COASTAL FLOOD RISK AND TRENDS FOR THE FUTURE IN THE NORTH SEA REGION

Results and recommendations of Project Safecoast

SYNTHESIS REPORT

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Keeping our feet dry in the North Sea lowlands

Colophon

This synthesis report is the final result of Safecoast, a project co-funded under the European Regional Development Fund INTERREG IIIB North Sea Region Programme – A European Community Initiative concerning Transnational Co-operation on Spatial Development 2000-2006

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EXECUTIVE SUMMARY

Background and objectives

Since the early nineties of last century coastal managers responsible for coastal defence and management in five North Sea countries (United Kingdom, Germany, The Netherlands, Denmark and Belgium) have come together in the North Sea Coastal Managers Group (NSCMG). The project Safecoast (July 2005 – July 2008) has emerged from this network. Safecoast is funded by the national and regional governments of the five North Sea countries and is co-financed by the European Union's Regional Development Fund (ERDF).

Safecoast's aim: to learn from each other by discussing our different contexts and approaches to coastal flood and erosion risk management. Faced with climate change, and associated impacts on our coasts, it is important to analyse, compare and benchmark our methods and ideas, focusing on the question: *'How to manage our North Sea coasts in 2050?'*

Approach and execution

Safecoast was divided into work packages called 'Actions'. The results of these actions were used for developing the views on the (future) management of coastal risks as described in the present synthesis report. In project Safecoast, we have pursued the following:

- Utilise tools like scenario analysis: for climate change and future land use, and risk assessments on different scales of space and time to define future challenges for a range of coastal situations;

- Search for best practices in risk assessment: Project Safecoast illustrates best practices in terms of flood and erosion risk assessments and underlines the need for better co-operation between countries and regions and between scientists, managers and policy makers;

- Identify promising approaches: looking 'outside the box' for measures to prevent or cope with the negative consequences of coastal flooding and erosion considering a wide range of possible future (planning) strategies and solutions. This means either to protect our vulnerable coasts with measures of "no regret", or to limit or compensate for the potential negative consequences of coastal flooding and erosion where needed or possible;

- Informing our societies about the challenges related to managing coastal flood and erosion risks seeking consensus and support for the benefit of sustainable coastal risk management.

Findings and recommendations

Safecoast findings have confirmed the similarities in coastal problems and possible solutions, and the commonality in methodological approaches, among the various North Sea countries. By continuing, intensifying and expanding current management practices it is expected that most of the North Sea flood prone areas could be kept safe at acceptable risk levels and at acceptable costs, under presently assumed trends in climate change. In achieving this, the findings of Safecoast effectively point towards the need for a more *integrated* approach to coastal risk management, where the main aspects of integration would include: different types of problems, developments, stakeholders, solutions, and types and scales of planning. Recommendations following these main findings are categorised for different target groups related to coastal policy makers and managers and the various research communities:

Policy and management

- Make use of the full potential of measures considered within the risk management cycle or 'safety chain'.
- Clearly define national and regional coastal risk management goals in a broad and long-term perspective.
- Increase the focus of coastal planning procedures at the participation of local communities and authorities.
- Continue the international cooperation and learning process.

Research communities

- Further develop the integrated planning approach to manage coastal risks.
- Improve the knowledge base on the aspects and impacts of climate change.
- Continue the exchange of knowledge for development and further improvement of risk assessment methodologies.
- Reduce, make explicit and better manage uncertainty in coastal flood and erosion risk assessments.

FOREWORD

This synthesis report is the result of 3 years of co-operation between a number of coastal risk management organisations in five countries bordering the North Sea: Denmark, Germany, The Netherlands, Belgium and the United Kingdom.

Societal awareness of and political attention to the topic of coastal flood and erosion risks has given rise to different approaches to coastal management in most of the North Sea countries. In the 20th century, there were major coastal floods in the North Sea region (listed in table 2.3) with storm surges claiming over 2,500 lives and causing extensive damage.

Responses across countries bordering the North Sea have varied, including shortening of the coastline by planning, constructing or strengthening of coastal flood defences, better prediction of storm surges (e.g. early warning systems) and/or rationalisation of defence management (e.g. in the Netherlands there were 3,500 water boards in 1953 and now there are 27).

In recent decades, the prospect of climate change, in particular sea level rise and its effects on low-lying coastal areas have generated renewed attention to flood and erosion risk. Human influence, particularly urbanisation and economic activities in the coastal zone has turned coastal erosion from a natural phenomenon into a problem of mounting intensity, and is, in many cases, linked to the probability of flooding. Coastal risk management needs, now more than ever, to encompass two fronts: coastal flooding and coastal erosion.

When deciding policies and strategies on risk based approaches, earlier projects such as Comrisk and Eurosion have shown that the physical and societal context is a defining factor. By means of example, coastal flood and erosion management in densely populated areas require different solutions than flood and erosion management along uninhabited coasts; this is because a 'minor' coastal flood can cause significant societal disruption in the former and fewer impacts in the latter. As a result, current coastal policy and management is organised at a variety of levels, from local to national level, in the five North Sea countries, leading to a wide range of perspectives, attitudes and solutions.

In project Safecoast, we have learned from each other by discussing our approaches to coastal flood and erosion risk management. Faced with climate change, and associated impacts on our coasts, it has proven important to analyse, compare and benchmark our methods and ideas. We found that despite the variety in societal attitudes and approaches towards flood risk in the North Sea countries, there are also large similarities in coastal risk management strategies. Also in view of the EU floods directive (2007), we hope that this synthesis report is a worthy contribution to, and inspiration for further cooperation in Europe and the North Sea region in particular.

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1 INTRODUCTION

1.1 Project Safecoast

1.2 The synthesis report

1.3 Scope

1.4 Contents and organisation of the report

1 INTRODUCTION

The responsibility and competence for (coastal) flood risk management is allocated in the different North Sea countries at different levels, i.e. national, regional and local, where different bodies are responsible for different tasks with respect to policy, management and research. Co-operation has the advantage of learning from each other and natural processes ignore administrative boundaries and borders. In this context, co-operation becomes important in order to develop a sound and integrated approach to management.

The EU promotes co-operation between European regions, as well as the development of common solutions for issues such as urban, rural and coastal development, economic development and environment management. There have been many initiatives related to exchanging knowledge and showing best practices in the last decades. In the table 1.1, a (non exhaustive) list is given of coastal and flood management related projects that are funded by the EU. Where possible and relevant, project Safecoast made use of the findings of these projects.

D EU research FP5-6	Focus	Interreg North Sea Programme	Focus	Interreg North West Programme	Focus
Coastview	Coastal monitoring	**Chain of Safety**	Transnational crisis management	**BAR** [c]	Coastal erosion
Conscience	Coastal erosion & sediment behaviour	**Comcoast**	Coastal management concept	**Branch**	Land use and climate change
Dinas-coast	Coastal vulnerability	**Comrisk**	Coastal flood risk management	**Copranet**	Practitioners network
Encora	Coordinated knowledge network	**Flows**	Flood plain land use	**Corepoint**	ICZM
Eranet-Crue	Science & policy integration	**Frame**	Flood risk in estuaries	**Espace**	Space for water
Erograss	Flood defence stability	**Lancewadplan**	Wadden sea cultural heritage	**Flapp**	Flood awareness and prevention
EuroGoos	Marine monitoring	**Norvision**	Spatial planning	**Floodscape**	Space for water
Eurosion [a]	Coastal erosion management in EU	**Response** [b]	Coastal erosion and climate change	**Messina**	Monitoring and valuation
Floodsite	Flood risk science and management	**Safecoast**	Future coastal risk management	**Nofdp**	Nature and flood prevention
Motiive	Data harmonisation			**Sail**	ICZM
Newater	Adaptive water management			**Scaldit**	Scheldt estuary integrated vision
Spicosa	Science & policy integration				
a) Service contract with EC / DG Env. b) EU Life programme. c) Interreg 3a project					

Table 1.1: An alphabetically ordered selection of recently EU funded (coastal or river) flood and erosion risk management related projects

1.1 Project Safecoast

What?

Since the early nineties of last century, coastal managers responsible for coastal defence and management in five North Sea countries have come together in the North Sea Coastal Managers Group (NSCMG). This group of policy makers and managers meets annually for the purpose of exchanging information and deciding on forms of cooperation. As a result, two projects, Comrisk (2001-2005) and its successor Safecoast have emerged from this network.

Project Safecoast is funded by national and regional governments of five North Sea countries and is co-financed by the European Union's Regional Development Fund (ERDF) in the framework of the Interreg 3b North Sea Programme for transnational projects.

Project Safecoast's total budget has been about € 2.3 million for the period between July 2005 and July 2008. Project Safecoast was led by the Dutch National Institute for Coastal and Marine Management / Rijkswaterstaat RIKZ that was in October 2007 re-organised and partly converged into Rijkswaterstaat - Centre for Water Management. Safecoast partners with their respective actions and tasks are listed in table 1.2

Why?

Knowledge on how to manage flood risk is widespread and fragmented across the North Sea region. Different countries focus on different aspects of policies and strategies in order to reduce the risk of flooding to people, property and the natural environment. It has proved essential for the process of knowledge and information exchange to cooperate, discuss and work together on jointly faced challenges and management questions.

In 2005, the NSCMG initiated project Safecoast, with the aim to further learn from each other about coastal risk management in the face of new challenges. Safecoast set out to answer the question: 'How to manage our North Sea coasts in 2050?' and focused on scenarios of future change and risk management with respect to coastal flooding and erosion. Earlier findings of project Comrisk were taken further into the context of future risks and challenges to inform science, management and policy.

The issue of global climate change and associated sea level rise has generally given rise to a societal concern, especially in coastal flood prone areas. However, the translation of the climate change threat to national, regional or local action is obstructed by issues of downscaling. Safecoast can be seen as an attempt to partly compensate for this mismatch of scales by keeping a North Sea perspective and connecting science with policy.

Project Safecoast also aims to give examples of strategy development for specific situations and gives messages, conclusions and recommendations regarding further steps in the North Sea region cooperation towards the development of coastal risk management strategies. Project Safecoast is based on studies (either comparative, strategic or more technical) and knowledge exchange and does not aim to engage in any political process.

Additionally, Safecoast emphasises the need for enhancing public awareness to the topic of climate change in relation to coastal risk management. Also, the implementation process of the EU flood directive that is based on the river basin approach could benefit from having an overview of the coastal system-specifics of flooding and erosion from the sea.

How?
The Safecoast project was divided into work packages called ‘Actions’. Depending on their goals these actions could either compare between countries (cohesion actions), translating knowledge into pilot site risk assessments or plans (focused actions) and finally converging the knowledge and lessons learnt into a synthesis (synthesis action).

Separate results can be found on the Safecoast internet site (www.safecoast.org). The main themes and actions of Safecoast and the responsible partner are listed below:

Action	Theme	Partner	Country / Region
1A/1B	Common scenario developments: Climate change and spatial / infrastructure developments in the NSR	VenW / Rijkswaterstaat - Centre for Water Management (Former Rijkswaterstaat RIKZ)	Netherlands
2	The informed society: - improve coastal risk communication and awareness and personal responsibility.	Federal state ministries of Environment (MLUR) and Internal Affairs (IM)	Germany / Schleswig-Holstein
3A	Integrated risk assessment: - transnational flood risk assessment for NSR coastal regions.	VenW / Rijkswaterstaat - Centre for Water Management (Former Rijkswaterstaat DWW)	Netherlands
3B	Integrated risk assessment: - comparison of flood risk methodologies in the NSR.	Flanders MOW / Flanders Hydraulics Research	Belgium / Flanders
4	Integrated coastal master plan to control coastal flood risk in Flanders	Flanders MOW MDK / Agency for Maritime and Coastal Services, Flanders Coastal Division	Belgium / Flanders
5A	Risk assessments for different coastal erosion pilot sites: - Danish coastal pilot sites on coastal erosion and a coastal erosion atlas.	TRM / Ministry of Transport, Danish Coastal Authority (DCA)	Denmark
5B	Risk assessments for different pilot sites on coastal flooding: - Lower Saxony pilot sites on flood risk scenarios.	Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency (NLWKN)	Germany / Lower Saxony
6	Synthesis of Safecoast and external orientation on integrated coastal zone management solutions in the NSR.	Environment Agency (EA)	United Kingdom / England

Table 1.2: Safecoast Actions and division of tasks

Since exchanging knowledge starts with exchanging information, considerable effort has been made to make relevant information accessible. Over 325 downloadable documents and over 80 news updates from the five North Sea countries with respect to coastal flood and erosion risk management and related themes are now available though the Safecoast internet site. With over 60,000 unique visitors in 3 years, there seems to be a need for a continuation of the internet site as an information exchange platform for research, policy and management, especially in view of sharing best practices as part of the implementation of the EU floods directive (2007) and EU recommendation on Integrated Coastal Zone Management (2002).

1.2 The synthesis report

The objective of this synthesis report is to provide an overview and comparison of the current practices, challenges, and possible responses with respect to coastal flood and erosion risk on the North Sea region, both for present and future, aiming to raise general awareness to these topics. Target readers of this report are scientists, managers, policy makers and the 'interested' general public.

The synthesis report focuses on Safecoast results and putting these in a logical context (see section 1.4). For this purpose, it has been important to also reflect on other (inter)national reports, projects and processes in order to provide a framework and context for Safecoast.

Safecoast aims to answer the question: **How to manage our North Sea coasts in 2050?**
In order to answer that question, a number of separate key questions need answering and are addressed in the synthesis report as follows:

- *What is the present context of coastal flood and erosion risk?*
- *How do we deal with problems now in terms of policy and management?*
- *What risk-related trends do we foresee by analysing scenarios for the future?*
- *What will be the trend of coastal flood and erosion risk in the future?*
- *Are current policies and measures sustainable with respect to the future?*
- *What could be promising adaptive strategies for the future?*

The questions above are dealt with in the respective chapters of this report (see section 1.4).

This report does not aim to provide detailed information on real or perceived personal or group risks to flooding, nor does it provide personal guidance on 'what to do'. The main objective of this report is to give an insight of Safecoast findings in the context of the current and possible future situation regarding coastal flood and erosion risk management in the North Sea region.

1.3 Scope

The concept of risk and risk management is fundamental to the focus of project Safecoast. In relation to the project Safecoast, risk is defined as the probability of coastal flooding or erosion happening, multiplied by the consequences (possible impacts), of such an event or process. Hence:

Risk = probability x consequence

Parameters such as water levels, wind, waves, the type and condition of coastal defences are parameters that can be used to assess the probability of flooding and the potential failure of coastal defences. Elevation data, socio-economical and demographic values are used to assess the extent and possible consequences of flooding or erosion in terms of damage to people and the built or natural environment.

Risk, however, is a dynamic concept that changes in both time and place. Climate change impacts and socio-economical change drive these changes, and also the condition of flood defences may worsen or improve. Hence:

Future Risk = probability under changed scenarios x consequence under changed scenarios

In project Safecoast attempts have been made to give quantitative and qualitative insight and information on current and future flood and erosion risks. Also, an overview is given for current and possible future management options based on Safecoast outcomes and other available information at different geographical and administrative levels.

To the extent possible the arbitrary year 2050 has been used as a future reference year. However, other reference years have occasionally been chosen where management decisions may need to be taken either in the shorter or longer term.

The geographical scope is restricted to the North Sea coastal zone of Denmark / DK, Germany / DE (coastal states of Schleswig-Holstein, Hamburg, Bremen and Lower Saxony), the Netherlands / NL, Belgium / BE (Flanders) and United Kingdom / UK (England). Together, they are referred to as the North Sea Region (NSR). Scotland and the Scandinavian Peninsula are not within the geographical scope of this report.

The thematic scope has been limited to the aspects of coastal and (occasionally) estuarine flooding from storm surges and to aspects of coastal erosion (illustrated by the coastal erosion atlas for Denmark). The interaction with riverine or pluvial (flash) flooding has not been the focus of this report.

1.4 Contents and organisation of the report

This report presents a compilation of the main findings from the different Safecoast projects, presented in the context of coastal flood and erosion risk management in the North Sea region. It also reflects the views, to the degree possible, of all stakeholders present in the different workshops that were organised between 2005 and 2008. Although priority has been given to the outputs from the different Safecoast actions, external sources of data have also been included where these contribute to the objectives.

The ‘backbone’ of this report is the framework of Driver-Pressure-State-Impacts-Response (DPSIR). Although this is a sequential approach to problem analysis and solution, it is not always easy to set the boundaries between the stages with accuracy, because of the changing nature of the problem and the interaction between the different stages. This approach has however been followed where possible.

The limitations on the scope of the project however only allow us to answer these questions in broader terms. For more detail and specific information the reader is referred to the different action outcomes or the extensive documentation that can be found on the Safecoast internet site. The table below shows how the different results of the Safecoast actions have been incorporated into the synthesis report.

Safecoast themes	Safecoast Actions		Reference to DPSIR approach	Chapter of synthesis report
Scenario development	1A/ 1B	Climate change and spatial / infrastructure developments in the NSR Integrated risk assessment:	Developments driving future coastal risks – Analysis of Drivers / Pressures	3. Developments driving future coastal risks
Flood risk assessment methodology	3B	Integrated risk assessment: - comparison of flood risk methodologies in the NSR	Risk assessment in coastal management – Assessing State / Impacts	4. Risk assessment in coastal management
Integrated risk assessment for the North Sea region	3A	Integrated risk assessment: - transnational flood risk assessment for NSR coastal regions		
Detailed risk assessments	5A	Risk assessments for different coastal erosion pilot sites: - Danish coastal pilot sites on coastal erosion and a coastal erosion atlas		
	5B	Risk assessments for different pilot sites on coastal flooding: - Lower Saxony pilot sites on flood risk scenarios		
Coastal protection master planning	4	Integrated master plan for Flanders' future coastal safety	Integrated planning to develop coastal management strategies – Drawing a Response	5. Strategy development to manage coastal risks
Risk communication and awareness	2	The informed society: - improve coastal risk communication and awareness and personal responsibility		
Synthesis and orientation on coastal zone management solutions	6	Synthesis of Safecoast and external orientation on integrated coastal zone management solutions in the NSR.		6. Key findings and recommendations

Table 1.3: Incorporation of Safecoast Actions in Synthesis Report

In table 1.3, the Safecoast actions have been associated with a number of topics, according to the sequence of the DPSIR approach. The different chapters of the synthesis report in relation to these are also given.

This synthesis report brings together the work from all Safecoast actions to provide a reference document for coastal managers and other interested parties. This report is not a technical report but does draw on technical expertise from the countries contributing. The report has been kept reasonably short in an effort to make it accessible to a large audience from different backgrounds.

The report is organised as follows:

- Chapter 2 describes the present flood and erosion safety situation and existing coastal risk management practices in the NSR;
- Chapter 3 describes the pressures from land use developments and climate change and describes some tools to model and assess these pressures;
- Chapter 4 describes risk assessment methods and presents an integrated risk assessment for the NSR, as well as a number of detailed risk assessments for specific pilot sites;
- Chapter 5 describes the integrated planning approach to coastal risk management and identifies management responses and adaptation strategies, both on-going and with potential to be used in the future.
- Chapter 6 summarises the main findings and recommendations of the Safecoast project.

The results of the individual Safecoast Actions have been documented in a set of separate and more detailed reports as presented in table 1.4:

Action	**Respective report** (draft or final)
1A/B	"Climate change and spatial / infrastructure developments in the North Sea Region", 2008
2	"The informed society", 2008
3A	"Flood risk trends in the North Sea region", 2008
3B	"Comparison between different flood risk methodologies", 2008
4	"Integrated master plan for Flanders future coastal safety", 2008
5A	"Consequences of Climate Change along the Danish Coasts", 2008
5B	"Flood risk assessment at two pilot sites – methods and measures", 2008
6	"Quick scan climate change adaptation", 2007

Table 1.4: Safecoast Actions reports

The above Safecoast reports and sub reports are available on the Safecoast internet site (www.safecoast.org) if further detail is required, and will be referred to in this report by the respective Action number.

2 COASTAL RISK MANAGEMENT: THE PRESENT CONTEXT

2.1 Overview of the North Sea coastal zone

2.2 Coastal flooding and erosion in the North Sea region

2.3 Overview of national and regional management policies

2 COASTAL RISK MANAGEMENT: THE PRESENT CONTEXT

2.1 Overview of the North Sea coastal zone

This chapter describes the present context of coastal flood and erosion risks and existing coastal zone policy and risk management practices in the North Sea region.

People and economy

The North Sea region is of high economic importance. The five North Sea countries are well developed western societies with considerable gross domestic products (GDP) that exceed the average of the 27 countries of the EU (expressed per capita). The population along the coasts however is not evenly distributed. Large stretches of rural areas are interspersed with urban areas with high population density. From North to South, major cities like Copenhagen (Baltic Sea), Hamburg, Bremen, Amsterdam, The Hague, Rotterdam, Antwerp and London predominate the coastal and estuarine zone (see table 2.1 and figure 2.1).

Country	**Region / State**	**People** [mln] 2007	**Area** [km^2 x 1000]	**GDP** current prices [Bln €] [a]	**Large coastal agglomerates** (more than 0,5 mln people) and (partly) below +5m Mean Sea Level
Denmark		5,5	43,1	188	Copenhagen [b]
Germany		82,4	357	2165	
	Schleswig-Holstein	2,8	15,8	67	
	Hamburg	1,8	0,8	78	Hamburg
	Bremen	1,5	0,4	24	Bremen
	Lower-Saxony	8,0	47,6	184	
Netherlands		16,6	41,5	468	Amsterdam, Rotterdam
Belgium		10,6	30,5	274	
	Flanders	6,1	13,7	157	Antwerp
		60,8	245	1672	
United Kingdom	England	50,7	130	1434	London

Source: Eurostat
a) Nominal Gross Domestic Product (GDP) year-averaged for the period of 2000-2005 b) Baltic Sea coast

Table 2.1: Area, people and economy

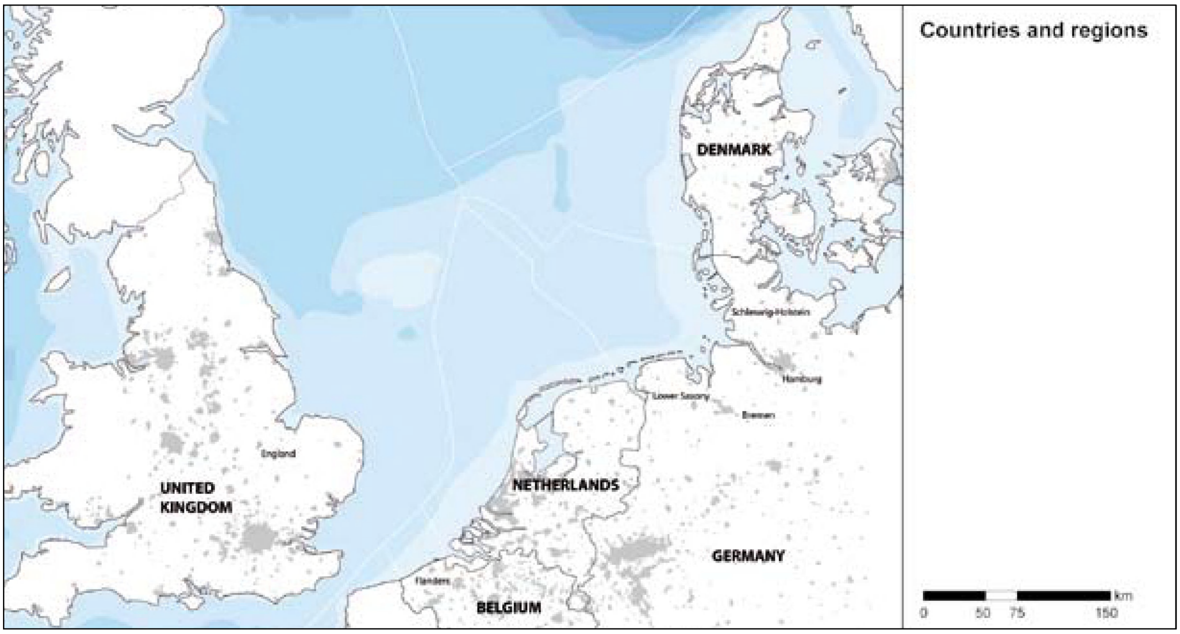


Figure 2.1: North Sea countries and regions.

Grey delineated urbanised areas adjusted from Corine land cover 2000

Environment

The North Sea is one of the world's major shelf areas. It is a relatively shallow semi-enclosed basin of continental shelf water, highly productive, with a depth ranging from around 30 m in the southeast to 200 m in the northwest. The North Sea includes one of the most diverse coastal regions in the world with a great variety of habitats (e.g. fjords, estuaries, deltas, banks, beaches, and marshes) some of which are designated as conservation areas at an international level. For example, Germany has nominated four Natura 2000 sites in the exclusive economic zone of the German North Sea (ICES, 2008). All areas that are protected under the Birds and Habitats Directives, including land and marine based Special Protection Areas (SPAs) and Special Areas of Conservation (SACs), form an ecological network known as NATURA 2000 (see also annex 3.3).

The Wadden Sea, covering parts of the Netherlands, Germany and Denmark, is a 25.000 km^2 area of mudflats, sandbanks, salt marshes, and shallow seas. It is one of the largest wetlands in Europe, and is important for many different species. It is a valuable nursery area for commercial fish such as herring and plaice, whilst harbour seals can be found along the coast. Over a third of this area is designated as a Natura 2000 site.

Internationally important wetlands border the North Sea. Ramsar listed wetlands are significant at a global level due to particular characteristics such as their ecology, botany, zoology or hydrology (Ramsar, 2008).

Minsmere-Walberswick, on the east coast of the United Kingdom, and Zwin, on the Belgian-Dutch border, are classified as Ramsar sites (Secretariat of the Convention on Wetlands, 2008).

Setting the coastal scene

The North Sea coast is diverse. It comprises large stretches of sandy or gravel beaches, sand dunes, soft and rocky cliffs, wadden and intertidal coasts, estuaries and human engineered coastlines with harbours, sea walls, dikes and storm surge barriers.

