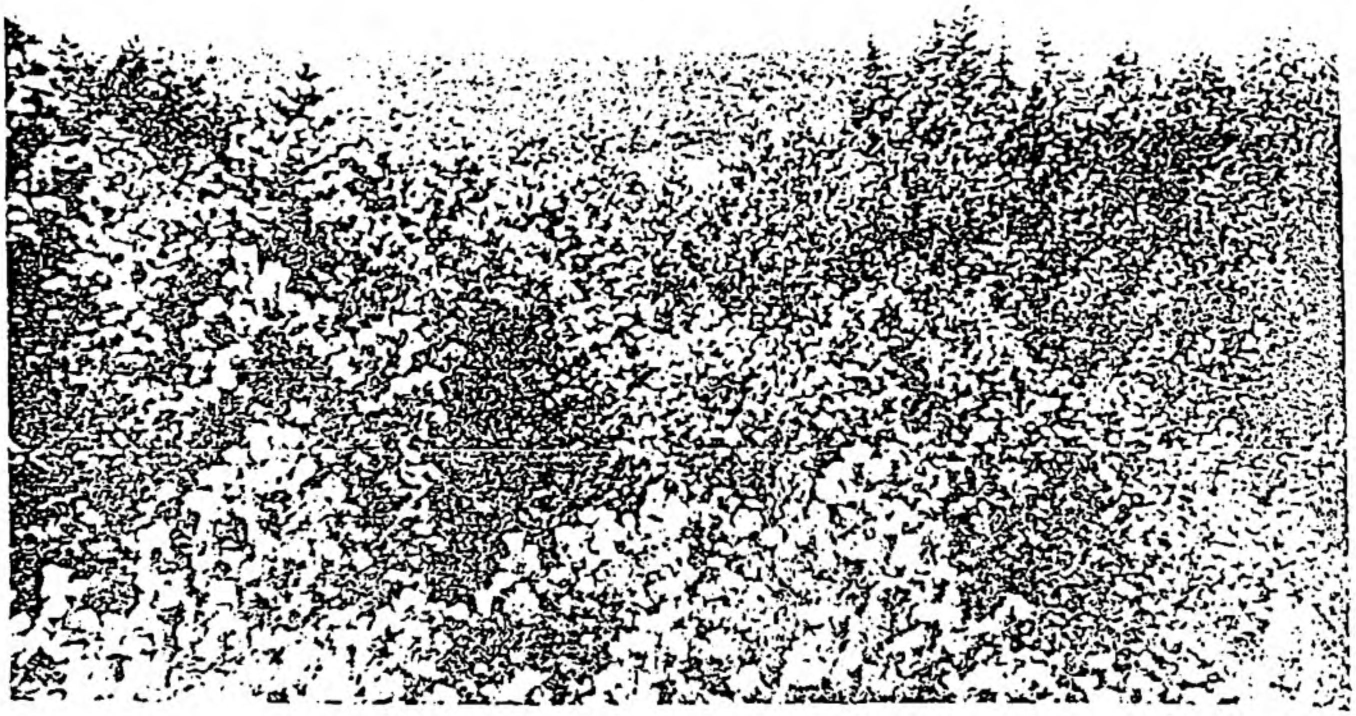

Fig. 5. Mountain pine (*Pinus mugo* var. *mughus*) planted 1895 as first generation.

mugo var. *mughus*) and Scots pine (*Pinus sylvestris*). The latter was not very successful, and the Austrian pine seemed the most promising, but after 15 years it was heavily attacked by a fungus that destroyed the young shoots so that few trees survived. This left only the mountain pine and with this tree most of the dune plantations were laid out (Fig. 5). Here and there in better and less exposed places, Scots pine, Sitka spruce (*Picea sitchensis*) and white spruce (*Picea glauca*) were introduced.

Mountain pine has been of the greatest importance for the afforestation of both the heath and dunes in Jutland. Without this pioneer it would have been impossible to obtain a succesful result. After old stands of mountain pine it is possible to cultivate more valuable trees.

When the time came for renewing the first crop of mountain pine, it became obvious that Scots pine which grows naturally in large areas of Europe, though mainly in a more continental climate, should be used. The Scots pine is also a very frugal tree, both with regard to nourishment and water supply, but here the question of provenance arises.

The Scots pine is especially susceptible when moved from one climate to another. We have made several experiments with trees originating in Scotland, Norway, Sweden, Finland, the Baltic and Germany, with the result that trees from a strictly continental climate will not thrive in Denmark, whereas trees from coastal areas in Norway and Scotland are able to grow satisfactorily in our dunes.

Pinus contorta grows naturally along the west coast of America and Canada. We have recently found good supplies in the centre of British Colombia. The production of wood is 50-60 percent greater than that of Scots pine. The advantage of lodgepole pine (*Pinus contorta*) lies in its rapid development and easy and cheap cultivation.

Fig. 6. Sitka spruce (*Picea sitchensis*) planted 1935 as second generation after mountain pine (*Pinus mugo* var. *mughus*).

but its life duration is short, being only about 40 years. It is perhaps an unsatisfactory development to plant large areas with such a tree as Lodgepole pine.

Another of our usual trees is imported from the Pacific coast of USA and Canada, namely Sitka spruce (*Picea sitchensis*) (Fig. 6). Sitka spruce is one of the most common trees in dune plantations. It is a wind-resistant tree, and even on sandy soil the yield is good and under the best growth conditions the yield is extremely high and the timber of great value, however Sitka spruce suffers from bark-beetle, rootrot and windfall.

The disadvantages of the Sitka spruce caused an increase in planting of *Abies*. Three species of *Abies* are used - the *Abies alba* from Central Europe, *Abies nordmannia* from the Caucasus and *Abies procera* from Canada.

Cultivation of *Abies* is more difficult than cultivation of Sitka spruce, because owing to its susceptibility to frost in the spring *Abies* needs shelter wood during its first 10-15 years. Fencing is also necessary as the young plants are very susceptible to wildlife damage. Denmark lacks natural coniferous trees. On the whole it is a great disadvantage for forestry both in dunes and elsewhere that it is necessary to import all coniferous trees.

Broadleaved trees are only planted on a small scale in dune plantations because of a low output although they are very popular for visitors to the plantations. Broadleaved trees are therefore planted mostly along roads and close to views and other tourist attractions. Borders of plantations may be planted with broadleaved trees to shelter conifers.

Fig. 7. Tved Church, painted 1875, surrounded by dunes.

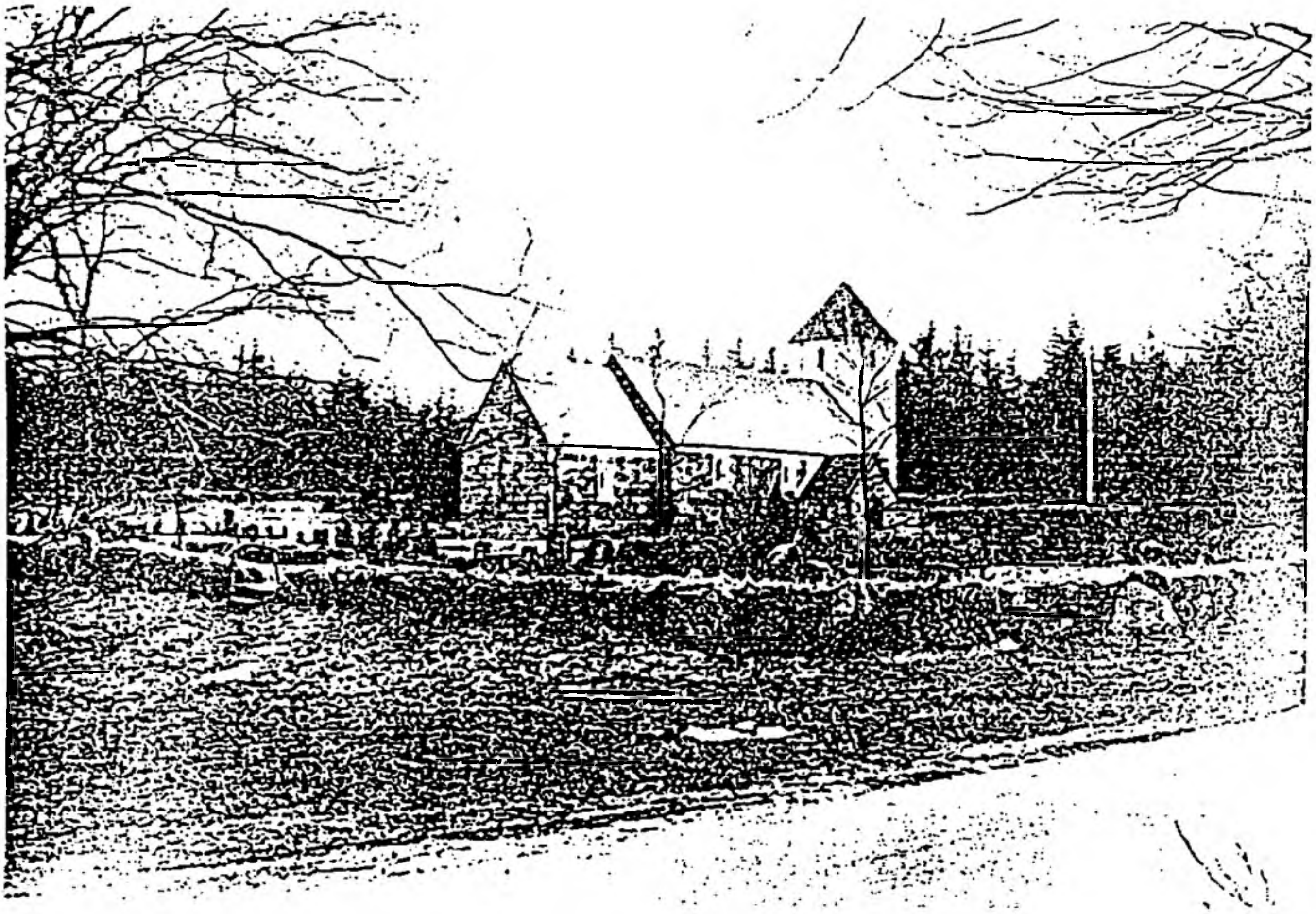

Fig. 8. Tved Church photo 1987, surrounded by forest.

By afforestation of the dunes we have achieved a permanent fixation and a good return from many of the plantations (timber, wood for fibreboard, pulpwood, chips, Christmas trees, etc.).

Results along the coast of Jutland

As a result of the programme outlined above we now have about 9,000 ha privately owned, protected dunes, for which the sanddrift commission decides what has to be done for fixing the sanddrift; and where nothing must be done without permission according to the sanddrift law, and about 21,000 ha are privately-owned dune plains, unprotected dunes, etc. that are supervised by the sand drift commission. This adds up to a total of approx. 30,000 ha privately owned dune areas.

The Danish state owns about 50,000 ha of dune area which are managed by local State Forest Districts under the Ministry of Environment and of this are 30,000 ha afforestated.

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APPENDIX E

"Master Plan for Coast Erosion Management in Sri Lanka"

MASTER PLAN FOR COAST EROSION MANAGEMENT

By

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ABSTRACT

The preparation of a National Cosatal Zone Management Plan is a mandatory requirement of the Coast Conservation Act and a major policy goal of the Coast Conservation Department (CCD), Sri Lanka. Sri Lanka has adopted an incremental problem oriented approach towards the preparation of the said plan. As an integral part of this Coastal Zone Management effort,highest priority has been given to the preparation and implementation of a Master Plan for Coast Erosion Management. Thus in 1984 it was decided to commence the preparation of the Plan in relation to which the Danish International Development Agency, DANIDA, granted assistance during 1984-1986.

The Master Plan document,is the result of many months of hard work by a team comprising the local staff of CCD and two expatriate consultants. It is also a compendium of all available information on the status of Sri Lanka's coastline. No such Master Plan can be presumed to be a definitive document for all time. It must be considered a live document that will be continuously updated as new data and information is gathered as a result of continuing research and investigations into the processes influencing the stability of the country's coastal frontier.

The document <u>defines</u> the problem of coastal erosion in Sri Lanka within the constraints of available information and <u>sets out the best possible technical approach</u> towards mitigation and the <u>capital investment necessary</u> for such action.

1 BACKGROUND

Since medieval times, when colonial powers took possession of the coasts of Sri Lanka, the coastal zone has been subject to an increasing development pressure.

Furthermore, the 1,561 Km coastline of Sri Lanka,has been subject to erosion since time immemorial. Coast erosion is therefore a major natural hazard that Sri Lanka is faced with. In economic terms the private and public costs of erosion have now reached staggering proportions.

*Kim Boye Jensen, temporarily attached to Danish Hydraulic Institute for this assignment.

The effects of erosion are mostly felt in the West,Southwest,and the South coastal sectors. These sectors are also the most densely populated and the most economically active. Major cities and towns, railroads and highways are situated in very close proximity to the coastline. Important components of the economy,such as tourism and fisheries,also depend on the quality of the coast for their sustenance.

The Coast Conservation Department of Ministry of Fisheries,Sri Lanka, is required by the Coast Conservation Act No.57 of 1981,to prepare a Coastal Zone Management Plan. The Department has identified three major concerns which are to be initially addressed in the Plan viz, Coast Erosion Management, Conservation of Natural Coastal Habitats, and Conservation of Cultural,Religious and Historic Sites and Areas of Scenic/Recreational Value.

Even though coast protection work has been carried out in Sri Lanka since 1930,the non-availability of a well researched document,providing a sound over-view of the problem of coast erosion,mitigation measures that could be adopted,and the investment required for such measures precluded the harnessing of the capital resources necessary for effective action. Therefore the Coast Conservation Department in 1984, decided to embark on a project for the preparation of a Master Plan for Coast Erosion Management. The Master Plan was prepared by the Coast Conservation Department (CCD),under a project supported by the Danish International Development Agency (DANIDA), by the provision of 32 m/m of services for two consultants from the Danish Hydraulic Institute.

The preparation of the Plan was undertaken during the period October 1984 through March 1986. The work has been carried out under the direction of S.R.Amarasinghe,Director Coast Conservation and guidance of H.J.M.Wickremeratne, Head of Planning Division,CCD.

A "Master Plan Group" with representatives from all CCD Divisions and Lanka Hydraulic Institute has met on a regular basis to discuss and co-ordinate the progress of work.

2 BASELINE DATA

Sri Lanka's coastal erosion problems are not new.The 1928 Transactions of the Engineering Association of Ceylon contains a paper by Dassenaike,a provincial engineer,arguing for the necessity of coast protection schemes to inhibit erosion.

Erosion studies conducted in the 1940s and 1950s by Kahawita resulted in similar recommendations. In the 1960s two foreign consultants, Eaton and Zeper, argued for the necessity of coastal studies that would result in positive steps to deal with the erosion problems. Their concerns were echoed by Gerritsen in the 1970s who regarded erosion control as constituting part of a larger programe of coastal resource management.

More and equally important studies which are listed in the references have been performed by geographers Swan,and Madduma Bandara and geologist Cooray.

The importance of multi-disciplinary integration of data cannot be stressed highly enough. It is the experience of the authors that any country has an unexploited fortune of valuable coastal data, that for obvious reasons should be scrutinized and 'taken in' before new,ambitious and costly,investigations are launched.

3 PLANNING APPROACH

A Master Plan Group,the "Master Plan Team" (MPT), the core of which was,2 engineers and 1 technical assistant,from CCD plus the 2 expatriate consultants was set up and given the task of preparing the plan. The MPT worked as a separate staff group under direct responsibility of the Director of CCD. This ensured that work was given the necessary high priority and that local and foreign expertise and know-how could "merge in a synergetic environment".

With due considerations to the requirements of the CZM Plan for Sri Lanka the following scope of work for the Master Plan was agreed :

- To compile,organise and synthesise available material which is required for understanding of coastal processes and identification of critical areas prone to erosion.

- To recommend and initiate such general investigations and studies which are considered required to fill gaps in existing information and knowledge.

- To formulate approaches/project concepts for works in erosion areas and recommend approaches towards implementation of recommended actions.

- To carry out a cost assessment of the protection works recommended and prepare time schedule/priorities for implementation with due consideration to funding and construction resources.

The basis for the planning has been delineation of the coast of Sri Lanka into 6 main coastal sectors, Figure 1. The sector boundaries are selected to coincide with administrative district boundaries. Interestingly, it was found that geographical, coastal and administrative boundaries to a major extent were coinciding.

The coastal erosion problems were divided into three categories.

1) Medium-term problems

These problems are known to CCD and listed in "The Sri Lanka Shore Line Status Report" prepared by CCD in 1978 and updated in 1985.

They are the problems - the solutions to which are of moderate order of magnitude - often subject to regular maintenance or may be identified to be included in the coming years' work programmes.

A number of these problems are located in key areas and whatever urgent character they may have, they should be planned and executed in a way,which will not obstruct the later implementation of an integrated total scheme for the key areas in its entity.

2) Singular Cases

These are typically problems of a certain order of magnitude with respect to economy and lay-out. At the same time, they cover a limited area only. Finally, they should not interfere with coastal processes to an extent, which will require massive studies for possible project proposals.

3) Key Areas

These areas are of morphological complexity, incorporating several characteristic morphological elements, where diverse development pressures predicate the need for complex solutions encompassing a coastal reach of several kilometers in length.

Key areas can often be delineated fairly easily, because the on-going battle between the dynamics of the coast and man's encroachment already has necessitated extensive mitigating measures. However, more virgin areas could also be nominated key areas. These being areas which are of significant importance for the understanding of coastal processes and areas which are expected to be developed or areas where a development is wanted.

The collation and review of all available data, was given high priority. Files and technical volumes have been established and structured for optimal use in the present, and in the future, to supplement the Planning document.

Based on this historical data, supplemented by additional investigations conducted as a part of the Plan preparation effort, the nature of the erosion problems, its magnitude and causes, have been identified and recommendations regarding solutions and investments required, have been proposed.

The Master Plan is based on the following principles which are used worldwide, and have in fact been given recognition in Sri Lanka through their adoption as basic planning concepts for coastal zone management.

1) The Coastal Zone is dynamic and subject to long-term and short-term changes. Therefore, any human intervention in the dynamics of coastal behaviour needs careful planning.

2) Coast erosion is a common phenomenon affecting most coastlines.

3) The best time to deal with coastal erosion problems is in the planning phase for coast development activities.

4) Coastal erosion management must never be undertaken other than as a part of a holistic approach to planning and management of the coastal zone.

5) It is neither technically feasible nor economically justifiable to prevent coast erosion at all threatened sites.

6) Any alteration to normal coastline should be undertaken only after an understanding of the system (direction and magnitude of the sediment transport system) has been established.

4 ASSESSMENT OF COASTAL EROSION

A prerequisite for the Plan has been the preparation of a quantitative assessment, of the order of magnitude of erosion. This task was challenging, but in view of all the uncertainties involved a little bit frightening. Nevertheless it is the task of the engineer, to transfer qualitative information into quantitative information.

Comprehensive studies based on comparison of accurate maps and aerial photographs, and/or decades of extensive coastal monitoring surveys, are required to determine even approximate trends of coastline movements. The general lack of such information has justified a different approach towards quantification of coastline development trends.

A survey of the Coastal Zone, prepared by Madduma Bandara for CCD 1982, contains figures for coastline development trends obtained through interviews with coastal residents along the entire coastline of Sri Lanka.

The figures given in the reference have been reworked and plotted. Subsequently, they have been compared with the relative few check measurements and studies which are available. There is reason to believe that interviews are biased in favour of erosion, and it is also known that facts from remote areas where accretion may be predominant tend to be scarce.

The team has therefore corrected the final plot, Figure 2, based on qualitative morphological information (Swan). It is the view, that the figure gives a fairly realistic overall description of "Coast Development Trends, Sri Lanka". The number of corrections and modifications introduced by the team is largest in the North and Northeast Coast Sectors.

Of the coastline of 660 Km in the West, Southwest and South sectors 45% to 55% has been identified as being subjected to erosion. The land area lost annually due to erosion has been estimated at 200,000 m^2/year to 300,00 m^2/year. Of the coastline of 900 Km in the remaining three sectors, 35% to 65% have been identified as being subjected to erosion. The land area lost annually due to erosion has been estimated at 150,000 m^2/year to 200,000 m^2/ year, however these figures are of a very indicative nature only.

It is a never ending task to correct, improve and update this coastal scenario though already at this stage it has proven its value.

The most important finding appears to be that erosion is wide spread even in areas where man's influence is minor. A fact which tells us that nature itself is the major cause of erosion although known problems caused by man, such as coral and sand mining, and improperly situated coastal structures also are reflected in the overview.

ARE THE DEVELOPMENT TRENDS OF THE COASTLINE OF SRI LANKA SIGNIFICANTLY DIFFERENT FROM OTHER COASTS AROUND THE WORLD ?

The percentage distribution of erosion and accretion in Sri Lanka Figure 3 (range shown in arrows) have been compared with World's Coastlines (International Geomorphological Union), West Coast of Denmark (Danish Coast Authority), and New Jersey South (Galvin 1983).

Figure 3 - Percentage Distribution of Erosion and Accretion

Therefore it cannot be argued that the erosion problem in Sri Lanka differ significantly from those elsewhere. Corresponding figures on accretion rates are not immediately available.

The net average erosion rates shown for Sri Lanka do not exceed 0.5 m/year. However, site specific analysis of priority areas such as Negombo, Crow Island and Hikkaduwa have shown yearly net erosion rates of more than 1 m/year.

It may then be concluded that a large part of the Sri Lanka coastlines suffer from an erosion level which corresponds to the level of medium to severe for exposed coasts of the world.

5 RECOMMENDATION FOR EROSION MANAGEMENT

Historically, the primary means of combating coastal erosion have been to construct revetments and groynes. In addition, beach nourishment has been used on a very minor scale. Most of the structures have been constructed to deal with some immediate coastal erosion problem. Poor design has led to the collapse of some structures. Incomplete understanding of coastal dynamics too has led, in some cases, to structures contributing to an increase of coastal erosion.

Basically, the structural measures available to the coastal engineer remain fairly simple in this age of high technology, although modern efficient construction equipment has changed the balance between the methods preferred.

CHOICE OF TECHNIQUES

Generally, the management of coastal erosion including the choice of a particular erosion control technique involves several levels of analysis, ranging from the most general to site-specific. Four such levels of analysis were defined in the Master Plan. For each level of analysis, several questions have been identified which are relevant to the management decisions that must be made.

Level 1 : The decision whether to engage in erosion control

Relevant Questions :What is the rate of erosion ? Is the rate increasing over time ?Are human settlements or property threatened? What is the degree of threat? What is the value of property threatened? Is resettlement or relocation a practical alternative? How important is the erosion problem relative to other coastal erosion problems ?

Level 2 : The identification of erosion control objectives

Is the objective to control local erosion, prevent local erosion, or engage in a more general erosion prevention program ?

Is it to control beach erosion, control fastland, control flooding, stablize inlets etc ?

Is the objective of control or management to halt erosion retard it, or rebuild beach or fastland ?

Level 3 : The choice among erosion control techniques

Given the objective of erosion control, is the technique to be structural or non-structural ?

If the choice is structural, what is the most relevant criterion for choosing among structural techniques ?

Is it cost only or some type of cost/benefit technique?

How broadly or narrowly will costs and benefits be cast ; ie. will the emphasis be on direct costs and benefits or will some examination be made of costs and/or benefits to specific groups such as fishermen and hoteliers ?

Level 4 : Implementation of a specific erosion control technique

When the erosion control technique is chosen, how long will a scheme program take from start to finish ?

What social, economic and environmental impacts are likely to be associated with the scheme ?

Once conditions have been improved how are "rights" to its use distributed ? What legal rights do neighbouring owners have to an accreted beach ? What traditional rights do users have ?

If there are multiple users,can agreements about how conflicting users are to be managed be established prior to putting the programme into effect : indeed making the resolution of conflicts a precondition for implementing the scheme ?

At all four levels,there has to be close,mutual understanding and cooperation between the engineers and the planners.

The Master Plan for Coast Erosion Management has been prepared with a view to the necessity of this joint approach.

EROSION CONTROL MEASURES

The following main groups of coast protection techniques adopted in Sri Lanka experience is still recommendable :

Temporary structures - Permanent "hard" structures - Dynamic "Soft" structures.

Temporary Structures

During the year, and especially during the onset of the south-west monsoon,CCD is exposed to a number of "protection requests" of an urgent and emergency nature.

Examples demonstrate the need for the development of techniques of flexible response to these problems.

In view of the importance of this issue, it was recommended that the CCD develops a preparedness for future handling of such problems. This implies :

- Management guidelines
- Establishment of stockpiles and depots of construction materials for low-cost emergency structures
- Operational plans for emergency works

The methods to be preferred and applied,should be selected among those listed in Table 1 below :

Methods	Requirements
Refill with coarse materials	- Stocks of metals and quarry run
Ballasted geotextiles	- Stock of geotextiles, rails/concrete elements etc.
Flexible gabion matresses	- Stocks of gabions filled with stones and prepared in batches
Flexible slabs	- Stock of prefabricated concrete slabs.

Table 1: Methods preferred and requirements for temporary structures

It cannot be recommended to use a too great variety of low-cost protection approaches due to risk of visual pollution and the creation of an understanding among the public, that any method is acceptable.

The approach recommended will require engineers with know-how and experience for quick assessment of urgent needs and a talent for improvisation. Furthermore a well-trained work force,which is familiar with materials and methods and which can work round the clock is required. Finally, it is evident that logistics in terms of fuel, transport, machinery etc. should be geared to fulfil the requirements, for rapid deployment.

Permanent "Hard" Structures

The group of "hard" structures represents the traditional approaches to coastal defence and protection in contrast to more modern - and environment conscious "soft" structures.

Revetments and to some extent seawalls are, by far the methods, which have been used most extensively in coast protection in Sri Lanka, in the past.

When the structures are used to protect reaches subject to long-term erosion, beaches fronting them will gradually be depleted, leaving no beach for the fishermen or for recreation.

Revetments and seawalls are still recommended to be used in the future, and are specially beneficial to "catch" the effects of extreme dynamic variations in beach sand,buffer capacity.

Breakwaters were advocated in Sri Lanka as far back as 1920s.

Their use have, however, been very limited,which is somewhat surprising considering the fact that nature itself repeatedly demonstrates the environmental and protection advantages of such constructions in natural coastal forms such as offshore islets, reefs, and rocky outcrops. They appear to meet use requirements of the fishermen better than revetments.

The Master Plan recommends increased use of these structures. They are somewhat expensive,but in several cases the material of inefficient groynes can be used in construction of breakwaters,implying at least a saving in material costs.

Groynes have upto recent times been used indiscriminately and without little prior analysis and designs in Sri Lanka - as in most other countries.

The groyne systems are - to some extent fortunately - generally inefficient, they are too short and bulky ; it is therefore foreseen that a major part of the 186 groynes existing at present, will have to be replanned, reshaped, and in some cases removed or used for breakwater construction.

Fishermen involved in fishing from open coast seem to prefer groynes as coastal protection, provided these are located off the demarcation of individual beach seine lots.

Dynamic "Soft" Structures

Erosion is basically a negative balance in coastal sediment household. A logical and widely considered and environmentally preferable beach erosion control techniques is therefore to supply sand to the balance.

Too much valuable beach/coast material has over the years been dredged and dumped in deep water - also in Sri Lanka, ie. at Tangalle Bay fishery harbour 150,000 m^3has been removed since 1964.

A UNDP team has recently visited Sri Lanka to give special advice on beach nourishment techniques. Their findings have been coordinated with and incorporated in the planning.

The implementation scheme 1986 to 1988 for Negombo envisages a beach nourishment programme of 400,000 m^3 as the best approach to meet simultaneously the requirements for beach protection and user requirements of fishermen and hoteliers.

6 IDENTIFICATION OF INVESTMENT LEVELS

Volume I of the Plan discusses in great detail all coastal structures so far built on the west, southwest and south coasts and assign a cost to them in terms of 1985 prices - Table 2.

In general terms it can be considered that a revetment provides protection to the length of the coastline it covers, and a groyne if completely effective to about three times its length. Hence it would be seen that all the protective structures so far built provide protection only to approximately 68 Km of coastline in these sectors, whereas the total erosion prone reaches in these sectors are approximately 340 Km in length.

This would provide an indication of the magnitude of the coast erosion problem in these sectors, and the impossibility of providing structural solutions for mitigating the coast erosion hazard in every reach.

Coastal Sector	Revetment Length	Groyne Length	Total Investment Recommended
West	6,000 m	2,000 m	126.0
South West	35,000 m	3,400 m	146.5
South	8,000 m	900 m	35.0
North, North-east & East			29.5
Total	49,000 m	6,500 m	
Total value	Rs. 150 M	Rs. 35 M	Rs. 337.0 M

Table 2 : Value of and proposed investment in coast protection, Sri Lanka

Hence, the Master Plan, in its identification of the required investments for erosion management has only selected reaches where an investment in structural solutions can be justified in terms of cost. The proposed investment distribution as indicated in the Master Plan is given in the above Table 2.

The pricing is based on the assumption that the required investment will be generated through local fund expenditure and that the work will be executed by local contractors. If however, the funding sources are to be bi-lateral aid, which would require the projects to be carried out within a limited time frame using the services of foreign contractors, the investment would exceed Rs.600 M.

This expenditure would in terms of the Master Plan recommendations, provide protection to a total of 155.0 Km of coastline, leaving 150-220 Km of erosion prone coastal reaches in the west, south west and south, where coast erosion will have to be accepted as a "fact of life", and developemnt activities and human settlements will have to be planned accordingly.

7 IMPLEMENTATION

The Sri Lanka Government was desirous of having the coast protection proposals for the west, south and southwest coasts implemented during the period 1986 to 1990. Hence, it was decided to propose the Master Plan implementation to available donor agencies on a district basis, depending on available funding.

It is proposed that a minor part of the Plan be implemented using available local consolidated funds. For major schemes, it is recommended to seek foreign funding.

DANIDA has already committed Rs. 210.0 M (DKK 70.0 M) for implementing the Coast Protection Schemes in the key areas, Moratuwa and Negombo. The Government of Sri Lanka as per Cabinet decision has pledged support funding amounting to Rs.39.0 M to match the above 5th Danish Loan. These funds being made available from 1987.

The following main implementation directed planning programmes were prepared during 1985 :

- Revision of CCD Plan 'Coastal Works 1985' and preparation of 'Works Plan 1986'.
- Plan for utilisation of Sri Lanka funds to match the 5th Danish Loan.
- Preparation of Implementation Infrastructure.
- Preparation of studies and investigations through Lanka Hydraulic Institute Ltd, specifically directed towards the implementation 1986 to 1988.

The implementation of the Master Plan project constitutes a 25-fold increase in the present levels of investment. The Coast Conservation Department therefore has to build up its staff resources in coastal engineering to service the needs of the Master Plan implementation and thereafter for the proper maintenance of structures built during the implementation period.

