Márcia Esteves Cabarrão

Urban Development In Vulnerable Coastal Lowlands. The Study Of Aveiro Region Incorporated By Denmark Case Studies
URBAN DEVELOPMENT IN VULNERABLE COASTAL LOWLANDS

THE STUDY OF AVEIRO REGION

INCORPORATED BY DENMARK CASE STUDIES

Márcia Esteves Cabarrão

M.Sc. Thesis

On Environmental Engineering

Field of Specialization on Coastal Environments

Scientific Supervision:
Professor Doutor Fernando F. M. Veloso Gomes

Department of Civil and Environment Engineering

Faculty of Engineering at University of Oporto

Porto, Dezembro de 2003
Previous Note

This report presents the dissertation report from Master of Science on Environmental Engineering, in the field of specialization of Coastal Environments.

During a one year project a bilateral co-operation agreement between Portugal (Faculty of Engineering - University of Oporto) and Denmark (Danish Technical University) was established. By the analysis of urban areas under high risk situation of erosion and flooding in the Northwest Portuguese coast and two case studies in the North Sea coast of Denmark, it was possible to compare and enhance potential common planning strategies and best practices on coastal erosion management.

I would like to express my gratitude to the CIRIUS programme for this exchange opportunity; To the Faculty of Engineering at University of Oporto and the Danish Technical University for all the facilities and information access;

To my scientific supervisor Professor Fernando Veloso Gomes for his kind project supervision, material/information facilities, and pleasant project meetings.

To the LabSIG-UNAVE at University of Aveiro, for project work conditions and improvements on GIS skills.

To AMRIA that kindly authorised the use and publishing of its cartographic data and made possible the project analysis.

I also would like to thank the Danish Coastal Authority for the essential data material, interviews and site visits, Kort and Matrikelstyrelsen for all aerial photographs concerning the case study of Thyboron /Thorshamne, Miljo Butikken- of the Danish Ministry of Environment for the institutional and legal information of spatial planning in Denmark; County of North Jutland; Harboore and Hjoring Municipalities for the time made available for discussion in clarify all my doubts, and to visit historical archives. Poul Jakobsen from the SIC -Skagen Innovation Center, Tove Marquardsen from Lonstrup - Maarup Church Association, Mogens Christensen and Hans J. Mikkelsen for historical information on the case studies.

To Duncan Fagg for the revision of English and the fun moments; To Mette Damgaard and Klaus Tonnesen, for Danish translation assistance and friendship.

To Carlos Coelho for fruitful study discussion and kindly sharing information and books.

To my beloved family for their presence, understanding and major support to overcome the not so easy moments.

To Miguel Duarte for his love and trust.
Summary

In common with extensive sections of the European coast, much of the coast in Portugal is vulnerable to coastal erosion and flooding. At the moment, one of the main conflicts is motivated by the intensive human settlement in sand-slip areas at high risk of erosion – Vagueira, Costa Nova, and many other human/economic assets located in areas potentially at risk from flooding as the urban development on inland low-lying areas of Gafanhas (Ilhavo and Vagos municipalities).

To a country as Portugal where Coastal erosion management is a critical issue, the good practices experience can be complemented and enhanced by other European country such as Denmark, in order to investigate how the two different national approaches can be attained, identifying ways in which integration can be fostered within the technical availability and the existing coastal policy framework.

In that way, the fundamental objective of this study was to identify efforts and experiences in incorporating erosion/flood control measures at low-lying vulnerable coastal areas, after thorough assessment of knowledge gained from Denmark case studies.

Thus, the report was structured as the following: The Chapter 2 sets the basic approach of the project by introducing the main concepts and definitions directly pertinent as a theoretical background for this study. It considers terms of reference for a better understanding of beach erosion processes, the specific case study of barrier-slip beaches and evolution process.

In Chapter 3 a close description of the Aveiro south barrier-slip appeared to be an essential contribute to the understanding of global area (land-use; urban occupation) and the different reasons for the coastline behaviour, which was investigated in depth in Chapter 4.

In Chapter 5 by the vulnerability pre-analysis it was possible to identify the most low elevation areas facing the Atlantic sea thus, the general vulnerability (or lack of natural resilience) degree of this coastal stretch. This survey clearly demonstrated the increase of potential flood risk area at the Gafanhas location as a rupture situation which was analysed considering flooding scenarios.

In Chapter 6, with the incorporation of Denmark case studies (Case-study 1- Danish North sea coast at West of Jutland and Case-study 2- The west coast of the County of North Jutland facing the North Sea by the Skagerrak Sea), it is concluded that, a detailed policy for coastal maintenance has been developed using buffer dune-dikes, high number of groynes, detached breakwaters, combined with yearly nourishment at beach and on shoreface. By the monitoring / evaluating efforts it has been anticipate what erosion might be caused and take appropriate defensive measures before considerable coastal property is lost. Similarly non-structural options to reduce vulnerability to impacts erosion and flooding, such as land use planning, may require actions to implement and enforce them. A comparative analysis was conducted in Chapter 7 and the Main Project findings are described in Chapter 8.
Resumo
Tal como se verifica noutras zonas costeiras da Europa, Portugal enfrenta situações de grande
vulnerabilidade costeira traduzidas por problemas de forte erosão e inundação.
Atualmente, a gravidade de algumas situações poderá ser motivada quer pela ocupação urbana
intensiva em áreas já classificadas como zona de risco elevado (o caso da restinga da Vagueira e
Costa Nova), quer pela densificação urbana em áreas de baixas altitudes, potencialmente em risco
de inundação – Gafanhas (no concelho de Ilhavo e Vagos).
Deste modo torna-se importante complementar e enriquecer as boas práticas com base no
conhecimento/experiência partilhada por outros países como o caso da Dinamarca. Assim, o
objectivo principal desta dissertação consiste na identificação das diferentes abordagens de cada
um dos países ao problema da ocupação de zonas costeiras muito vulneráveis. Por outro lado,
interessa também investigar as formas de integração das várias metodologias nas intervenções e
técnicas disponíveis, bem como, nas opções de política de ordenamento e protecção costeira.

No sentido de se fazer cumprir o objectivo, este relatório foi organizado da seguinte forma: o
Capítulo 2 apresenta o contexto teórico, definindo os vários conceitos e termos utilizados ao longo
do estudo, de modo a uma melhor compreensão dos assuntos a tratar (processo de erosão, evolução
do sistema – Restinga, distinção entre as diversas estruturas de defesa).
No Capítulo 3 é feita uma caracterização da zona de estudo (características de hidrodinâmica,
regime climático, usos do solo, evolução da ocupação urbana) de forma a possibilitar um
conhecimento global da área a tratar. Os processos costeiros e a evolução da linha de costa são
investigados no Capítulo 4.
Através da análise preliminar de vulnerabilidade, são identificadas no Capítulo 5 as áreas mais
criticas e vulneráveis à acção do mar. Por seu turno, a construção e interpretação de diferentes
cenários de inundação em caso de situação de rotura da restinga (a sul da Costa Nova e sul da
Vagueira), aponta para um aumento da área potencialmente em risco às acções da água – as
Gafanhas.
A integração dos dois casos de estudo da Dinamarca é apresentada no Capítulo 6, onde se descreve
a política assumida de protecção costeira e manutenção de sistemas de restingas, recorrendo a
diques de protecção, campos de esporões, quebra-mares destacados, e outras soluções combinadas
com as técnicas de alimentação artificial. Esforços de monitorização e de avaliação da linha de
costa têm antecipado os efeitos possíveis da erosão, de maneira a ser possível intervir com as
medidas de prevenção e mitigação dos riscos associados. Além de medidas estruturais, é seguida
uma clara política de planeamento e uso do solo. Uma análise comparativa Portugal – Dinamarca é
organizada no Capítulo 7 e as principais conclusões e considerações finais são apresentadas no
Capítulo 8.
# TABLE OF CONTENTS

**CHAPTER 1 – PROJECT PRESENTATION** ................................................................. 1

1.1. Introduction ......................................................................................... 2
1.2. Motivation Statement ........................................................................ 2
1.3. Aims and Objectives ........................................................................ 3
1.4. Geographical Areas of Interest ............................................................ 3
1.5. Project Structure and Methodology ...................................................... 4
1.6 Data Acquisition ................................................................................... 4

**CHAPTER 2 – PROJECT DEFINITIONS – TERMS OF REFERENCE** .................. 6

2.1. Introduction ......................................................................................... 7
2.2. Coastal / Littoral Area ........................................................................ 7
   2.2.1 Coastal Components and Boundary Conditions ............................... 8
   2.2.2 Wave Generation .......................................................................... 9
   2.2.3 Wind Waves ................................................................................ 9
   2.2.4 Swell .......................................................................................... 10
   2.2.5 Coastal Tide Regime .................................................................. 10
2.3. Barrier Beaches and Sand-Spits ........................................................... 11
   2.3.1. Origin of Barrier Beach and Sand-Spits ........................................ 12
2.4. Vulnerability of a Coastal Unit .............................................................. 13
   2.4.1. Vulnerability Analysis ................................................................. 14
   2.4.2. Dune Vulnerability .................................................................... 14
2.5. Definition and Causes of Coastal Erosion .............................................. 15
2.6. Definition of Risk from Coastal Erosion/Flooding ................................................. 17

2.7 Types and Purpose of Structures Built in the Nearshore ........................................... 18
  2.7.1 Jetties ................................................................. 18
  2.7.2 Breakwaters ....................................................... 19
  2.7.3 Seawalls ............................................................. 19
  2.7.4 Groynes ............................................................. 19

CHAPTER 3 – GENERAL DESCRIPTION OF THE PORTUGUESE STUDY AREA ............... 21

3.1. Introduction .......................................................... 22
3.2. Geographical Area ................................................... 22
3.3. Historical Aspects .................................................... 23
3.4. Climate and Hydrodynamics Elements ................................................................. 25
  3.4.1 Wind Regime ...................................................... 25
  3.4.2 Wave Climate ...................................................... 26
  3.4.3 Storm Surge ....................................................... 27
  3.4.4 Littoral Drift Currents .......................................... 28
  3.4.5 Tidal Regime ...................................................... 29
  3.4.6 Sediment Transport ............................................ 30
3.5. Morphological Elements ................................................ 31
  3.5.1 Aveiro Lagoon .................................................. 31
  3.5.2 Dune Cordons ................................................... 32
3.6. Land-use Dynamics, Process of Change ............................................................... 33
  3.6.1 Land-use Patterns ................................................ 33
  3.6.2 Territorial Elements ............................................ 36
  3.6.3 Urban Occupation- Evolutionary Analysis ................................. 38
3.6.4 Urban and Tourist Pressure ......................................................... 40
3.6.5 Future Development Trends ...................................................... 42
3.7 Main Aspects for Conclusion .......................................................... 44

CHAPTER 4 — COASTLINE EVOLUTION .............................................. 45

4.1 Introduction ...................................................................................... 46
4.2 Erosion Phenomenon ...................................................................... 46
4.3 Main Causes for Erosion ................................................................. 53
  4.3.1 Sea Level Rise ......................................................................... 54
  4.3.2 Weakening of the River Basin Sediment Sources ..................... 54
  4.3.3 Human/Urban Pressures ............................................................ 57
  4.3.4 Hard Defence Structures .......................................................... 58
  4.3.5 Other Causes ........................................................................... 65
4.4. Coastal Protection Measures and Policy ......................................... 66
  4.4.1 Coastal Defence Works .............................................................. 66
  4.4.2 Other Measures to Coastal Protection ....................................... 67
  4.4.3 Coastal Plan - Protection Policy and Interventions ................... 69
  4.4.4 New Approaches ................................................................... 71
4.5 Main Aspects for Conclusion .......................................................... 71

CHAPTER 5 — VULNERABILITY PRE-ANALYSIS AND FLOODING SCENARIOS ......... 73

5.1 Introduction ...................................................................................... 74
5.2 Coastline Evolution and Predictions ................................................. 74
  5.2.1 The Coastal Plan — POOC ......................................................... 74
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2.2 Littoral Map Risk</td>
<td>76</td>
</tr>
<tr>
<td>5.3 Analysis of Critical /Vulnerable Areas</td>
<td>80</td>
</tr>
<tr>
<td>5.3.1 Vulnerability Criteria 1: Sea Level Rise</td>
<td>82</td>
</tr>
<tr>
<td>5.3.2 Vulnerability Criteria 2: Break Zones, Historical and New Potential Inlet</td>
<td>83</td>
</tr>
<tr>
<td>5.3.3 Vulnerability Criteria 3: Overtopping Events /Fragile Dune Cordons</td>
<td>84</td>
</tr>
<tr>
<td>5.3.4 Vulnerability criteria 4: Site Elevation</td>
<td>86</td>
</tr>
<tr>
<td>5.3.5 Vulnerability Criteria 5: Coastline Behaviour</td>
<td>88</td>
</tr>
<tr>
<td>5.3.6 Vulnerability criteria 6: Human Alterations</td>
<td>95</td>
</tr>
<tr>
<td>5.4 Representation of the Impacts: Flooding Scenarios</td>
<td>98</td>
</tr>
<tr>
<td>5.4.1 Construction of Hydrologic - Flooding Scenarios</td>
<td>99</td>
</tr>
<tr>
<td>5.4.2 General Associated Impacts</td>
<td>101</td>
</tr>
<tr>
<td>5.5 Main Aspects for Conclusion</td>
<td>102</td>
</tr>
<tr>
<td>CHAPTER 6 – EVALUATION OF SIMILAR CASE STUDIES – DENMARK</td>
<td>105</td>
</tr>
<tr>
<td>6.1. Introduction</td>
<td>106</td>
</tr>
<tr>
<td>6.2. Denmark – The land and Sea Interaction</td>
<td>106</td>
</tr>
<tr>
<td>6.3. Geological Background</td>
<td>107</td>
</tr>
<tr>
<td>6.4 Overview of Danish Coasts</td>
<td>109</td>
</tr>
<tr>
<td>6.4.1 North Sea Coasts</td>
<td>109</td>
</tr>
<tr>
<td>6.4.2 Inner Coasts</td>
<td>110</td>
</tr>
<tr>
<td>6.4.3 Coastal Exposure</td>
<td>111</td>
</tr>
<tr>
<td>6.5 Coastal Planning System in Denmark</td>
<td>112</td>
</tr>
<tr>
<td>6.5.1 The Planning Act</td>
<td>113</td>
</tr>
<tr>
<td>6.5.2 The Protection of Nature Act</td>
<td>114</td>
</tr>
<tr>
<td>6.5.3 The Coast Protection Act</td>
<td>117</td>
</tr>
</tbody>
</table>
Table of Contents

6.5.4. Institutional Framework ................................................. 119

6.6- CASE STUDY 1 – NORTH SEA COAST (THYBORON/THORSMINDE) ................................................. 122

6.6.1 Introduction ................................................................. 123

6.6.2. Historical Considerations ............................................... 124

6.6.3 Hydrodynamics and Natural Conditions ................................ 127

6.6.3.1 Climatic and Water Level Conditions ................................ 127

6.6.3.2 Geology ................................................................. 128

6.6.3.3 Sediment Transport Processes ....................................... 129

6.6.3.4 Sediment Budget ....................................................... 130

6.6.3.5 Coastline Retreat ....................................................... 132

6.6.4 Coastal Protection Measures ............................................. 133

6.6.4.1 Safety and Erosion Control ......................................... 133

6.6.4.2 Profile Steepening ...................................................... 137

6.6.4.3 Beach Nourishment .................................................... 138

6.6.4.4 By-Pass Operations .................................................... 143

6.6.5 Main Aspects for Conclusions ........................................... 144

6.7. CASE STUDY 2: SKAGERRAK SEA COAST (LONDSTRUP/SKAGEN) ................................................. 145

6.7.1 Introduction ................................................................. 146

6.7.2 Historical Considerations ............................................... 148

6.7.2.1 Sea Trade ............................................................... 150

6.7.2.2 Tourism ................................................................. 151

6.7.2.3 Campsites ............................................................... 151

6.7.2.4 Urban Occupation ..................................................... 151

6.7.3 Hydrodynamics and Natural Conditions ................................ 156

6.7.4 Coastal Protection Measures ............................................. 159
Table of Contents

6.7.4.1 Coastal Protection Works .................................................. 159
6.7.4.2 Coastal Protection By Pressure Equalisation Modules ............... 163
6.7.5 Main Aspects for Conclusion .................................................. 168

CHAPTER 7 – COMPARING PERSPECTIVES ........................................... 170

7.1 Introduction .................................................................................. 171
7.2 Coastal Planning approach-Portugal and Denmark ....................... 171
7.3 Atlantic and North Sea Key Subjects ............................................. 175
7.4. Rupture Scenarios - Maintenance of a Sand-Spit System .............. 178
    7.4.1 Coastal Defence Policy ....................................................... 179
    7.4.2 Technical Measures in Response to Coastal Erosion /Flooding ...... 180
    7.4.3 Protection Option Within Adaptive Strategies Approach .......... 186
        7.4.3.1 Retreat ................................................................. 187
        7.4.3.2 Accommodation ..................................................... 187
        7.4.3.3 Protection .......................................................... 188
7.5 Main Aspects for Conclusion ..................................................... 188

CHAPTER 8 – FINAL CONSIDERATIONS AND MAIN PROJECT FINDINGS ........... 192

8.1 Project Overview .......................................................................... 193
8.2 Good Practices on Planning with Erosion ..................................... 194
8.3 Critical Review and Difficulties .................................................. 199
8.4 Future Developments ................................................................. 200
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIBLIOGRAPHY</td>
<td>202</td>
</tr>
<tr>
<td>ANNEXES</td>
<td>213</td>
</tr>
</tbody>
</table>
INDEX OF FIGURES

CHAPTER 2 – Project Definitions – Terms of Reference
Figure 1- Definition sketch of a typical beach profile (in: CAMBERS, 1998) 7

CHAPTER 3 – General Description of the Portuguese Study Area
Figure 3- Portuguese study area location (source: AMRIA, 1998) 22
Figure 4 -The inlet position and Barrier- Spit evolution (Adapted from IHRH, 2003) 24
Figure 5 -Wave direction frequencies reaching the Portuguese West coast(in: IHRH, 2003) 26
Figure 6- Littoral Drift direction and north accretion on groin – South Vagueira (source: aerial photo-INAG, 2001) 28
Figure 7- Aerial view of dune cordon aspect at the study area: 1-South Vagueira – Dune cordon eroded; 2- South Areão - Starting erosion at the dune cordon; 3- South Mira Beach -Dune cordon in good conditions - (Photos: MCOTA, 2002) 32
Figure 8: Land Use Maps Costa Nova - Vagueira Beach (Adapted from: IHRH, 2003) 34
Figure 9: Land Use Maps Vagueira – Mira Beach (Adapted from: IHRH, 2003) 35
Figure 10: Aerial view of the main territorial elements of the study area (photo in MCOTA, 2002) 36
Figure 11: Characterization of the Study Area (Data source: AMRIA, 1998) 37
Figure 12 - Sand-Spit Urban occupation – Evolutionary analysis since 1958 to 1998, (Adapted from. CAETANO, 2002) 38
Figure 13 - Urban occupation and urban proposals at municipal level - South of Sandspit and Aveiro lagoon (in. Fidélis, 2001) 41
Figure 14: Aerial view of urban development at the sand spit and inland low-elevation areas- Vagueira Beach and Gafanhas (photo in: Aeroguia do Litoral, 2002) 42
Figure 15: Proposal location for the Marina-Barra Project- Mira Channel 43
CHAPTER 4 – Coastline Evolution

Figure 16: Coastline evolution–erosion rates maps (From: CAETANO, 2002) 49
Figure 17 – Coastline migration rate between 1940 and 1990 for the coastal stretch 50
Barra-Cape Mondego (Adapted from FERREIRA, 1998)
Figure 18: Coastline variation between 1996 / 1998–Barra Beach and Costa Nova 52
(source: INAG, 1996 and AMRIA, 1998)
Figure 19: Coastline variation between 1996 / 1998–Costa Nova and Vagueira Beach 52
(source: INAG, 1996 and AMRIA, 1998)
Figure 20: Coastline variation between 1996 / 1998–Vagueira and Areão (source: 53
INAG, 1996 and AMRIA, 1998)
Figure 21: Dams location in River Douro National Basin (in: IHRH, 2003) 55
Figure 22: Urban Development at Vagueira Beach (MCOTA, 2002) 57
Figure 23: Aveiro Harbour Jetties cut off sand supply to the down drift beaches. The 59
updrift S. Jacinto larger beach (MCOTA, 2002)
Figure: 24: Defense works-Situation till 1983 (Data from AMRIA, 1998) 61
Figure 25: Defense works at Barra and Costa Nova - Present situation 62
Figure 26: Defense works between Vagueira / Areão - Present situation 63
Figure 28: hard defense works ( groin 4 and 5 with seawall)- Costa Nova (In: Foto 64
Engenho-Francisco Piqueiro, 2002)
Figure 29: Groins and seawalls at Costa Nova Beach 65
Figure 30: Beach scraping operations South Vagueira beach 67
Figure 31: dune restoration and sand fencing at Barra and Costa Nova Beach 67
Figure 32: Emergency retreat dune between Costa Nova and South Vagueira 68
Figure 33: Construction of the new groyne- Poço da Cruz – Mira 69

CHAPTER 5 – Vulnerability Pre - Analysis and Flooding Impacts

Figure 34: Coastal Plan - POOC Forecast (Adapted from: COELHO; VELOSO 76
GOMES, 2002)
Figure 35: Risk (vulnerability) definition zones at Western Portuguese coast Aveiro- 77
Mira - (INAG, 1999)
Figure 36: High risk (red) (vulnerability) for the study area between Costa-Nova and 78
Areão - (from: INAG, 1999)
Figure 37: Zoom view at high risk (red) (vulnerability) between Barra Beach and 79
Vagueira Beach - (from: INAG, 1999)
Figure 38: Zoom view at high risk (red) (vulnerability) Southern Vagueira Beach - 80
(from: INAG, 1999)
Figure 39: Terrain profile, South Vagueira Beach (Data source: AMRIA, 1998-2001) 83
Figure 40: Old inlets positions. Aerial view of Southern Aveiro sand-spit (Based on IHRH, 2003) 84
Figure 41: Aerial view- often overtopping events (Data source: INAG 2001) 85
Figure 41a: Vulnerable fore dune at Sand-spit possible breaking of a new or more inlets to the Aveiro Lagoon (photos: MCOTA, 2002) 86
Figure 42: Aerial view of lowland Gafanhas area behind the sand-spit (photo: MCOTA 2002) 86
Figure 42a: Profile Terrain Gafanhas (Data source: AMRIA, 1998; 2001) 87
Figure 43: Coastline behaviour analysis for 1998/2000 (Data source: AMRIA, 1998) 90
Figure 44: Aerial coastline information - analysis based on Grid data and dune overtopping situations (Data source: INAG, 1996) 91
Figure 45: Aerial coastline information - analysis based on Grid data and dune overtopping situations (Data source: AMRIA, 1998) 92
Figure 46: Vulnerable areas analysis using Map Calculator extension (Data source: AMRIA, 1998/2001 and INAG 1996) 93
Figure 47: Vulnerable areas analysis using Map Calculator extension and dune overtopping situations adjacent Gafanhas area (Data source: AMRIA, 1998/2001 and INAG 1996) 94
Figure 48: Map calculation Query- arcview extension tool 95
Figure 49: Possible logical for increase of total risk area at the study area (based on: CARVALHO; COELHO, 1998) 97
Figure 50: Urban density at the Biotope Aveiro Lagoon and adjacent areas (Adapted from: FIDÉLIS, 2001) 98
Figure 51: Digital Terrain Model showing Scenario 1: Base-line Scenario - (Data source: AMRIA, 1998) 99
Figure 52: Digital Terrain Model showing Medium Scenario 2 - (Data source: AMRIA, 1998) 100
Figure 53: Digital Terrain Model showing High Water Scenario 3- (Data source: AMRIA, 1998) 100
Figure 54: Digital Terrain Model showing Extreme Scenario 4 - (Data source: AMRIA, 1998) 101
CHAPTER 6 - Evaluation of Similar Case Studies – Denmark

Figure 55: Population density per square kilometre at municipality level (in: Miljo Ministeriet, 2001).

Figure 56: Main characterization of Danish coasts (in: DCA, 2001)

Figure 57: The North Sea countries and classification of the Danish coasts (in: Laustrup and Madsen, 1998)

Figure 58: Water level and wave height statistics (in: Laustrup and Madsen, 1998)

Figure 59: Ministry of Environment and its specialist agencies (in: MILJO MINISTERIET, 2001)

Figure 60: Case-study 1: Thyboron/Thorsminde area location

Figure 61: Thyboron, an inlet at the North Sea and the Limfjord (DCA, 2000)

Figure 62: Overall safety system description at Thyboron (DCA, 1998, aerial photo, Kort and Matrikelstyrelsen, 2002)

Figure 63: North Sea coast distribution of wind Data, Waterlevels and wave height (DCA, 2000)

Figure 64: Aerial photo of Thyboron and Ferring area (South of Thyboron) Sediment Transport direction (Kort and Matrikelstyrelsen, 2002)

Figure 65: The sediment budget for the West Coast 2001 (Volumes in m3/year) (source: DCA, 2001)

Figure 66: Coastline evolution at North sea coast (between Thyboron and Hvide Sande) since 1977 (Source: DCA, 2001)

Figure 67: Coastal defense at North Sea Coast – Ferring / Thyboron - Groin field and Breakwaters (photo 22/03/2003)

Figure 68: Coastal defense at North Sea Coast – Protection Dike at Thyboron (photo 22/03/2003)

Figure 69: Dune revegetation; Dune revetment works (photo 22/03/2003)

Figure 70: Dune revetment works at North Sea Coast – Ferring /Thyboron (DCA, 2000)

Figure 71: Beach and shoreface nourishment techniques (DCA, 2001)

Figure 72: Sand nourishment operations between Agger and Thyboron, relating the locations of extraction (Sandindvindings omrade) and the supplied bar/beaches (Strandfodring). (in: Kystsinspektoretatet, 1998)

Figure 73: Sand nourishment operations on the West Coast between Thyboron and Ferring (In: Kystsinspektoretatet, 1998)

Figure 74: Sand nourishment operations on the West Coast between Ferring and Thorsminde (in: Kystsinspektoretatet, 1998)
Figure 75: Aerial view showing how the sand is brought in at Thorsminde and pumped ashore for the beach (Kort and Matrikelstyrelsen, 2000)

Figure76: Case-study 1: Skagen/Lonstrup area location

Figure77: Case study 1: Skagen/Lonstrup area location (HANSEN et al, 2000)

Figure 78: Skarregat Sea General view (photo DCA, 2000)

Figure 79: Lonstrup location (photo DCA, 2000)

Figure 80: Skagen Odde location (photo DCA, 2000)

Figure81: Bubjerg Knud and the Sand Drift effect – NorthJylland (HANSEN et al, 2000)

Figure82: Summer cottage area at Lonstrup (photo 24/11/2002)

Figure 83: Wind and wave regime for Lonstrup area (from: Kystsinspectorated, 1981)

Figure 84: Coastline evolution for Lonstrup (adapted from: Kystsinspectorated, 1981)

Figure 85: German World War II bunker at retreating sea (photo 23.11.2002)

Figure 86: Coastal protection works at Lonstrup and Skagen – The Skagerrat Sea (photo 23.11.2002)

Figure 87: Aerial view of sea action at Lonstrup and summer cottage areas (in: Kystsinspectorated, 1981)

Figure 88: Coastal protection works at Lonstrup after the storm of 1981 (from: Kystsinspectorated, 1981)

Figure 89: Groynes and Detached breakwaters at Skagen

Figure 90: Dune rehabilitation at Skagen area (photo 23.11.2002)

Figure 91: Aerial view of the groynes at Old Skagen, before the implementation of pressure equalisation modules and the same location in 1999, 15 months after the implementation of pressure equalisation modules (in: SIC, 2002).

Figure 92: General draw of SIC- Pressure Equalization Modules (in: SIC, 2002) and Conventional groynes at Old Skagen covered with new sand (1) and the Pressure Equalization Modules (2) (photo 26.11.2002)

Figure 93: SIC – System at Skagen Test area – Visible beach enlargement; Paul Jacobs -Project coordinator (photo: 22.11.2002)

Figure 94: Typical example showing the use of fascines at skagen (Photo- 22.11.2002)

Figure 95: Test area and measurements stations location (In: SIC, 2002)

Figure 96: Diagram showing the current situation after twelve months research (In: SIC, 2002)

Figure 97: Diagram of comparison of SIC System and conventional dredging over the period of May 1999 and January 2000 (in SIC, 2002)
CHAPTER 7 – Comparing Perspectives

Figure 98 - Planning and Protection Scheme - Denmark 172
Figure 99 - Planning and Protection Scheme – Portugal (in: IHRH, 2003) 173
Figure 100: Aerial view of Portuguese area (1) and Danish areas (2; 3) related with risk 178
for rupture (photo,MCOTA 2002; MADSEN, 1999)
Figure 101: Aerial view of Denmark Case-study 1: urban areas at risk from sand-spit 182
rupture Harboore and Thyboron (photo DCA, 2000)
Figure 102: Aerial view of Denmark Case-study 1: urban areas at risk from sand-spit 182
rupture Thyboron and Agger (photo DCA, 2000)
Figure 103: Aerial view of the Portuguese study area urban areas at risk from sand-spit 183
rupture Gafanhas and Sand-spit waterfronts (photo: Rota da Luz)
INDEX OF TABLES

CHAPTER 1 – Project Presentation

Table 1 - Project methodology and structure 5

CHAPTER 2– Project Definitions – Terms of reference

Table 2- Beach components and impacts (Adapted from SHORT, 1999) 9
Table 3 - Relationship between sea level stability, sediment supply (wave energy) and barrier beach type (Adapted from, SHORT, 1999) 13

CHAPTER 3 – General Description of the PT Study Area

Table 4 - Estimation of frequencies for different directions (IHRH, 1993) 25
Table 5- storm surge classes in three different locations in Portuguese West coast (adapted from Gama et al, 1994- in ANDRADE; FREITAS, 2002) 27
Table 6 – Synthesis of value estimation for littoral drift between Espinho and Cape-Modego (Adapted from BOTO, 1997) 29
Table 7 – Synthesis of value estimation for littoral drift between Espinho and Cape-Modego (from COELHO, VELOSO GOMES, 2003) 29
Table 8- Littoral urban evolutionary aspects at the Southern Aveiro Sand-spit 39
Table 9- Littoral urban evolutionary aspects at Aveiro Lagoon / Mira Channel 40
Table 10 - Population territorial distribution on the study area – (source:INE- Censos 2001) 41

CHAPTER 4 – Coastline Evolution

Table 11- Retreat (-) and accretion (+) rates presented by several authors (Adapted from IHRH, 2003) 47
Table 12 – Retreat(-) and accretion (+) rates between 1958 and 1998, presented by CAETANO, 2002 48
Table 13 – Predictions on Sea level rise on Portuguese coast (IHRH, 1992) 54
Table 14 – Douro river sediments budget capacity (in: IHRH, 1992) 56
Table 15 – Main seafront urban extension (based on aerial photos INAG, 2001) 58
Table 16 - Hard defense structures historical review 60
Table 17- Coastal erosion causes - Synthesis

CHAPTER 5 - Vulnerability Pre-Analysis and Flooding Impacts

Table 18 - Shoreline trend evolution - Coastal Zone Management Plan (POOC). (in: IHRH, 2003)

Table 19- Field parameters to determine category of risk in coastal areas (Adapted from: Bush et al, 1996)

Table 20- Impact of urban development on sand spit natural support environment (Adapted from Bush et al, 1996).

CHAPTER 6 - Evaluation of Similar Case Studies - Denmark

Table 21- Synthesis of protection and management of the coastal zone

Table 22: Thyboron- Characteristics and Chronology

Table 23- Nourishment methodology in Denmark (Kystinspektoratet (1998)

Table 24: LONSTRUP- Characteristics and Chronology (FAERCH, 1992).

Table 25: GAMMEL SKAGEN / SKAGEN- Characteristics and Chronology (HANSEN et al, 2000).

Table 26: Hydrodynamic Conditions at the Skagerrak Sea Coast (source: Kystinspektoratet, 1981)

Table 27: Erosion and accumulation over twelve months (in: SIC, 2002)

Table 28: Gain and loss of coastline immediately after the hurricanes (in: SIC, 2002)

CHAPTER 7 - Comparing Perspectives

Table 29: Main characteristics of Coastal Planning in Portugal and Denmark (in IHRH, 2003 and MILJOMINISTERIET (2001)

Table 30- Hydrodynamic Conditions -Comparing Analysis – The Pt coast and case study1

Table 31 - Hydrodynamic Conditions ( Lonstrup information from FRYDENDAHL, 1991)

Table 32: Current use of different coastal defense categories (Denmark- Case study 1 and Portugal)
Table 33- Comparing policies on nourishment practice in Portugal and Denmark.  
185

Table 34- Information on NW Portuguese CoastCosta Nova/Mira Sand-spit and inner  
lowlands- Gafanhas  
189

Table 35 -Information on Case-Study1: North Sea Danish Coast Thyboron / Torsminde  
coastal stretch  
190

Table 36 -Information on Case-Study2: North Sea /Skagerrak Sea Coast  
191
CHAPTER 1 –
PROJECT PRESENTATION
CHAPTER 1 – PROJECT PRESENTATION

1.1. Introduction

The dynamics of the coastal zone are in many cases a situation of delicate equilibrium, easily affected by processes, natural or man-induced. The coastal erosion is a natural process, which has significantly transformed coastal landscapes throughout history. However, due to the intensity of human and economic pressures in coastal areas, this natural process has become a major concern whereas local/regional authorities and communities are facing more and more damage and risks situations.

It is estimated that one quarter of the European Union’s coast is currently eroding despite the development of a wide range of measures to protect shorelines from eroding and flooding (EUROSION, 2002). The prospect of further sea level rise that will accelerate over the next decades (based on scientific studies from UN Intergovernmental Panel on Climate Change -IPCC), in combination with the increasing frequency and magnitude of exceptional storms and storm surges and the heritage of mismanagement in the past, imply that the risks and the impacts of erosion and flooding are expected to increase considerably during the 21st century.

In common with extensive sections of the European coast, much of the coast in Portugal is vulnerable to coastal erosion and flooding. Various sources have published data that demonstrate a generalised retreat of the Portuguese coastline, which is of worrying proportions in some areas. Considerable advances have been made in understanding coastal processes, such as the morphodynamic responses of beaches. Most of the coastal erosion problems were identified, exhaustively studied and published since many decades ago. Unfortunately, sometimes this fundamental understanding is not being incorporated into the planning process and the compulsory measures to reduce coastal erosion impacts were not taken into account lead to the erosion problem to be further aggravated. At the moment, one of the main conflicts is motivated by the intensive human settlement in areas at high risk of erosion – the sand-spit of Vagueira, Costa Nova.

Erosion is progressing with great intensity on several known stretches of coast, despite the existence of seawalls and groins. Many urban areas are at risk and human /economic assets are located in areas potentially at risk from coastal erosion or flooding. The problem is the most acute along the Portuguese NW coast as a consequence of the higher energetic- high vulnerability of coastal areas and the urban development on these low-lying areas, increasing the risk of exposition to the sea action (VELOSO GOMES et al, 2002). Although some urban developments are considered adequately protected by defences, in other locations hard defences have offered a false sense of security to developments, which now appear inappropriately sited. Before the 80 decade, there was no effort at land-use planning in view of strategies to reduce such risks.
Coastal erosion costs can be very high. Remedial action requires familiarization with the genesis and the history of the beach, examination of the current state of the system, and the natural evolution trends.

Solving land-use problems in the coastal zone requires, more than in other regions, careful planning and the prior knowledge of the coastal area dynamics. It is important to recognize that decisions today on planning for coastal development will greatly influence cost for later adaptation to impacts of sea level rise. Some areas are more vulnerable today because of decisions made 50 years ago. It is thus important to establish some immediate priorities for planning and management of coastal areas and for technical assistance, (required planning for coastal development), in order to reduce vulnerability to impacts of coastline retreat.

This study will be based on the assumption that coastal erosion is a phenomenon that can never be completely controlled but can be managed in an economically and ecologically sustainable way. Its great impacts can be mitigated if there is an effective coastal protection policy and the incorporation of coastal erosion risks into the coastal planning and decision-making process.

To a country as Portugal where coastal erosion management is a critical issue, the good practices experience can be complemented and enhanced by other European country such as Denmark in order to investigate how the two different national approaches can be attained, identifying ways in which integration can be fostered within the existing legislative and policy framework.

In that way, a developed comparison study provides a sound basis for present and future developments on this subject, together with an overview on coastal planning and protection policy backed by both countries specific arrangements.

1.2. Motivation Statement

Denmark as well as Portugal, is a maritime and offshor nation with old traditions for study, management and exploitation of the sea. Historically, management traditions are strong. In pace with the increasing complexity of society and growing environmental concerns, sectoral legislation and planning has been in progress in Denmark for many decades even through centuries. The Management of the coastal zone has been considered an integral part of physical planning and has as such especially matured and developed basis. On other hand, it has been updated legislation on erosion management, which at the same time takes into account the increasing erosion pressure and the modern demographic/recreational coastal encroachment.

It might be emphasized that some of the problems and barriers facing coastal management in Denmark are similar to the ones in Portugal. Some of these problems are:
The coastal areas are subject to multiple and complex environmental problems ranging from pollution of marine waters and watersheds, to the loss of genuine natural areas and landscapes due to urban development, recreational use, tourism, industrial activity, fisheries, agriculture, transport (harbours, roads), and environmental infrastructure (treatment of waste and wastewater).

- The growth of the coastal cities cannot be stopped, however a balance growth must be secured.
- The need for coastal defence to protect urban/human occupation land due to high energetic coasts.

1.3. Aims and Research Objectives

The aim of this work is to identify efforts and good practice experiences in incorporating erosion/flood control measures at low-lying vulnerable coastal areas, after thorough assessment of knowledge gained from Denmark case studies.

The main objectives are:

- To highlight some different strategies and erosion/flood control measures, (Portugal / Denmark) presented by the local, regional and national authorities.
- To establish a comparing analysis between Portuguese study area and Danish situation where coastal erosion patterns and associated local decision-making processes will be analysed.
- To contribute to the urban planning practices of South of Aveiro coastal strip and avoid in the future the development of high risk exposition areas to coastal forcing, by evaluating the consequences of the present situation focusing on urban exposure and coast vulnerability/high energetic sea action
- Enhance potential interaction and exchange of knowledge and experience from the two countries- Portugal and Denmark

1.4. Geographical Areas of Interest

This project will focus on the down drift component of the Aveiro lagoon system – South barrier beach (sand spit) of Costa-Nova/Mira as well as the inner and southern part of Aveiro lagoon. This coastal stretch includes the low altitude sandy shore facing the North Atlantic, with high recreational value characterized by dune system towards inland elevations, and the lowlands of Gafanhas along the Mira channel of the lagoon.
Denmark coastal case studies have been identified, and they are situated on the North Sea coast:

**Case-study 1**- Danish North sea coast at West of Jutland where the coastline consists of sandy beaches, lagoon-like inlets and posterior dunes. The project will focus mainly at Thyboron / Thorsminde stretch.

**Case-study 2**- The west coast of the County of North Jutland faces the North Sea by the Skagerrak Sea. The coast is flat and sandy as most of this land is elevated seabed broken only by a few high points that reach all the way out to the sea. The project will focus mainly at Lonstrup /Skagen stretch.

### 1.5. Project Structure and Methodology

The whole project methodology structure is presented on Table 1.