The flood risk area in the NSR amounts to some to 38,000 square kilometers, in which some 14 million people live and work. Table 2.2 gives some figures and estimates illustrating the coastal scene in the North Sea countries. In terms of population at risk, the Netherlands is the country with the greatest number of population at risk. England and Denmark have long coastlines to manage and Belgium holds the largest percentage of socio-economical developments in the 1 km coastal strip (as a percentage of the total coastline length, based on data from the Corine Land Cover 2000 database).

	Denmark	Germany	Netherlands	Belgium	United Kingdom	*Round off totals*
Total coastline length [a]	4,605 km	3,524 km	1,276 km	98 km	17,381 km	~27,000 km
Developed 1 km coastal strip [b]	9 %	11 %	12 %	48 %	-	-
Area below +5 mean sea level [c]	1,500 km^2	9000 km^2	19,000 km^2	2,500 km^2	6,500 km^2	~38,000 km^2
Population below mean sea level [c]	< 5,000	1,800,000	9,000,000	380,000	2,500,000	~14 million

Sources:
a) EUROSION (2004), the coastline length is a fractal and can never be precisely determined. Eurosion has used a uniform method; however, note that the coastline length in this table includes all bordering seas.
b) EEA (2006)
c) Estimates and in constant debate.

Table 2.2: Figures and estimates for the coastal scene

Brief regional description

Giving a detail description of the different systems would be impossible within the scope of this report. However, general distinctions are presented to give an overview of the regional variation. Below, five separate regions are briefly described. The five regions A to E correspond with the regions outlined on figure 2.2.

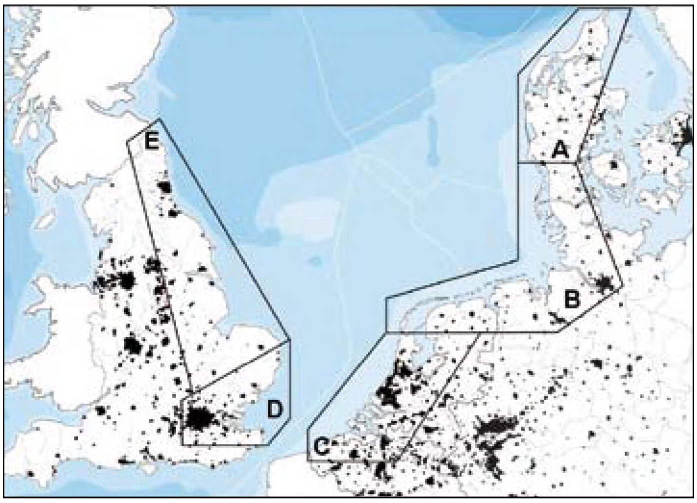


Figure 2.2: North Sea Region and a selection of areas (A-E) for regional description below

A. North and central Jutland: glacial landscape, beaches, dunes, fjords and sand spits
The Danish coastal area from Skagen to Esbjerg is characterised by beach ridges, large coastal dune systems (up to 10 km wide) and low population densities. Although coastal dunes are very common in Denmark, they cover less than 700 km² or 2% of the total land area. Famous for summer beach houses, the northernmost part of Jutland borders the Skagerrak and is separated by the Limfjord from the mainland, but is still commonly reckoned as part of the peninsula. It became an island following a flood in 1825.

The Western coast of Jutland belongs to the highly wave exposed and micro-tidal North Sea coast and is particularly vulnerable to coastal erosion (see figure 2.5). In the fjords of Nissum and Ringkøbing intertidal zones and salt marshes with brackish lagoons, meadows and reed beds are found. The Ringkøbing Fjord is a shallow body of water that is fed by tributaries from the land and that exchanges water with the North Sea through a narrow channel on its western edge. A barrier with 14 gates has been constructed across this channel in order to regulate water flow between the fjord and the sea.

The peninsula of Skallingen is found further south and at the northernmost edge of the Wadden Sea, close to Esbjerg, the largest shipping port of Denmark. Skallingen, a barrier-spit, contains one of the largest salt marsh areas in Europe and is protected under several international directives and conventions, including Ramsar.

B. Wadden coast: barrier islands, muddy coastlines and salt marshes
The coastline of the south-eastern North Sea is formed by a large intertidal transition zone, the Wadden Sea. With a length of about 450 km and an expanse of up to 30 km the Wadden Sea is one of the largest coherent tidal wetland in the world with all components characteristic for a gently sloping down soft bottom coast with a medium tidal range. As a postglacial formation - just about 10,000 years old - it is a young and highly dynamic ecosystem, still depending and constantly reacting on the forces of wind and waves and a changing sea level. Sand and, where the conditions for sedimentation it allows, mud are the natural soil components.

The Wadden coast stretches from Esbjerg, Denmark in the north to Den Helder, the Netherlands in the west, and therefore borders the entire German North Sea coast. The Wadden sea counts about 25 smaller and larger barrier islands and about 11 offshore dwelling mounds (DE: *Halligen,* see figure 5.4) and is proposed to become one of the Unesco World Heritage areas. There is no similar area in northern latitudes to be found.

With some exceptions, like the major port-cities of Hamburg and Bremen, the mainland coast of south Denmark, Germany and the north of the Netherlands is not densely populated despite a large number and variety of coastal towns. The mainland predominantly protected with sea dikes, usually with a gentle sloping, shallow and muddy foreland. The mainland still counts many villages and properties on dwelling mounds (NL: *Terpen,* DE: *Warften*), havens of refuge for humans and livestock in the centuries before the dikes were built.

The Ems estuary enters the Wadden Sea at the border between the Netherlands and Germany. Since the Ems estuary is an important navigation route, the estuary is heavily dredged, increasing the turbidity of the area. The morphology of intertidal flats, channels and gullies is complex and unstable. The sediment composition in the estuary varies from very muddy to very sandy. Other estuaries like the Elbe have been altered in order to optimize their function as shipping routes and they have an overall tendency for sedimentation instead of erosion and shipping channels are in constant need of dredging.

C. The Rhine-Meuse-Scheldt delta surrounded by the sandy beaches of Holland and Flanders
The Rhine-Meuse and Scheldt delta runs more or less from Den Helder (NL) to the Belgium-France border near De Panne (BE).

With the exception of the old but highest (about +12m NAP) Hondsbossche and Pettener sea dikes (see figure 4.4), sandy beaches and dunes characterise the Holland coastline. The Holland coast consists of a number of coastal towns and larger coastal cities like Den Haag. The Dutch lowlands ('hinterland, behind the dikes and dunes') are considered to be one of the world's most vulnerable areas to coastal flooding. About half of the Netherlands is situated below mean sea level, and about 60 % of the Dutch GDP (see table 2.1) is earned here.

Southward from Den Haag lies the Dutch-Belgian estuarine delta of the rivers Rhine, Meuse and Scheldt. In terms of casualties, the South-Holland and Zeeland area suffered the most from the 1953 storm surge. In general, this area is predominated by the large Rotterdam and Antwerp harbour areas and the estuaries with sand dunes on their seaward end. The estuarine peninsulas are connected by the storm surge barriers of South-Holland and Zeeland, known as the Delta Works. The Delta Works (see annex 2) were completed with the construction of the Maeslant storm surge barrier (1997) that, when closed, can protect the entrance of the Rotterdam harbour and the surrounding areas.

The open Western Scheldt holds important ecological intertidal areas and forms the harbour entrance of Antwerp. The relatively short Flanders coastline is bordered in the north by the ecologically important mouth of the river Zwin, and south by the French border. Zeebrugge, Dunkirk and Ostend hold important commercial sea ports. Most of the Flanders coastline may be typified as a sandy beach-dune system reinforced by constructions as groynes and boulevards. Coastal towns with hotels close to the shoreline are predominant in this area and characterise this highly developed coastal zone (see table 2.2).

D. Southeast England and London: Chalk cliffs, Thames Estuary and Essex Estuaries
Roughly defined, this area runs from Dungeness (Kent), one of the biggest expanses of shingle in the world, to Felixstowe (Suffolk), the largest container port in the UK.

Starting in the southwest, the high limestone cliffs around Dover are familiar landmarks in southern England. Moving north, the Thames Estuary is a large estuary where the river Thames flows into the North Sea. This estuary is one of the largest inlets on the coast of Great Britain and parts of it constitute a major shipping route to and from London. The appellation Greater Thames Estuary applies to the coast and the low-lying lands bordering the estuary itself. These are characterised by the presence of salt marshes, mudflats and open beaches: in particular the North Kent Marshes and the Essex Marshes. These are internationally important for wildlife (over 90% of the shoreline is of importance in view of EU directives on birds and habitats). Man-made embankments are backed by reclaimed wetland grazing areas; there are many smaller estuaries, including the Rivers Colne, Blackwater, Dengie, Crouch and Foulness, i.e. the so-called Essex Estuaries.

In terms of population density, this varies along the estuary. There are some larger settlements, such as Clacton-on-Sea (to the north in Essex), Herne Bay in Kent, and the Southend-on-Sea area within the narrower part of the estuary. In addition, the inner Thames Estuary, on both sides of the river, has been designated as one of the principal development areas in Southern England (see chapter 3).

E. East to North East England: the Norfolk cliffs, the Wash, and the Yorkshire headlands and pocket beaches

Near the port of Great Yarmouth, straddling the Suffolk-Norfolk border, are the Norfolk Broads. This 303 km^2 area of rivers, man-made broads and grazing marshes is designated as a National Park, and attracts 2.3 million visitors per year. The habitat is predominantly a freshwater ecosystem, although it is at risk of coastal flooding and incursion by salt water. Further round the coast are the cliffs of North Norfolk. These are made of silts, sands, clays and gravels and have been eroded by the North Sea for thousands of years. Kings Lynn, on the west coast of Norfolk, is where the River Great Ouse enters The Wash. The Wash is the largest intertidal embayment in England, stretching from Norfolk round to Skegness in Lincolnshire. It includes a large area of intertidal mudflats and salt marshes, and is one of Britain's most important winter feeding areas for waders and wildfowl.

Moving north, the county of Lincolnshire has a range of coastal habitats. Part of the coast is developed for tourism, for example the resort of Skegness. However, salt marshes, sand dunes, intertidal mudflats and saline lagoons all feature, giving the area a high conservation importance. Further up the coast is the Humber estuary, where the River Trent and the River Ouse drain into the North Sea. This estuary has a catchment of 24000 km^2 and a tidal range of 7.2 m. Around one third of the estuary is exposed as mud or sand flats at low tide. Large ports present include Immingham, Grimsby and Hull. In total, the estuary's port facilities deal with 13% of the UK's trade. The entry to the estuary is protected by Spurn Head, a spit connected to the mainland on the north side by a bank of sand, shingle and sediment. Further north, the Yorkshire coast displays a number of coastal landform types. These include high cliffs, bays, beaches and pocket beaches, shore platforms, headlands, stacks and sea caves, spit formations and rapidly eroding coastal sections. For example, the boulder clay cliffs at Holderness and the surrounding area are particularly vulnerable to erosion. The coast near Durham and Newcastle-Upon-Tyne is a designated Heritage coastline. It consists of coal layers overlain by lime stones and boulder clay, with coastal erosion being a main issue today. Figure 2.3 gives an overview of urbanised and protected natural areas.

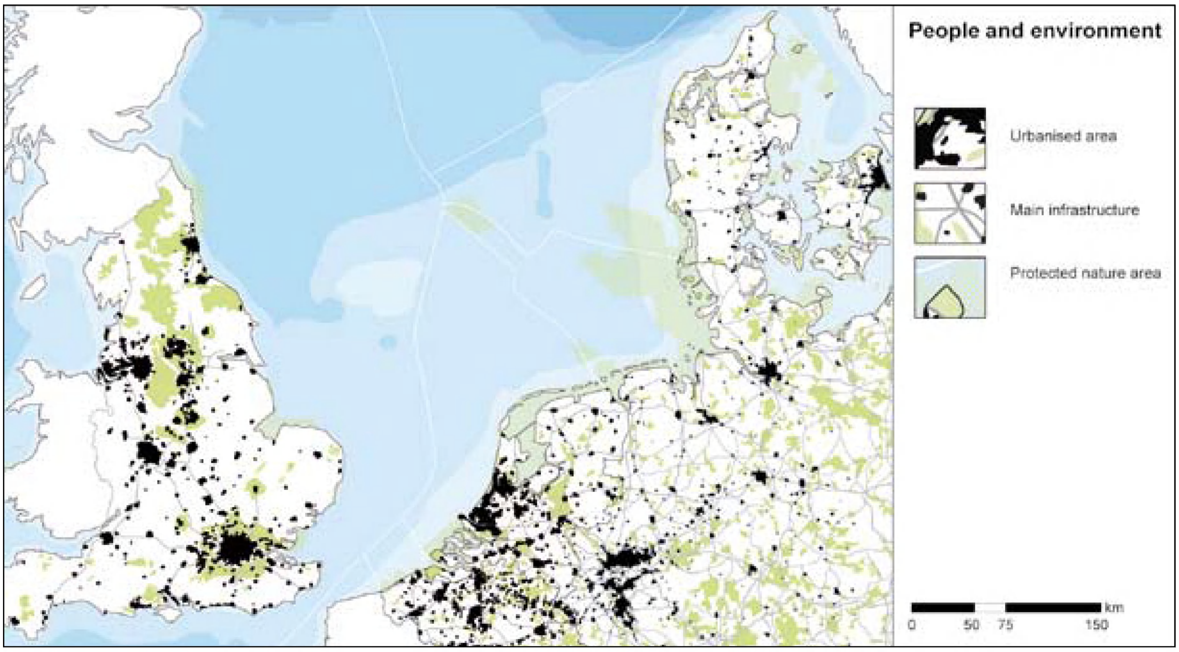


Figure 2.3: People and environment in the North Sea Region (see annex 3.3 for detailed map)

2.2 Coastal flooding and erosion in the North Sea region

Throughout history, numerous storm floods have struck the countries and regions around the North Sea. Over time, storm surges have altered parts of the geography of the mainland. Although for decades no major coastal flood disaster has happened in the North Sea region, the risk is ever present. Coastal erosion is closely linked to coastal flooding and is considered a natural phenomenon. Directly after a storm surge, erosion is easily spotted, especially on coasts defended by dunes. Over time, and without countermeasures, gradual coastline retreat occurs. The rate of this retreat depends on factors like the type of coast and energy of waves and tides. Coastline retreat therefore varies, but may be in the order of centimeters to tens of meters per year locally.

Figure 2.4 shows for 'the first-time' a compilation of national and regional elevation data (see annex 3.1). Within project Safecoast seven national and regional datasets have been accessed and referenced to match Normal Amsterdam Level (NAP). As shown, large stretches of low lying areas correspond with the deltas and estuaries of rivers such as the Thames, Scheldt, Rhine, Meuse, Elbe and Weser. Even so, elevation data is only one factor for assessing coastal flood risk. Water levels, presence and condition of flood defence measures, breach locations and breach growth rates, potential extent of a flood, potential damage and other factors are also important elements in flood risk assessments (see chapter 4).

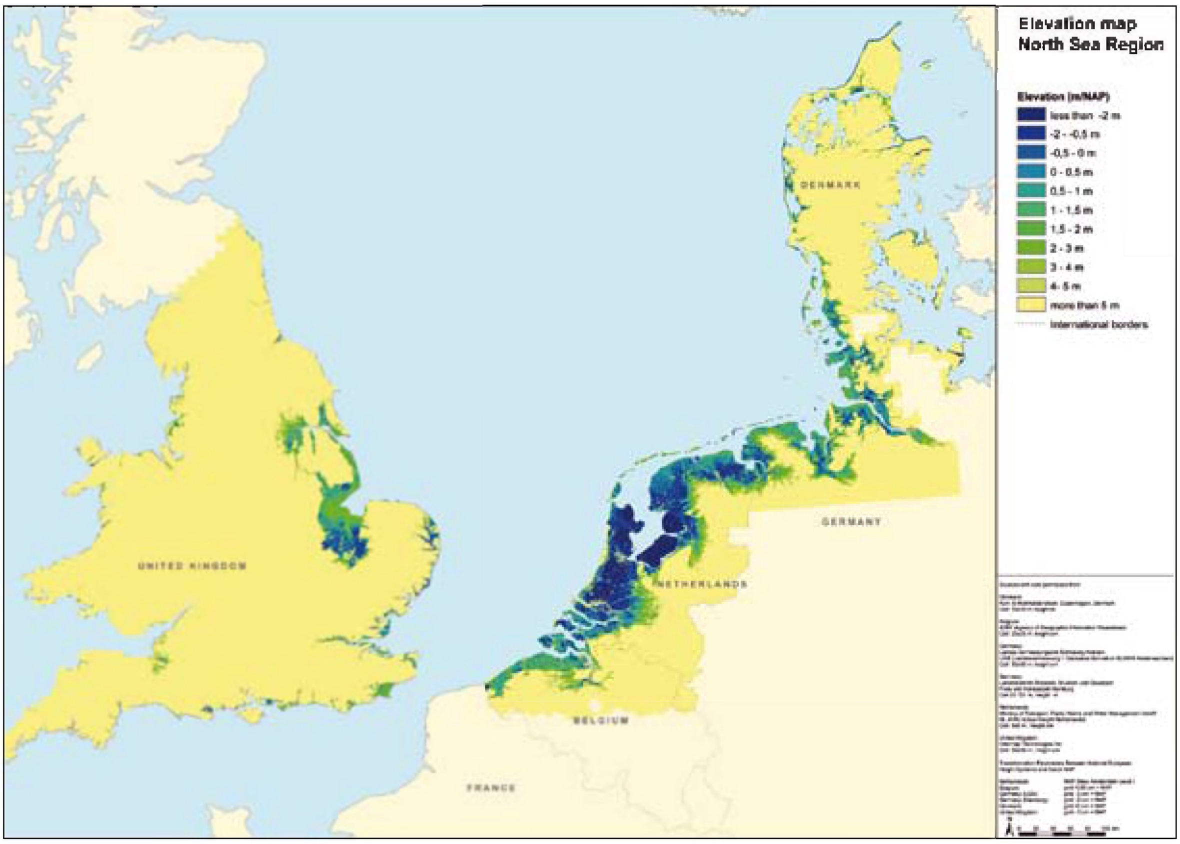


Figure 2.4: North Sea Region low lying areas, compiled and connected in Safecoast from seven national and regional databases (see annex 3.1)

Coastal flooding

Floods from the sea can be caused by overflow, overtopping and breaching of flood defences like dikes and barriers as well as flattening of dunes/dune erosion. Land behind the coastal defences may be flooded and experience damage. A flood from sea may be caused by a heavy storm (storm surge or tidal flood), a spring tide, or particularly a combination thereof. Also the combination of high river discharges during the winter storm season can cause flooding in estuaries and other transitional coastal areas.

A timely reminder of the ever present risk was the storm surge on 9 November 2007 which resulted in the highest water levels for 50 years along parts of the North Sea coastline and - in the Netherlands - led to the operation of a full scale dike watch for the first time in 30 years. The surge also caused considerable erosion at some Wadden islands and minor floodings in certain harbour areas. Storm surge barriers like the Thames barrier and Maeslant barrier were closed. In England, several hundreds of people were evacuated.

In the 20th century, major North Sea coastal floods occurred in 1916 (NL), 1953 (NL/UK/BE), 1962 (DE) and 1976 (BE). In total, the storm surges claimed over 2,500 lives in coastal flood plains and caused considerable psychological, economic and infrastructural damage (see table 2.3). Since 1976, no flood disaster from the North Sea has claimed lives.

year	countries	name	casualties	other consequences
1916	NL	Zuidersea flood	16	~300 km^2 flooded around the Zuidersea (later closed by closure dike, creating the 'IJssel lake')
1928	UK	1928 Thames flood [a]	14	London city centre flooded, ~4000 people roofless, flooding of Tate gallery and Westminster hall.
1953	NL/BE/UK	1953 storm surge	2161 [b]	>2500 km^2 flooded, >120,000 people evacuated, >200,000 killed livestock
1962	DE	Hamburg flood	345 [c]	~120 km^2 flooded, > 60,000 people roofless, 6000 collapsed buildings
1976	BE	Ruisbroek flood	1	~20 km^2 flooded, 900 properties flooded to about +4m MSL, 2000 people evacuated

a) combination high river discharge and storm surge; b) NL: 1836 / BE: 18 / UK: 307, excluding the 307 people that drowned at sea;
c) including 7 victims near Bremen, and 20 in Schleswig-Holstein.

Table 2.3: Coastal floods with casualties in the 20th century

All countries have responded to these flood disasters by introducing and intensifying flood risk management policies and management procedures. In the second half of the 20th century, major effort has been undertaken to strengthen the coastal defences in most countries (see section 2.3 and the historical timeline in annex 2).

Coastal erosion

Coastal erosion is the natural process of wearing away material from the coastal profile due to imbalance in the supply and export of material from a certain section. It takes place in the form of scouring in the foot of the cliffs or in the foot of the dunes. Coastal erosion takes place mainly during strong winds, high waves and high tides and storm surge conditions (acute erosion), and may result in net coastline retreat over time (structural erosion). The rate of erosion is correctly expressed in volume/length/time, e.g. in m^3/m/year, but erosion rate is often used synonymously with coastline retreat, and thus expressed in m/year.

Human influence, particularly urbanisation and economic activities, in the coastal zone has turned coastal erosion from a natural phenomenon into a problem of growing intensity. Coastal erosion is usually the result of a combination of factors - both natural and human induced - that operate on different scales. Most important natural factors are: winds and storms, near shore currents, relative sea level rise (a combination of vertical land movement and sea level rise) and slope (weathering) processes. Human induced factors of coastal erosion include: coastal engineering, land claim, river basis regulation works (especially construction of dams), dredging, vegetation clearing, gas mining and water extraction (Eurosion, 2004).

Major stretches of beach-dune systems are found on the Danish west coast, most of the Wadden islands, Holland and Flanders coast and parts of the English coast. Erosion and accretion processes of beach-dune systems are complex and dynamic. For acute erosion it is quite common that after the storm a recovery towards the original situation will occur due to natural processes under normal conditions (if there is a surplus of beach material). Coastal erosion of these sandy coasts is mainly caused by:

- A long shore gradient with redistribution of sand, because the long shore profile is not in a state of geologic equilibrium (may take thousands of years) or loss of sediment to meet the demand from adjacent basins as sea levels rise (e.g. the Wadden Sea, see box 2.1 in chapter 3).
- The so-called Bruun effect as a *local* adjustment of the cross-shore profile to sea level rise (see also p. 49).
- Wind erosion and dune formation, as winds blow the sand inland.

Also, retreating cliffs and coastal land sliding present significant threats to land use and development, for example on the south and east coasts of England (Defra / EA 2002). Although individual failures often tend to cause only small amounts of cliff retreat, the cumulative effects can be considerable. For example, the Holderness coast in England has retreated by around 2 km over the last 1000 years; at least 26 coastal villages were abandoned. On rocky coasts, coastal erosion may result in dramatic rock formations in areas where the coastline contains rock layers or fracture zones with different resistances to erosion.

Among other drivers, such as waves and tides, coastal retreat of soft cliffs is also caused by the wash out of fine sediments by rainfall and associated run-off. Subsequently, these finer sediments (sand and silt) are transported by coastal waves and currents and deposited in deeper water or in sheltered estuaries. Occasionally, there are some public misconceptions on the effect of dredging activities on coastal erosion. So far, there are no serious studies supporting this link.

Coastal erosion is widespread in the North Sea region. Since the sedimentary build up of the North Sea sandy coasts (over the past 10,000 years, in which sea levels rose about 40 m), no significant sediment (sand and gravel) input from either the North Sea floor or output from rivers exists anymore. It is primarily the available sediments budget that are shaped and redistributed by natural processes like wind and waves.

Structural, long-term erosion yields a gradual loss of sediments from a cross-shore profile. Figure 2.5 shows retreating coastlines due to sea level rise since 9000 BP (before present).

Box A shows average *annual* cliff retreat up to 2 m/yr (locally) over a length of 30 km coastline from Weybourne (west) to Happisburgh (east) in England in the period 1966-1985 (adjusted from North Norfolk District Council);
Box B shows beach-dune coastline retreat (adjusted from Taal et al, 2007) at the Dutch town of Egmond aan Zee (1650-1996). Parts of the old town have been lost to the sea. Today, the coastline is nourished annually with sand to (dynamically) maintain the coastline at its position in 1990.
Box C shows the beach-dune coastline retreat for two periods at a 30 km long Danish stretch of coastline between Thyborøn (north, at the Limfjorden) and Thorsminde (south, at the Nissum fjord). The graph (DCA, 2008) shows that coastal erosion (1 to 7 m/yr before 1977) is compensated by sand nourishments.
Without countermeasures or compensation for the loss of sediments (see section 2.3), most mainland coastlines in the North Sea region would further retreat landward under prevailing conditions.