Therefore a detailed examination of the implementation organisation and its project procedures was undertaken as part of the Master Plan preparation.

The implementation will be handled by a Project Implementation Group supported by expatriate consultants.

Project Implementation Group

The recruitment of experienced professionals to service this requirement cannot be fulfilled through the normal recruitment process. It was therefore agreed to utilise a small percentage of the DANIDA loan funds for the establishment of the core project staff as it is the first project on stream.

The CCD will in addition increase its present cadre of seven engineers to provide for the recruitment of young graduate engineers on a permanent basis, so that they can gain experience by working with the project staff and thus continue to be available to the Department in the future.

In continuation of project analysis and preparation executed within the framework of the Master Plan preparation, the Project Implementation Group shall carry out pre-investment studies of projects in the west, southwest and south coastal sectors.

Design and Supervision

Design and supervision of construction for schemes of work already identified as Stage I of the Master Plan Implementation will be carried out by a selected Danish Engineering Consultancy firm.

8 EXPERIENCE GAINED AND RECOMMENDATIONS FROM THE SRI LANKAN STUDY

The experience obtained from the Plan preparation and the fact that the Plan is being implemented, provides, a background from which one could draw some general conclusions for use by other developing countries.

The Plan, although taking into consideration new concepts and ideas, has considered, the use of practical solutions to combat erosion. In the preparation stage one must consider the use of local material and resources. This would indeed mean, that certain stages could be implemented by local decentralized authorities. Such tasks should be clearly identified at an early stage and thus implementation could commence even before the total plan is finalised.

The priority usage of the coastal zone must be identified and solutions adopted so as to minimize the dislocation of such activities. As an example, the construction of groynes, and offshore breakwaters would tend to dislocate, the seine/drift fishing industry, which in turn could harm the economy of developing country.

Categorizing all erosion, problems, in an order of priority to be decided in conjunction with all concerned parties is another aspect of the planning exercise. Grouping together of such problems with reference to multifacted nature, geomorphological detail, complexity of the users etc. be done, and solutions adopted in conjunction with all such users, - Working Groups - so as to facilitate the solutions and make them acceptable.

Priority listing is an essential part of the planning process as it is near impossible to implement the entirety simultaneously. This priority should also have the approval of the "Policy Makers" and the general public made aware of same.

If foreign funding and assistance is obtained for the preparation of such a Plan, transfer of technology (both ways !) must be ensured. This would then enable the state of the art in that country to be elevated, and also ease the burden of implementation by having more trained local staff.

Investigations should be commissioned at a very early stage. Financial commitments for such investigations too should be clearly stated, so that funds could be identified and allocated, even before the finalization of the Plan. It is sometimes easy to justify a construction but difficult to justify the pre-requisite investigation to a 'Policy Maker'.

The required infrastructure for the preparation of a plan and infrastructure facilities for implementation stage must be available. Fortunately, in Sri Lanka, the mandate - as per the Coast Conservation Act,the agency - the Department and the base for carrying out the vital investigations - the Lanka Hydraulic Institute Limited was in place.

Finally, but not necessarily as the final component of the planning exercise, the levels of investment should be identified.

These should be accepted by the National Planners, and incorporated into the general financial commitments of the country. This would thus facilitate funding to be done either through foreign donor agencies or from the National consolidated funds or as the case in Sri Lanka, a combination of both.

In concluding, one may then ask ;

CAN DEVELOPING COUNTRIES AFFORD SUCH LARGE INVESTMENTS FOR COAST PROTECTION ?

Paradoxically the answer lies in a statement made by Dassenaike in 1928 : "There is no royal road to cheapness in Coast Protection"

9 CONCLUSION

The Master Plan Document must be viewed as one that sets out rational guidelines to managing the Coast Erosion hazard and not one that proposes a panacea by which the problem of the coast erosion can be solved for every reach of coastline for all time.

The preparation of the Plan required many months of hard work by a team of dedicated specialists, both from the Coast Conservation Department and the Consultants from the Danish Hydraulic Institute.

The incorporation of the integrated Master Plan Team with direct reference to the Director of the Department ensured support and priorities requried for the intensive plan preparation.

It also appeared of paramount importance that the Lanka Hydraulic Institute (LHI) already was in place and operational. Close collaboration was maintained between the Master Plan work and LHI, which could backup and supplement the data base, and perform additional investigations and try out some modern concepts developed by the Master Plan Team.

The Plan Document - which is also a compendium of all available and indispensable information on the status of Sri Lanka coastline - has given credence to the view that erosion is widespread along the coasts of Sri Lanka.

It is thus concluded by the Master Plan Team that erosion effects such a large percentage of the coast, that it is deemed impossible from a technical/economical viewpoint to 'move in' at all erosion localities. To this effect a quantitative assessment of erosion trends have been prepared which will be used to direct investigations, delineate setbacks and choice of protective approaches including the 'no-action' alternatives.

Problem identification took off from existing registers supplemented by site visits and desk studies. Early during the planning, preparation of an investment plan was given high priority. Although the required preparation of project concepts and cost estimates were at a preliminary stage subsequent revisions of the investments schedules showed how well targeted the first approach had been.

This daring initiative proved its value during subsequent phases. It implied that the dialogue between planners, administrators and politicians was established early, resulting in considerable feedback and allowed the planners to launch important supporting projects.

The investment-level is a function of distribution of local/foreign funding and local/foreign work components. The proposed levels of investments are in the rate of Rs.350 to 500 M = 20 M US$,1985 price level.

The Sri Lanka Government is desirous to have the Plan implemented. This means an upto 25-fold increase in the present levels of investment. DANIDA has allocated funding of selected projects and activities 1986-1988, corresponding to 7 M US$ matched with 1 M US$ provided from local consolidated funds.

Tender for engineering services has been completed and the detailed designs have been finalised with construction likely to commence in August 1987.

Many plans never get off the ground. The Master Plan certainly is an exception which is attributed to the spirit of close cooperation which developed between the plan makers at all levels and the political understanding of the importance of the task. The planning did not have to start from scratch. The Act, the Department and the Laboratory were in place ; however, nobody probably had expected that implementation would be on stream in February 1986, about 1.5 years from commencement of planning, in fact even before the completion of 'the Plan'.

Valuable experience has been gained by all involved in this accelerated process, the results of which have proved that 'It is possible'

ACKNOWLEDGEMENTS

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APPENDIX F

"Erosion Control with Breakwaters and Beach Nourishment"

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Erosion Control with Breakwaters and Beach Nourishment

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ABSTRACT

LAUSTRUP, C., 1988. Erosion control with breakwaters and beach nourishment. Journal of Coastal Research, 4(4), 677-685. Charlottesville (Virginia). ISSN 0749-0208.

On some parts of the Danish North Sea coast the erosion average is 3-4 m per year. The peak average erosion is 11 m per year. On those eroding locations the dune system is weakened or has disappeared leaving low areas behind the dune system open to flooding. The measures against erosion are a combination of beach nourishment and low breakwaters close to the shoreline. The flood protection is re-established by building artificial dunes that are protected by a revetment.

INTRODUCTION

During the last 100 years, structures have been built at several locations along the Danish North Sea coast. Some of those structures, harbours and major groin systems, have caused severe leaside erosion. The subject of this paper is to describe how the erosion is stopped and how the damages are repaired.

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THE EROSION PROBLEM

Figure 1 shows the Danish North Sea coast and Figure 2 shows the average shoreline

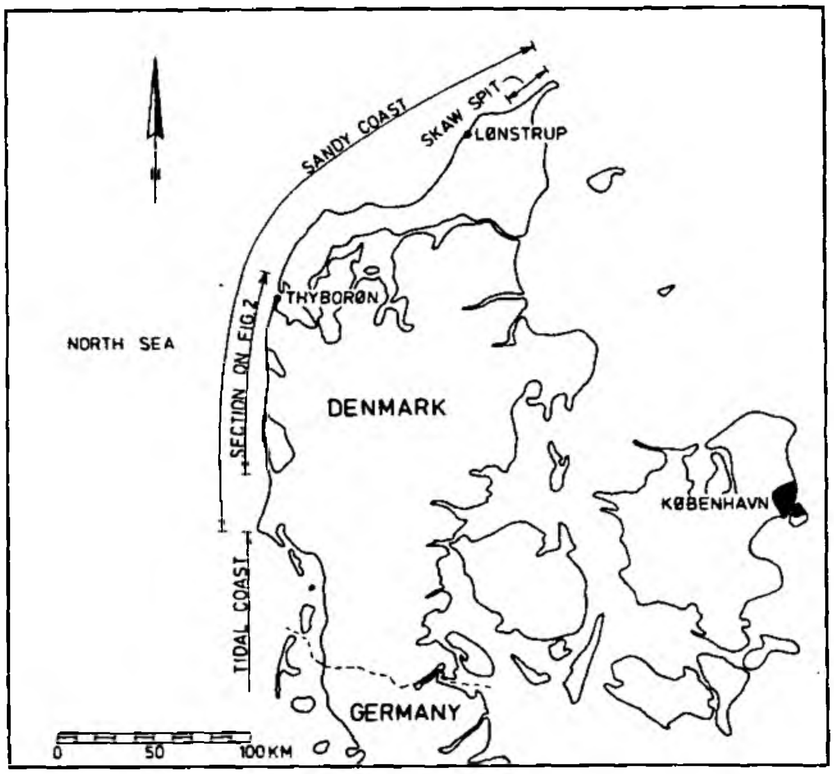


Figure 1. Map of Denmark.

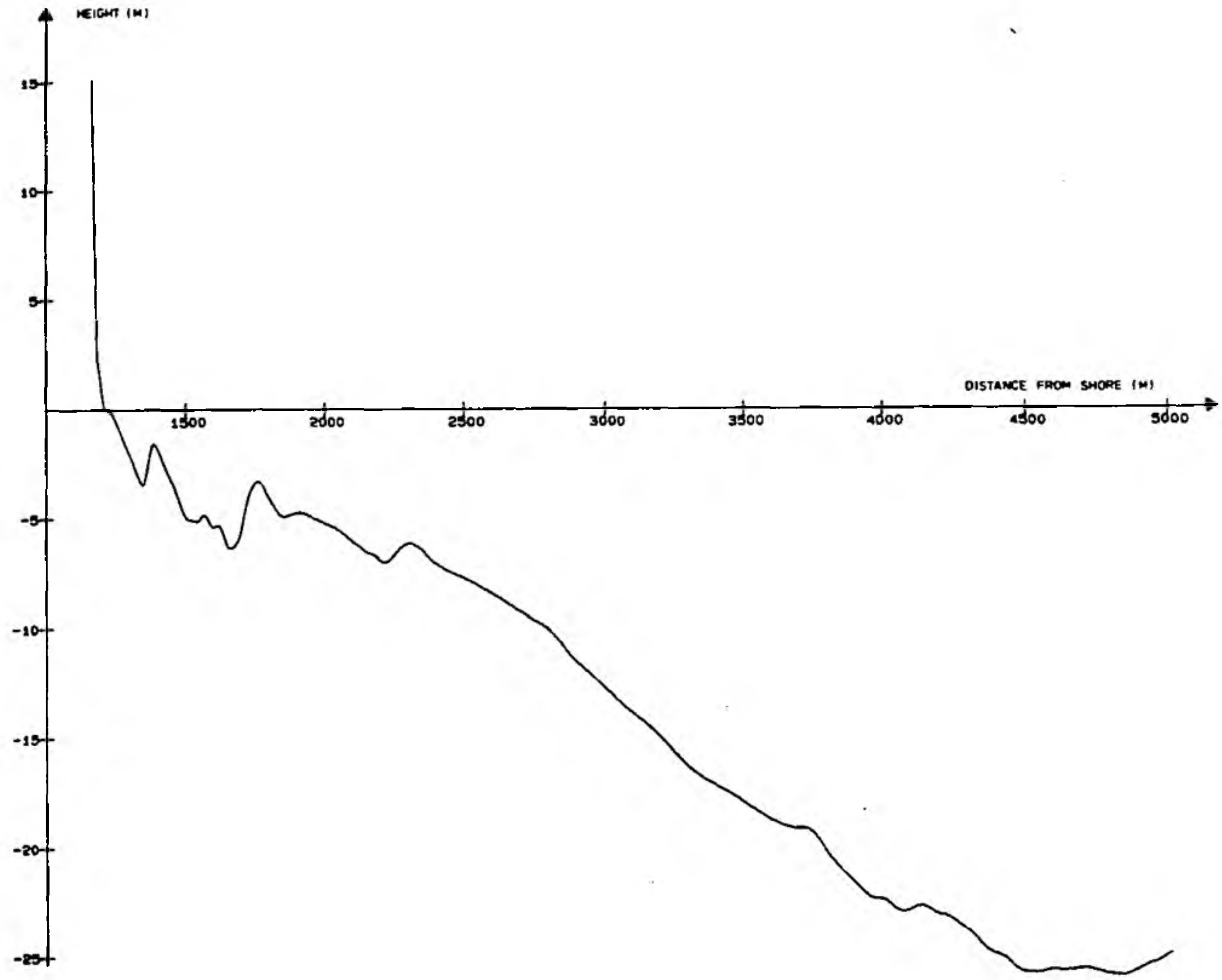


Figure 3. Example of coast profile.

Table 1. *Statistics of water level and waves in the area with most severe erosion.*

Return Period (years)	10	30	50	100	200
Waterlevels (m)	2.7	2.9	3.1	3.3	3.5
H_{os} (m)	6.2	6.9	7.2	7.5	7.9
T_{o2} (sec)	9.3	10.2	10.4	10.7	11.1

retreat in metres per year over a period of years on a part of this coast. The peak erosion of about 11 m per year has taken place on the leaside of a major groin group built in the first part of the century. On the parts with large erosion, the dune system has disappeared or is very weak which means that low areas behind the dunes are open to flooding. It is therefore necessary to re-establish the dune protection in order to stop erosion.

Erosion control is primarily achieved by supplying sand to the beach and coast. This is, in many cases, combined with construction of low breakwaters close to the shoreline. The re-establishing of highwater protection is achieved by construction of an artificial dune protected by a revetment.

WATERLEVEL, WAVES AND COAST PROFILES

Waterlevel and wave statistics in the area with the most severe erosion are shown in Table 1. A typical shore profile is shown in Figure 3.

DESIGN OF BREAKWATERS

The reasons to use breakwaters in combination with nourishment are (a) to minimize the total cost of nourishment and breakwaters and

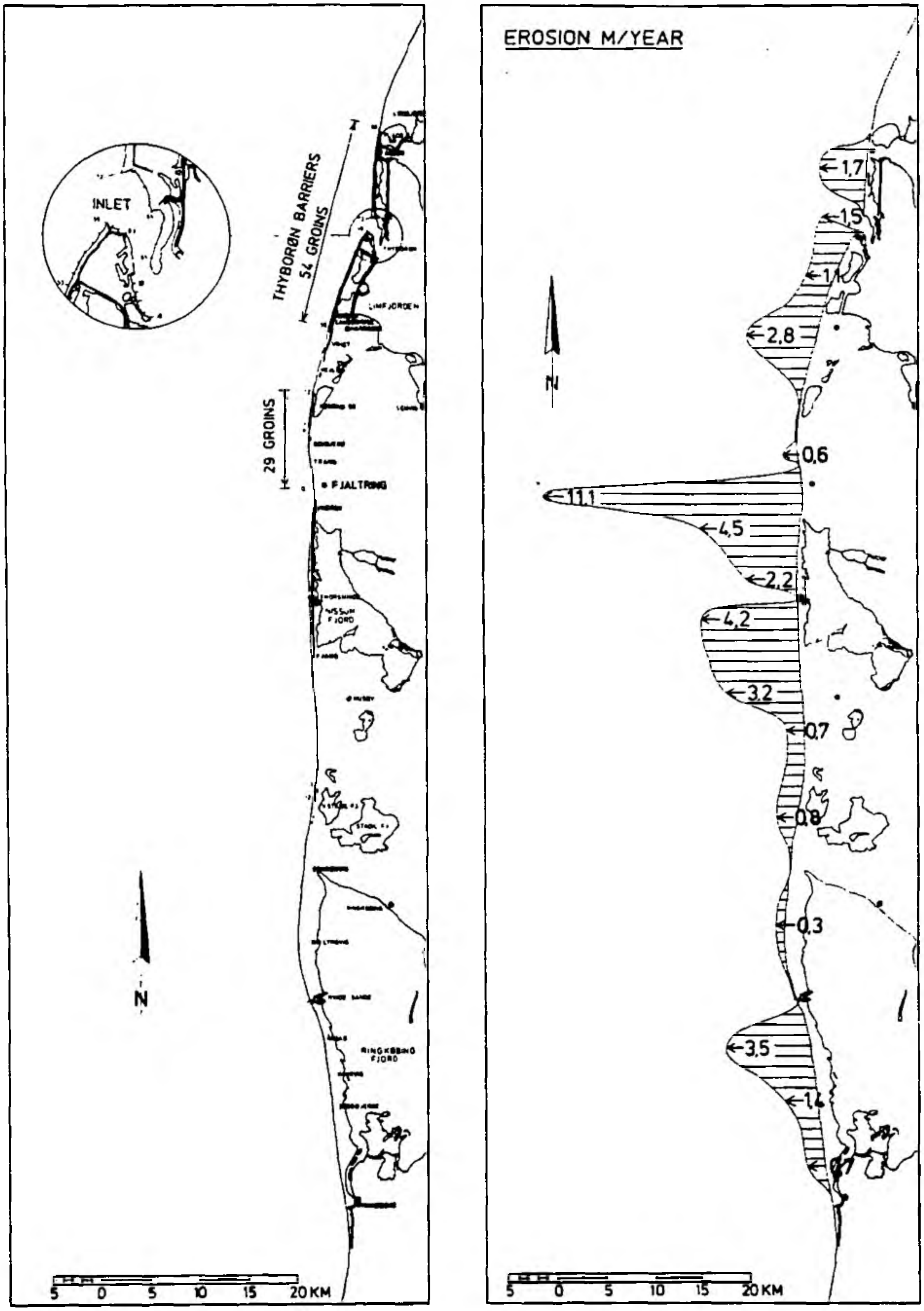


Figure 2. Average erosion, m per year.

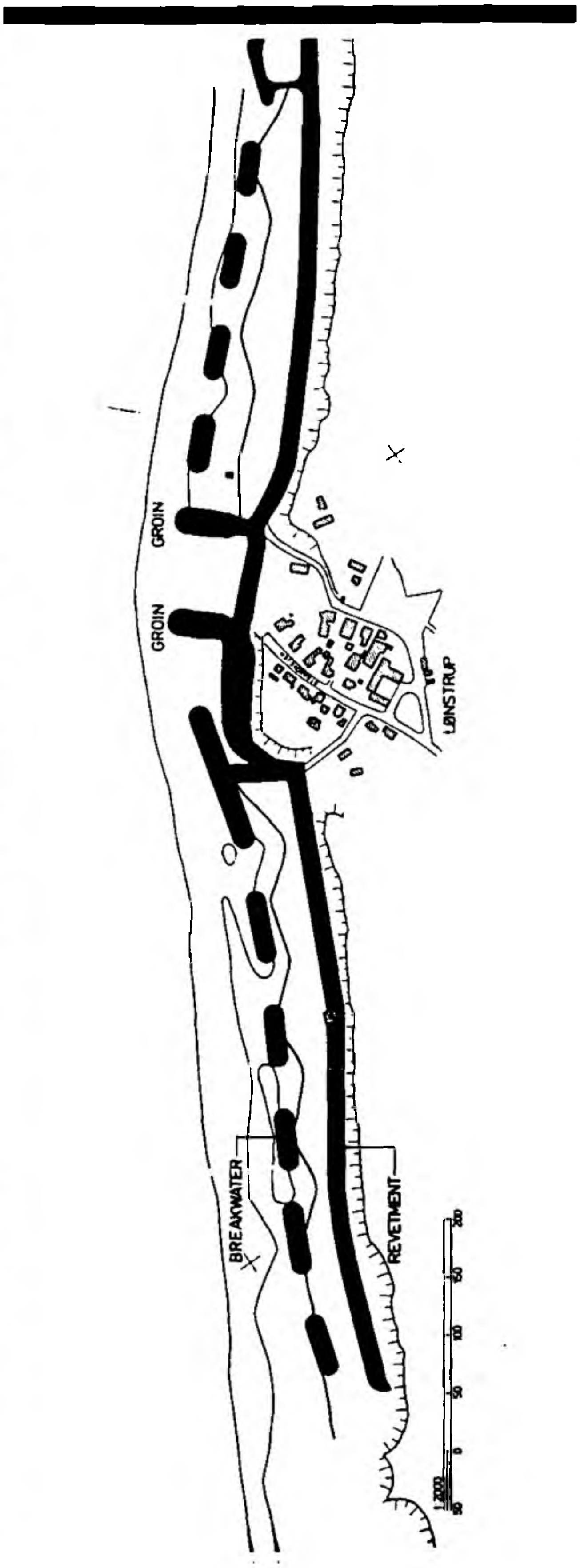


Figure 4. Group of breakwaters built in 1983 at Lonstrup.

(b) to also maintain a high level beach during rough weather.

Some economic design considerations concerning breakwaters are summarized in what follows. The most landward position in which a breakwater should be built is the shoreline in its most retreated position during the year. The seaward extension is determined by considering how far out in the profile it is possible to work with land-based equipment. The greatest depth we have been working in is 3 m and the farthest distance from the shoreline is about 50 m. Besides that, the positions of longshore bars set a limit for reasons of minimizing leaside erosion caused by the breakwaters, *i.e.* they should not effect more than the sediment transport on and close to the beach. Figure 4 shows the layout of a group of breakwaters built in 1983. Between the landward and seaward limits it is possible to optimize the position of the breakwaters. It is likely, that if the dunes are high and the costs of sand supply are high it will lead to higher and more seaward breakwaters, and vice versa. The concept is that the position and design height of the breakwaters represented by the level of the seabed and top level of the breakwaters can theoretically be estimated when certain presumptions are made, so that the total costs of shore protection are minimal. Total costs include building costs, capitalized maintenance, and nourishment costs.

The optimal design and position of the breakwaters are determined as follows:

(1) A frequency table of H_{rms} at the position of the wave recorder is calculated. The waves are transferred to deep water where the direction is set equal to the direction of the wind.

(2) A frequency table of waves just in front of the breakwater is calculated. The calculation is carried out by refraction and shoaling of each wave component from deep water to breaking. After breaking the waveheight is calculated according to (GODA, 1985).

(3) When reaching the breakwater, wave energy is transmitted through and over the breakwater. Calculations of the transmitted wave height are made according to (SPM, 1984). Only the wave component perpendicular to the beach is considered. Waves passing through the gaps are considered not to be reduced.

(4) It is assumed that the percentage of total reduction of wave energy flux per m of beach

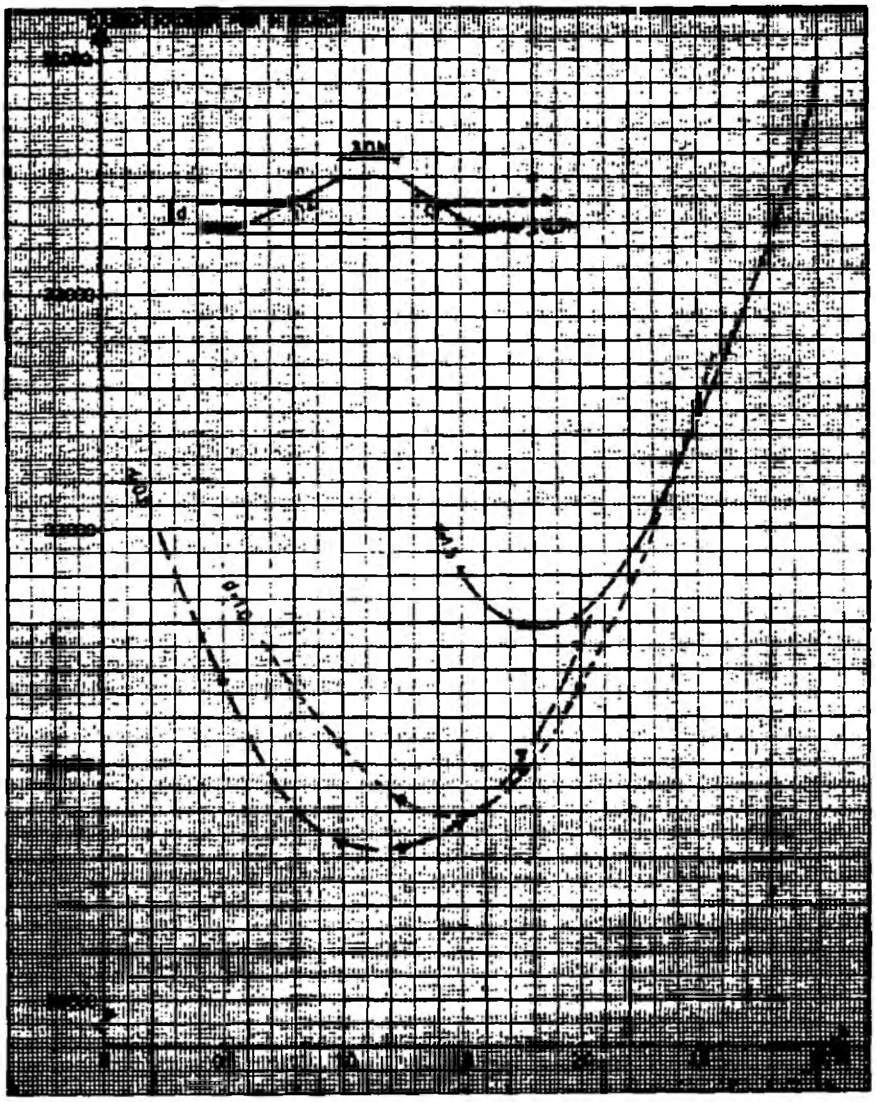


Figure 5. Design curves for breakwaters, example.

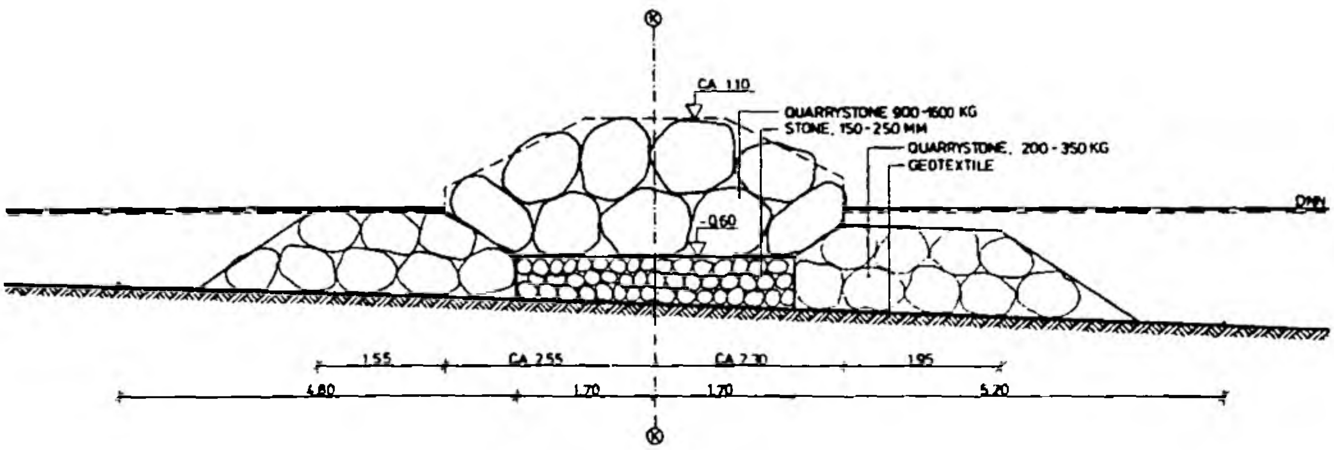


Figure 6. Breakwater cross section.

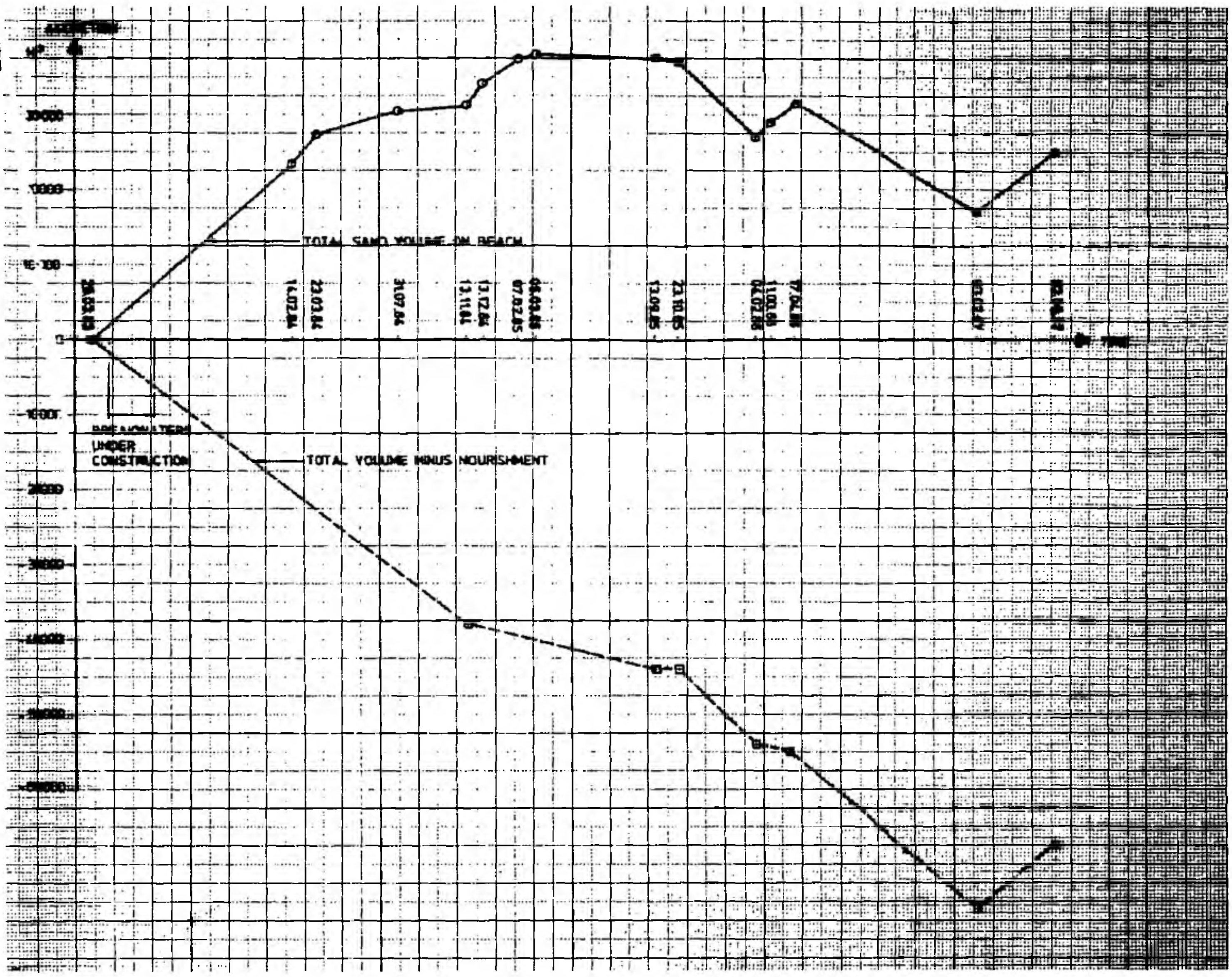


Figure 7. Effect of breakwaters on erosion.

perpendicular to the beach equals the percentage of total reduction of the erosion behind the breakwater.