### 1.6 Data Acquisition

For the Portuguese coast characterization, data have been gathered from the AMRIA-Aveiro’s Lagoon Municipalities Association; IHRH /FEUP –Faculty of Engineering at University Oporto and INAG- Ministry of Environment

For Denmark case studies data have been gathered from DTU – Danish Technical University Kort and Matrikelstyrelsen (aerial photographs); Miljo Butikken- Ministry of Environment; County of North Jutland; Harboore and Hjorring Municipality and DCA-Danish Coastal Authority - Ministry of Transport

In addition to the analysis of relevant legislation, guidance and policy, the research has involved in-person interviews with coastal management professionals, and representatives of municipalities: of Portuguese and Danish study areas (Ilhavo, Vagos, Mira, Harboore and Hjorring); engineers from DCA; key persons related to undergoing projects for the study areas -Seaside Tourism Project in the North Sea Region; COMRISK Project and EUROSION Project.
PROJECT METHODOLOGY AND STRUCTURE

THEORETICAL BACKGROUND: BEACH AND DUNE MORPHOLOGY/DYNAMIC VULNERABILITY AND RISK CONCEPTS

GENERAL CHARACTERIZATION AND UNDERSTANDING OF COSTA-NOVA/MIRA SAND SPIT

PRELIMINARY VULNERABILITY ANALYSIS AND FLOODING SCENARIOS

EVALUATION OF SIMILAR CASE STUDIES – DENMARK COMPARING PERSPECTIVES

CONCLUSIONS / RECOMMENDATIONS

Coastal defence measures and prevention policy on urban planning

Historical review: Present situation
Future trends

Human/Urban occupation

Beach/Dunes/Lagoon
Wind/wave regime;
tides; storm-surge; sea
level rise

Climate Hydromorphic
Morphology

Evolution aspects of the coastline

GIS applications:
Theme maps; MDT
Terrain profiles for
Gafanhas / urban areas

Characterization of the defence structures: "hard/
soft" protection

Coastal Plans POOC
intentions and proposals

Identification of critical points

Vulnerability criteria:
Sea level rise; new /historical inlets; overtopping;
Coastline behaviour; site elevation; human alterations

Case study 1 – North Sea
cost (Thyboron)

Case study 2 – Skagerrak
Sea coast (Lorstrup)

Historical review and
location

Shoreline evolution
trends (10 and 30
years); Plan defence
proposals

Information from different reports /updated data by interviews
with experts, partners,
University of Aveiro, INDLA, ALBRIG,
Government institutions,
Ministry of environment,
City authorities, etc.
CHAPTER 2 –
PROJECT DEFINITIONS – TERMS OF REFERENCE
CHAPTER 2 - PROJECT DEFINITIONS – TERMS OF REFERENCE

2.1 Introduction

This chapter sets the basic approach of the project by introducing the main concepts and definitions directly pertinent as a theoretical background for this study. It will consider terms of reference for a better understanding of beach erosion processes, the specific case study of sand barrier beaches and sand spit evolution process.

2.2 Coastal/Littoral Area

The coastal zone can be defined as the interface between the atmosphere, hydrosphere or ocean, the lithosphere or geology and the biosphere. The four spheres interact to produce a wide range of beach systems and types (modified from SHORT, 1999). It constitutes a high energy zone with very active and complex dynamics, in which the Quaternary record shows clearly a history of considerable instability. It is logical to assume that this instability is going to continue, probably even to increase because of human interference (SILVESTER; HSU, 1997).

Subject to natural evolution trends and several geological hazards, the coastal zone has their effects compounded by human interference. Frequently a close relationship exists between environmental quality and some important economic activities (CAMBERS, 1998).

Figure 1 - Definition sketch of a typical beach profile (in: CAMBERS, 1998)

A typical beach profile with related terms, as shown in Figure 1, has been generally accepted. The shoreline is defined as the line "where land and water meet," which migrates to and from with the tide, so referred to as high water shoreline or low water shoreline. The exact state of the shoreline is
dependent upon the state of tide, wave conditions, and slope of the beach. Beach (or shore) is the zone from mean low water line to the inner edge of the landward limit of effective wave action; normally to the foot of a coastal cliff or to the line of permanent vegetation. A beach includes foreshore and backshore, the former lying between the low and high water marks where waves up rush and backwash, and the latter extending from the high water shoreline to the landward limit of waves during the most severe storms (SILVESTER; HSU, 1997).

Taking into consideration the physical reality, and the human activities, a coastal zone encompasses expanses on both sides of the "land-sea boundary", the inner part of the coastal shelf, and a hinterland. Its dynamics, in a delicate equilibrium, are easily affected by natural processes and anthropic activities (CHARLIER, MEYER, 1998). Their impact can be felt at considerable distance in time and space.

2.2.1 Coastal Components and Boundary Conditions

While beach systems can be generated in the laboratory devoid of natural input, natural beaches will to varying degrees be influenced by a range of parameters that will imprint a regional and/ latitudinal character. The major controls are exerted by regional tectonics and by latitude. Tectonics, through plate boundaries, influences the size, mineralogy and quantity of sediment delivered to the coast, as well as overall coastal gradient and stability. Latitude, through its influence on both land and ocean climate, influences the delivery of sediment to the coast, its size, mineralogy and quantity, and the ocean wave climate. As waves and sediments are the two key components of all beach systems, the imprint of tectonics and latitude is often dominating, and as such induces predictable regional variations in beach type and character (SHORT, 1999).

Waves and sediments are essential for beach formation while a sub-surface boundary as a base is required for beach to rest on (SHORT, 1999). During and subsequent to its formation and maintenance, beaches also depend on the sediment budget, wave climate and tidal regime, together with other factors including wind regime or regional biota (table 2).
Table 2- Beach components and impacts (Adapted from SHORT, 1999)

<table>
<thead>
<tr>
<th>Component</th>
<th>Presence</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geology</td>
<td>Cross-shore gradient</td>
<td>Beach gradient window</td>
</tr>
<tr>
<td></td>
<td>Nearshore bedrock</td>
<td>Wave shoaling refraction</td>
</tr>
<tr>
<td></td>
<td>Longshore boundaries</td>
<td>Beach dimensions, length</td>
</tr>
<tr>
<td>Sediment budget</td>
<td>Sand supply</td>
<td>Long term stability</td>
</tr>
<tr>
<td>Sediment type</td>
<td>Sediment size</td>
<td>Beach gradient/type</td>
</tr>
<tr>
<td></td>
<td>Sediment mineralogy</td>
<td>Beach colour</td>
</tr>
<tr>
<td>Wave type</td>
<td>Shunting and breaking waves</td>
<td>Energy source</td>
</tr>
<tr>
<td>Tidal regime</td>
<td>Periodical tidal waves</td>
<td>Periodic shoreline oscillation</td>
</tr>
<tr>
<td>Wind regime</td>
<td>Wind waves</td>
<td>Local waves energy</td>
</tr>
<tr>
<td></td>
<td>Aeolian processes</td>
<td>Beach sediment budget</td>
</tr>
<tr>
<td>Biota</td>
<td>Calcareous sediments</td>
<td>Increase sediment budget</td>
</tr>
<tr>
<td></td>
<td>Calcareous structures</td>
<td>Modify wave shoaling, breaking</td>
</tr>
</tbody>
</table>

Ocean waves are the major source of energy for coasts, with Inman and Brush (1973, in: SILVESTER; HSU, 1997) estimating that half the energy budget of the world’s coast is derived from waves. The wave characteristics of a particular location will, with sediment, determine the nature of the beach system. As waves are produced by wind blowing over a water surface, the nature of the world’s waves is intimately linked to the size and shape of the ocean basins and seas, and the zone and regional winds that blow over them.

2.2.2 Wave generation

There are many forms of waves in the ocean ranging from small nipples, to wind waves, swell, infragravity waves, shelf waves, tidal waves and tsunamis. In this book the term ‘waves’ refers to the wind waves and swell, while other forms of waves are referred to by their full name.

2.2.3 Wind waves

Wind waves are generated by wind blowing over the ocean. They are the waves that occur in what is called the area of wave generation, and as such they are called seas. According to SILVESTER; HSU, (1997), five factors determine the size of wind waves:

- Wind velocity- wave height will increase exponentially as velocity increases.
- Wind duration - the longer the wind blows with a constant velocity and direction the larger the waves will become until a fully arisen sea is reached, that is the maximum size sea for a given velocity and duration.
- Wind direction will determine, together with the Coriolis effect, the direction of wave travel.
- Fetch - the sea or ocean surface is also important, and the longer the stretch of water the wind can blow over, called the fetch, the larger the sea.
- Water depth is important as shallow seas will cause wave friction and possibly breaking; however this is not a problem in the deep oceans which average half of the wave length in depth, (wave height and period are directly related to wind velocity and duration and fetch)

2.2.4 Swell

Wind waves become swell when they leave or cease to be in the area of wave generation, either by travelling out of the area when the wind is blowing or when the wind stops blowing. Wind waves and swell are also called free waves and progressive waves (SILVESTER; HSU, 1997). This means that once formed they are free of their generating mechanism, the wind, and can travel considerable distances without it. They are also progressive, as once formed they can move or progress unaided. Once swell leaves the area of wave generation, it undergoes a transformation that permits it to travel great distances with minimum loss of energy. Whereas sea waves are highly variable in height and length, swell emanating from a sea decreases in height, increases in length, and becomes more uniform. As the speed of wave propagation is proportional to their length, they also increase in speed, (SHORT, 1999).

Swell not only travels faster than seas, but also in what surfers call 'sets' or more correctly wave groups, that is, groups of higher and lower waves. Wave groups are also a source of long, low waves that are the length of the wave group. Wave group velocity is less than wave velocity in deep water, but equal to it in shallow water. As wave groups enter shallow water and the surf zone they become very important in contributing gravity energy to surf zone processes.

2.2.5 Coastal tide regime

As most beaches are affected by tides, it is important to understand the contribution of tides, particularly tide range, to beach morphodynamics. The contribution can range from tideless seas and lakes, to a dominating factor in macro-tidal environments. While tidal range will always play a secondary role to waves in beach morphodynamics, increasing tide range will increasingly spread the impact of shoaling, breaking and swash wave activity (SHORT, 1999).
Tides are the periodic rise and fall in the ocean surface due to the gravitational force of the moon and the sun, acting on a rotating earth. The amount of force is a function of the size of each and their distance from the earth. While the sun is much larger than the moon, the moon exerts 2.16 times the force of the sun because it is much closer. The whole cycle takes 28 days and is called the lunar cycle over a lunar month.

2.3 Barrier Beaches and Sand-spits

Once sediment deposition on the coast becomes important and the sea cliffs are fronted by beaches, a new set of coastal formations prevail. Besides the beach itself, one of the more common depositional features are the barrier beach and the spit, a beach that is tied to the coast at one end and free at the other (KOMAR, 1976). Barrier beaches comprises a sand or pebble spit which are accumulations of sand of limited width, generally comprising sand dunes, which stretch lengthwise along the coast, either to partially or fully enclose bodies of water between them and the mainland (SILVESTERS; HSU, 1997). A barrier beach can be defined as a shore-parallel, sub-aerial and sub-aqueous accumulation of detrital sediment (sand/boulders) formed by waves, tides and aeolian processes. It constitutes a definable coastal landform or sequence of landforms which is clearly separate in either age, lithology, and/or form from adjacent, underlying or landward landforms (SHORT, 1999). The barrier may block off or impound drainage from the hinterland, but this is not a pre-requisite for definition as a barrier. Essentially a barrier is a coastal landform which acts as a ‘barrier’ between the sea and older coastal landforms, like coastal lagoons (Aveiro lagoon Portugal) or fjords (Nissun Fjord – Denmark) as focus on this project study.

There is general consensus that barriers may range from barrier islands to some degree of mainland attachment, and there is generally universal agreement that they may be stable, transgressive or regressive (SHORT, 1999). In order to incorporate these two elements, the approach used by ROY et al. (1994) is adopted, whereby sea level movement (transgressive/regressive/stable) is the prime control on barrier development, and the substrate gradient is the controlling factor on the location of the barrier relative to the mainland, as well as the regional coastal morphology. Other factors which will also influence barrier type and stability are the sediment supply, the contribution of wave/tide energy, (onshore) wind energy, geological inheritance and tectonism. As a consequence of the range of factors that can influence barrier evolution it is to be expected that barriers will range considerably in nature and location.
2.3.1 Origin of Barrier Beach and Sand-spits

A spit grows in the direction of predominant longshore sediment drift, and is often a continuation of the beach that is adjacent to the coast; at other times the spit departs from the trend of the coast and aligns itself nearly at right angles to the prevailing wave direction. The free end terminates in a hook or recurve, formed either by wave refraction around the terminal end or by the interplay of wave trains arriving from different directions. Often older hooks can be seen trailing landward from the spit, with almost the same configuration as the active hook. Spits are most common on irregular coasts, where they grow across bay mouths, sometimes completely closing them. The main requirement for their formation is plentiful supply of sediment (KOMAR, 1976) which is transported by obliquely arriving swell or predominant locally generated waves.

The age of these spits is generally less than 6000 years and hence they have been mainly constructed during a still stand of sea level (Fairbridge 1961 in SILVESTER; HSU, 1997).

There has been a considerable body of field evidence (ROY et al., 1994) to support the conclusion that ‘most barriers beach appear to form as a result of some type of landward transport and upward accretion of sands’.

There is now common agreement that barriers form at sea level on suitable substrates by the action of waves (and tides). Most barrier models now contain these elements (SHORT, 1999), while some also include sediment supply and relative sea level (ROY et al., 1994). There is also agreement that during the past Postglacial marine transgression many low sea level barriers were eroded, truncated and reworked into new transgressive barriers, with some remnants left on the shelf (ROY et al., 1994).

It now appears that most modern barriers were established during the final stages of the Postglacial marine transgression in the mid- to late Holocene and, depending on regional sea level, local sediment supply and other factors, may have since continued to retrograde (rising sea level, diminished sediment supply), remain stable, or progressing seaward (stable to falling sea level, positive sediment budget). In addition, factors including wave, tide and wind energy, tectonics and geological inheritance can all influence barrier behaviour (SHORT, 1999).

Barrier beaches long spits that partially or fully enclose bodies of water, are an important geomorphological feature of significance around the coastlines of the world. It is contended by these authors that the major energy input is wave action, particularly pulsational littoral drift. The more recent age of most of these features indicates a constructional process that discounts major changes in sea level.

Since these barrier spits are narrow they can be overtopped by severe storm waves and broken through to form inlets or island features, hence, the more general term barrier islands. Like the bays discussed above this physiographic feature is ubiquitous, being found along margins of oceans or
enclosed seas. The main requirement for their formation and maintenance is persistent oblique swell or locally generated waves and abundant sediment supply.

Table 3 - Relationship between sea level stability, sediment supply (wave energy) and barrier beach type (Adapted from, SHORT, 1999)

<table>
<thead>
<tr>
<th>Sea level</th>
<th>Barrier Type</th>
<th>Sediment Supply</th>
<th>Low to high wave / wind energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transgressive</td>
<td>Prograded barriers and strandplains</td>
<td>+</td>
<td>Chiangi beach - fore dune plains, parabolic - transgressive dune fields, overwash terraces</td>
</tr>
<tr>
<td></td>
<td>Retrograding barriers</td>
<td>- to +</td>
<td>Fore dunes, blowouts</td>
</tr>
<tr>
<td></td>
<td>Welded barriers</td>
<td>+ to +</td>
<td>Blowouts; Parabolic - transgressive dune fields</td>
</tr>
<tr>
<td>Regressive</td>
<td>Prograded barriers and strandplains</td>
<td>+</td>
<td>Tidal flats, Chiangi beach - foredune ridge plains</td>
</tr>
<tr>
<td></td>
<td>Retrograding barriers</td>
<td>-</td>
<td>Receded barriers (foredune, parabolics)</td>
</tr>
<tr>
<td>Stable</td>
<td>Prograded barriers and strandplains</td>
<td>+</td>
<td>Chiangi beach - fore dune plains, parabolic - transgressive dune fields</td>
</tr>
<tr>
<td></td>
<td>Retrogradational barriers and barrier islands</td>
<td>-</td>
<td>Overwash fans, erosional foredunes</td>
</tr>
<tr>
<td></td>
<td>Welded barriers</td>
<td>+ to +</td>
<td>Beach, dunes, cliff, cliff-top dunes</td>
</tr>
</tbody>
</table>

2.4 Vulnerability of a Coastal Unit

According to VELOSO GOMES et al (1999b), the vulnerability of a coastal unit exposed to natural processes (waves, tides, currents, floods and winds) represents the sensitivity to those actions expressed through hydromorphological changes. A natural shoreline will be more vulnerable, and will recede more rapidly, due to high tide and wave energy action, a lack of natural "defence" in the case of lowlands, and if there is high sediment transport deficit. The environmental vulnerability could be described as a system response ability in a catastrophic situation. The bigger this response ability is, the lower the environmental vulnerability as well as the damage (VELOSO-GOMES, et al 1999b).

It has been accepted that the natural beach can defend itself extremely well, but is generally accompanied by littoral drift by pulses (SILVESTER; HSU, 1997). However, if the shoreline is reoriented to become parallel to the breaking waves, this longshore drift can be reduced or even made zero.
2.4.1 Vulnerability Analysis

The vulnerability analysis of each coastal unit should include the study of several coastal forcing (hydrodynamic and aerodynamic processes, tidal range, run-up levels), the study of the physical and human coastal characteristics (geomorphology, hydrography, topography, geology lithology, vegetations; the artificial coastal works, urban areas, agricultural areas, infrastructures, social economic aspects, tourism/ recreation), and as well the consideration of the coastal management aspects (jurisdiction, legislation and policies) VELOSO-GOMES et al. (1999b).

Thus, the vulnerability analysis aims at the identification, of the values that could be assumed for each case study. A quantitative or qualitative ranking variable is obtained through hydrodynamic evaluation models for each factor or physical process. The influence of some physical components is quite important, (VELOSO-GOMES et al, 1999b):

- Greater or smaller wave energy concentration near the coastline;
- Wave incidence near the coastline, for long shore sediment transport;
- Presence of estuary and sea works and area of influence;
- Coastal zone biophysical characterisation (geomorphology, hydrology, hydrogeology);
- Coastal zone human characterisation (demography, land-use, tourism pressure, accessibility);
- Waterfronts, could increased the vulnerability to erosion and direct wave action.

2.4.2 Dune Vulnerability

Changes in the coastal dune systems are generated through interaction between the objective and subjective variables constituting the environment. Objective variables are those parameters accurately measured within the physical environment, for example beach width, vegetation cover, dune area. Subjective variables are set within the complex of socio-economic and cultural factors influencing system utilisation (WILLIAMS et al, 1995).

In the past most researchers have regarded dunes as vulnerable because of their propensity to show dramatic change under stress. Vulnerability can be defined as conditions causing accelerated erosion, ecosystem decay and an advanced state of degradation with obliteration of the dune surface. This could be induced by natural factors, for example storm damage in Portugal (ALVEIRINHO-DIAS et al, 1994).

The dune vulnerability checklist presented by (WILLIAMS et al, 1995) is a structured and systematic procedure, which summarises the present condition of a coastal dune and indicates a
range of possible vulnerability states. Potential vulnerability is determined by parameters which constitute the physical environment e.g. geomorphological, ecological.

In some locations, parameters related to "Recent Protection Measures", should be related to effectiveness rather than existence. For example, no one is allowed to walk through dune systems in Portugal, but in practise this is ignored in several places. Experience suggests that up to 10% of the parameters may have to be modified for dune sites within specific regional contexts (WILLIAMS et al 1995). There is some evidence that single parameters can dominate the behaviour of dune systems. For example an abundance of sand supply can compensate a high potential vulnerability within any individual dune complex.

2.5 Definition and Causes of Coastal Erosion

The term coastal erosion applies to the shoreline proper and to a strip of seafloor immediately bordering on the coast. The most visible manifestation is coastline recession, a phenomenon which is of a primary concern in this study. Cliff erosion in hard rocks is less obvious than for unconsolidated beaches. Coastal erosion - and accretion - is subject to significant changes.

Beaches are a very dynamic section of the land/sea interface margin, the understanding of these requires many measurements at frequent and longer term intervals. Although there had not been any standard quotation as to what would be considered as severe beach erosion, BIRD (1993) suggested that a loss of more than 10 meters per year can be regarded as exceptionally rapid.

The coastal erosion is a consequence of different processes acting in the land/sea interface area. These processes have their origin in either human or natural actions, but all of them contribute to the degradations of coastal landscape. This degradation is strongly correlated to the intense human occupation of coastal areas, resulting in areas with a greater environmental vulnerability and risk (VELOSO GOMES, et al 1999b).

Coastal erosion of beach, is not only the result of a complex interaction of natural processes, it is furthered, markedly, by man's actions. The so-called anthropic factor takes several aspects. It results from a general migration towards coasts and ensuring demands for space and habitat. The explosion of tourism and water-related recreation has increased the stress placed on the coastal zone. A search for easily accessible materials, sand and gravel, has contributed to exploitation of marine aggregates. Railroads and highways have been built close to shorelines. Dunes have been bulldozed to accommodate developments (CHARLIER; MEYER 1998).

According to these authors, the causes of beach erosion can be divided into those induced by Nature and by Man. The primary natural factors, can be summarized by:
Wave obliquity- Waves have a specific impact on the coastal lands upon which such waves break. Wind-generated waves can be a primary cause of erosion themselves, or, due to the energy they have stored, they can create various nearshore currents and develop specific sand transport patterns. The amount of energy stored depends on the duration of the storm that produced the waves and the extent of the fetch area.

Tidal Effects- Tides and storm surges rise the water level, thereby flood low elevation coastal land and by pushing landward the surf zones, let waves attack directly set-back areas.

Storm attack.

Imbalance of sediment transport, and

World-wide sea level rise, which can originate, dune cordons overtopping and flooding resulting on the partial / total beach disappearing.

In the same way the anthropic factors can be indicated as:

river dams and big hydroelectric plants cause the weakness of river sediments supply to the coast.

Harbour jetties which interrupt the sediment transport.

The man's influence on longshore drift, related with the attempt at retaining sand on certain sections of shoreline by groins, causing erosion downcoast, implies that one beach's salvation can be another's destruction. This may be transitory or more permanent depending on the length and number of these structures. Since they are installed only where an erosive situation already exists, there was already a dearth of sediment available on that section of coast.

This lack of supply has not been dealt with and is exacerbated by the retention of part of it on any segment (CHARLIER; MEYER 1998).

Similar effects are experienced when breakwaters are constructed on a mobile shoreline to protect harbours (SILVESTRE; HSU, 1997), and navigation channels. Those generally produce further seaward than groins and therefore exert a greater influence just downcoast of such complexes. This is purportedly overcome by seawalls or groins in an attempt to protect facilities associated with the harbour itself.

Associated with any harbour in the context above is generally a deep channel excavated across the inner continental shelf to provide access for deep-draft vessels. Longshore drift, both within the surf zone and beyond to the limit of disturbance of the persistent waves, will be deposited in such a depression. When this is dredged sporadically the sediments are normally dumped out at sea for convenience or used for civil construction works. This channel therefore, becomes a complete
interceptor of longshore drift, as effective as a groin-type structure of the same length. Thus, the seabed out to its seaward extremity is devoid of material, which results in the deepening and steepening previously alluded to. The consequence is severe erosion of the downcoast area. The magnitude of the problem is dependent on the wave climate, especially the obliquity of the persistent swell (SILVESTER; HSU, 1997).

2.6 Definition of Risk From Coastal Erosion / Flooding

The Risk concept within this study can be based on the Risk Assessment for Flood and Coastal Defence Systems for Strategic Planning Project (RASP, 2001), defined as the combination of likelihood and consequences of specified outcomes. The likelihood is the probability of flooding or coastal erosion, usually but not always given as an annual probability or chance. The outcomes include erosion and sea action of flooding and damage to properties, damage / disruption to infrastructure, environmental harm, impacts on agriculture and harmful effects on people. More severe events have a lower probability of occurring but cause more damage. They may cause damage over a wider area, or a higher degree of damage and harm over a similar area.

A key aspect of risk is that it must usually be estimated or calculated, typically by carrying out modelling of the flooding or erosion dynamic system. Risk assessments should often be 'calibrated' against recorded extremes events, but it is not possible to rely only on known events as these provide only a guide to what may happen in the future. Two erosion flood are never the same. It is important to develop a range of tools and techniques to support risk assessment.

The risk of a coastal unit can be considered as "the weighed average of the consequences of each action mode judged by the probability of each failure". The exposure risk of that unit to natural processes depends not only on its vulnerability but also on the characteristics of the land use. To define environmental risk is to characterise the potential adverse effects resulting from exposure to environmental danger and to the uncertainties related with the risk analysis process. When the damages can be measured, the risk is the occurrence probability of that action, multiplied by the perjury importance. Usually the undesirable consequences are not measurable, and the risk is then considered equal to the probability itself, (RASP, 2001).

The natural risk is related to an extreme geophysical event that can cause a certain damage, as a consequence of both natural system and coastal zone interaction. An important factor that could be on the risk basis is the "random effect", which could be able, facing an implicit danger, to cause what is called the potential risk. If the risk is caused or increased by human activities it is called the induced risk (SHORT, 1999).

The potential risks identification and exposure evaluation is related to the analysis of all existing
elements from all factors detected in the study area, its distribution and evaluation, and identifying those with a greater potential risk (VELOSO GOMES et al., 1999b). The risk evaluation needs a clear understanding of all-important factors and its environmental influence on the local and surrounding physical systems. Special care should be taken for identification of the more sensitive systems and to the short and long term exposure estimates.

According to the last mentioned authors, the acceptable risk levels are related to social and economic criteria and the risk quantification on a specific risk analysis can include:

- the results from the vulnerability analysis,
- the characteristics and possible failure modes of the coastal unit (beaches, dunes, cliffs, defence works)
- the land use near the shoreline,
- the alternative "scenarios" of urban expansion.

2.7 Types and Purposes of Structures Built in the Nearshore

There are two main purposes for the construction of structures in the nearshore zone (KOMAR, 1976): to improve navigation and to diminish coastal erosion. Jetties and breakwaters are built for the protection of ships and boats and also to aid navigation, whereas groins and various types of seawalls are constructed to prevent erosion of the coast (KOMAR, 1976).

2.7.1 Jetties

Jetties are built at the mouth of a river or tidal inlet to a bay, lagoon, or estuary in order to stabilize the channel, to prevent shoaling by littoral drift, and to protect the channel entrance from storm waves. Jetties direct or confine the stream and tidal flow to aid in the channel's self-scouring ability, and help prevent immediate filling if dredging is relied upon to deepen the channel entrance. In order to prevent littoral drift from entering the channel, jetties generally extend through the entire nearshore to beyond the breaker zone. However, in doing so, they also act as a dam to the longshore drift of sand in the nearshore. As the sand moves along shore under the natural processes of waves breaking obliquely to the shoreline, the drift must stop when it reaches such an obstacle placed across the littoral zone. As a result the sand accumulates on the updrift side of jetties and the shoreline advances. At the same time, on the downdrift side of jetties the sand transport processes continue to operate and so cause sand to drift away from the jetties; erosion and shore retreat therefore occur on the downdrift side of jetties (KOMAR, 1976). The construction of jetties can therefore interrupt the natural movement of sand along the beach and cause erosion of the adjacent
beaches and coastal property. Later in this thesis situations studies illustrating this will be examined.

2.7.2 Breakwaters

Breakwaters are structures which protect a portion of the shoreline area, thus providing a harbour or anchorage shielded from the waves. Breakwaters are constructed in a variety of shapes, but are generally attached to the coast at one or both ends, with a gap for ship and boat entrance, and extend outward through the surf zone. One variety, the detached breakwater, is built as a barrier parallel to the shoreline and therefore has no attachment with the coast. Initially it was thought that such a construction would provide a protected area for boats while at the same time allowing the sand to drift alongshore, since there is no direct obstacle across the nearshore. However, breakwaters diminish the wave energy at the shoreline and therefore reduce the capacity for waves to transport the sand alongshore (KOMAR, 1976). The result is deposition of littoral sands within the protected lee of the detached breakwater.

2.7.3 Seawalls

A variety of seawalls, bulkheads, and revetments are built along the shoreline to prevent property erosion and other damage due to wave action. They are placed parallel, or nearly parallel, to the shoreline, separating the land from the wave action. A secondary purpose is to diminish slumping of the coastal sea cliffs which they may front. Seawalls are constructed of solid or block concrete, steel sheets, timber, or commonly of natural stone known as riprap (KOMAR, 1976). They are sometimes constructed as a vertical wall; however, this promotes erosion at the toe of the wall, since the wave energy will in part be reflected, leading to increased scour and possible wall failure. More commonly the seawall slopes upward toward the land so as to help diminish the wave energy and decrease reflection, the height of the seawall being sufficient to prevent severe overtopping by wave run-up. A seawall affords protection only to the land immediately shoreward and none to adjacent areas along the coast nor to the beach fronting the seawall. When built on an eroding shoreline, the recession continues on adjacent shores.

2.7.4 Groynes

A groyne (or groin), is a rib built approximately perpendicular to the shoreline to trap a portion of the littoral drift and thereby build out the beach. This helps prevent further erosion of the existing beach, and since the beach in turn helps to protect the shoreward coastal property, groins also
diminish erosion of sea cliffs. Groins are relatively narrow in width and may vary in length from less than 10 meters to over 300 meters. In this regard they appear similar to jetties, although their function is very different. They have the same effect of damming the littoral drift so that the shoreline builds out on the updrift side and erodes on the downdrift side (KOMAR, 1976). To protect a large area from erosion, a series of groins, or groin field, may be constructed to act together. This enables an extended stretch of beach to be built out and shifts the zone of erosion out of the immediate area to your down coast neighbour.
CHAPTER 3 –

GENERAL DESCRIPTION OF THE PORTUGUESE STUDY AREA
CHAPTER 3 – GENERAL DESCRIPTION OF THE PORTUGUESE STUDY AREA

3.1. Introduction

This Chapter aims to a better understanding of Costa-Nova/ Mira Sand Barrier study area. It describes the main characterization aspects in order to enhance future dynamics based on past and present situations. Firstly, it will be given an historical overview concerning lagoon inlets and sandspits evolution thorough centuries. Secondly, a main characterization procedure is presented, focusing either on the hydrodynamic, climate and morphological elements, or on the land-use and socio-economic dynamics related with the urban occupation evolutionary analysis process of change and main pressures. Finally some conclusions are drafted highlighting the main aspects of this analysis.

3.2 Geographical Area

The area is located at Northwest Portuguese coast in the southern part of the Aveiro region- centre of Portugal. The study area is characterized as a Barrier coast, which separates the Aveiro Lagoon branch from the Atlantic Sea, and the inland area separated by the Mira channel. The two Barrier sand spits are connected to mainland with an artificial inlet controlled by two breakwaters (Aveiro harbour entrance).

Figure 3- Portuguese study area location (source: AMRIA, 1998)
3.3. Historical Aspects

Following the analysis of the formation process of the Aveiro lagoon, it can be concluded that it was originated by the evolution, north-south direction, of a sand-spit that had been wasting away the exit of the fluvial water into the ocean, 6000 years ago. In the same way, and according to ALVEIRINHO DIAS (1997), the great changes in the Portuguese littoral would have occurred in the last millennium associated to important weather changes, which would have been noticed by periods of very intensive cold, ice formation and lowering of the sea level. According to this author, there are indications that, 2000 years ago, the sea level was a little lower than it is nowadays (Roman Low Level), in the Middle Age and more recently (Small Ice Age).

In the tenth Century, the littoral between Espinho and Mondego Cape formed a gulf with a small recess, with the villages of Esmoriz, Ovar, Estarreja, Aveiro, Ilhavo, Vagos and Mira, (figure 4) located nearer the sea than they are today, (AMARAL, 1968).

This shallow lagoon in the North coast of Portugal (38°YN, C44°W), has a very irregular and complex geometry characterised by narrow channels and connected with the Atlantic through an artificial channel, which was opened in the beginning of the XIX century.

Morphologically Ria de Aveiro is a typical bar-built estuary, having experienced incision during an ice age and subsequent inundations, however recent sedimentation has equilibrated the inundation (FERREIRA; DIAS, 1991).

The Portuguese littoral passed through a strong regressive trend from the tenth Century until the end of the nineteenth Century, due to an increase of sediment delivery to the littoral, produced by the rivers of the North of Portugal, mainly by the river Douro. The action of a strong drift stream along the littoral in the north-south direction may have been the cause of the formation of a sand-spit that was spread from Espinho in the direction of the mouth of river Vouga, which was the cause of the posterior individualisation of the Aveiro Lagoon (MORAIS; ABECASSIS, 1978).

This sand-spit formation was also caused by the oscillations of the sea level, by the sediment availability and by the existence of low depths. During the evolution of the ancient coastline, the Mondego Cape (figure 4) may have performed a role, similar to the present jetties and spits, in the retention of sands that came from north (seaward) and carried by the littoral drift stream.
The formation of the shoal of Gafanha could have been caused by the inversion of the littoral drift stream, as a consequence, not only of the action of strong southwest (SW) winds, but particularly of the presence of a flow delta, which its original elevation, through refraction and diffraction phenomena, originated a strong deformation of the flutter (ALVEIRINHO DIAS, 1997). It was the cause of the dragging of a part of the sediments to the mouth of the estuary, forcing its orientation from SE to NW.

The erection of the dune on the littoral sand-spit may have started in the thirtieth century (CUNHA, 1930). Meanwhile, inside the Lagoon, some small isles may have appeared, formed by alluviums, because the tide entrance was more difficult, the low tide speeds were also less and, consequently, the sediments transport dragged by the river out of the Lagoon was similarly more difficult. On the
other hand, the sands were carried from the shore to the inside of the lagoon by the winds, that made them to have a strong cooperation in its silting up, which led to some problems to the navigation (CUNHA et al., 1997).

This sedimentary action led to the closing of the Lagoon of Aveiro and some other lagoons. The first interventions to open the Bar of Aveiro were reported in 1549 (JUNTA AUTÓNOMA DA BARRA DO PORTO DE AVEIRO, 1932).

3.4 Climate and Hydrodynamic Elements

The principal factors of forcing upon the Atlantic coast are partly weather -dependent and within a short-term in time scale of operation (e.g. waves, surges) while others correspond to the cumulative effect of macro to micro scale forcing (e.g. tides, sea level changes). The sea action regime is the most energetic and dynamic force acting in this area, being therefore, its main modeller agent (VELOSO GOMES et al., 2002).

The North-West Atlantic tide and the wave regime associated with the littoral drift currents generate a very severe natural climate important to understand on the context of the global process of coastal erosion.

3.4.1 Wind Regime

The local wind climate generates currents and small waves with different intensities and directions, which can be related to the velocity, persistence and direction of the wind that has originated them (IHRH, 2002). Those currents have an important role on biologic point of view, however with a very small intervention compared with the main currents originated from the Atlantic wave regime.

During 23 years several observations were realized in Boa Nova lighthouse (north of Porto) that had allowed the elaboration of the estimation of frequencies for the different directions, presented on table 4.

Table 4 - Estimation of frequencies for different directions (IHRH, 1993).

<table>
<thead>
<tr>
<th>Direction</th>
<th>N</th>
<th>NE</th>
<th>E</th>
<th>SE</th>
<th>S</th>
<th>SW</th>
<th>W</th>
<th>NW</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>31.7</td>
<td>6.1</td>
<td>14.8</td>
<td>8.5</td>
<td>12.0</td>
<td>9.3</td>
<td>4.6</td>
<td>13.0</td>
</tr>
</tbody>
</table>
Occurrences of strong intensity wind in the Portuguese coastal zone are related to the establishment in the area of intense circulations in the low troposphere. This results from intense horizontal gradients of the atmospheric pressure associated with almost stationary systems that create long periods with great wind intensities are due to the approach and passage of disturbances, such as depressions and front surfaces (IHRH, 2003).

The occurrence of high wind intensities in the West coast of Portugal is more frequently associated with the passage of front depressions on the North of the Iberian Peninsula, accompanied by the passage of front systems in Portugal. This type of situations causes the circulation on the sea surface that is, usually of the SW quadrant, including S, SW and W directions.

3.4.2 Wave Climate

The wave climate is the normal seasonal wave regime along the shoreline. In Leixões (near Porto) the wave climate is characterized, in most part of the year, by waves from Northwest that can combine with waves generated by local winds. The sea state is generated and characterized, always, from large spectrum in frequency and small in direction. All the storms occur during the winter period. The local winds and waves are, in most part, from north, northwest and southeast. In the last case this winds can be associated to storms. Most of the storms are originated by strong or very strong waves from West. The most frequent periods are 10 s, 11 s, 12 s and 13 s, with highest percentage of the significant wave height of 1-2 m, following by waves height of 0-1 m and 2-3m. The higher significant wave height could reach 11m (IHRH, 1993).

![Wave direction frequencies reaching the Portuguese West coast, based on Leixões buoy. (in: IHRH, 2003)](image)
In the period from 2001-05-25 to 2002-05-03, the wave climate could be characterized from the Leixões buoy with medium significant wave heights from 2 to 3 m, with periods ranging from 8 to 12 s and storm significant wave heights exceeding 8 m, with periods reaching 16 to 18 s. Local wave conditions are different from the offshore ones due to the effect of the bathymetry and local phenomena, especially refraction, diffraction and shoaling. The most important wave directions are NW with 43.8% of occurrences, WNW with 28.0% and NNW with 21.2% of the occurrences (figure 5).

The main storms that reach the North-western coast of Portugal come from the North Atlantic, particularly between October and March.

3.4.3 Storm Surge

Storm surge (meteorological tides) is the rise above the normal water level on the open coast due to action of wind on the water surface.

Storm surge event has been underestimated in maritime works and planning in Portugal until the pioneer works of MORAI; ABECASSIS (1978) and TABORDA, ALVEIRINHO DIAS (1992) which reported and characterized that surge-induced vertical set up of the mean sea level of 0.5-1 m in locations of the west coast, recorded during Storms in 1973, 1978 and 1981 (reached 1.17 m in Aveiro during a big storm of 1981).

At present, storm-surge and associated forcing of the Portuguese coast is still poorly characterized and known, the contributions of GAMA ET AL. (1996) and CARVALHO (1999) containing a summary of the current knowledge relying on both instrumented data and modelling. The results suggest a statistical analysis of the frequency distribution of surge levels in five stations yielded the results presented in Table 5. Care should be taken in extrapolating the return periods derived from this data due to the short length of the time-series used (ANDRADE; FREITAS, 2002).

Table 5- storm surge classes in three different locations in Portuguese West coast (adapted from Gama et al, 1994- in ANDRADE; FREITAS, 2002)

<table>
<thead>
<tr>
<th>Storm surge (cm)</th>
<th>Viana do Castelo</th>
<th>Aveiro</th>
<th>Cascais</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significant</td>
<td>59</td>
<td>31</td>
<td>26</td>
</tr>
<tr>
<td>Very significant</td>
<td>54</td>
<td>42</td>
<td>34</td>
</tr>
<tr>
<td>Highly significant</td>
<td>90</td>
<td>67</td>
<td>45</td>
</tr>
<tr>
<td>Maximum observed</td>
<td>110</td>
<td>117</td>
<td>72</td>
</tr>
</tbody>
</table>
Relevant Storm Surges along the Portuguese coast are associated with NW to SW high waves and intense rainfall. Their combined effects increase the washover, overtopping or breaching ability of either natural barriers (beaches, barriers, dunes, cliffs) or artificial barriers (jetties, breakwaters, bulkheads, sea-walls, dykes). In addition, by incoming waves it may retard the natural outflow rate of fluvial and tidal currents during several hours.

3.4.4 Littoral Drift Currents

Littoral drift currents move along the shoreline as a result of waves, thus having a great importance in the littoral sediment transport process. In the study area this currents act as the main factor for sediments transport to the beaches (BETTENCOURT; ÁNGELO, 1992). The currents with a parallel component to the coast can reach significant intensities between the breaking zone and the beach. They have origin in the wave obliquity (WNW) relatively to the beach (long-shore currents by oblique breaking waves) as well in the most frequent wind system, and as a compensation of medium water level (wave set-up currents) (VELOSO GOMES et al, 2002).

The littoral drift currents act mainly in the North-South direction although some singular events of Southeast direction can be found. This can be easily shown directly by the fact that accretion occurs in the North of coastal defences (updrift) (e.g. groynes) and erosion in the Southern (downdrift) ones (figure 6). Exception is done on SW wave regime: in the south of estuary mouths refraction and diffraction of waves can change or even invert littoral drift direction.