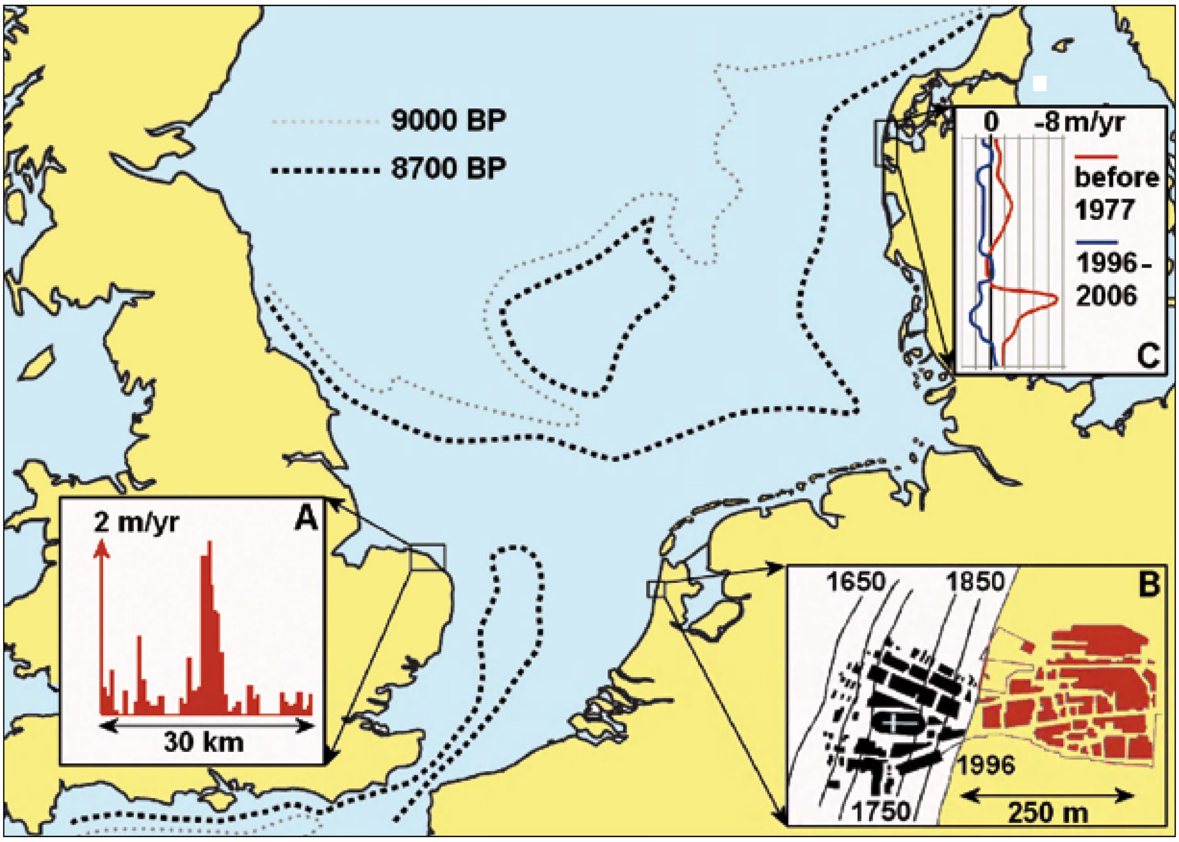


Figure 2.5: Retreating coastlines since 9,000 BP due to sea level rise. Historic coastlines adjusted after Jelgersma, 1979. Boxes A, B and C show recently retreating coastlines and are explained in section 2.2.

2.3 Overview of national and regional management policies

In this section the current attitudes, policies and management practices towards coastal flood and erosion risk in the North Sea region are described. Effort was undertaken in the Comrisk project (2005) to analyse this context and compare policies and measures between the North Sea countries. Some of that work is briefly described here (and updated where possible) to set the scene in the following chapters of this report.

Historical perspective

Throughout history, citizens and their governments have struggled with the challenges presented by the risk of flooding and coastal erosion. Their methods have varied in time and place from dwelling mounds, land reclamation, hard and soft engineering measures to zoning and planning policy, to evacuation planning and combinations thereof. The objectives served by these methods are not static either. Trade-offs made between economy, flood safety and, later, environment have differed in time and place.

Historically, local authorities have been responsible for the safety of most coastal zones along the North Sea. Densely populated areas are traditionally protected with 'hard' defence structures, whereas sparsely populated areas and natural reserves are usually protected with 'soft' measures like dunes and wetlands. The historic timeline in the Annex 2 provides an overview of policy and management milestones in the 20th century in the different North Sea countries. An interactive digital timeline can be found on the Safecoast internet site.

Attitudes to flood risk in the North Sea region

The five North Sea countries show similar attitudes towards managing flood risk, but at some points they may differ, caused by the fact that physical context defines the appropriate strategy. However, driven by history and culture, societal views on how to cope with risk may differ as well. For instance, the choice between either permissive or prescriptive legal or non-legal structures for managing flood risk is often a result of societal views on who is responsible or who funds or benefits from a certain measure.

The underlying contextual factors in combination with the values, norms, beliefs and attitudes in societies in general, and in the policy field in particular are shaping risk philosophies. The cultural plurality in risk attitudes implies that the question of how society ought to deal with risks can only be answered through a public debate – a debate in which people will necessarily discuss their perception of risks and risk management from different points of view and different conceptual and ethical frameworks.

Superimposed on incremental policy changes, the effect of disaster events has played and still plays an essential role in the decision making in flood risk management. A major flood disaster considerably influences societal view on and support for government initiated measures. A Dutch study (COT, 2004) and also a study from the UK (Johnson et al, 2005) with the revealing title 'crises as catalysts for adaptation' describe this phenomenon more closely. The historic timeline in annex 2 also visualises this phenomenon and clearly shows that this is not country or region specific. It may be observed that an appropriate response to a perceived risk is more difficult to realise than response to crisis (to prevent a next crisis).

A precautionary (DE: *vorsorgenden*) attitude to risk based on safety standards (embedded in law or not) is dominant in Denmark, German coastal states, the Netherlands (dike ring system) and Flanders. For instance, the German coastal state Schleswig-Holstein works with a 'leitbild' (Probst, 2002) or 'leitmotiv' where flood risk management to some extent overrules nature protection. However, in some instances, the precautionary system of flood defences does leave parts of coastal areas less protected, such as parts of harbour areas (e.g. Bremerhafen) and in parts of coastal towns. For example, this year specific protection levels will be developed for thirteen Dutch coastal towns that are partly seaward of the protective dunes. In contrast, in England the strategic objective is not to solely minimise flood or erosion losses but to maximise the efficiency and sustainability of the system (river catchment or sediment cell) by means of strategic planning (e.g. shoreline and estuarine management plans, SMP's and EMP's respectively).

Coastal risk management policy context

Despite the fact that policy options need to be highly contextualised, some general approaches and differences may be identified across the North Sea countries (see table 2.4).

	Denmark	Germany	Netherlands	Belgium	United Kingdom
Main policy	Protect where needed	Protect (e.g. 'leitmotiv' in Schleswig-Holstein)	Protect	Protect	Holistic approach to manage risks from all types of flooding
Decision criteria	Size of population at risk, pragmatic	Absolute standard, but differs somewhat in each coastal state.	Legal safety standards	Absolute standard	Economic efficiency, appraisal led and indicative standards, funding priority system
Legislation	Permissive legislation - Planning Act (3km) - Nature protection Act (300m zone) - Coastal protection Act (licensing DCA) - Specific dike Acts	Permissive legislation - State Water and Dike Acts - 50m reservation behind dikes (Lower Saxony Dike Act) - Coastal defence arranged in Master Plans (Generalpläne, no legislation)	Prescriptive legislation - Flood defence Act - Only applies for dike ring areas. - Legal safety standards - 5 year evaluation - Hold 1990 coastline decree - 50m reservation behind dikes	Permissive legislation - Regionalisation Act - Dunes decree	Permissive legislation - PPS25 Planning Policy statement 25 with non-binding advice from EA (in consultation) - Coastal protection Act 1949 - SMP's and EMP's
Safety standards	Safety levels are proposed by DCA and approved by Ministry. Safety levels are based on CBA and range from 50-1000 years	Deterministic safety levels expressed as a combination of design water level, wave run-up and slope criteria. In practice more than 100 years	Legal safety standards (standards partly based on CBA in 1960) per dike ring area. Standards in coastal area range from 2000 to 10,000 years - Tailor made safety standards underway for 13 coastal towns	In practice a minimum safety level of at least 1000 yrs is normal	No target risk or safety standard. Based on appraisal led design using risk analysis and CBA (moving to MCA). Indicative standards range from 50 to 1000 years
Organisation	Centralised, but with emphasis on private ownership in coastal zone	Centralised at level of 4 North Sea states (not federal): Lower Saxony, Bremen, Hamburg and Schleswig-Holstein. De-centralised operational management (water boards)	Centralised policy framework. De-centralised operational management (water boards)	Centralised at the level of Flanders (all coast)	Centralised policy framework, decentralised decision making and engineering
Funding	National level funds sand nourishments, private owners finance coastal protection slightly co-funded by national government)	Federal level funds 70% State funds 30% Occasional EU contribution	National level funds sand nourishments and strengthening costs flood defences Water boards fund maintenance costs (water board taxes)	Regional level (Flanders) funds coastal protection (both construction & maintenance)	National funding based on risk and CBA and priority system for funding requests balancing high level targets with local interests
Source: Adjusted from Jorissen et al., 2000					

Table 2.4: Description of current coastal risk policy context in five North Sea countries.

The range of *main policy* options ranges from precautionary measures (e.g. robust designed flood defences based on safety standards) to making proportional decisions based on the principles of cost/benefit analyses accompanied with risk assessments (e.g. the holistic and appraisal led approach used in England). In Denmark a pragmatic mix is used given its long coastline, predominantly low density population, and emphasis of private ownership of coastal land. Even though main policies may somewhat differ in the North Sea Region countries, it still leads to similar management choices, especially when protecting densely populated areas from flooding.

Decisions involving the effort of constructing or maintenance of protection works are naturally influenced by the main policy or traditions in a specific country or region. As a result, *decision criteria* may differ. For instance in the Netherlands, the lawfulness of safety standards or a legally defined coastline influences funding, construction or maintenance decisions, in which national government consults the water boards. More pragmatic, prioritised or appraisal led approaches benefit more from tailor made options locally, but sometimes lack consistency in strategic planning and overview.

Several forms of *legislation* related to coastal risk management exist in the North Sea countries. In the Netherlands, the safety standards of the Flood Defence Act (1996) are only partly based on a nation-wide cost-benefit analysis from 1960. The Act describes responsibilities and prescribes 5 yearly evaluations, based on frequently updated evaluation regulations and guidance documents provided by national government. In other countries, certain Acts or binding decrees are also present, but mainly focus on the division of responsibilities (German Water Acts), development zoning and planning (Denmark) or nature protection, such as the Dune Decree in Belgium. In the last decades the role of EU legislation has increased significantly. The bird and habitats directives (Natura 2000), as well as the EIA and SEA directives (see section 5.2) also influence decision making in terms of mitigating or compensating for environmental impacts of coastal development initiatives.

Comparing *safety standards* (if present) between countries is difficult if not impossible. This is because of the various methods, models and underlying assumptions in monitoring, hydraulic boundary conditions, and design of flood defences. In many countries the risk based approach is currently studied and evaluated, although England remains unique having this approach embedded in decision making. The 10,000 year safety standard in the Netherlands was matched with the most unfavorable water level (+5m NAP at Hoek van Holland) that could have happened during the flood disaster of 1953, if all possible negative conditions would have interacted. Most safety standards in the other North Sea countries are based on (deterministic) design water levels for a certain return period. However, the actual defence standard may be ascertained by its ability to withstand a certain hydraulic conditions or be based on a risk assessment or cost/benefit analysis approach.

Historically, individuals and local authorities have been responsible for the safety of most coastal zones and flood prone areas along the North Sea. Today, the *organisation* of coastal flood and erosion risk management shows a more diverse setting. In general, policy responsibility is at the national level (Netherlands, UK, Denmark), or regional level (German states, Flanders). However, in Denmark, coastal management decision making is usually a local affair as the emphasis on private ownership of coastal land is particularly strong. The responsibility for operational management is in most countries is organised at a decentralised level (e.g. water or drainage boards).

The *funding* of coastal risk management measures, such as coastal protection schemes or sand nourishments follows the differences in organisation. Usually, funding for coastal protection is shared and divided by different administration levels according to their tasks and competences. In the Netherlands all funding for strengthening flood defences or nourishments comes from the national government. The sub-regional water boards tax their residents for the operational management of flood defences. In Denmark funding of protection works is private or arranged within municipalities, whereas sand nourishments are funded by national government. Even though coastal protection is the full responsibility of the German coastal states, the federal German government funds about 70% of the total costs. In the UK, the majority of funding comes from central government and is based on cost-benefit analysis (CBA) within the appraisal of schemes.

Table 2.5 shows estimates of current governmental expenditure on flood risk management (in million €) for different NSR countries, averaged over the period 2000-2006. The figures are estimates and there are information gaps, and are therefore not strictly comparable since some of the figures also include flood risk management from river flooding. Hence, the figures may be observed in terms of their order of magnitude. Also National Gross Domestic Products (in billion €) are presented for reasons of comparison and are averaged over the period 2000-2005. Sub-national GDP's are presented when relevant for financing coastal protection, such as in the four federal North Sea coastal states of Germany, Flanders and England. Costs related to private flood insurance (e.g. England) or private ownership (e.g. Denmark) are not included in the table. As observed, the annual government spending on (coastal and/or river) flood protection, expressed as percentage of GDP is estimated to be far below 0.1% in all North Sea countries and regions.

		Denmark	Germany	Netherlands	Flanders	England
Annual spending on coastal protection 2000-2006 averaged	[Mln € / yr]	11 [a] (coast)	110 [b] (coast)	550 [c] (coast / rivers)	20 [d] (coast)	620 [e] (coast / rivers)
GDP (nominal) Current prices	[Bln €] national	188	2156	468	274	1672
2000-2005 averaged	[Bln €] subnational		353 [b2]		157 [d2]	1434 [e2]
Sources: National and regional policy documents and master plans, National treasuries, Eurostat						

a) DCA (2008) – Annual coastal protection spending on 110 km of Danish west coast in 2004-2008 are 86 mln Krone – Euro conversion fixed at 0,134. Dikes at Danish Wadden coast funded locally (no data, but expected to be below € 5 million).
b) Estimate total of average coastal protection spending in the 4 coastal states that border the North Sea.
b2) Cumulative (regional) GDP of 4 North Sea coastal states (sum of the figures as presented in table 2.1)
c) This amount includes total flood defence (rivers and coasts) spending from both national government and the water boards. The part of this amount that is allocated annually for coastal protection alone is estimated at 10-20% (among which annual nourishments of 45 million). Water in beeld, 2007 and Dutch National treasury (2008)
d) Figures by MOW MDK Flanders coastal division (~50% nourishments). Excluding spending related to the Sigma plan (880 million until 2030)
d2) GDP of Flanders region only (Vlaams Gewest).
e) Includes central and local government spending. Pound – Euro conversion fixed at 1,45 (Defra, 2006c)
e2) GDP England (excluding Scotland, Wales and Northern Ireland)

Table 2.5: Estimates of current governmental expenditure and GDP in the North Sea countries

Coastal risk management measures

In the North Sea countries, an extensive list of different measures and instruments within coastal risk management exists. For a selection of these measures and instruments, a brief overview is given in table 2.6. The next description follows the measures and instruments as depicted in the table.

		Denmark	Germany	Netherlands	Flanders	England
Flood and erosion protection	Dike foreland management	●●	●●●	●		●
	Coastal nourishments	●●●	●●●	●●●●	●●●	●
	Primary defences	●●	●●●●	●●●●	●●●●	●●●
	Secondary dike lines	●	●●	●●		
	Managed realignment					●●●
Limiting potential consequences of floods and erosion	Restricting (new) developments coastal zone	●●●●	●●●	●●●	●●	●
	Restricting (new) develop-ments in flood-prone areas	●	●	●		●●●
	Construction of flood resistant buildings	●●	●	●		●●
	Storm surge warning	●●●	●●●	●●●	●●●	●●●
	Risk/crisis communication	●	●●	●●	●●	●●●
	Evacuation planning	●●	●●	●	●	●●●
	Flood insurance	●●●	●		●●	●●●●

● Limited use
●● Some importance
●●● Quite important
●●●● Crucial

Table 2.6: National / regional emphasis in coastal risk management measures. Adjusted after Comrisk (2005)

Flood and erosion protection measures

Although present in other countries, *dike foreland management* or salt marsh management is a particularly important aspect of coastal defence in Germany and parts of Denmark. Salt marshes in front of main dikes are defined by law as elements of coastal defence. In Schleswig-Holstein, the salt marshes have to be preserved in a defined width and maintained as a protection element for the main dike as a legal obligation. Groynes also stabilize the dike toe against erosion were salt marshes are absent and therefore can enhance salt marsh creation (CPSL, 2005). Salt marsh management restoration techniques are also widespread in the North Sea region for reasons of nature conservation.

Today, *coastal nourishments* are a widespread soft engineering option in the North Sea region, and intensively used in the Netherlands for maintaining the base coastline of 1990 (see box 2.1). The link with flood risk management is especially present where dune areas or salt marshes are vital elements of flood protection. Other types of coastline protection, such as break waters, groynes and revetments have been used commonly along the North Sea coasts. However, to a large extent these hard constructions have been replaced by sand nourishments in the course of the 20th century, especially in Denmark, Germany, the Netherlands and Belgium. For instance, in Denmark, groynes were the only type of protection until 1977 and have gradually been replaced by sand nourishments.

BOX 2.1: Coastal nourishments

Since the fifties of last century, all countries in the North Sea region have experimented with artificial provision of material to beaches. Beach nourishment may be defined as the supply of material that has been dredged from the seabed or (rare in most countries) from inland sources (e.g. sand or gravel pits). In literature synonyms for beach nourishment are beach recharge, beach feeding or beach replenishments. For some decades more (larger) nourishments have been performed on the shore face (the lower submerged part of the coastal profile), especially at the beach-dune systems of the Netherlands and Denmark. This was to reduce costs (easier to reach by seafaring dredgers) and resulted from improved understanding of morphodynamic coastal behaviour (see section 2.2). In the **Netherlands**, sand nourishments are since 1990 an important part of the 'soft measures where possible' policy and mainly used along the outer shores of the Wadden islands and the sandy Holland coast, aiming to maintain the legally defined base coastline (BKL) of 1990. In 2000 it was decided to raise the annual volume from 6 to 12 million m^3 to compensate for the effects of sea level rise (see figure 2.6). Since then, the 'eroding' percentages of exceedence of the base coastline (BKL reference year 1990) have fallen from more than 30% in 1991 to a steady 8% in 2007 (RWS, 2008). Evaluations in 2002 and 2005 have concluded this to be a successful policy. Since the start of nourishments in 1965, a total volume of about 200 million m^3 of sand has been added to the Dutch coast. In **Germany**, sand nourishments are restricted to the Wadden islands of Norderney, Langeoog, Föhr and particularly Sylt, also for its importance for tourism. Estimates are that a cumulative volume of about 45 million m^3 has been added to these islands since the first sand nourishments in 1951 (CPSL 2001 / 2005). Occasionally, sand is used for strengthening of the protecting dunes, as was done on the islands of Langeoog and Juist in 2007. Also in **Belgium** sand nourishments are used frequently. For the purpose of coastal protection and beach tourism, in the period 1992-2006, almost 9 million m^3 has been added to the beaches of Flanders, mostly by lorries (Mira, 2007). Although poorly documented (and therefore not incorporated in figure 2.6) in **England**, estimates are that an average of 0.3 million m^3 of sand and shingle were added annually to the English beaches between 1970 and 1994, even though annual totals rose over this period. Since the 1996 peak level of 3.4 million m^3, average annual quantities are estimated to be less than 2 million m^3. The largest beach nourishment in England (1994-2007) is intended to defend a stretch of 24 km Lincolnshire coast with about 9.4 million m^3 of sand (BAR, 2005). As part of a Comcoast realignment pilot, in 2007 a first of its kind mud nourishment (recharge) of a salt marsh was performed at the Crouch estuary for reasons of habitat restoration and flood defence. In **Denmark**, with an annual average of about 2.5 million m^3, about 97% of the nourishment volume was applied on the Danish west coast, (see also figure 2.5 and 2.9) where dunes protect the hinterland from flooding (Hanson et al, 1999).

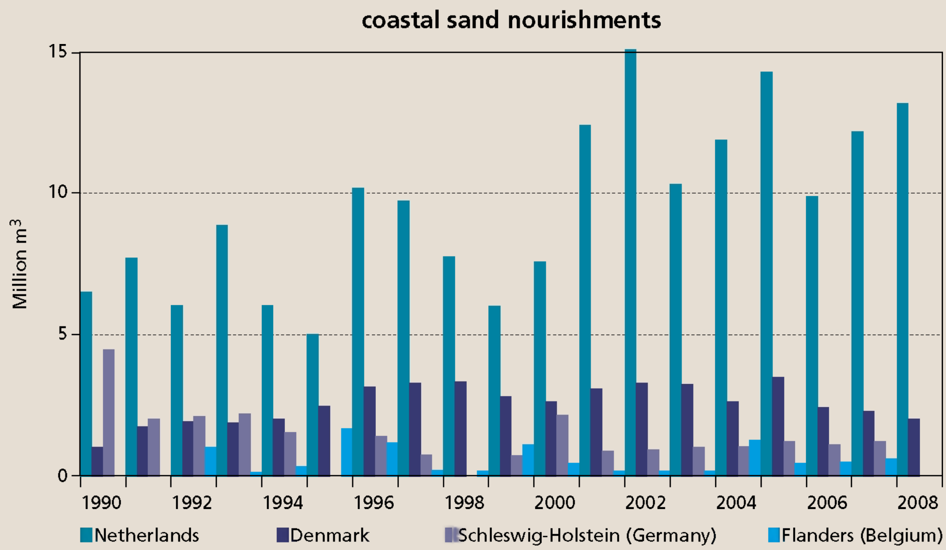


Fig. 2.6: Coastal sand nourishments in a selection of North Sea region countries. For Schleswig-Holstein the (small) quantities for the isle of Föhr are missing since 2001 *) planned for 2008.

Primary defences can be defined as main elements for flood defence such as dikes, sea walls, dunes or flood barriers and are common practice in the North Sea region. Along most of the North Sea coasts a combination of coastal urbanization and the expertise of coastal engineers has led to the profound modification of the coastline, especially in the periods after flood events (see historical timeline, annex 2).

Belgium, The Netherlands, Germany and the southern part of Denmark rely greatly on their primary flood defences such as dikes, dunes and storm surge barriers. Especially after the 1953 and 1962 storm surges primary defences have been strengthened and raised significantly in the North Sea countries and has greatly reduced the probability of coastal flooding (see figure 2.7 and 2.9).

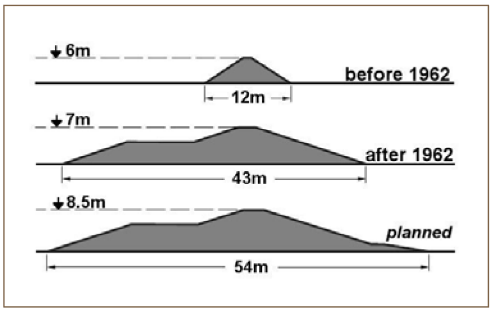


Fig 2.7: Development of the dike profile near Hamburg, Germany. (adjusted from: Hamburg construction programme 2007)

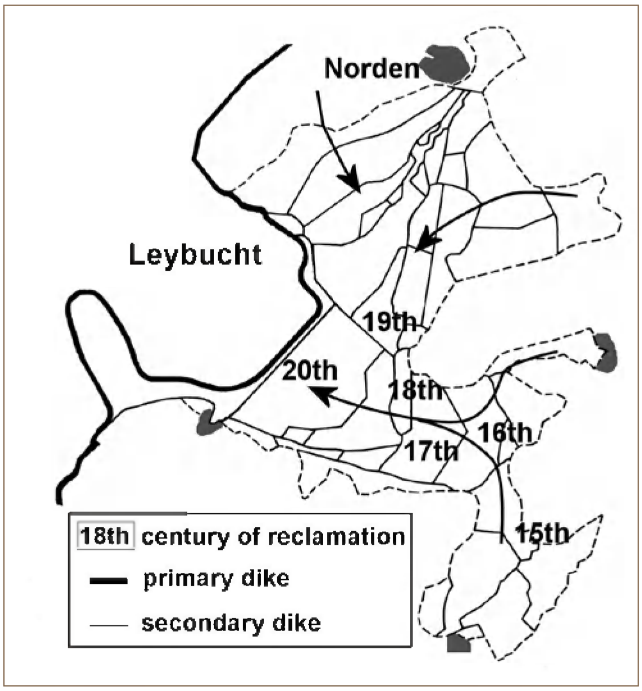


Fig 2.8: Example of step wise land reclamations over the centuries, resulting in older, secondary dike lines near the town of Norden, Germany (adjusted from source: NLWKN, after Homeijer)

Secondary dike lines or defences are situated landward of a primary sea dike. Normally, they are former primary sea dikes, which shifted into their present status as a new dike was built in front of them. These secondary dikes may be several centuries old and lack the dimensions of modern sea dikes. Further, as the coastal defence interest is normally focused on primary dikes, the state of maintenance may be poor. Small stretches may even be removed or lowered for, e.g. roads or houses. Secondary dikes are widespread along the Dutch and German mainland coast and are sometimes called 'summer dikes'. In some areas, several secondary dikes are arranged in a row as a result of repeated reclamations (see fig 2.8). (CPSL 2005). In case of breach of the primary defence, secondary dikes can divert or delay floods, which can be important for detailed risk assessments and informing crisis managers when preparing for evacuations. In the Netherlands a study is underway to assess the possibility to further compartimentalise vulnerable dike rings for this reason.

Managed realignment, or managed retreat, is one of several 'soft' engineering options available to coastal planners, especially in England. In most cases it involves breaching an existing coastal defence, such as a sea wall or an embankment, and allowing the land behind to be flooded by the incoming tide. This land is then left to be colonised by saltmarsh vegetation. When established, the vegetation disperses wave energy during storm events, reduces erosion rates and provides an important habitat for coastal flora and fauna. If the newly breached area is backed by low-lying land, a new embankment is usually constructed beforehand on the landward side of the site to reduce the risk of flooding. Although a relatively new idea, it is widely recognised that managed realignment can reduce the costs of coastal defence whilst offering numerous environmental benefits. In England and on Germany's Baltic Sea coast, managed realignment is often seen as the cheap and sustainable coastal defence option. On the North Sea coasts of Germany, the Netherlands and Belgium, however, managed realignment as a flood risk management strategy is not used for different reasons: lack of public support, especially where flood disasters have happened in the past, or simply for economical reasons (see chapter 5).