(5) With that assumption, the total costs of building and nourishing the breakwaters can be calculated for different combinations of distance from the beach and height of the breakwaters. In figure 5, costs are calculated for a 20 year period.

When considering the actual positioning and heights of the breakwaters, the following considerations also have to be made: (1) recreational use of the beach, (2) profile shape and position of the bars, and (3) streamlined layout along the coast.

EXPERIENCE WITH BREAKWATERS

The first group consisting of 9 breakwaters with a length of 50 m each and a gap of 50 m was built in 1983. The cross section is shown on Figure 6. The coast where it was built was not subject to very strong erosion, only 1.3 m per year. The effect of the group has been carefully surveyed since March 1983 to verify the theoretical design procedure. The result is shown on

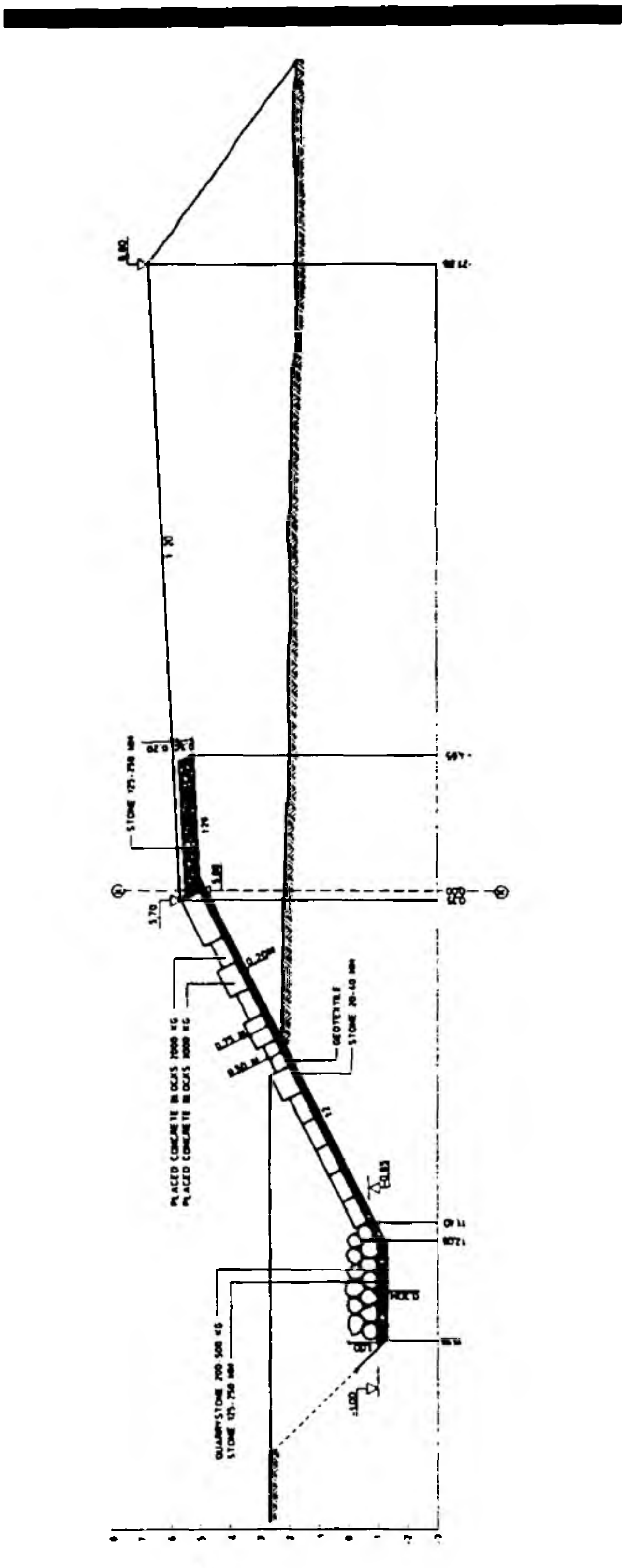


Figure 8. Revetment and artificial dune.

Figure 7. The upper curve shows the actual development of sand volume behind the breakwaters, including the nourishment. The lower curve shows the sand volume when the nourishment has been subtracted.

During the surveyed period the total erosion was 16,200 m^3 per year, on average. Before the construction of the breakwaters this erosion was 28,700 m^3 which means that erosion has been reduced to 56%. According to the theoretical design calculations above, the reduction should be to 50%. Water level statistics show that the weather in the period has been close to normal.

DESIGN OF DUNE AND REVETMENT

Dune and revetment are constructed as shown on Figure 8. Design principles are listed below.

(1) The top of the revetment is designed so that wave impact occurs on the revetment.

(2) The dune is built so wide that theoretical wave overtopping is 2%. Model tests (see below) and experience indicate that the dune width is designed too small by this method. This is partly compensated by the development of windblown dunes on top of the constructed dune.

(3) The design of the different layers in the revetment has been tested with numerical models developed by Delft Geotechnics. Some of the concrete blocks are higher than normal to reduce overtopping.

(4) The foot of the revetment is constructed on a level which is safe for undercutting.

NOURISHMENT

Nourishment is placed partly on the beach and partly seawards of the breakwater. The reasons are (a) sand stays longer in the nourished profile if nourishment is placed where it is needed (BRUUN, 1985) and (b) erosion is not the same all over the profile—peaks occur at the revetment foot and at the seaward foot of the breakwater.

The minimum nourishment at the revetment foot is calculated as shown in Figure 9. In practice, the beach nourishment is placed on the upper part of the beach because that is the best way to maintain a stock of sand for the winter storms.

The sand for beach nourishment is normally unloaded at the harbours. In Fjaltring (Figure

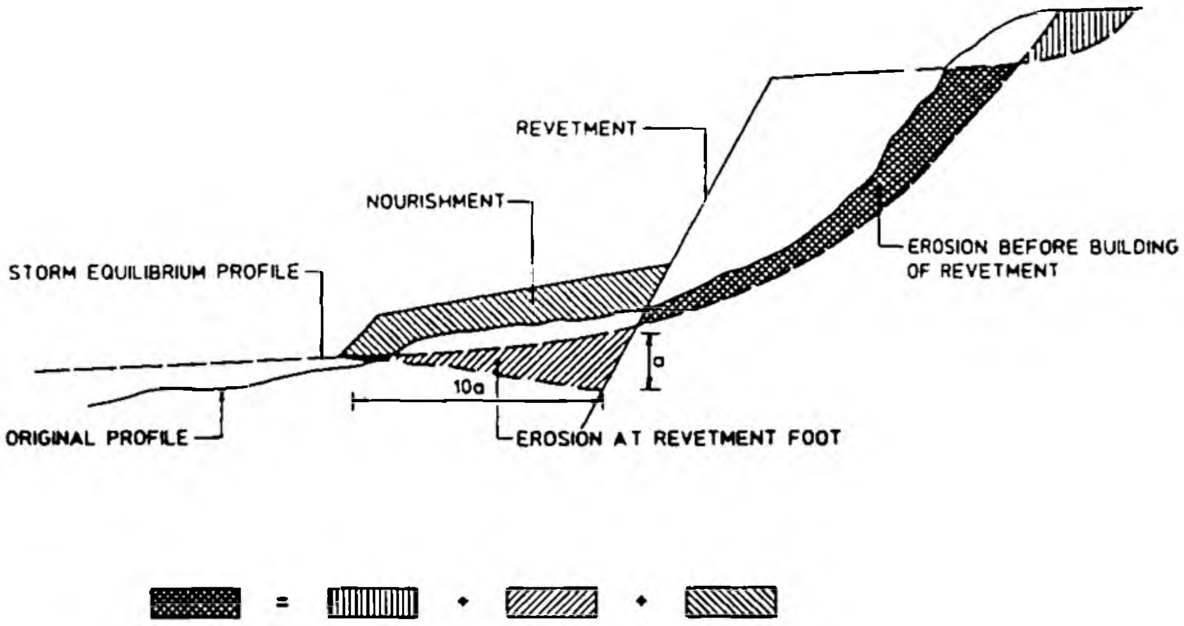


Figure 9. Erosion at revetment foot.

2) where the average shoreline retreat has been 11 m per year, the need for sand has been so high and the distance to a harbour so long that a 20" pipeline of 700 m length has been buried in the seabed permanently. Thus, each year sand can be supplied to the beach through the pipe. In 1987, 200,000 m^3 were pumped and in 1988, 400,000 m^3 will be pumped through the pipeline.

The sand is transported along the beach in lorries or dumpers. At present, we are developing a system of pipes and booster pumps which can easily be moved between the locations along the coast where sand is supplied. The idea is to use this sytem for transport along the beach instead of lorries and dumpers.

The nourishment needed on the seaside of breakwaters is placed as close to them as possible. Nourishment on the coast is performed either by splitbarges or by hoppers. In the case of hoppers, the sand is pumped over the bow. In some cases there are no longshore bars and the vessels can go close to the beach. In most cases, however, there is a bar just outside the breakwater and one or two more bars further out. Vessels can only move shoreward as far as the second bar.

In an attempt to find out how much of the sand dumped on the second bar is carried onshore by waves and currents to the inner bar we dumped 240,000 m^3 on the second bar in spring 1983. 80,000 m^3 were dumped on each of 3 positions along the coast. One position was just in the leaside of the groin system which had caused the strong erosion and the two other positions were 1 km and 3 km further down line. The main result was that the amount dumped just in the lea of the groin group was carried onshore to the inner bar. The sand dumped at the two other positions remained on the second bar. These results can be used to plan the nourishment from the sea side of both the inner and the second and third longshore bars.

SUMMARY

By the end of 1987 about 8,700 m of revetment and 80 breakwaters (of length 50 m) had been built to stop erosion and re-establish flood protection along strongly eroding beaches. In 1987 the total yearly nourishment of the Danish North Sea coast will be about 620,000 m^3. A method for designing the breakwaters and calculating the necessary beach nourishment, based on reduction of the wave energy by the breakwaters, is presented. Survey results show good agreement with theory.

APPENDIX G

"DCA West Coast - General Information"

Danish Coast Authority (DCA)

DCA is an institution under the Ministry of Public Works.

DCA was founded on November 1st 1973 to carry out a number of tasks hitherto the responsibility of the Department of Hydraulic Engineering.

DCA acts as the Ministry of Public Works' technical advisor on all matters relating to installations in Danish territorial waters, such as dikes, embankments, dams, road bridges and tunnels, yacht harbours, landing-stages etc.

DCA has full power of approval with respect to coast protection installations and the laying of certain pipelines and cables in territorial waters.

DCA is responsible for constructing and maintaining coast protection works established by the Government, and for constructing or supervising the construction of any other coast protection works along the west coast of Jutland which receive Government grants. Furthermore DCA supervises the maintenance of certain navigational channels in Danish waters and provides other Danish authorities with technical advice in matters concerning coast protection, the extraction of raw materials such as sand and gravel, etc.

DCA is in charge of the storm surge alert organisation which monitors the Wadden Sea area and the highly exposed stretch of coast between Holmsland and Thyborøn.

DCA has its administrative headquarter in Lemvig and it has a series of workshops and depots along the North Sea Coast, in Agger, Thyborøn, Ferring, at Blåvand and at the Rømø causeway.

The total number of staff is the equivalent of 120 full-time employees, 45 in administration and 75 in construction and related areas, including the survey section.

The administration is subdivided into a technical department and an administrative-financial department, each headed by a chief engineer.

The technical department consists of 2 planning and project sections, a computer section, a drawing office and a survey section.

The administrative-financial department has a section which deals with all aspects of the installations in territorial waters, a section which carries out or supervises contract work and a secretarial and accounts section.

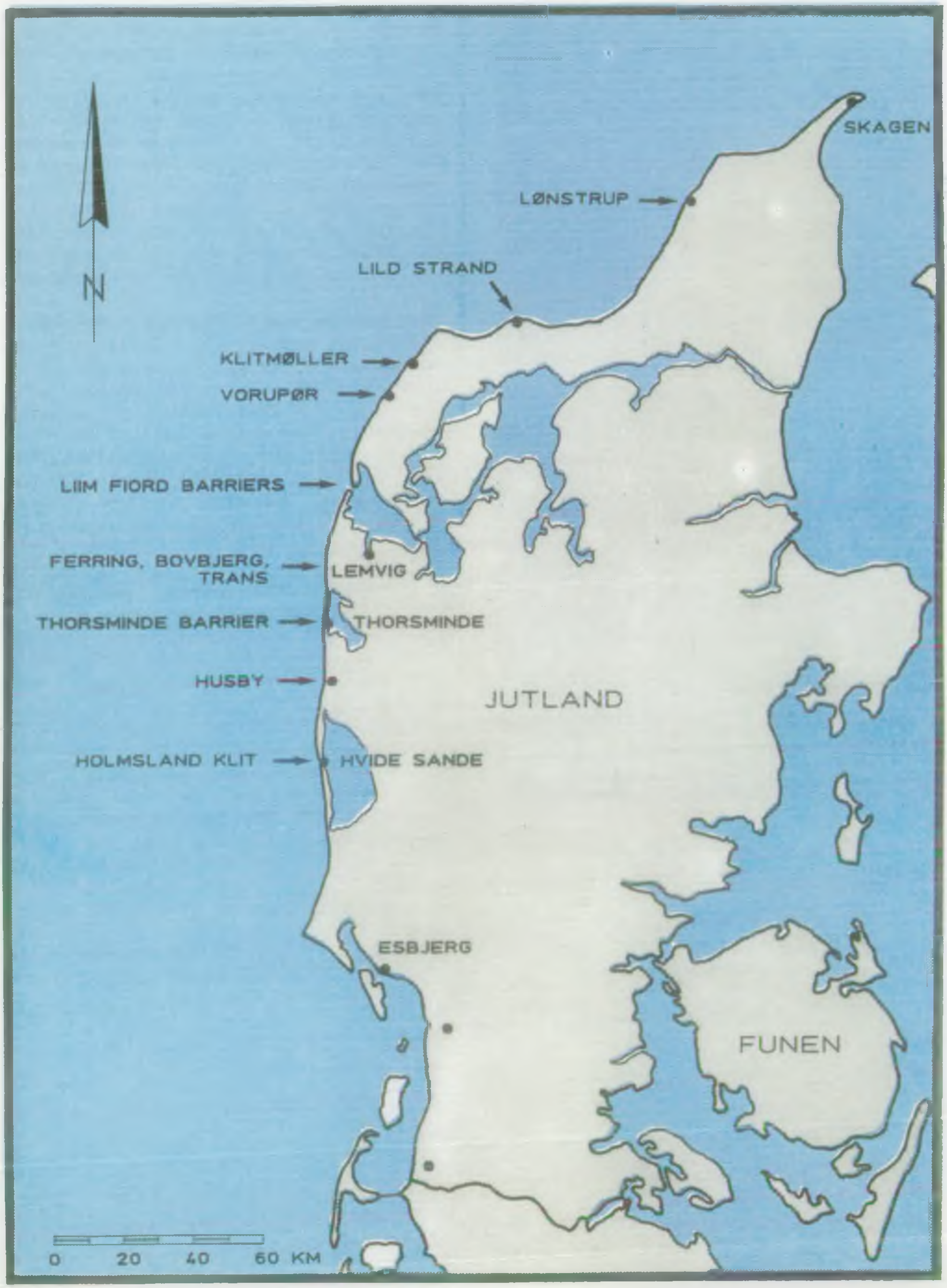
The various depots along the North Sea Coast carry out construction and maintenance work on the coast protection installations between Flade Lake, north of Agger, and Langerhuse at Harboøre, a stretch of coast which includes the Thyborøn Inlet. They also cover the coast between Ferring Lagoon and Mærsk, the coast at Blåvand-Oksby and strips along the Rømø causeway. In addition, coastal protection is also carried out with aid of Government grants on other parts of the coast in Ringkøbing county.

The survey section carries out a line survey of the inshore waters from Skallingende to Skagen. Soundings are also made in a number of navigational channels throughout the country, the most important of which are the channels in the Lim Fiord and the Grønsund and Bøgestrøm channels.

DCA uses a large number of private contractors for channel dredging and for coast protection construction work, both on its own account and on projects where it acts in a consultative capacity for local councils operating on Government grants.

DCA had for 1988 a budget for operating expenses (including maintenance) of 42.2 million D.kr., while the construction budget was 76 million D.kr. of which the Governmental share was 54 million D.kr.

General map


N
SKAGEN
LØNSTRUP
LILD STRAND
KLITMØLLER
VORUPØR
LIIM FIORD BARRIERS
FERRING, BOVBJERG, TRANS
LEMVIG
THORSMINDE BARRIER
THORSMINDE
HUSBY
JUTLAND
HOLMSLAND KLIT
HVIDE SANDE
ESBJERG
FUNEN
0 20 40 60 KM

Lønstrup

Lønstrup village is situated behind Lønstrup Cliff, which is formed through erosion from the North Sea.

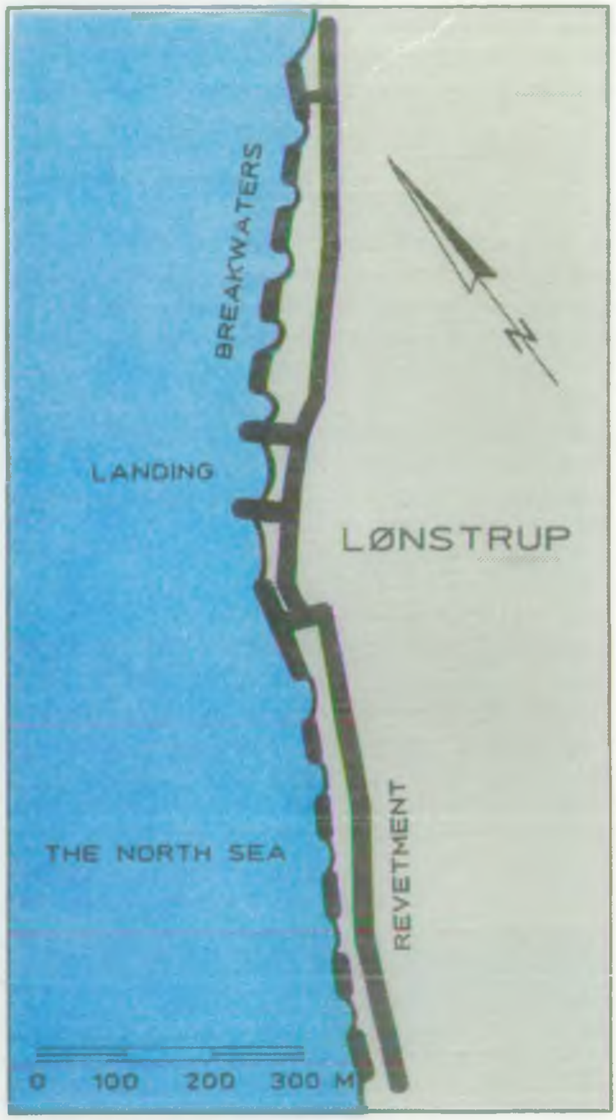
Formerly a rather busy fishery took place from the beach at Lønstrup. Therefore two groynes were built in 1923 to secure the landing site on the beach. During a storm on the 24 November 1981 the landing site was nearly destroyed. The remaining cliff was standing only a few meter in front of the house for the rescue boat.

A project for protection of the area against attack and erosion from the sea was started before the November 1981 storm. This project was readjusted and during 1982 - 83 the present coastal protection was constructed. A revetment with top-level +4.5 m DNN was built at the foot of the cliff, and 10 detached breakwaters were built at a waterdepth of 1 meter, cfr. drawing.

Around the landing site - today only used by leisure fishermen - 2 new groynes were constructed. Heavy quarry stones from Norway were used for all those constructions.

Furthermore the beach and the landing site were nourished with 100,000 m^3 of sand. The total initial costs were 18 mio Dkr. incl. VAT, of which the Danish Government paid 50%. The remaining amount was paid jointly by the county and the local authority.

It is necessary to nourish the beach artificially with 20 - 25,000 m^3 of sand every year in order to maintain the projected level of the beach.



General map

Beach landing sites

Since early times it was necessary for the rural population - in particular along the North Sea Coast - to supplement living with shore fishing. By this several beach landing sites grew up. Due to growth in the trade by small wessels - especially between Norway and Denmark - some of these landing sites became more organized and by economic support including beach landing systems they developed to communities, which largely made living by fishery.

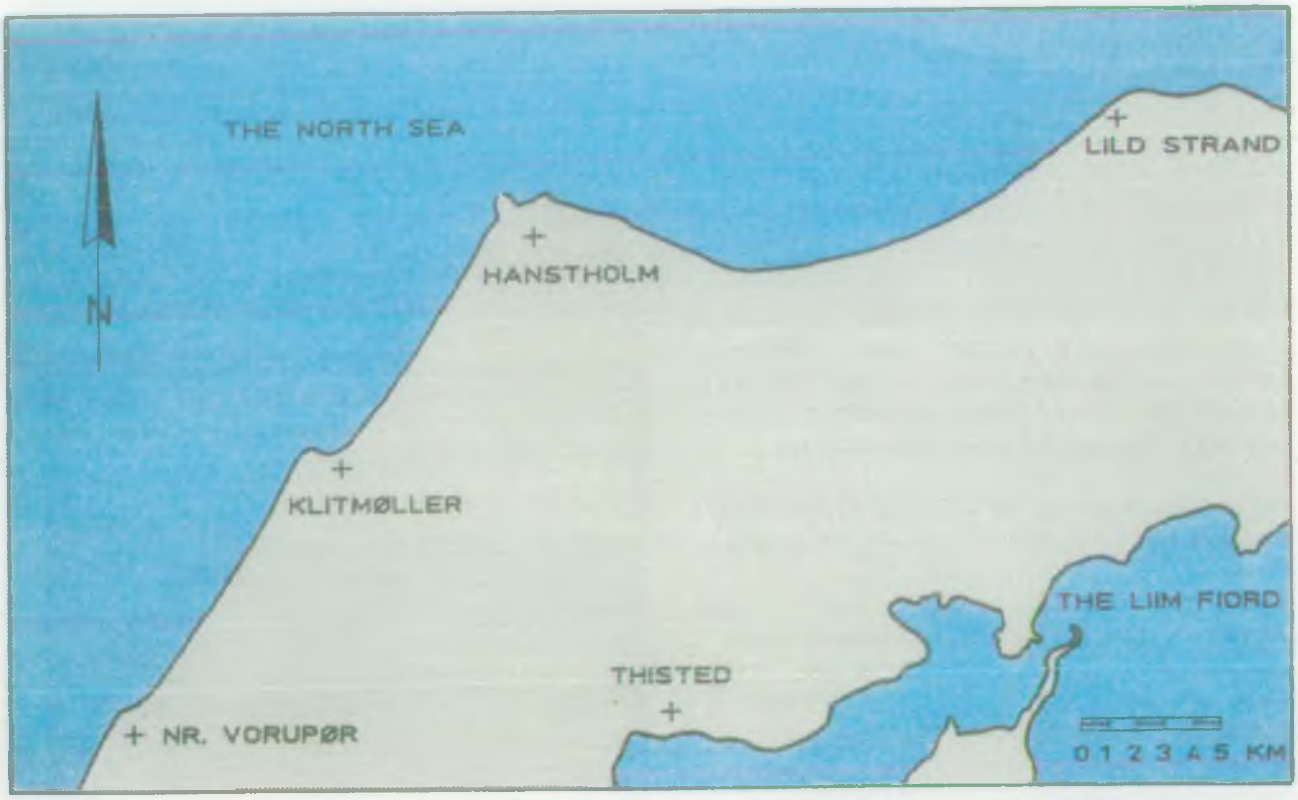
After completion of the Fishing Harbours at the North Sea Coast, latest Hanstholm Harbour in 1967, it was expected that the fishermen from the beach landings would move to the harbours and perform their fishery from there.

However, this special form of fishery, was still attractive to many also young fishermen and for the last twenty years The Government again have supported local initiatives concerning shore fishery and related coastal protection. The Danish Coast Authority have carried out coastal protection at the beach landings Vorupør, Klitmøller and Lild Strand.

COASTAL DEVELOPMENT.

Along the coast from Nr. Vorupør to Lild Strand, see map, the resulting littoral transport is going north and east. It is characteristic for the coast, that it between "hard points" at Vorupør, Klitmøller, Hanstholm, Lild and Bulbjerg have formed festoon shaped bights. The "hard points" are formed in chalk and are therefore relative resistent against erosion. The chalk is overlaid by marine sand formations and dunes.

During the last centuries the coast has been relatively stable, even though there locally have been considerable movements of the coastline. Typically there has been accreation to the south of the hard points and lee-side erosion to the north.



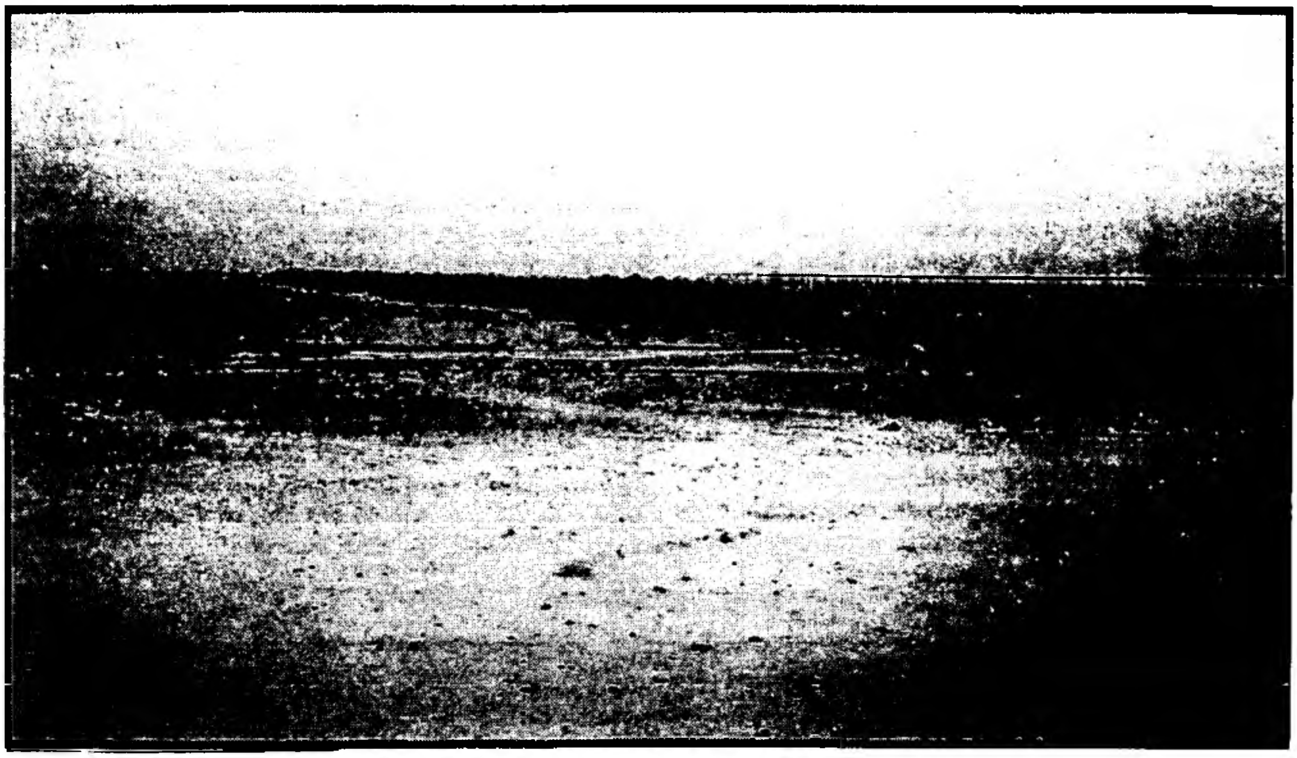
General map

VORUPØR

During the years 1904 - 12 a 310 m long breakwater was built primarily to give shelter to the landing operation on the beach. To reduce the interaction with the littoral transport the breakwater was constructed nearshore and perpendicular to the coastline and it was connected to the beach by a pile bridge. Since the breakwater was finished there was in several occasions a necessity to adjust the gap between the beach and the breakwater.

In 1975 - 77 the breakwater was completely renovated after a project worked out by DCA.

The top surface was leveled with 4-ton rectangular concrete blocks and the slopes were covered with 4-ton dolos blocks. The pile bridge was placed by six steel span supported on circular concrete piers. Around the piers were laid small dolos blocks to break the waves and prevent damage on the bridge deck from wash.



Vorupør Breakwater

KLITMØLLER

In 1909 the fishing steamer Lepanto was stranded in front of the landing site. A favorable tombolo sanding up followed and the fishermen bought the wreck and filled it with concrete.

Later on it was tried to stabilize the beach further by construction of small groynes.

A severe storm in 1981 damaged both buildings and the landing site and showed a need for a storm surge protection in front of the village.

The government decided to compensate the damages and in 1982 a 340 m revetment was built after a project by the DCA. It was constructed by 2.5 ton concrete blocks with top level +4,5 m and a front slope 1:2.