![Figure 6- Littoral Drift direction and north accretion on groin – South Vagueira (source: aerial photo-INAG, 2001)](image)

TEIXEIRA (1994) presents few results to quantify this littoral drift since 1950 till 1994 (Table 6) from different authors and sources.
Table 6 – Synthesis of value estimation for littoral drift between Espinho and Cape-Modego (Adapted from BOTO, 1997)

(C.E.R.C – Coastal Engineering Research Center)

<table>
<thead>
<tr>
<th>Authors</th>
<th>Database</th>
<th>Methodology</th>
<th>Littoral drift (10^3m^3/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abecassis (1950)</td>
<td>Cartographic</td>
<td>Volume analysis</td>
<td>0.2</td>
</tr>
<tr>
<td>Abecassis et al. (1968)</td>
<td>Atlas U.S.N.H.O.</td>
<td>Bonnifille (1967)</td>
<td>2.6</td>
</tr>
<tr>
<td>Hidrotécnica Portuguesa (1980)</td>
<td>Cartographic and Photos</td>
<td>Sediment balance</td>
<td>2.0</td>
</tr>
<tr>
<td>Ferreira (1993)</td>
<td>Aerial photo</td>
<td>Sediment balance</td>
<td>1.4</td>
</tr>
<tr>
<td>Teixeira (1994)</td>
<td>Historical data</td>
<td>Sand-silt evolution</td>
<td>1.7</td>
</tr>
<tr>
<td>Teixeira (1994)</td>
<td>Cartographic and Photos</td>
<td>Sediment balance</td>
<td>1.8</td>
</tr>
</tbody>
</table>

The authors COELHO and VELOSO GOMES (2003) also present recent evaluations concerning the estimation value for the littoral drift in the study area (table 7).

Table 7 – Synthesis of value estimation for littoral drift between Espinho and Cape-Modego (from COELHO, VELOSO GOMES, 2003)

<table>
<thead>
<tr>
<th>Author</th>
<th>Database</th>
<th>Littoral drift (10^3m^3/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coelho , Veloso Gomes (2003)</td>
<td>Cartographic</td>
<td>1.5 to 4</td>
</tr>
</tbody>
</table>

According to these last authors, the potential volume transported in a typical year of wave climate, can be found between 1.5 and 4 million cubic meters per year.

3.4.5 Tidal Regime

Tide is the periodic rising and falling of water resulting from gravitational attraction of the moon, sun and other astronomical bodies acting upon the rotating earth. This vertical water movement is accompanied by a horizontal movement of the water designated as the tidal current. Their own, tidal currents are unimportant to coastal processes except in the vicinity of inlets and across tide dominated basins such as estuaries and lagoons, where they may become prime agents of sediment and morphological dynamics, and usually capture sand to build tidal deltas. However, the combined effects of tidal-generated and oscillatory wave-borne currents are known to produce
synergetic enhancement of the sediment transport in the nearshore (VELOSO GOMES et al., 2002). This effect gaining relevance in sheltered coastal sectors, where the direct action of waves may be significantly reduced. The large tidal range that characterizes the whole Portuguese coast is of particular importance to processes shaping rocky cliffs and shore platforms.

In the Western Portuguese coast, tides are semidiurnal type, with tidal cycles of approximately 12h 25m and propagating from South to North.

The maximum range foreseen for spring tides reach values in the order of 3.7 m in Figueira da Foz and 3.3 m in Aveiro, while the minimum range of neap tides could be lower than 1 m, in both harbours. The maximum annual absolute value (1997) was 3.96 m HZ for the Figueira da Foz tide gauge and 3.64 m HZ for the Aveiro inlet tide gauge.

Meteorological tides are not significant outside enclosed waterbodies but they can contribute to increase onshore consequences when occurring simultaneously with spring astronomical tides or severe storms (VELOSO GOMES et al., 2002).

3.4.6 Sediment Transport

It is common practice to make a distinction between sediment transport parallel to the shoreline and sediment transport transverse to the shoreline. In general the longshore sediment transport, and in particular the gradients in this transport, are responsible for the medium and long-term changes in the coastline, whereas the cross-shore transport is responsible for the short-term variations. In this connection it should be observed that cross-shore transport may also cause long-term erosion or accretion of the coast, but this is often difficult to detect because of the different nature of transport phenomena (SHORT, 1999).

The longshore transport occurs in a relatively narrow zone along the coast, and the direction and magnitude is mainly determined by the height, period and direction of the waves apart from the effect of possible tidal currents. The presence of this longshore transport can be easily detected from the development of the coastline and sea bed geometry near river mouths, headlands, groins, harbor breakwaters, etc. The short-term effects of cross-shore transport can also be easily detected, from the changes in magnitude and position of breaker bars, erosion of the dunes during storm surges, etc. As such the effect of seasonal variations in the wave conditions on the coastline and seabed geometry are considered short-term effects.

The two major sediments sources of Portuguese coast are the river basin sources and coastal erosion -sediments removal sources. Relatively to the medium sediment transport of the Aveiro
Lagoon it was estimated in 240 000 m³/year, practically without the interference of the existent hydraulic structures.

Nowadays, Douro river only contributes with a small amount, that is estimated around 250 000 m³/year (strongly dependent on the annual flow regime), in consequence of the dam's construction that reduced the erosion power of the river bed and margins, the flow velocity and as consequence the amount of the transported sediments. Besides this, there is an important amount of sand extraction for construction, dredging works in several places and in quantities beyond the sustainable (VELOSO GOMES et al., 2000).

The main direction of sediment transport in this area is North-South, due to the existent littoral drift currents.

### 3.5 Morphological Elements

#### 3.5.1 Aveiro Lagoon

Aveiro lagoon is a lagoon connected with the Atlantic Ocean, with geographic characteristics that lead to the existence of big industries and more than 300 000 people around its channels, which are responsible by several environmental problems.

There are three main branches radiating from the sea entrance. Mira channel, which runs to the south and it is long, narrow and shallow. S.Jacinto channel, running northwards first being wide and deep but changes forms and character as it extends to the north giving a complex network of bays channels and dead arms of variable depth and shape. Finally, there is a third channel running eastwards towards the town of Aveiro, which is dredged to a depth of about 7 m to allow ship movements associated with the port activity (RUA; CABARRÃO, 1999). The lagoon has a mean depth smaller than 1 m with zones of tidal flats, except in navigation channels where dredging operations are carried out. Due to the small depth and depending on the tidal wave amplitude there are zones which are alternately wet and dry during each tidal cycle. With maximum length and width of 45 Km and 10 Km respectively, the lagoon covers an area of 47 km² at the highest tide which is reduced to 43 km² at the lowest tide (JAPA, 1996).

Vouga and Antuã rivers, located on the east side, are the main sources of fresh water input into the lagoon. The input of salt water occurs through the main channel by the penetration of the tidal wave which propagates from south to north along the west coast of Portugal. The hydrodynamics of the lagoon is affected by river runoff only in flood periods of Vouga River, during the winter months (JAPA, 1996).
The tides are predominantly semi-diurnal. They have a mean range of 1.8 m at the mouth and propagate as progressive waves coming from the continental shelf, generating tidal currents with maximum speeds of about 1.0 m/s. Non-tidal contributions to the circulation include wind-driven currents during small periods and gravitational flow due to gradients of density formed by fresh runoff water and seawater. The resulting flow is modified by the frictional drag due to bottom roughness and by the channels geometry, (JAPA, 1996).

3.5.2 Dune cordons

The importance of the dunes, especially the primary chain, is internationally recognised and one of aspects to be considered is the reserve of alluvial sources and of the adaptive barrier to runups and over-toppings (VELOSO GOMES et al, 2002). Dunes are built by winds blowing over foreshore and berm carry landward beach sand, and constitute a natural levee sometimes anchored by grass, bushes, even trees. They also provide a reservoir of beach sand and thereby a protective barrier against wave attack. Overtopping of a dune results in landward transport of beach and dune sand, thus lost to the dynamic beach system (SHORT, 1999).

According to CHARLIER and MEYER (1998), dunes have been accepted as Nature's safeguard against future unknown coastal erosion. However, Nature itself, has not been very efficient in such a provision, for where most material is needed the supply is the least. This author is on the opinion that this concept of a safety factor might be better termed a 'factor of ignorance: in fact, when a dune is attacked by a larger than normal storm sequence, the tendency is to dump stone or build a revetment to protect it. This negates the idea of the dune coping with an erosion problem'.

The forested areas and dune fields of Costa Nova, Vagueira and Mira (Figure 7), have played and should continue to play a very important role in the defence of the natural values of the seashore, constituting buffer zones in relation to the indiscriminate occupation of the land.
Figure 7. Aerial view of dune cordons aspect at the study area: 1-South Vagueira – Dune cordons eroded; 2- South Areão - Starting erosion at the dune cordons; 3- South Mira Beach -Dune cordons in good conditions - (Photos: MCOTA, 2002)

At present there are several interesting dune rehabilitation being undertake (ICN, INAG, and DRAOTs). The replanting of vegetation, should, as far as possible, respect the autochthonous varieties, which have a differentiated spatial distribution.

However, concerning the size of hydromorphological imbalance which is characteristic of the study area and the existing high wave energy, protection measures such as, the dune conservation, reconstruction and stabilisation measures, by themselves, will not lead to a stabilisation or even an inversion of the erosion situation. But they will be an important contribution, not only in terms of slowing down the ocean’s advance but also in terms of protecting and recovering other natural values (VELOSO GOMES et al, 2002).


This section aims to investigate the present scenarios of land-use in the study area based upon the analysis of Municipal Plans (Ilhavo and Vagos municipalities) and the Aveiro Lagoon InterMunicipality Plan (CPU, 2002).

3.6.1 Land Use Patterns

The land use in the area is mainly related with the agricultural activities, some significant forested areas and urban areas as well as an important harbour area.

Most of these urban areas are too much close to the shoreline, which leads to an important number of costal defences that can be seen on the sandy stretch of Costa Nova - Mira beach.

The land use maps dated from 1996 (figure 8 and 9) show the different uses and their interconnection, which could give a first preliminary analysis of potential conflicts (IHRH, 2003), originated from the intense use and development on unstable /environmental sensitive area.
Figure 8: Land Use Maps Costa Nova - Vagueira Beach (Adapted from: IHRH, 2003)
Due to the ecological value and its environmental sensitivity, this area includes a type of zone protected by law: the National Ecologic Reserve (REN). The protecting force of these areas does not allow any development within the defined limits and practically all of this area is classified as REN.

Figure 9: Land Use Maps Vagueira – Mira Beach (Adapted from: IHRH, 2003)
However, the main areas protected by REN are situated along the coastline, and between these there are small excluded areas (or islands) where mainly consist of urban zones or industries which existed before the introduction of the REN statute.

There is also a zoning area for agricultural use, defined as RAN – The National Agriculture Reserve that is observed to have a complex border, as a result of its coexistence with urban zones and small scale farming activity, which is extensive in the study area.

3.6.2 Territorial Elements

In this study area the main territorial and structural elements are:

- Mira Channel – Southern part of Aveiro Lagoon.
- Main traffic roads: IP5, EN109-7 (Barra/Areão) e EM591 (Mira/Gafanha da Nazaré).

![Aerial view of the main territorial elements of the study area](image.png)

Figure 10: Aerial view of the main territorial elements of the study area (photo in MCOTA, 2002)

The EN 109-7 is the only access road for all the urban settlements between Barra Beach and Areão Beach. This limited situation brings up several traffic problems, not only during the summer season but also on an all day basis, once this road is used as an alternative for the EN 109 (already at its capacity) specially the heavy transport.

Between the line of the coast and the EN109-7 the dunes are covered with wild vegetation and localised areas of small-scale farming. Between the EN109-7 and the Ria exist, predominately, zones which are under the influence of the inundating tides where habitation is nonviable.
All along the Mira Channel, between Costa Nova and Mira Beach there is an import group of farms, some of them very well known for its historic role.

The east side of the Mira Channel along the EM 591 is characterized by a continuous urban zone as a result of the private construction along the margins fields of the lagoon.

At the east side of the Gafanhas exists a dense forestry area combined with the Vagos dunes cordons.

Figure 11: Characterization of the Study Area (Data source: AMRIA, 1998)
Due to its nature, this strip of land is increasingly popular for recreational activities related to the lagoon. The existence of marsh (wetlands), small beaches, the sea, and pine forests, coupled with the close proximity of the lagoon, favours significant levels of use, especially in summer, such as recreation, leisure and sport activities, (for example fishing and nautical pastimes).

It is, therefore, important that this strip of land if subjected to any kind of intervention, that should always guarantee either the preservation and value of the natural character and to allow usage through the creation of rules which control both access and utilisation and also the designation and classification of adequate areas for recreation and leisure.

3.6.3 Urban Occupation – Evolutionary Analysis

An overview of the littoral / lagoon urban occupation is presented on Tables 8 and 9.

Yet, according to CAETANO, 2002, the urban expansion on the sand-spit can be well analysed by photo-interpretation methodology using aerial data from 1958, 1970 and 1998. Figure 12 presents partially the result of that analysis showing the seafront expansion for the urban settlements of Barra, Costa Nova and Vagueira.

Figure 12 - Sand-Spit Urban occupation – Evolutionary analysis since 1958 to 1998, (Adapted from CAETANO, 2002)
Table 8- Littoral urban evolutionary aspects at the Southern Aveiro Sand-slit

<table>
<thead>
<tr>
<th>Littoral Urban Evolution</th>
<th>Coastal Waterfronts – Littoral sand-slit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barra – Costa Nova – Vagueira</td>
<td></td>
</tr>
<tr>
<td>- <strong>Barra</strong> urban occupation started around 1880 and it was related to inlet maintenance works and tourism activity (PINHO, 1993).</td>
<td></td>
</tr>
<tr>
<td>- 1958 - Barra urban area of 185 000m²</td>
<td></td>
</tr>
<tr>
<td>- 1970 – According to CAETANO (2002), the urban area of Barra have increased: 327 000m²</td>
<td></td>
</tr>
<tr>
<td>- 1998 – Urban expansion to inland (CAETANO, 2002)</td>
<td></td>
</tr>
</tbody>
</table>
| - **Costa-Nova** urban occupation started around 1808 as a result of new lagoon inlet and Barra channel formation thus, the S. Jacinto fishery colonies had to move to Costa Nova because it was not as dangerous and difficult to get into the sea with their little boats- Bateiras (CACHIM, 1983). The fisherman houses were placed near the sea whereas sea trade man houses (connected to the traditional activity *arte xávega*) were placed near the lagoon – Mira channel (the so called “palheiros”)
| - During a crisis on fishing activity (1930’s) several families where living in very bad conditions and the State built a fisherman block on the dune cordon (CACHIM, 1983) Costa Nova was one of the most popular beaches of Aveiro region by the end of XIX, which attracted many people for summer holidays purposes especially after the construction of Aveiro-Ilhavo main road (CARVALHO, 1994)
| - After 1974 big changes on urban settlement occurred due to illegal construction near the sea resulting on dunes destruction (CUNHA *et al.*, 1997) and every winter time there were serious damages by sea action, overtopping events, floods, salinity on farm lands and road interruption during the winter of 1978, (PINHO, 1993) |
| - 1970 –According to CAETANO (2002) Costa Nova urban area was 172 000m² |
| - 1998 – Urban expansion through seaward and Mira channel direction (Costa Nova) (CAETANO, 2002) |
| - **Vagueira** as an urban settlement was recently formed (80’s) and was related to a big boom on construction due to potentialities location (between sea and lagoon landscape). Until then the population density was very low. According VAGOS MUNICIPAL PLAN (1989) Vagueira had only 121 inhabitants in 1981. (In the same plan it was predicted for the year 2025 a number of inhabitants of 3000 and 1000 for seasonal population). |
| - 1947- Dredging operation on the Mira channel and sand deposition on the tide action land where now is situated Vagueira urban settlement |
| - 1970 Vagueira urban area was 62 000m² and there were no coastal protection works |
| - 1998 the urban area increased 6 times than 28 years before with a total area of 373 000m² (CAETANO, 2002) |
Table 9 - Littoral urban evolutionary aspects at Aveiro Lagoon / Mira Channel

<table>
<thead>
<tr>
<th>Littoral Urban Evolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lagoon Waterfronts - Mira channel</td>
</tr>
</tbody>
</table>

**Gafanhas**

In the beginning XIX century (1803) there was an occupation of new areas for agricultural purposes on a very fertile land near the recently formed Mira Channel. During the XX century an increase on activities related to the Lagoon raised new infrastructures, new industries and tourism which lead to urban expansion of the existing urban settlements and development of new ones - Gafanhas (CARVALHO, 1994). According to this author the founding creation dates for the Gafanhas urban settlement are assumed:

- 1910 - Gafanha da Nazaré
- 1926 - Gafanha da Encarnação
- 1957 - Gafanha do Carmo

3.6.4 Urban and Tourist Pressure

Concerning the present urban pressure matters, the areas of Barra, Costa Nova and Vagueira support an increasing attention by the seasonal summer population. The tourist industry of recreation and leisure has driven the growth and type of the aforementioned zones. Apart from these zones, the territory of this sector and of the west side finds itself in the most part free of significant urban occupation.

The beaches are used by thousands of people during summer and the requalification of the Aveiro Lagoon and urban seafront is included on a major national programme for the POLIS programme (Improvement and requalification of urban areas Programme).

The urban concentration is observed most prolific along the border of the lagoon and extends into the periphery zones (Figure 13). In global terms the number of buildings increases at higher rate then the population growth. This is partly as a consequence of secondary homes and of summerhouses in the vicinity of the Aveiro lagoon (FIDELIS, 2001).
To understand the population territorial distribution, it is presented on Table 10 the population density concerning the study area. It can be stated that the most populated area is related to the Gafanha da Nazaré, which also includes the Barra and Costa Nova dwellings. It is observed a strong occupation and density for the area of Gafanhas, mostly the Gafanha da Nazaré (far above the municipal average) and the Gafanha da Encarnação, at Ílhavo municipality.

Table 10- Population territorial distribution on the study area – (source:INE-Censos 2001)

<table>
<thead>
<tr>
<th>Ílhavo</th>
<th>Inhabitants</th>
<th>Area (km²)</th>
<th>Density (inh/km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Municipal - total</strong></td>
<td>37,209</td>
<td>7.5</td>
<td>496.1</td>
</tr>
<tr>
<td>Gafanha da Encarnação</td>
<td>4,907</td>
<td>11.7</td>
<td>419.4</td>
</tr>
<tr>
<td>Gafanha da Nazaré</td>
<td>14,021</td>
<td>15.6</td>
<td>899.8</td>
</tr>
<tr>
<td>Gafanha do Carmo</td>
<td>1,521</td>
<td>6.1</td>
<td>249.3</td>
</tr>
<tr>
<td><strong>Vagos</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Municipal - total</strong></td>
<td>22,017</td>
<td>165.6</td>
<td>133.0</td>
</tr>
<tr>
<td>Gafanha da Boa Hora</td>
<td>2,277</td>
<td>30.9</td>
<td>73.7</td>
</tr>
<tr>
<td><strong>Mira</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Municipal - total</strong></td>
<td>12,872</td>
<td>122</td>
<td>105.5</td>
</tr>
<tr>
<td>Praia de Mira</td>
<td>985</td>
<td>39.8</td>
<td>75.0</td>
</tr>
</tbody>
</table>
At Gafanha da Nazaré, Encarnação and Boa-Hora (Figure 14), the urban occupation presents an outward extension based on the development from the main roads of several secondary paths.

Figure 14: Aerial view of urban development at the sand spit and inland low-elevation areas- Vagueira Beach and Gafanhas (photo in: Aeroguia do Litoral, 2002)

3.6.5 Future Development Trends

The principal trends in future development can be pointed as:

- One predicted improvement in the environmental quality at the lagoon area, with an increase on nature protection investment actions;
- On the other hand an increase of pressure promoting the urban occupation;
- The perspective on the construction of the Marina Barra, at the entrance of Mira channel. This project has been originated a polemic discussion in a way that besides its potential contact relation with the whole lagoon raising a completely different tourist demand, it can have also high negative impacts, compromising the general environmental equilibrium of the lagoon. The project was already target of a EIA;
- A predictable increase on tourism activity revealed in the Municipal Plans of Vagos and Mira, which both enhance the advantages of the littoral and lagoon territory for potential touristry interventions. According to (CPU, 2002), almost every municipalities related to the littoral stretch still have land provision to be used in the future for touristry activities in close relation to the existence of beaches;
- The complete implementation of the Urban Plan for the Vagueira Beach, which represents the increase of the total urban area. This Urban Plan aims to a consolidation of the existing
urban structure, however, the main worry has been the seafront protection. The direct Lagoon/Vagueira relation so far has been forgotten, expecting new concretisation within the plan proposals, mainly on public space uses;

- The implementation of several urban projects developed by the Ílhavo Municipality and GTL (Technical Urban Planning Local Division), focusing on the urban rehabilitation and improvement of public space for the Costa Nova urban settlement – Southern part.

Figure 15: Proposal location for the Marina-Barra Project- Mira Channel

The tendencies of the last years have been in the search of defense and protection of the agricultural fields from the salty water.

The following previsions are suggested in the interest of urban nature control (CPU, 2002):

- Minimal infrastructure (garbage cans, water, parking areas) located in appropriate areas to facilitate usage of the margins of the Lagoon;
- A new “profile” for the roads alongside the Lagoon (walkways, vegetation and trees, cycle paths);
- Traffic control, (in particular heavy vehicles);
- The installation of lifesaving equipment located on the small landing platforms of the Lagoon;
- Directions of usage to areas most adequate with the provision of infrastructure.
3.7 Main Aspects for Conclusion

The Barrier coast which is the target on the study area, was naturally instable. Following the analysis of the formation process of the Aveiro lagoon, it can be concluded that it was originated by the evolution, north-south direction, of a sand-spit that had been wasting away the exit of the fluvial water into the ocean 6000 years ago.

The sea action regime is the most energetic and dynamic force acting in this area, being therefore, its main modeller agent (VELOSO GOMES et al., 2002).

The North-West Atlantic tide and the wave regime associated with the littoral drift currents generate a very severe natural climate important to understand on the context of the global process of coastal erosion.

The land use in the area is mainly related with the agricultural activities, some important forested areas and urban areas as well as an important harbour area.

In this study area the main territorial and structural elements are the Mira Channel – Southern part of Aveiro Lagoon, the urban settlements of Barra, Costa Nova, Vagueira as coastal waterfronts and Gafanha da Nazaré, Gafanha do Carmo, Gafanha da Vagueira, Gafanha da Bea Hora, Gafanha do Areão as a lagoon waterfronts - East side of Mira Channel, and finally the main traffic roads: IP5, EN109-7 (Barra/Areão) e EM591 (Mira/Gafanha da Nazaré).

Most of the urban areas are too much close to the shoreline, witch leads to an important number of costal defences that can be seen on the sandy stretch of Costa Nova - Mira beach. At inlands urban areas Gafanhas, the urban occupation presents an outward extension based on the development from the main roads and of several secondary paths. An increase of pressure promoting the urban occupation on these lagoon low-lying areas is presented at Municipal Plans.

Concerning the present urban occupation at the sand-spit, the urban settlements of Barra, Costa Nova and Vagueira support an increasing attention by the seasonal summer population. The tourist industry of recreation and leisure has driven the growth and type of the aforementioned zones.

The principal trends in future development can be pointed as one predicted improvement in the environmental quality at the lagoon area, with an increase on nature protection investment actions. On the other hand an increase of pressure promoting the urban occupation and touristy activities is also expecting.
CHAPTER 4 –
COASTLINE EVOLUTION
CHAPTER 4- COASTLINE EVOLUTION

4.1. Introduction

In this chapter a special concern for the erosion phenomenon is presented, in order to understand the main causes of the coastline variation at the study area. However, to understand the complexity of the processes of change and the link between human and physical factors, it is important to develop a clear analysis at the local scale.

Focusing on the hydrographical database from the year 1996 (INAG, 1996) and from the year 1998 (AMRIA, 1998) with data improvements concerning the year 2000 (LabSIG- University of Aveiro), a comparison analysis was made in order to highlight the main significant changes on the coastline. An overview of the present coastal erosion interventions and the analysis of coastal defence options within the Coastal Zone Management Plan (POOC) Ovar - Marinha Grande, for the maintenance of the actual uses and activities in this coastal zone, are also presented.

4.2. The Erosion Phenomenon

The first data concerning erosion events at NW coastal areas, was related to 19th century when several fisherman houses were destructed during a big storm near Furadouro beach, at the northern part of Aveiro Lagoon. However, the high erosion rates concerning the study area, are relatively recent and were presented mainly after the second half of 20th century. Between 70/80 decades the Costa Nova Beach and Vagueira Beach were severely affected, and later on the 90’s the erosion event has been generalized (M.C.O.T.A., 2002).

The littoral area between Costa Nova and Vagueira has approximately 9 km, from the South breakwater of Aveiro harbour to the North groin of Vagueira. The entire area suffers from the influence by the Aveiro harbour interventions, especially the dredging channels and the large breakwaters. Several groins, seawalls and artificial dunes were built to protect the shoreline. Between 1947 and 1978 a retreat of 200 m up to 300m has been recorded. The first groin field was built in 1972. Between 1978 and 1996 the erosion outside the groin zone reached 100m (IHRH, 2003).

Several authors have presented erosions rates for the study area, using different methodologies and database (Table 11).
### Table 11 - Retreat (-) and accretion (+) rates presented by several authors (Adapted from IHRH, 2003)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Barra Beach</td>
<td>-8.2       -4.0</td>
<td></td>
<td>-1.7</td>
</tr>
<tr>
<td>Costa Nova</td>
<td>-2.4</td>
<td></td>
<td>-1.7</td>
</tr>
<tr>
<td>North Vagueira</td>
<td>-2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vagueira Waterfront</td>
<td>-2.4</td>
<td>-3.0</td>
<td>-3.3</td>
</tr>
<tr>
<td>South Vagueira</td>
<td>-2.4</td>
<td>-0.7</td>
<td>-3.3</td>
</tr>
<tr>
<td>Areião</td>
<td>-0.7</td>
<td>-3.3</td>
<td></td>
</tr>
</tbody>
</table>

### Ângelo, C. (1993)

| Beach   | 1870/1954 (84 years) 1954/1990 (36 years) 1984/1990 (6 years) |
|---------|---------------------------------------------------------------|-----------------------------------|
|         | Average retreat m/year Total retreat area ha Average retreat m/year Total retreat area ha Average retreat m/year |
| Barra Beach | 1.6 75 +0.7 90                                          |
| Costa Nova   | 1.5 -5.2 -8.0                                           |
| Vagueira Beach | +12.0                                               |
| South Vagueira | -3.0 -16                                                 |
| Areião                                   |

### Ferreira, O., Alveirinho Dias (1993) and Ferreira, O. (1993)

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m/year</td>
</tr>
<tr>
<td>Barra Beach</td>
<td>-4.6</td>
</tr>
<tr>
<td>Costa Nova</td>
<td>-1.5</td>
</tr>
<tr>
<td>North Vagueira</td>
<td>-6.6</td>
</tr>
<tr>
<td>Vagueira Waterfront</td>
<td>-0.1</td>
</tr>
</tbody>
</table>
According to (CAETANO, 2002) the average retreat rate for the last 40 years (between 1958 and 1998) was around 146m on the study area (Table 12 and figure 16) and the annual retreat was considered as 3.7 m/year.

**Table 12 – Retreat (−) and accretion (+) rates between 1958 and 1998, presented by CAETANO, 2002**

<table>
<thead>
<tr>
<th>Location</th>
<th>Beach sections</th>
<th>Total calculated variations (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1E1</td>
<td>Costa Nova do Prado</td>
<td>252.9</td>
</tr>
<tr>
<td></td>
<td>Costa Nova do Prado</td>
<td>311.0</td>
</tr>
<tr>
<td>P2E1</td>
<td>Costa Nova do Prado</td>
<td>30.6</td>
</tr>
<tr>
<td></td>
<td>Costa Nova do Prado</td>
<td>-70.2</td>
</tr>
<tr>
<td>P3E1</td>
<td>Costa Nova do Prado</td>
<td>-156.8</td>
</tr>
<tr>
<td></td>
<td>Costa Nova do Prado</td>
<td>-127.9</td>
</tr>
<tr>
<td>P4E1</td>
<td>Costa Nova do Prado</td>
<td>-144.9</td>
</tr>
<tr>
<td></td>
<td>Costa Nova do Prado</td>
<td>-305.1</td>
</tr>
<tr>
<td>P5E1</td>
<td>Costa Nova do Prado</td>
<td>-283.3</td>
</tr>
<tr>
<td></td>
<td>Vagueira</td>
<td>-210.8</td>
</tr>
<tr>
<td>P6E1</td>
<td>Vagueira</td>
<td>-172.1</td>
</tr>
<tr>
<td></td>
<td>Vagueira</td>
<td>-66.6</td>
</tr>
<tr>
<td>P7E1</td>
<td>Vagueira</td>
<td>-140.0</td>
</tr>
<tr>
<td></td>
<td>Vagueira</td>
<td>-144.6</td>
</tr>
<tr>
<td>P8E1</td>
<td>Vagueira</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Vagueira</td>
<td>0.0</td>
</tr>
<tr>
<td>P9E1</td>
<td>Vagueira</td>
<td>-34.6</td>
</tr>
<tr>
<td></td>
<td>Vagueira</td>
<td>-33.1</td>
</tr>
</tbody>
</table>
Although these several authors present clearly data on erosion rates it is necessary to recognise that those quantifications studies have some limitations regarding the (IHRH, 1992):

- lack of data-base concerning topohydrographic and bathymetric elements survey on a bigger extensions on time/space of the beach and shoreface.
- The need for assessment criteria, which not only should consider the dunes and coastline evolution (by comparing analysis of photo aerial and topographic survey), but also the
global morphological evolution aspects on emerse and submerse areas as well transition zones which lead one to a 3D complex natural phenomenon.

And finally, for overlapping the sum effect of long-term evolution showing huge variations related to extreme/seasonal events (storm) from both natural causes and anthropic actions.

Besides the difference in figures according to each author, by the table analysis there is a clear and significant trend for retreat on the study area. The immediate pointed cause for those erosion rates which have been increasing since the construction of breakwaters from the Aveiro harbour, by the end of 40 decade (BETTENCOURT, ÂNGELO, 1992 ; TEIXEIRA, 1994 ; FERREIRA, 1998) It is also consensus that in the last decades, erosion is spreading southward affecting a longer coastal area. This behaviour shows an increase on deficit sediments on the region, which tends to be in part replaced by beach and dunes erosion processes (FERREIRA, 1998).

![Coastline migration rate](image)

Figure 17 – Coastline migration rate between 1940 and 1990 for the coastal stretch Barra-Cape Mondego (Adapted from FERREIRA, 1998)

The interruption of the littoral drift, caused by the retention of the northern Breakwater (S. Jacinto) and by the exterior bank, translated in an accumulation of about 20 millions of cubic metres between 1950 and late 70's (BETTENCOURT, ÂNGELO, 1992). This retention caused a high deficit of sediments in the south, having, as a result, an important recess of the coastline. The littoral stretch of the study area, from 1870 to 1900, was maintained stable in a general way. However, between 1900 and 1958, the dismantling of the sandy dune cordon occurred, as a consequence of the recess of the coastline, being the situation more and more worrying.

The different authors that have been studied the stretch correspondent to the study area, show different figures for the recess rates of the coastline. However, they are unanimous when
considering very high rates. These differences, some of which are very significant, are, overall, due to the different methods used by the authors (comparison of aerial photographs, of maps, observation and screening of the soil), as well as the figures being dependent of the analysed period and of the extension of the area that is being studied (ALVEIRINHO DIAS et al., 1994).

In the period of 1947/58, the highest recess medium rates occurred in the sand-spit and immediately south from the jetties of Aveiro. The big increase of the erosion may have been a consequence of these buildings, which started in 1948 and of a strong retention verified north from them. However, between 1980/90, in the sector Barra-Costa Nova, an accretion has occurred, which was caused by the artificial feeding that has been made there in the beginning of the 90’s (FERREIRA, 1993).

In the period 1958/70, the highest recess medium rates have occurred between Costa Nova and Vagueira, because the erosion was being gradually extended to the south. However, from 1970 to 1990, a diminishing of the recess medium rates was noticed, mainly as a consequence of the spit of Vagueira, built in the end of the 70’s (FERREIRA, 1993).

In the sector Vagueira – Beach of Areão, a trend more or less gradual of the increase of the recess of the coastline has been shown (FERREIRA, 1993).

The erosion problems on the south of the jetties of Aveiro forced the building of several coastal engineering works in the areas of Costa Nova and Vagueira.

Focusing on the hydrographical database from the year 1996 (INAG, 1996) and from the year 1998 (AMRIA, 1998), a comparison analysis was made in order to highlight the changes on the coastline. As presented in figures 18, 19, 20 during this 2 years period, a general retreat occurred mostly at the south of Costa Nova Beach and southern part of Vagueira Beach.
Figure 18: Coastline variation between 1996 / 1998 - Barra Beach and Costa Nova (source: INAG, 1996 and AMRIA, 1998)

Figure 19: Coastline variation between 1996 /1998 – Costa Nova and Vagueira Beach (source: INAG, 1996 and AMRIA, 1998)
For a better understanding of this coastline behaviour it can be stated that it should have been done a careful climatological characterisation of the analysed years 1996/1998, thus the conclusions could be far more credible.

4.3 Main Causes For Erosion

There have been reported multiple erosion induce factors, and they can result from natural causes or mostly from anthropic activities. In this specific area the main causes for erosion can be indicated as the following (VELOSO GOMES, 1993b):

1. Sea level rise
2. Weakening of the river basin sediment sources and river sediment transport
3. Urban pressures
4. Hard defence Structures
5. Other causes
4.3.1. Sea Level Rise

When focusing on generalised coastal erosion present situation, it firstly comes up the cause/effect relation of sea level rise. In fact the sea level rise effects are related with the coastal line specificities once it originate a raise on the wave regime, on tides, on coastal erosion, on floods, salinity (estuaries and lagoons) and on the sediment dynamics. The predictable effects on coasts will be bigger when there is lack of natural protection as on sandy coasts or lower coastlands -the case of central region of Portugal (IHRH, 1992).

According to ALVEIRINHO DIAS, (1990), the sea level rise over the last decades was estimated in 1,5+0,2 mm/year, and indicates a transgressive trend along the coast. The former predictions may be challenged by the few available data and the controversial assumption that this rise rate will be maintained.

Table 13 – Predictions on Sea level rise on Portuguese coast (IHRH, 1992)

<table>
<thead>
<tr>
<th>Year</th>
<th>2030</th>
<th>2070</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raise (cm)</td>
<td>6</td>
<td>12</td>
<td>16,5</td>
</tr>
</tbody>
</table>

The contribution of sea level rise to the erosion of the coast has been assessed in the NW low coast between the Aveiro inlet and Cape Mondego, using Bruun’s Rule. Results suggest that in all coastal stretches the rise in sea level observed in the 20th century accounts for only but a small fraction (10-15%) of the erosion observed after the 1950s (ÂNGELO 1991; FERREIRA 1993, VELOSO GOMES, 1993b). It follows that the amount of sediment eventually lost to the shelf and necessary to readjust the shape and dimensions of the littoral wedge in response to sea level rise is quite small when compared with the stock reworked in the shallow nearshore by wave-driven longshore transport. Sea level rise is therefore a secondary factor of coastal change at the time-scale typical of engineering and the shelf is not a relevant sediment sink at this scale of observation (FERREIRA, 1993).

4.3.2. Weakening of the River Basin Sediment Sources

One of the main causes for erosion on this study area has been identified as a coastal response to the weakening of the river basin sediment sources and river sediment transport (VELOSO GOMES, 1992).
The sandy coast erodes because potential transport capacity of oblique waves (between 1 and 2 million cubic meters per year) is greater than the annual sediment volume supplied by the rivers (at present between 0 and 0.2 million cubic meters per year) (VELOSO GOMES et al, 2002). Sediment supply to the shore is crucial to saturate the potential transport capacity of waves and maintain beach-dune systems, inlets, tidal deltas and the littoral drift currents in balance (ANDRADE; ; et al., 2002).

The sediment budget of the Douro river basin, it is an important source of sediments to nourish the downdrift beaches, including the study area. The Douro river basin has a very long extension thus it can cause huge impacts on the South coast of Douro mouth. In fact, River Douro can produce around 750 0000 m3/year to 1 200 000 m3/year of sediments on a natural regime (IHRH, 2002).

![Dams Location in Douro River National Basin](image)

Figure 21: Dams location in River Douro National Basin (in: IHRH, 2003)

Nowadays Douro, river only contributes with a small sediments amount, which is estimated around 250 0000 m3/year, in consequence of the dam's construction that reduced the erosion power of the river bed and margins, the flow velocity and as consequence the amount of the transported sediments. These hydroelectric plants, in Portuguese (built between 1971 and 1988) and Spanish rivers currently constitutes an indispensable component for supplying renewable energy. However, the use of water for the production of energy, water supply to humans, industry and agriculture is
drastically reducing the volume of solids transported to the sea, worsening coastal erosion (VELOSO GOMES et al, 2002).

The reduction of sediment transport is also associated to the extraction and dredging of large amounts of sand (along Douro river and Aveiro harbour) for navigation and civil construction industries in quantities beyond the sustainable, which impacts on the coastal zones have not been assessed.

Table 14 – Douro River sediments budget capacity (in: IHRH, 1992)

<table>
<thead>
<tr>
<th>Natural situation</th>
<th>After Harbour works – Leixões (1893, 1940, 1969)</th>
<th>Present situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.400 000</td>
<td>1.200 000</td>
<td>200 000</td>
</tr>
</tbody>
</table>

According to BETTENCOURT, P.; ÂNGELO, C. (1992), the sediments supply has considerably decreased for the last 3 decades, referring that the present volume is less than 250 000m3/year comparing with the 1.5 to 2 millions m3/year on a natural situation, neither considering Hydroelectric plans nor extraction and dredging of sand.

Equally, in natural regimes and before the beginning of the dam's construction in 1930, the National Water Plan, (INSTITUTO DA ÁGUA, 2001), refers that the total littoral sediment transport in the Portuguese north coast was near an amount of 2 000 000 m3 /year, with the Douro river guaranteeing itself 90% of this value.

There is scientific evidence of this impact supported by the hydrodynamic changes that have been predicted and recorded along the main rivers (particularly in the river Douro) due to the reduction of flow velocity fields comparatively to the same flow rates before damming. The reduction in the flow of solids and nutrients, the progression of saline intrusions to higher and neighbouring areas are impacts that cannot continue being ignored in the studies and decision processes (VELOSO GOMES, 1993b).

Relatively to the medium sediment transport of the Aveiro Lagoon fluvial system, it was estimated in 240 000 m3/year, practically without the interference of the existent hydraulic structures. The Vouga River contributes approximately with 75% of these sediments. Comparing the two river hydrographical surveys (between 1952/1953 and 1987/1988) it is possible to estimate in this period of 35 years an increasing of its depth of 0.4 m, largely explained by the dredging activities realized for the inlet opening and maintenance (INSTITUTO DA ÁGUA, 2001).

In the Aveiro Lagoon the sediments from the dredging operations for inlet and harbour maintenance are sold for the construction.
4.3.3. Human / Urban Pressures

Urban occupation has been an important factor as a modelling agent of the coastal landscape. Hence, urban + waterfront locations conflict with natural coastal evolution. The human occupation and dune destruction is responsible, at least locally, for morphological unbalance situations (IHRH, 1992) and therefore, increasing beach vulnerability, since the dunes play an important role as a natural barrier to sea forward advances.

Several times after an emergency interventions to protect urban waterfronts some new pressure for construction appeared, besides, this protection works originated or anticipated new southward erosion problems.

In global terms the number of buildings is growing up faster than the population growth in this study area (FFIDÉLIS, 2001). There is a continuous pressure towards consolidation, growing density, and expansion of building on waterfronts. The model adopted in various Municipalities along the coast, despite not being openly assumed in the Municipal Land-use Plans, is equivalent to an effective coconsolidation and denseness of the construction along the coast.

![Figure 22: Urban Development at Vagueira Beach (MCOTA, 2002)](image)

Several built waterfronts, protected by groins and seawalls have increased the vulnerability to erosion and direct wave action (figure, 22). Water front development was intensely promoted by local authorities and it was not controlled at a national level. The intense rate of occupation, use and transformation of several Portuguese coastal zones has been reported as of worrying. There is a continuous pressure towards consolidation, growing density, and expansion of buildings on the waterfronts (VIELOSO GOMES, 1994; 1997; VELOSO GOMES et al, 2002).