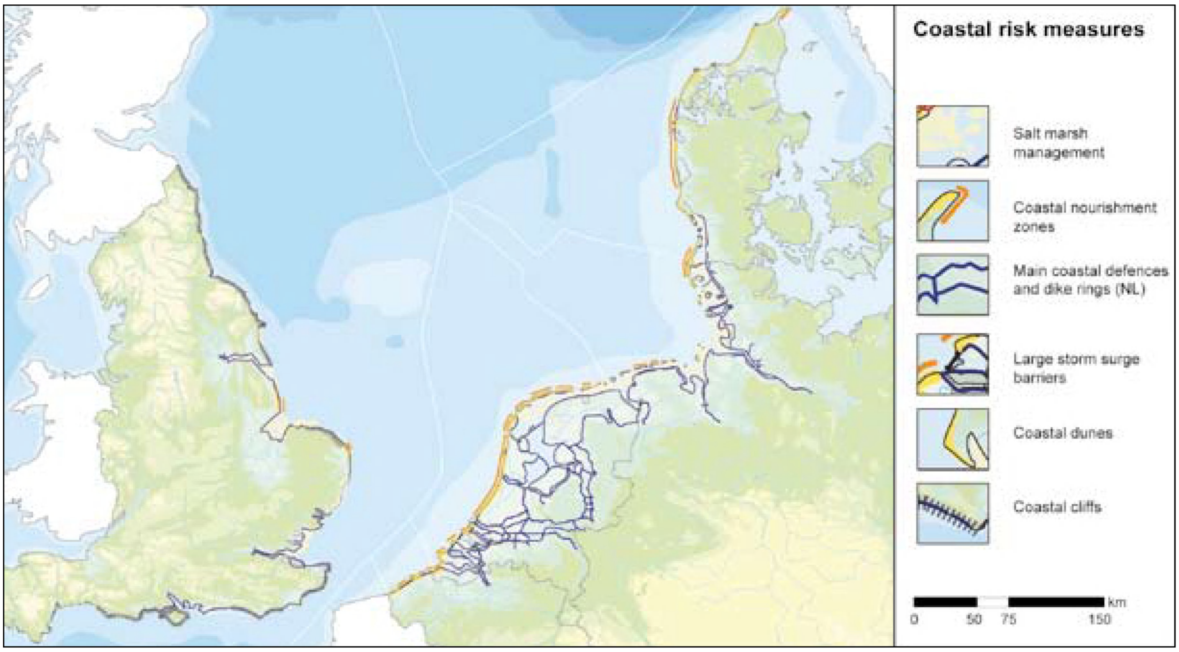


Figure 2.9: Overview of coastal risk management measures in the North Sea region.
See Annex 3.2 for a more detailed map.

Limiting consequences of floods and erosion

When considering coastal flooding and erosion, physical measures as described above are not the only way of coping with the forces of nature. In many North Sea countries policies with respect to limiting the adverse consequences of flooding and coastal erosion are implemented or in development, ranging from planning policy, evacuation planning, risk and crisis communication and compensation for certain kinds of damage. Below some of these instruments are described briefly.

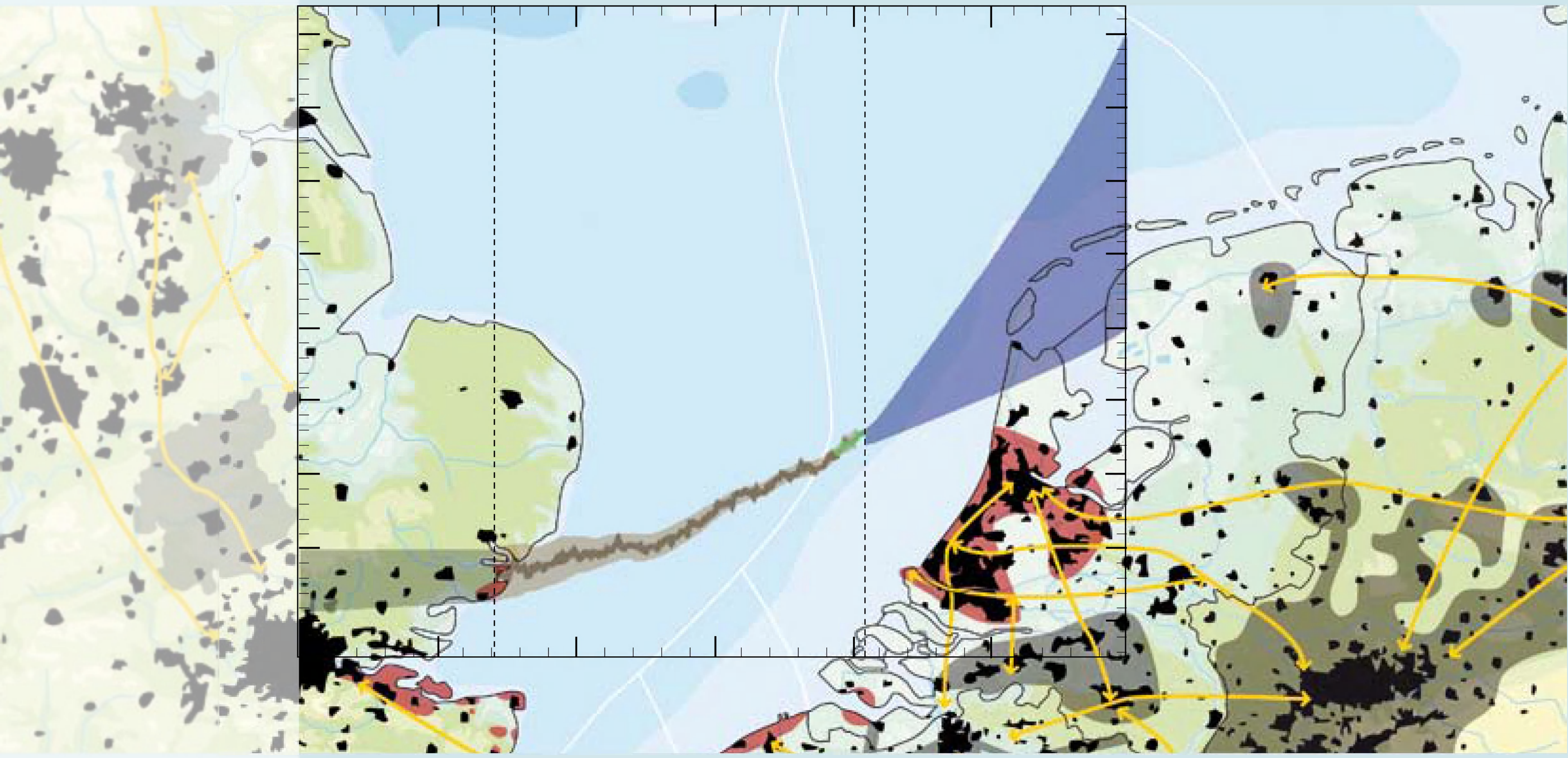
With respect to *restricting developments in the coastal zone,* these are mainly focused on for instance the status of dune areas as a flood defence element (e.g. in the Netherlands) and for nature conservation purposes in most countries, since a large part of the North Sea dune areas are part of the EU Natura 2000 network. Also, the areas directly behind dikes are commonly reserved for future dike strengthening, since the raising of dikes by one metre usually affects its width by a factor 5-15 (depending on the type of dike, see also figure 2.7 for a common dike profile in Hamburg). In Denmark, The Nature Protection Act lays down a 300 meter in- land prohibition zone along almost the entire Danish coast. In summer cottage areas the protection zone is reduced to 100 meters however, urban areas are exempted. In the Netherlands the ongoing discussion on developments in the coastal zone has led to the introduction of the 'coastal foundation' in the National Spatial Planning Strategy (VROM, 2005) and in 2007 a further clarification of responsibilities in the coastal zone was described (VenW, 2007).

With respect to *restrictions on developments in flood-prone areas*, the North Sea region countries show even more complex decision and planning structures and are mainly driven by the issue of riverine flooding. Although recently under discussion, in the Netherlands, the dike ring system with its safety standards has led to considerable disregard of flood risk in the planning policy within the dike ring areas. In England, the recently introduced Planning Policy Statement 25 (PPS25; C&LG, 2006) aims to ensure that flood risk is taken into account at all stages in the planning process to avoid inappropriate development in areas at risk of flooding, and to direct development away from areas at highest risk. PPS25 uses a 'sequential test' so that there is clearer matching of development to the degree of risk. However, PPS25 does not impose an outright ban on developments in high-flood-risk areas where for economic reasons development could go ahead with suitable risk reduction measures.

In the North Sea region countries, the construction or existence of *flood resistant developments* or robustly designed property is only used occasionally and especially in areas that are not directly protected by flood defences. Examples are in parts of Hamburg's 'hafencity' where residents live on the third flood or above, and similar attitudes are found in other coastal towns along the North Sea region. This approach, sometimes called flood mitigation, may result in many forms and types of adjustments to regular building code in order to minimise adverse effects of occasional flooding.

Also in the field of crisis management many instruments exist to limit the potential adverse consequences of coastal flooding. In all North Sea region countries advanced monitoring and *storm surge warning* systems are operational. Early warning is essential for coastal flooding since storm surge forecasting times tend to be shorter than for river flooding. Storm surge warnings serve authorities for taking repressive action on vulnerable flood defences (e.g. sand bags) and are important for *crisis communication* towards citizens. In England, the *Floodline* information service provides up to date local flood warnings and gives guidance to the public on how to prepare and cope for/with floods. *Risk communication* in the North Sea countries is predominantly done with general awareness campaigns and government-provided flood risk maps that are mostly accessible via the internet. In the framework of Safecoast, a communication campaign was held in Schleswig-Holstein (see chapter 5).

In most North Sea countries, except the Netherlands, also *flood insurance* is available. In Flanders this is integrated in the regular fire insurance. In 1961, the UK government made an agreement with the Association of British Insurers (ABI) to continue with private flood insurance, but only if the government would put plans in place to improve flood defences and flood management. Since the recent river and pluvial floods of 1998, 2000 and 2007 this agreement is topic of renewed discussion.



3 DEVELOPMENTS DRIVING FUTURE COASTAL RISKS

3.1 Need and function of scenario analysis

3.2 Spatial and infrastructure developments

3.3 Climate change scenarios

3.4 Planned developments in coastal risk management

3 DEVELOPMENTS DRIVING FUTURE COASTAL RISKS

Climate change is putting an additional pressure on the capacity of coastal defences to protect human life and assets because of sea level rise and possible increased storminess. The risk of erosion and subsequent loss of land is also greater because of the increasing rate of erosion of soft defences that may undermine the existing flood defences. These changes in risk however are not easy to predict with accuracy.

The impacts of climate change on the extent, duration and intensity of rainfall can be considerable and may lead to increasing drainage issues related to pluvial and riverine flooding. Other impacts of climate change that influence flood risks include higher river discharges that may coincide with storm surges especially in estuaries. Although these can be considerable, these impacts are not within the scope of this report neither are land subsidence either from tectonic rebound and/or the subsidence of peat areas.

Also, developments such as spatial planning will influence the risk of flooding in terms of potential damage and casualties.

Figure 3.1 illustrates some of the drivers/pressures behind future coastal flood risks. In the past century the North Sea countries have commonly increased protection levels and many plans for the future are currently being developed. This chapter aims to compare, describe and map the trends or scenarios related to developments driving future coastal risks.

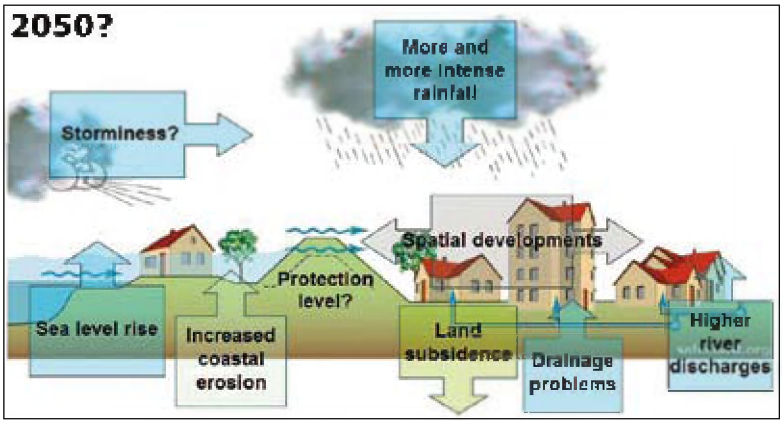


Figure 3.1: Overview of drivers for future flood risks

3.1 Need and function of scenario analysis

Coastal risk assessment is involved with the analysis of a complex setting of natural and man-made systems exposed to the pressures of water and climate conditions. From the viewpoint of policy planning and future developments, coastal risks are considered within a longer time perspective. However, the physical and man-made characteristics of coastal areas, as well as the hydraulic loads imposed on these areas, are subject to continuous development and change. Typically, these changes and developments are characterised by a high degree of uncertainty.

In the assessment of future coastal risks, it is essential to explicitly take into account the future developments that are driving the outcomes of the risk assessment. A common way of dealing with uncertain, future developments is to make use of scenario analysis. In this respect, a scenario refers to a coherent set of assumptions regarding future developments affecting the condition and performance of the system considered, as determined by uncertain, external factors. A scenario analysis would typically include a number of different development aspects that would be reflected in different scenario variables.

From the viewpoint of coastal risk assessment the most relevant categories of scenario variables to be considered relate to:

- Climate change projections as the key driver to future hydraulic loads in terms of water levels and waves (as affected by changes in sea level rise and wind conditions).
- Spatial and infrastructural developments and related socio-economic values driving the extent to which society may be impacted upon (possible damage and/or casualties).

It is noted that the first category of scenario variables is related to changes in the probability and the extent of coastal hazards (such as erosion and flooding), whereas the second category is mainly related to changes in the consequences of such hazards (in term of economic damages or loss of life).

Scenario analysis is commonly applied in making longer term projections from a policy analysis perspective and is considered as a useful means to deal with some of the major uncertainties in coastal risk assessment. Scenario analysis will not take away the uncertainties but merely makes the effects of uncertainties explicit. This can be done by specifying a number of different scenarios within a realistic range of uncertainty, which can be considered as alternative, possible futures.

The consequences of these possible futures, as well as the impacts of possible responses (measures or strategies) can then be shown. The effects of different scenarios can be assessed by comparing alternative futures (in terms of functions and values) with a reference situation, such as the known present situation. In turn, the effects of possible responses are compared with reference to a future situation without responses. Alternatively, the effects of a particular response can be considered for different scenarios. These analysis principles are illustrated in Figure 3.2.

The use of scenarios can provide valuable information to decision makers on potential impacts from future changes. In particular, the scenario analysis would provide insights of a ‘what if’ nature, showing the impacts on coastal risks if certain developments take place. Different scenarios would be investigated to reflect different views and expectations that may exist within the policy making community.

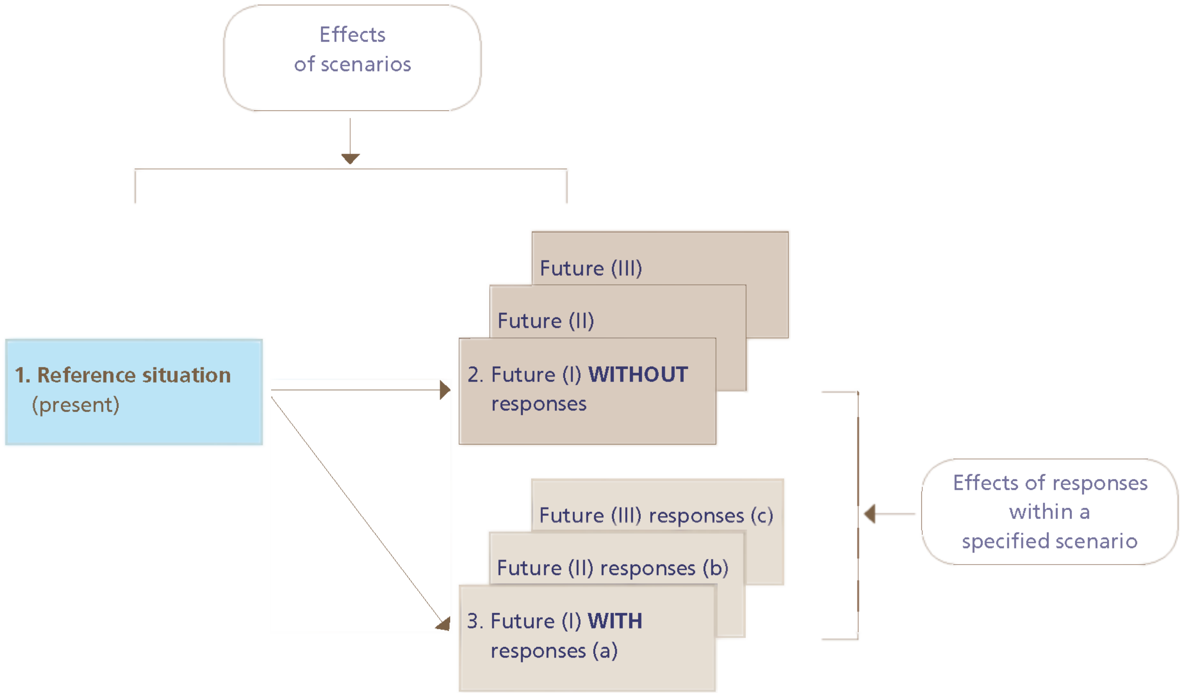


Figure 3.2 Effects of scenario developments and responses

Another important aspect of scenario analysis is that the impacts of policy responses or strategies (in terms of reducing coastal risks) would be investigated and compared under different scenarios specifications. This would provide valuable insights on the 'robustness' of the various policies, i.e. the extent to which the various policies would be able to keep up a good performance under different scenario specifications. Obviously, in trying to cope with the possible drawbacks of uncertainty, there is merit in selecting a policy that would do well under different, uncertain developments.

In order to perform a successful scenario analysis, a number of important conditions are to be met. First of all, the various developments to be included in the scenario specifications should reflect a realistic range of possible developments. In addition the various scenario variables should be clearly defined, transparent and internally consistent. Furthermore, the scenario analysis must be presented in such a way that it informs and assists the decision making process and does not add to confusion and complexity.

Within Safecoast's Action 1 specific attention was given to the possibility of surveying, describing and mapping scenarios for climate change and spatial and infrastructural developments (without 'responses', see figure 3.2), which are considered the most relevant developments from the viewpoint of coastal risks. In the following sections, the findings and results of this Safecoast effort are described in more detail.

3.2 Spatial and infrastructure developments

There is an obvious relationship between the consequences of (future) flooding events (damage, victims) and the extent of spatial and infrastructural developments in terms of land use, buildings, infrastructural facilities and related values, driven by other developments such as population growth and economic developments (in terms of e.g.: growth of GDP, income, production levels, trade and transport flows).

Over the past 50 years, the population living in European coastal municipalities has more than doubled to reach 70 millions inhabitants in 2001 and the total value of economic assets located within 500 metres from the coastline has multiplied to an estimated 500-1000 billion euros in 2000 (Eurosion, 2004). A similar trend is true for developments in coastal flood prone areas.

Hence, there is a need to explicitly consider such developments in future assessments, which would require the specification of a number of realistic scenarios on spatial and infrastructure developments. The possibilities for specifying meaningful scenarios on spatial and infrastructure developments should be closely connected to the spatial and temporal scales and the specific purpose of coastal risk assessment. For example, scenario approaches might be quite different for a long term view on national or transnational coastal risks, as compared to establishing structural coastal protection for a specific coastal area. These differences are also reflected in various studies dealing with coastal risk assessment.

Global and North Sea Region perspective

The future is difficult to predict. However, from a global and long term perspective, a common approach can be to base future development trends regarding specific scenario variables (such as growth in GDP, investments, population/households, land use, energy consumption, etc.) on a number of global, macro-economic development perspectives, driven by forecasting story lines based on views and visions from – among others – Fukuyama (liberal global market), Brundtland (sustainable future, see annex 2), Huntington (clash of civilisations) and the non-globalist vision of (e.g.) Schumacher (small is beautiful). In the North Sea countries, for instance the Netherlands and UK efforts have been made to transform these possible futures or story lines (see table 3.1) into quantitative data (MNP, UKCIP/Foresight)

Economic emphasis →

Global integration ↑ | Regional emphasis ↓

A1 story line World: marked oriented Economy: fastest per capita growth Population: 2050 peak, then decline Governance: strong regional interactions; income convergence Technology: 3 scenario groups: A1F1: fossil intensive A1T: non fossil energy sources A1B: balanced across all sources	**A2 Story line** World: differentiated Economy: regionally oriented; lowest per capita growth Population: continuously increasing Governance: self-relience with preservation of local identities Technology: slowest and most fragmented development
B1 Story line World: convergent Economy: service and information bases, lower growth than A1 Population: same as A1 Governance: global solutions to economic, social and environmental sustainability Technology: clean and resource-efficient	**B2 Story line** World: local solutions Economy: intermediate growth Population: continuously increasing at lower rate than A2 Governance: local and regional solutions to environmental protection and social equity Technology: more rapid than A2, less rapid, more diverse than A1/B1

← Environmental emphasis

Table 3.1: summary characteristics of four SRES storylines (IPCC, 2008)

This then provides a basis to project the extent of future values subject to flood risk. Moreover, through the use of global socio-economic scenarios, a relationship can be established between the scenarios on spatial/infrastructure developments and the global emission scenarios driving climate change. An example of such an approach is found in the Foresight Flood and Coastal Defence Project, aiming to produce a long term vision for the flood and coastal defence system in the whole of the UK, looking 30-100 years into the future. It found that in some English east coast locations, extreme sea levels that currently have a 2% chance of occurring could occur 10-20 times more frequently by the 2080s.

The Foresight study (2004) was based on considering four global socio-economic scenario specifications that could be linked to the four UKCIP02 climate scenarios (low, medium-low, medium-high, and high emissions) which are in turn linked to the SRES emission scenarios used by the IPCC (see table 3.1). Another example is a study in the Netherlands on the long term flood risks in a changing climate, assessing flood risk developments for the Netherlands as a whole up to the year 2040. In this study four socio-economic scenarios developed on European level by the MNP, the Netherlands Environmental Assessment Agency (WL I Delft Hydraulics, 2007) were used. These scenarios were used to develop a number of development 'factors' in flood damage assessments due to changes in land use and economic growth, reflecting an 'average' and 'high pressure' development trend

In Safecoast, an inventory (Action 1) was made of some of the major spatial and infrastructure developments in the North Sea Region. Based on a qualitative compilation national and regional spatial development documents and visions, a scenario impression of these developments has been mapped in the NSR context, as seen in figure 3.2 (see also annex 3.4):

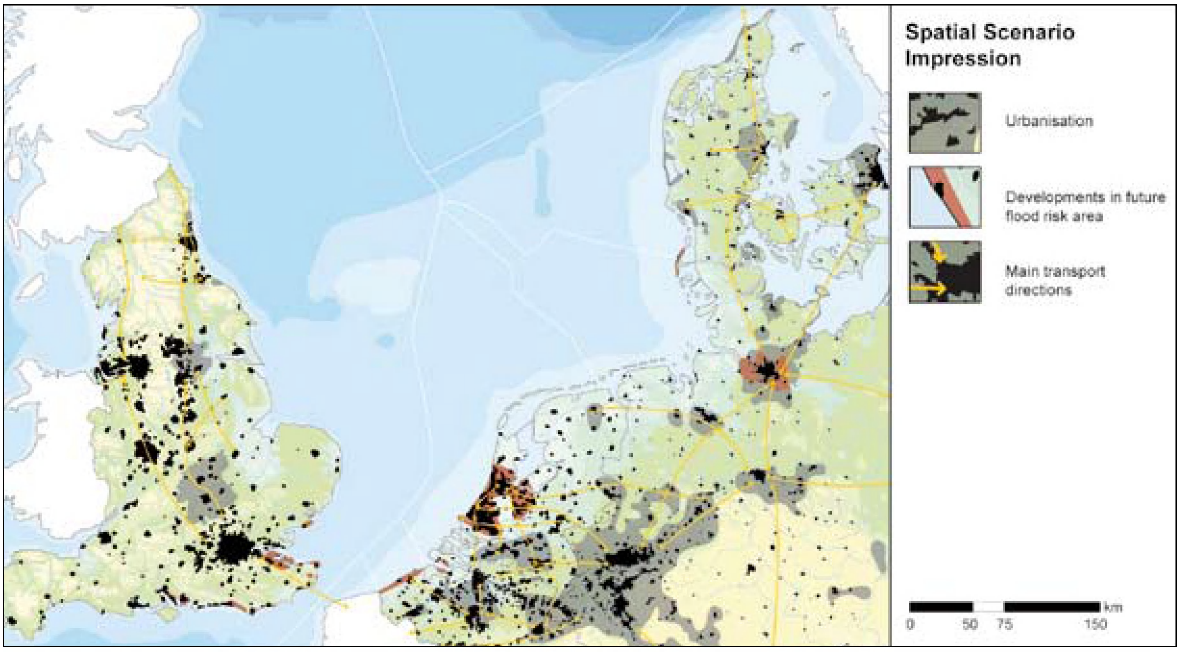


Figure 3.3: Spatial Scenario Impression 2050 of the North Sea region (see Annex 3.4 for detailed map)

The spatial scenario impression map is a compilation of maps, visions and development scenarios that are used in the five North Sea countries (see table 3.3). However, aiming for the reference year 2050, the diversity, scope and time frame of several sources are qualitatively balanced to achieve an overview that is as consistent as possible. The urbanised basic layer (in black) is based on the Corine land use data in 2000 (CLC, 2000), see chapter 2.

In addition to expected changes in national and regional investments and land use change that might influence future flood risk, the expected population in most countries is likely to stabilise or decline, but is certain to age (table 3.2). Regional effects with respect to the coastal flood risk assessments are uncertain, but for instance in Flanders, the coastal population is already both denser and much older than average (Belgium ICZM report 2005). Similar trends are noted in England (ABI, 2006), where the number of people aged over 75 years living in coastal areas of the East coast is expected to increase more rapidly than general population trends, by around 75% (430,000 to 740,000) in 2028.

Country	Population 2000	Population 2000 Aged 65+	Population 2050	Population 2050 Aged 65+
	Observed [mln people]	Observed [%]	Baseline variant [mln people]	Baseline variant [%]
Denmark	5,3	14,8	5,4	24,1
Germany	82,2	16,2	74,6	31.5
Netherlands	15,9	15,4	17,4	23,5
Belgium	10,2	16,8	10,9	27,7
United Kingdom	58,8	16,2	64,3	26,6

Table 3.2: Population estimates for 2050 and an aging population (Source: Eurostat)

The five North Sea countries more or less follow a general European trend compared to other parts in the world. Especially in developing countries, population growth rates are still higher, but are also expected to decline in the second half of this century (OECD, 2007).