Klitmøller, revetment

LILD STRAND

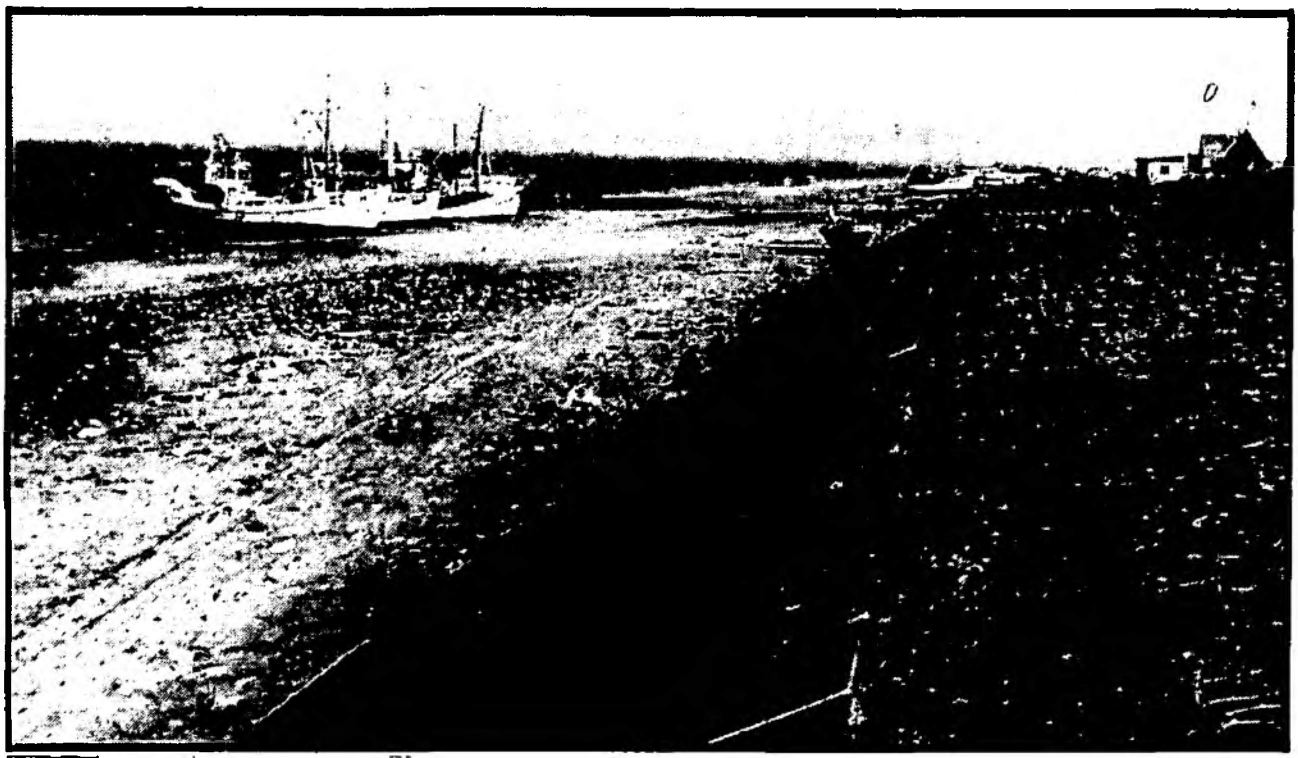
The landing site is sheltered by a chalk reef about 2 km off the coastline and therefore there have been no need for a breakwater.

In the 1960ties an intensive shingle mining activity took place on the surrounding beaches. It caused a heavy erosion, which continued after the mining activities were stopped in 1970 by preservation of the beach.

The fishery had stopped due to erosion of the beach and damage on the beach landing system and auction facility before the preservation was set in force.

In the following years the beach stabilized and in 1981 the fishery was restarted. A few weeks after restart a heavy storm caused great damage. After pressure from the local community the Government in 1983 subsidized construction of a storm surge protection after project by the DCA. The project included a 470 m revetment built by 3 ton and 4 ton rectangular concrete blocks.

In front of the machinery house the revetment was constructed with a smooth frontslope covered with sand for better operation of the haul system. The remaining part was built with toplevel +5.0 m and frontslope 1:2.



Lild Strand, revetment

The Thyborøn Barriers

History

In the Viking Age open water connected the Liim Fiord with the North Sea. Around the year 1100 the estuary sanded up and for more than 700 years the fiord was closed at its western end by a low isthmus of sand. Then as now this tongue of land was exposed to the force of the sea with the result that the coastline moved steadily eastwards. Not infrequently the sea would flood over the isthmus, cutting the road between Ringkobing and Thisted.

In the 1825 the sea broke through the isthmus south of Agger. By 1833 the Agger Inlet had become navigable for small ships, but by 1875 it had sanded up again. However, just before this (1862) a severe storm broke through the isthmus at Thyborøn, creating the present Thyborøn Inlet. The Thyborøn Inlet has been navigable since 1868, and there has been an open channel between the fiord and the sea since 1825, with two tongues of land commonly known as the Thyborøn Barrier and the Agger Barrier.

The Thyborøn Inlet has been of major importance for maritime trade in the western Liim Fiord and for the fishing industry.

Groyne construction.

As early as 1840 attempts were made to protect the isthmus from sea floods by building small dikes between the dunes. However, this proved insufficient protection and in 1874, after a new series of floods, the Government set up the first West Coast Commission to:

1. *Consider whether the sea's incursion could be checked.*
2. *Suggest suitable measures.*
3. *Evaluate whether the benefits justified the costs.*

In the ten years it existed the Commission was responsible for building 12 groynes at Ferring Lagoon, 26 groynes on the Thyborøn Barrier, 5 groynes at Flade Lake and a number of dikes.

The Commission's final proposal was that a total of 99 groynes be built from Bovbjerg to Flade Lake and that dikes be built wherever necessary. The Commission also recommended that the Thyborøn Inlet be kept open.

In the following years, 1890 - 1910, most of these measures were carried out. The groynes were built at 380 metre intervals and each groyne was 190 metres long.

The groynes brought about a considerable decrease in the rate of coastal regression.

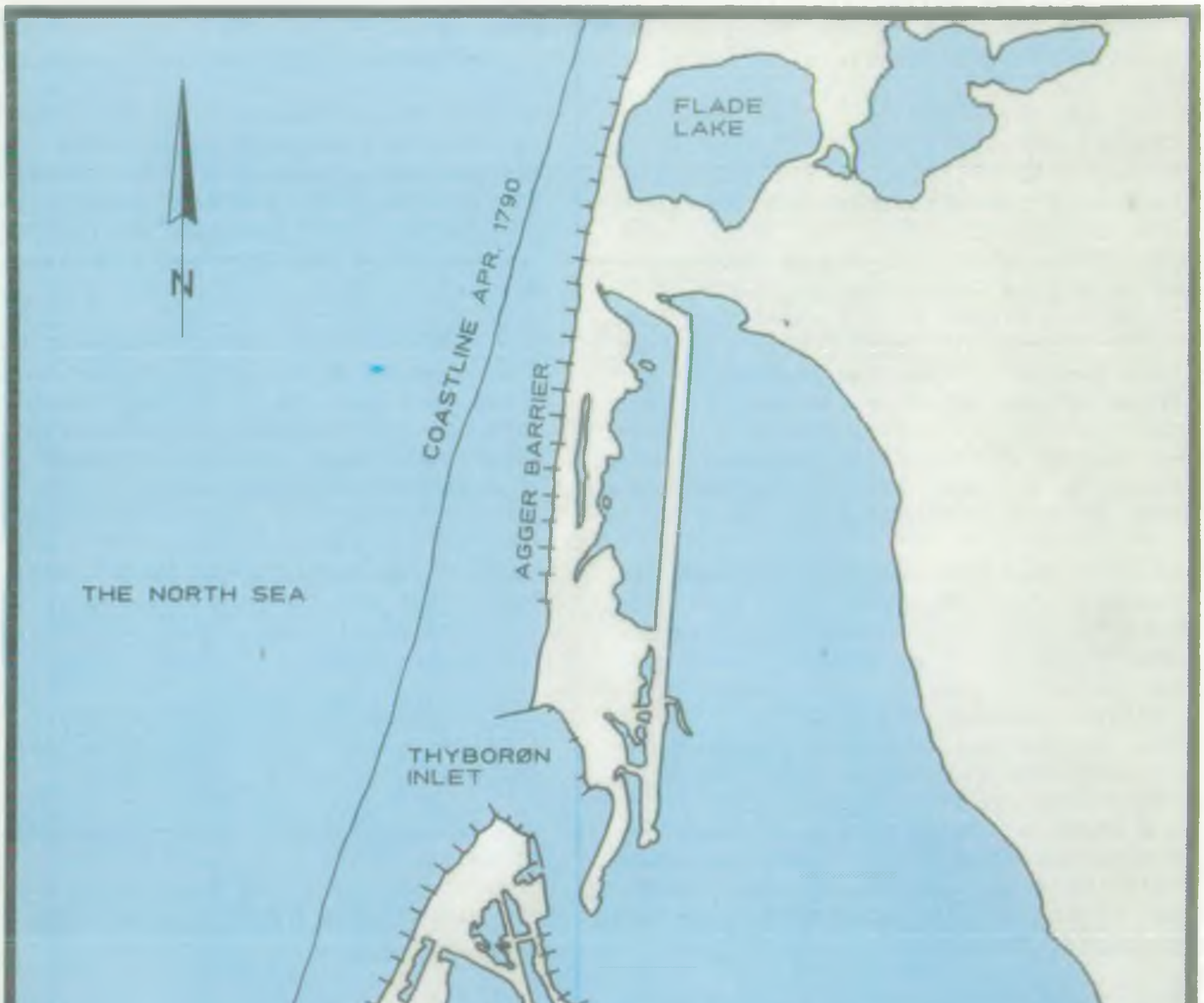
In 1915 work started on the harbour at Thyborøn.

The Catastrophe Theory and the Thyborøn Law.

Even though the groyne constructions underwent continual improvement, the groynes could not prevent erosion. The groynes had to be lengthened at their land ends while their heads had to be abandoned, and the dikes were gradually moved east. The shore profile became steeper and sand was lost at the rate of about one million cubic metres per year, carried through the Thyborøn Inlet and deposited on the Fjordgrund (tidal delta) in the Liim Fiord.

The steepening profile of the coast created widespread concern that the protection afforded by the groynes would be completely undermined. In 1946 the Danish Parliament passed the Thyboron Law, designed to protect Thyborøn Harbour and the town itself by:

1. *Building safety dikes for protection in the event of a breakthrough of the barriers.*
2. *Closing the Thyborøn Inlet by building a dam with a lock for shipping and a drainage sluice to*



General map 1:100.000

control salinity in the fiord.

3. Building two large jetties to prevent Thyboron Harbour from sanding up.

In the following years point 1) was carried out, whereas points 2) and 3) were shelved in the face of local resistance to closure of the inlet and "diverse technical criticisms of the Catastrophe Theory".

Thyborøn Law repealed

Critics of the theory pointed out that a new state of equilibrium was developing in the shore profile of the barriers, and that there was therefore no danger of the groyne system breaking down. Furthermore there were now safety dikes, so that the time was right for a new examination of coast protection measures, for example carrying out model tests in Holland. Finally a number of new arguments were put forward regarding the water levels in storm surges.

In 1968 a committee published a new report which recommended:

1. Repealing the 1946 Thyborøn Law, in other words keeping the Thyborøn Inlet open.

2. Protecting the population of Thyborøn by reinforcing the dikes.

3. Monitoring coastal developments with a view to carrying out the necessary protective measures.

On the basis of this report the law was repealed in 1970, even though it was foreseen that parts of south Thyborøn would have to be given up in years to come.

Asphalt coating of sea dike at Thyborøn carried out 1974-75

The present situation.

The sea dikes at Thyborøn are reinforced with asphalt concrete and the shore profile is maintained by nourishment.

On the barriers the necessary repairs are continually being made to the groynes and the old sea dikes.

At Flade Lake the dike is reinforced with a revetment of concrete blocks and in continuation of the groyne system a series of detached breakwaters are being built.

Corresponding base protection and breakwater construction is being carried out at Langerhuse, south of groyne 30. Here the beach is also being maintained by nourishment.

Ferring, Bovbjerg, Trans

The Ferring region represents the birthplace of the Danish State´s efforts to protect the west coast of Jutland from erosion.

In the winter of 1873 - 74 severe storm surges caused considerable damage to the West coast. As a result, a commission was set up on February 23rd 1874 to look into "Various Conditions Prevalent on the West Coast of Jutland".

On the recommendation of the commission a number of groynes were built as an experiment in the following years. Groynes 1 - 3 were established in 1876, and numbers 4 - 12 in the period up to 1883. The first groynes were placed at intervals of approximately 90, 180 and 375 meters, so that different spacing effects could be observed.

The commission´s report of November 19, 1883 concluded that the 12 groynes already built should be reinforced, and that later on groynes would have to be built at the cliffs of Bovbjerg to prevent the low shore at Ferring Lagoon from developing into an exposed promontory. The report also concluded that future groynes should be built with a spacing of 375 m.

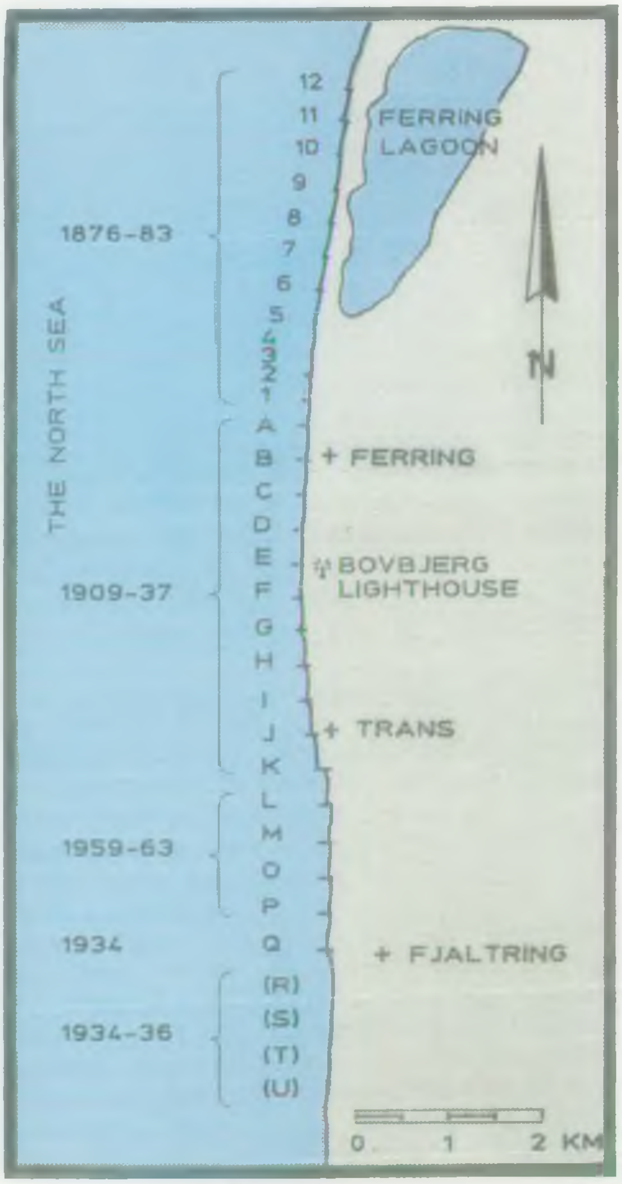
Groynes A - K were therefore built at Bovbjerg in the period 1909 - 37.

In the following years the unprotected stretch of coast between groyne K and the group of groynes further south, Q - U, suffered severe erosion due to the strong leeside effect. In response to appeals from the local population the decision was made to build groynes between K and Q. Groynes L, M, O and P were built in the period 1959 - 63.

Building these four groynes immediately stabilized the coastline between K and O, and as anticipated moved leeside erosion from the area south of K to the area south of Q (see section on Dybå - Fjand).

Building the various groups of groynes in the Ferring-Bovbjerg-Trans region has significantly reduced and in some places completely stopped coastal regression in the area. In the northern section of the protected area the coastline has only moved back about 50 meters in the last 100 years, and most of this regression took place prior to 1930; since then the coastline has been highly stable.

Leeside erosion, means that the cliffs behind the northern groynes at Ferring Lagoon will have to be reinforced. It is estimated that in future years only maintenance work will be required on the remaining part of the section from A to O. In recent years various structures have been built on section P to Q to reduce leeside erosion (see section on the Thorsminde Barriers).



The Thorsminde Barriers

Geological Structure

The Thorsminde Barriers are believed to have been formed by the regression of the Stone Age Sea depositing material eroded from neighbouring stretches of the coast. The sand dunes which have built up on these marine deposits are comparatively recent.

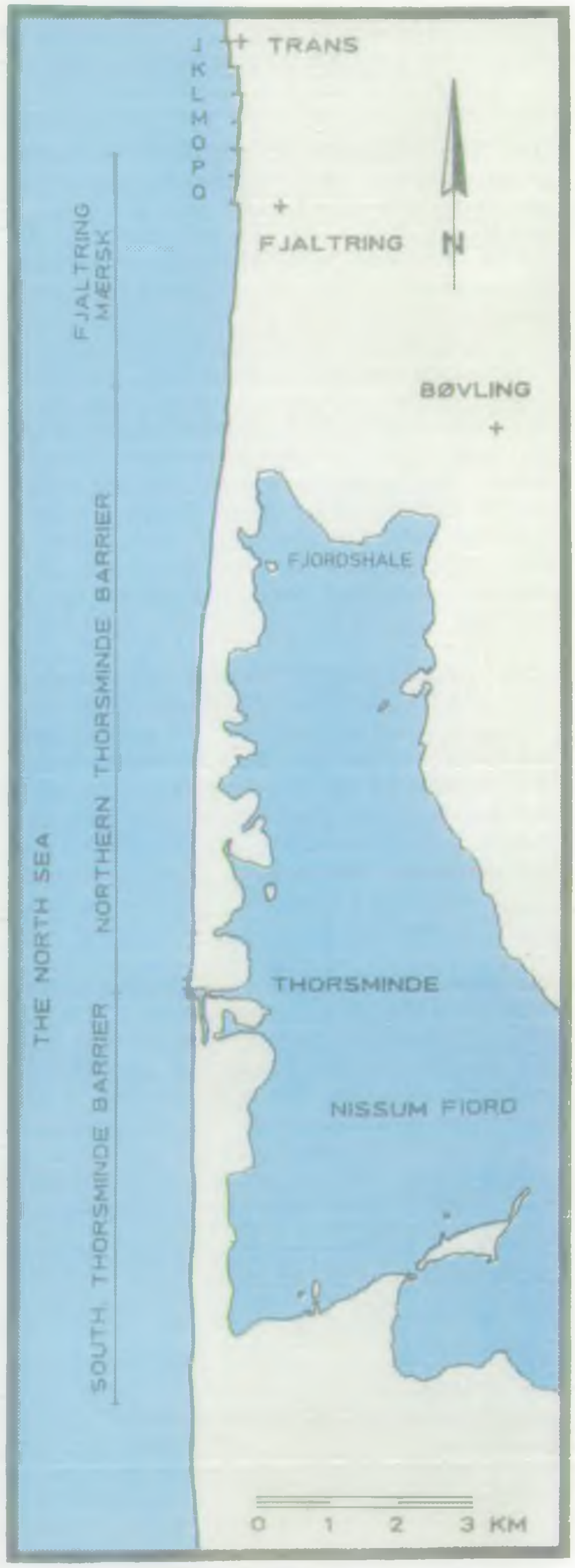
North and south of the barriers, at Fjaltring and south of Fjand respectively, the marine deposits settled on more stable moraine deposits from the penultimate Ice Age.

Dybå - Mærsk

Groynes Q, R, S, T and U (the Keldberg group) and groynes I, II, III, IV and V (the Mærsk group) were established in the 1930'.These groynes were built to protect dikes established in 1901 and 1921 as storm surge protection for the low land which at that time lay south and west of Fjaltring Church. It was feared that a storm surge inundating this area could flood Nissum Fjord.

The open stretches of coast between and south of these groynes (between K and Q, between U and I, and south of V) suffered severe erosion in the following years, largely due to the leeside effect. In 1951 maintenance of these groynes and the dikes behind them was abandoned, with the exception of Q, and instead the Thorsminde dike was extended behind the Mærsk group to the higher ground to the north.

After groynes were built between K and Q (see section on Ferring-Bovbjerg-Trans) the powerful leeside erosion moved to the unprotected area south of Q. The dramatic decrease in sand accumulation and shore build-up from north to south in the L-Q groyne group indicates that groyne construction from Ferring to Fjaltring has reached such proportions that the major part of sand migration along the coast is caught by the groynes further north. The groyne system is therefore regarded as having reached its maximum capability with respect to sand accumulation and coast build-up. In the 70's



General plan 1:100.000

and early 80´s a number of measures were taken to combat the continured erosion of the coastline between the southernmost groynes and south of Q. Groynes O, P and Q were therefore shortened, and the top of Q lowered to facilitate sand migration at high tide. Dybå´s outlet into the sea was channeled through a conduit. A revetment was established from Dybå to just south of Q, and breakwaters were built between the three southernmost groynes. Groyne Q was again shortened to reduce leeside erosion, and a spur was built parallel to the coast at the end of the groyne to stabilize the coastline and protect the slope immediately to the south.

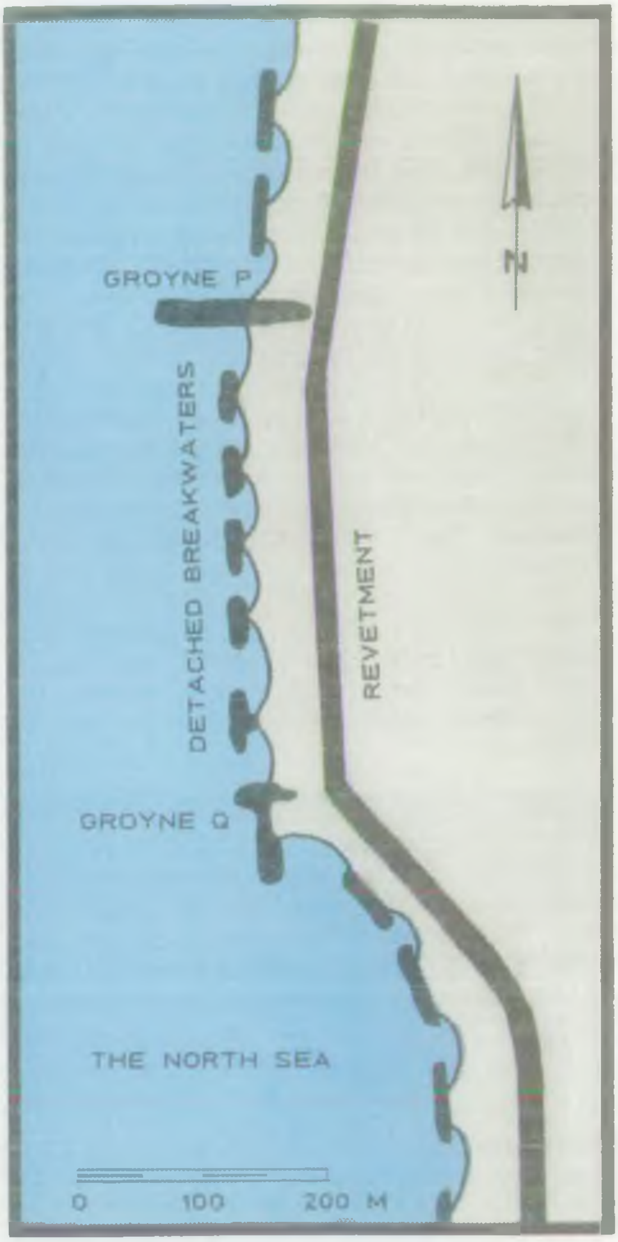
Three groups of breakwaters were built on the most vulnerable stretches south of Q, i.e. immediately south of the groyne, at Tuskær and at Fjordshale.

However, the beach was still comparatively weak and it was obvious that substantial nourishment would be required on this stretch of coast. In 1981 a pipe was laid on the sea bed and 50,000 cubic metres of sand were pumped from a dredger off-shore to groyne Q and then distributed along the coast by trucks.

In the summer of 1983 approximately 80,000 cubic metres of sand was dumped in the shallows in front of the three breakwater groups. The theory was that the swell would carry the sand further in towards the beach while the wave current would distribute it along the shore.

Distributing sand directly on the beach is still the most effective nourishment method for protecting dunes and dikes in high water situations. As it could be foreseen that large volumes of sand would have to be supplied at frequent intervals, and as laying a plastic pipe on the sea bed had not proved very effective, a metal pipe was buried under the sea bed at right angles to the coast at Tuskær in 1984.

In 1985 DCA drew up a long-term plan for the area. This laid out the coastal protection strategy for the next decade taking into account both the evolution of the coast and economic limitations. The primary objective is to maintain an even coastline from



Coast protection at groyne Q

Mærsk to the Northern Thorsminde Barrier. The protection measures themselves consist of a combination of breakwaters and nourishment to stop coastal recession, and a revetment in front of the dunes/dike as protection against high tide erosion.

Some of these measures have already been carried out. A new Mærsk dike was built in 1984-85 to close the gap opened by the erosion of the 1952 dike in the early Eighties.

The new dike is protected by a revetment, and series of breakwaters have been built on the coastline to maintain a high, broad beach. A revetment extending 500 metres south of Q has also been established.

Revetments and breakwaters will be established on the adjacent unprotected strech in the coming years.

From 1985 to 1988 a total of 640,000 cubic metres of sand has been pumped ashore and distributed along this section og the coast. This form of nourishment will continue in future years.

<u>The Thorsminde Barriers</u>

In the middle of the last century the decision was made to try to control the water level in Nissum Fiord. In 1868, after two abortive attempts, a sluice was successfully completed at Thorsminde.

In 1931 the sluice was extended and a lock built for sea traffic. At the same time two jetties were established to reduce sand accumulation at the entrance.

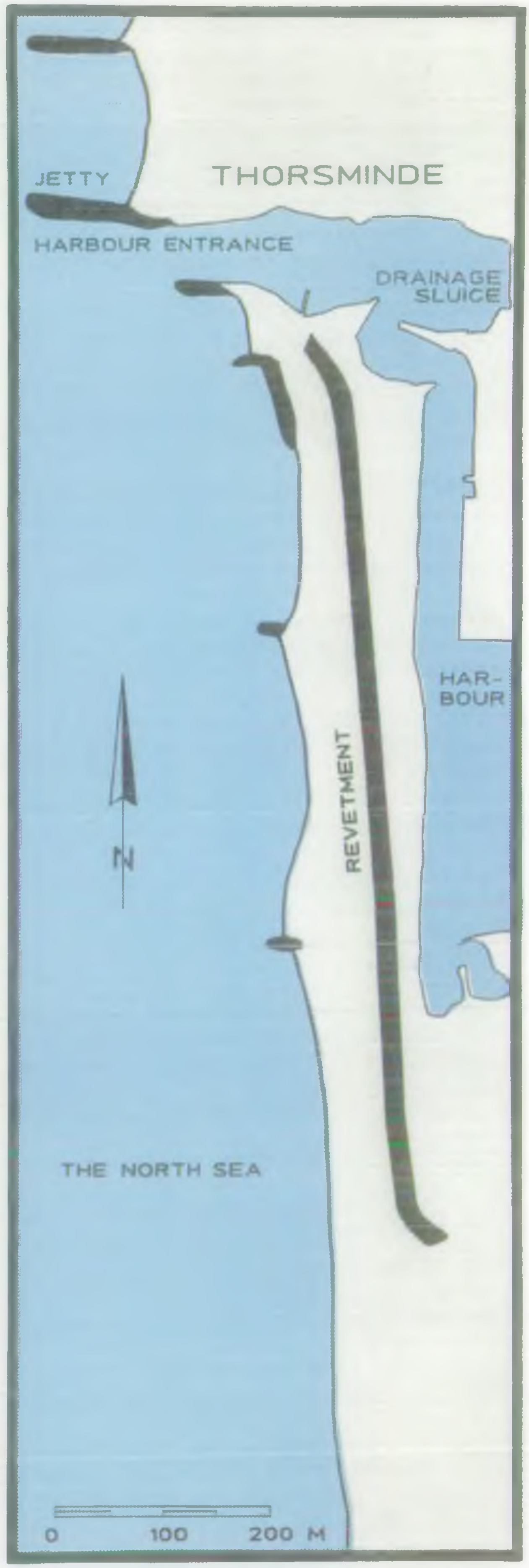
These jetties did not however solve the sanding problem. Therefore the northern jetty was extended in 1947, and a groyne was built about 150 metres north of the entrance in 1958-60. 50 - 100,000 cubic metres of sand is however still dredged each year.

In their natural state the barriers are highly vulnerable in storm surge situations. The present sand dike, with the road behind it, was therefore built in the 1940's.

Coastal recession on unprotected stretches of the Northern Barrier is 2 - 6 metres a year, highest at the northern end, and about 4 metres a year on the Southern Barrier.

It is with these figures in mind that coast protection has been planned for this particular section of the coast, so that the most vulnerable stretches are protected first.

The barrier immediately south of the entrance is particularly vulnerable as it is to leeward of the jetties. The beach groynes built in the 1940's provided insufficient protection, and therefore a revetment has been established in recent years. In order to maintain a reasonably strong coast profile, sand is fed onto the beach and also off-shore in approximately 4 metres of water. The sand is dredged



Coast protection south of Thorsminde harbour *from the entrance. The sand used for beach nourishment is pumped through a pipe on the southern jetty.*

Another vulnerable spot is the Fjordshale stretch immediately south of Mærsk, where the dike has been in danger of breaking on several occasions. Therefore breakwaters have been built on this section in recent years and work has begun on establishing a revetment. In the coming years sand pumped in via the pipeline at Mærsk will also be fed onto the beach. Sand will also be dumped on the west side of the bar.

In the coming years the plan is to gradually extend coast protection on the barriers so that the dike can withstand a wave and tidal condition which on average will occur once every 100 years, i.e. a water level of +3,20 m.

On the Northern Barrier this means working our way south from the constructions at Fjordshale with revetments, breakwaters and nourishment.

As far as the Southern Barrier is concerned, in addition to the stretches mentioned above which are already protected, there is a relatively vulnerable section roughly half-way down the barrier. Here a revetment will be established, and sand will be distributed along the beach and bar.

The experience gained in connection with all the various coastal protection measures taken over the years, will play an important part in planning protection on the barriers in the future.

Beach nourishment through permanent pipeline at Mærsk

Holmsland Klit

History

Previously Ringkøbing Fiord was bounded on its western side by a series of islands. In time, erosion and the subsequent deposit of the eroded material formed an unbroken barrier. Dueen.

It was not until the sluice was built at Hvide Sande (1931 - 33) that a permanent solution was found for the fiord's drainage problems. Now the sluice maintains a virtually constant water level in the fiord.

Dune reinforcement.

The large dune formations on the Holmsland Barrier and north of Søndervig provide natural protection against the sea flooding the fens and the shores of the fiord.

However, severe storm surges have on occasion broken through the chain of dunes at certain points, flooding the hinterland and leaving their mark on the barrier in the form of runnels.