Up to the late 1980s, there was not a perspective of coastal management in Portugal, and illegal construction for summer houses on dunes cordons was a serious problem during the 60’s- 70’s
assuming as a total disrespect and destruction for landscape values and for occupation of public land which belongs to everyone. Besides the local erosion problem, it also could promote public health problems.

Table 15 - Main seafront urban extension (based on aerial photos INAG, 2001)

<table>
<thead>
<tr>
<th>Beach</th>
<th>Main Urban Extension (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beachfronts</td>
</tr>
<tr>
<td>Barra</td>
<td>1.20</td>
</tr>
<tr>
<td>Costa Nova</td>
<td>4.25</td>
</tr>
<tr>
<td>Vagueira</td>
<td>2.10</td>
</tr>
</tbody>
</table>

Besides the urban occupation on the dune cordons it could be noted several paths of public access to the beach using of vehicles motorcycles, causing the vegetation destruction which originate the eolic corridors and small breaks on dunes (IHRH, 1992) which facilitate overtopping events:

- Costa Nova – Vagueira beach, on 4.5 km extension where several farm-lands exist near the beach.
- Vagueira beach – Mira beach, on 11 km extension

The conservation of dunes and their replanting with vegetation should merit special attention due the rapid degradation that is occurring in areas of easier access and even in remoter ones (VELOSO GOMES, 1999b).

4.3.4. Hard Defence Structures

With established sediment sources and under a certain wave climate, a beach will tend toward a natural equilibrium where the waves are just capable of redistributing the sands supplied from the sources. When jetties, breakwaters, or other structures are constructed in the coastal zone, the natural equilibrium will be upset, sometimes with disastrous consequences (KOMAR, 1976). Many of the most severe cases of coastal erosion can be attributed to this disturbance of the natural equilibrium.

The construction and enlargement of breakwaters at the harbour entrance seriously affected the sediment transport southgoing which could be demonstrated by the sediments retention at north beaches and on the submerse sand bank out inlet – 20 millions m3 on the 50 to 70 decades, (MOTA OLIVEIRA, 1990)

The assumption of groin fields and parallel defences as technical solutions for coastal erosion have underlined that after the updrift sand increase (after several years) there should be a re-establishment of sediment transport downdrift (10 to 100 metres away from the groyne). However
this situation so far it is not happening and some authors say that due to the groins barrier effect on longshore drift (currents deflation) the sediments could be removed far on depth in a way that it will not be possible for shore currents to bring them back again to the beach. Thus this can lead to a permanent erosion situation downdrift the groins system which must be taken into account in future decision — making process (IHRH, 1992).

These hard structures turn the beach as more reflective one thus the waves can approach the coast with a higher energy. Strong currents can be generated with a bigger remobilised power which lead to coastal adjacent erosion in both structure extremity and consequently increase the sediments transport to deeper zones (ALVEIRINHO DIAS, 1990).

The harbour jetties and breakwaters may also provide areas to either side, which are partially protected from the waves. Sand is transported into these areas and accumulates, the weak, diffracted waves being unable to remove the sand. Therefore, the long-term result is an accumulation of sand near the jetty within the "embayments" and sheltered areas created by the jetty construction. To supply this sand to the deposition zone, erosion occurs at greater distances from the jetties (KOMAR, 1976).

Figure 23: Aveiro Harbour Jetties cut off sand supply to the down drift beaches. The updrift S. Jacinto larger beach (MCOTA, 2002)

The stretch of sand spit Costa Nova/Mira has approximately 14 km from the South breakwater of Aveiro harbour to the North groin of Vagueira. It is influenced by the interventions made in the Aveiro harbour, especially the dredging channels and the large breakwaters. The existent commercial harbour in the region (Aveiro Lagoon) will continue to require breakwaters of considerable dimension and might even claim their extension for safety and operational reasons. These barriers to the littoral transport will remain.
The first groin field was built in 1972, and between 1978 and 1996 the erosion outside the groin zone reached 100m. Between 1947 and 1978 an erosion of 200 m up to 300m has been recorded (BOTO, 1997).

On Table 16 it is presented an historical review of the hard defence structures based on the following maps, in order to facilitate an understanding on the coastline.

Table 16: Hard defence structures historical review

<table>
<thead>
<tr>
<th>Hard Defence Structures - historical review</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nearly in the 50's, there was the need to try to protect the populations, its properties and real estates. That way seawalls and groins were built to stabilise the sand-spit of Barra-Costa Nova, because this one was the first being affected by the building of the harbour jetties (FERREIRA, 1993).</td>
</tr>
<tr>
<td>Facing the continual worsening of the coastal erosion, in 1972/73, a continuous longlittoral enroclment and a field of 11 groins were built in Costa Nova do Prado, in an extension of 2 400 m, to try to control the erosion (OLIVEIRA et al., 1982)</td>
</tr>
<tr>
<td>The structures built since the 50’s, are responsible for the relative stabilisation of the recess rates in the sector Barra-Costa Nova, between 1947/80, once they stop the beaches recesses. However, as the erosive process was still very active and extending south, it was necessary to build new coastal engineering works. Therefore, in 1975/78, there was the protection immediately south from the Bar, with a longlittoral enroclment and, in 1978, the first frontal emergency defence works were built in Vagueira Beach urban seafront.</td>
</tr>
<tr>
<td>In the next year, due to the relatively high recess rates in that area, two more groins were built (250 m), one, in the south of Vagueira and the other immediately south of the groin field of Costa Nova (VELOSO GOMES, 1992).</td>
</tr>
<tr>
<td>As a consequence, there was a diminishing of the medium recess rates in the sector Costa Nova – Vagueira, mainly due to the first referred groin. As an example, in front of Vagueira, in the first year after the building of the groin, there was an increase of the width of the beach of about 20 m, though it had an increase of the recess rate in the stretch Vagueira – Areão.</td>
</tr>
<tr>
<td>Due to the severe wave regime in this area, the enrocllements and groins are the target of several ruptures, which forces successive repairs and replacements throughout the time, generally by others that are bigger and stronger.</td>
</tr>
</tbody>
</table>
Defence Structures Before 1983

LEGEND

Defence structures before 1983

1. Groyne field Costa Nova - 1972/73
2. Groyne - project only
4. Seawall - Barra 1975/78
5. Urban areas

Márcia Cabarroso
MSc Environmental Engineering
May 2003

Figure 24: Defence works - Situation till 1983 (Data from AMRIA, 1998)
Figure 25: Defence works at Barra and Costa Nova - Present situation
Figure 26: Defence works between Vagueira / Areão - Present situation
As stated above, several attempts to control the shoreline retreat between Costa Nova and Poço da Cruz (Mira), led to the construction of the following groins and revetments, along the urban waterfronts and adjacent areas. For each structure, the year of construction and the length is presented between brackets (VELOSO GOMES, 1999a):

- Groin 1 Costa Nova (1972; 120 m)
- Groin 2 Costa Nova (1972; 120 m)
- Groin 3 Costa Nova (1972; 120 m)
- Seawall (before 1981; 750 m)
- Groin 4 Costa Nova (1972; 120 m)
- Seawall (before 1981; 300 m)
- Groin 5 Costa Nova (1979; 100 m)
- Groin 6 Vagueira (before 1984; 130 m)
- Seawall (before 1984; 800 m)
- Groin 7 Vagueira
- Groin 8 – Areão (2002, 150m)
- Groin 9 – Poço da Cruz (2003, 150m)

Figure 27: hard defence works (groin 2, 3 and 4)- Costa Nova (In: Foto Engenho-Francisco Piqueiro, 2002)

On the other hand, it must be highlighted that if those hard structures did not exist it could be foreseen that several new inlet would be formed and the existing urban areas would be partially or totally destroyed, or prevailing as small islands.
4.3.5. Other Causes

Natural high dynamic situations can explain the past erosion rates when did not exist the harbour structures or protection works along the coast or even river dams to reduce sediments supply to the coast.

Extreme storm events, small changes on wind and wave directions (mainly to north) can increase erosion action as a result of a bigger obliquity in relation to beach bathymetric characteristics, (IHRH, 1992).)

Table 17 - Coastal erosion causes - Synthesis

<table>
<thead>
<tr>
<th>Coastal Erosion Causes</th>
<th>The identified erosion problems in the study area are mainly due to:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Reduction of river sand transport and strong flood events due to river damming;</td>
</tr>
<tr>
<td></td>
<td>• Reduction on the volume of sediments transported by the littoral drift both due to natural and artificial causes;</td>
</tr>
<tr>
<td></td>
<td>• Dredged sands with economic purposes and not reintroduced on the sedimentary cells through the artificial nourishment of the downdrift beaches;</td>
</tr>
<tr>
<td></td>
<td>• Sandy low coast with lack of natural protection submitted to highly energetic wave climate;</td>
</tr>
<tr>
<td></td>
<td>• Destruction of the dunar systems as a natural barrier to sea action;</td>
</tr>
<tr>
<td></td>
<td>• Human settlement on areas at risk, demanding for seafronts protection with large groynes and sea walls which will affect negatively the downdrift areas;</td>
</tr>
<tr>
<td></td>
<td>• Sea level rise</td>
</tr>
<tr>
<td></td>
<td>• Natural dynamic and high energetic conditions</td>
</tr>
</tbody>
</table>
4.4 Coastal Protection Measures and Policy

4.4.1 Coastal Defence Works

Up to the end of the 1980s, coastal protection was exclusively associated to the construction of defence works (seawalls and groynes), to reduce the risks of exposure of the edified building fronts to action of the waves and the tides. There was no effort at land-use planning - which has objectives that are much greater than just reducing such risks (VELOSO GOMES et al, 2002). It was also clear by section 4.3.4 that, the defence works may permit a reduction of coastal risks, but they do not cancel or reduce them to predictable levels when the time span adopted in new building projects is taken into account.

During the 70 and 80-decades coastal defence structures were built after large storms and intense coastal erosion. Up to 1994 their vital role to protect consolidated urban waterfronts was neglected and no maintenance actions were provided. Then they have been serious affected by storms and the structural and functional levels decrease below failure and safety limits. The beaches, which were stabilised by the groin fields, became very narrow and erosion problems have increased down-drift VELOSO GOMES, F., TAVEIRA PINTO, F. 1999a).

After serious emergency situations intensely reported by the mass media local emergency actions have been taken in order to avoid the flooding or the destruction of built waterfronts during storm events.

In June 1995 the Portuguese Ministry of Environment, which is responsible for coastal protection, defined a plan for reconstruction and repair measures of the most critical defence structures, and the coastal stretch of Costa Nova and Vagueira was elected as a first priority action. VELOSO GOMES et al, 2002) presented a report about the reconstruction and repair actions undertaken on the existing coastal defence structures.

The low altitude sandy shore of Costa Nova – Vagueira have a groin field of nine groins and seawalls (figure 25 and 26), and new groins have been constructed – Groin-Areão Beach and Poço da Cruz (figure 33).
4.4.2 Other Measures to Coastal Protection

Besides the construction of «hard» structures (groins and seawalls) it was also conducted since 1996 several «soft» measures to coastal protection, such as: dune system recovery -dune restoration (Figure 31) up-drift and downdrift groin fields, bailey recovery, dune revegetation, sand dunes retention, dunnes pathway with the improvement and limiting of public access to the beach.

Figure 30: Beach scraping operations South Vagueira beach (photo in MCOTA, 2002)
At the present there are several interesting dune rehabilitation being undertaken on this coast. The conservation of dunes and their replanting with vegetation should merit special attention due to the rapid degradation that is occurring in areas of easy access and even in remote ones.

Figure 31: dune restoration and sand fencing at Barra and Costa Nova Beach (photo 27/04/2003)

During 2001 and 2002, some emergency interventions were implemented by the Ministry of Environment, in order to avoid ruptures on the fragile dune system at the sand spit between Costa Nova and south Vagueira. This is specially the case of the construction of an artificial retreat dune system (figure 32), using ripping sand beach techniques (figure 30).

Figure 32: Emergency retreat dune between Costa Nova and South Vagueira (photo 27/04/2003)
4.4.3 Coastal l Plan - Protection Policy and Interventions

According to the Coastal Zone Management Plan (POOC) Ovar - Marinha Grande, (approved by the year 20000), coastal defence interventions were defined as a group of actions considered indispensable, for the maintenance of the actual uses and activities in this coastal zone.

The proposed approach for management and development includes the following line of actions:

1. Coastal defence at urban areas;
2. Elimination of the dune cordon rupture risk;
3. Coastal erosion risk evaluation and control;
4. Monitoring of the coast line evolution.

The interventions related with the coastal defences are subdivided in:

- Maintenance of sea work defence - maintain the sea work defence foreseen in the POOC;
- Dune systems rebuilding - Embrace a group of complementary works, previously referred, and that have as main objective to reduce the level of overtopping;
- Other proposed defence works - Embrace a group of temporary/experimental interventions to avoid risk situations like rupture/flooding. In this situation there are three works foreseen, being two of them located on the pilot study area in the south of Vagueira beach.

In general, the adopted coastal protection policy in POOC Ovar - Marinha Grande, was:

- To hold the line for coastal urban areas;
- To manage the realignment for not urbanized areas and specially, down drift of the groins, in order to establish a new “line of equilibrium”.

By the analysis of this coastal plan it can be stressed out that:

- there is no plan of emergency for intervention in the study area;
• It is referred and indicated interventions in case of ruptures and flooding. In the most part of the cases of dune cordon rupture, the intervention/actions consists on reconstruction of dune even temporarily, adding more sand to avoid the worsening land flooding and lost of more territory;

• When floods and ruptures occur there are no evacuation and reconstruction plans. These plans do not exist, may be because the area where the major floods and ruptures occur don't have urban seafronts, being of the agriculture or forest type. The urban zones more threatened by these situations, are protected by seawalls and groins;

• Some alternatives for coastal defence actions are being studied, such as the construction of a retreated dune system in Costa Nova - Vagueira and Vagueira - Mira stretches, which has been in study, and the artificial sand nourishment, referring that there is a need for conditioning the sand extraction and use part of the high volume dredged for navigation purposes for beaches nourishment.

The intervention concerning the construction of a retreated dunar system located parallel to the coastal line along the shoreline stretch of Costa Nova - Vagueira, foreseen in a situation of static equilibrium by the Costal Plan (POOC), can be considered as an important coastal measure once, this specific shoreline is suffering significantly erosion and it has been retreating further and further. This can lead to the opening of new inlets in Ria de Aveiro with significant consequences such as the flooding of agricultural lands and the salinization of the lagoon (VELOSO GOMES et al, 2002).

This predicted dune would have the crest at a level equal to +11 m HZ. The symmetric profile crest with 10 m of width, to the +11.0 HZ, slope 1/1), will be reconfigured by the wind, being foreseen that the leeward face is softer than the windward one to the constructive profile too. However, now exists the possibility of after one/two years, because of sand's salinity degree, there will be made planting works to reduce the capacity of wind erosion and make the dune even more consistent (IHRH, 2003).

According to VELOSO GOMES et al, (2002), these solution seems to be, however, not sufficient due to the threat and intensity of the existent problems and might probably have to be combined with other coastal defence techniques (e.g. artificial sand nourishment, groyne maintenance). The artificial dune will need great amounts of sand (total volume of sand needed to construct this artificial dune is around 1 000.000 m3), from the offshore. In addition, it must be noted that there are important legal and economical issues related to the land expropriation, which might have to be judged in court. Another possibility is to reinforce the retreated dune system with a rocky nucleus to improve the defence capacity to the sea actions, or with a sand container core (IHRH, 2003).
4.4.4 New Approaches

The artificial re-establish of river sediments on breakwaters—cost-benefit study from (OLIVEIRA, 1968), refers to the hypothetic sand bypassing in the Aveiro lagoon inlet, and it might be considered as an interesting option, despite the technical constrains and due the high potential transport of the waves that could made the intervention ineffective in a short period. This is also an intervention very expensive and without guaranties of great durability. Some studies are in process to know the possibility and the effectiveness of this hypothesis (IHRH, 1992).

4.5 Main Aspects for Conclusion

The study area, is located, downdrift the component of the Aveiro lagoon system that has been evidencing a morphologic evolution extremely dynamic. It is patent that after some hundreds of years of progress in seaward direction of sedimentary territories, it is detected a dynamic in the inverse direction, to areas where a human occupation is verified, and that could tend to be reached progressively by the sea, suffering for a general retreat.

The wave action and the erosion phenomena are very critical, plus, there are no natural defences and there is a very coastal dynamic past situation actually opposed by human occupation.

The different authors that have been studied this coastal stretch, have refered different figures for the recess rates of the coastline. However, they are unanimous when considering very high rates. A simple exercise was made in this chapter, focusing on the hydrographical database from the year 1996 (INAG, 1996) and from the year 1998 (AMRIA, 1998), in order to achieve a comparison analysis. It was possible to highlight the changes on the coastline during this 2 years period, as a general retreat occurred mostly at the south of Costa Nova Beach and southern part of Vagueira Beach.

Coastal erosion in this study area is seen as a response to the continuous weakening of the river sediment sources, the harbour and coastal defence works, the mean sea-level rise, the human / urban pressurees and other causes as the natural high beach dynamics and storm events. Further on, it can be concluded that, in this coastal area the serious vulnerability situation was directly started with the sedimentary retention capacity of the northern breakwater of the Aveiro lagoon inlet.

Another reason is the great amount of sand extracted from the S. Jacinto beach and the successive dredging works, without a reposition on downdrift beaches, for the maritime access to Aveiro
harbour resulting in a great deficit of sediments downdrift the inlet. These problems could be worst as the sea level rise and climatic changes, which could introduce modification in the wave regime (frequency, intensity, direction), adding a more destructive effect (VELOSO GOMES et al, 2002).

During the 70's and 80's, several coastal defence structures were built after the occurrence of large storms and intense coastal erosion. Coastal Protection was exclusively associated to the construction of defence works (seawalls and groynes) to reduce the risks of exposure of the edified building fronts to action of the waves and the tides. This coastal stretch has a large groyne field (of 9 groynes) and seawalls, where two new groins have been constructed for the last 3 years: Groin-Areão Beach and Poço da Cruz.

Besides these hard protection measures, it was also conducted since 1996 several «soft» measures to coastal protection, such as: dune system recovery -dune restoration, dune revegetation, sand dunes retention, dunes pathway and sand fencing. Dune rehabilitation is underway and it will continue in the next years.

A general analysis of the Coastal Management Plan – POOC was conducted referring the adopted coastal protection policy of holding the line for coastal urban areas and on the other hand, to manage the realignment for not urbanized areas and specially, down drift of the groins, in order to establish a new “line of equilibrium”.

Along this coastal zone (Costa Nova, Vagueira) there are no plans for retreat operations, and above all, a retreat proposal was not even considered in the Coastal Plan.

It is important to refer that in some places of this area some ruptures on the dune system happened. In these situations a number of emergency interventions were made to avoid a more complicated situation. That was the case of an artificial retreat dune system construction and sand nourishment operations.

The existing urban waterfront areas, actually defended by coastal structures are a source of permanent maintenance problems and will demand increased financial resources. The effectiveness of sea defences in water fronts (groynes) is located and partial.

It has to be highlighted that until recently, repairs were hardly ever undertaken, leading to a rapid progression of the damage and risk situations, which are unacceptable in the adjacent edified areas (VELOSO GOMES et al, 2002).
The question whether is necessary to implement defence structures, or even the project definition and location, have raised strong public discussion. Therefore it is important to clearly understand the causes for erosion and be open minded to accept new alternatives.
CHAPTER 5 -
VULNERABILITY PRE-ANALYSIS AND FLOODING SCENARIOS
CHAPTER 5- VULNERABILITY PRE-ANALYSIS AND FLOODING SCENARIOS

5.1- Introduction

The aim of this chapter is to demonstrate how unstable and vulnerable the study area is to the sea action, based on the general coastline behaviour. Concerning the available data for the year 1996 / 1998 / 2001, an assessment is made of the vulnerability conditions and possible territorial/physical impacts of new break zones along the South area of the sand-spit undertaking different “flooding scenarios”. This analysis only indicates the expected relative changes. Hence, it was only possible to achieve qualitative flooding scenarios based on the present state of database sources, practical experience and within the study limits of this project.

In section 5.2 an overall reading on the Coastal Zone Management Plan (POOC) of Ovar-Marinha Grande and at the same time of the Littoral Map Risk, was conducted in order to analyse the established coastline predictions as well the risk areas classification for the study area.

An empirical vulnerability analysis is presented in section 5.3 using GIS tools, in order to evaluate the main critical areas, complemented by aerial photo to represent the several vulnerability adopted criteria: Sea level rise; Break zones Migration, Historical or potential inlet; Overtopping events; Site elevation; Wind exposure /dune configuration; Erosion rates; Human alterations.

In section 5.4 the construction of flooding scenarios is presented and finally, the consequences for safety, and edification are described and summarized in section 5.5.

5.2 Coastline Evolution and Predictions

5.2.1 The Coastal Plan - POOC

By the Coastal Plan - POOC analysis, it was possible to identify the degree of vulnerability (Table 18) and some possibilities of coastline evolution, presented as a new “equilibrium position” for the shoreline in the future.
Table 18: Shoreline trend evolution – Coastal Zone Management Plan (POOC). (in: IHRH, 2003)

<table>
<thead>
<tr>
<th>Sand-spit stretch</th>
<th>Classification in terms of erosion problems</th>
<th>Future Evolution considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costa Nova- Vêagüeria</td>
<td>Very vulnerable</td>
<td>Groynes field. The shoreline evolution depends whether or not a sand by-passing system is implemented. Urban seafronts highly exposed to erosion</td>
</tr>
<tr>
<td>Vagueira – A Mira</td>
<td>Very vulnerable</td>
<td>The shoreline is suffering significantly from erosion and it has been retreating further, which can implicate the appearance of a new inlet in Aveiro lagoon.</td>
</tr>
</tbody>
</table>

Regarding the PPOOC guidelines, some relevant comments and contributions were presented by (VELOSO GOMES et al, 2002), for the sand-spit area (Figure 34):

- The shoreline evolution trends (10 and 30 years) presented in the POOC (1998), are possibly very optimistic. The actual situation (2002) demonstrates that, because of the sea movement landwards, this evolution is about to be reached (figure 26);

- The evolution considered in the POOC does not take into account the existence of critical zones on the dune cordons. In case of breaking of those dune cordons (Costa Nova - Vagueira), there would be a significant aggravation of erosion and land loss in large extensionss, due to the fact that the dune cordons are rather narrow and the adjacent inland zones are flat and located at low altitude.

The erosion affecting some coastal stretch is progressing rapidly and even some of the physiographic coastline evolution scenarios presented on the Coastal Zone Management Plans from 1998 are largely outdated. At this moment there are several areas at risk and in some cases there are not many feasible coastal protection alternatives. Indeed, there are several urban seafronts that are surrounded by coastal defence structures of considerable dimension entering the sea. Some of these areas will, most certainly, have to be further reallocated (VELOSO GOMES et al. 2002).

It is predictable that the shoreline will retreat to a position that will result in the breaking of a new or more inlets in the Ria de Aveiro. This situation has not yet happened because of the emergency works, which have been made in the last few years. These are emergency interventions, supported by local people and by the local and central administration authorities in order to prepare more sound solutions ((IHRH, 2003).
5.2.2 Littoral Map Risk

Within the framework of a sustainable coastal management, the Ministry of the Environment launched a programme of a first Risk Map on the Portuguese coast, in order to map the parcels of the coastal territory that may be considered as threatened by the sea. The Risk Map was developed under protocol between INAG and CEHIDRO-Instituto Superior Técnico.

When identifying land at risk three main threats were considered: erosion, flooding and dune migration (TRIGO-TEIXEIRA, 2002). Coastal erosion is particularly important in the study area as soft low lying coastal stretches in the west coast. In some locations also the severe erosion rates, higher than 10 m/yr, were measured based on the comparison of coastline position at different
dates. For the region of Vagueira and Costa Nova where the erosion is more severe, protection works were built to sustain erosion. For this area, the shoreline position is depicted with an interval of twenty-three years (1973-1996).

The scale of the maps is 1:8000. The support is an Arcview project incorporating pieces of information from different sources. Altimetry from the 1:25000 coverage produced by the "Instituto Geografico Exercito" (IGeoE) from different dates; bathymetry selected from hydrographic charts; altimetry from 1:2000 coverage of "INAG-Instituto da Água" made in 1996; aerial photographs at a scale that is approximately 1:8000, also from 1996.

The mapping was made defining three classes for the risk (vulnerability): low (yellow), medium (orange) and high (red). Areas are bounded by the sea and by a conventional line inland. The bathymetry represented on figures is related to the -5m (HZ) and -10m (HZ) lines.

![Figure 35: Risk (vulnerability) definition zones at Western Portuguese coast Aveiro-Mira - low risk (yellow), medium risk (orange) and high risk (red) - (from INAG, 1999)](image)

Some cases of land prone to flooding were also identified. According to this analysis dune migration proved not to be a real threat in the Portuguese coast. When focusing on the study area (between Ilhavo and Mira), this area is at the moment suffering by chronic erosion (high risk – red – figure 35), hence, the tendency of coastal evolution shows a high likelihood that they will be lost
in the near future.
Coastal flats prone to flooding by seawater are also considered in the same category. Land loss by erosion is considered as permanent and non-reversible. Within the Map Risk concerns, the costal flooding is considered to be the inundation of territories usually behind a sand dune barrier that breaches during a storm. On figure 36, 37 and 38 it is represented a more detailed views of risk mapping at the study area, between Costa Nova and Areão Beach.

![Figure 36](image_url)

Figure 36: High risk (red) (vulnerability) for the study area between Costa-Nova and Areão - (from: INAG, 1999)

The analysis and interpretation for mapping the risk was done taking into account: the morphology of the coast, the geology, the coastline orientation, the natural protections, the local wave climate, the past events, the evolution trends and the field work. The presence of most of the coastal protection structures was considered in the mapping exercise (TRIGO-TEIXEIRA et al, 2001).

The Risk Map may be interpreted instead as a vulnerability chart of the coastal territories to the action of the sea, however with strong limitations, as the human occupation and present land use were virtually not taken into account when elaborating the maps.

According to INAG (1999), for mapping procedures, risk area was defined the land that technically may be considered as threatened by the sea. In these locations, the coast is eroding resulting in permanent loss of land to the sea, and direct actions from waves may take place resulting in the flooding of low laying coastal territories.
The concept of threat is closely related with the idea of vulnerability, since only those vulnerable coastal territories to the sea action are considered as threatened. The vulnerability of the coast is measured mainly by the morphologic changes that the coast suffers under the action of the sea. Rocky coasts will tend to be in general less vulnerable than sandy coast. In this sense the map of land at risk shall be seen as a true vulnerability map of the coast to the action of the sea, since the mapping procedure does not take into account the present use of coastal territories (human settlements and housing) (TRIGO-TEIXEIRA et al, 2001).

A coastal stretch is considered to be eroding when the records show that the coastline is retreating (as presented on Chapter 4, Section 4.2), or there are reasons to be believed in this kind of movement in the near future. Seasonal variations that are registered in beach profiles are not considered as erosion in the mapping exercise.

The mapping of areas at risk is made with the available information at the time being concerning the coast. This means that these areas may be revised in the future to reflect new data made available, and also to adjust to the trend coastal evolution. Coastal protection works (jetties, seawalls, breakwaters), which are in place or considered in the coastal master plans (POOCs) were also included in the mapping exercise, since they definitely influence coastal erosion and flooding.
Another question that must be addressed is the question of compatible uses in land that is classified or mapped as “Risk areas”. The main problem is certainly of the permanent human settlements and urban expansion that shall be avoided at any cost.

![Figure 38: Zoom view at high risk (red) (vulnerability) Southern Vagueira Beach - (from: INAG, 1999)](image)

### 5.3 Analysis of Critical / Vulnerable Areas

According to (BUSH et al, 1996), important determinants of risk potential for a given area include several criteria analysis such as sea level rise criteria; elevation above sea level and above ground level; exposure to wind and wave hazards (presence or absence of thick maritime forest or shrub cover, presence or absence of high, wide dune fields); and distance from the ocean which determines the likelihood of impact by storm and wave attack. Using these criteria it is possible to define the risk at areas of coastal zone.

The approach of classification risks into categories such extreme, high, moderate, low and even very low in some cases is very useful. According to BUSH et al, (1996), all sand-spits have a high element of risk. In fact low-elevation coastal areas (beaches and low elevation dunes with lack of
vegetation and wind exposure), facing a high energetic wave regime may fall entirely into the extreme and high-risk category.

When dealing with sand-spit and barrier beaches, the qualitative approach is an important first approximation of risk level based on past experiences and the analysis of several vulnerability criteria. These criteria can be defined as on Table 19.

<table>
<thead>
<tr>
<th>Geo-indicator</th>
<th>High Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site elevation</td>
<td>&lt;- 4m</td>
</tr>
<tr>
<td>Low elevation</td>
<td></td>
</tr>
<tr>
<td>Erosion/Accretion rate</td>
<td>Severely to slowly eroding</td>
</tr>
<tr>
<td>Beach width, slope, thickness</td>
<td>Narrow and thin with mud or stumps exposed</td>
</tr>
<tr>
<td>Overwash</td>
<td>Frequent overwash</td>
</tr>
<tr>
<td>Site position relative to inlet</td>
<td>Near to river / lagoon inlet; near migrating, historic or potential inlet position</td>
</tr>
<tr>
<td>Dune configuration</td>
<td>Low frontal dunes; frontal blowout; inner dune trough; flat interior grasslands</td>
</tr>
<tr>
<td>Coastal shape</td>
<td>Concave or embayed</td>
</tr>
<tr>
<td>Vegetation cover on site</td>
<td>Little or toppled vegetation; greatly disturbed by development</td>
</tr>
<tr>
<td>Drainage</td>
<td>Poor</td>
</tr>
<tr>
<td>Area landward of site</td>
<td>Lagoon, marsh</td>
</tr>
</tbody>
</table>

Flooding is a phenomenon that usually occurs in low laying coasts. Vulnerability to flooding is different to vulnerability to erosion, since usually does not lead to the loss of land in a permanent and irreversible way. Flooding however may cause destruction to harvests, damage housing and alter the quality of soil through saline deposition.

To characterize the possible physical consequences for the area of sand –spit and adjacent Gafanhas (mainly flooding affected areas), six vulnerability criteria have been selected. These vulnerability criteria were analysed within a common approach, once it was considered that they act closely together. The impact upon selected study area was investigated considering several flooding scenarios by using a Digital Terrain Model, approaching the Database from AMRIA.
Vulnerability criteria:

1. Sea level rise (continuation of present sea level rise within a long term analysis, concerning the lower and vulnerable break zones at the sand-spit).
2. Break zones migration, historical, or potential inlet. New inlets formation as a consequence of sand-spit retreat, (vulnerability of narrow low sand-spit due to aggravation of erosion of dune cordons).
3. Predominant overtopping events/Fragile fore dune cordons
4. Site elevation/ Sea-Lagoon Exposure (terrain Profiles of Sand-spit and Gafanhas area)
5. Coastline behaviour
6. Human alterations - Urban development; Engineering structures concerns

5.3.1 Vulnerability Criteria 1: Sea Level Rise

The current sea-level rise, plus predictions of both on acceleration in that rise and an increase frequency and intensity of storms, contributes to the urgency of taking measures to assess coastal hazards and to reduce property vulnerability.

Generally sea level rise will increase erosion. By applying the Brunn rule, it is possible to conclude that the impact of sea level rise on the coastline retreat is 100 times larger than the rise itself. In that way, for example a sea level rise of 25 cm to 50 cm will cause an additional retreat of ca. 1.50 m per year or more (REISE, 1998).

A large range of morphological reactions to present sea level rise exists (from retreating to prograding), depending on the sediment availability or, rather, the long-shore drift. In general a barrier beach / sand-spit is retreating, in response to sea level rise (CPSL, 2001). Thus, an increase in sea level rise and/or storminess will accelerate this trend, and under present conditions, the sand-spit study area already seem to suffer from a sediment deficit.

It was analysed that, generally, changes caused by sea level rise will not easily be distinguishable from changes resulting from the high natural vulnerability, which is specific feature of the sand-spit system (CPSL, 2001). Hence, because this area has a low resilience to changes it was considerable plausible that the system will not be able to adapt to a high sea level rise (up to some 50 cm per 50 years as the most realistic scenario, in (ANDRADE; FREITAS, 2002), without substantial changes, if some coastal defense intervention would not take place. Besides, the sedimentary structure of the study area offers sea lack of resistance towards the Gafanhas area (figure 39).
5.3.2 Vulnerability Criteria 2: Break Zones, Historical and New Potential Inlet

With the reduction of the width of the sand-spit beyond the present retreat rates and with the proximity to the Mira channel, probably a breakpoint will occur. The capacity of the sand-spit system to balance the changes and direct sea action will become exhausted. An increase in storminess would further enhance this development (REISE, 1998). When such a breakpoint has been passed, substantial changes in morphological and physical are expected. Once the new inlet would create a new permanent lagoon connection to the sea, one of the major impacts will be the strong flooding event.

The historical inlet positions can lead to new inlets formation as a consequence of sand-spit retreat, and the general increase of vulnerability of narrow low sand-spit due to aggravation of erosion of the fragile foredune cordons.

As already stated on Chapter 3, Section 3.3, in a very narrow sand-spit with historical inlet areas increases the risk and damage potential. The inlets opened in the past means that the likelihood for recurrence is high (BUSH et al, 1996). According to historical documentation (Chapter 3-figure 4: Old coastline inlet positions from 1200 to 1756), it is presented now on figure 40 the area of sand-spit for South Vagueira Beach area which is one of the most unstable zone at sand-spit concerning the opening off historical inlet (relating to 1643; 1685 and 1756). Therefore, due to the presence of a relatively wide Mira channel a new break zone would produce severe damage concerning the
surrounding urban development at Gafanhã do Carmo and Gafanhã da Vagueira.

Figure 40: Old inlets positions. Aerial view of Southern Aveiro sand-spit (Based on HIRH, 2003)

5.3.3 Vulnerability Criteria 3: Predominant Overtopping Events / Fragile Dune Cordons

The stretch is protected by a dune system, which is currently very vulnerable. The erosion phenomena and dune overtopping are clearly visible along the stretch Vagueira - Areão beach and even though it has not urban seafronts to be preserved, this recession can cause serious problems. The several dune overtopping events can be represented on figure 41 for the south part of Costa nova Beach and south part of Vagueira Beach.
Besides the urban occupation on the dune cordons it could be noted several paths of public access to the beach using of vehicles motorcycles, causing the vegetation destruction which originate the eolic corridors and small breaks on dunes (IHRH, 1992) which facilitate the observed overtopping events.

Regarding the last criteria – Historical inlets, it can be observed that the most frequent overtopping events occur at the old inlets area.

The frontal dune cordon is a very fragile one at this coastal area, therefore some emergency coastal intervention were taken in 2001 by the locals and the Ministry of Environment to avoid the worsening scenario of sand-spit rupture.

It is predictable that the shoreline will retreat to a position that will result in the breaking of a new or more inlets in the Aveiro Lagoon (Figure 42 a). As referred before, this situation has not yet happened because of the emergency works, which have been made in the last few years. These are
emergency interventions, supported by local people and by the local and central administration authorities in order to prepare more sound solutions (IHRH, 2003).

Figure 41 a: Vulnerable fore dune at Sand-spit possible breaking of a new or more inlets to the Aveiro Lagoon (photos: MCOTA, 2002)

5.3.4 Vulnerability criteria 4: Site Elevation

The following terrain profiles at Southern Vagueira area show the low elevation position of the study area at sand-spit and Gafanhas, and the close connection to the water level (Mira channel and the Sea). The observed upper elevation at the san-spit is mostly due to the presence of the emergency coastal protection – elevated dune. Some data was update with respect to 2001 altimetry data. It can be also observed the elevation area of the inner dune cordons- Ilhavo and Vagos municipalities.

Figure 42 : Aerial view of lowland Gafanhas area behind the sand-spit (photo: MCOTA 2002)
Figure 42 a: Profile Terrain Barrier-slit and Gafanhas area (Data source: AMRIA, 1998, 2001)
5.3.5 Vulnerability Criteria 5: Coastline Behaviour

The analysis concerning the years 1996 and 1998 can be observed on figures 43 and 45 respectively relating to the data provided by INAG and AMRIA, and converted in the Grid form as a result of a first converting data shape as Triangulated Irregular Network (TIN) data models for the South Vagueira area. TIN is a topologic model of vectorial data used for topographic information representation. The terrain surface is represented through a set of net triangular faces where each (x, y) point (as geographic localization) and z point (as elevation) has a defined value. Grid image is created based on TIN data in order to achieve a better interpretation map analysis.

By this attempt it is possible to identify the most low elevation areas facing the Atlantic sea action thus, the general vulnerability (or lack of natural resilience) degree of this coastal stretch. The aerial information of 1996 was integrated with the hydrological data from 1998 – coastline (Figure 43) to highlight the most retreat zones at this time range.

It is possible to identify values of 0,08 meters as the lowest part immediately south Vagueira Beach and Quinta do Inglês, showing one of the most critical areas on the sand-spit, in part largely affected by the presence of south Vagueira groyne- (groyne 7) due its downdrift effect.

In addition, is presented on figure 44, the integration of data with the most frequent dune overtopping situations.

However at present days (2003) the new built groyne of Areão Beach and the emergency frontal sand dune, have avoided worse scenarios at these local areas (Chapter 4, Section 4.4).

The upper values of 13,7-15,6 meters, relate to dune cordons at Mira area still well consistent (Chapter 3, Section 3.5.2.).

Relating to the 1998 data, (figure 45) it can be observed a general aggravation of the low fore strip and the interruption of Areão frontal dune cordon, which might explain the urgency for Areão groyne construction-Groyne 8).

Using Map Calculation tool (figure 48) it was possible to analyse the main loss and gain in terms of sand volume during 1996 and 1998 (figures 46) In this south Vagueira area, some of the most significant sand loss are evident (−) and it can be observed the groin effect with accretion (+) updrift and erosion downdrift (−).

The representation of the main critical areas where sand erosion (loss) situation were more acute, added to frequent overtopping events (figure 47).
This initial phase of vulnerability analysis thus, constitutes an assessment of the several criteria that have led to the interpretation of the fragile sand-spit system with the significant probability of rupture.

However, the analysis of these values must be carried out with some caution, given that, the complete characterisation of climate regime (waves, winds, storm events, etc) should have been done for the years under analysis. That could enable a better understanding of map calculation results and general coastline behaviour, such that it might not be significant conclusions for any prediction exercise.
Coastline Behaviour Analysis

South Vagueira

Legend
- Urban areas
- Altimetric data - 1998
- Hidrographical data

Grid Information 1996 (meters):
- 0.079 - 2
- 2 - 3.9
- 3.9 - 5.9
- 5.9 - 7.8
- 7.8 - 9.8
- 9.8 - 11.7
- 11.7 - 13.7
- 13.7 - 15.6
- 15.6 - 17.6
- No Data

Figure 43: Coastline behaviour analysis for 1996 (Data source: INAG, 1996 and AMRIA, 1998)
Figure 44: Aerial coastline information – 1996. Analysis based on Grid data and dune overtopping situations (Data source: INAG, 1996)
Figure 45: Aerial coastline information - 1998. Analysis based on Grid data and dune overtopping situations (Data source: AMRIA, 1998)
The Map Calculation analysis (figure 46) shows exactly the areas where there was a more intense erosion volumes between the year 1996, 1998, (analysis of 1996 and 1998/3D data) and it might highlight the potential vulnerability degree for new break zones – sediments deficit, along the South area of Vagueira.

Figure 46: Vulnerable areas analysis using Map Calculator extension (Data source: AMRia, 1998 and INAG 1996)
Figure 47: Vulnerable areas analysis using Map Calculator extension and dune overtopping situations adjacent Gafanhas area (Data source: AMRIA, 1998/2001 and INAG 1996)
5.3.6 Vulnerability criteria 6: Human Alterations

The potential for risk is often increased by human alterations (urban development and engineering structures concerns) to the coastal environment that reduce the existing natural protective capabilities, thus increasing the vulnerability of the coastal area (VELOSO GOMES; TAVEIRA PINTO, 1997).