National / regional perspective

Spatial planning in the North Sea region differs by country. In UK the top down approach seems stronger than for instance in Germany and the Netherlands, where municipalities may have more room for decision making. Information for future developments is widespread and fragmented. The EU has no remit for spatial planning, but does promote knowledge and trans-national spatial development analysis. In 2004 almost three quarters of the European inhabitants lived in cities and the spatial pressure on the low-lying coastal zone is considerably high in the urban areas of London, central Holland, Flanders and Hamburg.

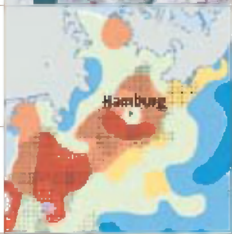
Country	national/regional scale perspectives	Envisaged spatial and economical developments and future trends relevant for coastal flood and erosion risk related scenarios
Denmark New map of Denmark, 2006		The reform of local government structure in Denmark will renew spatial planning, with increased decentralized autonomy for the municipalities. Even though not directly under the influence of coastal flooding from the North Sea, the metropolitan areas of Copenhagen and Eastern Jylland are considered economic growth areas.
Germany Perspectives of spatial developments in Germany, 2006		The North Sea coast of Germany is dominated by coastal developments of coastal harbours, like Bremerhafen and Wilhelmshafen, and developments at the agglomerates of Bremen and Hamburg. The coastal area in between is predominantly rural with smaller and larger towns with a stabilising population level (NLS, 2008). Pressure from tourism (e.g. island of Sylt) is expected to increase due to climate change.
Netherlands Netherlands spatial planning strategy, 2005		Envisaged spatial developments in the low lying areas of central Holland are expected to increase the economic value by 32-38% (including about 400,000 homes) by 2030 (Action 1, see annex 3.5). In a recent report, the growth of vulnerability by land use developments is estimated to roughly equal the adverse impacts of climate change (WL, 2007).
Flanders Flanders spatial planning strategy, 2003		There are planned and partly executed developments at the harbours of Ostend and Zeebrugge, and foreseen residential planning and infrastructural investments in hinterland. Major coastal zone developments are not foreseen. Here, an ageing population is expected. The Antwerp conglomerate is expected to expand.
England East of England Assembly plan, 2004 Thames Estuary 2100		Major ambition to develop over 120,000 homes and over 200,000 new jobs in the Thames Gateway area by 2026, of which a large part in the Thames estuary flood plain. Without adaptation the number of people exposed to coastal flooding may rise from 0,9 million (2002) to 1,3 up to 1,8 million by 2080 (depending on the scenario) (Hall et al, 2006).
Sources: National and regional spatial plans and vision documents		

Table 3.3: A selection of envisaged spatial and economical developments influencing coastal erosion and flood vulnerability

In table 3.3, a qualitative description is given for development scenarios and forecasting in the five North Sea countries. The table lists observations on areas with specific developments (which are clearly larger or smaller than average), e.g. of population growth, specific infrastructural and industrial developments.

There is considerable variation between land use, economic values and investment levels, and population density of coastal regions both across and within countries (this reinforces the need to consider specific coastal regions in coastal risk assessment, rather than countries).

For the North Sea region as a whole, a high general demand for space is observed especially in and around Hamburg, Bremen, London Thames gateway and central Holland. This means flood risk will increase under the assumption that no appropriate additional or strengthening coastal defence measures are undertaken.

Regional / local perspective

More specific coastal risk assessments would be involved with the development of coastal protection master plans for specific coastal areas, comprising the evaluation of alternative measures or strategies within a future context. Typical time horizons for the development of such plans would be of the order of 20 to 40 years. In these cases, scenarios on spatial and infrastructure developments would need to be more specific. For this purpose, the information to be used for scenario development would preferably be based on specific local and regional spatial projections and land use development plans. This could be a valuable addition to regional and local cost-benefit or vulnerability analyses with respect to the appraisal of coastal management schemes. In Safecoast, such a vulnerability analysis was performed as a case-study (Action 1) on the dike ring of Central-Holland that showed an increase in the economic value of the area of 32-38% between 2000 and 2030 (annex 3.5) and implies an increased vulnerability to flooding.

Given the relationships between expected spatial developments and the increase in future coastal risks, it is noted that there may be large potential benefits associated with considering the possibilities for developing spatial plans that will meet required spatial demands while minimising the impacts from flooding and erosion. This provides an important linkage between land use planning practices and coastal risk management. The adjustment of spatial planning procedures in order to reduce (the increase in) future coastal risks is to be considered an important potential measure or strategy to be explicitly considered in coastal risk management.

Spatial and infrastructure developments used in Safecoast

In addition to the studies and mapping efforts of Safecoast Action 1, in Action 3A, the change in number of houses and cars between 2007 and 2050 is based on the change in population. By using Eurostat trend figures on the number of people per household and people per car, the change in population was translated into the change in houses and cars. These numbers were used in the damage calculations.

3.3 Climate change scenarios

There is general consensus that climate change will increase in future due to the effects of global warming, induced by human emissions of greenhouse gases such as CO_2 and others. With respect to coastal risks, sea level rise is the main direct aspect of climate change to be considered. In addition there are the effects of changes in wind speed and related effects on storm surge frequency and intensity. Climate change leads to an increase in the hydraulic loads on coastal defences protecting human life and assets. Moreover, the effects of sea level rise lead to increasing erosion rates of soft defences and loss of wetlands which may further reduce the protection capacity of flood defences (CPSL, 2005).

The future emissions of greenhouse gases and the related impacts on global warming and climate change are highly uncertain. For this reason, the relevant aspects of climate change are generally taken into account by considering a number of climate change scenarios. In developing such scenarios, a distinction is to be made in the available estimates of climate change based on scientific research and the climate change scenarios actually applied in coastal zone management policies and management practices.

Climate change estimates based on scientific research

There is strong evidence that global sea level gradually rose in the 20th century and is currently rising at an increased rate, after a period of little change between AD 0 and AD 1900. Sea level is projected to rise at an even greater rate in this century. The two major causes of global sea level rise are thermal expansion of the oceans (water expands as it warms) and the loss of land-based ice due to increased melting. Table 3.4 shows the approximate estimates of sea level rise ranges of the last four leading reports of the Intergovernmental Panel on Climate Change (IPCC).

IPCC report	IPCC estimates of global sea level rise ranges (cm) in the period 1990 – 2100
1990 (FAR)	30 – 110
1995 (SAR)	15 – 95
2001 (TAR)	9 – 88
2007 (AR4)	18 – 59

Table 3.4: Estimates of sea level rise (IPCC)

In the most recent report of IPCC (AR4, 2007) a certain range is given for the expected average global sea level rise (between 18 cm – 59 cm at 2090–2099 relative to 1980–1999, depending on the underlying CO_2 emission scenario). The third assessment report of IPCC (TAR, 2001) presented a range of 9 cm – 88 cm at 2100 relative to 1990.

Figure 3.3 shows the evolution of global mean sea level in the past and as recently been projected by IPCC in 2007 for the 21st century for the total span of six emission scenarios that were used (SRES B1, A1T, B2, A2 and A1FI, see also table 3.1).

Recent satellite measurements have suggested a melting of a larger part of the Greenland ice sheet than currently was assumed. The time span of these measurements is relatively short. It is therefore unclear if the measurements are representative for the longer term trend.

The complete melting of the Greenland ice sheet could in total lead to a maximum of 6 to 7 metres additional sea level rise (although lower estimates are emerging because of effects of gravitation). This melting would nevertheless take many centuries. The contribution of the Greenland ice sheet to the sea level rise of last century is estimated to be zero. The expectation is that the volume of the Greenland ice will decrease in the coming century. The expected contribution to global sea level rise is – according to current insights – no more than 9 cm.

For now, the IPCC has concluded that understanding of these ice flow processes is limited and there is no scientific consensus on their magnitude. New insights could therefore lead to a higher uncertainty band for sea level rise than which is currently suggested. The IPCC AR4 (2007) therefore clearly states that the upper values of the ranges given are therefore not to be considered upper bounds for sea level rise.

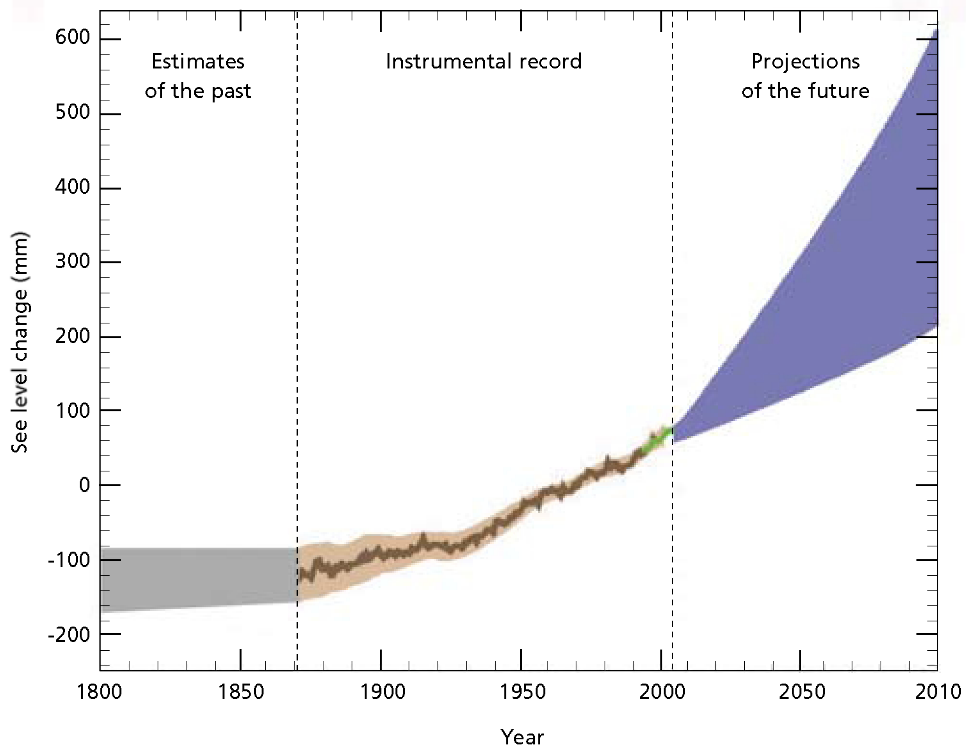


Figure 3.4: evolution of sea level in past and future for the span of six emission scenarios (adjusted from AR4, IPCC 2007)

Within each of the North Sea countries, scientific research has been applied to determine country specific and regional scenarios (based on measurements and climate change model predictions). In these assessments different assumptions may have been used for future changes in greenhouse gas emissions or in the impact of these greenhouse gases on climate change. Other (regional) differences may be caused by existing differences in the effects of tectonic movements and isostatic rise. Quantitative information on sea level rise may be presented in absolute or relative number depending on the fact whether the effects of tectonic movements and isostatic rise are taken into account.

Depending on specific study results, country information may be available on other aspects of climate change such as wind speed, storm surge increase and wave height increase.

Although flooding by increases in mean sea level over the 21st century and beyond will be an issue for low-lying areas, the most devastating impacts are likely to be associated with changes in extreme sea levels resulting from storms and storm induced tidal surges. Detailed patterns and magnitudes of changes in extreme water levels remain uncertain; better quantification of this uncertainty and further field validation would support wider application of such scenarios (IPCC 2007).

It appears, furthermore, that certain climate parameters are not yet considered in the climate change policy scenarios. An example is the storm duration and the wave period. Climate change experts indicate that it is not yet possible to provide any insight in the future changes of these parameters. These are, however, important parameters to be considered in studies related to long-term coastal protection schemes. In the Netherlands this omission is compensated by sensitivity analyses in which assumptions are made of the change of these parameters.

Safecoast (Action 1) has provided an overview of a low, medium and high estimate for the various scientific climate change parameters based on the estimates of IPCC and the various meteorological offices in the North Sea countries. This overview may be found in the Action 1 background documentation on the Safecoast internet site.

Policy guidance and management scenarios for sea level rise

Policy and management scenarios are commonly used to (1) encourage and guide additional research and modelling efforts; (2) justify modifications of engineering designs; (3) alter the land-use planning process and options appraisal to accommodate a rising sea level; and (4) develop impact assessments to help policymakers decide the appropriate level of attention warranted by the climate change issue.

In addition to scientific scenarios, an inventory has been made of climate change scenarios that are actually applied in coastal management and policy guidance in the North Sea countries. Table 3.5 gives an overview of the assumptions for sea level rise found in management and policy documents related to coastal risk management in the North Sea countries.

<table>
<tr><th colspan="2"></th><th>Minimum
(mm/yr)</th><th>Average
(mm/yr)</th><th>Maximum
(mm/yr)</th></tr>
<tr><td>Belgium</td><td>Flanders</td><td></td><td>5
2005-2055 Mean Sea Level</td><td>6
2005-2055 High Tide</td></tr>
<tr><td colspan="2">Denmark</td><td colspan="3">pragmatic
No formal climate scenarios.
For metro-construction at ‘Orestad’ 0,5 m/century was assumed</td></tr>
<tr><td colspan="2">Netherlands</td><td>2
short term design /
nourishments (5 yrs)</td><td>6
mid-term design dikes,
storm surge barriers (50-100yrs)</td><td>8,5
long term spatial reservations
(> 100/200 yrs)</td></tr>
<tr><td rowspan="3">Germany</td><td>Lower Saxony</td><td></td><td>5
(50cm/100yrs)</td><td>10
for design dike foundations
to be able to raise 1m</td></tr>
<tr><td>Schleswig Holstein</td><td></td><td>5
(50cm reserve)</td><td></td></tr>
<tr><td>Hamburg</td><td></td><td>3</td><td>8
spatial reservations: 30cm MSL +
50 cm reserve for metropolitan area</td></tr>
<tr><td colspan="2" rowspan="2">United Kingdom</td><td>2,5
(1990 to 2025)</td><td>ranging up to:</td><td>15
(2085-2115)</td></tr>
<tr><td colspan="3">reflect an almost exponential and regionalised curve</td></tr>
<tr><td colspan="5">Sources: Safecoast Action 1, scenarios stated in mm/yr for reasons of comparison.
BE: IMDC (2005) en MIRA (2006), not official policy but internal work-scenarios for design of flood defences
DK: EEA (2005); no official policy, but pragmatic and precautionary for long term projects.
NL: VenW (2000) and TAW (2002)
DE: NLWKN (2007); MLUR (2001); Siefert (1998); Hamburg (1994).
UK: DEFRA (2006b), update for climate change impacts</td></tr>
</table>

Table 3.5: policy guidance and management scenarios for relative (net) sea level rise in the five North Sea countries.

For reasons of comparison, the figures in table 3.5 are presented in a minimum to maximum structure. If countries only mention one scenario, it will be listed as ‘average’. Some of the figures above are of course subjected to change. Here, only millimetres per year are given for certain minimum, mean or maximum scenarios that might have different time horizons. In general, however, three observations can be made:

1) Even though sea level rise measurements from tidal gauges in the North Sea have given no indication for a further increase of sea level of more or less than 2 mm/yr, it can be observed that coastal policy scenarios more or less follow the IPCC average or upper limit scenarios or go beyond. To cope with the range, sometimes minimum and maximum scenarios are given.

2) Scenarios used in management and policy seem to balance agreement between scientific global or regional sea level rise expectations (either from IPCC or from national climate offices) and the practical purpose they have in coastal management choices. In some cases they are regionalised and split in time segments (UK), combined with coastal erosion and flood risk management measures with different time horizons (NL and Lower Saxony) or pragmatically chosen for no regret choices in large scale projects (DK).

3) The relationship between the scientific based scenario estimates in the various countries and the scenario assumptions actually applied for coastal zone management policies is not very straightforward. In general, the actual scenario applications are limited to sea level rise only. In this respect there is a reasonable consensus on the mean order of magnitude (5 to 6 mm per year).

Sea level rise assumptions used in Safecoast

In the Safecoast integrated risk assessment (Action 3A) and case studies on detailed risk assessments on flooding (Actions 1, 3A, 3B and 5B) and coastal erosion (5A), the following assumptions for climate change impacts were used:

- In the integrated risk assessment for the North Sea region (Action 3A), 6 mm/yr sea level rise was assumed, which was translated into 30 cm in 2050. Assumptions for changes in wind speed and associated set-up of water levels were included where the information was available. However, due to the uncertainties in forecasting wave characteristics, the current estimates have been used for 2050.
- In the case study Flanders (Action 3B) assumptions for 6 mm/yr sea level rise have been translated into potential return periods for extremes. The higher the sea level, the higher chance of failure of flood defences. For example, a 1:1000 storm (design water level) could be equivalent to a 1:300 storm in 2050.
- Combined scenarios were applied on the Danish North Sea coast (Action 5A) to account for the rise in sea level already experienced since 1990 (see section 4.4.3)
- In the case study Lower-Saxony pilot sites (Action 5B) an average of 50 cm per century was assumed, which was translated in 25 cm in 2050 and 50 cm for 2100 and added to a tidal hydrograph that reflect the specific characteristics of the pilot sites.

Policy guidance and management scenarios for wind and wave regime

As expected from the scientific uncertainties regarding forecasts of changing wind and (therefore) wave characteristics, scenarios used in policy and management are either absent or without a real function. In the Netherlands, for the maximum scenario of 8.5 mm/year a 10% increase in wind speed is also assumed, which is translated into a 40 cm extra set-up (water level) for reference years 2050, 2100 and 2200 (TAW, 2002). In German coastal states these assumptions are generally taken into account by adding extra reserve in the design of flood defences.

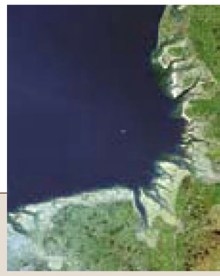
In England, besides the policy scenarios ('allowances') for sea level rise *indicative sensitivity* ranges are given that refer to peak flows, extreme rainfall, extreme waves and winds. The degree of certainty in these figures is lower compared to those of sea level rise and further evidence and research to understand local and regional variations are required to develop management of uncertainty in the appraisal of coastal risk management options options (Defra 2006b, update for climate impacts). For both offshore wind speeds and extreme wave heights indicative ranges are given in the order of 5% (until 2055) and 10% (2055-2115).

Consequences of sea level rise on coastal erosion and wetlands

The majority of coastal erosion issues are induced by human presence or activities and artificially stabilised seafronts that are progressively encroaching on sedimentary coastlines and cliffs. Dynamic ecosystems and their undeveloped coastal landscapes are gradually disappearing, due to a lack of sediment. In many places the process of 'coastal squeeze' is responsible for this phenomenon.

Acceleration in sea level rise will widely exacerbate beach erosion around the globe although the local response will depend on the total sediment budget. Bruun model (1962) suggests that local shoreline recession is in the range 50 to 200 times the rise in relative sea level, but the model sometimes fails under less ideal circumstances.

An indirect, less-frequently examined influence of sea level rise on the beach sediment budget is due to the infilling of coastal embayments or basins. As sea level rises, estuaries and lagoons attempt to maintain equilibrium by raising their bed elevation and hence potentially act as a major sink of sand which is often derived from the open coast. Estuaries, tidal basins and lagoons will suffer from insufficient sediment import due to a rise in sea level, and subsequently will aggravate erosion of adjacent coasts. See also section 2.2 and box 2 for a brief description of this phenomenon in the Wadden Sea.



BOX 2.2: Sea level rise and the Wadden Sea

The main elements of the Wadden sea system are the barrier islands, the tidal inlets, the ebb-tidal deltas, the tidal channels, the tidal flats and the salt marshes and that there are strong interactions between these elements. The main driving forces are the tides, the waves and the wind and the main linking factor is the sediment transport. All parts of this sediment- or sand-sharing system are coupled and can be, or strive towards, dynamic equilibrium with the hydrodynamic conditions. Changes in any part of the system will cause a sediment transport to or from other parts of the system, leading to a new dynamic equilibrium.

All parts of this sediment- or sand-sharing system are coupled and can be, or strive towards, dynamic equilibrium with the hydrodynamic conditions. Changes in any part of the system will cause a sediment transport to or from other parts of the system, leading to a new dynamic equilibrium. Therefore, a moderate sea level rise in the Wadden Sea, resulting from both natural and man-induced processes, will be compensated by the import of sediment which, in the long term, derives from the tidal channels, shoreface and the beaches and dunes of the barrier islands (CPSL 2001).

Because the Wadden Sea has a high resilience to changes the CPSL considered it plausible that the system will be able to adapt to a sea level rise up to some 25 cm per 50 years (the most realistic scenario), without substantial changes. Beyond such levels probably a breakpoint will occur because the capacity of the system to balance the changes will become exhausted. When such a breakpoint, which will differ for different tidal basins, has been passed, substantial changes in morphological and, consequently, biological parameters are expected. One of the major changes will be a reduction of the size of the intertidal area. Estimates are that, under the worst case scenario (50 cm / 50 years), the size of the tidal flats could decrease by 15% (720 km^2), the tidal basins transform into the direction of tidal lagoons. An increase in storminess could further enhance this development (CPSL 2001 / 2005).

3.4 Planned developments in coastal risk management

Not only are climate change and spatial developments important drivers, but changes in protection levels are also important when assessing future coastal risks. In this section an overview of the plans and foreseen future projects and funds for strengthening the flood defences in the North Sea region is given. Currently, master plans generally do not exceed the 2020 planning horizon (with the exception of the Flanders Sigma plan). However, there are signs of policy development aiming for longer timescales, especially in the emerging climate adaptation policies.

For **Flanders** the Sigma plan was set up in 1976 and updated in 2004. Implementation is expected to commence this year. The plan consists of flood controlled areas and local flood defences. The costs of the measures in the Sigma plan up to 2030 are estimated at € 830 million. There is also € 50 million allocated for supporting projects for agricultural purposes. Total costs up to 2030 will be approximately € 880 million.

Government spending on coastal protection of the open coast is expected to rise from an annual € 20 million to € 32 million by 2011. Estimates of annual volumes for sand nourishments per kilometre coastline will need to increase by 100,000 m^3 for every 10 cm of sea level rise. Given a 65 km long Flanders coastline and a sea level rise of 6 mm/yr, this means an annual average nourishment volume of 400,000 m^3, roughly three times the current annual volume (Verwaest, 2005).

Flanders is currently formulating a new integrated master plan for the future coastal safety of Flanders. The master plan is partly developed in Safecoast (Action 3B and 4) and aims to formulate the coastal protection strategy for the short and long term. A possible risk based approach, which would possibly need public acceptance of differentiated safety levels, will be studied. Also, environmental impact assessments and costs-benefit analyses for expected measures will be undertaken (see chapter 5). The different measures and associated costs will be evaluated and the master plan is expected to be completed by 2010.

Major projects related to coastal defence are the works at the Ostend harbour (€ 150 million) and the Zwin river mouth where nature and safety (€ 9,5 million for coastal protection) are addressed in an integrated way. Also a long term vision (2030) for the Western Scheldt is underway (Kustkompas, 2007).

In the **Netherlands** an overall rise in government spending for flood protection is foreseen at least until 2020, when government aims to meet the safety standards of the Flood Defence Act. An amount of € 745 million, with a timeframe up to 2020, will be invested in 13 different part of the coastline, i.e. "weak links" (Rijksbegroting, 2008). Weak links are parts of the coastline which are expected not to comply with the standards by 2020. Sand nourishments will be major part of the solution. To comply with the safety standards a budget of € 1072 million has also been assigned for 321 km sea dikes in Zeeland (Rijksbegroting, 2008). To compensate for rising sea levels, the annual quantity of sand nourishments to maintain the coastline at its 1990 position is expected to increase from 12 (€ 45 million annually) to 19 million m3 assuming a sea level rise of 6 mm/yr (VenW, 2000). Also, protection levels for 13 coastal towns are under development and are expected to add 10% to the annual budgets for sand nourishment.

Currently plans are developed for the 30 km closure barrier (NL: *afsluitdijk*) between Holland and Friesland. Discussions regarding the possible replacement of certain storm surge barriers are progressing. By the end of 2008, a National Water Plan is expected to guide further future water policy and management, also based on the advice from the recently installed Delta Committee on sustainable coastal development (VenW, 2007a/b).

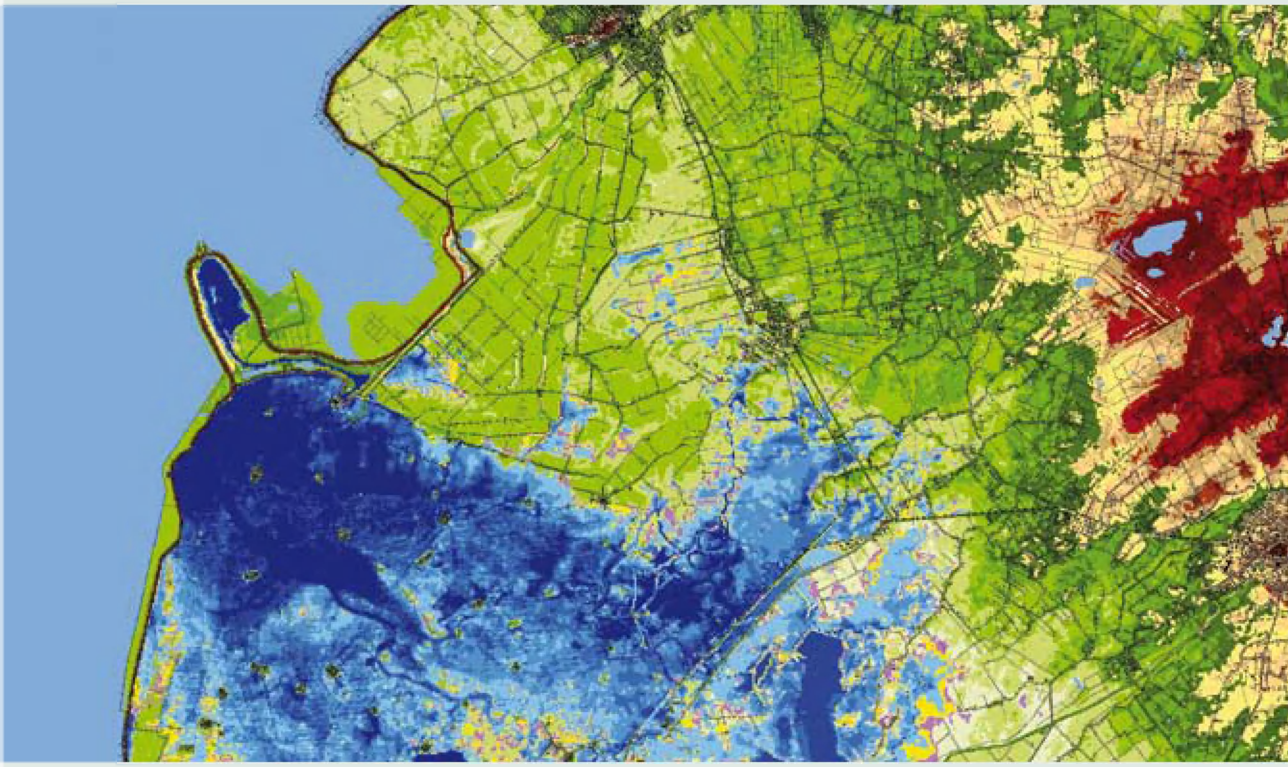
In **Germany**, the four coastal states are operating separate master plans. The master plan for coastal defence of Schleswig-Holstein (MLUR, 2001) addresses the possible consequences of climate change. It also prescribes adaptation of the dikes to include rising sea levels. Furthermore, the height of the dikes is evaluated every 10 years and sea levels are monitored. A reserve of 50 cm is included in the dike designs to consider sea level rise until 2100. The measures to adapt to climate change until now are mainly focused on technical measures.