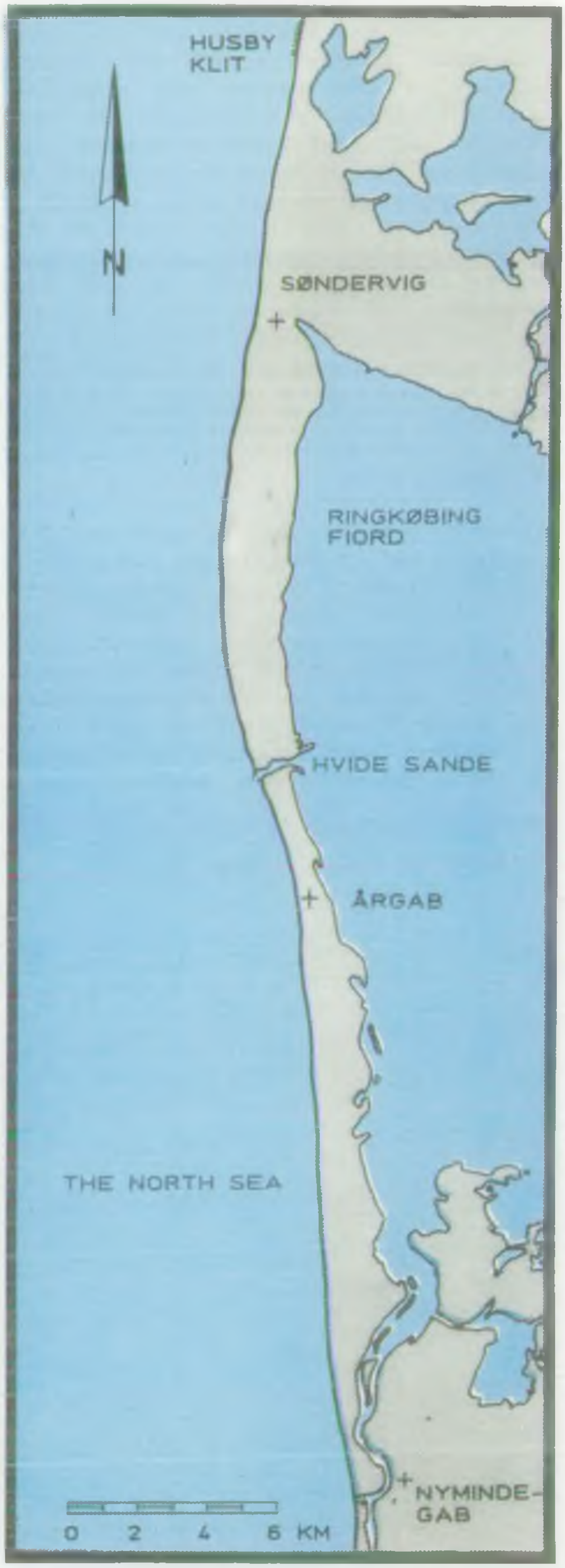
Due to sand drift the dunes moved east at the same pace as the shoreline. This natural balance has been upset by planting lyme grass on the dunes in an effort to reduce the sand drift. Planting keeps the dunes in position, but as the west side of the dunes continues to be eroded the dunes gradually become narrower.

At certain particularly exposed spots small recessed dikes have been established between relatively strong dunes in an attempt to build up storm surge protection. One of the main areas where this has been done is at West Stadil Fiord. A group of groynes was also built here in 1926/27 after a breach at Husby Klit.

After the storm in November 1981 new recessed dikes and dune reinforcements were built on threatened sections and the shore ends of the Husby groynes were extended.

Effect of Hvide Sande Harbour

In connection with the construction of



General map 1:200.000

the sluice at Hvide Sande a small fishing harbour was established west of the sluice. The harbour entrance was protected by two short jetties, but strong sediment transport made it difficult to keep the channel clear. To make navigation of the channel easier a 400 metre long jetty was built in 1962. As a result, a large volume of sand started accumulating north of the entrance while there was corresponding leeside erosion south of the harbour, where the foot of the dunes was being eroded at the rate of up to 15 metres a year in the late Sixties.

This development has been arrested to a certain extent by the following measures:

1. *Nourishment*

   Since 1973 additional sand has been supplied to the 3 km stretch of beach south of the harbour to protect the foot of dunes. The nourishment material consists partly of sand dredged from the channel and pumped ashore at the southern jetty, from where it is trucked and dumped, and partly of sand accumulated north of the harbour, which is again trucked and dumped. The average volume of nourishment each year is 120,000 cubic metres.

2. *Breakwaters*

   On a 5 km stretch south of the harbour 10 breakwaters have been built in the period 1983 - 85, and sand has been dumped at the foot of the dunes.

3. *Dune Reinforcement*

   On the same stretch, vulnerable spots in the first row of dunes have been reinforced by supplied sand.

The Present Situation

The coastline from Husby Klit to Hvide Sande is fairly stable, with an annual regression of less than 1 metre.

South of Hvide Sande the rate of regression decreases fairly steadily from 3 metres a year at Årgab to zero regression south of Nymindegab.

The coast and storm surge protection works planned for the coming years will be along the same lines, i.e.:

1. *Breakwater construction and maintenance.*

2. *Nourishment*

3. *Dune reinforcement.*

APPENDIX H

"A Coastal Study of the Skagen Spit, Denmark"

REPRINT FROM

Iceland Coastal and River Symposium

PROCEEDINGS

edited by
G. Sigbjarnarson

The University of Iceland
Icelandic Harbour Authority
National Energy Authority
National Power Company
Marine Research Institute
Public Roads Administration

REYKJAVIK, ICELAND

A COASTAL STUDY OF THE SKAGEN SPIT, DENMARK

by

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ABSTRACT

The Skagen spit forms the northernmost part of Jutland, Denmark. A coastal study has been carried out to clarify the rather complicated processes which take place along the spit. What is interesting about the Skagen spit, from a coastal point of view, is the coincidence of low water levels and high waves and vice versa on the southeast coast, and the morphologic effect of the coastal current. Also the coastal effect of the rise of the land compared to the sea level represents a point of special interest.

INTRODUCTION

The Skagen spit forms the northernmost part of Jutland, Denmark, see fig. 1 and 2.

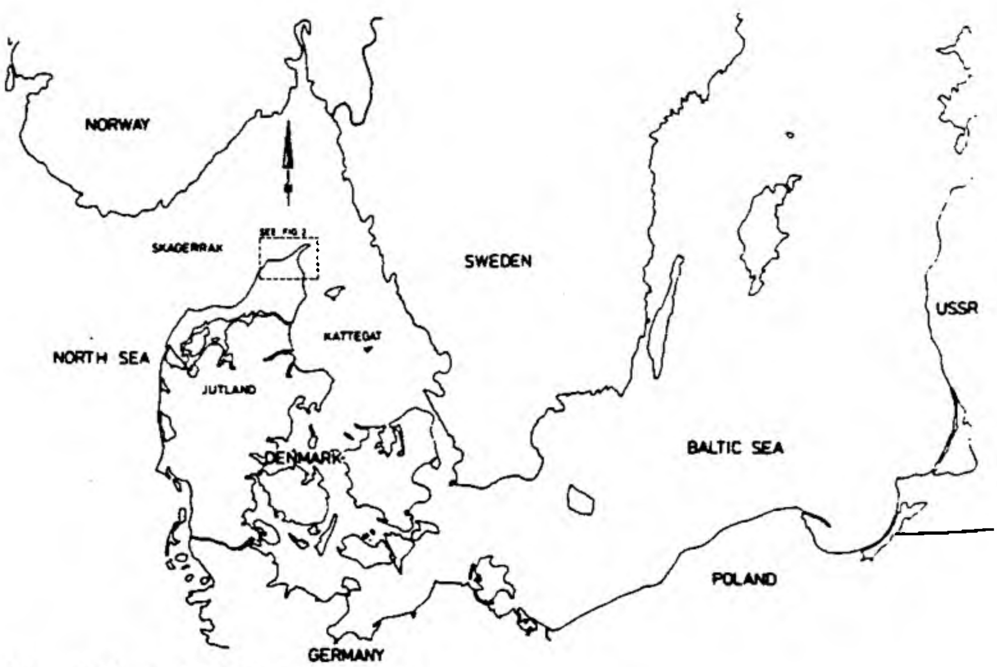

Fig. 1 Map of Northern Europe

Sigbjarnarson (ed.), Iceland Coastal and River Symposium, Proceedings. pp. 63-73.

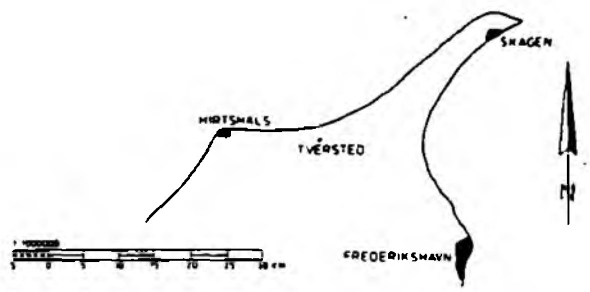

Fig. 2 Map of Northern Jutland

With the aim of creating a basis for a coast protection plan for the northern part of the Skagen spit, a coastal study of the area was carried out by the Danish Coast Authority in 1981.

GEOLOGICAL DEVELOPMENT

When the latest Ice Age ended in Denmark approximately 15,000 years ago, the northern part of Jutland was considerably lower than it is today, both absolutely and in comparison with the sea level.

In the succeeding millennia both the land and sea levels rose. The actual position of the coastline was determined by the rate at which the land rose in relation to the sea level. The so-called Continental Period, in which Denmark was connected with England, was succeeded approximately 8,000 years ago by the Littorina Period, in which the sea level was high compared to the land level. The coastline was for several thousand years located between what is now Frederikshavn, Tversted and Hirtshals, see fig. 2. Within the coastline a characteristic cliff was formed, and this can still be seen today.

It was on the basis of this coastline that the development of the Skagen spit started. The material involved in this process was material carried by the resultant northerly wave current along the coast south of Hirtshals. Because the transportation capacity of this current decreased east of Hirtshals, much of this material was deposited on the sand bars along the ancient coastline. In periods with heavy swells this material was carried on to the beach, forming a beach ridge. Gradually new beach ridges formed outside the old ones, resulting in a coastline progression. The spit never developed into a recurved spit because of the forces operating on the Kattegat side.

An important factor in the rapid progression of the spit is the continuing rise of the land compared to the sea level. As a result of this rise, the areas just outside the old Littorina coastline now lie about 13 m above present sea level.

CLIMATIC AND HYDROGRAPHIC CONDITIONS

In order to be able to analyse the coastal development in detail, we have to begin with an analysis of climatic and hydrographic conditions in the area.

Starting with the wind conditions, the prevailing winds are W and SW. However, wind forces of 5 and above on the Beaufort scale occur most frequently in connection with W and NW winds.

The water level is determined primarily by wind setup and the tide, where the former is the dominant factor. To give an impression of the high water levels in the area it can be stated that the water level in Skagen harbour is +1,24 m or more 1 hour every 10 years on an average.

The wave climate off Skagen harbour has been evaluated on the basis of 6 months of wave recording with a waverider buoy, supplemented by observations of wave direction. The short-term wave statistics have been transformed into long-term statistics on the basis of a comparison between the wind statistics for the wave recording period and long-term wind statistics. Fig. 3 shows the wave height statistics. A large part of the waves from ENE in particular have been generated in the North Sea and in the Skagerrak. Due to refraction on the reef east of the tip of the spit, these waves end up running towards the east coast of the spit.

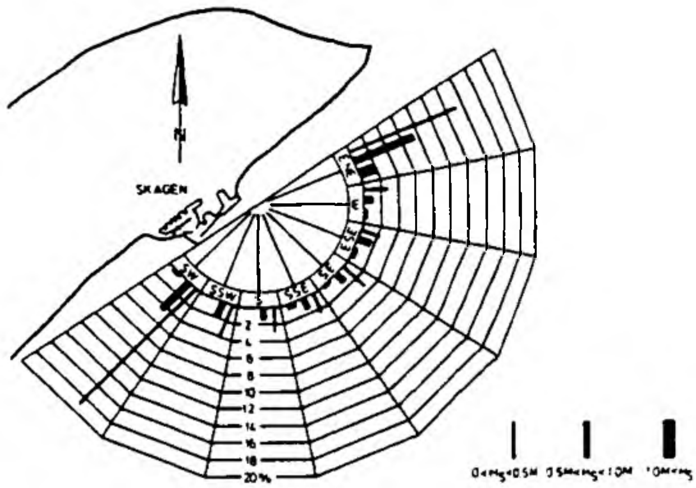

Fig. 3 **Wave height statistics.**

The coastal current plays an important part in the development of the spit. The summary shown as fig. 4 has been prepared on the basis of current registrations described in ref. 1.

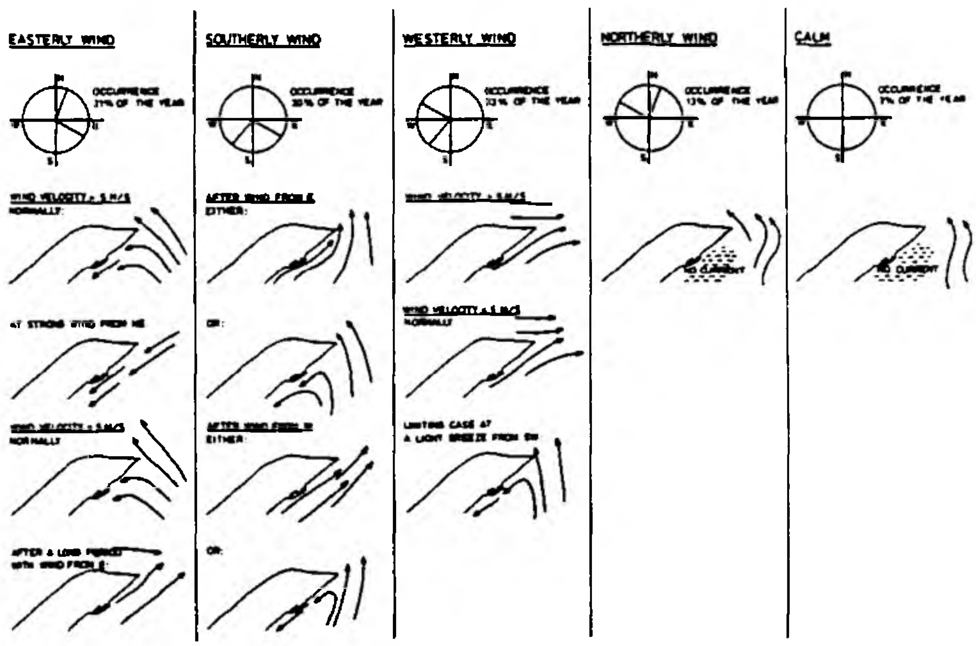

Fig. 4 Coastal currents at different wind conditions.

close to the coastline. Therefore we can have a situation at the harbour with a north-easterly wave current and a south-westerly coastal current at the same time.

To illustrate how the wave conditions and water level fluctuate during a fresh gale, we have plotted wind, water level, wave height, direction and period for a period around new year 1980 - 81, see fig. 5.

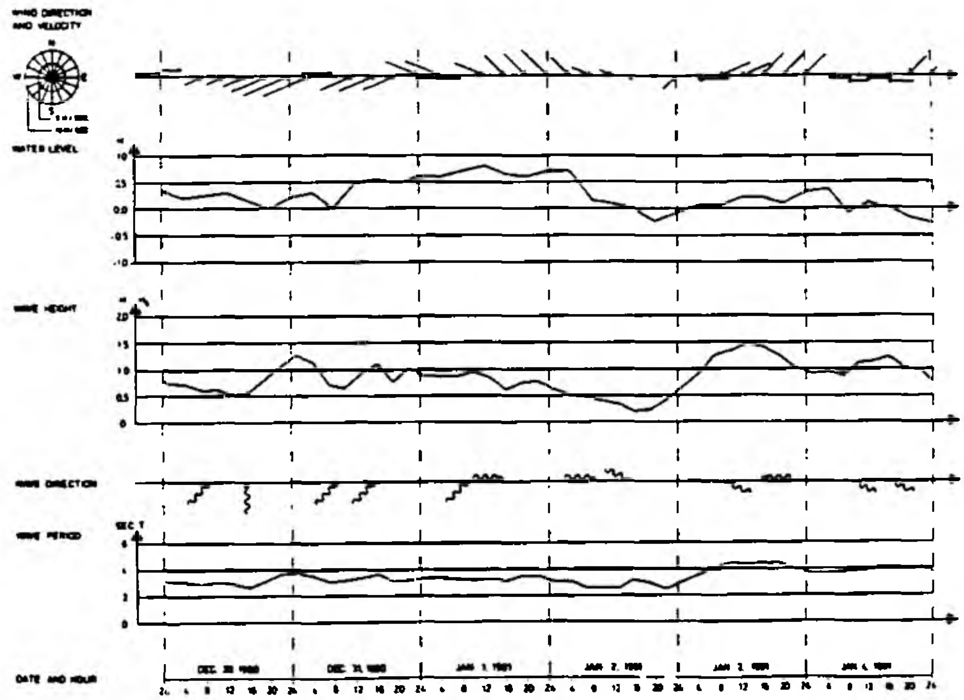

Fig. 5 Observations at Skagen harbour during a fresh gale.

While the wind is westerly, the water level is high, because water is pressed from the North Sea into the Skagerrak. When the wind turns to NE and E, the water level falls, while the wave height increases.

Fig. 6 shows the wave spectrum for the waves registered between 19^{00} and 19^{20} on January 1st, 1981. As can be seen, the spectrum has two peaks.

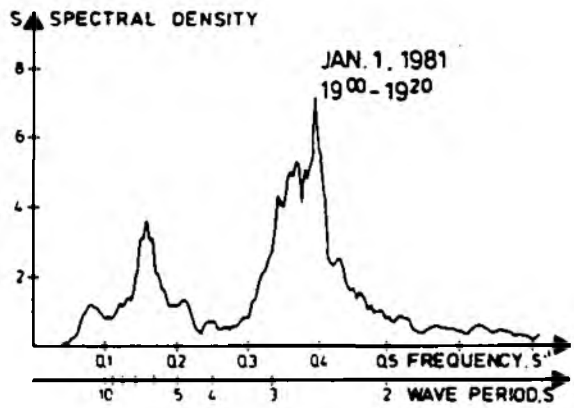

Fig. 6 **Wave spectrum.**

The peak at wave period 2.6 sec. corresponds to waves generated between the coast and the waverider buoy, while the peak at wave period 6.3 sec. corresponds to waves generated in the North Sea and in the Skagerrak and refracted on the reef, resulting in a direction towards the harbour.

As it appears from fig. 5, high waves and high water level do not necessarily occur simultaneously at Skagen harbour, as is the case for most coasts. Therefore statistics have been compiled showing the relationship between water level and wave height, see fig. 7.

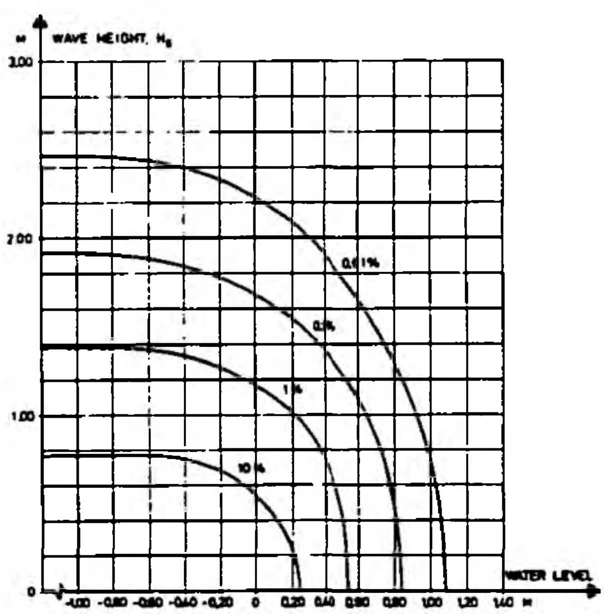

Fig. 7 Statistical relationship between water level and wave height.

From the figure it appears that high waves generally correspond to low water level and vice versa. The reason being the above-mentioned currents in the North Sea, the Kattegat and the Baltic Sea.

COASTAL DEVELOPMENT

As described earlier, the spit has developed from the old Littorina coastline. Fig. 8 shows that the growth of the spit still continues.

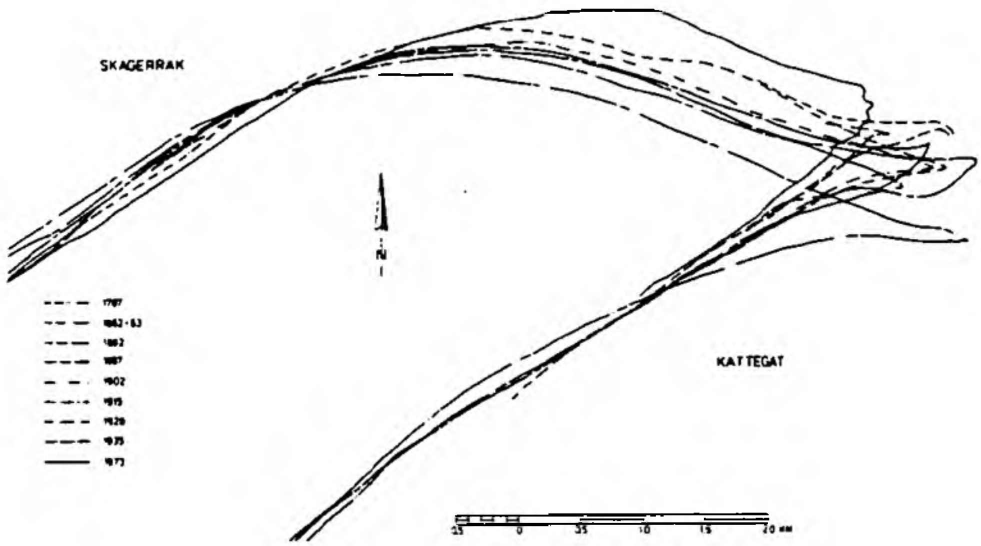

Fig. 8 Old coastlines.

The aerial photograph, fig. 9, shows the system of beach ridges which forms the spit.

Fig. 9 Beach ridges at the tip of the spit.

In order to get a more detailed description of the coastal development in the area we have analysed all relevant survey material. The results are shown in fig. 10. Where annual coastline movement prior to the building of the coastal constructions is known, it is indicated in brackets.

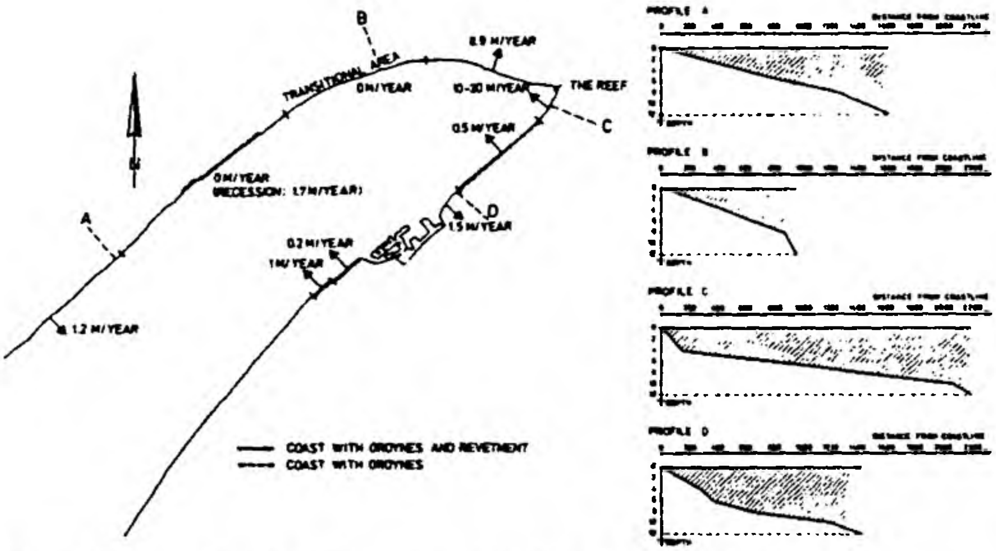

Fig. 10 Mean annual coastline movement and typical profiles.

It appears from fig. 10 that there is erosion on the west coast of the spit, while there is coastline progression on the north coast. What happens is, that the transportation capacity of the wave current decreases drastically off the north coast, causing sedimentation on the bars and the subsequent formation of successive beach ridges. The rest of the material in the wave current is carried out onto the reef just east of the tip.

The tendency to develop into a recurved spit is counteracted by the predominantly north-easterly coastal current just south of the tip. This current, which runs close to the coastline, causes a recession of the coastline, and most of the eroded material is carried out onto the reef.

Further down the southeast coast, the prevailing south- westerly wave current becomes dominant, resulting in a progression on the northeast side and a recession on the southwest and lee side of the harbour. Southwest of the influence area of the harbour there is a small progression of the coastline.

Fig. 10 also shows 4 typical profiles from the area. The considerable depths in the Skagerrak can be seen on profile B, while the steep inner part of profile C is a result of the above-mentioned coastal current, which runs close to the coastline at this point.

The reef, which is a deposit area, normally runs ENE, but the direction changes in response to the relative strength of the forces operating on each side of the spit.

With the reservations, which always have to be made for this kind of calculations, a littoral budget for the examined coastal area has been set up, see fig 11. Survey results have been used in combination with energyflux calculations carried out according to the methods described in ref. 2. Where the two methods give conflicting results, greater weight has been attached to the survey results.

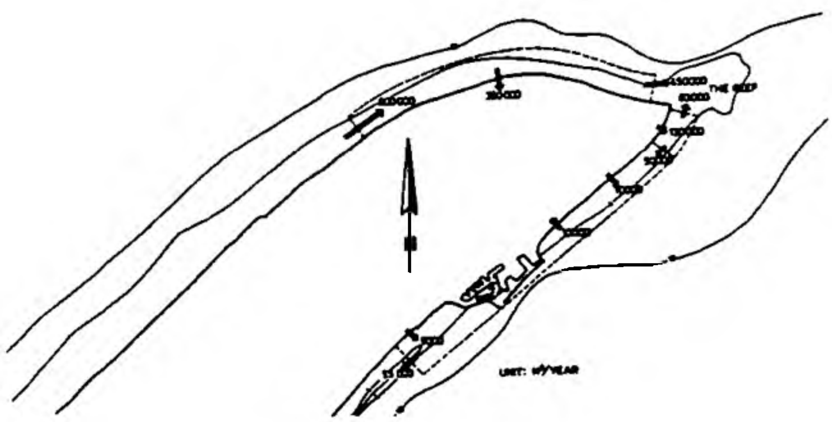

Fig. 11 Littoral budget.

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(1) Isotopcentralen, "Recipientundersøgelser i farvandet ved Skagen", April 1968 (in Danish).

(2) U.S. Army Coastal Engineering Research Center, "Shore Protection Manual", 1977.

APPENDIX I

"SYLT - Germany"

Protection of the West Coast of Sylt

1. Introduction

About 8000 years ago the island of Sylt had the shape of a round oval moraine, which was located several kilometers further west than today.

With the rising of the sea level after the last ice-age, the moraine of Sylt got increasingly affected by the Nothsea. Sea motion and tidal forces continuously eroded material from the west side of the moraine and transported the sand north and south, where in the course of the millenium existing dunes have been blown up. In this way the long shape of the island with the dunes adjoining in the north and south to the old core of the moraine developed (Fig. 1). The dunes are also affected by recession due to steadily progressing erosion from west to east.

The present shape of the island's base also emerged during the millenium. The island's base rises gradually from the sea ground, which cannot be reached by the wave forces (water depth of NN-10 m until NN-12 m) to the cliff or the bottom of the dunes. In the foreshore zone the reef is situated on the island's base and works as a transportation mean (Fig. 2).

While sea motion and tides continuously erode and move away material from the sandy shore and fore shore area, dunes and cliffs are only affected in irregular intervals during storm surges. The eroded material moved to the shore and fore shore section and is steadily transported north and south by surf and tidal currents parallel to the coast; then it is deposited in shallow areas in front of the deep of List and in the Vortrapp deep or is moved ahead the eyelet and is therefore lost for the sediment balance of the island.

The average annual losses at the west coast of Sylt for the years 1870 until 1950 amount to 0,90 m. The frequency of storm surges with longer lasting high water level has increased considerably during the past 35 years. Thus the energie influence by sea motion at the west coast has grown. Corresponding to the increase in storm surges, the annual average coast recession was intensified. It was determined that the annual loss of material on the island from the south point of the Hörnum Odde to the Ellenbogen revetment in the average of the last 35 years amount to 1,4 Mio m³.

As a result of the storm surges of the past years, the ALW Husum has worked out a specialist project "Coast protection on Sylt" in order to obtain a general concept for the future coast protection measures on Sylt (intermediate planning period: 10 years). In this specialist project the possible solution offered by the latest developments and technologies, e.g. solid constructions (every kind of bank revetment, groynes) and sand nourishments were examined. It turned out that continuously repeated sand nourishments are the best solution from the technical, economical and environmental point of view.

2. Construction work

The sand nourishment consist of a fill material and a stockpile of sand. In front of the erosion line an artificial dune is layed out that works as stockpile of sand. Even in the case of extremely severe storm surges not the existing shore but the artificial dune in front of this will be affected and eroded (Fig. 3). The 60m wide artifial dune works as wearing structure and has to be completed in certain time period.

For the sand nourishment suitable sand sources have been tapped west of the island of Sylt (Fig. 1). The borrow area for the nourishment of sand, i.e. according to the project, during the following 10 years is located 7-10 km in front of the island's west coast. The average water depth in this area is 14 m. According to geological and hydrological knowledge no additional pressure on the island's base by the planned sand borrowing is expected. An observation of the sand borrowing is planned in order to recognize unfavourable developments in time.

The winning of the sand on the sea ground in the borrow area is effected by automatic trailing-suction-dredgers (hopper dredgers) following either the "Schleppkopf- or the Stechkopf" technique (see Fig. 4 and 5).

3. Analysis

The sand nourishments are accompanied by a research program with the aim to improve knowledge about the development at the west coast of Sylt and to optimize the method of sand nourishment.

Therefore the land Schleswig-Holstein has initiated a large research program "Aims of the Optimization of Coastal Protection on the Island of Sylt", in which the following institutions participate:

- Franzius Institute, Hydraulic Engineering and Littoral Sciences, University of Hannover
- Geological-Paleontological Institute, University of Kiel
- Institute of Mechanical Flow Dynamics, University of Hannover
- Leichtweiß-Institute, Hydraulic Engineering, Technical University of Braunschweig
- Official Department of Agriculture and Hydraulic Economics, Husum, Schleswig-Holstein, (ALW Husum)

For this research project a research team under the chairman ship of the Schleswig-Holstein Minister of Nature and Environment has been formed, which accompanies and coordinates the whole research program. For that the West German Parliament has granted the necessary funds, which are going to be provided by the Minister of Research and Technology.