Table 20, lists the impact of urban development on sand spit natural support environment. Each type of human adjustments alters the natural environment, usually exacerbating the damaging effects of natural processes (BUSH et al, 1996).

At Gafanhass area, potential for property risk is high and will only increase as development density increases or as a single-family home, give way to multifamily dwellings and commercial establishment.
Table 20- Impact of urban development on sand spit natural support environment (Adapted from BUSH et al, 1996).

<table>
<thead>
<tr>
<th>Development Type</th>
<th>Direct Effects</th>
<th>Indirect Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Building site modification</strong></td>
<td>Changes landform configuration</td>
<td>Establishes property in risk areas</td>
</tr>
<tr>
<td>Grading</td>
<td>Eliminates sources of sediment</td>
<td>Increases exposure of property to wind and wave hazards</td>
</tr>
<tr>
<td>Paving</td>
<td>Decreases sediment stability, changing rates of on/off sand-slip sediment exchange</td>
<td></td>
</tr>
<tr>
<td>Dune removal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paths through dunes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roads and other infrastructures</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Construction of buildings</strong></td>
<td>Alters wind patterns</td>
<td>Focuses human use and human impacts</td>
</tr>
<tr>
<td>Single-family</td>
<td>Obstruction to sediment flow</td>
<td>Leads to construction of support infrastructure and implementation of protection structures</td>
</tr>
<tr>
<td>Multifamily</td>
<td>Truncates beach or dune zone</td>
<td>Increases population density</td>
</tr>
<tr>
<td>Commercial/tourist</td>
<td>Channels storm surge</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reflects waves</td>
<td></td>
</tr>
<tr>
<td><strong>Hard shoreline stabilization</strong></td>
<td>Alters sediment flows and reduces sediment exchange</td>
<td>Can encourage urban construction leading to further development, putting more property at risk</td>
</tr>
<tr>
<td>Seawalls</td>
<td>Changes location of erosion/deposition and its severity</td>
<td>Leads to need for more structures and maintenance</td>
</tr>
<tr>
<td>Groins</td>
<td>Alters natural balance of coastline, however prevents some existing developments to collapse</td>
<td>Destroys recreational beach</td>
</tr>
<tr>
<td>Jetties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breakwaters</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Occupation and degradation of sand dune barrier increase coastal erosion risk at the study area. The attraction of the coast has led to an intensive use of the shoreline, namely urban development in high-risk area, which affects local population, through flooding, and the stability of the sand-slip system (VELOSO GOMES, 1991).

Until the 1970's, the beach-dune system was well developed with very low human occupation. During the 1980's, a decrease in winter storm frequency led to the notion of a stable coast sandbar, which gave rise to an increased use of the coastline. Buildings, parking areas and camp sites were established in the dunes very close to the beach, which together with the natural changes in the sand-slip system, contributed to changes in coastal configuration. In turn this led to enhance risk damage potential (CARVALHO; COELHO, 1998).

Coastal developments at the sand-slip are exposed to high-energy destructive waves, and because people want secure for their properties they demand for coastal protection measures paid by the Government, following the consequences as described on figure 49.
Despite the real potential for coastal risk at this area, population and edification is increasing towards the SSand-spit as well as at the low elevation adjacent areas at a rapid rate. Urban pressure is more notable at the nearest zones (0-500 meters) of the Biotope – Aveiro Lagoon, (figure 50) a fact that is not completely in evidence concerning the planning strategies of the several municipalities related to the lagoon. The zones where the urban perimeters stand as even dense waterfront barrier are located at the southern part of the lagoon: the Mira channel and Boco River (Ilhavo Municipality).

Yet, according to (FIDÉLIS, 2001), the main urban proposals (most of them already approved by the municipalities) are located along the Mira channel within an urban consolidation planning strategy at Gafañhas area. It is important to highlight that an increase of edified areas along the Mira channel and within the sand-spit territory, will result on a proportional increase of total flooding risk area. Hence, denser development explains the increasing in property damage risk exposure.
Mitigation efforts in the interior of sand-spit study area - Gafanhas may be as important as on the shoreline, and look beyond site-specific requirements of front approaches and considerer all the aspects of the Sea/Lagoon sensitive area.

5.4 Representation of the Impacts: Flooding Scenarios

The exhausted capacity of the sand-spit system to balance the changes resulting from the coastline retreat and in case of no application of others coastal protection measures (such as artificial nourishment, sand by-pass or a new retreat dune/dike), significant break-points can be expected. These break points or new lagoon inlets will represent a significant change in the morphology, hydrology, biological parameters and also on the territorial uses within the study area.

It is important to realize that the defence works may permit a reduction of erosion/ flooding risks, but they do not cancel or reduce them to predictable levels when the time-span adopted in new building projects is taken into account (VELOSO GOMES, et al 2002).

To give a better view of the main flooding affected areas, several scenarios were elaborated. Despite this empirical analysis, it can contribute for a close understanding on the more vulnerable affected areas, in case of water level variations and unbalances. This hydrological unbalance situation can be pointed as result of a sand-spit system rupture, enhanced by the vulnerability criteria presented above.

It has to be highlight that the aim of this dissertation it is not the medium/long term modulation of the erosion phenomenon, once those studies has been carried by others several research works.
5.4.1 Construction of Hydrologic - Flooding Scenarios

The analysed scenarios are not directly associated to the sea level rise but instead to a first estimative related to land lost and an equivalent flooding area.

The created Digital Terrain Model indicates a general representation of the expected impacts -flooding areas at the Gafanhos and Sand-spit, towards enhancing the fragile system under study.

Scenario 1: **Base-line Scenario** - close to present situation, maintenance of the coastal defense interventionss; water level increasing factor of 0 meters

Scenario 2: **Medium Scenario** – assumes a water level increasing factor of 2.5 meters

Scenario 3: **High Water Scenario** – assumes a water level increasing factor of 4 meters

Scenario 4: **Extreme Scenario** – assumes a water level increasing factor of 5.5 meters

![Digital Terrain Model showing Scenario 1: Base-line Scenario - (Data source: AMRIA, 1998)](image)

The total edified areas at Gafanhos are located at low elevation once it can be stated that those areas are gradually submerged on the increasing water level scenarios, till totally affected on the worse case scenario (the extreme scenario - 4 with a water level increasing factor of 5.5 meters).
On Scenario 2 the primarily affected low areas are: Gafanha da Nazaré – towards inland Barra Beach, and a large area of Vagueira. The main traffic roads EN 109-7 and the EM 501 are also strongly affected.

Figure 52: Digital Terrain Model showing Medium Scenario 2 - (Data source: AMRIA, 1998)

Figure 53: Digital Terrain Model showing High Water Scenario 3 - (Data source: AMRIA, 1998)
In general terms by the scenarios analysis it can be stated that besides the risk of erosion/flooding faced by the urban areas located at the sand spit, it can underscore the instability and vulnerability affecting the inland agricultural and edified areas of Gafanhas.

5.4.2 General Associated Impacts

By the end of this Scenarios analysis it can be stand out the following impacts associated to this rupture scenario:

- Sand spit loss territory;
- Overwash / Flooding of agricultural soils salinization along the sand spit;
- Overwash / Flooding and streets interruption along the sand spit;
- Mira channel water salinization, with impacts on the bivalves, fishes and in other biological communities;
- Lowlands exposition to the sea direct actions, with high probabilities of overtopping and erosion processes start to happen in the aluvionar plains of low altitude,
- Flooding affecting many urban areas beyond the sand-spit and along the municipal road EM 591 and EM 592 affecting also the Gafanhas urban areas, as well the lowlands flood/salinization intensively cultivated;
- Influences on local sedimentation patterns, with strong implications to navigability of the lagoon and its channels
- Influences on tourism activity and interests

As socio-economic consequences it can be stress out the efforts to achieve safety standards, such as dikes, other hard constructions, sand nourishment and structures maintenance costs.

It is also expected changes in biological parameters such as salinity and a decrease in benthic biomass and in typical wetland vegetation (JAPA, 1996) depending on frequency of high floods events.

The coastline needs to be artificially, repaired or reconstructed, otherwise the rich agricultural lowland areas (30 km) and several hundreds of houses behind it will be flooded as they are located in a lower level than the beach medium sea level. If new inlets break, the Southern lagoon system will suffer the influence of coastal waters, the agricultural lands will be salinized, and the ecosystems will have strong impacts.

5.5 Main Aspects for Conclusion

The sand-spit is a very vulnerable system, and the risk of breakpoints either new inlets formation is high. The urban development, on these areas is destroying a critical and limited ecosystem, and increasing the property damage potential. The associated density of development is in the study area, more vulnerable in a way of being impacted by natural processes such as wind, waves storm flooding, coastal erosion, and related processes. The different land-uses is either a precondition on the erosion/sand-spit break consequences, and its evolution or propagation.

In general terms, without hazards and high vulnerability there is no risk. When the processes are ignored and natural protection removed, the vulnerability to break points is increased. The loss of territory with no inhabitants or with a low cultural/ecological value is in a way, better acceptable according to people, if compared with the potential loss of extensively occupied/edified territory.
Because natural processes and environmental settings determine vulnerability, nature should be the guide in mitigation methods rather than relying solely on engineering and social regulation (seawalls, building codes, zoning regulations). A useful approach is to classify risk into categories such as high, moderate and low. All sand spit formations have a high element of risk (BUSH et al., 1996).

According to INAG (1999), for mapping procedures, risk area was defined as the land that technically may be considered as threatened by the sea. In these locations, the coast is eroding resulting in permanent loss of land to the sea, and direct actions from waves may take place resulting in the flooding of low-lying coastal territories.

In this area, the erosion problems are very serious, with great repercussions in terms of losses of territory, ecosystems, patrimony and great impacts at a socio-economic level.

In the stretches Costa Nova-Vagueira, Vagueira-Mira, several localized situations of dune cordon rupture have been occurred which, requires reconstruction interventions in some parts of the dune system. If such scenario happens, the sea establishes a new connection (or several connections) with the Mira Channel and the consequences at ecological and socio-economic level will be extremely serious.

The vulnerability preliminary analysis have demonstrated the aerial information concerning the graduate values for the terrain elevation and characterization in meters along the Aveiro sand spit, specially at the Southern part of Vagueira Beach. It was estimate based on topographic, altimetry and hydrographical data, the main vulnerable zones to rupture and the consequently flooding area extension throughout the edified Gafanhas area.

The MapCalculation tools on Arcview (3.2) enable to represent the sand volumes resulting from the comparison on coastline behaviour between specific data from Grid – altimetric, (INAG, 1996 and AMRIAA 1998) regarding the 3D extensions and volumes analysis.

A complete characterization on climate regime (waves, winds, storm events, etc) should have been done for three years under analysis, to a better understanding of map calculation results and general coastline behaviour.

It is important to realize that the total risk area would increase due to presently pressure on urban development at lowlands-lagoon adjacent areas (visible on Municipal Plan -Ilhavo and Vagos analysis, as stated on Chapter 3, section 3.6).

It also must be concluded that, in the long term, the application of the coastal protection measures may alleviate impacts of new break points, but will not be able to prevent such impacts, certainly not under the Extreme Scenario.
This approach can highlight the possible impacts of flooding scenarios towards the several existing urban settlements at low elevation areas. However it must be bearing in mind that is only an empirical / demonstrative analysis and more data and modelling, will be necessary to achieve a more credible and readable results. On the other hand a complete characterization on climate regime for the on focus year 1996 / 1998 / 2001 should be conducted in order to give a better understanding of the map calculation analysis out coming results.
CHAPTER 6 –
EVALUATION OF SIMILAR CASE STUDIES – DENMARK
CHAPTER 6 – EVALUATION OF SIMILAR CASE STUDIES – DENMARK

6.1. Introduction

This chapter aims to a better understanding of case studies approach, and the following structure has been chosen:

- Firstly, an overview of the country as the Land and Sea Interaction as well of the Danish coasts, emphasizing the North Sea coast characteristics.
- Secondly, a description of the setting coastal planning system in Denmark, as a basis for understanding the present faced coastal situations.
- Finally, it will be focus on the two case studies, which combine several coastal risk situations and different coastal approaches. This approach works as an important development on this dissertation, subsequently identifying trends and activities, which are believed to set some comparative guidelines in the Portuguese study area.

6.2. Denmark - The Land and Sea Interaction

The land area of Denmark comprises 43 000 km and consists of a mainland, peninsula, and an archipelago of 406 islands, of which 78 are inhabited. The coast stretch is 7300 km, and it also means that there is 1.4 m of coastline per inhabitant. The land is used for agriculture (67%), forest (12%), semi-natural areas (0.1%) and urban zones and transport installations (0.09%) (MILJO MINISTERIET, 2001).

The population of Denmark is 5.4 million and the population density is 725 per km. According the latest publications (MILJO MINISTERIET, 2001) 80% of the Danish population lives in the coastal areas, 56% of the population lives in coastal cities and towns (Figure 53). One-third of the coastline is developed or planned for new development and half of the coastline is visually affected by urbanization. The formation of the landscape behind the coastline has been influenced in particular by the presence of Man and his use of the country's natural resources.

The geography of Denmark has conditioned the Danes to become a nation of seafarers already in the early Middle-Ages, where the Danes, together with the Swedes and the Norwegians conquered and settled near and far - from North America over the British Isles, Russia, and Normandy to Spain and Italy. Likewise, fishing has always played an important role in the life of the Danes. These activities and the fact that the land consists almost exclusively of sedimentary soils and is located in a region with a rough climate in terms of winds and waves, created the need to observe
and understand the interaction between sea and land, thus the need for coastal science and engineering.

Figure 55: Population density per square kilometre at municipality level (in: MILJO MINISTERIET, 2001).

6.3 Geological Background

The genesis of the contemporary Danish coast has its origin in the late quaternary, which means that, the coast is dominated by soft marine deposits, between which mostly long, uninterrupted sandy beaches are suspended in gently curved forms. The large scale Holocene tilting of Denmark has resulted in coasts with raised beaches and wide marine forelands in the northern part, and an archipelago in the sinking southern part. In this drowning glacial landscape the coasts of the numerous smaller and larger islands expose a horizontal section in the glacial landscape, which is superimposed by recent erosion, barrier spits and tombolos (WORM, 1997).

When the ice melted, the land rose again, though only after a long delay. This gave the sea time to flood large areas during the deglaciation period, particularly around North Jutland. The North Sea and the Kattegat were then glacial seas, and deposits from these are found at heights of 20-60 m near Vendsyssel in North Jutland (SVERDRUP, S; BLANNER, P. 1996).
Approximately 6,000 years ago, the Littorina Sea (also known as the Stone Age Sea) in the northern part of Denmark reached a relatively higher level than today. It flowed into a number of East Jutland valleys, creating a flat valley floor. In Central Jutland, the water reached as far as Viborg. Many overgrown littoral cliffs from this period can today be found above the present coastline. Since then, the land around Vendsyssel has risen 15 m in relation to the sea. South of a line between Nissum Fjord and North Falster, however, the land has sunk a few metres below the present sea level. Eroded littoral cliffs are often seen in these areas. In the tidal areas (in southwest of Jutland) marshes created under partly natural conditions keep pace with the relative subsidence of the land (BONDESEN, 1996).

The most important landscape elements created since the ice age are mostly found near the coasts. The appearance of the coast changes constantly as a result of erosion and shifting sands. Large dune areas are found in particular along the west coast of Jutland, where active coastal dunes are found closest to the sea, and behind these are inactive, overgrown green dunes and grey dunes. The inland dunes, found on heath plains like the one near Billund, have also been inactive for long periods. The dune areas along the coast were dominated by recurring periods of shifting sands during the Holocene period. The last of these lasted from the 14th to the 20th century. The climate then was comparatively cool and windy. Floods in the 19th century broke through many of the isthmuses on the west coast of Jutland (JAPPE, 1996). Efforts to prevent sand drift, combined with fewer storms, meant that the shifting sands gradually receded towards the end of the 19th century, or as early as the 18th century in North Zealand.

In a way of synthesis, the changing between land and sea may be understood by considering three postglacial extremes (Denmark Nature Conservation, 1979 in SORENSEN et al, 1996):

- The Ice-Sea, which left the northern Jutland as an archipelago, the evidence of that is found today in old coastlines at elevations of 10-60 m above present sea level.
- The continental period, during which land extended far beyond the present coastline.
- The Stone Age sea, which transgressed considerable parts of the present coastal landscape
- The post Stone Age relative land rise has been the predominant process over the last 6,000 years in the northern part of the country. During the same period the south-western part, which includes the Danish part of the Wadden Sea, has been subject to a relative land depression in the order of 0,10 –0,15 m per century, a trend which is also known from Northern Germany.

These dramatic changes in land levels are mostly the result of tectonic movements caused by the disappearance of the ice of the last glacial period. To a large extent the present coastline thus represents a fragile balance between possible extremes.
At present day processes, the balance between the global trend of relative sea level rise and the slowing down of the glacial rebound, has changed in such a way the former tilting line theory, that the zero line runs almost through the northern part of Jutland (MILJOMINISTERIET, 1997). The consequence of this is, that all along the already exposed Danish North Sea coast there is a relative sea level rise of 0-2 mm/year (SORENSEN et al, 1996).

6.4. Overview of Danish Coasts

Denmark is surrounded by four seas: the Baltic Sea, the Kattegat, the Skagerak and the North Sea. Combining the geological background, the geographical conditions and the climatic impacts, the Danish coasts can be classified in two major categories (the North Sea Coasts and the Inner Coasts) and, further, for each of these in three distinct subgroups (JAKOBSEN et al, 1998).

![Map of Danish Coasts](image)

**Figure 56: Main characterization of Danish coasts (in: DCA, 2001)**

6.4.1 North Sea Coasts

With a total length of the 450 km, of which the Headland Coast is 200 km, the Central West Coast 140 km, and the Wadden Sea outer coast 110 km long, the main characteristics of the North Sea Coast are:

- The Northern Jutland Headland Coast along which erosion is predominantly in the order of 2 - 4 m/year over the last 20 years. The coast is predominantly with sand and clay cliffs.
Littoral drift is northward due to the sheltering effect of Norway. It grows from zero in the south to about 1 m/year at the Skaw Spit–Skagen, at the extreme North.

- The Central West Coast is dominated by barrier beaches, which are separating major lagoons: Lime Fiord, Nissum Fiord and Ringkøbing Fiord, from the sea with sandy beaches where dunes protect the low hinterland against flooding. Erosion rates used to be high but are now balanced by large beach nourishments.

- The Wadden Sea coasts: A tidal coast with a tidal range of 1.5 -2 m where the low hinterland is protected against flooding by dikes. Despite the relative rise in sea level, which has been the dominant process over several thousand years, it appears that this area is in an overall sediment balance. The situation may be even better, because the two major barrier islands of Fano and Romo have grown considerably over the last several hundred years (JAKOBSEN et al., 1998).

6.4.2 Inner Coasts

The Inner Coasts are defined as all the other coasts than the North Sea coasts. They account altogether for about 7000 km and show, naturally, much variation (JAKOBSEN et al., 1998) and they comprise:

- Northern medium exposed coasts along the Kattegat with littoral drift rates of an order of magnitude less than along the North Sea, i.e. 10–75,000 m³/year.

- Eastern and southern medium exposed coasts in the Baltic, mainly with clay cliffs.

- All remaining coasts of low exposure along straits, belts and fiords or on sheltered islands, with a littoral drift less than 10,000 m³/year.

Figure 57: The North Sea countries and classification of the Danish coasts (in: LAUSTRUP AND MADSEN, 1998)
6.4.3 Coastal Exposure

Both types of coasts have different degrees of exposure to the sea action namely the wave regime, the water level and tides. Water level differences caused by tides (tidal amplitude) are greatest near the North Sea (1-2 m) and smallest near the Baltic (0.1 m). In the same way, the wave regime observed at North Sea is larger than the inner coasts (figure 58).

Wind, waves and littoral processes including sedimentation and erosion, constantly change the coastline. The relatively flat landscapes provide wide views, but they are generally vulnerable to visual effects of buildings and technical installations. Furthermore, many low-lying areas need to be protected against high tides. The increasing need for land near the coastline for urban development, industrial installations, and holiday and leisure facilities, has also made it necessary to protect the coast against erosion and flooding. The ocean coasts are highly exposed to wind and sea, and the coastline consists of long stretches of high quality beaches alternating with cliffs. The coast is dominated by agricultural activities, urbanization and tourism (holiday and leisure facilities), technical installations and wind turbine plants which create a substantial pressure on these areas.

![Graphs showing water level and wave height statistics](image)

Figure 58: Water level and wave height statistics (in: LAUSTRUP AND MADSEN, 1998)

In contrast, the sheltered fjords present a great variety of habitats and landscapes, but are not attractive to leisure and tourism. These areas—primarily agricultural—are therefore relatively unspoiled. Many of the 406 Danish islands are located close to the shore or in the fjords.

These varied and dynamic surroundings create the framework for a multitude of biological habitats and ecological systems. The bird life along the Danish coasts has international importance. Thus, 90% of the nature reserves in Denmark are designated for protection of migrating birds (JAPPE,
1996). One of the most important ones is the Wadden Sea. A total of 27% of the main marine coastal areas are designated as reserves according to the 1971 Ramsar Convention, and 111 areas, including the 27 Ramsar areas, are designated as bird protection areas according to the 1981 EU Bird Directive (MILJO MINISTERIET, 1998).

As a maritime nation Denmark has a long tradition for exploiting the sea. In the Middle Ages a maritime culture associated with trade and fisheries developed in small coastal towns and settlements near the fjords and also on smaller islands. Growing industrialization from the late 19th century onwards further increased the demands for development sites in the coastal cities. In this process, former natural areas, dunes and meadows have disappeared as has the original coastal profile in many areas (WORM, 1997).

The Danish coasts are therefore faced also with a multitude of threats:
- Pollution from land, land reclamation, land development, fishing, exploitation of raw materials, coast protection and infrastructures, inshore shooting, disturbance from recreationists, forestation, regrowth and cultivation, oil pollution and pressure from industry, urban development and related infrastructure, and technical installations.

6.5 Coastal Planning System in Denmark

The development in the coastal areas has been of large importance to the general interest in economic growth and it was therefore also a challenge to policy as well to planning.

Together with numerous sectorial regulations (sand drift and dunes as far back as 1539, coastal conservation, nature conservation, coastal fishery, coastal protection and a number of specific construction acts) the coastal regulations are now an integral part of regional planning act. This was due to European Community directives and the increasing recreational pressure to the Danish coasts.

Danish government has completely stopped the expansion of summer cottage areas, and in 1981 a national planning directive was issued in order to ensure the protection of the remaining open, unspoiled areas between summer cottage areas and urban areas, and to ensure public access to the coasts. Furthermore, in 1992 the Danish government changed the directive in order that the regulation should encompass all economic activities within the coastal zone and not only recreational facilities thus that national planning directive for the Coastal Zone was adopted, with small changes, in the Planning act (MILJO MINISTERIET, 1997).
Finally, in 1994 the Planning Act was amended in order to strengthen the legal aspects of coastal management related to the new types of development pressure.

6.5.1 The Planning Act

The Planning Act of 1992, which was revised in 1994, enforces the regulation of interests in the coastal zone by the establishment of a 3 km "Coastal Proximity Zone" and a 300 m "Beach Line Protection Zone" as basic planning tools. The Act specifies regulations on land use within this zone, which differ in urban, summer cottage and rural areas, and must be implemented by county and municipal councils in their plans. This approach does not involve separate coastal planning, but is integrated into the ordinary planning process. Environmental impact assessment and public participation are also key elements in the Planning Act.

The Act has been amended several times since. The latest amendments were adopted in June 1999 and are the basis for the translation presented here. The amendments in 1999 ensured the implementation in Denmark of the amended European Union directive on environmental impact assessment (97/11/EC). The changes include the introduction of an obligation on the regional planning authorities to conduct environmental impact assessment, expanded rules for publication of decisions in connection with the rules on environmental impact assessment and a special environmental impact assessment permit in the Planning Act. Other amendments in 1999 include minor changes in the rules on local plans and certain changes in the rules on appeals (JAPPE, 1996).

By analysing the Planning Act Document (MILJO MINISTERIET, 2001), it is stated in the preamble of the planning act, that one of the purposes is to secure, that the open coasts shall remain important nature and landscape resources. For that reason the coastal areas shall be kept free of buildings and construction not depending on nearness to the coast.

The Planning Act divides the national territory into:

- urban zones,
- summer cottage areas and
- rural zones.

All rural zones and summer cottage areas generally within a distance that extends three kilometres inland from the coast are defined in the act as coastal zone. In this zone the regional and local planning authorities shall carry out their planning in respect of the following principles:
- Designation of new urban zones and planning for constructions in rural zones are only allowed, when there are certain arguments, related to planning or function, for nearness to the coast. The intention is to reduce the pressure on the coastal areas. Commercial arguments on needs for scenic beauty are not accepted.
- Buildings and constructions on land shall, with exception of commercial harbours, generally be planed so, that marine areas are not filled up, and in order to avoid new, special, coastal defense. The intention is to keep the shores in their natural shape as far as possible.
- New summer cottage areas may not be designated and the existing areas shall be kept for leisure purposes.
- Other constructions for leisure- and holiday purposes shall be located in accordance with comprehensive considerations on tourism strategies and only in connection with towns or larger, existing leisure areas. The intention is to avoid accidental constructions, with natural beauty as single argument, especially on the open coasts.
- Public access to the coast shall be secured and improved. The intention is especially to secure and improve the recreational possibilities for the public in built-up areas, where it is often blocked by private property.

Besides these principles there are special provisions for the regional and municipal planning. Among those it shall be mentioned, that the planning authorities are obliged to reassess areas, that have been appointed for urban or leisure development in previous plans but not used, in order to cancel plans out of date.

With the purpose of increasing the quality of new, inevitable buildings and constructions, it is also stated, that local plan proposals must contain information about the anticipated visual effect on the landscape and other relations, which may affect the surrounding nature. Projects, that have been through an EIA procedure, which in Denmark is done by regional planning, are excepted from this obligation.

Concerning the existing urban zones which are not included in the coastal zone, it was also added some provisions for the planning in these areas in order to secure a qualified development in connection with the surrounding coastal landscape and reduce the need for new urban development through careful planning.

6.5.2 The Protection of Nature Act

Since 1937 a 100-m protection zone has been stipulated in the Nature Protection Act, and in this zone it is prohibited to alter the state of the beaches and other stretches of the coast (WORM,
The Protection of Nature Act of 1992, which was amended in 1994, establishes a protection zone outside urban areas, extending 300 metres inland along the coast, from the start of continuous land vegetation. With few exceptions, new developments are prohibited in this zone.

On the urban waterfront the protection zone may be 100 m or less. By the above mentioned revision of the Planning Act and the Nature Protection Act, the Danish Government took the opportunity to emphasize once again that it is of national concern to ensure that the open coasts will remain as an important natural and landscape resource, and several planning regulations necessary to face the growing pressures on the coastal areas were carefully stipulated (JAPPE, 1996).

However, the adoption of the laws was met with a certain amount of criticism from local authorities and private enterprises.

The main arguments were:

- The regulations conflicted with the traditions of local self-government, which is deeply rooted in Danish society.
- The regulations blocked any possibility for making use of the market value associated with the genuine natural, cultural and landscape values in coastal areas.

In opposition to these arguments, the national planning authority in Denmark has highlighted that the coastal regulation does not prevent, but does in fact promote tourism development primarily by securing the economic assets of the coastal areas. Furthermore, the evaluation of the individual development projects in the context of a regional plan prevents erratic investments, which may result in heavy competition and ultimately investment loss (ENEMARK, 1996). Finally, the environmental provisions ensure the economic sustainability of individual development projects. In fact, a substantial number of foreign tourists in Denmark are attracted by the clean environment in general, and the possibilities of eco-tourism and fishing in particular.

The distance is counted from the point, where the continuous land vegetation starts, respectively from the innermost boundary of the beaches. This means, that the protection line may be located more than 300 m from the sea, for instance in areas with salt marshes. Within urban zones and areas already designated for summer cottages the protected zone will remain 100 meters.

It is prohibited, with few, specified exceptions, to alter the state in these protected zones. It is also prohibited to erect fences and to place caravans. Finally it is prohibited to establish new boundaries by parcelling out, registration land and transferring of ownership.
Exemptions may be granted in special circumstances. In dune conservation areas the Minister for Environment is the one who has the authority. In other areas the county council has the authority of granting exemptions, which can be trialled for the national Nature protection Board of Appeal.

The enlargement of the protection zones was implemented through a special procedure. A commission, representing many different interests, examined all Danish coasts in order to locate the protection lines and to define the stripes, where the protected zone shall be less than 300 m due to existing built up areas. The new provisions came into force, when the commission worked out a proposal, which was accepted by the Minister for Environment.

The measures in the Planning Act and Protection of Nature Act are concentrating on land use, and are inapplicable to the sea, which is regulated instead by sectoral legislation. These laws, which are administered by the national government, include the Marine Environment Protection Act, the Harbour Act, the Fishery Acts and the Raw Materials Act (The Raw materials Act gives some guidance as to a 300 m zone and the 6 m depth contour).

Denmark is a party to the Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area, and the coastal planning zone and protection zone are intended to implement BELCOM Recommendation concerning the protection of the coastal strip. Denmark is also a member of the Trilateral Co-operation on the Protection of the Wadden Sea, and has designated the Wadden Sea as a nature and wildlife reserve for this purpose.

The general laws in Denmark relating to nature conservation incorporate some regulations that directly influence the administration of the coastal zone. The National Forest and Nature Agency, under the Ministry of Environment and Energy, has overall responsibility for the protection of the International Nature Conservation Areas (Ramsar, EU Bird Directive, and EU Habitats). The counties administer most of the regulations. They carry out inspections, issue permits and refusals, carry out maintenance tasks, monitor, plan and disseminate information. Some regulatory measures worth mentioning include a ban on changes to the natural conditions in salt and freshwater marshes and other areas, a 300-meter general protection zone along the coast and conservation regulations for protected dune areas (MILJO MINISTERIET, 2001).

Besides the Danish Nature Protection Law, the most significant nature protection regulation is the Executive Order on Nature Conservation and a Wildlife Reserve in the Wadden Sea. This executive order covers large parts of the Danish section of the Wadden Sea Area, and is an expression of efforts to establish sustainable development for the region as a national and international nature conservation area, as well as, a way of ensuring that Denmark meets its obligations for the area including those under the EU Bird and Habitat Directives. The Executive
Order contains prohibitions that regulate in detail aspects such as land and sea traffic, the collection of organisms from the sea bed, hunting, civil engineering work including coastal defense, alteration of the terrain, canals, mineral extraction and other technical installations. The Executive Order falls under the jurisdiction of the Ministry of Environment and the National Forest and Nature Agency. The provisions of this order make it possible to involve other authorities, such as the Ministry of Transport and the counties.

Table 21 - Synthesis of protection and management of the coastal zone

<table>
<thead>
<tr>
<th>Protection and Management of the Coastal Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>In a way of synthesis:</td>
</tr>
<tr>
<td>- In 1978 a moratorium for designation of new summer cottage areas and new larger leisure constructions within a 3 km-zone from the coast, was issued.</td>
</tr>
<tr>
<td>- In 1981 this moratorium was replaced by a national planning directive banning new summer cottage areas in the 3 km-zone and demanding a comprehensive, strategic planning on recreation as a condition for other new leisure constructions in the zone. Beside this, it was stated, that such constructions, higher than 8.5 m should have a special permission from the Minister of the Environment (EIA study).</td>
</tr>
<tr>
<td>- In 1992 The Minister launched a new national planning directive- Planning Act- repeating the former but extending the provisions so, that also urban development and technical installations in the zone should be limited to the absolutely necessary level. It was at the same time stated, that the Coastal Zone of 3 km should be a planning zone, not a prohibition zone except for new summer cottage areas.</td>
</tr>
<tr>
<td>- On June 1, 1994 the Danish Parliament passed a law on protection and management of the coastal areas in Denmark. This decision was the last step in a long tradition that leads back to the first Act for Nature Conservation introduced in 1917. The law is justified by the fact, that the coastal areas are an essential part of the national nature and landscape values. The law consists of amendments to existing legislation, the Planning act and the Protection of Nature Act.</td>
</tr>
<tr>
<td>- In 1999 the amendments of Planning Act were made to ensure the implementation in Denmark of the amended European Union directive on environmental impact assessment (97/11/EC); the changes include the introduction of an obligation on the regional planning authorities to conduct environmental impact assessment.</td>
</tr>
</tbody>
</table>

6.5.3 The Coast Protection Act

The Coast Protection Act is the main legislation regulating all coastal defense measures. This law is mainly a procedural code, stating the procedure that the relevant authorities are obliged to follow when an application or public initiative for building or altering coastal defense constructions comes
up. This legislation deals with coastal erosion, and is implemented by the Danish Coastal Authority (DCA), under the supervision of the Ministry of Transport.

Coastal erosion management carried out according to the Coast Protection Act tended in the past to be executed to the cost of the landscape, nature aspects and the coastal profile. However, this new Danish Coast Protection Act of 1988 has given the county authorities significant influence in the decision process relating to coastal-erosion management issues, and has changed the approach from property protection to a more holistic method that emphasizes environmental values, 'concern for the landscape, and changes in land-use patterns' (LAUSTRUP et al, 1996).

The overall principle of the National Coast Protection Act is that the responsibility for establishing and maintaining protection measures lies with the persons who profit. On the other hand, landowners do not have an immediate right to protect property. Each new measure has to be considered appropriate by several authorities. The main considerations within the framework of the Coast Protection Act are whether a construction is necessary, can fulfill its purpose, will cause undesirable side effects or conflict with nature protection rules (JACOBSEN, 1996). The county considers project drafts and decides whether the project in question, is suitable to be passed on for further consideration or can be rejected immediately. The local municipality and other relevant authorities are always asked to comment on projects considered suitable, and approval for all such projects has to be obtained from the DCA. In general there is no public obligation to undertake coastal defense. In particularly extreme conditions the political bodies have considered it a public duty to protect the high energetic North Sea coast and to enforce or erect dikes at the Wadden Sea coast financed by public funds in part or in full through the issue of special construction laws.

Since 1874 and 1927, respectively, Denmark has had a Dike Protection Law and a Coastal Defence Law based on the landowners individual responsibility for the coastal activity. The integrated act of 1988 substitutes the previous laws and takes into account the new dimensions in the coastal situation, including changed economic relations.

In principle the protection of land and property affects only the front property owners, while coast erosion management relates to areas and interests in considerable depth of the hinterland. Furthermore, especially beach nourishment schemes require conceptual thinking, planning and financing on a larger scale than previously imagined (MILJOMINISTERIET, 1997). The regional authority has a leading role in the approval process with a solid background in its role in the general planning process, and is thus well suited to combine a good understanding of the local values at stake, with property balanced problem assessment.
Often the regional authority lacks, however, the expertise required for a proper technical evaluation of proposed actions. Therefore it is required that DCA shall be involved directly in examination of the projects and subsequent approval.

In addition, the regulatory procedures still require final permission from DCA for all coast protection works and other man made changes in a zone 100 meters in landward of the coastline as well as seaward in the territorial waters.

The financing of coast protection schemes remains the responsibility of individuals, municipalities and regional authorities, except along the exposed North Sea coast, where considerable governmental resources are allocated to schemes of general and regional importance. (JAKOBSEN et al., 1998). The actual policy for safety assessment and the erosion control policy are established as an agreement between local authorities and the government based on Danish Coastal Authority recommendations.

The costs of coastal protection on the North Sea coast are shared between the government and the local authorities. The government typically pays 50 to 70 %. And in some cases the government pays 100 % (COMRISK, 2002).

On the Baltic Sea coasts, coastal protection is regulated by an act passed in 1988. According to this act, the counties are responsible for the administration of coastal protection projects.

Since the counties do not have any coastal engineering expertise, the Coastal Authority provides assistance at the planning stage and the consultants provide assistance at the project stage. The general practice is that there is no public funding of coastal protection in the Baltic Sea area where the individual landowner has to bear all the costs (MILJOMINISTERIET, 1997).

6.5.4 Institutional Framework

Though the legal framework in the Danish coastal zone can scarcely be characterised as a coherent management system, there is a fairly high level of coordination of these sectorial laws which has been developed over the years. The planning process constitutes the most important coordination measure (AKSIG 1994). Basic principles derive from the parliamentary system established in 1849. Other principles are founded in the local administration system in Denmark established in 1970, which gives considerable powers to the local authorities, i.e. the 14 counties and the 275 municipalities. Thus, the authorities responsible for carrying out integrated coastal zone management in Denmark are the counties that are in cooperation with the municipalities within the framework set by national authorities.

In Denmark, the Ministry of Environment, which was established in 1994 firstly as the Ministry of Environment and Energy, is the national government department responsible for environmental and
planning policy. This Ministry is supported by specialist agencies, including the Danish Environmental Protection Agency (figure 59). Regional planning is undertaken by the counties, and the municipalities carry out local planning.

![Diagram of the Ministry of Environment and its specialist agencies](image)

Figure 59: Ministry of Environment and its specialist agencies (in: MILJO MINISTERIET, 2001)

The regulation of the coastal zone in Denmark is covered by a number of legislative instruments which place the responsibility on several authorities. For the most part the state authorities are responsible for the administration of the sea territory. The Ministries with the greatest responsibility for coastal defense and nature protection are the Ministry of Transport and the Ministry of Environment, respectively. The administration of the land territory is mainly carried out by the counties, and the Ministry of Environment.

The planning legislation in Denmark is based on the principle of framework management and control. This means that planning at any level must be in agreement with the framework established at the next level above. But the objectives and the content of planning are different at the three administrative levels (JAKOBSEN et al, 1998).

National planning and legislation on major development projects establish an overall framework for such tasks as protecting coastal areas and extending the infrastructure. Regional planning implements common national interests, as it establishes the main guidelines for land use and infrastructure outside the urban zones in each region (JAPPE, O., 1996).

Municipal planning comprises structure and land-use planning for an entire municipality with a special focus on urban zones. The municipal plans constitute the framework for the more detailed local developments.

The planning process is highly political dealing with shaping the future human environment based on public debate and the balancing of different interests.

Denmark has a highly decentralised system of public administration. Local administration (regional and municipal level) administers more than 50 per cent of the total public expenditure. More and
more responsibilities have been transferred from the state level to local governments. The purpose
is to solve the tasks at the lowest possible level in order to combine responsibility for decision-
making with accountability for financial consequences (the principle of subsidiarity). The activities
of the local authorities are financed by income taxes, land taxes and by state block grants (WORM,
K., 1997).

The planning system, which is based on decentralisation and public participation, has been an
effective tool in nature protection. The Ramsar Convention and the Bird Protection Directive have
for instance been implemented through the regional planning (JAPPE, O., 1996).
6.6 Case study 1 –
North Sea coast (Thyboron/ Thorsminde)
6.6 CASE STUDY 1 – NORTH SEA COAST (THYBORON/ THORSMINDE)

6.6.1. Introduction

The Danish North sea coast is partly a coast of tidal flats and the overall length of the coast is approximately 450 Km. The northernmost 340 km of coastline in this area consists of sandy beaches, and is characterized by wide beaches, lagoon-like inlets and posterior dunes and is equally unique, despite many summer cottage areas, some towns, technical installations, harbours, etc. The areas along the coast are relatively sparsely populated, with few harbours areas, (existing five or six ports with more than 1000 inhabitants). In addition to this, there are fifteen to twenty smaller towns, and in general the whole stretch of coast has good bathing beaches, the area has many holiday and leisure facilities. The first and foremost expanding summer cottage areas with thousands of summer cottages were built here.

This case-study focuses only on the North Sea coast between Thyboron and Thorsminde, and special attention is made to the Thyboron area as been considered as one of the main interesting and update challenge to the Danish coastal protection experience.

Figure 60: Case-study 1: Thyboron/Thorsminde area location
Thyboron is placed at the entrance to a fjord system, which connects the North Sea with Kattegat. The inlet acts as a trap for the littoral transport from both sides. The adjacent barrier beaches suffer from severe erosion, which is alleviated by large structures and nourishment. The entrance was formed only 135 years ago and is still undergoing morphological changes. During its lifetime engineers have investigated various schemes for stabilising the shoreline. The most radical suggestion has been to close the entrance to avoid the ongoing loss of beach material.