Lower Saxony and Bremen have recently launched their master plan for coastal protection (NLWKN, 2007). Here, 1 metre of sea level rise is assumed until 2100, especially for large construction works affecting the foundation of coastal defences. Currently, in Hamburg a flood construction programme is underway to raise the dikes by 1m. Total budget is about € 600 million (LSBG, 2007). Also, Hamburg is evaluating the deepening of the Elbe channel and its possible effect on coastal defences.

The annual budget for maintenance of hard constructions and sand nourishment along the central part of the West coast in **Denmark** is about 80 million DKK (€ 11 million). Due to rising sea level an increase of the nourishment of 9% in a period up to 2025 and of 18% in the period 2025-2050 is estimated (DCA, 2008). Denmark aims at raising the public awareness of climate change to underpin changing budgets for coastal protection. It is proposed to increase the annual budget from € 11 million to € 13.5 million per year. To date, these budgets have not been approved. At this moment there are no planned budgets up to 2020 since the approval of the annual budgets is interrelated closely to analyses of how the coast reacts on the annual sand nourishment programs. For future planning of the dikes (private ownership) in the Danish part of the Wadden Sea no information is available.

Both the Stern review on the economics of climate change and the Foresight Future Flooding report (2004) highlighted that climate change in the **United Kingdom** is likely to increase the severity (damage) and frequency of flooding events. Accordingly, the central government (Defra) has announced the rise of total government expenditure on flood and coastal erosion risk management from £600 million (€ 870 million) in 2007-08 to £800 million (€ 1160 million) in 2010-11.

The government will allocate this budget in new protection schemes such as physical structures or management regimes and at the same time improves defences by replacing or upgrading areas where an existing protection already exists. Furthermore Defra is aiming to promote more holistic and sustainable approaches through 'Making Space for Water' (2006). The Government has also announced the introduce an adaptation toolkit of £10 million (€ 14,5 million) per year to assist communities, especially where coastal protection is considered unsustainable.



4 RISK ASSESSMENT IN COASTAL MANAGEMENT

4.1 Nature and purpose of coastal risk assessment

4.2 Coastal risk assessment methodology

4.3 Integrated risk assessment for the North Sea region

4.4 Case studies on detailed risk assessments in the North Sea region

4 RISK ASSESSMENT IN COASTAL MANAGEMENT

The aim of this chapter is to give an overview of risk assessments that were carried out in project Safecoast, after a brief introduction to the concept of coastal risk assessments.

Section 4.1 addresses the nature and purpose of coastal risk assessment and introduces it as a dynamic concept, requiring a probabilistic approach. Challenges related to spatial / temporal scales and associated uncertainties are briefly introduced.

Section 4.2 describes the methodologies applied for the assessment of coastal risks in the NSR region and a number of related, recent developments. This section reflects some of the main results of the Safecoast Action on the comparison and development of flood risk methodologies in the NSR.

Section 4.3 provides a description of an integrated (top down) flood risk assessment for the NSR region according to the methodology developed and applied in the Safecoast Action 3A on transnational flood risk assessment for NSR coastal regions. This section also includes the results of the Safecoast Action on the development of an erosion atlas for the Danish coastline, as an example of a large scale coastal erosion assessment in the NSR.

Section 4.4 provides an overview of the approaches and results of a number of more detailed coastal risk assessments in the NSR region which have been carried out as part of a number of different focussed Safecoast Actions 3B and 5A, i.e. the comparison and development of flood risk methodologies in the NSR; the Danish pilot sites on coastal erosion assessment; and the Lower Saxony pilot sites on flood risk assessment.

4.1 Nature and purpose of coastal risk assessment

Nature of coastal risk assessment

Coastal risk is defined as the probability of a natural, hazardous coastal event, multiplied with the consequences of such an event. The type of event commonly considered in coastal management is flooding. A related type of problem in this respect is coastal erosion. It is noted that coastal erosion is to be regarded from two perspectives. First, coastal erosion may be leading to the loss of land and intertidal area and associated economic and ecological values, warranting a separate coastal erosion risk assessment. Second, coastal erosion poses a potential threat to existing natural and man-made flood defence systems, e.g. by erosion of dunes or cliffs or by undermining flood defence systems. From the latter perspective, coastal erosion should be considered an integral part of flood risk assessment. Within Safecoast, both flooding and coastal erosion are addressed. However, the focus is on flood risk assessment, taking into account the possible adverse effects of coastal erosion.

Typically, the various NSR countries and regions are subject to different flooding probabilities, representing different flood safety levels which may or may not be explicitly defined and maintained. The probability of flooding depends on the hydraulic loads of water levels and waves driven by the interplay of water movement and wind, in relation to the physical characteristics of existing natural or man-made flood defence systems. Actual probabilities are determined by a number of complex, natural processes which are of a stochastic nature. Therefore, risk is to be considered a dynamic concept, requiring a probabilistic approach.

Given the nature of the processes and mechanisms involved, flood risk assessment is subject to a number of major uncertainties related to 1) natural variability and 2) knowledge uncertainty. Among the most important uncertainties dealt with in Safecoast are:

- the occurrence and development of hydraulic loads leading to failure of flood defence systems (in relation to climate change);
- the performance of defence systems and the location and nature of the failure (failure mechanism and extent of possible breaches);
- the extent, duration and depth of the flooding event;
- the extent of flood damages and casualties (in relation to economic and demographic developments).

Purpose of coastal risk assessment

The aim of coastal risk assessment is to understand and quantify the present and future coastal risks in order to identify and evaluate possible actions to reduce these risks.
In principle, coastal risk assessment is the analysis and evaluation of a broad range of measure and strategies to reduce coastal risks, either by reducing the probability or the consequences of flooding events. Such analyses would generally consider both the present and future situation, subject to a specification of relevant scenario developments (such as economic and spatial developments and climate change).

More specific analyses would be used to establish required flood protection measures to maintain future safety levels. Other applications may include establishing desired safety levels for coastal areas. Desired safety levels would follow from balancing the reduction in risks that would be achieved by decreasing the probability of failure of flood defence systems and the costs of improving flood defence systems to achieve a decrease in failure probability.

In view of the different purposes and levels of coastal risk assessment, a number of analysis levels could be defined as follows (see figure 4.1):

1. Top down analysis at national or transnational level, e.g. to support: the comparison of flood risks across regions; the identification of most vulnerable areas for further analysis to reduce risks; or the analysis of desired safety standards.
2. Analyses of specific flood prone areas to identify and evaluate possible measures.
3. Detailed analyses for design of specific measures.

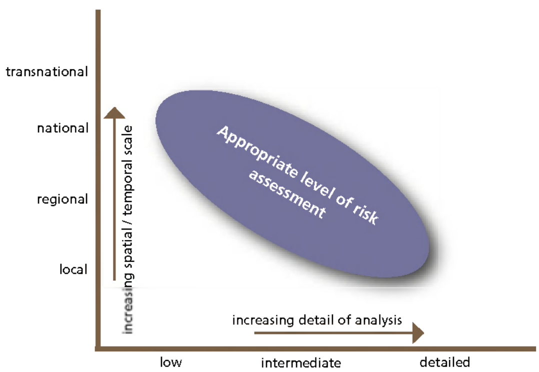


Figure 4.1: The appropriate level of risk assessments

4.2 Coastal risk assessment methodology

4.2.1 Steps in coastal risk assessment

The following provides a generic description of the various steps involved in coastal risk assessment, distinguishing between flood and erosion risk assessment and establishing a link between them.

Flood risk assessment

The main steps to be considered in flood risk assessment include the analysis of:

1. Hydraulic loads and failure behaviour of flood defence systems.
2. Flooding events (flooding scenarios).
3. Flooding consequences.
4. Combining probabilities and consequences into risk.

1. Analysis of hydraulic loads and failure behaviour of flood defence systems

This step involves the assessment of:

- (Developments in) hydraulic loads.
- Characteristics of existing flood defence systems and specific failure probabilities.
- Failure behaviour and probability of flood prone areas.
- Identification of failure scenarios (failure locations and mechanisms).

The relevant hydraulic loads for flood risk analysis relate to water levels and wave characteristics in relation to wind speed and wind direction, whereby each of the relevant parameters is characterised by its own probability distribution function. Based on available historic information and measurements, statistical analysis techniques are applied to link representative combinations of hydraulic loads with return periods. In this process, the impacts of climate change on water levels and wind should be taken into account.

The assessment of characteristics of existing flood defence systems applies to the physical characteristics (height, dimensions, shapes, roughness, profiles and grain sizes) of both man-made and natural protection systems. This information is linked to the probability of failure according to a number of possible failure mechanisms, such as: overflowing and wave overtopping; piping; slope instability and erosion of outer slopes. Specific geo-technical modelling procedures would be required to determine the failure probabilities according to the various relevant failure mechanisms.

From the viewpoint of a specific flood prone area, the overall failure behaviour is determined by the characteristic of the available types of flood defence systems and the relevant failure mechanisms. More or less sophisticated methods could be applied to provide estimates of an integrated failure probability for a flood prone area, taking into account the combination of flood defence systems and failure mechanisms, each with their own probabilities of failure. Obviously, the resulting failure probability would be predominantly determined by the critical failure probabilities of specific components and mechanisms of the overall flood defence system.

The identification of actual failures is based on establishing possible combinations of failure locations and mechanisms that could occur if critical hydraulic loads were reached. Such an assessment would follow from the overview of failure probabilities of the various flood defence system components and failure mechanisms. Typically, there may be several or many possible combinations of critical locations, failure mechanisms and associated probabilities to be considered. This gives rise to considering different failure scenarios.

2. Analysis of flooding events (flooding scenarios)

The analysis of flooding events includes:

- The assessment of volumes/discharges entering the flood prone area.
- The assessment of flooding event characteristics.

For each combination of failure locations and failure mechanisms to be considered in a particular failure scenario, there should be an assessment of flooding volumes or discharges entering the flood prone area as a function of time, for the assumed duration of the flooding event. This assessment should take into account the dynamics of inside and outside water levels (given the effects of tide and wind) and the specific behaviour of the failure mechanisms. For example, in case of a breach in the existing flood defence system, this assessment could include the use of more or less sophisticated procedures for breach growth modelling.

Given the locations and volumes of water entering into the flood prone area as a function of time, an assessment should be made of the characteristics of the flooding event in terms of the extent of the flooded area; flooding depths; flow velocities; and rates of water level increase. These assessments would be typically based on more or less sophisticated simulation procedures, using a combination of hydraulic modelling tools and a physical description of the elevations, obstacles and surface roughness within the flood prone area based on a Geographical Information System (GIS). In general terms, the latter type of tool is often referred to as a Digital Elevation Model (DEM).

Figure 4.2: One of the hundreds of breaches in the Dutch dikes in 1953 (Source: ANP, library KNMI)

3. Analysis of flooding consequences

The consequences considered in flood risk assessment are usually analysed as damages. These damages refer to all varieties of harm caused by flooding (Floodsite, 2006). Flood damage includes a wide range of harmful effects on humans and theirenvironment, which can be categorised in terms of direct or indirect damages; in terms of tangible and intangible values; and in terms of primary and secondary damages.

Direct flood damages follow from the immediate physical contact of flood water to humans or to assets at risk, while indirect damages follow from the disruption of processes (e.g. losses emerging from interrupted production). Tangible damages are those that can be quantified in monetary terms, which may pertain to both direct and indirect damages. Casualties or effects on ecosystems are examples of intangible effects that cannot easily be associated with traded values. The terms primary and secondary may be used to refer to damages occurring during the flood event and (causally related) damages after the flood event.

In many cases, the focus of the assessment of flooding consequences is on the assessment of (direct) economic damages and casualties. Direct economic damages would typically be determined by applying different damage functions, relating damages to critical flood characteristics such as water depth and flow velocity. The assessment of casualties would require an assessment of the number of people present in the flood affected area, taking into account the possibilities of timely escape or evacuation. Given the number of people present, casualty rates would be mainly determined by water depth, flow velocity and the rate of increase of the water level. More specific approaches or relatively simple estimates might be used to relate the various indirect damages to the direct economic damages and/or to asses other types of damages.

Figure 4.3: The 'Fährstraße' in Wilhelmsburg, Hamburg in the aftermath of the 1962 storm surge (source: wikipedia)

4. Combining probabilities and consequences into risk.

Flood risk is the combination of flood consequences and associated probabilities for different scenarios of storm events and failure locations/mechanisms. The flood consequences arising from a particular flooding event can be given a weight based on the occurrence probability of the underlying storm event and the probability of the various plausible scenarios of failure locations/mechanisms. Depending on the desired level of detail of the risk assessment, more or less storm events and failure scenarios can be considered. An overview of the steps involved with flood risk assessment is provided in figure 4.5.

Coastal erosion assessment

Common steps in coastal erosion assessment include:

1. Analysis of sediment balances and erosion rates
2. Analysis of coastal erosion consequences

1. Analysis of sediment balances and erosion rates

The analysis of sediment balances and erosion rates includes the assessment of:

- (Developments in) hydraulic loads.
- Sediment transport mechanisms, sediment balances and erosion rates.
- Impact of coastal erosion on flood defence systems.

The assessment of (developments in) hydraulic loads mainly relates to the relative changes in water levels, as a consequence of climate change and the isostatic and tectonic effects causing land masses to rise or sink. In addition, there is the effect of natural currents and possible changes in relation to natural variation or climate change.

The assessment of coastal erosion (or accretion) follows from the analysis of the sediment balance of 'sediment cells' that represent designated coastal areas. A sediment cell is defined as a length of coastline, which is essentially self-contained as far as the movement of sand and other sediments is concerned, such that changes in the sediment movement in one cell should not have a significant effect on adjacent sediment cells. The boundaries of the sediment cells generally coincide with large estuaries or prominent headlands and not with socio-political boundaries. The impacts of changes in water levels and natural currents (as affected by developments in hydraulic loads) on sediment transport mechanisms would be analysed within the sediment cells in order to make an assessment of the effects on coastal erosion or accretion rates. For this purpose, a number of different approaches are available.

Coastal erosion will lead to a decrease of available sediment volumes which may cause the volumes and profiles of existing natural protection systems be below desired or required standards for the flood safety of the hinterland. Moreover, coastal erosion may lead to a deepening of foreshore water levels, undermining the stability of man-made flood defence systems and aggravating wave attack. Hence, the effects of coastal erosion should be taken into account in the assessment of future flooding probability of flood defence systems (see figure 4.4).

Figure 4.4: The Hondsbossche sea dike in North-Holland (NL) under influence of coastal erosion (source: RWS)

2. Analysis of coastal erosion consequences

This step is involved with the assessment of:

- Losses of coastal area and intertidal areas.
- Impacts of land losses on economic and ecological values.

Coastal erosion will generally lead to a direct loss of coastal area and intertidal areas. The extent of these area losses is quantified, from a detailed description of the coastal bathymetry within the coastal sediment cells, and the information on sediment deficits, coastal erosion/accretion and changes in water level.

Depending on land use and ecological characteristics of the specific areas potentially lost, an assessment can be made of the loss of economic and ecological values associated with the area losses. An overview of the steps involved with coastal erosion assessment is illustrated in figure 4.5.

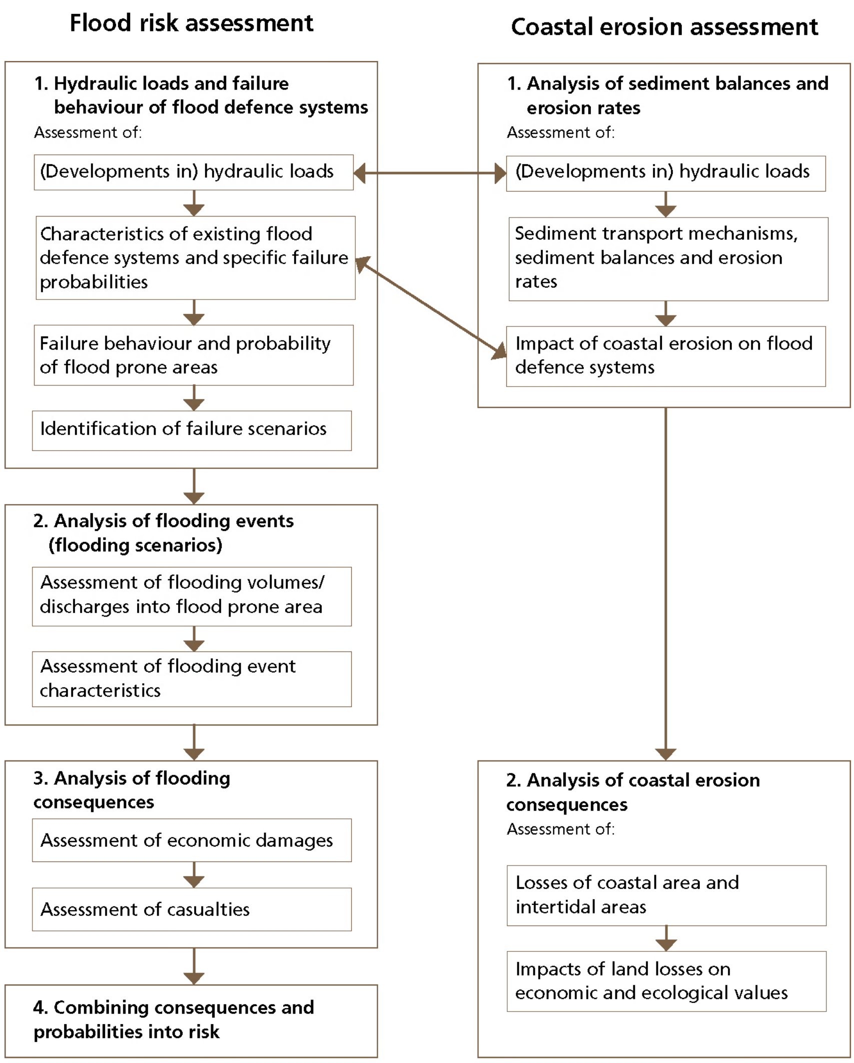


Figure 4.5: Overview of steps in flood risk and coastal erosion assessment

4.2.2 Coastal risk assessment applications in North Sea countries

Basically, all countries in the North Sea Region have their own approaches in dealing with coastal risk assessment. Although there are differences, there is also considerable commonality in methods and approaches. Within Safecoast, methods for coastal flood risk assessment were further explored and applied. As part of these activities, several comparisons were made across a number of applications in the various North Sea Region countries. The following provides an overview of the main results of this comparison, based on the results of Safecoast Action 3B (see section 1.4). The comparison only considers the assessment of flood risk, according to the following steps (see section 4.2.1):

(1) Analysis of hydraulic loads and failure behaviour of flood defence systems.
(2) Analysis of flooding events (flooding scenarios).
(3) Analysis of flooding consequences.
(4) Combining consequences and probabilities into risk.

(1) Analysis of hydraulic loads and failure behaviour of flood defence systems

Hydraulic loads are usually expressed in terms of water levels and wave characteristics (in terms of wave height and forces). These hydraulic conditions are of a stochastic nature and need to be associated with a probability distribution. In order to establish the hydraulic conditions at critical locations (relevant for the flood protection systems and failure mechanisms to be considered) a variety of statistical techniques and modelling approaches may be used. The usual approach is for the analysis of hydraulic conditions leading to the definition of one or more sets of hydraulic conditions that can be associated with an annual exceedence probability or return period.

Safety standards are generally expressed in terms of a maximum admissible annual failure probability or minimum required return period. Flood protection systems are then designed in such a way that the hydraulic conditions associated with the minimum required return period can be withstood. As was shown in table 2.4 in Section 2.3 in this report, the present flood safety standards in terms of return periods may be quite different between countries and regions.

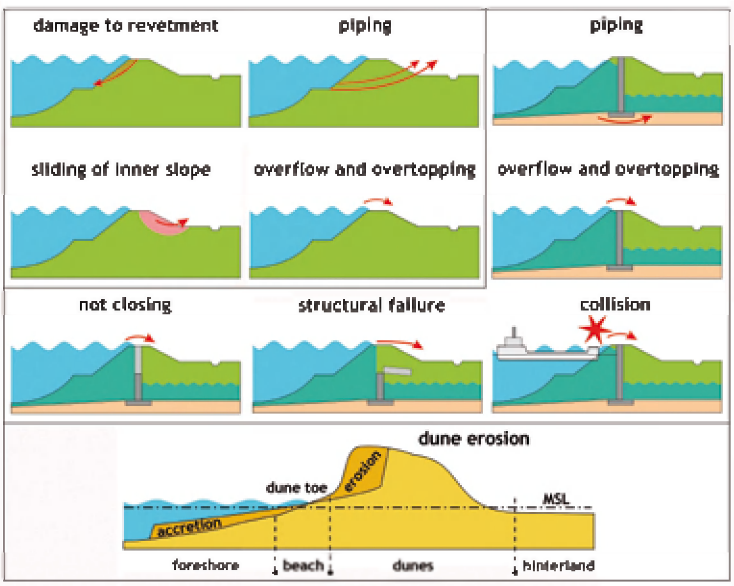


Figure 4.6: Examples of failure mechanisms for a selection of flood defence systems (Source: project Floris)

Depending on the level of detail of the failure behaviour analysis, more or less information would be available for the identification of the most critical locations and mechanisms. However, in general there would be a large potential number of failure locations and failure mechanisms (see figure 4.6) that could be considered. In view of the probabilistic nature of the assessment there would be no deterministic basis to decide where the actual failure(s) would be. Hence it is necessary to formulate reasonable assumptions about possible (combinations of) failure locations and mechanisms. Usually, a number of different situations regarding possible combinations of failure locations and mechanisms would be considered, referred to as failure scenarios. If a detailed analysis of the failure probability of different parts of the flood protection system is available, the specification of such scenarios could be based on a comparison of failure probabilities within the overall flood protection system. If this is not the case, the specification of failure scenarios would have to be based on plausible assumptions.

(2) Analysis of flooding events

This main step involves the analysis of flooding events as they would occur in the event of a failure of the flood protection system. An example can be found in annex 3.8 as part of the flood simulations performed in Action 5B (see section 4.4.4). Such flooding events would generally be considered within a specified flood prone area that can be regarded as a logical entity (flood cell) from the perspective of potential flooding events. Given the location and types of failures of the flood protection system following from the failure scenario the flooding event should be specified in terms of the flooding volumes or discharges entering the flood prone area as a function of time within the duration of the storm surge. There are a number of different approaches to be considered here, which generally range from simply specifying the flooding volume over time in the form of a hydrograph to the application of more sophisticated models. The latter would describe the flooding volume as a function of the hydraulic conditions and the deterioration of the flood protection system at the failure location (e.g. a breach growth model). For this purpose, several commercial modelling tools are available.

Based on the locations and volumes of water entering the flood prone area as a function of time, the flooding event can be simulated by applying a flooding model based on a physical description (elevations, obstacles, and roughness) of the flood prone area, usually in the form of a GIS-based Digital Elevation Model (DEM). Again, there may be some variation in the possible level of detail and sophistication in the types of models that could be applied. For example, in its simplest form a flooding model could be to just assume that the storm surge water level would be present within the flood prone area, without including any of the physical processes involved with the internal water flows. At the other extreme, there could be a detailed 3D simulation of horizontal and vertical water movement within the flood prone area. Similarly, the assessment of the flooding characteristics (such as: flooded area, flooding depths, flow velocities, etc.) could be based on a crude or detailed schematic of grids, objects and depth classes. A number of commercial modelling tools are available for the purpose of flood modelling. It should be noted that often the above steps of breach development and flood propagation are combined in one model, although possibly in different modules.

Analyses of flooding events along the above lines are, and have been, conducted in all North Sea countries considered in Safecoast. Although there may be differences in specific modelling assumptions and in the tools used, there is considerable agreement in the general approach. It is also noted that the same models have been applied in several countries. Different levels of sophistication in methods and approaches applied, is often related to the specific characteristics of the area investigated and the specific purpose of the analysis.

(3) Analysis of flooding consequences

The analysis of flooding consequences is based on the physical characteristics of the flooding event. The basis of the direct and indirect economic damage assessment is a detailed inventory of movable and immovable economic assets and values associated with different forms of land use (such as agriculture or recreation). The assessment of casualties would be based on the physical characteristics of the flooding event and the number of people present in the flooded area (as affected by daily, weekly or seasonal variation), taking into account the possibilities of evacuation.

Damages and casualties are determined on the basis of explicitly defined functions relating to critical flood characteristics, such as water depth, flow velocity, rate of water level increase.

As was found for the analysis of flooding events, methods for the assessment of flooding consequences are commonly applied within the North Sea countries considered in Safecoast. However, in the country assessment procedures that were compared in Safecoast, various differences were observed in the specific details relating to:

- the damage categories considered (direct versus indirect, monetary versus non-monetary);
- the types of assets and values considered within the direct damage assessment;
- the procedures and levels of accuracy in data collection;
- the impacts considered in damage and casualty functions.

For example, in the German case considered, indirect economic damages are expressed as added values to direct damages and direct non-monetary damages include e.g. tourist beds and jobs. In Flanders, indirect economic damages are taken into account by applying factors to some selective direct damages (housing, industry and agriculture).