The research program is above all aimed at
- the hydrodynamical pressure on the west coast of Sylt and the island's points by sea motion and tidal forces,
- their effects on coast erosion and sediment balance.

Therefore it is necessary to analyse the sediment transportation in front of the coast of Sylt and its dependence on sea motion, tides and artificial interference. Subsequently it shall be examined how the sediment transportation can be influenced positiveley with regard to protection of the island and how sand nourishment can be optimized and additional economic measures can perhaps have to reduce the energy effects on the west coast of Sylt and the island's points.

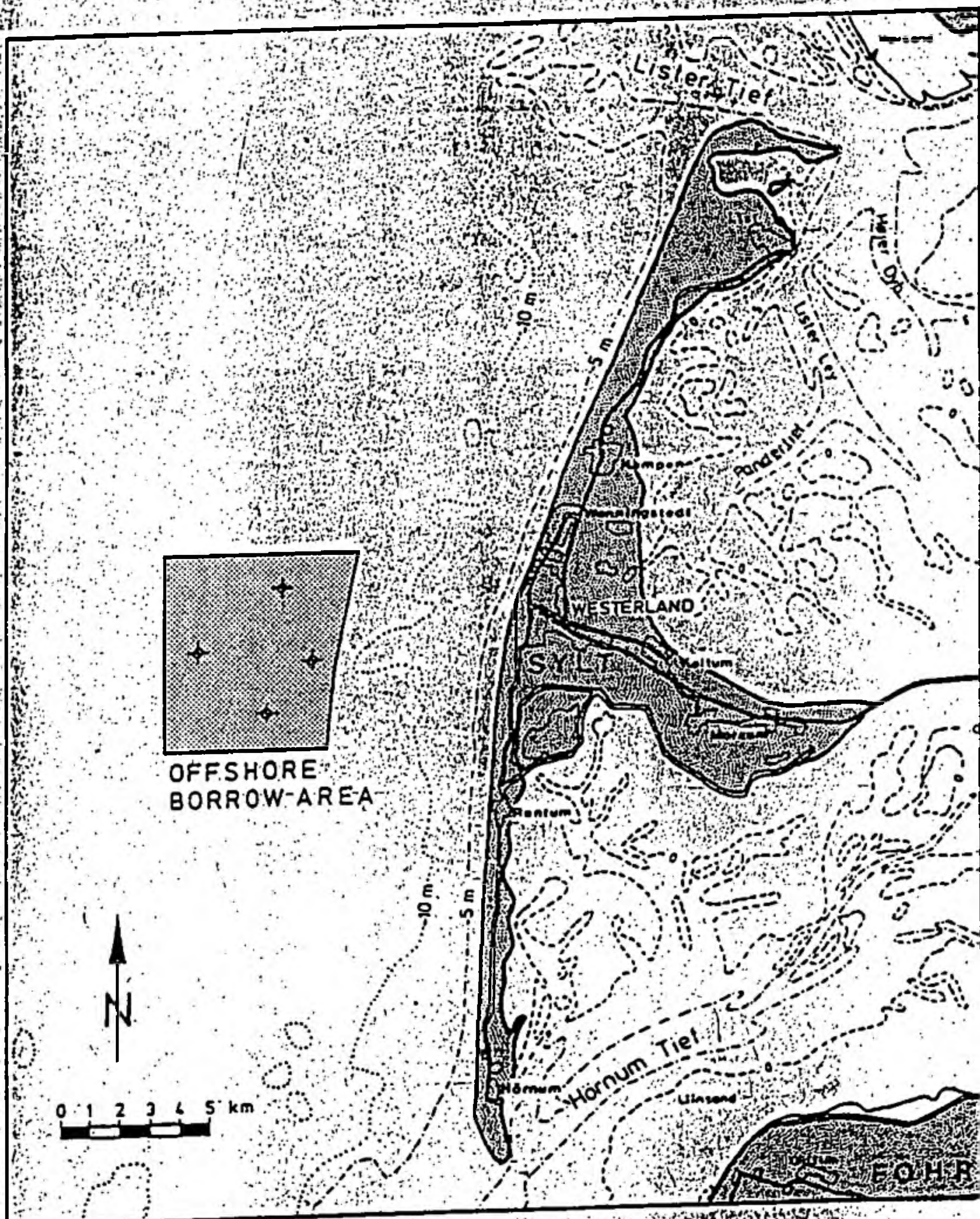
The examinations of the interdisciplinary research program, which consists of a naturel monitoring program and model testing, include the following main points:

- recording of the sea motion in deep sea areas in front of Sylt (seawards, NN-10 m depth) using directional wave recording buoys
- hydrological measurements in front of the coast and in chosen test-fields for the recording of water level, wave heights and current characteristics

- regular survey of the beach and the dune area along the west coast of Sylt as well as the survey of the sea in test-fields
- sedimentological analysis of chosen test-fields with the aim to record the periodical season-caused and the event-caused transportation of sediment along the coast
- examination of the wave direction, for the heights of the waves close to the coast, the evaluation of sea motion causing transportation parallel to the coast
- hydrodynamical-numerical modelling to analyse large tide-caused currents and the resulting sediment transportation around Sylt.

Amt für Land- und Wasserwirtschaft
Husum, June 25th, 1990.

Fig. 1


Lister Tief
10 m
5 m
Kampen
Wenningstedt
WESTERLAND
SYLT
Keitum
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10 m
5 m
OFFSHORE
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N
0 1 2 3 4 5 km
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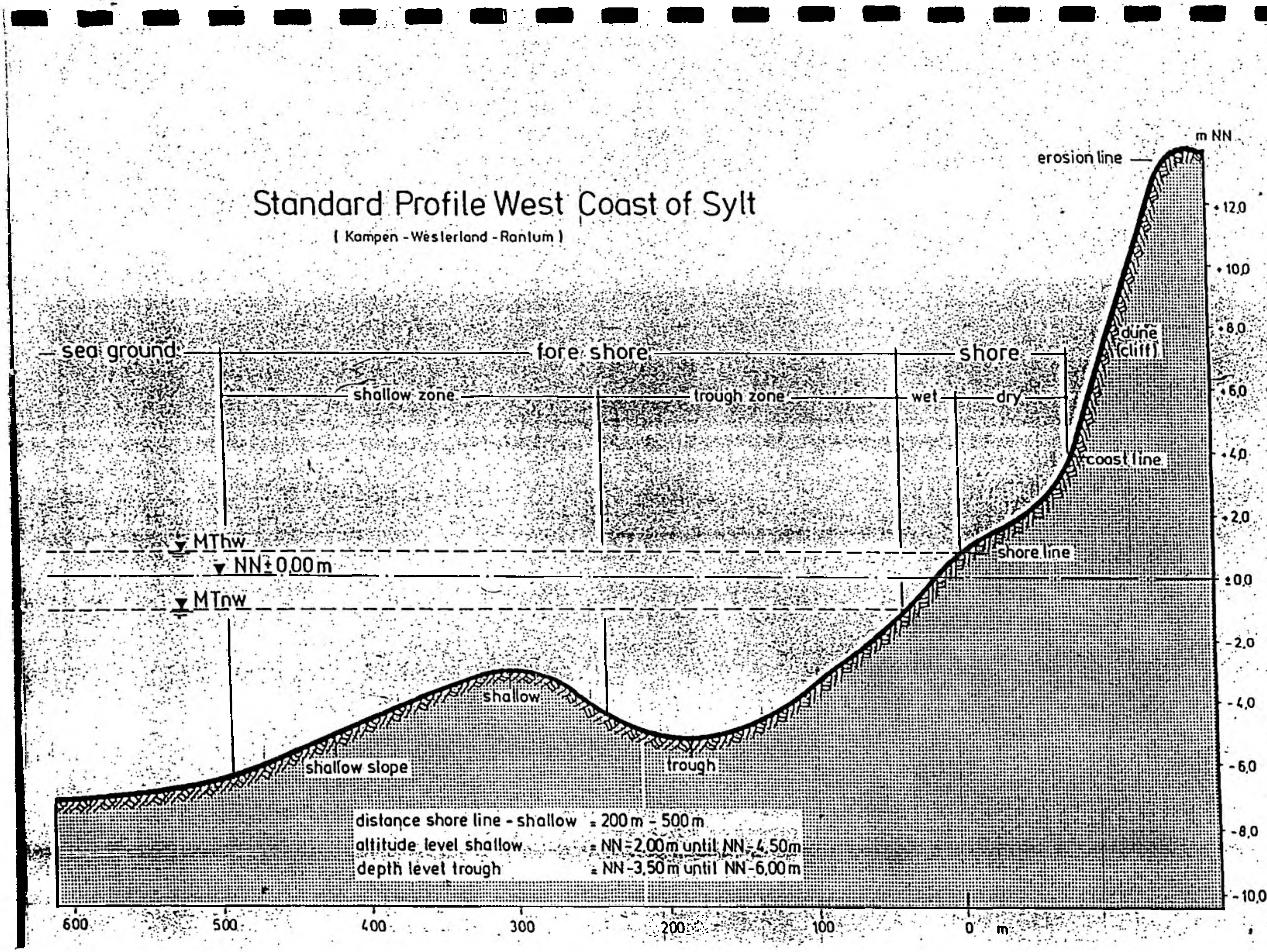
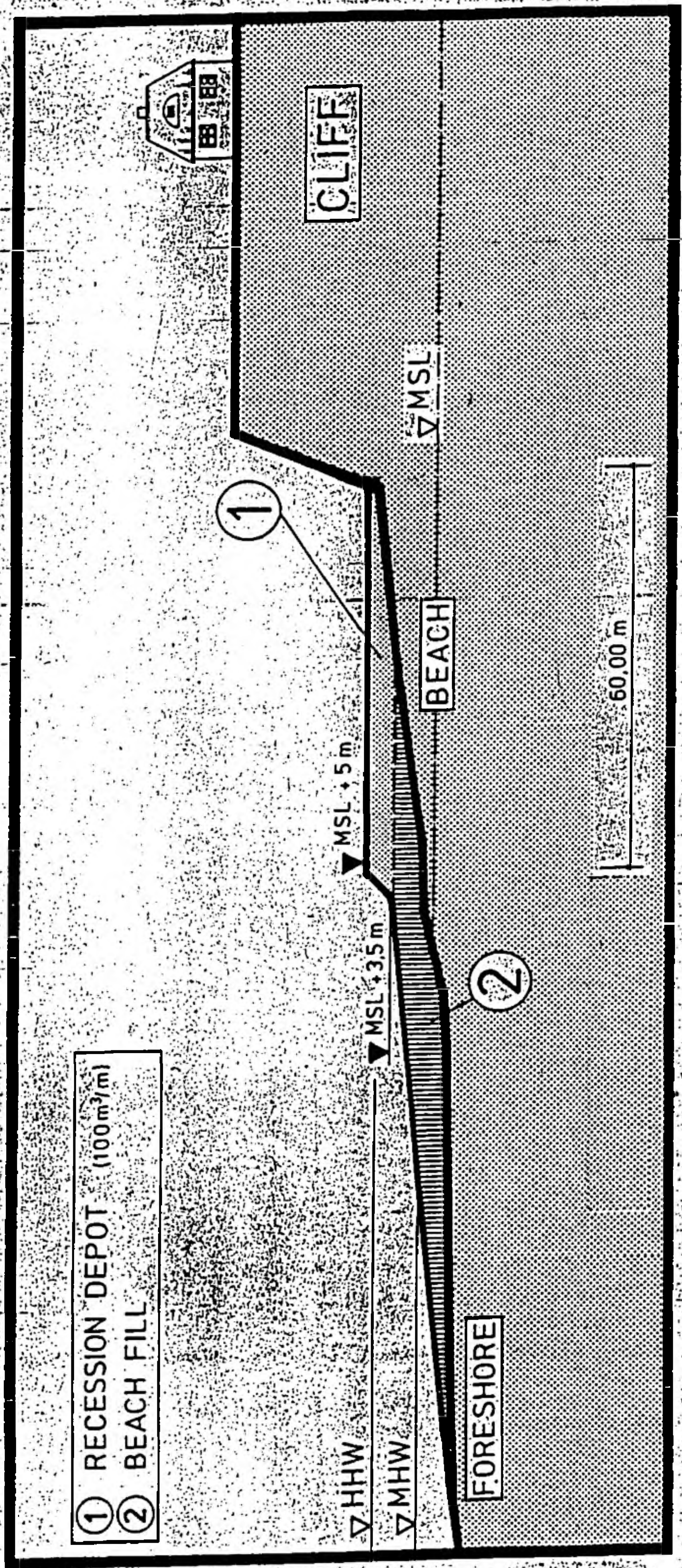
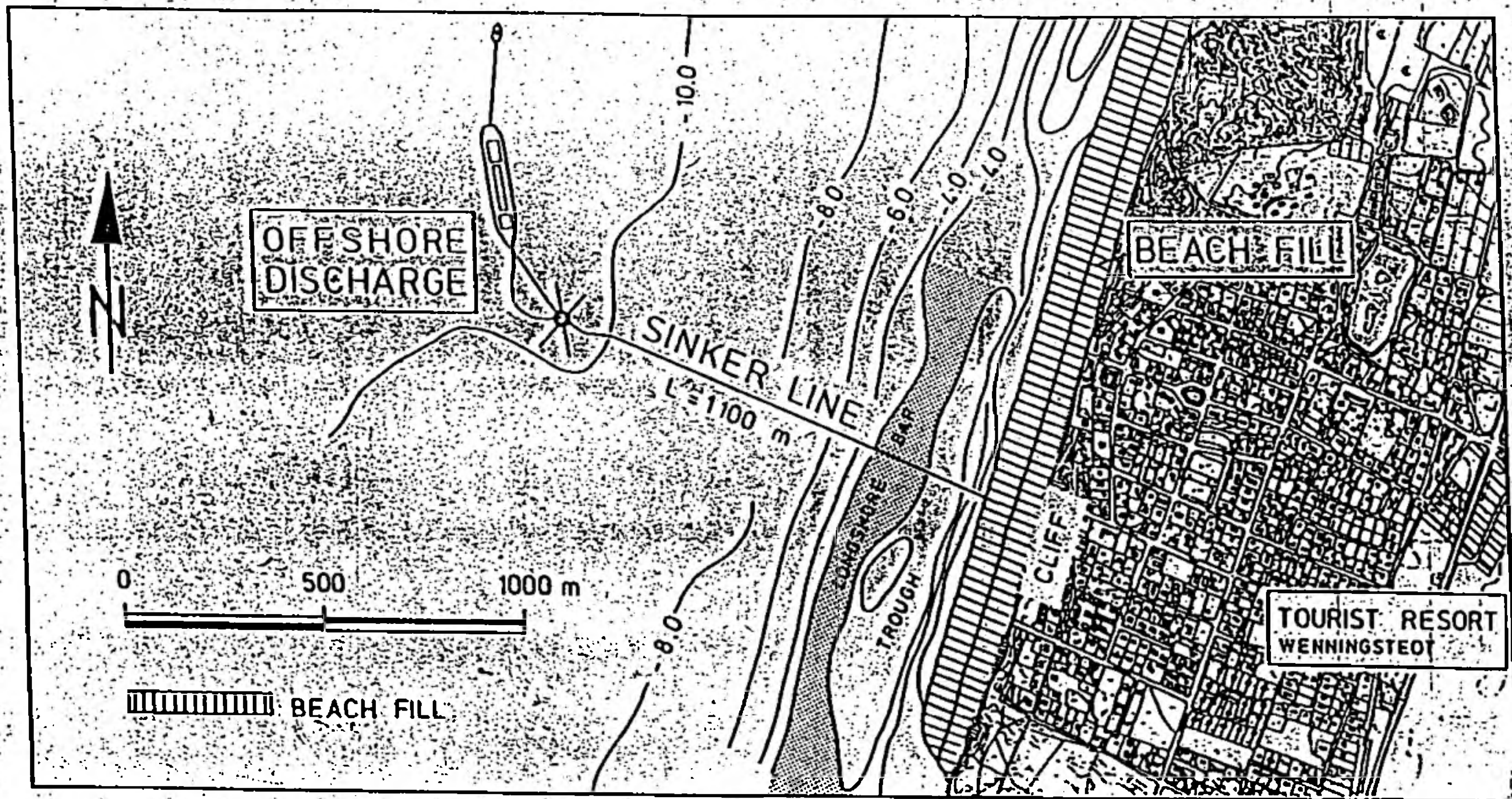

Standard Profile West Coast of Sylt
(Kampen - Westerland - Rantum)
m NN
erosion line
sea ground
fore shore
shore
shallow zone
trough zone
wet
dry
dune (cliff)
coast line
shore line
MThw
NN ± 0,00 m
MTnw
shallow
shallow slope
trough
distance shore line - shallow = 200 m - 500 m
altitude level shallow = NN -2,00 m until NN -4,50 m
depth level trough = NN -3,50 m until NN -6,00 m
+12,0
+10,0
+8,0
+6,0
+4,0
+2,0
±0,0
-2,0
-4,0
-6,0
-8,0
-10,0
600
500
400
300
200
100
0 m

Fig. 2

Fig. 3



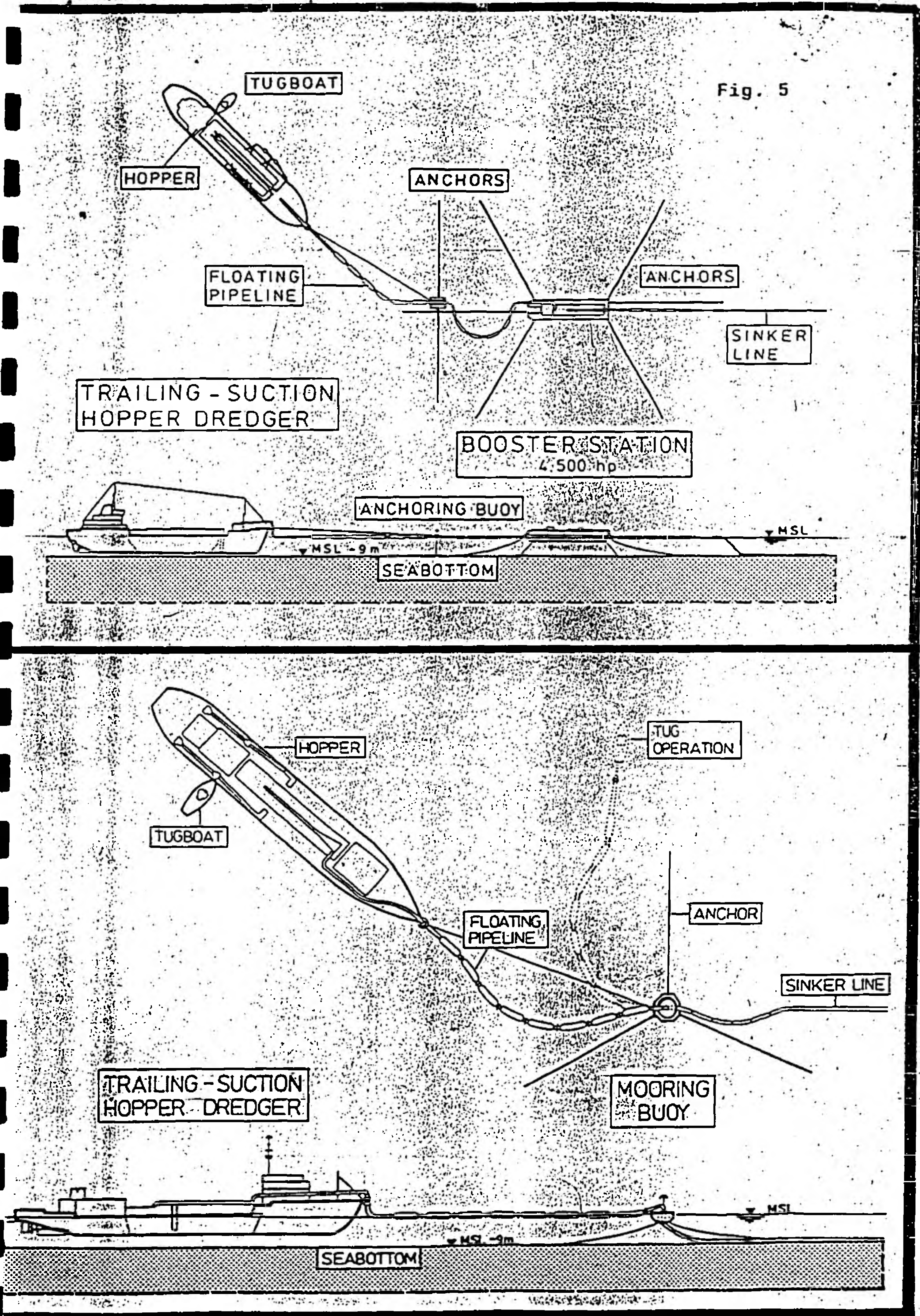
CLIFF
MSL
BEACH
60,00 m
MSL +5 m
MSL +3,5 m
HHW
MHW
FORESHORE
① RECESSION DEPOT (100m³/m)
② BEACH FILL



Offshore discharge from trailing-suction hopper dredger via sinker line

Fig. 4

Fig. 5


TUGBOAT
HOPPER
ANCHORS
FLOATING PIPELINE
ANCHORS
SINKER LINE
TRAILING - SUCTION HOPPER DREDGER
BOOSTER STATION
4.500 hp
ANCHORING BUOY
MSL
MSL -9m
SEABOTTOM
HOPPER
TUG OPERATION
TUGBOAT
FLOATING PIPELINE
ANCHOR
SINKER LINE
TRAILING - SUCTION HOPPER DREDGER
MOORING BUOY
MSL
MSL -9m
SEABOTTOM

APPENDIX J

"Block Revetment Design with Physical and Numerical Models"

BLOCK REVETMENT DESIGN WITH PHYS. AND NUM. MODELS

A. Bezuijen[1],
J. Wouters[2],
C. Laustrup[3],

Abstract

A combination of a physical model and numerical models has been used in the design of a block revetment for the Danish North Sea coast. The wave pressure loading on the revetment during design conditions was investigated in a physical scale model. The measured wave pressures were used as a boundary condition for the numerical models. Solutions for the flow equations through the coverlayer, filter layer and subsoil were then obtained in the numerical models, taking into account the influence of turbulence. With these solutions the stability of the coverlayer and subsoil was evaluated. The paper presents a description of the various models and information about the design of the revetment.

1. Introduction

Numerical models were developed within the scope of a research programme on block revetments in order to calculate the loading on a block revetment during wave attack, Hjortnaes-Pedersen et al (1987) and Bezuijen et al(1987). This research programme was commissioned by the Dutch Department of Public works (Rijkswaterstaat) and was performed by Delft Hydraulics in cooperation with Delft Geotechnics. The numerical models were used to calculate the pressure distribution in the filter layer and subsoil below a block revetment when the pressure distribution on the revetment due to wave attack is known. Both the wave pressures and the calculated pressures underneath the revetment determine the uplift pressures on the coverlayer of the revetment. These uplift pressures can be compared with the "strength" of the coverlayer.
The wave pressures which were required as inputs for the numerical models were determined by means of physical model tests. Since only wave pressures on the slope had to be measured and the influence of wave impacts on the stability of a block revetment could be neglected, these pressures could be measured in a small scale model.

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The combination of a physical scale model and numerical models was used to evaluate the design of a dune toe protection which is now under construction in parts of the Danish North Sea coast.
The design of the block revetment is presented in this paper and the physical model tests described. A brief description of the numerical models is given together with the results of the calculations for this revetment. Finally the modifications in the design, based on the results of the calculations, are discussed.

2. Block revetment used as dune protection

On some parts of the Danish North Sea coast erosion has been very large, on average 3 - 4 m a year. This has caused some dunes to disappear and others to become very weak. As a result the low areas behind the dunes are open to flooding. On these stretches of coast it is necessary to stop the erosion and to re-establish the flood protection. The measures being taken against the erosion are a combination of onshore and offshore beach nourishment and low detached breakwaters parallel and close to the shore line. The flood protection is being re-established by building artificial dunes protected by a concrete block revetment. Concrete blocks are being used because:

a. They are cheap compared with other types of artificial coverlayers.

b. Denmark has no quarries close to the North Sea coast.

c. Concrete blocks look relatively atractive into the sandy coast environment.

d. Constructional procedures are relatively easy and a high quality can be achieved.

e. The concrete is very durable in a marine environment.

A sketch of the concrete block revetment is presented in Figure 1. Water level and wave conditions vary depending on the location. The conditions expected with a return period of 100 years, for the most exposed structure, are shown in Table 1.

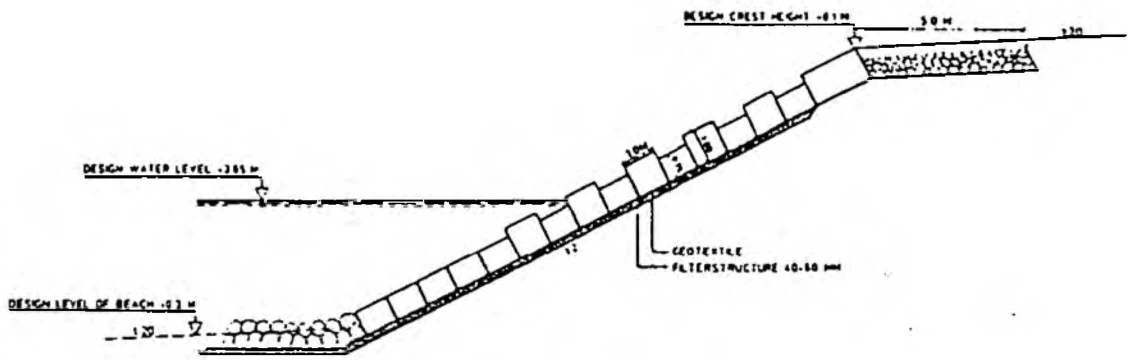

Figure 1: Original cross section for the design parameters given in Table 1

Waterlevel:		3.65 m above datum
Waves in a depth of 19 m	H_s = 8.2 m	
	T_p = 12 s	
Shore profile: slope	1:20	from -0.30 to -6.00 m below datum
	1:100	below -6.00 m below datum
Revetment slope	1:2	from - 0.30 to + 8.10 m above datum

Table 1: Design conditions

The design crest height at the various locations is taken as the sum of the high water level, the wind set-up and the maximum breaking wave height above still water level. For the conditions given in Table 1 the crest height will be 8.1 m. Since waves will run-up the slope to above the level of the block revetment, the first 5 m of the crest of the structure has been protected with rubble.
The toe of the structure has been designed at such a level, that there will be no damage by scouring during the design storm.
The blocks are placed on a filter structure of 40 - 60 mm rubble between two layers of geotextile. The purpose of the upper layer is to prevent the rubble layer from being filled with sand from above. The blocks are 0.75 m high and weigh 3,000 kg. Some of the blocks are 1.0 m high in order to introduce slope roughness.
The following questions were raised when evaluating the design:
- Can block thickness be reduced?
- Is a 1:3 slope preferable to a slope of 1:2?
- What is the influence of revetment roughness on run-up produced by using blocks of different height?

3. Physical model

Small-scale model tests were carried out in a wave flume to obtain information about the wave pressure distribution on the slope. The wave flume has a depth of 0.8 m and is equipped with a system to compensate for wave reflections. The tests were carried out with irregular waves on slopes of 1:2 and 1:3. Since only the wave pressures on the slope had to be measured in a physical model test (to provide inputs for the numerical models) it was unnecessary to model the revetment itself. Only the geometry of the revetment and the foreshore were of interest in the physical model and these were modelled in concrete. The model layout is shown in Figure 2.

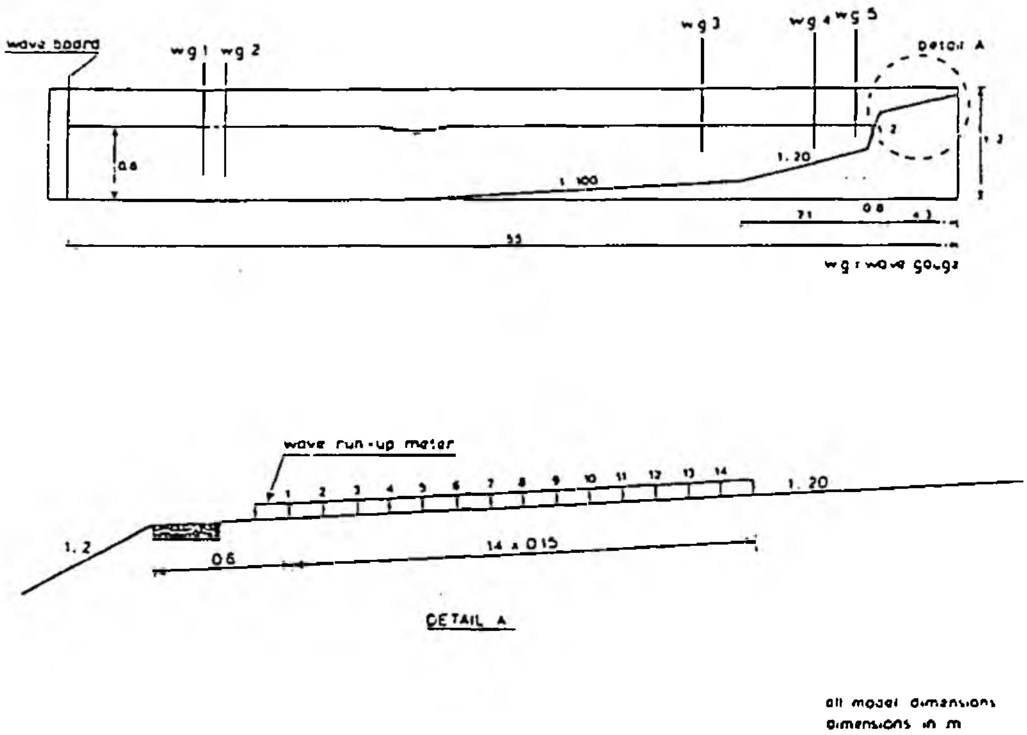

Figure 2: Model layout

Wave heights were measured on the profile with five wave gauges; run-up was measured with a wave run-up meter on the 1:20 slope, see Figure 2. The positions of the pressure gauges on the 1:2 slope are shown in Figure 3. Because wave impacts shorter than 0.2 s duration are not of importance to the stability of the revetment, the pressure signals could be filtered by a 6.25 Hz (in model 25 Hz) low pass filter. The low-pass filter is necessary to prevent interference with high frequencies. Most tests were run at a geometric scale of 1:16. The stability of the rubble on the crest was measured directly in the model tests and therefore this was modelled to the same geometric scale factor. The nearshore incident wave conditions for the model tests were calculated from the deep water conditions with the ENDEC computer program, Stive (1984).