![Figure 61: Thyboron, an inlet at the North Sea and the Limfjord (DCA, 2000)](image)

6.6.2. Historical Considerations

Sea trading had its heyday in the middle of the 19th century. With the permanent opening of the Thyboron Canall in the middle of the 1830s which made it possible to sail through the Limfjord to the North Sea, and the opening of the Vendsyssel railway in 1871, trade became concentrated further inland. After that sea trading from the coast gradually lost its significance. Fishing took over as the principal industry in many of the coastal communities (HANSEN et al, 2000).

The generation of the present Thyboron barriers (Figure 61 and 62) started around year zero as a part of smoothening of the coastline. From the Icelandic sagas is known that there has been a connection between the fjord and the North Sea since there are narratives of the Vikings passing on to the North Sea through the Limfjord in the 11th century (TVERSTED-Local Archive). The barrier system at the earliest first was closed about year 1100. There have been multiple breaches in the barriers during the period from 1600 until 1800, but none serious until 1825 where the Agger channel was formed and it lasted until 1868 (LAUSTRUP et al., 1998).
However the most severe breach came in 1862 and formed the Thyboron Channel. Immediately after this happening, the retreat of the coastline started, and shortly after the breach the construction of a large groyne system was initiated. Since the construction of the groyne system, the initial flattening of the coast profiles, caused by the excessive recession of the shoreline, was replaced by a gradual steepening of the seabed seaward of the groins, which is ongoing but declining. In the 1930s, this steepening gave rise to deep concern among the responsible engineers who felt that disaster was looming ahead. They feared that the coast profiles were becoming so steep that even a short series of severe storms could generate such effects that control of the development would be lost. This was called "The Theory of Disaster" (LAUSTRUP et al., 1998).

On this basis an act was passed by Parliament in 1946 whereby the Thyboron Channel would be closed such that the loss of sand from the seacoasts to the Limfjord would be stopped and the seacoasts thereby stabilised. The project included (JAKOBSEN et al., 1998), the construction of 16 km of “safety” embankments placed approximately 2 km behind the coastline as well as the building of two major breakwaters and two sluices for vessels and salt water inflow, respectively.

Before the works to close the Channel were initiated, and PER BRUUN (1954) in his doctoral thesis, Coast Stability, raised serious doubts as to the "disaster theory" which was the basis for the project and proposed new investigations of the problems. Along similar lines, Helge Lundgren in 1954 and 1956 made specific proposals for new investigations, including scale model tests with movable bed to be carried out in Holland, particularly with a view to keeping the channel open and to saving a major part of the project costs (LAUSTRUP et al., 1998).

The government followed these recommendations and a range of studies of various aspects of the problem were initiated, the most important ones of which were carried out at the Technical University of Denmark (DTU) headed by Helge Lundgren and Torben Sorensen (FREDSOE, 1996).

The crucial question of whether the steepening of the coast profiles indicated a risk of disastrous development was resolved by an analysis demonstrating that the steepening was simply a question of the coast profiles adjusting to the reduced shoreline recession achieved by the construction of the groyne system, (SORENSEN, 1996). This realisation in fact eliminated the basis for the very expensive and in many ways controversial project. The soundings of coast profiles over 125 years have confirmed the validity of this analysis.

In consequence of these investigations, the 1946-law was repealed in 1970 under the condition that the Danish Coastal Authority should follow the situation for at least 50 years. This was done the first time in 1975. The major conclusion in this work so far, was that the steepening almost had stopped and that the system to some extent was stable (DCA, 2000).
Figure 62: Overall safety system description at Thyboron (DCA, 1998, aerial photo, KORT AND MATRIKELSTYRELSKEN, 2002)


<table>
<thead>
<tr>
<th>THYBORON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Characteristics of Development</td>
</tr>
</tbody>
</table>

* Thyboron is placed at the entrance to a fjord system, which connects the North Sea with Kattegat Sea. From the Icelandic sagas it is known that there has been a connection between the fjord and the North Sea since there are narratives of the vikings' passing on to the North Sea through the Limfjord in the 11th century.
6.6.3 Hydrodynamics and Natural Conditions

The North Sea coast of Denmark is very dynamic and high energetic producing some of the highest sediment transport rates in the world. It undergoes large average annual coastal erosion, sometimes exceeding 10 meters (JAKOBSEN et al, 1998).

The astronomical tide on this coast is very small, max. 0.3 m, whereas extreme high water levels caused by wind set-up with westerly winds may reach 3m. For example, during a storm period (20/1 - 24/1 1993), the storm started in Southwest and turned towards Northwest with wind speeds up to 22 m/s, wave heights reached 6 m and the water level raised to 2 m above MSL off Thyboron (DCA, 2000).

6.6.3.1 Climatic and Water Level Conditions

To give an impression on the weather conditions at the West Coast of Jutland, wind, wave and extreme water level conditions for Thyboron are shown in figure 63.
Directional wave measurements have been undertaken since 1991. These detailed measurements supplement 15 years of wave height recordings and have formed the basis for the statistical analysis of the wave conditions.

The meteorology is dominated by low-pressure systems travelling from West towards East. The westerly winds and waves are responsible for the morphological development of the coast. Typically, in the beginning of a westerly storm, the water level rise off Thyboron, and, due to the connection across the peninsula of Jutland, strong in-going currents may last for the entire storm period, 3 – 5 days. Strong outgoing currents seldom occur in combination with severe wave action. Waves from south-westerly directions cause northward littoral drift along the barrier beaches (DCA, 2001).

6.6.3.2 Geology

The upper layers of the barriers consist of sand and gravel while below –6 m, marine clay can be found to a great extent. Underneath this are glacial deposits. The clay layer has been found until 75 km further to the west of the present coastline out on ‘Jutland Reef’, which consists mainly of deposits of eroded glacial material. This indicates that the glacial formations in the early Holocene period extended further to the west protecting a calm basin where the clay layer could be deposited. The start of the barriers build up as a part of the formation of the present glacial coastline is dating back to the start of this era, and the barriers properly closed early in the 12th century, as explained in the historical review (JAKOBSEN et al, 1998).
6.6.3.3 Sediment Transport Processes

The sediment transport processes around the inlet have been studied and quantified through a comprehensive set-up of numerical models, (DEIGAARD et al., 1986).

The Thyboron entrance is too wide to allow for any significant natural bypass and most material is deposited in the entrance area. During north-westerly storms, the littoral drift is southgoing, and for these wave directions the layout of the entrance allows for significant wave penetration into the channel. Nevertheless, the predominant littoral drift at the inlet is northgoing, and immediately south – Ferring area, is southgoing (figure 64). Therefore, during north-westerly storms, the sediment is kept in suspension further into the channel, and it may be transported all the way through the channel before it deposits on the shoals on the inside of the channel. The net effect of these processes is that littoral drifts for both barriers are directed towards the central channel (DCA, 2001).

Figure 64: Aerial photo of Thyboron, Harboore and Ferring area. Sediment Transport direction (KORT AND MATRIKELSTYRELEN, 2002)
Transport patterns and the corresponding initial morphological changes for cases with south-westerly and north-westerly waves combined with in-going current and north-westerly waves combined with out-going current. It is seen how the channel tends to migrate to the East during in-going flow and towards west during out-going flow. These calculations correspond to a distribution of sediment properties described from about 240 bed samples in the area (JAKOBSSEN et al., 1998).

The yearly transport and morphological development are functions of the yearly climate, and at the present location even small variations in the dominant wave conditions change the sediment balances significantly. According to this last author, the modelling complex has been used to quantify this variability. Both the water level and the currents in the channel are strongly correlated to the instantaneous wave conditions. The frequency of occurrence of combinations of wave height and direction, water levels and currents in the channel have been analysed based upon 6 years of simultaneous measurements of water levels and waves, and 1 year of simulations of the currents through the 'fjord' which crosses the peninsula of Jutland (ANDERSEN, O.N., 1992).

The waves, currents and sediment transport have been modelled in detail for a number of historical events in total 255 days, and 448 different combinations of waves, water level off the channel and current through the channel have been picked from the simulations. These sediment transport patterns are subsequently weighted to reflect the yearly transport pattern for different periods of time, (JAKOBSSEN et al., 1998).

It appears that the transport capacity off the southern barrier-island increases slightly towards the entrance, giving rise to the erosion, which today is compensated by nourishment. Inside the channel the calculations indicate ongoing redistribution of material and a loss of material to the internal shoals. The sediment transport capacities inside the channel area have been adjusted to account for the presence of the non-erodible clay surface (DCA, 2001).

6.6.3.4 Sediment: Budget

Both south and north of the barriers there exists a nodal point for the littoral transport from which the net transport is directed towards the central channel. Based on the data (DCA, 2000), the total volume of eroded sand between the northern and southern nodal point has been calculated. Depending on the distance from the coastline taken into account, which is from the top of dunes until 12 to 16 meters depth, the volume range is 450 000-600 000 m³/year for the stretch from the southern nodal point up to the channel and 150 000-200 000 m³/year from the northern point down to the channel. This gives of total of 600 000-800 000 m³/year between the two nodal points.
Calculations of shoal deposit behind the barriers has been carried out based on soundings of the shoals in 1972 and in 1991. The calculations leads to the conclusion that 500 000-700 000 m³ is deposited on the shoals every year (DCA, 2000).

Figure 65: The sediment budget for the West Coast (Volumes in m³/year) (source: DCA, 2001)

The numerical model (DCA, 2000), gives some ranges for the transport capacity through 7 sections along the seashore and through the channel, (figure 65). The transport capacity through the central part of the channel is 5-750 000 m³/year for the mildest and roughest year, respectively, during the period 1991-1997. The transport capacity along the coastline varies between 0-100 000 m³/year for the northern barrier and 150 000-400 000 m³/year for the southern barrier.

Combining these information's ranges for the overall longshore sediment budget can be obtained. The north going transport is in the range 3-500 000 m³/year and the south-going is up to 200 000 m³/year. The transport rate through the channel is 500 000-700 000 m³/year.
6.6.3.5 Coastline Retreat

Figure 66 shows the coastline retreat rate before 1977 for the southern part of the North Sea coast. There are very high rates of downdrift erosion caused by harbour breakwaters and large groyne groups. Besides the loss of valuable recreational areas, the high erosion rates had the effect of significantly reducing the protection against flooding provided by the dunes. About 100 years ago, the dunes were stabilized by marram grass planting. At the same time, harbours and groyne groups were built which resulted in serious downdrift erosion. The combined result of the stabilization of the dunes and the erosion was that in 1982, the dunes had disappeared or were weak along 50 km of the coast. Therefore, in 1982 it was decided to implement a coastal protection scheme.

Figure 66: Coastline evolution at North Sea coast (between Thyboron and Hvide Sande) since 1977 (Source: DCA, 2001)
6.6.4. Coastal Protection Measures

Most of the coastal protection activities on the Danish North Sea coast are concentrated on the 110 km long central part. The reason is a combination of high autonomous retreat rates and a vulnerable coast due to the sections with narrow sand spits. The northern part of the central North Sea coast is characterised by the 98 groynes (figure 67) built between 1880 and 1950. When the present coastal policy was agreed in the beginning of the 1980s, structures were also a central means. In the following 10 years, 24 km revetment and 71 breakwaters were built (DCA, 2000). These structures were combined with nourishment. However, nourishment volumes were small compared to the present level. In the 1970s small nourishment projects have been implemented. From the beginning of the 1980s annual nourishment volumes increased gradually and today the level is about 3 million m$^3$/year. The total nourishment volume since the 1970s is more than 30 million m$^3$ of which by far the largest part has been carried out as beach nourishment. However, today about one third of the annual volume is shoreface nourishment. The nourishment volume for a particular section of the coast is calculated so as to compensate for the erosion to −6 m bathymetric line (RASMUSSEN, 2003-Personal Interview).

Figure 67: Coastal defence at North Sea Coast – Ferring / Thyboron - Groin field and Breakwaters (photo 22/03/2003)

6.6.4.1 Safety and Erosion Control

The increase in severity of the coastal climate since 1976 required new and more intensive efforts on the Central West Coast. Previously, governmental schemes had dealt only with stretches, where typically, government owned groyne groups existing from earlier periods (PIONTKOWITZ, 2003 -
Personal Interview). This was the case for about 25% of this exposed coast with a total length of about 125 km. As a consequence the coast had been in a squeeze between steadily increasing attacks from the sea side and a growing demographic pressure from the interior. It was therefore decided to establish cooperation between state, regional, and municipal authorities along the coast to finance and execute a program, the objectives of which were:

- To restore and enhance the storm flood protection of the area.
- To control coastal erosion reducing it to acceptable and agreed-upon limits.
- To enhance technical benefits and environment values by introducing beach nourishment on a larger scale.

![Coastal defence at North Sea Coast – Protection Dike at Thyboron](PHOTO 22/03/2003)

Figure 68: Coastal defence at North Sea Coast – Protection Dike at Thyboron (PHOTO 22/03/2003)

Particularly, for the Danish North Sea coast the goals for the coastal protection are in order of priority (JAKOBSEN et al, 1998):

- To maintain a safety level against flooding of a 100 years return period as a minimum. At Thyboron the safety level is 1000 years.
- To stop erosion where towns are located close to the beach.
- To reduce erosion on parts of the coast where erosion in the near future would reduce the safety against flooding to less than 100 years.

The goals mean that the coastal retreat is stopped along the unstable coastal stretch where lowlands from urban land-use are threatened by flooding as a result of rupture (figure 68). For the rest of the stretch the natural retreat is accepted, either because it is very small or because there is no associated risk (no urban and human occupation). In fulfilling these goals the DCA aims at coastal protection with sand instead of rock and concrete, i.e. the aim is to use soft solutions if possible.

* For the remaining part of the Danish coast (the Kattegat and the Baltic Sea coasts) no goals and aims for erosion control or safety against flooding are defined by the Government. This case-study focuses only on the North Sea coast.
As seen before on Chapter 4, once a groin is filled, it may allow littoral drift to pass by its seaward end, so that it would trap only a certain quantity of sand. While sand is accumulating between the groins, that sand is prevented from reaching the beaches in the downdrift direction, so that erosion is enhanced, analogous to the erosion that occurs downdrift from jetties. To prevent such damage to adjacent areas of beach, in this North Sea coast of Thyboron, groins are filled artificially by beach nourishment that is, by trucking sand out onto the beach. If this is done, the groins will not take their supply of sand from the natural littoral drift, which will continue to reach the downdrift beaches just as it did before groin construction.

![Coastal defence at North Sea Coast – Ferring / Thyboron - Dune revegetation; Dune revetment works](PHOTO 22/03/2003)

The segment of beach between two adjacent groins acts as a small pocket beach. The beach between two groins aligns itself with the crests of the incoming waves and may therefore depart from the shore alignment that existed prior to groin construction. Similarly, the beach will oscillate between the groins due to waves arriving from a variety of offshore directions.

The Coastal Authority is responsible for maintaining and extending the government’s coastal protection interventions along the West Coast, and several measures are undertaken. This is the case of Dune revegetation; Dune revetment works (figure 69 and 70).

The gale in November 1981 caused great damage to the coast, and increased efforts to reduce or stop the erosion of the coast were required. Till then the government had paid all costs of its own stretches but after negotiations an agreement was concluded - the Joint Agreement - on the scope and the distribution of expenses for coastal protection, between the Ministry of Transport, the
County of Ringkøbing and the five coastal municipalities of the county. The agreement is renewed on a continuous basis, and the funds involved are currently approximately 2.7 million euros per year (DKK 100 million/year), of which the government pays approximately 80 per cent, (PIONTKOWITZ, 2003 - Personal Interview).

The DCA –Ministry of Transport, regularly prepare evaluation reports which in part sum up the coastal developments observed, in part form the basis for laying down future initiatives. The Joint Agreement has for a number of years been performed under the headline: "To preserve and to prioritise". The objective was to stop coastal retreat in areas where there is a risk that the sea will break through, and where large material values are now threatened. For other stretches a reduced and reasonable retreat is acceptable. On the basis of a completed Research and Development Programme it has been possible for the DCA to optimise several coastal protection methods (DCA, 2001).

The extreme water levels at Thyboron have been reassessed based on data from the passed 20 years. The period just after 1975 covers a number of very extreme events, and therefore the analysis, based on the latest period only, shows a somewhat higher level than the analysis from the first period and the full series (JAKOBSEN et al, 1998).

![Dune revetement works at North Sea Coast – Ferring / Thyboron (DCA, 2000)](image)

Figure 70: Dune revetement works at North Sea Coast – Ferring / Thyboron (DCA, 2000)

The dikes have been reinforced, the beach better maintained and the total system will therefore be able to provide flood protection in a 1000 event even accounting for the new analysis of extreme water levels. Further, it has been investigated if there should be a certain limit to extreme water levels at Thyboron due to the nearness of more open and deeper waters to the north. Simulations in a numerical model of the North Sea were performed for a recorded storms called to predicted
extreme conditions. The simulations showed that the extreme water levels are functions of the barometric conditions mainly, and that a limit could not be identified. Although the outer part of the profiles close to the inlet is still getting steeper, the rates of steepening are significantly decreased and the nearshore zone can be kept stable by comprehensive nourishment.

6.6.4.2 Profile Steepening

Foresighted engineers started profile surveys only 12 years after the final breach in 1862. With few interruptions, such as during the Second World War, the profiles have been surveyed every second year ever since and the database now forms a unique basis for evaluating the long-term trends of profile development, notably steepening of the profiles. The volume of eroded sand along the coast and profile development have been calculated based on these surveys.

From the geological study, the position of the clay surface is known, which means that it has been possible to calculate erosion along the coast for the sand layers only. The sediment balance has been calculated for 4 periods, 1874-1900, 1900-1936, and 1936-1978, 1978-1992 and 1992-1999. For the first two periods the calculations are carried seaward to a depth of 8 meter HZ. In 1930s, DCA started measuring seaward to a depth of 16m DNN. The calculations for the last two periods are therefore carried out to this depth (DCA, 2001).

The results clearly have shown the large erosions immediately after the breach in the barriers. This continued in the following years also after the construction of the groynes. As the steepening began the erosion decreased. On the basis of the long series of profile sounding the retreat of the coastline, the cliff and the 7, 8, 10 and 16 meter depth contours have been calculated (PIONTKOWITZ, 2003 - Personal Interview).

Nowadays, with 125 years of available data, it is possible to extract reliable long-term trends from the otherwise confusing data. It is seen that the retreat of all elements was larger in the beginning of the period compared with the retreat today (PIONTKOWITZ, 2003 - Personal Interview). For the coastline, the four, and six meter depth contours, the retreat has stopped. The depth contours off the groynes are still retreating. This leads to the conclusion that the steepening of the profiles has not yet stopped along all sections of the coast as earlier concluded in the 1975. This is especially true close to the inlet. It should however be noted that the wind and wave conditions were extremely severe for almost 20 years after 1975 (JAKOBSEN et al, 1998).

The effects of the profile steepening on the sediment transport capacity have been quantified by modelling of waves, currents and sediment transport for historical storm using a recent bathymetry and a bathymetry constructed from the old profile measurements.
The groynes have been moved backward in pace with the ongoing erosion, however leaving submerged parts still active on the seabed (DCA, 2001). The erosion rates are significantly reduced compared to a hundred years ago due to the steepening of the coastal profiles. These simulations illustrate the sediment transport processes which are reflected in the measurements of the morphological evolution of the area.

6.6.4.3 Beach Nourishment

For a number of years coastal protection was effected through construction of fixed structures - slope protection and breakwaters - combined with coastal nourishment. In the beginning of the 1980s nourishment played a much smaller role than today. This was due to a number of reasons, such as, (LAUSTRUP; MADSEN 1998):

- The local politicians believed in and, hence, preferred solid structures such as groynes and breakwaters. The main reason for this was the successful design and construction of the large groynes around the turn of the century. Later on it was realised that the building of long groynes in a lee side erosion area would accelerate erosion. It was therefore decided to build coast-parallel breakwaters with the main function of protecting the beach.

- The principle of beach nourishment was new to politicians and the argument behind ("the erosion of the nourishment during storm is part of the plan") was hard to bring across.

Today, efforts are almost entirely concentrated on coastal nourishment, which is in agreement with the general aim to use soft solutions if possible. The annual nourishment volume is about 3 million m³, which is placed in part on the beach and in part on the coastal profile at a water depth of up to 6 m.
Gradually the shoreface nourishment percentage has increased and after the Nourtee project the DCA-Ministry of Transport, decided that one third of the total nourishment volume should be shoreface nourishment and the rest beach nourishment. The nourishment programme is supplemented by other means such as dune reinforcement, marram grass planting and beach scraping, (PIONTKOWITZ, 2003 - Personal Interview).

| Figure 71: Beach and shoreface sand nourishment techniques (in: DCA, 2001) |
As already stated, over the past 10 years the hard structures have been supplemented by comprehensive nourishment of the beaches. Apart from following the evolution by bathymetrical surveys, DCA initiated studies in 1994 to quantify the sediment transport mechanisms in the area. These studies are at the present, undertaken by the Danish Hydraulic Institute (DHI).

In that way, in order to face the natural erosion, the DCA have been undertaken several sand nourishment operations, between the coastal stretch of Thyboron and Thorsminde. Mostly of these operations, pumping off the sand from identified natural sand deposits – 'sinks' area (figures 72 to 74). The DCA today's policy concerning sand nourishment refers if sand is required to be put back into the system, it should be borrowed from natural 'sinks' (PIWORTIZT, 2003).

Those sand accumulation zones are carefully studied and never overexploited, and EIA analysis is always under progress before each extraction intervention, and approval is always needed by the nature conservation authorities (Table 23).

Figure 72: Sand nourishment operations between Agger and Thyboron, relating the locations of extraction (Sandindvindings område) and the supplied bar/beaches (Strandfodring). (In: KYSTINSPEKTORATET, 1998)

Figure 73: Sand nourishment operations on the West Coast between Thyboron and Ferring (In: KYSTINSPEKTORATET, 1998)
Previous studies have led to the conclusion that the profile from the bar, and out should be nourished by dumping sand on the bar. This is also cheaper than placing the sand on the beach. There was nearly no migration of sand from the bar to the beach so for the inner part of the profile it was recommended to place the sand on the beach. Part of the nourishment on the beach is used as a buffer to prevent erosion of the dunes during storms.

Table 23- Nourishment methodology in Denmark (KYSTINSPEKTORATET (1998))

<table>
<thead>
<tr>
<th>Aspects of reference</th>
<th>NOURISHMENT METHODOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ASSESSMENT OF VOLUMES IN RELATION TO DESIGN PERIOD AND DESIGN STANDARD</strong></td>
<td>The overall nourishment volumes are decided for a 5-year period by the political approval of an investment level proposed in a master plan prepared by the DCA. The present nourishment volume has been calculated so as to compensate for the long-term erosion between the natural retreat and the retreat goal in the inner part of the profile above the level -6 m for the particular section of the coast. Every year the DCA prepares an action plan where the nourishment volumes are settled in detail for the different sections of the coast. The overall distribution is according to the master plan, but the specific nourishment project is adjusted according to local erosion, contractual considerations etc. The design period is one to three years.</td>
</tr>
</tbody>
</table>

| **CONSIDERATIONS ABOUT SOURCE AREAS** | About 300,000 m³ of the annual nourishment volume comes from maintenance dredging in the entrances to harbours. The rest is dredged at about 20-23 m depth normally just offshore from the nourished stretch. The source areas are selected on the basis of a large number of test dredgings where the approximate layer thickness and grain size are determined. The present source areas are all located outside the 20 m depth contour where dredging of sand is expected only to have a marginal effect on the inner part of the profile. In specific nourishment project the optimal source area is selected by optimisation of sailing distance, grain size, size of sand resource etc. The grain size has been particularly focused upon over the years. In (Laustrup et al., 1998) an estimate is presented of the connection between the grain size and the nourishment effect. |

| **DESIGN CONSIDERATIONS** | The design of a nourishment starts by checking the safety level for the specific section of the coast. If the width of the dune is below the defined minimum or close to it, beach nourishment is necessary. Normally safety is not critical and in these cases shoreface nourishment is an alternative. After the Nourtee project |
DCA decided that about one third of the total nourishment volume should be shoreface nourishment. Beach nourishment is normally carried out with sand pumped in from offshore. It is specified that the pipeline must be placed at the dune front. Also the source area from which the sand should be dredged is specified. To get the more attractive coarse sand rewards for coarser material are included in the tender document. With regard to the profile of the delivered sand there are no demands, except that the use of temporary dumps is not accepted. When beach nourishment sand is delivered by dump trucks, which is generally the case when the sand is dredged in the harbour entrances, the nourishment sand is profiled according to a specified profile. The shape of this profile is close to the natural beach profile. Shoreface nourishment is carried out in one of two ways. If the profile is without a bar, the nourishment sand is placed at 2-3 m water depth. This is the case along the land spits north and south of Thyboron. If there is a bar, the sand is placed at the outer side of the bar normally inside the 5 m depth contour. In the design of both beach and shoreface nourishment the effect of existing structures is included based on simple estimates. Until now mathematical modelling has not been used in the design of a nourishment project.

**APPROVAL PROCEDURES**

The DCA is responsible for the administration of the 300 m wide coastal zone according to the Coast Protection Act and the Sovereignty of the Sea Territory. This means that all coastal protection schemes need an approval from the DCA before they can be initiated. Part of the approval procedure is the hearing of other public bodies, which are in charge of other laws or regulations concerning the coastal and sea territorial areas. For the central part of the North Sea coast this formal procedure is replaced by a praxis by which the Ministry of Traffic, the county and the relevant municipalities agree on a coastal protection programme for a five-year period. After concluding this agreement, which includes both the coastal protection measures and how the expenses are shared between the three parties, the different projects can be started without further approval procedures. However, a precondition is that an approval has been given for the dredging in the source areas. The National Forest and Nature Agency manage the Danish sand resources. To get a dredging licence requires that a number of conditions have been fulfilled, for instance pilot studies, an environmental impact assessment and monitoring. The DCA has 10 of these licences, which are normally valid for a 10-year period.

**CONTRACTUAL ASPECTS**

Every year the nourishment programme is sent out for EU-tendering based on fixed price per m³. Long-term contracts have been considered by the DCA, but the Ministry of Traffic did not accept this system. The main argument was that the ministry does not accept nourishment contracts beyond the actual fiscal year. Normally the total nourishment programme is split up into three parts, for which the contractor can bid separately. This is done to give the small contractors a fair chance. The approval of delivered volumes for both beach and shoreface nourishment is based on photos of the full and empty hopper taken by the contractor. The procedure is supplemented by different kinds of random check.

**COSTS**

The average price paid for beach nourishment sand was in 1999 4.20 Euro/m³ and for shoreface nourishment sand 2.60 Euro/m³. The distance to the source areas is about 6 km. In those prices are included general mobilisation and demobilisation together with transport of the pipeline between the beach nourishment sites. The price correction used in the reward system to get coarse sand is 1.5% per 0.01 mm in grain size D50.

**MONITORING PROGRAMMES AND TECHNIQUES**

The source areas are surveyed every year mainly to inform the contractors and The National Forest and Nature Agency. The nourished sections of the coast are normally not surveyed separately. The general monitoring of the North Sea coast is considered to be sufficient. However, selected nourishment projects are monitored in detail. An example was Nourtec. In these years a monitoring programme called Nourtec 2 is running in which a large shoreface nourishment with 2 mill. m³ supplied in 2 years is followed. The monitoring programme consists of surveys in lines with 200 m interval every 2 months and sand
The analysis programme is similar to the Nourtec programme and includes mathematical modelling. Also two nourishment projects where the nourishment sand is especially coarse are monitored in detail. Environmental monitoring is also part of the total monitoring programme. The DCA participated in the Riacon project and since then an environmental monitoring programme of a source area has been implemented. In 2000 a large environmental monitoring programme will be started up as part of the environmental assessment procedure.

**EVALUATION OF RESULTS**

The general effect of nourishment is evaluated in status reports published every second year (Kystsinspektoret, 1998). The main question for the reports has been whether the goals for the safety level and the profile retreat have been fulfilled in the previous period. At a more detailed level much effort has been used to calculate the effectiveness of nourishment in relation to the grain size for the sand. Parallel to these status reports more detailed studies have been running. An example is Nourtec where beach and shoreface nourishment were compared and where the goal was to come to a complete understanding of the coastal processes. At the moment the DCA is running the so-called Nourtec 2 project. In this project shoreface nourishment with about 2 mill. m³ sand is analysed in detail like in Nourtec.

**CURRENT AND FUTURE CONCERNS ABOUT NOURISHMENT**

Because the nourishment volume is equal to the natural erosion inside the 6 m depth contour, a coastal profile steepening is inevitable. The steepening is well documented, but the question is how the steepening will develop in the future. An answer to this question is the DCA’s opinion that it is necessary to reach to a better understanding of the sediment balance for the Danish North Sea coast. In particular, a better understanding of what happens in the outer part of the profile and the interchange of sediment between the outer and inner part of the profile, is crucial. A number of projects are running for the moment with the overall purpose of improving this understanding. Besides steepening, shoreface nourishment versus beach nourishment is still a hot item. At the moment the Nourtec 2 project is running and a Nourtec 3 project has been discussed in which shoreface nourishment at a coastal section without bars should be studied. Also the environmental impact of nourishment is an item of concern. Therefore a large environmental monitoring programme will be started up in 2000 as part of the environmental assessment procedure. Finally, the effect of sea level rise on nourishment, coastal protection structures and dikes is considered to be an item of concern. However, until now sea level rise has not been included in the design of any of these coastal measures.

Beach nourishment today accounts for about 80% of all coast protection activities along the Central West Coast. On top of this a considerable effort is also spent on reinforcement and maintenance of the somewhat deteriorated dune systems along the coast.

It is expected that the coastal protection methods can be further optimised (DCA, 2001). Simultaneously, the sand used for coastal nourishment will become more expensive because it must be borrowed further away from the coast.

In the long term it may be necessary to increase coastal nourishment initiatives, in part to prevent the erosion taking place outside the 6 m depth curve, in part as a result of the sea level rise caused by global warming.
6.6.4.4 By-Pass Operations

According to a new sediment budget analysis, nature and society together have to by-pass 700 000 and 1000 000 m³/year, at the two inlets of Thorsminde and Hvide Sande, respectively. The maintenance of proper access conditions to the two harbours is the responsibility of the State Port Authority. Previously, maintenance was executed on and off, which did not satisfy the requirements for safe and continuous operations. Therefore it was decided to order two custom-made hopper dredgers of 200 m³ capacity each. The dredgers operate permanently. (Frisch, 1991 in SORENSEN et al., 1996).

Furthermore, it has been agreed that these dredgers, when having fulfilled their main objective of keeping the entrances clear, can provide sand for the nourishment work carried out by DCA. In 1991 DCA installed a permanent booster at Hvide Sande to assist the by-pass operation. In 1995 it thus boosted 200 000 m³ out of a total of 300 000 m³ by-passed artificially. At Thorsminde north of Hvide Sande the by-pass quantity is about 200 000 m³/year. (JAKOBSEN et al., 1998).

Figure 75: Aerial view showing how the sand is brought in at Thorsminde and pumped ashore for the beach (KORT AND MATRIKELSTYRELSEN, 2000)
6.6.5 Main Aspects for Conclusions

Thyboron channel is located on the West coast of Jutland, Denmark. The channel was formed naturally during a severe storm in 1862 when waves broke through the coastal sand dunes and the narrow barrier beaches which separated the North Sea from the Limfjord. In the years after the opening of the channel, the neighbouring coasts experienced substantial erosion, which threatened the town of Thyboron. The coastal urban settlements at this North Sea coast, from Thyboron, Harboore till Thorsminde, were also at a rupture risk situation.

It was decided to establish cooperation between state, regional, and municipal authorities along the coast to finance and execute a program, the objectives of which were:
- To restore and enhance the storm flood protection of the area.
- To control coastal erosion reducing it to acceptable and agreed-upon limits.
- To enhance technical benefits and environment values by introducing beach nourishment on a larger scale.

Particularly, for the Danish North Sea coast the goals for the coastal protection were established in order of priority of (1) to maintain a safety level against flooding of a 100 years return period as a minimum. At Thyboron the safety level is 1000 years; (2) to stop erosion where towns are located close to the beach; (3) to reduce erosion on parts of the coast where erosion in the near future would reduce the safety against flooding to less than 100 years.

The goals mean that the coastal retreat is stopped along the unstable coastal stretch where lowlands from urban land-use are threatened by flooding as a result of rupture. Today, the system configuration comprises a dike safety structure (high dune cordon with hard nucleus), a large number of groynes, about 400 m long, breakwaters, and yearly nourishment at beach and on shoreface. Besides, several dune restoration, dune revetment and By-Pass interventions are continuously undertaken.

The maximum retreat of coastline since 1862 was 1.5 km. Coastline retreat is now mitigated by yearly nourishment and protection structures maintenance.

By the evaluating efforts it has been anticipate what erosion might be caused and take appropriate defensive measures before considerable coastal property is lost. The usual protective measures include also the strategic placement of seawalls, riprap, groin fields, beach nourishment, or a combination of these.

Costs of nourishment and withdrawal of groynes and buffer dikes in line with coastline retreat on 1 - 2 m/year are equal, which leaves full flexibility for the detailed policy for coastal maintenance.
6.7 – CASE STUDY 2:
SKAGERRAK SEA – LONSTRUP / SKAGEN
6.7 - Case Study 2: Skagerrak Sea - Lonstrup / Skagen

6.7.1. Introduction

The northern part of the North sea coast is also a target of the case-study analysis in Denmark. The west coast of the County of North Jutland faces the North Sea by the Skagerrak Sea, (the Skagerrak, creates a shallow transition between the oceanic North Sea and the Kattegat continental Baltic Sea).

The coast is flat and sandy as most of this land is elevated seabed broken only by a few high points that reach all the way out to the sea.

In this area (figure 76 and 77), it is possible to find the Denmark's northernmost point today - Skagens Odde - which continues to grow at a rate of about 7 to 8 metres a year. This chapter section will mainly focus on the Skagen area (Skagen Odde, Skagen town) and the Lonstrup area.

Figure 76: Case-study 1: Skagen/Lonstrup area location
Figure 77: Case study 1: Skagen/Lonstrup area location (HANSEN et al, 2000)

The overall objective of this case-study is to contribute to a better understanding on different Danish coastal situations, which implies different coastal policy approaches, as well as the innovative measures on beach protection been carried out on this coastal stretch.

Figure 78: Skarregat Sea General view (photo DCA, 2000)
6.7.2. Historical Considerations

During the Stone Age, the highest points of Denmark were islands protruding out of the sea. The land has since then risen 6 to 15 metres, and as a consequence of this the ancient coastal slopes, it can still be found in the hinterland along almost the entire coastline. The rain has
formed many gorges in this area (HANSEN et al. 2000), the most well known being Fosdal en as a popular place for excursions since old days.

The countryside is predominantly sandy today due to the sand drift that started in the 16 century along the whole coastline. At that time, if not actually fertile land, this coast area at least had farms and farm animals. Lyme grass and marram grass grew here on the dunes and the long roots of these plants held the sand. The cattle were put out to graze on the dunes and the marram grass was used as roofing material. Consequently, nothing was left to hold the sand, and it started to fly with the catastrophic effects still visible today. Large areas with farms and villages were lain waste along the entire coastline and far to the north, the town of Skagen experienced a number of floods that washed the houses away, forcing the inhabitants to leave.

At the end of the 19th century, the Danish state bought up large coastal areas and began to plant the dunes with lyme grass and marram grass again to stop the sand drift. Mountain pine was also planted on extensive areas along the coast in an attempt to hold the sand (NATUROVERVFLIGNING, 1994). It is these dune plantations, that today stretch in an almost continuous belt along the entire coastline, that make the area attractive, as they also provide shelter from the strong winds prevalent along this coast.

The West Coast not only suffers coastal erosion but also has a continuous problem with sand drift in areas along the coast and often further inland as the case of the Bubjerg Knud in North Jylland (figure 81). Through the ages sand drift has ruined forests and agricultural areas along the West Coast. It does not take many centimetres before an otherwise fertile field loses its agricultural value (HANSEN et al., 2000).

Over 200 years the Danish State has therefore tried to implement measures which could limit the adverse effects of sand drift through various Acts - from the Sand Drift Decree of 1792 through the Sand Drift Act of 1867 to the Nature Conservation Act of 1992. Since 1935, for example, general coast conservation regulations have prohibited or governed construction on the beach and in all dunes, but with a maximum limit of 500 m from the innermost edge of the beach (WORM, 1997). The reason for these restrictions is the wish to protect the vegetation, which binds the dunes together. To this aspect is added that the vegetation could be subject to wear and tear by people's coming and going in the terrain. Such traffic will naturally be more intense, the denser the buildings are.
In turn, public access has been secured for walking and staying for short periods of time in the preserved stretches. This opportunity for stays and bathing can, however, is restricted in consideration of the danger of sand drift.

From about the middle of the 19th century and onwards, life-saving stations were established all along the coast (HANSEN et al., 2000). They were made necessary by the many shipwrecks along this coast, where the current is often very strong and ships were blown into the shore by harsh westerly winds. The life-saving stations were manned by local people who had a thorough knowledge of the sea.

6.7.2.1 Sea trade

Sea-based trade took place all over Denmark but the north-west Jutland was one of the main centres. While most of the trade was with Norway, ships also sailed to England, Germany, Belgium, and Copenhagen (FAERCH, K., 1992). The growth of towns like Lokken and Blokhus was based on sea trade, but such trade existed to some extent all along the coast. Traces of this trade can still be seen in Lokken and Blokhus, where several of the homes of sea-traders have been converted into hotels (HJORRING KOMMUNE, 1987). A few of the homes in the small coastal communities where trade was carried out are still intact. Most of the warehouses that stood on the shore have been pulled down, and, in some cases, the building materials have been used to build other buildings.
6.7.2.2 Tourism

During the first half of the 19th century, visitors began to come to the coastal communities. This "out of the way" corner of Denmark was far from Copenhagen in both distance and mentality. The first visitors were artists or writers: authors such as Hans Christian Andersen and Goldschmidt visited North Jutland in the middle of the 19th century, and their accounts of these journeys inspired people from the upper class to travel to the area. Goldschmidt published a diary describing his journey that became a kind of travel brochure of today. Those who were most famous in this connection were the artists who went to Skagen and depicted daily life there in their paintings, but, in fact, artists settled all along the coast (HANSEN et al, 2000).

When more railway lines were opened at the turn of the century, this made for, by the standards of that time, an explosive growth in the number of visitors to the seaside resorts. The number of tourists along the coasts has steadily grown and nowadays many tourists, in particular from Germany and the other Scandinavian countries, come to this area. The main attractions are still the wide, white, sandy beaches and the clean seawater (MOGENS, 2002-Personal interview).

6.7.2.3 Campsites

During the years between the wars, camping was not at all organised but the first proper campsite was already built in the early 1930s. Like the youth hostels, this provided a cheap form of accommodation and more campsites were set up as more and more working class people started to take holidays. At the beginning, these sites were often small and there were no facilities to speak of, but today many campsites are very well equipped (FAERCH, 1992). There are campsites all along the coast.

6.7.2.4 Urban occupation

The first summer houses were built at the turn of the XIX century. People from the towns were the first to build their own holiday homes: they came both from the local area and from Copenhagen. Many of the guests at the seaside hotels got to like the area so much that they bought plots of land on which to build their own summer houses. During the first decades of the 20th century, only a few summer houses were built along the coast and, where possible, these were built on top of the dunes, so their owners could enjoy a good view of the sea. Local people, on the other
hand, built their houses so they were sheltered from the prevailing westerly wind (FAERCH, 1992). In Lokken and Lonstrup some fine examples of these houses can still be seen.