Damage to buildings is generally to be considered as an important damage category. In the German situation, sometimes the exact locations of buildings are known and sometimes merely the location of parcels in which buildings are contained. However in Flanders, known numbers of houses within statistical sectors are divided across residential areas taken from land use maps. Values of residential buildings are based on average selling prices in Flanders; on data in public registers in Denmark; and on a method using guideline prices in Germany (for the example considered). Moreover, in certain cases (Denmark, Flanders) the land values of private property are included, whereas these are separately treated in the real estate class of residential areas in the German case.

In some cases, industry, recreation or infrastructure are taken into account as separate categories. In others, the impacts associated with industry, recreation and infrastructure are considered within other categories, such as buildings. Livestock is taken into account in the German and Danish cases, but not in the Flemish example.

The Danish case considers a time damage function by crop type and period of the year. The Flemish case considers depth-damage relationships by crop type for fresh and salt water.

The number of inhabitants is defined differently in all cases. Sometimes the inhabitants in every house are known (Germany); sometimes an average number of people per house is assumed (Denmark); the Flemish case divides the inhabitants in statistic sectors by the number of houses. Casualties in the German case can only occur when there is no dry floor left in the house (requiring information about the number and use of storeys in buildings). In other cases, casualties merely depend on flood characteristics (such as water depth and rate of water level increase).

(4) Combining consequences and probabilities into risk

The Danish and German assesments consider a single return period or probability (2.5 x 10^{-4} in the Danish and 1 x 10^{-4} in the German case). In the UK and Flanders, a range of return periods is considered. In the UK Lincolnshire case (Comrisk) 5 return periods were used (T = 1, 20, 50, 200 and 500 years). In Flanders a series of return periods is used for navigable waterways as well as coastal areas (namely T = 1, 2, 5, 10, 25, 50, 100, 250, 500, 1000, 2500, 4 000, 10 000, 40 000 and 100 000 years) but in practice only a subset of these return periods is relevant for a given area.

In Flanders a further extension of the scenarios considered is used to deal with the large uncertainties of risk assessment models, in particular the uncertainty on the extreme value distributions of storm surges and the uncertainty on the failure behaviour of flood defences.

4.2.3 Improvements and application of flood risk assessment methods

Suggestions for improvements of flood risk assessment methods

Continuous efforts are taking place within the various NSR countries regarding the application and improvement of coastal risk assessment methodologies. Within Safecoast Action 3B (see section 1.4), a number of possibilities have been considered for improving various steps in the flood risk assessment methodology applied in Flanders, among others, based on a comparison of different available methods and tools. This has led to a number of specific suggestions for methodological improvement, within the following categories.

- Analysis of flooding events:
  - Modelling of breach growth.
  - Incorporation of line-shaped elements in DEM for flood modelling.
- Analysis of flooding consequences:
  - Influence of flow velocity in calculation of flooding consequences.
  - Time aspects in damage calculations.
- Evaluation of flood risk:
  - Use of range of return periods and associated flooding events.
  - Impacts on risks of developments over time.
- Dealing with uncertainties in flood risk assessment.

Breach growth modelling

Sensitivity analysis in the modelling of flooding events has shown that the time aspects and behaviour of breach growth (vertical and horizontal growth rate) have an important effect on the modelling results of the flooding event. Within Action 3B, different methods were compared to describe breach growth, in particular the use of a time series description of the breach growth and an erosion–based breach growth model (based on an application of MIKE 11). The main conclusions are:

- There are good possibilities for calibrating the MIKE 11 erosion-based breach growth model based on theoretical descriptions and laboratory experiments, as well as historical breaching events.
- Breach growth calculated by the calibrated breach growth model of MIKE 11 represents a more realistic course than breach growth predicted by a time series description with the assumption of a steady growth velocity.

Incorporation of line-shaped elements in DEM for flood modelling

The grid size resolution of the digital elevation model for flood modelling can strongly influence the result of a flood risk evaluation, particularly in relation to the handling of line-shaped, potentially water blocking, structures. When flood resisting structures are taken into account, the influence of elevation model resolution can be reduced. Within Action 3B, a procedure was developed and applied for the incorporation of line-shaped, flood resisting structures in a relatively coarse elevation model, using simple, semi-automated procedures.

Influence of flow velocity in calculation of flooding consequences

In traditional approaches for the calculation of flooding consequences, the main damage factor is water depth. Depending on the failure mechanism, there can be an important impact on flooding consequences of flow velocity (e. g. in the vicinity of breach locations). In Action 3B, a number of possibilities have been considered to include the influence of flow velocity in both the computations of economic damages and casualties. With respect to the latter, attention was also given to the possibilities of more explicitly modelling the effects of evacuation.

Time aspects in damage calculations

With respect to other possible improvements, the results of Action 3B emphasise the need to look into the various time aspects of the damage assessments (both in terms of time period and duration). Examples given of the importance of the time element in casualty and damage assessments include:

- the seasonal effect of tourism on the number of people present in the area;
- the time effects on damages to buildings and man-made structures (collapsing);
- impacts of duration and season on agricultural damages;
- the time effects involved in indirect damages related to relocation of activities and production losses.

Use of range of return periods and associated flooding events

Flood prone areas may be subject to different types of flooding events that are associated with different return periods. This is particularly true in case of different types of flooding threats from different water bodies (such as rivers, lakes, estuaries or seas). Also, in the case of solely coastal flood risk, there may be a need to consider a range of different return periods and related flooding events to reflect the various potential threats. The method suggested in Action 3B is to consider a range of return periods and related flooding events, of which the relative weighted contributions are included in the total risk assessment. Within this method, subsequent assessments take place, starting from the highest return period, up to the point where critical water levels will no longer lead to actual inundations.

Impacts on risks of developments over time

Risk calculations are based on information on hazards and vulnerabilities which are developed for the existing coastal system (based on presently available data).

In order to predict the development of expected damages over a given time horizon (e.g. 2050), the method suggested in Action 3B is to make use of a so-called 'rate factor' that would combine the impacts of important trends (such as climate change and economic growth in the coastal zone) in a single factor. The risk that is calculated for the current situation could then be multiplied with this rate factor to express the increase in risk due to the various relevant trends for the time horizon considered. The reason for this is not to camouflage uncertainties into a single factor, but to add a statistically quantified parameter to get better insight in the magnitude of uncertainties and the net-effect of (cumulated) sources of uncertainty.

Dealing with uncertainties in flood risk assessment

Very explicit attention was given in Action 3B to the aspects of uncertainty in flood risk assessment. Based on an identification of a number of main sources of uncertainty, it was concluded that the uncertainty in the risk assessment is mainly due to uncertainties regarding the hydraulic load and failure behaviour of flood defences, and may be of the order of at least a factor of 10. This stresses the importance of analysing and quantifying the different sources of uncertainty.

Given the extent of the uncertainties involved, the following recommendations were made in Action 3B:

- To avoid the use of absolute numbers in flood risk assessments.
- To improve the knowledge on the behaviour of coastal defence systems.

According to the first recommendation, risk assessments should primarily be aimed at the comparison of flood risks in relative terms. Results of risk assessments should not be expressed in absolute numbers (e.g. € / year). Changes in risks from comparisons of flood defence configurations or locations within a given coastal system (in %) are relatively accurate, while absolute numbers cannot be given with accuracy. Hence it is recommended to use percentages as risk comparisons relative to a reference situation within the same coastal system.

With respect to the improvement of the knowledge on coastal defence systems, the aspects that merit specific attention include:

- Expanding available information on the characteristics of existing sea defences.
- Generation of improved hydraulic boundary conditions based on in situ measurements, physical modelling and more advanced numerical modelling.
- Verification of used geotechnical formulas (and underlying assumptions) based on historical data.
- Improvement of understanding of the physical processes of wave overtopping, breach initiation and breach growth along typical sea dikes through the combination of experimental and numerical modelling.

For further information see the Safecoast Action 3B report: *"Comparison between different flood risk methodologies"*, 2008.

Suggestions on application of flood risk assessment methods

The flood and erosion risk assessments for the various cases considered within Safecoast (in particular within actions 3A, 3B, 5A and 5B – see section 1.4) have illustrated the need to distinguish between different approaches (in terms of scope and scale) in relation to the specific objective of the assessment, the extent of the flood prone area, and the available and required data.

In this respect, reference is made to the distinction in different analysis levels which was introduced in section 4.1, i.e.:

1. Top down analysis on national or transnational level.
2. Analyses of specific flood prone areas to identify and evaluate possible measures.
3. Detailed analyses for design of specific measures.

The above analysis types would typically coincide with different scales of analysis that will be referred to as the macro, meso and micro level, respectively. Moreover, these analysis types could be related to different phases of the planning process (from problem assessment through identification and evaluation of measures/strategies to specification and design) and presumably with different parties. This may have a number of important consequences for the analysis requirements regarding the level of detail of modelling procedures and the accuracy and resolution of model schematisations and related input data. Table 4.1 provides an overview of these requirements for the various scales in relation to the major analysis steps in flood risk assessment. This overview is indicative, in that it provides an indication of the approaches to flood risk assessment associated with the macro and micro level. In between these extremes there is a wide variety of possible approaches, which will be dictated by the specific purposes and requirements of the assessment. In table 4.1, no attempt was made to further describe the meso (intermediate) level.

In relation to the analysis levels described in table 4.1 the following observations can be made:

- The various analysis levels can be interpreted as subsequent analysis stages in a tiered analysis approach covering the steps from the problem identification or master planning stage to the design and application of actual measures (such as dikes). The use of a generalised methodology that will be refined in subsequent stages may contribute to the consistency and efficiency of coastal zone management planning procedures and the cooperation and communication between the various parties involved.
- The efforts involved with the more detailed analysis stages may be considerable. In each stage there should be careful consideration whether the purpose of the analysis justifies this effort.
- Needs for improvement of methodological approaches are closely related to the purpose and scale of the application.
- Where the macro level would allow for the use of common or generalised approaches (e.g. for the North Sea Region as a whole), the applications on meso and especially on micro scale tend to be more location specific. It is noted that macro scale analysis could to some extent make use of the results of earlier more detailed assessments, while still making high level decisions.

The following sections of this chapter deal more specifically with the various application levels of flood risk assessment. In this respect, the results of Safecoast Action 3A described in Section 4.3 represent an example of a macro level application of flood risk assessment, whereas the case study examples of Actions 3B and 5B described in Section 4.4 represent examples of the meso/micro level.

Steps in flood risk assessment	Tiered flood risk assessment: scales and purposes of application		
	Macro level	**Meso level**	**Micro level**
	Top down analysis on national or transnational level	Analyses of specific flood prone areas to identify and evaluate possible measures	Detailed analyses for design of specific measures
1. Analysis of hydraulic loads and failure behaviour of flood defences	Regional assessment of hydraulic conditions	……	Flood defence system specific assessment of hydraulic conditions
	Generalised description of flood defence system characteristics and failure mechanisms (e.g. by using fragility curves)	……	Consideration of specific representative flood defence system sections and failure mechanisms
	Flooding probability of flood prone area based on a representative failure probability	……	Flooding probability of flood prone area based on weakest link considerations of different defences systems and failure mechanisms
	Simplified, worst case assumptions on failure location / mechanism	……	Different failure scenarios based on relevant combinations of failure locations and mechanisms
2. Analysis of flooding events (flooding scenarios)	Specification of flooding volumes or discharges over time by direct assumption	……	Explicit modelling of flooding volumes and discharges based on specific local hydraulic conditions and failure development (e.g. breach growth)
	Simplified modelling approach of extent and water depth of flooded area (or worst case assumptions on area and maximum flooding depth) on coarse grid size	……	2D/3D flood modelling based on detailed flood area characteristics (elevation, roughness, line and point obstacles) on fine grid size
3. Analysis of flooding consequences	Use of a limited number of damage categories	……	Consideration of a variety of damage categories and object types and detailed inventory of land use values and specific assets
	Use of generalised water depth - damage and water depth – casualty rate relationships	……	Use of specific damage and casualty rate relationships considering multiple flooding parameters
4. Combining consequences and probabilities into risk	Use of a single scenario for an extreme storm event and for failure locations and mechanisms	……	Use of a series of scenarios of extreme storm events Use of a series of possible models to describe the extreme probability distribution of hydraulic loads, and the failure locations/ mechanisms

Table 4.1: Analysis requirements for different scales of flood risk assessment

4.3 Integrated risk assessment for the North Sea region

4.3.1 Purpose of integrated risk assessment

Within Safecoast, attention was given to the possibilities of developing a North Sea wide (macro) view on coastal vulnerability with respect to flood risk and coastal erosion. The purpose of this integrated risk assessment is to facilitate the:

- comparison of present and future coastal risks across coastal regions and countries;
- identification of most vulnerable areas for further analysis to reduce risks;
- identification of differences and similarities in coastal risk problem areas and possibilities for common approaches.

Results of NSR wide and large scale coastal risk assessments have been particularly considered within the following Safecoast Actions (see section 1.4):

- Action 3A on the transnational flood risk assessment for NSR coastal regions.
- Action 5A on risk assessment for different coastal erosion pilot sites and development of a coastal erosion atlas.

The specific aim of Safecoast Action 3A is to provide a North Sea overview on changes in flood risks in the coastal areas and to present those risks in the future can be assessed in a more tangible way.

The objectives of Safecoast Action 5A include the production of an erosion atlas for the entire Danish coastline for the year 2050, taking into account the consequences of climate change.

The approaches and results of the integrated risk assessments on flooding and coastal erosion are further described in the next two sections.

4.3.2 Approach to and results of integrated flood risk assessment

Scope of integrated flood risk assessment

In Safecoast Action 3A (see section 1.4) a trans-national study was carried out to identify the developments in flood risk along the North Sea coasts.

The main questions addressed include:

- What are the likely changes in flood risk in the forthcoming years if the consequences of climate change (sea level rise, increased storm conditions) and an increase in vulnerability in the flood prone areas are taken into account?
- What management strategies would be most appropriate to counteract the changes in flood risk?

Safecoast Action 3A involves an exercise in flood risk assessment in order to map the changes in flood risk. In this exercise, relevant types of information to be provided include:

- The areas that may be affected by flooding and the water depths that will be reached.
- Information on the duration of flooding events.
- The assets, networks and the number of people and that will be seriously affected.

Information on disrupted networks of roads and railways, (air)ports, cables and wiring and commercial and industrial areas will provide further insights about the extent to which the (international) society at large may be affected.

The results of Safecoast Action 3A are indicative and may be used for a number of purposes:

- Enhancing the public awareness of flooding.
- The EU Floods Directive (see section 5.2), for which it may serve as a reference framework.
- Spatial planning.
- Crisis management arrangements (e.g. cross border).
- Macro-scale insight in possible differentiation in desired or required flood safety levels.
- If necessary: to provide insights on how to strengthen flood protection systems; how to finance flood safety; and when and where to start (infrastructural works generally take years before they will be executed).

When translating the flood risk issue into a European, transboundary perspective it is important to get an overview of the change in flood risk in the North Sea area based on a uniform method. The results of the flood risk assessment should be credible and support the already available local flood risk assessments. For that reason the study was based on local data available on a European level.

For the flood risk assessment the year 2007 serves as the bench mark. The future situation was based on the year 2050. For this year, a scenario specification was made regarding climate change and socio-economic development. It was assumed that the sea defences will not be systematically heightened and reinforced until the year 2050.

Approach

The integrated flood risk analysis approach comprises the following steps:

- For the North Sea area a GIS model including digital elevation data, data on flood defences and socio-economic data is constructed.
- The North Sea shoreline is divided in uniform stretches of flood defences.
- For each stretch of flood defence the hydraulic load on the flood defence is calculated. The hydraulic load on the flood defences is based on local knowledge regarding water levels and wave characteristics with their return periods; for the future hydraulic loads sea level rise derived from the medium-high IPCC-predictions was used.
- For each stretch of flood defence the probability of failure due to overtopping is estimated using the concept of fragility curves (in accordance with the approach developed by HR Wallingford). A fragility curve relates the overtopping discharges with the probability of failure of the flood defence system concerned.
- For the flood prone areas the extent and the depth of the flooding is estimated using a standard GIS tool (Flood Area).
- Damages to property and networks, and casualties are determined based on damage curves and on information available in Eurostat relating to population, assets and infrastructure at department level.
- In using future trends about demography, assets and infrastructure at department level a scenario for the change in population and socio-economic development is constructed.
- Based on the probability of failure and the flooding damage, the flood risks for the 2007 and the 2050 situation is derived.
- Information about the effects of disrupted networks is determined by expert judgement based on the results of the risk analysis.

The results include information about the changes in flood risks in the defined coastal areas between 2007 and 2050. From the comparison of the risk assessments the main contributory factor can be identified:

- The increase in the probability of failure of the flood defences; or
- The increase in the consequences of flooding following from the change in population in combination with an increase in assets and infrastructure.

Results and recommendations

Based on an intermediate scenario for sea level rise and socio-economic growth and assuming that the actual flood defenses will not be heightened or enforced, the trend in flood risk shows a significant increase along the North Sea coast towards 2050 (see figure 4.7).

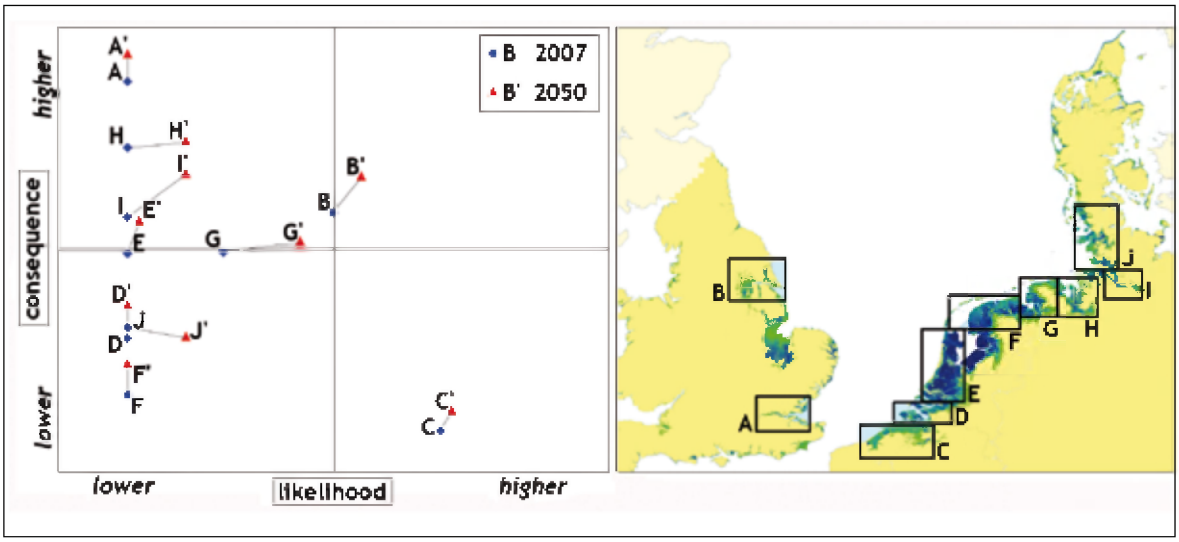


Figure 4.7: Changes in likelihood and consequences per defined region until 2050

The increase in flood risk is most marked in the Thames and Humber estuaries, West Flanders/Antwerp, Central Holland, and coastal flood prone areas of Hamburg and Bremen. These areas are major hubs in the transportation routes of goods and people into and out of Europe. Within these areas major cities, (air) ports, key industries and infrastructure are situated. Flooding of these areas will not only affect these areas themselves but also affect the economy of large parts of Europe.

When assessing the flood risk one should always assess both the probability of failure and the consequence of flooding (material damage, casualties and social and economic disruption).

If a significant increase in consequence occurs it may be necessary to take measures in e.g. spatial planning to minimise (or reduce) the potential impacts. However, if at the same time the probability of failure is very small, the effect of such an increase in consequence on the resulting flood risk may still be negligible.

Based on the price level of 2007 the consequence in terms of economic damage will increase by a factor of 1.3 - 1.5. This factor consists of the change in flood prone area, inundation depth and assets at risk. Preliminary calculations show that the increase in consequence due to an increased inundation depth will be about 20 to 30%. However, the increase in consequence towards 2050 due to spatial developments, such as the increase in urban area, was not incorporated in the analysis as there are no trend figures available. Therefore the consequences in 2050 are expected to be larger than presented in the present study

For flood prone areas protected by flood defences which at present have a low probability of failure the change in flood risk is dominated by the change in consequence. If however, a flood prone area is protected by a flood defence with a relatively high failure probability the contribution of the increase in failure probability to the increase in flood risk may be of the same magnitude as the contribution of the change in consequence.

At present there is a severe lack of uniform, widely accepted and available data on infrastructure and housing for flood risk assessment on a European level. There is also no data available on water levels, wave-heights and wave-periods for given return periods on a European level. As a consequence the results are presented in a qualitative and relative way.

Recommendations
Based on the results it seems appropriate and economically viable to reduce the risk of flooding by investing in coastal zone management. To effectively counteract the increase in flood risks, coastal zone management strategies should consist of a mix of three types of measures:

1. reinforcement of the flood defenses;
2. adaptive spatial planning strategies for the flood prone areas such as zoning of building restrictions, adaptive building, dividing the flood prone area into several flood compartments, the network of escape-routes, insurance policies for householders and residents, mandatory allowances for people to install self help provisions etc.;
3. the set up and functioning of a interregional calamity-organization with regard to flood early warning, flood risk communication, evacuations, medical care, aftermath crises handling and compensation of losses.

In order to conduct transnational risk assessments it is necessary to develop and maintain uniform and widely accepted databases on (trends in) housing, infrastructure, land use and hydraulic boundary conditions with return period. For further information see the Safecoast Action 3A report: *"Flood risk trends in the North Sea region"*, 2008.

4.3.3 Integrated coastal erosion assessment along the Danish coasts

Background
Safecoast Action 5A includes the production of an erosion atlas for the Danish coastline. The erosion atlas provides valuable information about the geomorphologic changes caused by sea level rise and increased storminess for the period until 2050. In addition, the erosion atlas for the Danish coastline provides an example of the information on coastal erosion developments on a larger scale, to be used in the overall interpretation of coastal risks.

Denmark has a long (7,300 km) and varied coastline. The geological and geographical characteristics, and impacts on the coastal landscape of the latest glaciations differ at local and regional levels. Open coasts and tidal flat coasts facing the North Sea and sheltered coasts in fiords and embayments with fetches (length of water over which a given wind can blow) that vary from a few hundred metres to several hundred kilometres add to the coastal complexity.

Objectives and methods

The focus is on how an approach for impact assessment of the consequences of climate change can be realised for the complex Danish coastline: how do we proceed in assessing potential consequences due to climate change? At a national level, an analysis of additional coastal erosion due to sea level rise along the entire coastline is undertaken, and at four pilot sites reflecting the coastal variability, a more detailed local level impact assessment is carried out (see Section 4.4.3).

The GIS-based Coastal Erosion Atlas of Denmark was based on combining

- a coastal classification scheme and wave-energy levels inferred from automated fetch calculations and regional wind-climate;
- recent coastal evolution trends and calculated and inferred littoral transport directions, and previous works to estimate the additional coastal erosion due to climate change.

The Coastal Erosion Atlas of Denmark can be found in Annex 3.7 of this report.

Coastal erosion depends on the combination of a number of parameters (e.g. water level, wave-energy, wave refraction, sediment composition and abundance, shifting points of wave attack). Since no adequate models for coastal erosion currently exist and as distinguishing between current erosion rates and additional future erosion is a difficult task, a simple projection is not possible.

Additional complications relate to the fact that the transitional zone between the North Sea and the Baltic Sea shows complex water level variations with non-periodic extremes and that the manifestation of a future global sea level rise differs regionally due to variations in glacial isostatic adjustment and in hydrodynamic forcing.

Results

The produced atlas may only be used to get an overview and to assess possible ranges of additional erosion. Locally, future erosion may be negligible or turn out to become considerably larger than assessed at the national level and has to be investigated in more detail and be divided into erosion, permanent inundation and risks of flooding. It has become increasingly apparent that in many cases the sea level rise itself is secondary to changes in the wind climate, and thus to the wave energies reaching the coast, and hence in determining the future rates of change. At many places a pragmatic approach may be justified due to a fairly straightforward relationship between climate change and coastal erosion. However, at some locations this will certainly not be the case.

Results thus far point both to the necessity of the assessment of future coastal erosion on a local level and to the importance of providing a good and detailed scientific basis for decision-making on both national and local levels that reflects the coastal complexity.

Conclusions

The approaches used for producing the national erosion atlas compared to those used for the local assessments at the four pilot sites (see Section 4.4.3) show that on the local level assessments are adequate if credible results are available to allow for sustainable decisions to be made. The reasons are:

- Impacts of climate change along the Danish coastline vary and have to be considered in decision-making processes and also be reflected in decisions made on a national level.
- Decisions regarding long-term adaptation measures should be made on the regional or local level, i.e. they should account for local variations in the coastal zone.
- Communicating adaptation measures, public perception on climate change and on its consequences must relate to local and thus well-known conditions and measures.
- The availability and quality of data is crucial in the impact assessment. On a local level data are easy to acquire or generate. The intention of a detailed impact assessment at national level to allow for sustainable decisions considering local variations is onerous due to the very high workload. On local level, the performance of impact assessments including the generation of necessary data is more manageable.

Further work is needed on coastal change models that accommodate the coastal variability and incorporate climate change. Tools for the assessment of impacts of climate change are very much in demand by local authorities and the results of the work carried out on the four pilot sites are currently in the process of being transformed into guidelines and tasks for utilisation at a broader scale. This, hopefully, will yield a basic reference for the sharing of knowledge between local authorities and provide realistic scenarios of the future coastal changes. For further information see the Safecoast Action 5A report: *"Consequences of Climate Change along the Danish Coasts"*, 2008.

Recommendations

The availability of data differs from location to location. However, adequate data are needed to perform impact assessments in the coastal zone to help make sustainable decisions. It is recommended, for the planning and initiation of a Danish *national monitoring strategy,* to collect data on local level to allow for local impact assessments. This strategy should define the type and quality of the data, as well as set the general framework for impact assessments to allow for the integration of neighbouring local impact assessments into one regional assessment.