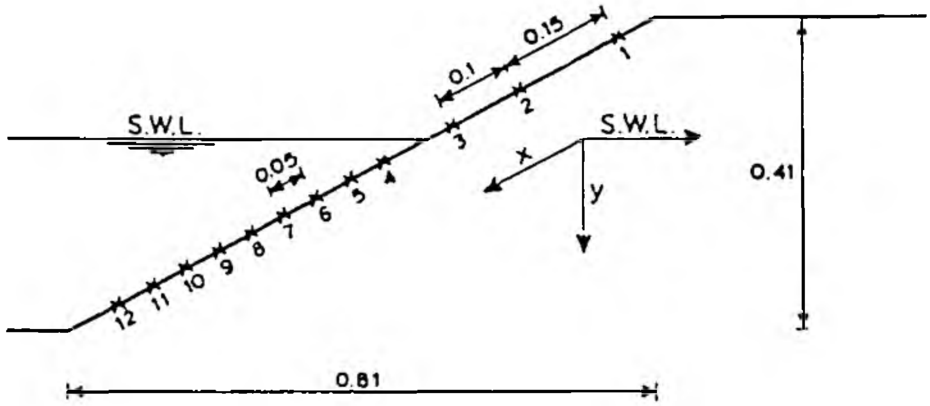

Figure 3: Location of wave pressure gauges on the 1:2 slope

The model tests indicated that the wave runup on the 1:20 slope can be considerable and during the design conditions, Table 1, and with a crest height of 8.2 m in prototype, more than 10% of the waves passed the highest indicator of the wave run-up meter. This implies a wave run-up of over 43 m up the 1:20 slope. These run-up values led to an investigation of the run-up as a function of the crest height. The results are shown in Figure 4, for the design conditions given in Table 1.

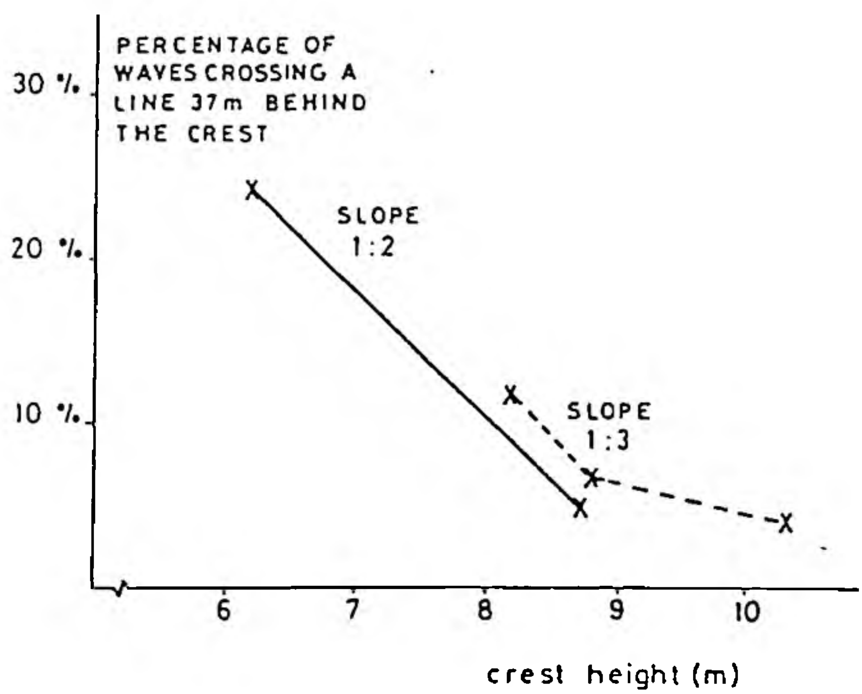

Figure 4: Percentage of waves crossing the 37 m line (see text) as a function of the crest height

On the 1:20 slope a line 37 m from the top of the revetment in prototype was chosen to indicate the extent of run-up, because information was available about the waves crossing this line also for the tests runned at different geometric scales.

More waves passed the 37 m line with the 1:3 slope than with the 1:2 slope, but the difference was small.
It appeared that the increased roughness, obtained by using blocks of different height, would led to a 10% reduction in the number of waves crossing the 37 m line during design conditions. During moderate storm conditions this reduction would be even higher. With a significant wave height of 3 m in deep water the reduction would be up to 25%.

The wave pressures measured in the physical model have been used in the numerical model. This topic is discussed in the following chapter.

4. Numerical models

In order to evaluate the stability of the revetment, it is essential to determine the uplift pressures on the blocks. These pressures are determined by the difference between the pore pressure in the filter layer under the blocks and the wave pressures on the blocks. If the mean uplift pressure on the block is larger than the pressure corresponding to the weight of the block plus the friction forces between adjacent blocks then a block can be lifted out of the revetment. The stability of the sand underneath the revetment is also important since no sliding may occur. These stability criteria cannot be investigated in a small scale model test because of the soil mechanical scale effects which occur in such a test. A large scale investigation is a possibility, but in this project it was decided to use a numerical approach to evaluate the stability criteria. The uplift pressures on the blocks and the stability of the blocks were calculated with the STEENZET/1 program, to calulate the pore pressure in the filter layer and the resulting block movement (see Section 4.1).
The pore pressure distribution in the subsoil was calculated with the STEENZET/2 finite element program which can be used to calulate the pressure distribution in both the filter layer and the subsoil, assuming no block movement (see Section 4.2). This pore pressure distribution was used in a stability calculation to evaluate the geotechnical stability against sliding. These numerical models are described briefly in the following sections.

4.1 STEENZET/1

The pressure distribution in the filter layer is determined by the flow through this layer and the flow through the joints around the blocks. The flow in the subsoil itself has no influence because of the low permeability of the sand compared to the permeability of the filter layer. Assuming a flow parallel to the slope in the filter layer, a flow perpendicular to the slope in the coverlayer and a coverlayer permeability which is concentrated in the "horizontal" joints, see Figure 5, the following formula can be derived for the potential in each joint:

$$\phi_i = \frac{1}{1 + 2\frac{kbD}{k'l^2}} \left(\frac{kbD}{k'l^2} \left(\phi_{i-1} + \phi_{i+1} \right) + \phi_{t,i} \right) \qquad (1)$$

Where: ϕ_i : the piezometric head in the filter layer near joint i (m)

$\phi_{t,i}$: the piezometric head on the revetment near joint i (m)

b : the thickness of the granular sublayer (m)

D : the thickness of the blocks (m)

l : the length of the blocks (m)

k : the permeability of the filter layer (m/s)

k' : the permeability of the cover layer (m/s)

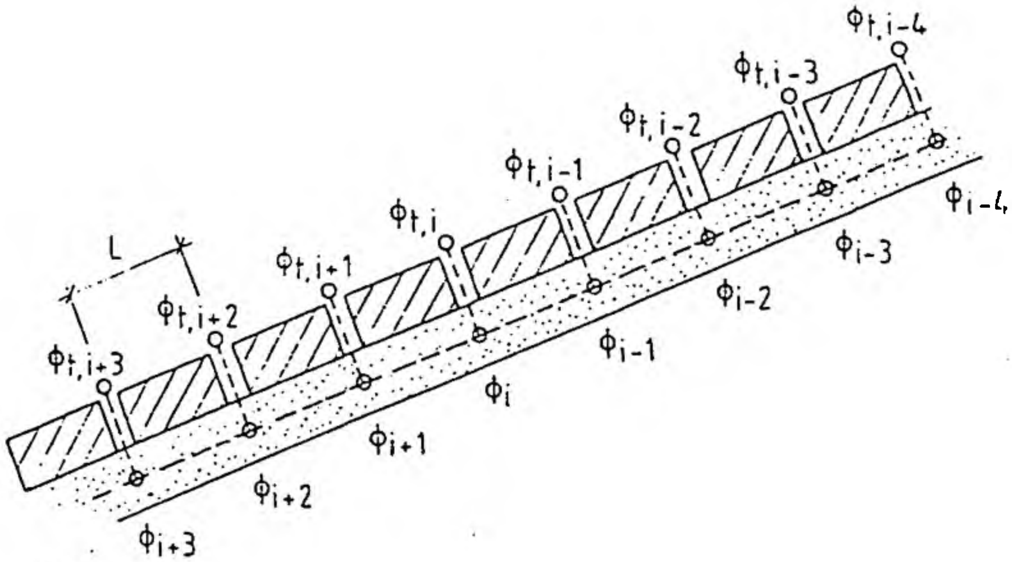

Figure 5: The STEENZET/1 finite difference scheme

At the phreatic surface the piezometric head in the filter layer is given by the position of the phreatic surface. At the lower end of the revetment the condition $\phi_{i+1}=\phi_{i-1}$ is assumed. If there is no phreatic surface, $\phi_{i-1}=\phi_{i+1}$ at the top of the revetment. The potential distribution in the filter layer can be solved numerically with Equation (1) for all joints if the different values of the piezometric head on the revetment ($\phi_{t,i}$) and the position of the phreatic surface are known. In the STEENZET/1 computer program this solution is obtained using an iterative scheme. Results of den Adel (1987) can be used to calculate the permeability of the filter layer. On the basis of permeability tests den Adel described the coefficients a and b in the Forchheimer relation ($i = av + bv^2$, with i the hydraulic gradient and v the filter velocity) as a function of the porosity and d_{15} of the granular material. The permeability of the cover-layer is determined by various flow resistances in and near the joints as described by Klein Breteler and Bezuijen (1988). Turbulence in the flow through the joints is included by adapting the permeability of the coverlayer to the calculated gradient during each iteration cycle. A linear flow condition is used in the filter layer.

The turbulent flow has therefore to be linearized. This linearisation is performed in such a way that the flow velocity calculated with the linear flow relation is the same as the flow velocity calculated using a turbulent permeability relation at a gradient equal to $\sin(\alpha)$, with α the slope angle.

The piezometric head on the revetment ($\phi_{t,i}$) is determined from measured wave pressures by linear interpolation of the results of the pressure gauges. The wave pressures measured in the small scale model can be transferred to prototype values by using Froude's law. The measured pressures can be scaled up using the geometric scale and the time scales using the square root of that scale. This means that the 50 Hz sampling frequency in the model tests, at a scale 1:16, corresponds to a 12.5 Hz sampling frequency in prototype.

The ϕ_i values were calculated for the various time steps using different values of $\phi_{t,i}$. The position of the phreatic surface is calculated for each time step by taking the still water level as a starting position and adapting the phreatic level to the nett flow of water in the filter layer. In this way the potential distribution can be calculated for each sampling of the wave pressures over a period of several waves. The results of this program have been compared with the results of large scale model tests and show good agreement (Bezuijen et al (1987)).

If the mean calculated uplift pressure on one block exceeds the pressure corresponding to the weight of the block and the friction forces, then a block will start to move. This movement can also be calculated in the program using a simple routine. The uplift pressure, multiplied by the block area, determines the uplift force. Subtracting the weight of the block and the friction force gives the nett force F_n, which causes block movement. The acceleration of the block can then be calculated using the well known relationship:

$$F_n = M_b \cdot a$$

Where: M_b : the mass of the block (kg)
a : the acceleration of the block (m/s^2)

Double integration of the acceleration giving the block movement.

The movement calculated in this way however is too large. In reality the block movement is less, because the moving block itself causes a pressure decrease in the filter layer. A routine that includes the influence of the moving block on the pressure distribution has been developed. This routine was not used in this project because, due to lack of experimental evidence, it was not certain that the results would always be on the safe side.

4.2 Results of STEENZET/1 calculations.

Calculations were made for slope angles of 1:2 and 1:3 and various coverlayer and sub layer permeabilities. The influence of the slope on the maximum uplift pressures appeared to be small. This mears that a 1:2 slope is in fact the most economical. The results of a typical calculation are shown in the Figures 6 and 7. The black area shows the measured wave pressures and the grey area the uplift pressure, but only when larger than corresponding to the weight of the blocks. The vertical height of the area represents the pressure, in metres of water, at the location were the pressure was measured. Figure 6 shows the position of the wave front at maximum wave run down; there is hardly any water on the revetment and as a consequence the wave pressures are very small.

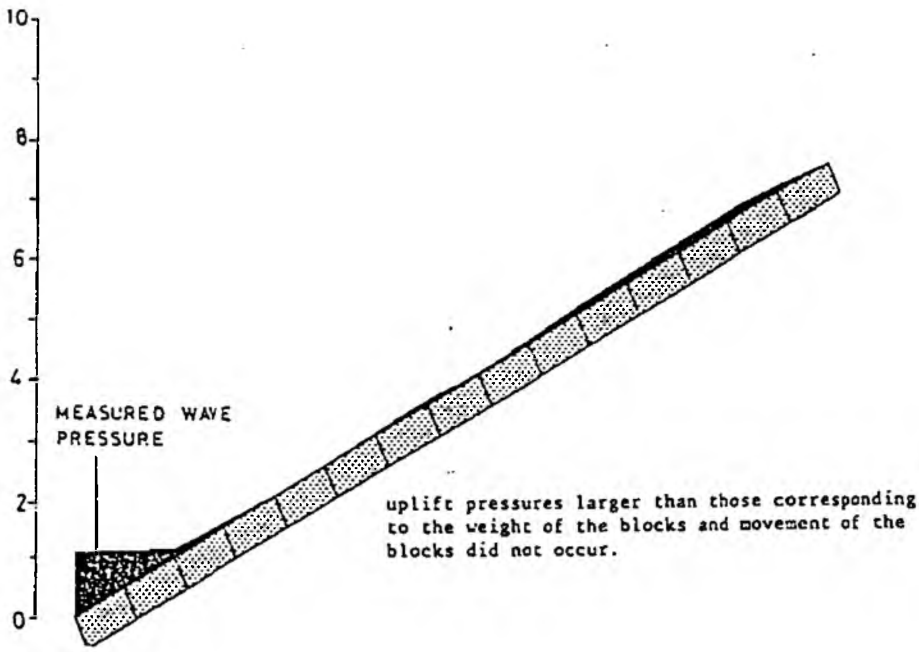

Figure 6: Wave pressure measured during wave run down. Results of STEENZET/1 calculations

Figure 7 shows the pressure distribution just after wave impact. From these figures it is clear that, for the revetment being studied the highest uplift pressures can be expected just after wave impact, when two areas of high wave pressure occur on the revetment separated of an area of low pressures. The high wave pressures are transmitted through the filter layer, leading to high uplift pressures in the area with small wave pressures.

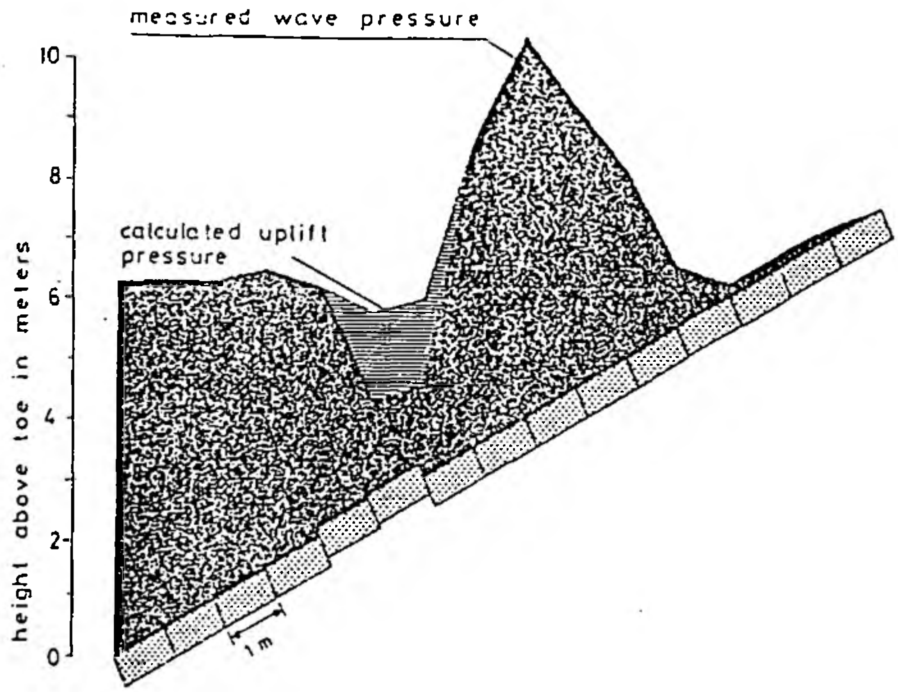

Figure 7: Wave pressure measured after wave impact. Uplift pressure when lagrger than corresponding to the weight of the bloks and calculated movement of the blocks. Results of STEENZET/1 calculations

Although during wave run down the filter layer is almost completely filled with water, the maximum wave run down does not appear to be a critical situation. The uplift pressure is never larger than the pressure that corresponds to the weight of the blocks. Due to the hydraulic gradient in the filter layer the pressure distribution in that layer is by no means hydrostatic, leading to small pore pressures and uplift pressures.

The permeabilities of coverlayer and filter layer had a distinct influence on the uplift pressures. The lowest uplift pressures were found for a minimum filter layer permeability and a maximum coverlayer permeability. The permeability of the coverlayer is determined by the permeability of the joints and is reduced due to the geotextile between the blocks and the filter layer. The design was therefore adapted and the geotextile removed. Without the geotextile some sand will be transported into the filter layer. However this sand will only reduce the filter layer permeability. Dutch experience has shown that this sand never causes trouble.

A design criterion had to be chosen for determining the block thickness. The criterion, no block shall ever move during design conditions, leads in fact to a very large block thickness and is too strict to be of practical use. The clamping forces between the blocks are completely neglected; however, due to these clamping forces, the strength of the revetment is increased significantly. Pulling tests have shown that sometimes forces more than 10 times the weight of a block are necessary to extract it from the revetment (Burger 1985). However the reliability of this extra strength decreases if calculations show that blocks immediately above and below can move at the same time. The following design criterion was therefore used: the revetment is considered to be stable if calculations with STEENZET/1 show that only one block moves and that the movement calculated is much smaller than the thickness of the block. In reality this will be a stable situation due to the clamping forces.
Apply this criterion a block thickness of 0.5 m was found, assuming a filter material with d_{15} of 20 mm and an average joint width of 5 mm.

An unexpected result was the influence of the toe permeability on the calculated uplift pressures. This was simulated in the calculations by changing the permeability of the lowest joint in the revetment; Figure 8 shows this influence. The increased permeability leads to higher piezometric head in the lower end of the filter layer and, as a consequence higher uplift pressures.

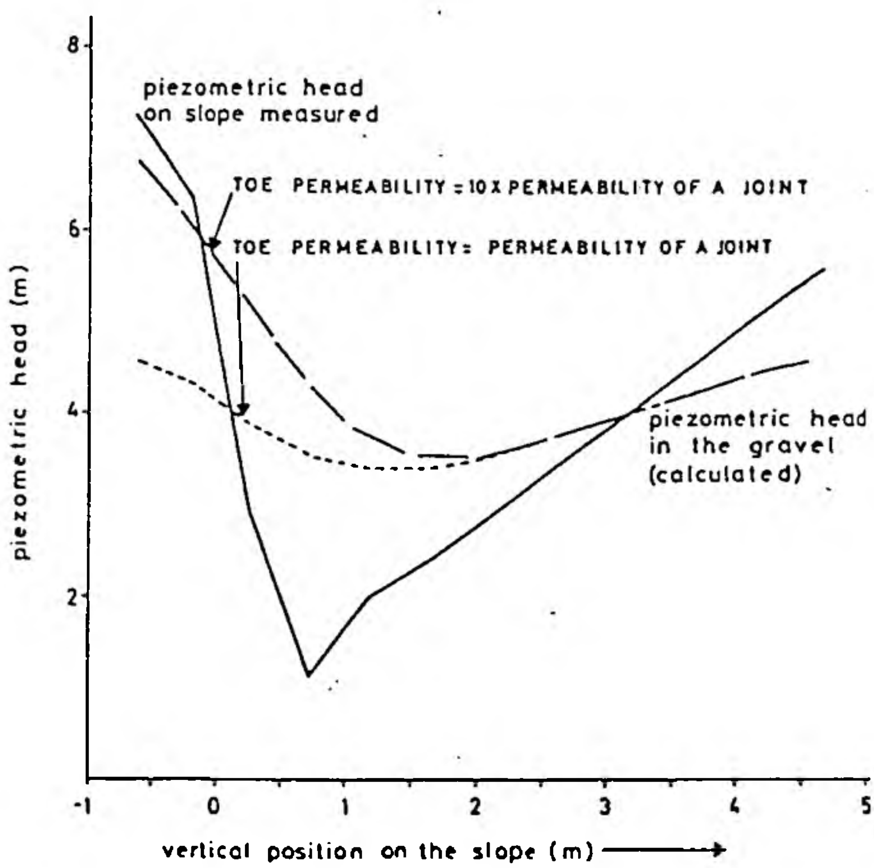

Figure 8: Influence of toe permeability on uplift pressures

4.3 STEENZET/2

The results of the STEENZET/1 calculations showed that a 1:2 slope would be more economical, because less concrete is needed. The calculation however omits the effects of sand body sliding. This kind of failure can occur locally when the grain stress in the sand is reduced by seepage.
The pore pressure distribution in the subsoil due the wave attack was therefore calculated with the STEENZET/2 program.

STEENZET/2 is a 2-dimensional finite element program specially developed to calculate the pore pressure response under revetments due to wave attack. The model is based on what is referred to as the storage equation:

$$\nabla q = C\, d\phi/dt \tag{3}$$

Where:	ϕ :	the piezometric head	(m)
	q :	the specific discharge	(m/s)
	C =	$\rho g n \beta$	(1/m)
	ρ :	the mass density of the fluid	(kg/m³)
	g :	acceleration due to gravity	(m/s²)
	n :	porosity	( )
	β :	compressibility	(m²/KN)
	∇ :	d/dx, d/dy	

With solutions of this equation it is possible to investigate the influence of the air content of the pore water on the results. The program can handle turbulent flow on the base of the Forchheimer relation and various materials can be considered, Measured wave pressures can be used as boundary conditions in the same way as in the STEENZET/1 program. A more extended description of this program is given by Hjortnaes-Pedersen et al(1987). The pore pressure distributions calculated with STEENZET/2, were used in a stability analysis as described by Bishop. This method is well known and is described in, for instance Terzaghi and Peck (1967).

4.4 Results of STEENZET/2 Calculations

Calculations were performed for the 1:2 slope and the block thickness indicated as stable by the STEENZET/1 calculations (0.5m). The element mesh used is shown in Figure 9. The model tests showed that a large amount of overtopping can be expected during design conditions and it was therefore assumed that, during these conditions, the sand body directly behind the revetment would be completely filled with water. Outward directed hydraulic gradients perpendicular to the slope, are most dangerous for revetment stability. The wave period which led to the highest uplift pressures in the STEENZET/1 calculations was used as a (time varying) boundary condition. Very little is known about the air content of the pore water and therefore calculations were run with different values of air content. Results are shown in Figures 10 and 11. In these figures lines of equal piezometric head are shown at the moment of maximum outward directed hydraulic gradient; the wave boundary condition is also shown at this particular moment.

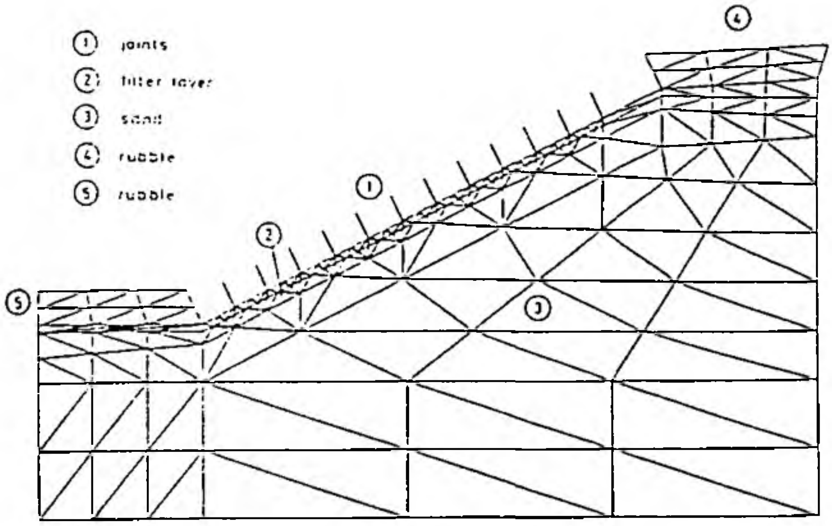

Figure 9: Finite element mesh used in STEENZET/2 calculations

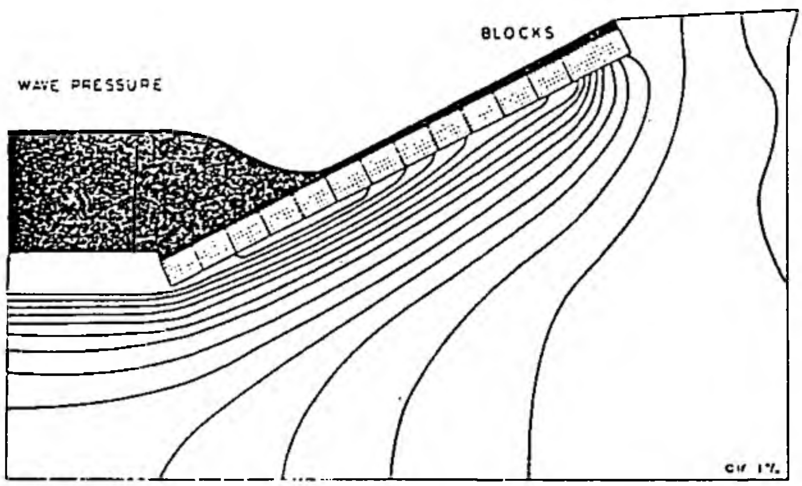

Figure 10: Measured wave pressures and calculated lines with epuipotential. Results of STEENZET/2 calculations -assumed air content in the pore water: 1%

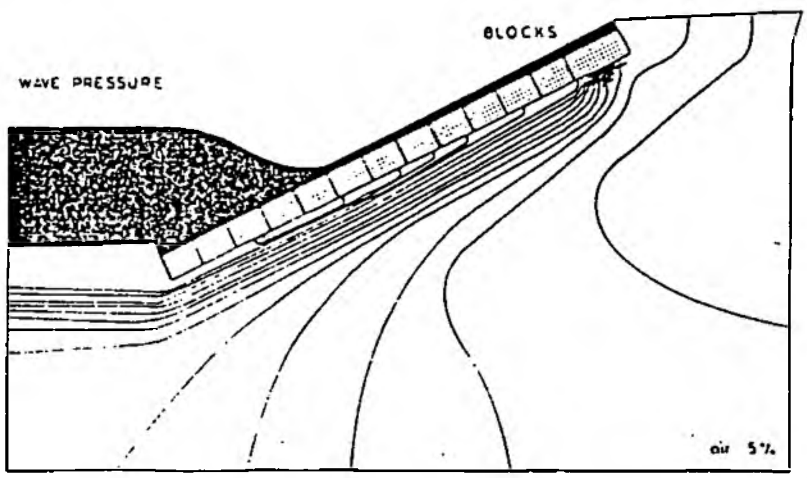

Figure 11: Measured wave pressures and calculated lines with epuipotential. Results of STEENZET/2 calculations -assumed air content in the pore water: 5%

This wave condition was measured just after a period of rapid run down. Since Equation (3) is a transient equation, the boundary condition prior to this particular moment is also of importance. The figures clearly show the influence of the air content. The higher the air content, the higher the outward directed gradient. The stability calculations showed however that even with an assumed air content of 5%, the safety of the 1:2 slope against sliding is more than 1.5 with a friction angle of 35° for the sand, 40° for the gravel and schematizing the concrete blocks to a friction material with a friction angle of 25°. From these results it was concluded that the 1:2 slope will be stable against sliding during design conditions.

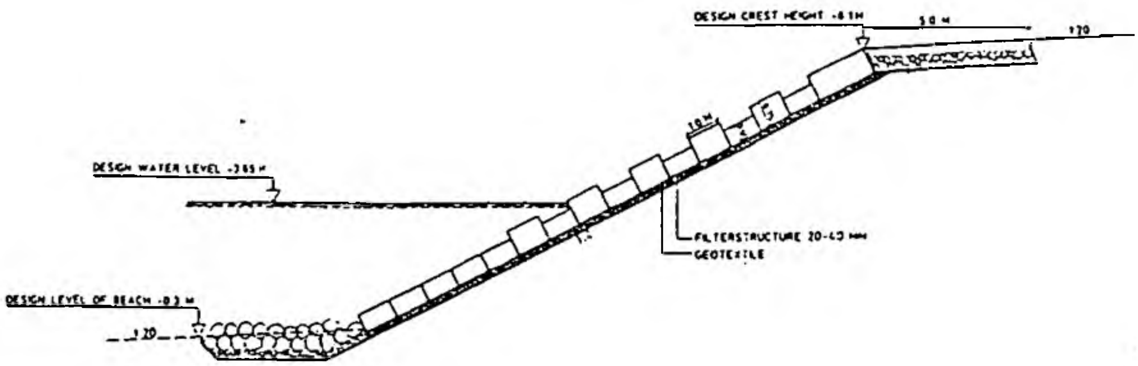

Figure 12: Adapted design based on model studies

5. Conclusions

The combination of physical and numerical models can be a valuable tool in the design of a placed block revetment. As a result of this study the following adaptations were made to the design:

- a heavier rubble is used for the crest protection.
- the geotextile between the blocks and the filter layer is removed.
- a filter layer of relatively small gravel (16-32 mm) is used.
- During the manufacturing process the surface of the blocks is made irregular so that the joints will be about 5 mm wide.
- The geotextile between the blocks and the filter layer is replaced by a filter of relatively small gravel in order to reduce the uplift pressures. This makes it possible to reduce the block thickness from 0.75 to 0.5m.

The model tests showed that increasing the roughness of the slope by varying the thickness of the blocks reduces the wave run-up, especially during moderate storm conditions. According to the stability calculations a structure with a slope 1:2 is stable during design conditions. Since the difference in calculated maximum uplift pressure and measured run-up with a 1:2 slope and 1:3 slope is only small, a 1:2 slope is preferred because less concrete has to be used. Figure 12 shows the adapted design.

A total of 11,420 m of this revetment had been built by September 1988.

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APPENDIX K

"Coastal Protection Along the Danish Wadden Sea"

International Saltmarsh Management Symposium, Rømø 1989.

COASTAL PROTECTION ALONG THE DANISH WADDEN SEA

Per Roed Jakobsen*

PROTECTION CONCEPT

It may be generalized that major areas of the Danish Wadden Sea morphologically have been in dynamic equilibrium for quite a long period.

If we relate this to the low demographic pressure pressure on the islands Rømø, Mandø and Fanø and the peninsula Skallingen it is easy to comprehend, that major schemes for combatting classical coastal erosion have not been required. This may be in contrast to the much less favourable conditions in our neighbouring areas to the south.