During the 1920s and 1930s, summerhouses popped up all along the coast very haphazardly. Interested buyers were allowed to buy a plot from a farmer, for example, north of Lonstrup, "Rajen" near Hirtshals and "Prwrien" at Lokken, and in "Harerenden" (Figure 77). Summer houses in these areas were mainly small wooden houses, often with only one room. They were enlarged as needs arose and means allowed (HANSEN et al., 2000). These summer house areas still have a somewhat haphazard appearance. The many different types of architecture and the type of the buildings bear witness to an overall lack of planning. Most of these small cottages have now been replaced by more modern summerhouses (Figure 82).

Figure 82: Summer cottage area at Lonstrup (photo 24/11/2002)

Extensive summerhouse estates were first established in the 1960s. They came in the wake of general improvements in the standard of living which enabled a large sector of the population to afford their own summer houses. Prior to the vote taken in 1972 as to whether or not Denmark should join what was then the Common Market, there was a boom in the sale of summer houses and building plots as many Danes feared this would be their last chance to acquire such property before the market was opened to foreigners (FAERCH, 1992).

Many of these estates are very uniform in appearance with wooden houses painted in natural colours with turfs on the roof. There was a general feeling among the authorities that the houses would thus melt into the landscape and thereby be less visible.

The first coastal town planning laws containing restrictions regarding the size of plots and the location and appearance of the summer houses were passed as early as 1950 for land near the towns of Blokhus, Tomby and Tversted (HJORRING KOMMUNE, 1987).
Lonstrup has become a town of artistic craftsmen, since the beginning of 1900, and many work in their workshops all year. The town has an "authentic" atmosphere thanks to the early preservation efforts that protected the older houses. The aim here is peaceful family tourism and there are, therefore, no discotheques nor nightclubs. Almost all the shops stay open all year, and this attracts many people from the surrounding districts during the winter. In Lonstrup there is, therefore, less difference between summer and winter (FAERCH, 1992). In North Jutland, a private initiative was made first. Towards the end of the Second World War, a group of people from Hjørring suggested setting up a holiday village in an area north of Lonstrup (HIJØRRING KOMMUNEN, 1987). After the war, extra refugee camps were needed, and the group behind the holiday village project suggested building such a camp at Skallerup, so this could later be turned into a holiday village (HANS, 2002 – Personal Interview).

During the first half of the 20th century, several other large areas along the coast were preserved. For example, Fosdalven was preserved in 1902 in order to safeguard the scenic beauty of the landscape. Grenen at Skagen was preserved in 1940. These preservations were carried out in an effort to keep part of the coastline free of buildings to make it a recreational area for the use of the general public. Subsequently, the whole coastline today is characterised by both large and small colonies of summer houses and small urban communities - in combination with open countryside (OVESEN, 1994).

The unique countryside gives Skagen its special character. The artists who settled here spoke highly of the light where the sun is reflected both by the surrounding sea and the expanses of white sand and light-coloured vegetation. The Kattegat and Skagerrak meet at Grenen, and to the south off the town lies Northern Europe's largest drifting dune - Ribbjerg Mile which is slowly moving eastward (HASLOV, 1996).
Table 24: LONSTRUP- Characteristics and Chronology (FAERCH, 1992).

**LONSTRUP**

**Main Characteristics of Development**

Lonstrup is situated on a sand and clay cliff on the shores of the Skagerrak. As at Nt Lyngby, the sea removes chunks of the cliff here and over the years, the coastline has moved further inland.

* Maarup Church, which stands a little south of the town, was built in the 14th century. The church and the neighbouring village were in the centre of the parish, but drifting sand forced the inhabitants to move their houses and, as the graveyard was filled and the church itself stood so far from the "new" town, a new church was built in Lonstrup.

* Lonstrup became widely known after a fierce thunderstorm in August, 1877. During the following cloudburst, the stream that ran through the town burst its banks, and 7 houses and several outhouses were dragged away by the current. The catastrophe resulted in an influx of tourists who wanted to see this natural phenomenon.

* Considerable sea trading was carried out in Lonstrup, and the inhabitants also lived by fishing. As in Blokhus and Lokken, very large buildings were built in Lonstrup from which sea trading was conducted. Sea trading ceased at the end of the 19th century, and industrial fishing ended about 1970 when the fishing grounds near the town were plagued by the death of many fish.

* Lonstrup rapidly became a fashionable seaside town, and at the beginning of the 20th century, the town was the largest bathing resort in North Jutland with about 800 holidaymakers.

* The inn, Lonstrup Kro was converted into a hotel, and at the turn of the 19th century, more hotels and boarding houses appeared, and many private families rented out their homes.

* Up to and adjust after the First World War, characteristic villas were built by the well-to-do on the hills surrounding the town: several of the builders were the so-called "new rich".

* In the 1960s, extensive summer house development started.

* In 1974, a preservation plan was agreed upon for Lonstrup as the local inhabitants with the help of municipal authorities wanted to gain more control over the growth of tourism. The preservation plan has since been revised several times.

This has resulted in the town becoming attractive, both to live in all year, and from the point of view of tourism.

**Chronology**

- 1877: A natural catastrophe made Lonstrup famous.
- 1880s: The inn was converted into a seaside hotel, Vrenstedst Afloldshotel opened and several fishermen’s wives opened boarding houses.
- 1913: The railway opened.
- 1920s: The summer house area, Harerenden, was developed (unplanned area small summer cottages in the dunes north of Lonstrup - Most of the houses were built on leased land. Over the years, several of the summer houses have fallen into the sea).
- 1928: A new church opened to replace Maarup Church.
- 1949: The holiday centre, Feriebyen Skallerup Klit opened.
- 1957: The Tourist Association opened the campsite, Mollebakkens Camping.
- 1974: A preservation plan for Lonstrup was agreed upon.
- 1981-82: Coastal Protection Plan was made by Coastal Authority after a big storm in 81 winter took away many meters of land at Lonstrup coast.
- 1990 and 1993: Local plans were adopted for the town of Lonstrup.
Table 25: GAMMEL SKAGEN / SKAGEN- Characteristics and Chronology (HANSEN et al, 2000).

<table>
<thead>
<tr>
<th><strong>GAMMEL SKAGEN / SKAGEN</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Characteristics of Development</strong></td>
</tr>
</tbody>
</table>

**GARNMEL SKAGEN**-

The town was presumably established in the 12th century.

* The area was hit by drifting sand in the 16th century, and most of the houses were either buried under the sand or washed away by the flood tides and floods that also occurred at that time.

* Throughout the 20th century, summer visitors have bought year-round houses as summer houses and prices are now extremely high.

The buildings at Gammel Skagen are close together and both old and new houses have the characteristic "Skagen look", that is, yellow facades, red-tiled roofs with white lines on the outer edges and along the ridge of the roof. Nowadays, the town is almost solely based on tourism as nearly all the buildings are hotels, many of which have been converted into timeshare flats, restaurants and holiday homes and one grocer's shop.

**SKAGEN**

Development

* The town Skagen traces its roots back to the 14th century. At that time, the town was near St. Laurentii Church which was built at the end of the 14th century. Today this church is known as "The church buried in sand". The town received its municipal charter in 1423 and, at that time, was the largest town in the district of Vendsyssel with 4,000 inhabitants. They lived by fishing and farming, as well as by trade and the income from numerous shipwrecks.

* At the end of the 16th century, the town suffered several catastrophes. Drifting sand, flood tides and floods forced many of the inhabitants to flee, and many fishermen drowned during heavy storms. Drifting sand was such a serious problem that the church was closed in 1795. By that time the population was down to about 600 persons living in extreme poverty.

* The few remaining inhabitants moved their houses and farms to the site of the present town of Skagen. No farmland remained, so the population lived mainly by fishing. Fishing gradually transformed the town into one of the most important fishing towns in Denmark, and, in 1907, a harbour was built there.

* By the end of the 1800s, Skagen had already become a fashionable seaside resort. The town had been "discovered" by the young artists.

* The opening of the railway in 1890 added to the flow of tourists.

* During the course of the 20th century, tourism grew, and about 1 million people currently visit Skagen every year, mostly day trippers who visit the spit, Grenen (the place where the two oceans meet).

* Large summer house areas were parcelled out in the second half of the 20 century in Skagen, and today there are at least 1 500 in the municipality.

* Many of the houses in Skagen's old all-year areas have been bought up as summer residences.
6.7.3. Hydrodynamics and Natural Conditions

There is a significant littoral drift along the coast, which in addition to being deposited on Skagens Odde, is also the reason why the beaches in the south are relatively narrow. The southern beaches are comprised of a mixture of sand and pebbles, whereas the beaches become wider and the sand finer the further north one travels. The dunes behind the beaches have been formed by flying sand blown there by the strong winds (DCA, 2000). The dunes vary in size and width; at some places there is only one row of dunes, whilst at others there are several.

Table 26: Hydrodynamic Conditions at the Skagerrak Sea Coast (source: KYSTINSPEKTORATET, 1981)

<table>
<thead>
<tr>
<th>Hydrodynamic Conditions</th>
<th>North sea Coast / Skagerrak Sea – North Jylland Lonstrup</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Astrological Tides</strong></td>
<td>tide: 0.6 m</td>
</tr>
<tr>
<td></td>
<td>+1.20 m ---- 1 time/10 years</td>
</tr>
<tr>
<td></td>
<td>+0.76 m ---- 10 times/year</td>
</tr>
<tr>
<td><strong>Meteorological Tides</strong></td>
<td>Storm tide: 1.5 m</td>
</tr>
<tr>
<td><strong>Wind</strong></td>
<td>Most frequent wind is west (W) and southwest (SW)</td>
</tr>
<tr>
<td>(Figure 83)</td>
<td>Most strong winds are from west (W) and Northwest (NW)</td>
</tr>
<tr>
<td><strong>Wave regime</strong></td>
<td>Wave heights:</td>
</tr>
<tr>
<td>(Figure 83)</td>
<td>4.1 m ---- 1 time/10 years</td>
</tr>
<tr>
<td></td>
<td>3.1 m ---- 10 times/year</td>
</tr>
<tr>
<td><strong>Sediment Transport</strong></td>
<td>Sediment dynamic is oriented from North to South with values of 900,000 m³/y</td>
</tr>
</tbody>
</table>
Erosion Rates

Average erosion rates: 4.6 m/y
(example: Marup Church 2 km from the sea in 1790)

Main Causes of erosion:
- Sea action and
- Intense Storm events
- Coastal protection structures

Figure 84 can give an overview of the coastline evolution for the area of Lonstrup between the 1787 and 1981. It can be noted the progressive retreat trend which is enhanced by winter storm events. The polemic case of Marup Church was located 2 km from the sea in 1790 and at present days, is 2 meters from the cliff at eminent risk of collapsing as well as several German bunkers from the II World war (Figure 85). Several cultural protection movements were created at local level and regional in order to instigate the efficiency of coastal protection on this particularly area.

![Image: Wind and wave regime for Lonstrup area (from: KYSTINSPEK TORATET, 1981)]
Figure 84: Coastline evolution for Lonstrup (adapted from: KYSTINSPEKTORATET, 1981)

Figure 85: German World War II bunker on the North coast undermined by the retreating sea (photo 22.11.2002)
6.7.4 Coastal Protection Measures

6.7.4.1 Coastal Protection Works

Since 1982, the Coastal Authority has been the consultant of Skagen Municipality with respect to coastal protection. The efficiency of coastal protection is evaluated on an on-going basis but in the opinion of the municipality and the Coastal Authority there is currently a need for a more thorough evaluation and re-evaluation of objectives and strategies (PIONTKOWITZ, 2003).

Before that, in 1980-81 the Coastal Authority prepared coastal technological reports for Skagen and Lonstrup areas. These reports formed the basis of a number of political negotiations. It was agreed that the government in the future should make a contribution of up to 50 per cent for coastal protection works along the West Coast (DCA, 2000). However, it was a precondition that the county and municipalities would make the same contribution as the government, and that the construction primarily protected all-year residences (MOGENS, 2002- personal interview).

Figure 86: Coastal protection works at Lonstrup and Skagen – The Skagerrak Sea (photo 23.11.2002)

From 1982 the government has participated in the restoration and extension of coastal protection works from G1, Skagen over Grenen (the place where the two oceans meet) to Damstederne. The projects have essentially concerned transformation of the old T-groynes into breakwaters (Figure 86), high tide protection through construction of small dunes slope protection measures and annual coastal nourishment of 60 000 m3 (DCA, 2000).
Based on 17 years of experience and the fact that a more comprehensive natural perspective increases the pressure for development of an alternative and financially competitive nourishment method, a new coastal technological survey was conducted in 1999. The survey describes alternative strategies for future coastal protection (DCA, 2001).

The landing in Lonstrup washed away completely during the gale in 1981. The project recommended by DCA- Ministry of Transport had recommended was carried out with government subsidies in 1982-83 (KYSTINSPEKTORATET, 1981).

Figure 87: Aerial view of sea action at Lonstrup and summer cottage areas (in: KYSTINSPEKTORATET, 1981)

Ten detached breakwaters (Figure 88), two short groynes around the landing and thorough slope protection measures were constructed along the 1100 long stretch. In addition, 100 000 m3 of sand was used for coastal nourishment. Each year 25 000 m3 of coastal nourishment sand (MOGENS, 2002) is placed along the stretch for maintenance purposes.
According to the DCA-Ministry of Transport report (DCA, 2000), several analyses made in the Skagen area have shown that the current initiatives have contributed to a stabilisation of the Skagerrak coast. The groynes and detached breakwaters, along the stretch at GI. Skagen (Figure 89) have maintained the coastline. A calculation of the development over the next 25 years shows that the position of the coastline on the protected stretches will broadly be stable provided that initiatives are intensified by approximately 10% during the next 25 years. It is expected that the coast at GI. Skagen will be put under pressure within the next 5-10 years due to cyclic variations.

A draft for more rigorous nature protection provisions has been made, the consequence of which may be that in future nourishment sand must be borrowed on the Skagen Reef and pumped on shore. The financial consequences of various objectives and scenarios have been calculated.
On the basis of the report, the local council of Skagen decided to enclavour that coastal protection in general should be effected according to the same principles as earlier. The local council supports an attempt to pump a large volume of sand from the sea onto the Skagerrak coast and it supports increased efforts to obtain a more environmentally sound design of fixed structures. The pumping in of large sand volumes is planned to take place during all this current year, 2003 (MOGENS, 2002).

The present effort on the Skagerrak coast has stabilised the coastline along the entire stretch. The groynes at G1. Skagen have been able to maintain the coastline, while it could be seen a coastal retreat along the unprotected neighbouring stretches. The coast at G1. Skagen is characterised by cyclic variations with a period of approximately 20 years which means that the coast must be expected to enter a more unfavourable development process within a few years unless increased efforts are made.

On the basis of the sediment budget a forward projection of 25 years of the expected position of the coastline has been made. The forward projection shows that the position of the coastline
along the protected stretches on the Skagerrak coast will broadly be stable provided that coastal protection efforts are increased by approximately 10% during the 25 years.

Concerning the Skagerrak coast a meeting was held on 10 October 2000 with participation of representatives from the Coastal Authority, Skagen Municipality, the County of Nordjylland and the State Forest District of Nordjylland and the following two proposals were selected for further discussion: 1) unchanged efforts compared with today and 2) removal of some breakwaters and building of a long groyne by the lighthouse Gra Fyr. Calculations of the expenses in connection with nourishment from the landward side and from the seaward side have been made for both proposals.

6.7.4.2 Coastal Protection By Pressure Equalisation Modules

The SIC - Skagen Innovation Centre has invented an environmentally friendly coastal protection system, based on pressure equalisation modules and fascines which was patented world-wide in 1998.

A long-term and comprehensive test of the efficiency has been carried out on the Northwest coast of Denmark. Furthermore, a twelve-month scientific research programme was performed in 1999.

Pressure equalisation modules build up a wide balanced coastal profile. This can lead to waves to loose their destructive energy while running uphill during high tide situations. Thus, the erosion of the coast profile is mitigated even in spring tide situations compounded by effects of hurricanes.

The next aerial photos (Figure 91) of the groynes at Gammel Skagen, on the Danish west coast, illustrate the action of the Pressure equalisation modules. The later aerial photo from 1999 illustrates that pressure equalisation modules can completely cover by sand the conventional groynes from 1950.
During the tests as carried out in Skagen it was recognised that the groundwater table was 2 metres above the sea level in a distance of only 70 metres from the coastline. Due to the gravity there is a considerable groundwater pressure from the land side. Thus, it can be illustrated that the sea water in the swash zone percolates through the sand and runs back into the sea "on top" of the groundwater discharge area (Figure 92). This promote the erosion process compounded with the back run of the sea water in the swash zone.

Pressure equalisation modules are vertical filters that are placed in a matrix along the coastline. The filters equalise the pressure of the ground water basin and an increased circulation of seawater in the coastal profile will take place. This will promote sedimentation of materials on the coastal profile. The pressure equalization modules increase the drop of the water level in the coastal profile in the period from high tide to low tide. Thus, the beach will be more effectively drained of water.
When the water level is low on the coast during the period from low tide to high tide, the water circulation in the swash zone increases, which again increases the depositing of materials on the foreshore, thereby building up the beach from the sediments transported along the coast. Over time the new materials in the coastal profile are increasingly coarse, due to a higher speed of the underlying water in the coast profile.

The result of these pressure equalization modules inside a coast profile is a strong and very wide equilibrium profile.

![Image](image.jpg)

Figure 93: SIC – System at Skagen Test area – Visible beach enlargement; Paul Jacobs, Project coordinator (photo: 22.11.2002)

To build up the dunes on the beach, the SIC system is using fascines techniques (figure 94) to collect the sand blown along the beach by the wind.

![Image](image.jpg)

Figure 94: Typical example showing the use of fascines at skagen (Photo- 22.11.2002)

The field research was performed along a coastline 8 km long S.W of Gammel Skagen. Before the pressure equalising plant was implemented, a baseline measurement of the selected coastline was made with laser equipment. The distance between each of the stations/ equalisation modules is 100 metres. The total distance from station 113200 to 114250 is 1050 metres. Adjacent flank areas, without pressure equalisation modules, on either side of the test area, were monitored with the same procedures as the test area.
All measurements during the field research programme were recorded and controlled by a reputed independent Danish consulting company.

Reference area I was located 4.0 km SW of the test area, ranging from station 117000 to station 118000. The objective of this reference area was to compare the development during the research period of the coastal profile in a nearby site without pressure equalisation modules (Figure 95).

Reference area II was located 7.0 km SW of the test area, ranging from station 120131 to station 121134. The objective of this reference area was to compare development of the coastal profile in a nearby site without pressure equalisation modules during the research period.

![Figure 95: Test area and measurements stations location (In: SIC, 2002)](image)

The measurements were carried out between January and October of 1999 and January 2000, and comprise the test area with pressure equalisation modules as well as the nearby reference areas, each 1 kilometre long. The following results presented on Tables 27 and 28 and Diagrams were observed.

<table>
<thead>
<tr>
<th>Site</th>
<th>Results</th>
<th>Quantity (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test area</td>
<td>accumulation</td>
<td>9350.00</td>
</tr>
<tr>
<td>Reference area I</td>
<td>erosion</td>
<td>2363</td>
</tr>
<tr>
<td>Reference area II</td>
<td>accumulation</td>
<td>3035</td>
</tr>
</tbody>
</table>
Table 28: Gain and loss of coastline immediately after the hurricanes (in: SIC, 2002)

<table>
<thead>
<tr>
<th>Site</th>
<th>Results</th>
<th>Quantity (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test area</td>
<td>Remaining</td>
<td>6543 *</td>
</tr>
<tr>
<td>Reference area I</td>
<td>Loss / erosion</td>
<td>10295 *</td>
</tr>
<tr>
<td>Reference area II</td>
<td>Loss / erosion</td>
<td>3446 *</td>
</tr>
</tbody>
</table>

* (The observed measurements from 27th January 1999 are used as base line values).

Figure 96: Diagram showing the current situation after twelve months research (In: SIC, 2002)

Figure 97: Diagram of comparison of SIC System and conventional dredging over the period of May 1999 and January 2000 (In SIC, 2002)
6.7.5 Main Aspects For Conclusion

The west coast of the County of North Jutland faces the North Sea by the Skagerrak Sea, (the Skagerrak, creates a shallow transition between the oceanic North Sea and the Kattegat continental Baltic Sea).

The West Coast not only suffers coastal erosion but also has a continuous problem with sand drift in areas along the coast and often further inland. Through the ages sand drift has ruined forests and agricultural areas along this West Coast. It does not take many centimetres before an otherwise fertile field loses its agricultural value.

At the end of the 16th century, the town suffered several catastrophes. Drifting sand, flood tides and floods forced many of the inhabitants to move and retreat. The few remaining inhabitants moved their houses and farms to the site of the present town of Skagen.

Lonstrup and Skagen have become towns of artistic craftsmen, since the beginning of 1900, and during the 1920s and 1930s, summer houses popped up all along the adjacent coast.

Sediment dynamic is oriented from North to South with values of 900,000 m³/y. The dunes behind the beaches have been formed by flying sand blown there by the strong winds (DCA, 2000). The hydrodynamic conditions on the coast are mainly characterized by storm tide of 1.5 m, most frequent wind of west (W) and southwest (SW) direction and the most strong winds are from west (W) and northwest (NW), the predominant wave heights reach values of 3.1 m.

Since 1982, the Coastal Authority has been the consultant of Skagen Municipality with respect to coastal protection.

Based on a mutual agreement it was decided that the government may contribute of up to 50 per cent for coastal protection works along the Coast (DCA, 2000). However, it was a precondition that the county and municipalities would make the same contribution as the government, and that the construction primarily protected all-year residences at Lonstrup and Skagen.

The average erosion rates were 4.6 m/y and the example of Marup Church 2 km from the sea in 1790 can highlight the coastline retreat situation.

The main causes for erosion are defined as the Sea action and the intense storm events and also the Coastal protection structures.

The coastal protection works at Skagen have essentially concerned transformation of the old T-groynes into breakwaters, high tide protection through construction of small dunes slope protection measures and annual coastal nourishment of 60,000 m³ (DCA, 2000).

Ten breakwaters, two short groynes around the landing and thorough slope protection measures were constructed along the 1100 long stretch at Lonstrup. In addition, 100,000 m³ of sand was
used for coastal nourishment. Each year 25 000 m³ of coastal nourishment sand is placed along the stretch for maintenance purposes.

The present effort on the Skagerrak coast has stabilised the coastline along the entire stretch. The groynes at G1. Skagen have been able to maintain the coastline, while it could be seen a coastal retreat along the unprotected neighbouring stretches. The coast at G1. Skagen is characterised by cyclic variations with a period of approximately 20 years which means that the coast must be expected to enter a more unfavourable development process within a few years unless increased efforts are made.

Some new initiatives have been taken in order to increase the beach and lower the costs to hold the coastline. A long-term and comprehensive test of the coastal protection system, based on pressure equalisation modules and fascines (patented world-wide in 1998), has been carried out on the Northwest coast. Furthermore, a twelve-month scientific research programme was performed in 1999, showing relative impressive results, concerning the hydrodynamic conditions of this specific case study.
CHAPTER 7 –
COMPARATIVE PERSPECTIVES
CHAPTER 7 - COMPARATIVE PERSPECTIVES

7.1. Introduction

The established cooperation during this MSc thesis provided the opportunity of comparing the Portuguese and the Danish context at two levels. Firstly, comparison was triggered at the institutional level. At this level, different coastal planning background and future trends were compared, focusing on the different perspectives, from which coastal realities are addressed in both countries within cultural, social and institutional contexts.

Secondly, comparison was triggered at the technical level, considering the different conceptual and methodological approach to coastal risk protection / erosion control actions focusing on the case studies specificity -hydrodynamics and physical coastal realities.

7.2 Coastal Planning approach Portugal and Denmark

Denmark as well as Portugal, has a long tradition for the utilization of the coastal zone. Together with numerous sectorial regulations (sand drift and dunes as far back as 1539, coastal conservation, nature conservation, coastal fishery, coastal protection and a number of specific construction acts) the coastal regulations in Denmark, are now an integral part of regional planning act. This was due to European Community directives and the increasing recreational pressure to the Danish coasts. Since 1937 a 100-m protection zone has been stipulated in the Nature Protection Act, and in this zone it is prohibited to alter the stale of the beaches and other stretches of the coast (WORM, 1997).

The Planning Act of 1992, which was revised in 1994, enforces the regulation of interests in the coastal zone by the establishment of a 3 km "Coastal Proximity Zone" and a 300 m "Beach Line Protection Zone" as basic planning tools (Figure 98). The Act specifies regulations on land use within this zone, which differ in urban, summer cottage and rural areas, and must be implemented by county and municipal councils in their plans. This approach does not involve separate coastal planning, but is integrated into the ordinary planning process. Environmental impact assessment and public participation are also key elements in the Planning Act.

On the urban waterfront the protection zone may be 100 m or less. By the above mentioned revision of the Planning Act and the Nature Protection Act, the Danish Government took the opportunity to emphasize once again that it is of national concern to ensure that the open coasts will remain as an important natural and landscape resource, and several planning regulations
necessary to face the growing pressures on the coastal areas were carefully stipulated (JAPPE, 1996).

On the other hand, Portugal is one of the few European countries that developed legislation regarding the ownership of the coast in the late 19th century, introducing the concept of Public Maritime Domain (PMD), which limits the property of land in the coastal zone to the State and restricts its use to specific permits. The primary consequences of this law is that lengthy sections of the coast have been spared from occupation for a long time but in reverse, the State is responsible for supplying and paying for protection if erosion affects or damages property landward of that zone. Since the 1950s increasing pressure for tourist development of the coast lead to the illegal appropriation of several land parcels from the PMD, and only in the late 1970s this trend has been opposed through a number of laws aiming to protect the coast from uncontrolled and risk occupation. At present, the coastal area is overlapped by the protection perimeter of the National Ecological Reserve Law (Reserva Ecológica Nacional - law 93/90, 19 March; law 213/92, 12 October; law 79/95, 20 April), which defines the areas crucial to maintain the ecological stability and sustainable use of natural resources - e.g., beaches, dunes, wetlands, nearshore - and by the Public Water Domain law (Dominio Público Hídrico -Law 468/71, 5 November), which includes the Portuguese coast within a protected strip ranging between 50 and 500m width (figure 99); in addition, all restrictions approved within the scope of the European Union also apply to the Portuguese coast.

Concerning the Coastal Zone Management Plans, Coastal Zone, Decree-Law 309/93 (2nd September), means the littoral band comprised between the bathymetry -30 m and an inland
protection zone with a maximum width of 500 m measured since the sea boundary limit line of the maximum spring tide neap.

Figure 99 - Planning and Protection Scheme – Portugal (in: IHRH, 2003)

In Portugal attention is centred on how coastal plans may be implemented to be consistent with the general coastal management programme. The coastal plan is considered as the only component of the coastal management programme which, in the present political and social conditions, may be implemented and oriented to avoid coastal conflict situations.

Over the last decades and up to present days the management of the Portuguese coastal zone was conducted within a complex juridical and institutional framework, involving different agents and resulting in a dilution of responsibilities (VELOSO GOMES, TAVEIRA PINTO, 2001).

Overall and specific topics will be described on Table 27, in order to highlight some aspects of present coastal planning in Portugal and Denmark

Table 29: Main characteristics of Coastal Planning in Portugal and Denmark (in IHRH, 2003 and MILJOMINISTERIET (2001)

<table>
<thead>
<tr>
<th>Coastal Planning</th>
<th>Denmark</th>
<th>Portugal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment and Planning</td>
<td>The Ministry of Environment and Energy, which was established in 1994, is the national government department responsible for environmental and planning policy. It is supported by specialist agencies, including the Danish Environmental Protection Agency. Regional planning is undertaken by the counties, and the municipalities carry out local planning.</td>
<td>Environmental policy in Portugal is administered nationally by the Ministry of Towns, Environment and Planning. Planning is primarily a responsibility of the municipalities. There are several laws that relate specifically to the coast.</td>
</tr>
</tbody>
</table>
7.3 Atlantic and North Sea Key Subjects

As a starting point, there are two different basic conditions, which have influenced the natures of the approach taken in Denmark and Portugal. Those conditions relate to the specific hydrodynamic characteristics affecting the coastal areas as represented on Tables 30 and 31. The second condition is related with the practice and experiences in the field of coastal engineering and protection.
<table>
<thead>
<tr>
<th>Hydrodynamic Conditions</th>
<th>NW Atlantic Portuguese Coast</th>
<th>Case-Study 1: North Sea Danish Coast – Thyboron/Torsminde</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Astrological Tides</strong></td>
<td>Tides are of the semidiurnal type, reaching a range of 2 to 4 m for spring tides.</td>
<td>Astronomical tide is very small; max 0.3 m</td>
</tr>
<tr>
<td>High tide Max: (+3.88 m) ZH</td>
<td>Low tide Min: (+0.45 m) ZH</td>
<td>Extreme high water levels caused by wind set-up with westerly winds may reach 3 m.</td>
</tr>
<tr>
<td><strong>Meteorological Tides</strong></td>
<td>Max: +0.50 m Min: +0.20 m</td>
<td>Average 1.2 m</td>
</tr>
<tr>
<td><strong>Tidal Currents</strong></td>
<td>Only important in the surrounding zone of the Ria de Aveiro inlet</td>
<td>Important factor at Thyboron channel</td>
</tr>
<tr>
<td><strong>Wind</strong></td>
<td>Local wind climate: most frequent wind is North (N) and Northwest (NW). Most strong winds are from Southwest (SW) and South (S).</td>
<td>Most frequent winds are from West (W) and Northwest (NW). Most strong winds are from West (W).</td>
</tr>
<tr>
<td><strong>Wave regime</strong></td>
<td>The wave climate has medium significant wave heights from 2 to 3 m, with periods ranging from 8 to 12 s and storm significant wave heights exceeding 8 m (maximum wave heights up to 1.7 times the significant wave heights), with periods reaching 16 to 18 s.</td>
<td>Significant wave height 2.5 m with periods from 6-9 NW direction. Storm 7.5 m.</td>
</tr>
<tr>
<td><strong>Littoral drift and Sediment Transport</strong></td>
<td>The potential littoral drift is of above 1 500 000 m³ a year. The littoral drift currents act mainly in the North-South direction.</td>
<td>Overall sediment dynamic is oriented from North to South and it is around values of 600 000-1000 000 m³/year. Dynamic high energetic coastal producing some of the highest sediment transport rates in the world.</td>
</tr>
<tr>
<td><strong>Erosion Rates</strong></td>
<td>The coast is of a sandy nature, average erosion rates of the order 10 m/yr were calculated.</td>
<td>Sandy beaches where dunes protect the low hinterland against flooding. Erosion rate of 2 m/yr some places there is large average annual coastal erosion, exceeding 10 meters. (Now is mitigate by yearly nourishment: 0.5 m/yr) After breach Thyboron barrier (1862) coastal retreat of more 100m/year</td>
</tr>
<tr>
<td><strong>Main Causes of erosion</strong></td>
<td>Sea action Weakening of the river basin sediment sources and river sediment transport, the mean sea-level rise, the human occupation of waterfronts and dune destruction.</td>
<td>Sea action Storm surge events Down drift erosion caused by harbour breakwaters and large groyne groups - 98 groyes The northernmost 340 km has 6 ports</td>
</tr>
</tbody>
</table>
### Table 31 – Hydrodynamic Conditions (Lonstrup information based from Hirtshals station (FRYDENDAHL, 1991))

<table>
<thead>
<tr>
<th>Hydrodynamic Conditions</th>
<th>NW Atlantic Portuguese Coast</th>
<th>Case-Study 2: Skagerrak – Lonstrup/Skagen</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Astrological Tides</strong></td>
<td>Tides are of the semidiurnal type, reaching a range of 2 to 4 m for spring tides. High tide Max: (+3,88 m) ZH Low tide Min: (+0,45 m) ZH</td>
<td>Tide: 0,6 m +1,20 m – 1 time/10 years +0,76 m – 10 times/year</td>
</tr>
<tr>
<td><strong>Meteorological Tides</strong></td>
<td>Meteorological tides are not significant outside enclosed waterbodies but they can contribute to increase or enhance consequence when occurring simultaneously with spring astronomical tides or severe storms. max: +1,50 m min: +0,20 m</td>
<td>Storm tide: 2,5 m</td>
</tr>
<tr>
<td><strong>Tidal Currents</strong></td>
<td>Only important in the surrounding zone of the Ria de Aveiro inlet</td>
<td>Not available</td>
</tr>
<tr>
<td><strong>Wind</strong></td>
<td>Local wind climate: most frequent wind is North (N) and Northwest (NW). Most strong winds are from southwest (SW) and South (S).</td>
<td>Most frequent wind is west (W) and Southwest (SW). Most strong winds are from West (W) and Northwest (NW).</td>
</tr>
<tr>
<td><strong>Wave regime</strong></td>
<td>It is the main modeller agent of the beach. The wave climate has medium significant wave heights from 2 to 3 m, with periods ranging from 8 to 12 s and storm significant wave heights exceeding 8 m (maximum wave heights up to 1.7 times the significant wave heights), with periods reaching 16 to 18 s.</td>
<td>Wave heights: 4,1 m – 1 time/10 years 3,1 m – 10 times/year</td>
</tr>
<tr>
<td><strong>Littoral drift and Sediment Transport</strong></td>
<td>The potential littoral drift is of above 500 000 m3 a year. The littoral drift currents act mainly in the North-South direction although some singular events of South drift currents can be found.</td>
<td>Sediment dynamic is oriented from South to North with values of 900 000 m3/y</td>
</tr>
<tr>
<td><strong>Erosion Rates</strong></td>
<td>The coast is of a sandy nature; average erosion rates of the order 10 m/yr were calculated.</td>
<td>Average erosion rates: 4,6 m/y Erosion from 4 -14 m before 1981 (Example: Marup Church 2 km from the sea in 1790)</td>
</tr>
<tr>
<td><strong>Main Causes of erosion</strong></td>
<td>Sea action Weakening of the river basin sediment sources and river sediment transport, the mean sea-level rise, the human occupation of waterfronts and dune destruction.</td>
<td>Sea action Storm surge events</td>
</tr>
</tbody>
</table>

In Denmark, there is not a basic coastline defined by law to establish the safety zone and risk zones. The actual policy for safety assessment and the erosion control policy are established as an agreement between local authorities and the government based on Danish Coastal Authority...
recommendations. There are a number of national regulations concerning coastal protection because the danger to property and human life is relatively high in many stretches at west North sea coast were land is retreating due to erosion, exposing several dwellings and summer cottage areas to sea action. The coast is strongly armoured with extended groynes fields, detached breakwaters, and full beach/shoreface nourishment, among other coastal protection operations. The costs of coastal protection on the North Sea coast are shared between the government and the local authorities. The government typically pays 50 to 70%. In some cases the government pays 100%.

However, on the Baltic Sea coasts, coastal protection is regulated by an act passed in 1988. According to this act, the counties are responsible for the administration of coastal protection projects. Since the counties do not have any coastal engineering expertise, the Coastal Authority provides assistance at the planning stage and the consultants provide assistance at the project stage. The general practise is that there is no public funding of coastal protection in the Baltic Sea area where the individual landowner has to bear all the costs.

7.4. Rupture Scenarios - Maintenance of a Sand-Spit System

An appropriate coastal defence is a prerequisite for almost every socio-economic activity in vulnerable lowlands coastal areas. In Denmark as well in Portugal properties at coastal lowlands are protected from sea action erosion and flooding. If a rupture scenario happens many urban areas and agricultural fields would be damaged, with strong economic and social repercussions.
In order to avoid/mitigate those property risk situations within unstable coastal stretches as sand barrier/sand spit, national protection policies and strategies for coastal risk management have been defined and improved in both countries.

7.4.1 Coastal Defence Policy

In Portugal and according to the Coastal Zone Management Plan (POOC) Ovar - Marinha Grande, the adopted coastal protection policy was (see also Chapter 4):

- To hold the line for coastal urban areas;
- To manage the realignment for not urbanized areas and specially, down drift of the groins, in order to establish a new “line of equilibrium”.

Coastal defence interventions were defined as a group of actions considered indispensable, for the maintenance of the actual uses and activities in this coastal zone.

The proposed approach for management and development includes the following line of actions:

1. Coastal defence at urban areas;
2. Mitigation of the dune cordon rupture risk;
3. Coastal erosion risk evaluation and control;

The interventions related with the coastal defences are subdivided in:

- Maintenance of sea work defence - maintain the sea work defence foreseen in the POOC;
- Dune systems rebuilding - Embrace a group of complementary works, previously referred, and that have as main objective to reduce the level of overtopping;
- Other proposed defence works - Embrace a group of temporary/experimental interventions to avoid risk situations like rupture/flooding. In this situation there are three works foreseen, being two of them located on the pilot study area in the south of Vagueira beach.

In Denmark a Coastal Policy Program, was defined and the main the objectives were:

- To restore and enhance the storm flood protection of the area;
- To control coastal erosion reducing it to acceptable and agreed-upon limits;
- To enhance technical benefits and environment values by introducing beach nourishment on a larger scale.

For the Danish North Sea coast the goals for the coastal protection are in order of priority:

- To maintain a safety level against flooding of a 100 years return period as a minimum. At Thyboron the safety level is 1000 years;
- To stop erosion where towns are located close to the beach;
- To reduce erosion on parts of the coast where erosion in the near future would reduce the safety against flooding to less than 100 years.

The goals mean that the coastal retreat is stopped along the unstable coastal stretch where lowlands from urban land-use are threatened by flooding as a result of rupture (figure 68). For the rest of the stretch the natural retreat is accepted, either because it is very small or because there is no associated risk (no urban and human occupation).
On the other hand, the Coast Protection Act is the main legislation regulating all coastal defence measures. This law is mainly a procedural code, stating the procedure that the relevant authorities are obliged to follow when an application or public initiative for building or altering coastal defence constructions comes up. This legislation deals with coastal erosion, and is implemented by the Danish Coastal Authority (DCA), under the supervision of the Ministry of Transport.

Coastal erosion management carried out according to the Coast Protection Act tended in the past to be executed to the cost of the landscape, nature aspects and the coastal profile. However, this new Danish Coast Protection Act of 1988 has given the county authorities significant influence in the decision process relating to coastal-erosion management issues, and has changed the approach from property protection to a more holistic method that emphasizes environmental values, concern for the landscape, and changes in land-use patterns (See also chapter 6).

The overall principle of the National Coast Protection Act is that the responsibility for establishing and maintaining protection measures lies with the persons who profit. On the other hand, landowners do not have an immediate right to protect property. Each new measure has to be considered appropriate by several authorities.

7.4.2 Technical Measures in Response to Coastal Erosion /Flooding

In Portugal successive emergency interventions have been taken to avoid rupture of the sand-spit, and some protection proposals are already defined on the Coastal Plan POOC (retreat dune cordon with hard nucleus). However some difficulties are expected specially concerning the legal matters and possible negotiations with the landowners at the dune implementation area. Meanwhile coastline artificialisation seems to be the general trend.

In Denmark, erosion control is done with a combination of nourishment and low detached breakwaters, building new dunes and by protecting the dune foot with a revetment, which has reduced the retreat rate at the case study 2 (Lonstrup and Skagen).

In general there seems to be a trend towards more emphasis on the regulation of use and protection of the Danish coasts. For instance a special 3 km broad planning zone has been imposed to the land territory and a 100m as a buffer zone.

A greater part of applications for defence measures to protect uninhabited areas is now rejected because it is considered important to protect the natural coastal processes. At the same time it is considered very important to maintain and if necessary improve the protection of the inhabitants in lowland and unstable areas threatened by eroding or flooding – Sand-spits.
The use of other hard constructions along the west coast is getting rare in favour of sand nourishment, used to fulfil the goals and aims been integrated with the coastal structures built over the years (mix solution).

However there is a common awareness that technical erosion/flood control measures cannot fully safeguard coastal zones. The requirement for new innovative strategies to minimize the risk by integration of coastal risk management on national policies and strategic planning tools; of methods to improve public perception of, and participation in coastal risk management; improving approaches and indicators to establish the performance of risk management measures.

In both countries there is a risk for rupture if mitigation measures would not have been taken so far. On the case study 1- Thyboron/ Thorsminde, a large area behind the sand barrier formation is protected from flooding. This situation can be related with the southern Aveiro sand-spit (Figure 100).