However, larger protections schemes for the prevention against inundation of low lands notably valuable farm land have been build. A total of about 80 km of dikes fronting the sea today protect more than 30,000 ha of lowland laying below +5 m DNN.

This is a classical scenario for coasts flanking the Wadden Sea, but the Danish situation differ in the sense, that demographic, infrastructural pressure on the lowlands has been comparatively low except within the two urbanized areas of Ribe and Tønder.

Till recently Denmark had seperate laws for dike/storm flood protection and coastal protection, in 1988 the new "Coast Protection Law" integrated these concepts which follows from the quote:

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* Director
The Danish Coast Authority
P.O. Box 100, Lemvig, Denmark

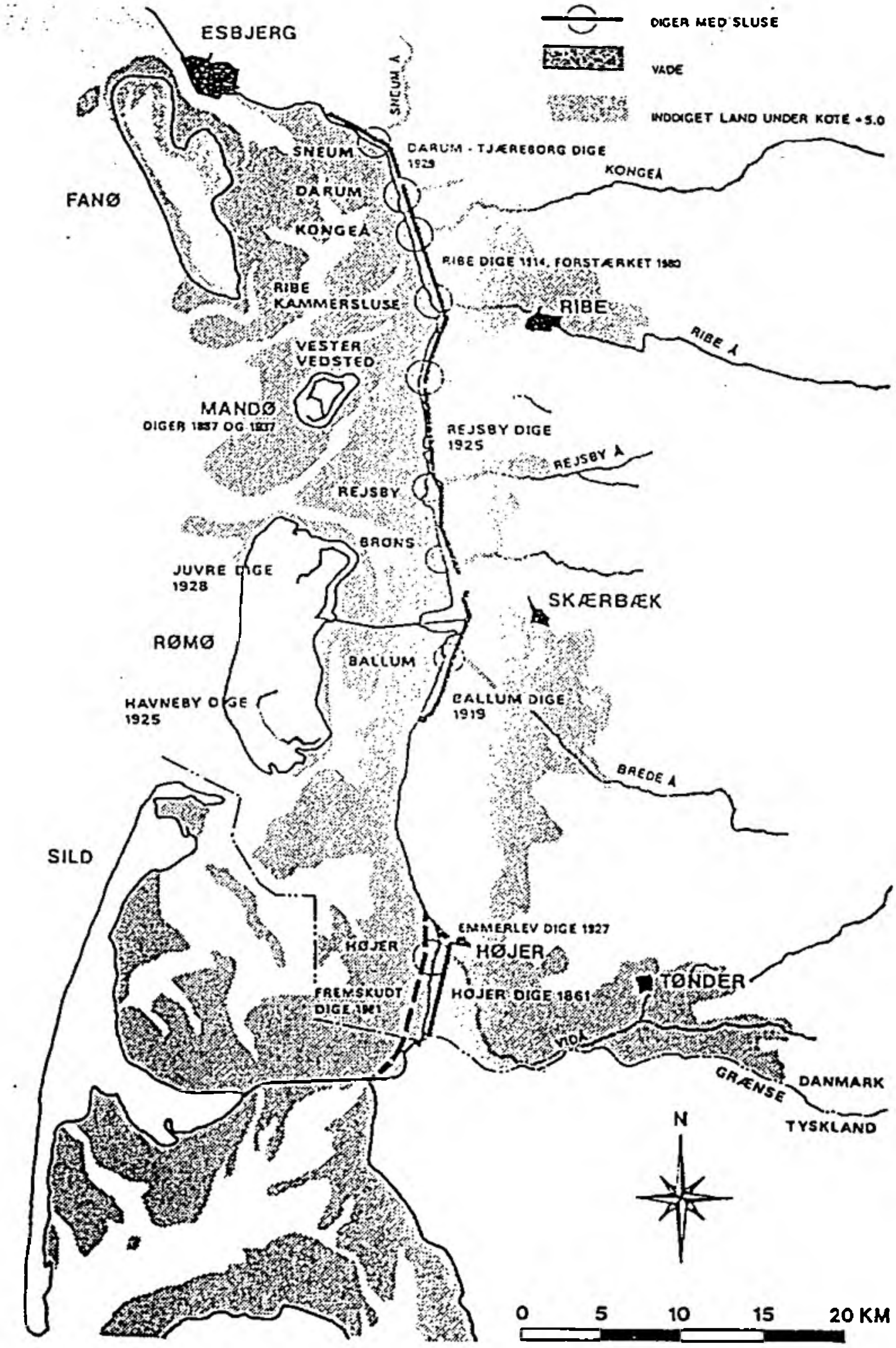
"The regional council can decide that works or similar undertakings shall be planned and executed for a given coastal reach to protect against inundation and or erosion".

The comprehensive work of the Danish Storm Flood Commission 1964 to 1975 resulted in recommendations for increase of safety levels for the Ribe and Tønder areas - to a socalled 200 yr criterion. Dike reinforcement schemes in Ribe and a forward/second dikeline in Tønder were subsequently constructed during the years 1978 - 1981.

Thereby the safety level for about 60% of the total low lands in the area has been increased, which has been obtained by improvement of the dike conditions over 25% of the total reach.

Comperative benefit/cost calculations for all dikes/lowlands have indicated that ratioes for remaining areas are well below Ribe and Tønder.

It appears on this overall background unlikely, that new diking schemes such as a moving forward of the front are to be foreseen for a considerable time to come.



The Dikes Along the Danish Wadden Sea.

MODERN DIKES

The plan lay out and shape of modern dikes are dictated by as well environmental as technical concerns of which shall only be mentioned a few:

A dike is an integral part of the surrounding environment and the safety level is a function of the state of not only the dike as such, but also the fronting foreland and even the tidal flats.

Dikes can still be built of natural materials such as sand and clay provided the dike profiles are shaped accordingly i.e. more voluminous and with slopes much flatter.

Modern dikebuilding has been made economically possible through the use of mechanical equipment such as excavators and dredgers, which can handle the large volumes required.

It is strongly believed, that the initial damage to the environment, which is caused by the moving around of large quantities of construction equipment and material, by and large is compensated by the improved quality of the end products, which harmonize well with the surrounding environment.

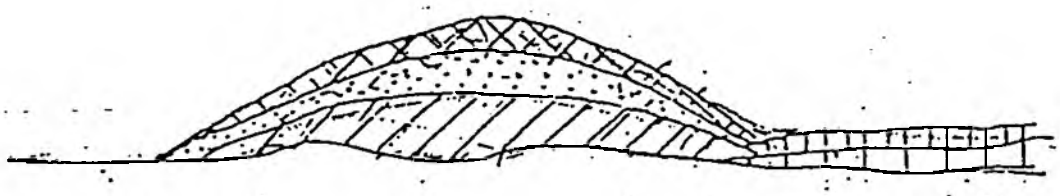
The figure shows the evolution of dike profiles over centuries.

A detailed description of the recent dike construction works in the Ribe and Tønder area are given in the references.

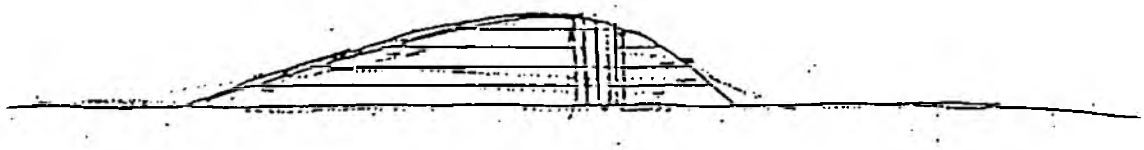
OUTLOOK

Land use patterns, agricultural economics and general ressource utilization within dike protected low lands have changed.

OLD DUTCH DIKE SCALE APP. 1:4(

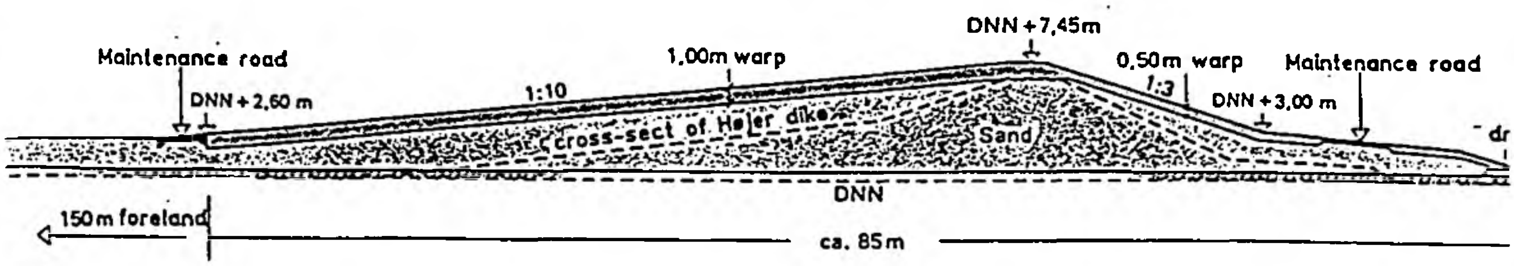


GERMAN DIKE PROPOSAL (BRAHMS) 1754 SCALE APP. 1:4



REJSBY DIKE; BUILT 1923-25 SCALE APP. 1:4

DANISH DIKE 1981 SCALE APP. 1:5



Evolution of Dike Profiles.

The legitimate needs that man has had over centuries to develop and settle in such areas is now increasingly measured against modern requirements to preservation of natural ressources and to some extend needs for space for recreational development.

These potential conflicts have in relation to coast protection been discussed in a fine and objective German pamphlet 1978 "Küsten und Naturschutz - nur ein Scheinkonflikt?"

The multidisciplinary group of authors concluded:

- The goals of modern coastal protection are identical with those governing the nature protection and preservation. Both are directed toward maintaining a biological highly active tidal area and wide and high forelands in order to provide protection against attack from the North Sea.

- The goals of the nature preservation and the coastal protection in the Wadden Sea are identical, because both are directed toward maintenance of land and seascape.

These statements prepared 12 years ago still hold valid to day although the future may set new requirements to which we have to respond.

One of them could be the Sea level rise which according to the latest predictions might be 0,25 - 0,4 m by year 2050.

The scientific back up of these hypothesis are still insufficient to justify concrete action, but for sure we will have to look out for possible morphological changes of the tidal flat systems over the years to come, because their actual state will be the significant indicators if the sea really is comming.

References:

Ribe Dige Reinforcement 1978 - 80 pamphlet.
(Can be obtained from the DCA)

Det Dansk-Tyske Dige
Der Deutsch-Dänische Deich
Sønderjyllands Amtsråd, Minister für Ernährung, Landwirtschaft und Forsten des Landes Schleswig-Holstein 1982.

Küsten und Naturschutz - nur ein Scheinkonflikt?
Husumer Nachrichten 1978.

Adaptive Options and Policy Implications of Sea Level Rise and Other Coastal Impacts of Global Climate Change.
IPCC Miami December 1989.

APPENDIX L

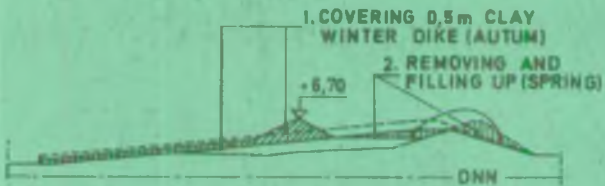
"Ribe Dige Reinforcement 1978-80"

WORK PROCEDURE

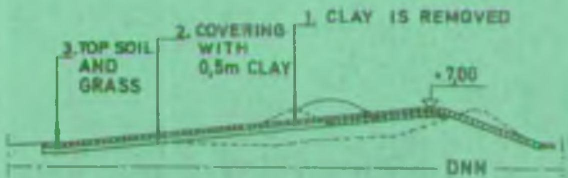
Head features of proceedings for earth work are illustrated by the sketches shown below.

A dam of foreland fill is pushed up to form a frame for sand fill, this is heightened in pace with the reclaiming of sand.

When the pumping is finished, the slope is regulated to an inclination 1:lo and the first ½ m clay is put on and compacted.



Before winther, a clay dike is made on the front slope. In spring, the back slope is removed to a new inclination 1:3 and fill is put on top of the new dike.



The clay dike on the slope is levelled, more clay is put on in layers of ½ m and compacted. Finally top soil is spread and sowed with grass.

The dike is constructed with up to loo cm height more than required in consideration to the calculated settlings. About 125 cubic m sand and about 5o cubic m clay are required pr. m dike.

ORGANIZATION

Organizing work is done by a building committee with 6 members appointed by the Minister of Public Works (2), Ribe county council (2), the involved municipalities and Ribe dike commission.

The State Treasury pays 6o% of costs, Ribe county council 2/3 and Ribe and Bramming municipalities 1/3 of the last 4o%.

The project for reinforcing and repairing of the 4 sluices is made by

COWIconsult A/S, Åbyhøj,

while the project for the dike it self is made by

KYSTINSPEKTORATET, Lemvig,

which is also in charge of construction accounts.

The work was offered to limited tenders among firms that were found qualified and by the tender held the 14th March 1978, bids from 11 firms/firm groups were given.

The lowest bid was received from

BOS & KALIS b.v., Papendrecht, Holland,

with an offer sum of about 54,3 mill. D. kr. excl. VAT

The work began in April 1978 and is to be completed the 1st November 198o.

The necessary area for the extended dike profile is, under provisions of the building act for the construction commission, obtained by expropriation and in the same way, areas on 3 locations are obtained for winning of clay to cover the dike.

RIBE DIGE

REINFORCEMENT 1978-80

BACKGROUND HISTORY

Ribe Dike was built in 191o-13.
Previously, several decades had past with discussions and attempts to create interest for a dike project. In the last half of the 19th century, several sketch plans appeared, but first when a number op plot owners, in 19o4, requested "Det danske Hedesleskab" to draw up an estimate, things began to happen.
On basis of a revised project, the "Rigsdag" passed law no. 92 og 3oth April 19o9 for building of a dike from Vester Vedsted to Store Darum in Ribe county.
Of the estimated expense of 1.78o.ooo D kr., the State Treasury was to pay 1.o55.ooo D kr., the plot owners 675.ooo D kr. and the county funds 5o.ooo D kr. The project used was worked out by "Det danske Hedeselskab" and included about 15,3 km dike, with wing dikes, a 2,7 km southern and a o,7 km northern, 4 sluices, 3 automatically regulating drainage sluices and in Ribe canal, a lock.
The dike protects a marsh area of about 9o sq. km which, among other things, includes the town af Ribe with about 8.ooo inhabitants.
After a flood on 3oth August 1923 the dike top was heightened.
The flood catastrophes in Holland, in 1953, and in Hamburg, in 1962, aroused renewed debate about the dike security and a commission was established by the Ministry of Public Works.
In the commission's report of February 1975, a reinforcement af Ribe Dike was recommended and in accordance to that, the "Folketing" passed law no. 319 of 1oth June 1976 for reinforcement of Ribe Dike.

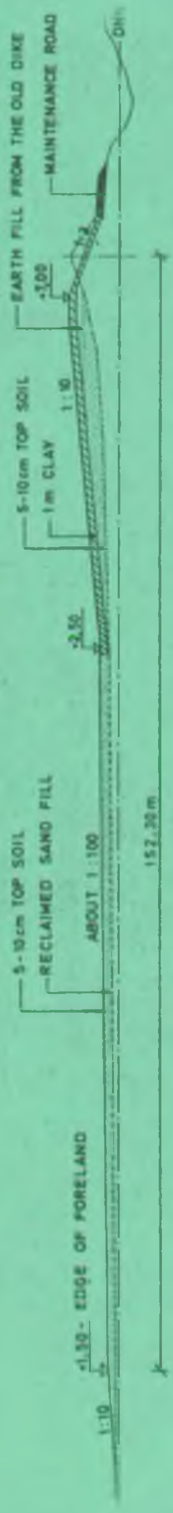
THE PROJECT

The dike is being totally reprofiled.
In fixing the foot of the back slope, the new profile will be inserted with an inclination of 1:3 on the back slope, the top at level DNN + 7,oo m with a width of 2,5 m, front slope with inclination 1:1o, which either runs over to the existing foreland, where it is sufficiently high, or at level + 2,5 m to a foreland of reclaimed sand with up to 1oo m width. Along the inside of the dike a 3 m wide maintenance road, with yielding places, will be made covered with an asphalt grouted gravel layer.
The dike's core consists of sand fill reclaimed from the tidal flats and the face is of clay which is recovered from 3 clay pits within the dike. The clay is being compacted, a 5-1o cm thick layer of top soil is spread and is finally sowed with a special grass blending.
The dike is estimated to resist floods which occur with an average time interval of 2oo years, that is a water level at + 4,85 m, where to different supplements for, among other things, wave run up and a rise of the mean sea level are added.

<u>Sluices</u> are rebuilt and fortified in accordance with the new dike profile.
The drainage sluices for Vester Vedsted Bæk, Kongeåen and Darum Bæk get new higher front walls and the existing concrete constructions will be reinforced by insertion of pre-stressing cables.

At Ribe lock, new edges, on the front side, new slope and bottom protection will be carried out. Before the reinforcement work, all sluice gates have been renewes or thoroughly repaired.

CROSS SECTION OF THE DIKE



APPENDIX M

"Coastal Drain System"

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YOKOHAMA

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Coastal Drain System
- a new approach to coastal restoration

SYNOPSIS The loss of beaches threatens recreative revenues, structures and has a direct impact on local and national economies. In combatting the erosive forces from wave actions soft engineering solutions are likely to be more effective than structional defences. The Coastal Drain System is a new effective soft approach to coastal erosion control and beach restoration which has no impact on human activity and the environment. By reducing the hydraulic pressure, the system produces gradient towards its drain, cut-off the natural ground water seepage and creates and unsaturated zone of depression under the beach face which allows downwards percolation of water from the up-rush. This reduces the backswash on the beach face limiting the erosion process while depositing more sand on the beach with a changed and more stable profile. Full-scale controlled facilities in Denmark and USA have shown that the system does not even halt the erosion but causes substantial accretion as well.

INTRODUCTION

Many different approaches have been made in attempt to solve or alleviate the problems of beach erosion. Hard engineering such as revetments, seawalls, groins, breakwaters and jetties normally offer only a short term respite merely serving to delay the inevitable - or even aggravate the ultimate losses that will occur during an infrequent event. Most of these constructions introduce serious long term detrimental effects on downstream beaches and have at the same time substantial adverse environmental effects.

For years Beach Nourishment has been considered the most effective response to the erosion of beaches and at the samt time a fair protection of the inland since a major part of the wave energy will be absorbed on a wide sandy beach. A well-known problem with beach nourishment is that sometimes it does not last.

In same cases a significat portion of the new sand is lost during the next storm or by the natural profile adjustment if the sand is not placed carefully in the profile.

A new approach to the alleviation of beach erosion problems has recently been introduced and tested in practice - The Coastal Drain System (Vesterby, 1987). This system causes artificial interference with natures morphology through a localized slowdown of one natural process, and speed-up of another.

It involves permanent installation of pipes and pumps, but is not a visible eyesore or physical obstruction as almost all components are buried. Extensive long-term, controlled full-scale demonstrations have shown the positive effect from the Coastal Drain System and no noticeable side effects on downstream beaches (Hansen, 1986; Terchunian, 1989).

THE COASTAL DRAIN SYSTEM

In Denmark in 1981 the North Sea Research Centre required large volumes of filtered seawater (400 m^3/hour) for aquaria and wave tanks, but primarily as a source of heat for a heat-pump system. The author proposed and designed a "horizontal" well, and it was installed below sea level and parallel to the shore line just inland of the high water line at Hirtshals, Denmark (Figure 1).

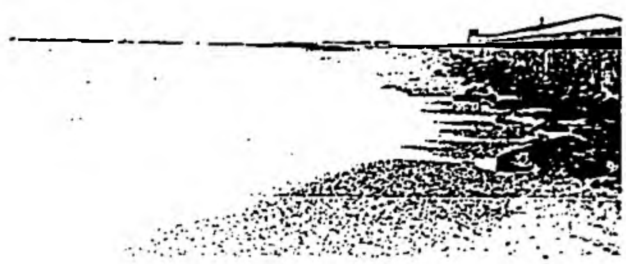

Fig.1 Beach at Hirtshals, before installation

This novel well, using the sand of the beach as a filter, produced the required quality and quantity of seawater - for about two weeks after which it was found that the amount of water was continuously tapering off.

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A site investigation showed that the slotted well pipe had not clogged, but the shore line was several meters farther from the well line that it had been initially, thus greatly lengthening the filter path of the intake water and thereby decreasing the yield of the well. The water supply quantity problem was solved by installing a second horizontal well as an extension of the first.

The use of this water in the heat pump system required full-time pumping from the filter system during the winter. It was noticed that the beach in the vicinity of the Coastal Drain System grows wider than narrower through the winterstorm season (Figure 2). Strong winds piced up the dry sand and blew it up to and over the sea wall into the city of Hirtshals.

Fig.2 Same as Fig.1 duning operation of the Coastal Drain System

Snow fences were installed to control the blowing sand, and sand dunes built higher and higher. Eventually this "excess" sand has been trucked away to nourish a nearby beach in an amount of 25,000 m³ every year.

PRINCIPLE OF FUNCTION

Some of the scientific principles behind the effect from the Coastal Drain System have been known for a long time (Duncan, 1964; Emery and Foster, 1948; Grant, 1948; Harrison et al, 1971; Harrison, 1972; Holland, 1972; Waddell, 1976) and small-scale tests performed (Chappel et al, 1979; Kawata and Tsuchiya, 1986; Machemehl et al, 1975; Sato 1986) but never ~~reduced to~~ practice.

Wave action brings sand as bed load onto the beach face by the wave rup-up and the returning bach swash takes sand off the beach.

The net effect under a specific set of conditions (wave period, wave height, beach slope, etc) may be either negative or positive. The balance may be tipped towards accretion by low-frequency, gentle waves during the summertime and towards erosion by higher-frequency, steeper waves from storms usually associated with wintertime.

With gentle waves, there is sufficient time between each wave run-up for a substantial portion of the water in the upper beach face to soak down to the water table, leaving a zone of unsaturated sand which can absorb a small portion of the next wave run-up. The result is that less water runs off the beach face than runs up and thus less sand is carried away than was brought to the beach face.

With steeper, high-frequency waves there is not enough time between waves for water to drain out of the upper beach face. This zone remains saturated and all the run-up from one wave runs back off. Because the upper beach face sand is saturated, sand grains are more readily incorporated into the runn-off bed load resulting in net erosion. The ground water table may actually become slightly elevated, causing a seaward seepage through the beach face, further enhancing erosion by the backswash.

The Coastal Drain System works by lowering the water table and creating an unsaturated zone under the beach face. This is accomplished by pumping water out of a buried almost horizontal slotted pipe.

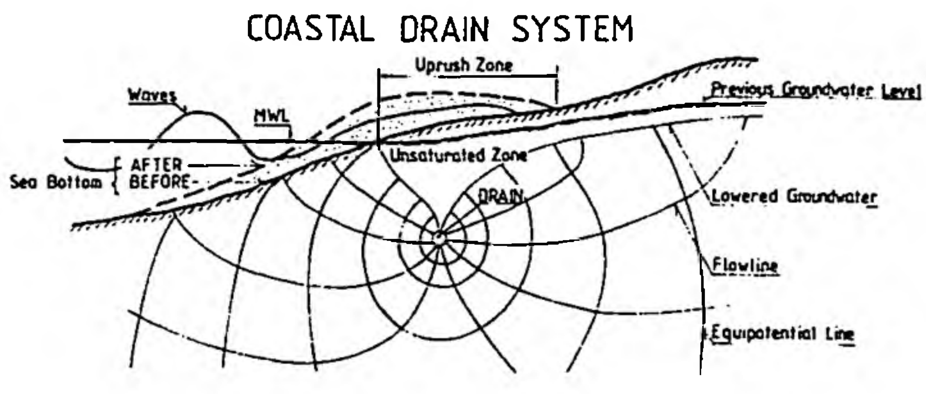

Fig.3 Cross-section lowered water table. Principles.

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The unsaturation allows downwards perculation of wave run-up all-season similar to that occuring during summertime low-frequency waves. The linear zone of lowered water table further acts to cut-off the local ground water flow towards the sea, and the reduced hydraulic pressure in the substratum under the seabed and the uprush zone forces the water to flow through the border between the water and the substratum towards the drain system (Figure 3), thus stabilizing the slope, reducing the return swash, the velocity of the bed load transport and "positive seepage forces" on the beach face, it decreases the erosion effect of wave run-off and leaves more sand on the beach.

Because of the complexity in the determining parameters for calculating the efficiency of the system, attempts have failed to cope with the factual results (Bruun, 1989).

Comprehensive monitoring shows that the "additional" sand apparently comes mostly from beach drift, but that downstream beaches do not suffer from any significant or measurable retreat (Hansen, 1986). On the contrary adjacent downstream beaches have benefitted by volumes of sand leaked from the continuously replenished bulge of sand in front of the drain system (Terchunian, 1989).

Downstream beaches are not starved or eroded because the Coastal Drain System does not block or divert the nearshore longshore drift of sand out to an area further off-shore.

DESIGN OF INSTALLATION

The design and installation of a Coastal Drain System is site specific - many factors must be taken into consideration. The method depends upon adequate permeability to allow drainage at a sufficient rate, wave climate, tidal range, slope of beach face, shape of nearshore bottom profile, quantity of gross nearshore drift, and direction and frequency of storm events.

A plain view of a typical installation is shown in Figure 4.

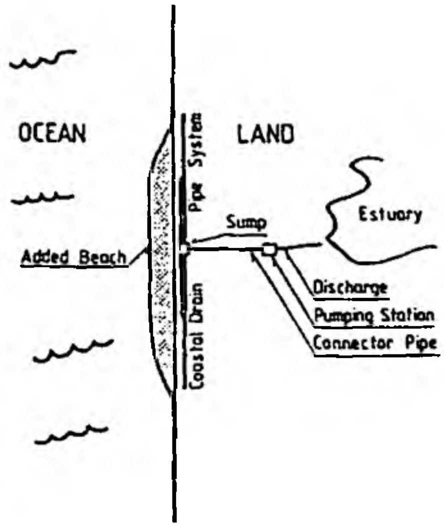

Fig.4 Plan view of installation

The output from the pump station can be discharged out into the sea, or - as it is pure filtered water be used in desalination plants, seawater swimming pools, or to oxygenate stagnant inland lagoons.

CONTROLLED DEMONSTRATION FACILITIES OF COASTAL DRAIN SYSTEMS

In 1985 a full-scale, controlled demonstration facility was initiated along the extremely wave-battered North Sea coast at Thorsminde (Jutland), Denmark, where the seasonal fluctuation of the coastline normally is ± 15 meters with an average erosion rate of 4 meters per year, Hansen, 1986). The Coastal Drain System was installed along a 500 meter stretch of beach, after extensive pre-installation surveying of control (untreated) zones both upstream and downstream of the test zone.

Exclusive monitoring (beach profiling) of the control zones and the test zones have been carried out over a six year period.

Operation of the system quickly stabilized the beach (halted the erosion), and accretion (widening and raising of the beach) took place for several months until a balance was achieved with a costline stabilized approximately 25 meters in front of the drain line. Brief episodes of retreat caused by severe storms were quickly "healed".

In order to distinguish the effect of the system from longshore migration etc, the system was closed down for a period of one year resulting in erosion back to - and behind - the start position of the borderline.

The measured effect of the system between level 0 m and +3 m given in m^3 sand accreted per meter of shoreline appears from Figure 5 (next page) not taken into account the sand volume deposited in the nearshore accordingly adjusted profile. The deposited sand here causes the waves to break in further distance from the inland.

The demonstration facility established 1988 at Hutchinson Island, Florida, USA, has shown similar results (Terchunian, 1989).

CONCLUSION

A high-technology, effective, and environment preserving method for beach restoration and management - The Coastal Drain System - has been developed and extensively tested in Denmark and USA. The method effectively stops beach retreat, widens and built-up beaches, and quickly recuperates storm erosion events.

The Coastal Drain System can not substitute nourishment in all aspects but the ability to re-establish and stabilize the shoreline makes the system particularly well-suited for use in connection with a beach nourishment programme: when installed concurrently the Coastal Drain System will efficiently hold the beach nourishment in place for a long period of time before further nourishment is needed.

ACKNOWLEDGEMENTS

Portions of this work (in particular the installation at Thorsminde and the controlled tests of the system) were supported by the Danish Foundation for Support of Development of New Technology, the Danish Coast Authority, and the Danish Geotechnical Institute.

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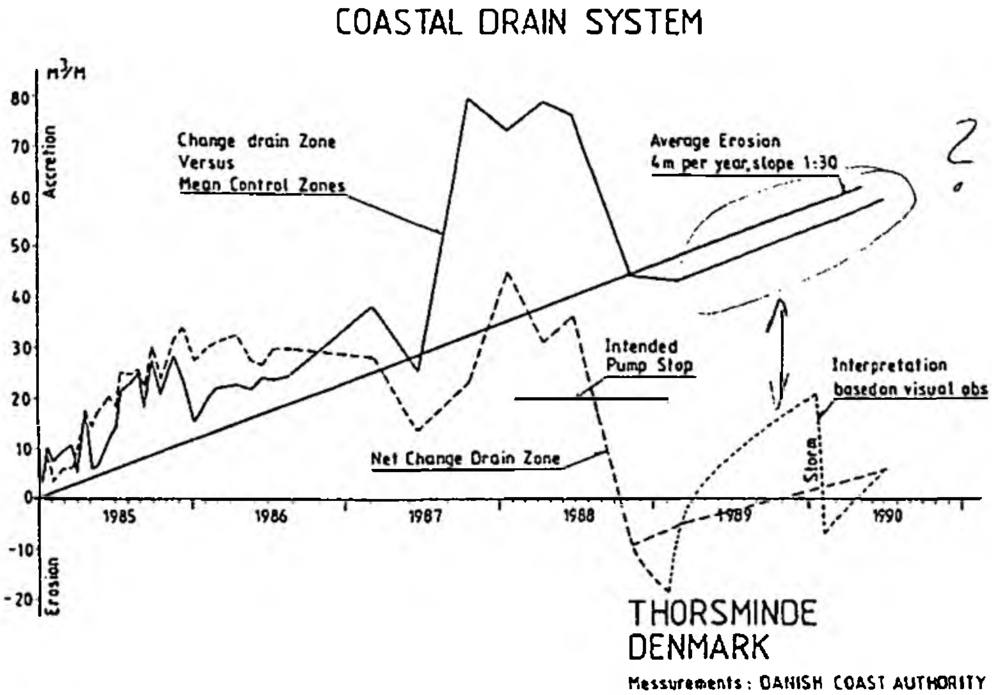

Fig.5 Summary of profile measurements. Accretion at the beach between level 0 m and +3 m.

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