By the analysis of the two Danish case studies it was possible to recognize different technical solutions concerning the severe rates of coastline retreat. However, some of those solutions, are not applicable to the wave energetic coast of NW of Portugal. This is the case of the Skagen SIC pilot project related with the drainage of beach by pressure Equalization Modules and the detached breakwaters at Lonstrup complemented with yearly sand nourishment. Those coastal erosion measures present visible positive effects and results, creating small tombolos and improving considerable sediment retention on the beach area.

Nevertheless, the wave energy on the Skarregat Sea is completely different as it can be found at the West North Sea coast and at the NW Atlantic coast (Table 30 and Table 31), where some hard protection structures such as groynes were partially destroyed or unplaced while periods of 10 meters waves height.

The consequences in terms of rupture scenario are very similar between the case-study 1 and the Portuguese study area (Figure 101 to 103), with impacts on large flooding areas. Further, as already stated, tourism, urban settlements and agriculture fields, are the three main significant uses in the NW Portuguese coast, as well as in the West North sea coast, with direct interrelations with coastal defense and nature conservation.
Figure 101: Aerial view of Denmark Case-study 1: urban areas at risk from sand-spit rupture Harboøre and Thyborøn (photo DCA, 2000)

Figure 102: Aerial view of Denmark Case-study 1: urban areas at risk from sand-spit rupture Thyborøn and Agger (photo DCA, 2000)
Figure 103: Aerial view of the Portuguese study area urban areas at risk from sand-spit rupture Gafanhas and Sand-spit waterfronts (photo: Rota da Luz)

On case study 1 – North Sea coast of Thyboron and Torsminde, the established protection policy defines the stability of the sand-spit areas in order to protect the inland areas (agricultural fields, industries, urban areas, camping site, etc). Thus, several interventions were carried out in order to avoid barrier rupture, such as the groynes fields, dune revetment, artificial dune with hard nucleus – dykes protection, dune revegetation, yearly sand beach and shoreface nourishment, by-pass operations, etc. Most of them it can be found also at the North West Portuguese coast.

Under the category safety and sand-spit non-break scenario in Denmark for case study 1, the existing strategies to maintain present safety standards in coastal defence are categorized as follows:

- Dikes and safety Dams
- Other hard constructions (a combination of dune revetment, groynes, seawalls, breakwaters)
- Beach and shoreface sand nourishment
- Dunes revegetation
- By-pass operation
A comparison (between case study 1 and the Portuguese study area), of the current use of each coastal defense categories is presented in Table 32.

Table 32: Current use of different coastal defense categories (Denmark- Case study 1 and Portugal)

<table>
<thead>
<tr>
<th></th>
<th>Dikes</th>
<th>Dams</th>
<th>Groyne field</th>
<th>Detached Breakwaters</th>
<th>Revetment</th>
<th>Seawalls</th>
<th>Beach Nourishment</th>
<th>Shoreface Nourishment</th>
<th>Dunes revegetation</th>
<th>Bypass</th>
<th>Artificial dune cordons</th>
<th>Harbour dredging deposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portuguese study area</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
</tr>
<tr>
<td>Denmark Case-study 1</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
</tr>
</tbody>
</table>

There have been many recent suggestions in Denmark, regarding beach protective measures beyond the more traditional approaches already described. At present there is some interest in submerged offshore breakwaters in some cases for boat moorings, but more often as a means of reducing shoreline erosion. The submerged breakwater stretches approximately parallel to the shore and acts to "trip" the waves and cause premature breaking. This reduces the energy of the incoming waves to a level below that under natural conditions, and thus reduces the rate of erosion of the beach. Such submerged breakwaters may be built of the traditional materials, but long, tubular sacks of polyethylene woven material filled with sand have also been considered. Such tubes, which have been used at the base of eroding sea cliffs in place of riprap or seawalls, have been successful in retarding erosion. Their disadvantage is that they are easily susceptible to damage by vandals. Other suggestions of ways to reduce wave energy include offshore fields of artificial kelp and barriers of bubble producing devices; however, these have not proved to be very satisfactory.

Experience with beach and shoreface nourishments is still limited in Portugal. In Denmark, the design of the nourishment (material, profile) should resemble the natural situation. Hence, in a first step investigations are conducted to establish the natural beach conditions (sediment properties, hydrodynamic situation, beach profile, etc.). Nevertheless, each nourishment disturbs the steady state profile of the beach. The larger the volume, the larger the disturbance and, therewith, the intensity of morphological readjustments (i.e., erosion of the nourishment). As a result, with diminishing nourishment volumes, the necessary replenishment volumes reduce as well. A yearly nourishment of small volumes, however, is not economic as the price per m³ increases rapidly with
Decreasing volumes. Further, the environmental (and recreational) impact is, of course, greater with yearly nourishment.

Table 33 - Comparing policies on nourishment practice in Portugal and Denmark.

<table>
<thead>
<tr>
<th>TERMS OF REFERENCE</th>
<th>DENMARK</th>
<th>PORTUGAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MAGNITUDE OF THE NOURISHMENT EFFORT</strong></td>
<td>Nourishment became important in the 1980s. Nourishment volumes are designed to compensate for erosion to the 6 m contour. The annual volume is 3 mill. m³ on a 110 km stretch giving an average of 27 m³ per m.</td>
<td>Beach nourishment and harbour by-pass operations are still under study for the Aveiro sand-spt area. Nourishment operations have been taken mainly in the south coast of Algarve at a singular level.</td>
</tr>
</tbody>
</table>
| **GOALS AND AIMS** | • Reduce risk of flooding  
• Stop or reduce erosion losses | • Stop or reduce erosion losses  
• Mitigation risk of exposed urban areas |
| **MEANS TO FULFIL GOALS AND AIMS** | • Beach nourishment  
• Shoreface nourishment  
• Hard protection at specific locations  
• Measures should be sustainable | • Beach nourishment  
• Hard protection |
| **ASSESSMENT OF VOLUMES** | • Volume is the difference between autonomous erosion and erosion according to the goal set for the profile above 6 m  
• Design period one to three years | • Under study |
| **SOURCE AREAS** | • Dredging of harbour entrances  
• Seaward of 20 m depth | • Dredging of harbour entrances; breakwaters up-drift (study under development-FEUP and harbour authorities) |
| **DESIGN CONSIDERATIONS** | • Beach profile close to the natural profile  
• Shoreface nourishment placement in the profile is determined by topography (5 m depth in case of a bar, 2-3 m depth in case of no bar) | • Under study |
| **APPROVAL PROCEDURES** | • Approval of extraction by nature conservation authorities  
• Nourishment does not need approval by nature conservation authorities | • Approval of extraction by harbours and environmental authorities |
| **COSTS** | Prices depend strongly on sailing distance and volume.  
• 4.20 Euro/m³ for beach nourishment and 2.60 Euro/m³ for shoreface nourishment. | Prices depend strongly on sailing distance, volume and place of deposition.  
• 2 Euro/m³ to 5 Euro/m³ |
| **MONITORING PROGRAMMES AND TECHNIQUES** | • General surveying of the coast  
• Monitoring of environmental impacts mandatory for source areas  
• Monitoring of environmental impacts for selected projects | • Surveying for research purposes of selected projects  
• Monitoring of environmental impacts |
| **CURRENT AND FUTURE CONCERNS** | • Concerns about sea level rise and the impact on nourishment volumes  
• Positive attitude to shoreface nourishment  
• Concerns about the effect of profile steepening | • Concerns about high energetic coast and the ineffectiveness of nourishment  
• Negative attitude to nourishment as an instrument in coastal defence among experts (mostly without a hard structures combination) |
7.4.3 Protection Option Within Adaptive Strategies Approach

Mitigation recommendations rely on the management strategies approach. According to CHARLIER, MEYER (1998) and VELOSO-GOMES, (1991), the retreat, accommodation and protection can be identified as alternative strategies to manage and mitigate coastal erosion/flooding risks.

The selection and timing of adaptive measures in response to coastal erosion and coastline retreat depends on the physical, social, economic, political and environmental characteristics of the affected areas. Although such measures can be implemented on a case-by-case basis, growing population pressures and conflicting demands in many of the worlds coastal areas favour implementation of comprehensive and systematic coastal management programs.

The three principal objectives of coastal planning and protection are (CHARLIER; MEYER 1998):

1. To avoid development in areas that are vulnerable to erosion/flooding
2. To ensure that critical natural systems continue to function;
3. To protect human lives, essential properties and economic activities against the sea action

Accordingly, such programs should give full consideration to ecological, cultural, historic and aesthetic values and to the needs for human safety and economic development.

As already said, the non-quantifiable aspects of cultural, environmental and social impacts must be considered when selecting any response strategy. Options may be restricted for some developing countries because of costs or lack of technology.

Responses strategies fall into three broad categories (IHRH, 1992):

1. Retreat: abandonment of land and structures in vulnerable areas and resettlement of inhabitants
2. Accommodation: continued occupancy and use of vulnerable areas
3. Protection: defence of vulnerable areas, especially population centers, economic activities and natural resources. It can involve a (1) sustainable land-use planning, (2) reduction in anthropogenic impact and (3) coastline maintenance.
7.4.3.1 Retreat

The strategy of retreat, argues for no action in risk areas. It can be a result of an enforced situation due to technical or economic inability or a positive response adopted following an environmental impact assessment and a consideration of the large economic costs, which would be involved. The infrastructures and buildings affected would be progressively reconstructed at inland sites and non-building area would be defined according to coastline retreat rates (CARVALHO, COELHO, 1998). By the Danish case study 2, it was possible to observe this retreat situation at Skagen area. The retreat strategy requires advanced planning and acceptance that some coastal zone values could be lost. Options for retreat can include (CHARLIER; MEYER 1998):

- Preventing development in areas near the coast. Governmental efforts to limit development generally invoice land acquisition, land-use restrictions, and prohibited reconstruction of properly damaged by storms and reductions of subsidies and incentives for development in vulnerable areas. Many nations have purchased large areas on the coast and designated them as nature reserves (national and regional parks). Preventing development can reduce future expenditures for adaptation.

- Allowing development to take place on the condition that it will be abandoned if necessary. This approach can be implemented through:
  - Regulations that prohibit private construction of protective structures,
  - Conversion of land ownership to long term or conditional leases which expire when the sea reaches a particular level or when the property owner dies.

- No direct government role other than through withdrawal of subsidies and provision of information about associated risks. Under this option, governments could take the more limited role of ensuring that all participants in potentially vulnerable areas have full knowledge about the expected sea-level rise and its associated uncertainties. Development would presumably not occur if developers, lenders and insurers were not willing to accept the risks. However, if people continue to build in vulnerable areas, governments must be prepared to take the necessary actions to ensure public safety.

7.4.3.2 Accommodation

The strategy of accommodation also requires advanced planning and acceptance that some coastal zone values could be lost (IHRH, 1992). Many coastal structures, particularly residential and small commercial buildings, could be elevated on pilings for protection from floods. To counter surging water and high winds, building codes could specify minimum floor elevations and piling depths, as
well as structural bracing. Drainage could be modified. Storm warning and preparedness plans could be instituted to protect the affected population from extreme events. Where salt water damages agricultural lands and traditional crops, salt tolerant crops may be a feasible alternative. Fundamental changes in land-use may be desirable, such as the conversion of some agricultural lands to aquacultural uses.

Requiring private insurance coverage in vulnerable areas is an important method to compensate injuries and damages caused by natural disasters. It forces people to consider whether risks are worth taking and provides the necessary funds to repair damages and compensate innocent victims. Human activities that destroy the natural protection values of coastal resources can be forbidden. Perhaps the most important controls would be to prohibit filling wetlands, damming rivers, dredging beach sands and cutting mangroves (CHARLIER; MEYER 1998).

7.4.3.3 Protection

This strategy involves defensive measures and other actions to protect areas against inundation, tidal flooding, and effects of waves on infrastructure, shore erosion, salinity intrusion and the loss of natural resources. The measures may be drawn from an array of "hard" and "soft" structural solutions. They can be applied alone or in combination, depending on the specific conditions of the site (CHARLIER; MEYER 1998).

The protection strategy is most relevant for areas having relatively large populations and an important infrastructure. These conditions inherently alter the environments. However, the structural measures related to a protection strategy can impose additional alterations not only to the immediate environment but also to the unaltered coastal ecosystems beyond the area of protection. By the analysis of case-study 1 (Thyboron/Thorsminde), it is clear the assumption of the protection strategy involving the adoption of hard and soft engineering measures to maintain the present coastal configuration and to avoid a rupture scenario at barrier spits. On the other hand, land-use planning is also carried out by creating a 100m of buffer zone and 3 km of coastal planning zone.

7.5 Main Aspects for Conclusion

As a conclusion it is presented on the next tables (Table 34 to 36) a general comparative description of the Portuguese study area, and both case studies from Denmark. Within this schematically overview it is possible to add elements as location and coastal characteristics to the predominant socio-economic activities, the driven coastal policy, the erosion management policy options, and the responsible entities.
Table 34: Information on NW Portuguese Coast/Costa Nova/Mira Sand-slit and inner lowlands - Gafanhas

<table>
<thead>
<tr>
<th>National level</th>
<th>Portugal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional level</td>
<td>Centre Region</td>
</tr>
<tr>
<td>Local level</td>
<td>Aveiro district</td>
</tr>
<tr>
<td>Name of the study area</td>
<td>Costa Nova – Mira Sand Barrier and inner lowlands - Gafanhas</td>
</tr>
</tbody>
</table>

**Short description of the coast**

- Type of coast: coastal plain, long sandy beach, south coastal lagoon inlet, artificial stretches (groins and breakwaters); weak frontal dune cordons
- Type of sediment: fine to medium sand
- Tidal regime: meso-macrotidal 1.3-3.8 m, semidiurnal
- Range of waves: 2-3m height with 8-12 s period max. wave height 8 m (storms)
- Longshore drift: N-S

**Socio-economic activities**

Tourism, Agriculture, Fishery, Harbours

**Coastal Planning Policy**

Public Maritime Domain: 50m of non private uses and Coastal Plans zone of 500m

**Erosion Management Policy options**

Management realignment;

Hold the line at urban seafronts

**Engineering techniques**

Hard structures (groins; breakwaters); retreated dunar system – ripping techniques, dunes revegetation and protection access, artificial beach nourishment

**Responsible entity**

Ministry of Environment – Water Institute

**Protection costs**

Government: 100%

NW Portuguese coast - Costa Nova/Mira sand-slit and inner lowlands of Gafanhas
### Table 35 - Information on Case-Study 1: North Sea Danish Coast Thyboron / Torsminde coastal stretch

<table>
<thead>
<tr>
<th>National level</th>
<th>Denmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional level</td>
<td>West of Jutland - County of Ringkobing</td>
</tr>
<tr>
<td>Local level</td>
<td>Thyboron / Harboor Kommune</td>
</tr>
<tr>
<td>Name case study site</td>
<td>Thyboron – Torsminde</td>
</tr>
</tbody>
</table>

**Short description of the coast**

- Type of coast: straight coast consisting of sand and gravel and glacial deposits below bathymetric line –6m. Longitudinal dune system, with Fjords-like inlets and posterior dunes
- Type of sediment: fine to medium sand
- Tidal regime: astronomical tide is very small 0.3m medium range but meteorological tide may reach 3.5m
- Range of waves: dominant swell, 2.5 m high with periods from 6-9 NW direction, H max about 7.5 m (storm).
- Longshore drift: N-S

**Socio-economic activities**

Tourism, forest, fisheries, Harbours

**Coastal Planning Policy**

The Planning Act: 3km of restricted planning zone; 300m or 100m coastal protection zone

**Erosion Management Policy options**

- To maintain a safety level against flooding of a 100 years return period as a minimum. At Thyboron the safety level is 1000 years.
- To hold the line- stop erosion where towns are located close to the beach.
- To reduce erosion on parts of the coast where erosion in the near future would reduce the safety against flooding to less than 100 years.
- Do nothing (forest)

**Engineering techniques**

Main Dune-dyke and embankment, Safety dams, groins, yearly beach nourishment, maintenance of the dune system, dune revetment

**Responsible entity**

Ministry of Transport – Danish Coastal Authority

**Protection Costs**

80% Government; 10% Regional; 10% Municipal

---

![Thyboron – Denmark's North Sea coast](image)

---

**Table 36 - Information on Case-Study 2: North Sea / Skagerrak Sea Coast**
<table>
<thead>
<tr>
<th>National level</th>
<th>Denmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional level</td>
<td>West coast of the County of North Jutland</td>
</tr>
<tr>
<td>Local level</td>
<td>Hjørring and Skagen Municipalities</td>
</tr>
<tr>
<td>Name case study site</td>
<td>Lonstrup / Gammel Skagen</td>
</tr>
</tbody>
</table>

**Short description**
- Type of coast: This coast faces the North Sea by the Skagerrak Sea. The coast is flat and sandy as most of this land is elevated seabed broken only by a few high points that reach all the way out to the sea. Straight coast with longitudinal dune system
- Type of sediment: fine to medium sand
- Tidal regime: Astrological tides of 0.76m to 1.20m, while meteorological tide can reach 2.5m medium range
- Range of waves: dominant swell, 3m high, H max about 4.5m
- Longshore drift: S to N

**Socio-Economic Activities**
- Tourism, forest, fisheries, Harbours

**Coastal Planning Policy**
- The Planning Act: 3km of restricted planning zone; 300m or 100m coastal protection zone

**Erosion Management Policy options**
- To stabilize the coastline - stop erosion where towns are located close to the beach.
- To reduce erosion on parts of the coast where erosion in the near future would reduce the safety against flooding to less than 100 years
- Do nothing (forest)

**Engineering Techniques**
- Main Dune-dyke, groins, yearly beach nourishment, maintenance of the dune system, dune revetment

**Responsible Entity**
- Ministry of Transport – Danish Coastal Authority

**Protection Costs**
- 50% Government, 25% Regional, 25% Municipal

---

Skagen - Skagerrak Sea coast- highest point of Denmark
Lonstrup – Skagerrak Sea coast
CHAPTER 8 –
FINAL CONSIDERATIONS AND MAIN PROJECT FINDINGS
CHAPTER 8 – FINAL CONSIDERATIONS AND MAIN PROJECT FINDINGS

8.1 Project Overview

The fundamental objective of this study was to identify efforts and experiences in incorporating erosion/flood control measures at low-lying vulnerable coastal areas, after thorough assessment of knowledge gained from Denmark case studies.

By the enhance of potential interaction and exchange of knowledge and experience from the two countries- Portugal and Denmark, it seems possible to contribute to the good planning practices of South of Aveiro coastal strip and avoid in the future the development of high risk exposition areas to coastal forcing.

Therefore, a close description of the Aveiro south barrier-spit appeared to be an essential contribute to the understanding of global area and the different reasons for the coastline behaviour. In fact, it could be observed that the coastline is highly vulnerable to natural processes as winter storm events and flooding. Besides the natural processes, the main causes for the high rates of coastal erosion has been identified as a response to the weakening of river basin sediments sources and river sediment transport due to dam construction (VELOSO-GOMES, 1992); sea-level rise, human/urban pressures, hard defence structures (harbour jetties and groin fields).

The barrier spit is all classified as high risk (Portuguese Littoral Map Risk), and the elevation of the area is mostly below 4 meters and elevations on the back side of barrier spit are still low (5 meters). In some areas the dunes are severely scarped and low thus do not have enough width to withstand a high storm surge. Dunes are sparsely vegetated and are therefore less stable, thus the area is particularly vulnerable as it can be overtopped during most storm events and would very likely become permanent inlets as sea level rises. The artificial dune – emergency intervention by INAG, in this stretch was built to offer some protection during storms.

By this attempt it is possible to identify the most low elevation areas facing the Atlantic sea action thus, the general vulnerability (or lack of natural resilience) degree of this coastal stretch. The aerial information of 1996 was integrated with the hydrological data from 1998 – coastline (Figure 43) to highlight the most retreat zones at this time range.

Despite the analysis limitations and difficulties related to the availability of temporal hydrographical data, the survey demonstrated that the increase of potential flood risk area at the Gafanhas location as a rupture situation which was analysed by several flooding scenarios. The
margins of inland lagoon are floodable and are at high-risk zones due the urban density, and not only open fields as agricultural lands but have been occupied by recently built single-family residences. A mere sandbar is separating the Atlantic sea from the Lagoon-Mira Channel, where urban development is continuously enshrouded along the EM 591 (low-lying road adjacent to the Mira channel).

Nevertheless, the intensive use of the sand-spit specially the development in high-risk area, affects the entire stability of that unstable and environmental sensitive coastal system. Dune gaps or breaches increase interior flooding.

With the incorporation of Denmark case studies it is concluded that, a detailed policy for coastal maintenance has been developed using buffer dikes, high number of groynes, about 400 meters long, detached breakwaters, combined with yearly nourishment at beach and on shore face. By the monitoring / evaluating efforts it has been anticipate what erosion might be caused and take appropriate defensive measures before considerable coastal property is lost. Similarly mon-structural options to reduce vulnerability to impacts erosion and flooding, such as land use planning, may require actions to implement and enforce them.

However, there are no simple or universal solutions to shoreline erosion, since there are often several factors, both human and natural, contributing to the problem at a particular beach. Each coastal area behaves differently, so it is advisable to find out as much information as possible about a particular beach before taking any corrective action.

At unstable coastal stretch such as barrier spits, protection policy for safety has to be defined. Property risk situations should be avoided by mitigation measures. The options taken by Denmark and Portugal depend on contextual matters and priorities of costs or technology available. The success of coastal protection policy on each country is depending on factors such as natural hydrodynamic/geologic processes the knowledge and understanding of those natural processes and the perception of the risk itself (CARVALHO; COELHO, 1998)

8.2 Good Practices on Planning with Erosion

By the end of this report it was recognised that there are some wise practices that help to slow down the rate of erosion, thus to mitigate the vulnerability and the risk:

Plan for existing and future coastline change by positioning all new development (large and small) at a ‘safe’ distance landward of the vegetation line. The location of urban waterfronts highly conflicts with the natural coastal evolution. Therefore, urban expansion or denseness
along vulnerable coastlines must be stopped. Local authorities and urban planners cannot continue to ignore the medium term / long term physical dynamic and consequent constraints. The emergency interventions absorb a great amount of economic resources and are not enough to stop the erosion progress, they can only delay the retreat of the coastline and the losses of territory.

**Ensure the coastal planning process** is fair, equitable and analysis based. In any decision-making situation it is important to undertake an appropriate level of analysis, which is justified by the importance of the decision and its sensitivity to uncertainty. The appropriate level of analysis will be guided by the cost and time associated with collecting and analysing data about the erosion/ flooding problem and the risks associated with any proposed erosion management option.

Planning new development so that it is at a ‘safe’ distance behind the beach will reduce the need for expensive sea defence measures in the future.

One experience that has been gained from this is that the solutions are not always optimal solutions, but pragmatic compromises. However, such compromises do contribute to the fulfilment of the overall objectives of the planning, in order to keep the coastal areas as free as possible from development projects that do not need a coastal location, and to direct the future growth of the cities further inland.

It seems fair to say that in Denmark a decentralized system for horizontal and vertical integration of decision-making processes to promote compatibility and a balance of uses, Environmental assessments and public participation, has been operational for about 20 years. It promotes compatibility between conflicts situation and a balance of uses, environmental assessments and public participation. As a result, a wide range of problem areas that impinges upon coastal areas, are on a recurrent basis being assessed and reconciled within a planning framework. In such cases, an often-applied solution is to establish co-management committees consisting of the relevant stakeholders within specific geographical areas.

**Review and carefully consider ALL options** when planning ways to slow down the rate of coastline change, these should include planning, ecological and engineering measures.

The need for a better articulation between potential areas of urban expansion and the potential risk from natural hydrodynamics coastal processes better efficiency on the relation between regional plans and municipal ones as well among the different entities with legal jurisdiction on the area.
To improve the performance of coastal defences it is necessary to consider systems of defences rather than merely considering single defences in isolation. If a town is protected by several different defences then it is necessary to consider how this coastal defence system functions as a whole in order to assess and manage the risk to the inhabitants and assets in the town.

At present there is little useful guidance on assessing risk to large erosion and low-lying floodplain areas.

With moves towards a more integrated erosion management, it is essential that risk managers have recourse to sound and practical tools and techniques for assessing the performance of whole systems in order to develop balanced, integrated risk management strategies.

**Continue to monitor the rate of coastline change** and share the findings with all other stakeholders.

The capacity to forecast the medium and long-term evolution of beaches, dunes and barrier-islands continues to be very limited due to scientific reasons. Apart from this limitation, many years of hydro-morphological characterisation were lost (namely, and at least, topo-hydrographic studies) that are essential for the quantification, comprehension and forecasting of the phenomena (DCA, 2002).

By means of an adequate monitoring and maintenance program of the coastal structures it will be possible to assure that the relevant stability and functional performances do not decrease to a level lower than pre-defined limits. It should include periodical inspection and repair when a warning limit is reached. Coastal structures are not permanent solutions.

Importance of long-term surveys (like profile steepening surveys- Thyboron case-study 1) due to the yearly large fluctuations on data being so large that even a period of 25 years of monitoring could have been misleading. Thus Data-base as a good basis for evaluating the long-term trends of profile development (as the volume of eroded sand along the coast) and bringing credible simulations in numerical models in order to predict and to assess the potential erosion risk.

**Good Database and Information access** Land-based and aerial photographs can support inspection of the dry components. Periodical topo-hydrographic surveys of the defence structures and adjacent shores and beaches are essential for a better quantification of the dynamic evolutions and technical actions.

Numerical modelling using good and updated database has greatly supported the understanding of the coastal processes around and in the Thyboron Channel. Comparison between modelled sediment transport for a historical and a recent bathymetry has illustrated that relevant processes are sufficiently well represented in the models to reflect the major morphological changes.
Inside the channel the modelling has illustrated how different hydrographical conditions lead to
different morphological developments such as migration of the channel and very varying
depositions in the entrance area.
Calculations of erosion on the coast, calculations of deposit material on inlet shoals and
numerical calculations of the littoral transport capacity have helped gaining a more narrow
range for the littoral sediment budget along the barriers, (DCA, 2002).

**Stop the dredging of sand from beaches and dunes and use dredging materials for
artificial nourishment.** Ensure that inland mining sites are restored after use, and investigate
alternative building practices. It is considered essential that the first priority for using the
dredged material from Aveiro harbour is the nourishment of the down-drift beaches (whether
the new retreated dune cordon is constructed or not). For this purpose it is necessary to collect
data on planned dredging operations near Aveiro Harbour Administration and to impose to the
harbour authority the mitigation of impacts related with harbour activities.

**Conserve and restore vegetative dunes cover,** both adjacent to the beach in order to stabilise
the sand, and further inland to reduce sediment reaching the reefs and sea grass beds. The
importance of the dunes, especially the primary chain, is internationally recognised and one of
the aspects to be considered is the reserve of alluvial sources and of the adaptive barrier to
run-ups and overtoppings they supply.

Revegetating dunes with native vegetation e.g. grasses, and planting beach areas beyond the
reach of storm waves with salt-resistant, deep-rooting trees. Maintaining the natural vegetation
helps to stabilize the beach. The conservation, reconstruction and stabilisation of the coastal
dunes, their protection from construction projects and pathways, as well as their replanting with
vegetation, are actions that have being undertaken by the Governmental Agencies,
Municipalities and environmental groups (VELOSO GOMES et al, 2002). They do not demand
large technical or financial means. Such operations, however, should be carefully programmed
and accompanied by experts and can be part of other environmental awareness and educational
initiatives. The replanting of vegetation, should, as far as possible, respect the autochthonous
varieties, which have a differentiated spatial distribution.

Unfortunately, in view of the size of hydro-morphological imbalance that is occurring on the
Portuguese coastal areas and the high wave energy present, the dune conservation,
reconstruction and stabilisation measures, by themselves, will not lead to a stabilisation or even
an inversion of the erosion situation. But they will be an important contribution, not only in
terms of slowing down the sea advance but also in terms of protecting and recovering other natural values.

**Engineering solutions towards a soft approach** living with the sea and not against it!

The use of more hard constructions along the west coast of Denmark is getting rare in favour of sand nourishment (combined with the already built structures- groins, breakwaters and seawalls). Beach nourishment alone, or more often combined with “hard” defences and ancillary structures, is an accepted approach to the problem of reducing flood risk on coastlines. It has become more popular in Denmark during the last 10-15 years for a variety of reasons:

- Understanding of coastal processes has improved through the Shoreline Management Plan process;
- Mathematical modelling has increased confidence in predictive capacities;
- There has been an increasing wish to “work with nature” to provide more sustainable and environmentally acceptable solutions avoiding undesirable ‘fixed’ defence lines where possible;
- Past nourishment schemes have proven successful from technical, economic and environmental viewpoints;
- Costs of pumping sand and shingle ashore have become more acceptable. With increasing volumes and experience, a better approach for nourishing the different parts of the profile has been developed. Today, three methods are used. The methods are pumping onshore through a submerged steel pipe, pumping over the bow and dumping from split barges.

In Lonstrup and Skagen case-study, erosion control is done with a combination of nourishment and low detached breakwaters which has reduced the retreat rate of coastline.

The sand bypassing intervention in Aveiro harbour inlet, as it is done in Torsminde - Denmark, is an interesting alternative, and it should be considered as a medium term alternative.

The artificial re-construction of the dune cordons in NW coast of Portugal presents another solution as the same in Thyboron, even for more retreated positions, must attend to extreme storm situations. Therefore, it will be necessary that these artificial cordons have a resistant core, made of riprap or other structural components as it was implemented in the Thyboron - Denmark study area (dune-Dykes).

Concerning the construction of the dune - dyke along the stretch Costa Nova - Vagueira, the initial profile of this artificial dune cordon must be "modelled" in a more irregular way (also the wind will help to do so) and a scientific based re-vegetation project must be implemented.
Coordinate an integrated approach to coastal management, by ensuring that individuals, groups and agencies work together. It seems fair to say that in Denmark, a decentralized system for horizontal and vertical integration of decision-making processes has been operational for decades in order to promote compatibility and a balance of uses, Environmental assessments and public participation.

The Danish system of planning regulations and intersector spatial planning is carried out in practice and such planning results in the definition of a framework for future development, which is expressed in guidelines for the administrative procedures of the regional and local authorities. The general public is always involved in the planning procedure. In certain situations the planning act also dictates that larger construction projects should be subject to an EIA (environmental impact assessment).

The most significant experience is, however, that the results are not achieved by legal requirements alone, but primarily by the legally prescribed negotiations horizontally between various sectors, and vertically between national, county (regional) and municipal authorities.

Planning Guidelines together with Protection

The Danish approach to coastal management through planning being comprehensive, decentralized and based on public participation, is considered unique in Europe. Most other European countries apply coast protection zones of 100-300 m. But the typical coastal regulation is carried out either by special acts or sectoral measures. Activities such as hunting, fishing, and recreation in coastal areas are regulated by special acts. Vulnerable areas may be designated as protected areas according to Nature Protection Acts, and in some cases accompanied by management plans that regulate the activities within the protected areas.

In general there seems to be a trend towards more emphasis on the regulation of use and protection of the Danish coasts. For instance a special 3 km broad planning zone has been imposed to the land territory. A greater part of applications for defense measures to protect uninhabited areas is now rejected because it is considered important to protect the natural coastal processes. At the same time it is considered very important to maintain and if necessary improve the protection of the inhabitants in areas threatened by eroding or flooding.

8.3 Critical Review and Difficulties

The availability of cartographic Data (AMRIA 1998 and INAG 1996 / 2001) was limited and it might be considered not up-date for the analysis. Therefore it was only possible to relate two coastline periods of analysis, from which it could raise up limitations on detecting any fundamental traits of changes, particularly:
- The cyclical character of changes
- Difficulty in defining tendencies

The possibility of more observations on European case studies would make possible the understanding of trends of protection policy and technical guidance within a regional/global context.

Bibliographic sources limitations concerning the Danish information, once it implied an effort of translation to English, in order to retain the main aspects. Thus the personal interviews appeared as an effective way of harmonise the collected information.

### 8.4 Future Developments

The use of the GIS is essential in the formulation of territorial management tools, and for their constant updating. Consequently, there is an urgent need to promote the production of digitalised data supports and to facilitate the availability of information in a digital format, which may allow the rapid formulation of these instruments.

By using the AMRIA, 1998 cartographic Data for the inland areas – Gafanhas and its integration with different temporal analysis it could be achieved a necessary support study for land-use understanding and perception of main trends.

Besides those topics it seems to be pointed out as a final marks, that:

- Medium and long-term predictions of the shoreline evolution appeared to be essential to provide a more planning awareness, contributing for a better decision-making process;
- The need to adjust municipal plans to an increasing vulnerability and risk exposure;
- The need to control urban development on the lowlands of Gafanhas;
- The need for a monitoring programme implementation, investing on hydrographical surveys.
BIBLIOGRAPHY


AMARAL (1968) – A laguna: vida, morte e ressurreição de Aveiro. Aveiro e o seu distrito, Publicação semestral da Junta Districtal de Aveiro, 6, p. 34 - 45.


CARVALHO, A. C., (1994) - A Urbanização, Construção e Habitação de Ílhavo – Projecto final de Economia Urbana, Faculdade de Economia da Universidade de Coimbra


COELHO, C. (2003)- Riscos de exposição de frentes urbanas a diferentes intervenções de defesa costeira, Relatório preliminar no âmbito da Tese de Doutoramento, Departamento de Engenharia Civil, Universidade de Aveiro

COELHO, C.; VELOSO GOMES, F. (2003)- Wave climate and longshore sediment transport in the northwest Portuguese coast, 3rd IAHR Symposium on River, Coastal and Estuarine Morphodynamics, - Poster session , Barcelona

COMRISK (2002)- Common Strategies to reduce the risk of storm floods in coastal lowlands. INTERREG North Sea Region, Preliminary Report.


CPU (2002)- Plano Intermunicipal de Ordenamento da Ria de Aveiro - Associação de Municípios da Ria de Aveiro, Versão Preliminar - Relatório I. Aveiro


DCA, (2001)- The Danish Coastal Authority – Research and Development Programme for West Coast, Limited edition, Lemvig - Denmark


FAERCH, KIRSTEN (1992) - Lonstrup fra fiskerby til turistby, Geografisk Institut, Aarhus University, Denmark


FIDELIS, T. (2001) - Planeamento Territorial e Ambiente- O Caso da Envolvente à Ria de Aveiro, Principia - Publicações Universitárias e Científicas

FREDSOE, J. (1996) - ISVA - Department of Hydrodynamics and Water Resources - Danish Technical University Publications Boek n.3, Denmark


GEOPLANETA (2002) - Aerografia do Litoral, 2ª edição. Publicações Dom Quixote


GRANJA, H. M. (1996) - A laguna de Aveiro no contexto da evolução da zona costeira do noroeste de Portugal nos últimos milhares de anos. Seminário Sobre Lagunas Costeiras e Ilhas-Barreira da Zona Costeira de Portugal, Associação Eurocoast-Portugal e Universidade de Aveiro, p. 87 - 106.


INE (2001) –Instituto Nacional de Estatística, resultados preliminares- Census


JAKOBSEN, P. (2002)- Effektiv Miljøvenlig Kystbeskyttelse, SIC, Skagen innovationcenter, Denmark


JAPA - JUNTA AUTÓNOMA DO PORTO DA BARRA DE AVEIRO (1996) – Caracterização sumária da Ria de Aveiro –Boletim Informativo, nº12


KORT AND MATRIKELSTYRELSEN (2002) – Aerial Catalogue for the coastal area from the Jutland Peninsula – Denmark

KYSTINSPEKTORATET (1998): Vestkysten 98 (In Danish). In the report it is assessed whether the objectives presented in the previous master plan have been fulfilled. Objectives for the next period are proposed supplemented with proposals for the necessary means.


MILJOMINISTERIET (1997)- The Danish Ministry of Environment Annual Report - Spatial Planning Department publications, Denmark

MILJOMINISTERIET (1998)- The Danish Ministry of Environment Annual Report - Spatial Planning Department publications, Denmark


PINHO, J. S. R., (1993) – Os Espaços florestais no contexto do Plano Director Municipal – O caso de Ilhavo e Vagos, Relatório de fim de curso de Engenharia florestal, Universidade Técnica de Lisboa

RASP, Project (2001)- Risk Assessment for Flood and Coastal Defence Systems for Strategic Planning Environment Agency – United Kingdom


RUA, J.; CABARRÃO, M.; (1999). A Participação do Porto de Aveiro no Projecto MARIA – Comunicação apresentada no Seminário Final do Projecto MARIA – Projecto de Gestão Integrada das Áreas de Mar e Ria da Região de Aveiro, Departamento de Ambiente e Ordenamento, Universidade de Aveiro.


UNITED NATIONS CONFERENCE ON ENVIRONMENT AND DEVELOPMENT. AGENDA 21, Chapter 17. Protection of the Oceans, all kinds of seas, including enclosed and semi-enclosed seas, and coastal area and the protection, rational use and development of their living resources. Final advanced version of a chapter of Agenda 21 as adopted by plenary in Rio de Janeiro on June 14, 1992.


VELOSO GOMES, F. (1993a). The Challenges to overcome the problems of NW coastal Zone of Portugal, Proceedings of 1st International Conference on MEDCOAST - Turquia.


Portuguese Study Area

Aveiro South Sand Spit and Gafanhas

LEGEND:
- Atmospheric Data
- Roads
- Hydrographic Data
- Sand Spit Coastline
- Urban areas
ANNEX C
AERIAL PHOTOS OF CASE-STUDY 1
1. Aerial photo of Agger Barrier-Spit maintained by Dune-Dike, yearly nourishment and groyne field. Safety Dam to flood control (source: KORT AND MATRIKELSTYRELEN, 2002)
2. Aerial photo of Thyboron /Agger Barriers and inlet connecting the North Sea with the Fjord (Limfjord) (source: KORT AND MATRIKELSTYRELSEN, 2002)
3. Aerial photo of Thyboron Barrier-Spit (Harboøre Tangue) maintained by Dune-Dike, yearly nourishment and a 98 groyne field (source: KORT AND MATRIKELSTYRELSEN, 2002)
4. Aerial photo of Barrier-Spit and Harboøre Town (source: KORT AND MATRIKELSTYRELSEN, 2002)
5. Aerial photo of groyne field at Ferring area. Land-use mainly agricultural fields and sparsely urban dwellings (source: KORT AND MATRIKELSTYRELSEN, 2002)
6. Aerial photo Dune –Dike protection structure at Bovling (south of Ferring) (source: KORT AND MATRIKELSTYRELSEN, 2002)
7. Aerial photo of Thorsminde Barrier-Spit maintained by Dune-Dike and yearly nourishment, Inlet Harbour and By-pass operations. (source: KORT AND MATRIKELSTYRELSEN, 2002)
ANNEX D
AERIAL PHOTOS OF SAND-SPIT – COSTA NOVA / VAGUEIRA
PHOTOS - PORTUGUESE STUDY AREA

Coastal hard defense works - Harbour jetties - Barra
_In: Foto Engenho-Francisco Paqueiro, 2002_

Littoral- hard defense works (groin 1)- Barra-Costa Nova
_(Foto Engenho-Francisco Paqueiro, 2002)_

Coastal hard defense works (groin 1 and 2)- Costa Nova
_(Foto Engenho-Francisco Paqueiro, 2002)_
Coastal hard defense works (Groin field 2 to 4) - Costa Nova
(Foto Engenho-Francisco Piqueiro, 2002)

Coastal hard defense works (groin 4 and 5 with seawall) - Costa Nova
(Foto Engenho-Francisco Piqueiro, 2002)

Coastal hard defense works (groin 6 and seawall) - Vagueira
(Foto Engenho-Francisco Piqueiro, 2002)
Coastal hard defense works (Groin 6 - Vagueira and Groin 7 - Vagueira South) (Foto Engenho-Francisco Piqueiro, 2002)

Artificial dune cordon - South Vagueira (photo: 22.04.2003)

Dunes overtopping zone - South Vagueira (Foto Engenho-Francisco Piqueiro, 2002)

Overtopping Events before the emergency intervention – artificial dune South Vagueira (photo: 13.05.2003)
South Vagueira - Arcão zone
(Foto Engenho-Francisco Piqueiro, 2002)

Construction of a new Groin - Arcão (Groin 8)
(photo: 22.04.2003)
Digital Terrain Models – Portuguese study area