4.4 Case studies on detailed risk assessments in the North Sea region

4.4.1 Overview of case studies

A number of specific case studies on local and regional coastal risk assessments have been considered in various Safecoast Actions, i.e. (see section 1.4):

- The Flanders case study on detailed flood risk assessment developed in Safecoast Action 3B.
- The case studies on coastal erosion assessment at four pilot sites in Denmark developed in Safecoast Action 5A.
- Case studies on detailed flood risk assessment at two pilot sites in Lower Saxony developed in Safecoast Action 5B.

A summary overview of the approach and some of the main results and observations is provided in the following sections.

4.4.2 The Flanders case study

In Safecoast Action 3B, a case study was executed for the flood prone area on the Flemish coast between Zeebrugge and the Dutch border (the coastal community of Knokke-Heist). This area includes the Flemish part of the case study 'Vlaanderen / Zeeuwsch-Vlaanderen' which was considered earlier in the Comrisk study. In this Safecoast Action, the hydraulic modelling part together with the damage and casualty calculations (including an extensive sensitivity analysis) were further elaborated using the methodological improvements developed in Safecoast (as described in Section 4.2.3).

The flood defences in the area consist of the combination of (nourished) beaches, dunes that are for the most part built up and sea walls with promenades. The coastal town of Knokke-Heist and the nature reserves around the Zwin tidal inlet are the main land use types in the coastal strip. In the coastal plain there is mainly agricultural land. The topography of the study area is shown in figure 4.8.

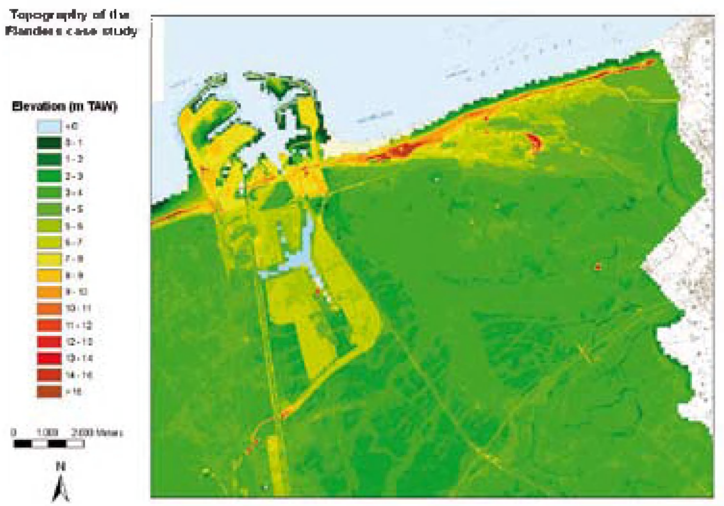


Figure 4.8: Topography of the Flanders case study

Flood simulations were carried out with the commercially available model MIKE FLOOD which is a dynamically linked 1D and 2D flood modelling package, including a module for breach development. The failures of the flood defence systems were simulated within MIKE FLOOD based on certain assumptions on breach development and maximum breach width. The 2D flood model was based on the elevation model used in Comrisk. The basis for the damage calculations was derived form land use classes taken from Corine Land Cover 2000.

The flood risk assessments were based on assumptions of breach locations. A total of 8 potential breach locations were assumed based on the relative weak spots in the flood protection system. An extensive sensitivity analysis of the hydraulic modelling was carried out; involving a large number flood simulations and damage assessments. The sensitivity analysis considered a range of different assumptions within the various modelling steps, among other including:

- time of breaching;
- horizontal and vertical breach growth rate;
- roughness in 2D flood modelling;
- resolution of elevation model and representation of linear structures;
- storm surge levels.

Flood simulations and damage assessments were made for different return periods, i.e. the 4000, 10 000 and 40 000 year events.

From the simulation results it was concluded that the time of breaching and breach growth strongly influence damage risk and casualty risk. The most important parameter is the number of breaches and its location. For given breach locations, dimensions and timing, the most influential parameter in the flood model is the surface roughness. Moreover, the resolution of the elevation model and the presence of linear structures can strongly influence the results of a risk evaluation. The relative importance of these factors depends on the type of risk (damage or casualties). When line-shaped, flood resisting structures are taken into account, the influence of elevation model resolution can be reduced.

Finally it is noted that in the risk analysis, the uncertainty on hydraulic boundary conditions and failure behaviour of the flood defences is dominant to the uncertainties related to flood modelling and damage assessments (see section 4.2.3). For further information see the Safecoast Action 3B report: *"Comparison between different flood risk methodologies"*, 2008.

4.4.3 Danish pilot sites on coastal erosion assessment

Within Safecoast Action 5A, case studies on coastal erosion assessment have been performed for four Danish pilot sites and with some attention also given to the risks of flooding. Main aims have been to:

- to improve the knowledge of the effects of climate change on coastal defence systems,
- to improve the understanding of the interplay between the coastal defence system and the related socio-economic system under changing boundary conditions,
- to improve the process of informing relevant parties (policy makers, public, media, etc.) about the consequences of climate change in the coastal zone in an appropriate way.

The pilot sites, that were selected to reflect the variability of the Danish coastline and to different challenges facing the communities in years 2050 and 2100 due to sea level rise, were (see figure 4.9):

- **Ballum-Koldby,** on the Danish Wadden Sea coast of Jutland, is a low-lying agricultural area protected only by a summer dyke.
- **Houvig,** on the open North Sea coast of Jutland, contains many holiday houses. The coast is sand nourished and managed dunes protect the hinterlands from flooding during storm surges.
- **Løgstør**, a small town in the Lymfjord of which a large part is liable to flooding during storms. Coastal erosion is currently experienced at the stretches adjacent to the town and harbour.
- **Aabenraa,** a town situated in a fiord in southern Jutland towards the Baltic Sea, is prone to flooding but is currently experiencing relatively little coastal erosion along the fjord.

Figure 4.9: Four Safecoast pilot sites on coastal erosion in Denmark

Approach

For the assessment of future coastal erosion the IPCC A2 (2001 & 2007) scenarios together with an assumption of 6 mm/y were applied. From Danish tidal gauges it is observed that the rate of sea level rise in the Danish Wadden Sea is currently larger (4 mm/y since 1973) than current rates reported by IPCC. Combined scenarios were applied on the Danish North Sea coast to account for the rise in sea level already experienced since 1990. At each pilot site the rates were consequently corrected to compensate for local isostatic movements. Further, attempts were made to assess the consequences of an increase in storminess, shown by some models, on coastal erosion. Finally, projections of extreme water level statistics from tide gauges under different scenarios are applied to assess flood risks and the combined effects of flooding and surge levels on the coastal erosion at the pilot sites in the future.

There is not one single model that can accommodate parameterizations for all different types of coast, and it is unknown in detail how to prioritize the different parameters (e.g. hydrodynamic forcing, seafloor gradient, morphological and geological conditions) controlling coastal erosion, making the assessments difficult.

Also, in general and at the pilot sites, the data availability is scarce and varying and four different methods are applied at the pilot sites based on the coastal type and on the amount of data available. First, however, the historic evolution at the sites is investigated from old charts, aerial photographs and from satellite photos. Together with investigations at the sites regarding the physical appearance of the coastlines, morphological features, the existence of coastal defences and the infrastructure, form a basis for the assessments.

Coastal erosion is a naturally occurring process that is a prerequisite in the formation of new land, and that three out of the four pilot sites owe their existence to coastal erosion in the first place as being situated on marine accumulation forms.

- All available data on hydrodynamic forcing, depth measurements etc. was gathered.
- An analysis of the sediment balances and erosion rates to present day was performed and, to a first approximation,
- The consequences of future erosion were assessed.

As coastal erosion does not occur linearly over time and in an ever evolving coastal landscape with a large natural climatic variability, this has been not an easy task. Where possible, coastal erosion may locally be assessed by morphological units that take into account the coastal areas of erosion, transitional areas and areas of accretion but, even so, this may not be sufficient .

One example is the pilot site at Løgstør where the breach towards the North Sea of the Lymfjord barriers in 1825 (see chapter 2, regional description) had a large impact of storm surge water levels and coastal erosion rates, and another is Ballum-Koldby where the shifting of sand further out in the Wadden Sea may lead to a different hydrodynamic forcing in the future. This also means that a differentiation between the "natural" coastal erosion and the extra erosion due to climate change is not clear, and therefore has not been made for all pilot sites.

Results
With respect to sea level rise, an increase in the 20th century rate of 1,5-1,8 mm/y will at lead to a higher risk of flooding and to larger erosion rates at the coast according to the assumptions based on the Bruun rule.

On the sandy North Sea coast at Houvig, where the model use can be justified in the assessment, erosion will increase as will the pressure on the dunes for flood protection. Therefore, in order to maintain the coastline in its current position, the amount of sand needed for nourishment will also increase.

The Ballum-Koldby site will experience more frequent floods, but as the area only contains a few farms and is currently only protected by a summer dyke, the consequences in the future are limited and can be solved in a cost-efficient way by not developing the area further.

The Aabenraa site is currently experiencing sea level rise and will under a climate change scenario be even more vulnerable to flooding in the lower-lying parts of the town. Regarding the coastal erosion, sediment transport rates have been small in the fjord over the last couple of centuries but may increase considerably at some locations in the future. The susceptibility to flooding, however, is the main issue here. As extreme water levels in Aabenraa are a result of rarely occurring wave phenomena in the Baltic Sea – North Sea transition, a future climatic deterioration may have larger implications on the surge levels and the associated consequences, than sea level rise alone.

Finally, Løgstør is currently experiences both flooding of the town and coastal erosion of the adjacent coastlines. Even with the current rates of erosion, problems are foreseen in the near future as breaches at the coast toward a canal behind the coastline may lead to new points of attack from the waves and to reduced effectiveness of some of the current natural flood protection.

In general, from the pilot sites and elsewhere along the Danish coastline, it may be concluded that assessments of future coastal erosion (and flooding) even at local levels may be a difficult task. Attention must be given to both the methodology and the way it is incorporated in the coastal management at all levels. Progress has to be made by local authorities in simply assessing consequences of sea level rise from elevation maps.
It is difficult to assess the impact of climate change on coastal erosion by year 2050, whereas in 2100 the coast is under an increased pressure form both a larger projected rate of sea level rise and from a possible climatic deterioration that may be even more important in altering the hydrodynamic conditions and lead to completely different patterns of coastal erosion than are experienced today. For further information see the Safecoast Action 5A report: *"Consequences of Climate Change along the Danish Coasts"*, 2008 and the coastal erosion atlas for Denmark in Annex 3.7

4.4.4 German pilot sites on flood risk assessment

Within Safecoast Action 5B, case studies on detailed flood risk assessment have been considered for two pilot sites in Lower Saxony, i.e. the island of Langeoog and the north western part of East Frisia. The protected flood prone area of Lower Saxony covers about 6600 km2 and is inhabited by about 1.2 million people. Surrounded by Lower Saxony is the federal city of Bremen with a flood prone area of 360 km^2 and 0.57 million inhabitants.

The island of Langeoog is one of 7 inhabited islands in the East Frisian Wadden Sea, few km distance from the mainland. The island is protected from floods by dikes on the Wadden Sea side and by dune belts on the northern and western coasts, with a total length of about 10.6 km. The crest height of the dike ranges from NN 5.4+ to 8.0+ m. The protected part of Langeoog as considered in the pilot site covers 6.62 km^2 and the number of permanent inhabitants is around 2000. However, Langeoog is an important sea resort and a large number of tourists may stay on the island depending on season.

The pilot area of East Frisia is bordered by the North Sea on its northern and western coasts and by the river Ems and a channel (Sauteler Kanal) in the south. The entire coastline is defended by dikes with a total length of about 109 km. The Ems-Jade channel with high embankments subdivides the project area in two parts. The total area considered is 1292 km^2 with about 305,000 inhabitants. The biggest settlements are the cities of Emden and Norden with 51,000 and 25,000 inhabitants, respectively. For a satellite image of the locations of the pilot sites, see figure 4.10.

Figure 4.10: Location of the pilot sites East Frisia and Langeoog. An example of a flood simulation is presented in Annex 3.8

The risk assessment was based on flood simulations with the numerical model Sobek, using a combination of a 1D module for channel flow and a 2D module for overland flow. Potential breach locations were defined by choosing representative points of every quasi-homogeneous coastal section. Those sections were identified to be almost homogeneous, regarding the coastal defence system as well as the topography.

For the island of Langeoog, five breach locations were considered in six different flooding scenarios. For East Frisia a number of possible breach locations were considered which has resulted in a specification of about one hundred different flooding scenarios. The failure development of the flood defence systems were simulated within the numerical model based on an empirical approach and plausible scenarios. The maximum breach width to be achieved at the end of breach development was determined from experience, a literature review, and a parameter study. Time series of water levels were provided based on hydrographs for each breach location, assuming a sea level rise of 50 cm per century. Simulations were carried out for the years 2007, 2050, and 2100 (with increased water levels because of sea level rise of 25 cm and 50 cm respectively).

As a basis for damage assessment, results of the numerical model were used on inundated area and inundation depth, based on uniform grid sizes. For the pilot sites Langeoog and East Frisia, respective grid sizes of 5 m and 50 m were used. Damage assessments mainly pertained to the direct, tangible primary damages for a variety of categories. In addition, the loss of gross value added was used to reflect one indirect type of damage. Additionally, an assessment of affected inhabitants and the value of the affected soil are provided.

Given the various flooding scenarios (especially in East Frisia) many simulations were carried out, including the consideration of a number of possible flood mitigation measures such as high forelands, summer dikes, second dike lines and break lines in the hinterland (see also section 2.3). Many flood simulations were carried out. Find a detailed example of a flood simulation in East-Frisia in Annex 3.8

The main findings of the case studies were discussed with local and regional expert groups and are summarised below.

1. Flood simulations:
    a. The use of state of the art numerical hydrodynamic models for simulations of flooding due to the failure of coastal defence structures is recommended.
    b. Simulations of coastal lowland's floods should include a 1D-stream network in addition to the 2D-overland flow.
    c. The extent of a dike breach (width and depth) and the number of simultaneous breaches in a certain area are the most influencing parameter.
    d. Additionally, the topography of areas sea and landward of the breach location strongly influences the inflowing volume and the flood propagation.
    e. The sea level rise affects coastal flooding in broad coastal lowlands by significantly increasing the inundated area.

2. Risk analysis:
    a. About 90% of the direct tangible values at risk are concentrated in four damage categories. Those are private buildings, private inventory, fixed assets and the gross value added.
    b. The predictions of future economical changes in flood protected areas and therefore the development of assets at risk is highly uncertain.
    c. In case of a flood event, the expected sea level rise results in significantly increased damages of all damage categories, even for constant damage potentials and breach conditions.

3. General recommendations:
   a. Development and management of forelands as well as maintenance and expansion of embankments in the hinterland, including 2nd dike lines, street dams etc., are found to be potential flood risk mitigation measures.
   b. Despite the benefits of the above risk mitigation measures, two types of possible negative effects were identified that need to be considered during the planning process. The mitigation measures take effect by hindering flood propagation and therefore strengthening the area's resistance against flooding. One possible negative effect is the flooding of areas which were safe before the measure was introduced. This results from changed flow paths which may occur even if the flooding hazard comes from the direction the measure was planned for. Another possible negative effect is that, if flooding occurs from another direction, the area which should be protected by the measure could be in even greater danger than before.

For further information see the Safecoast Action 5B report: *"Flood risk assessment at two pilot sites – methods and measures"*, 2008.

5 STRATEGY DEVELOPMENT TO MANAGE COASTAL RISKS

5.1 Problem orientation: present and future coastal risks

5.2 Measures and experiences in managing coastal risks

5.3 Identification of promising measures and strategies

5.4 Scaling issues and need for integrated planning

5.5 Use of Safecoast results

5.6 Developments on measure and strategy concepts

5.7 Suggestions for strategy development

5 STRATEGY DEVELOPMENT TO MANAGE COASTAL RISKS

5.1 Introduction: present and future coastal risks

The primary focus of the Safecoast Project is on the assessment and management of present and future coastal risks in the North Sea region. As is generally the case with most coastal areas in the world, the North Sea region has been, and will continue to be, subject to increasing coastal risks from a variety of pressures both natural and man-made.

Historically, the coastal zones have been the natural living area for a substantial part of the world's population, providing a major contribution to global food production and supporting a large number of economic activities. This has led to a continuing and often accelerating process of intensive development and modification of coastal areas. In many places, these human developments have decreased the resilience of the coastal system by disturbing natural processes and causing other adverse environmental effects. In addition to the increase in landward pressures, the impacts of climate change will significantly aggravate the future pressures from the sea, due to the combined effects of sea level rise, storm intensity and resulting wave height and energy. Given the rising pressures from land and sea in combination with the increase in population and capital investments, coastal zones are becoming increasingly vulnerable.

Safecoast looked in detail at the main drivers underlying the increase in coastal risks, in particular the spatial and infrastructural developments in relation to socio-economic activities and the various aspects of climate change (see Chapter 3 of the Synthesis Report). Some of the results provided in Chapter 3 clearly illustrate the potential for further spatial development in a number of key areas in the flood prone coastal zones of the NSR. Regarding climate change, there is some consensus within the NSR countries about the use of an average estimate for sea level rise of 5 to 6 mm/year, while the estimates for changes in wind speed and wave height are merely indicative at this stage. Obviously, such developments are subject to a large range of uncertainty, especially when looking further into the future. An important conclusion of Safecoast is that these uncertainties should be explicitly considered and transparently expressed in a number of different scenarios reflecting a realistic range of uncertainty. Such a scenario analysis would provide insights to the impacts on coastal risks under different possible developments, allowing coastal managers to anticipate and prepare for further courses of action.

Given a number of simplified scenario assumptions an illustrative assessment was carried out in Safecoast of the present and future (2050) flood risks for the flood prone areas of the NSR (see section 4.3 of this report). From these results it can be concluded that:

- A significant increase in flood risk towards 2050 is to be expected along the North Sea coast. This increase in flood risk is most marked in the Thames and Humber estuaries, West Flanders/Antwerp, Central Holland, and coastal flood prone areas of Hamburg and Bremen.
- The increase in flood risk follows from the combined effects of a change in consequence due to socio-economic development and a change in flooding probability due to climate change.
- Based on fixed price levels, the consequence in terms of economic damage will increase by a factor of 1.3 - 1.5. This increase is without the effect of possible increases in urban area following from spatial developments. In case the flood prone area is protected by a flood defence with a relatively high failure probability, the increase in flood risk due to the increase in flooding probability may be of the same order of magnitude.

In general terms, the coastal area is a mosaic of different land use types including densely developed areas for residential and holiday use; industrially developed areas; and more natural areas of e.g. extensive grazing or salt marsh. Separate trade-offs need to be made for different flood prone areas, given the specific land use and related values and its flood defence characteristics. Potential impacts of flooding events may include economic damages that can be assessed in money terms, as well as social disruption of communities (including casualties) or the loss of intrinsic values to conservation areas which are generally not easy to quantify in monetary terms.

The use of cost-benefit analysis could assist in decision making for coastal strategies in order to reduce risks. It is important to note that, in addition to the consideration of specific trade-offs and solutions for specific coastal areas there is an underlying need for developing a comprehensive view on coastal risk management from a large scale (national) planning perspective. For this purpose risk assessment analyses need to be carried out at different geographical and temporal scales, taking into account the long term development potential and the various interactions between different parts of the coastal system.

5.2 European policy context

Early European policies affecting the coastal zone were predominantly reactive and issue oriented (e.g. water quality). Since the 1970s the EU has been dealing with coastal zones through international conventions covering its regional seas. Later, the EU has begun to specifically address problems related to the environmental state of coasts and the coast as a regional entity.

Among others, specific environmental policies and legislation influencing coastal management are the Birds (1979) and Habitats Directives (1992) that form the basis for the Natura 2000 ecological network of protected areas. Their aim: to maintain or restore the habitats and species at a favourable conservation status in their natural range. Also, the EIA (1997) and SEA (2001) directives on environmental impacts of projects and plans are influencing coastal developments and plans in such a way that the environmental implications of decisions are either mitigated or compensated.

From 1996 to 1999, the EC operated the EU Demonstration Programme on Integrated Coastal Zone Management (ICZM), in which 35 projects and 6 thematic studies were aimed to initiate a broad debate among the various actors involved in the planning, management or use of European coastal zones.

In 2002, the EU adopted the ICZM Recommendation (CEC, 2002) in which a set of principles for implementing ICZM were described and countries were asked to report on their progress. In 2006 these reports were evaluated by the EC, and it was concluded that significant steps had been made with respect to: 1) awareness of long-term coastal challenges; 2) moving from traditional to sustainable planning; 3) participative elements in decision making. In a recent communication (CEC, 2007b), the EC has stated that ICZM will become an important component of the future EU Maritime Policy.

In addition, themes like coastal erosion and flooding have been actively pursued by the EC in the last decade. Between 2002 and 2005 the Eurosion project was commissioned by the EC to assess the issues related to coastal erosion in Europe. One of the recommendations was to increase coastal resilience by providing more space for natural processes.

The recently adopted EU Floods Directive (2007), triggered by the major river floods in Europe since 1998 requires Member States to assess the watersheds and coastal areas that are at risk from flooding (by 2011); to map the flood extent and assets and humans at risk in these areas (by 2013); and to take adequate and coordinated measures to reduce this flood risk (by 2015). The outcomes of project Safecoast may serve as a (coastal flood risk) reference framework for the implementation of the directive.

The challenges related to the compilation of elevation data from national and regional databases in project Safecoast (see annex 3), is only one example to illustrate the importance of the recent EU Inspire Directive CEC (2007) on an improved infrastructure for spatial information. More recently, the European ambition for a shared environmental information system (SEIS) underlines the need for accessible, connected, and comparable data and information for decision making on a European level.

5.3 Solutions to deal with coastal risks

Until recently, at the European level most debates and policies have concerned the mitigation of climate change (by reducing emissions of carbon gases). Increasingly however there is a move towards 'adaptation' to climate change in addition to, and sometimes complementary to, mitigation. The adaptation of coastal regions and coastal protection systems to climate change has entered the agenda in coastal zone management for both flood risk and erosion risk management.

When considering the possibilities for managing coastal risks from the viewpoint of adaptation, there is a variety of potential measures to be considered. Inventories of possible measures have been made in various studies, while recent studies and developments are still adding to these possibilities. Most existing studies and approaches distinguish between a number of different measure 'categories' that are related to different phases of risk management. Common categories used relate to:

(1) Actions that can be taken in advance within the area subject to flood risk reducing the consequences of flooding events.
(2) Actions aiming to protect flood prone areas in order to avoid actual floods occurring.
(3) Actions to improve preparedness and responses in a crisis situation in order to avoid flooding or reduce consequences.
(4) Actions involved with restoring the material and immaterial damages after a flooding event has occurred.

Different studies and approaches have used different terminology and distinctions for the different measure categories, however, there is a similarity in the meaning of these categories and the actual types of measures considered. Generally following the terminology as used in the EU Floods Directive, in Safecoast four different categories are used as defined above, which will be indicated by the following key expressions: (1) Prevention; (2) Protection; (3) Crisis management; and (4) Recovery. The table below puts these categories in perspective. The first two categories are involved with the management of primary risks to prevent a crisis situation, while the latter two relate to the management of residual risks (if a crisis situation occurs). Communication strategies play an important part in management of both primary and residual risks:

Manage primary coastal risk	Manage residual coastal risk
(1) Prevention	(3) Crisis management
(2) Protection	(4) Recovery
Risk/crisis communication	

Table 5.1: Managing risk and residual risk

The various countries within the North Sea Region have typically developed different practices and priorities regarding the application of principal solutions to reduce coastal risks, depending on the scale and nature of the problems and the political and cultural context. While some countries (such as the Netherlands, Belgium and Germany) have put the main emphasis on large scale protection measures, others (United Kingdom and Denmark) have also focused on a more differentiated approach based on the appraisal of specific local/regional options. Differences may exist within the various measure categories, for example regarding the use of safety standards that may range from strict, legal standards to dedicated and more flexible applications. Also there may be fundamental choices regarding more offensive or defensive protection principles, such as 'advance' (creating seaward oriented defence systems); 'hold the line' (maintaining existing defence lines); and 'managed realignment' which refers to the possibilities of setting back the line of the actively maintained defences, allowing the creation of intertidal habitats between old and new defence lines (sometimes also referred to as 'managed retreat' or 'setback').

Table 5.2 provides a non exhaustive overview of possible measures within the four categories according to the terminology used in Safecoast as defined above. Within each of these categories, a further distinction is made between structural measures and non-structural measures (related to institutional arrangements and management procedures).

Measure category related to risk management phase	Structural measures	Non-structural measures
1. Prevention	Spatial planning to reduce vulnerability (relocation, zoning) Space allocation/reservation: • for water storage/discharge • for future flood defence systems Dike compartments (secondary dikes) Adaptation of buildings and structures Local protection of structures Use of dwelling mounds Managed realignment	Spatial planning and enforcement procedures Awareness raising, coastal risk education and communication: • flood risk maps • information campaigns • self help kit & advice
2. Protection	Building, adjusting and maintaining natural and man-made flood protection systems (dikes, sea walls, dunes, barriers, boulevard systems) Building, adjusting and maintaining natural and man-made flood systems to reduce hydraulic loads (mud flats, foreland, artificial reefs, water management measures, emergency overflow) Building, adjusting and maintaining natural and man-made systems to counteract coastal erosion (dikes, sea walls, groynes, breakwaters, sand nourishments)	Inspection and monitoring procedures related to: • hydraulic boundary conditions • condition and functioning of natural and man-made coastal protection systems
3. Crisis management	Flood protection systems emergency repair and restoration facilities (sand bags, foils, mobile dams) Dry evacuation routes and safe havens Availability of equipment and emergency supplies (for search and rescue, survival)	Storm surge monitoring and warning procedures (dike watch) Contingency plans Emergency scenarios Evacuation plans and procedures Crisis communication and information procedures (cell broadcasting, radio messages)
4. Recovery	Pumping and drainage systems Flood defence system restoration Reconstruction of infrastructure Reconstruction of buildings and facilities (damage repair)	Insurance cover Disaster funds Psychological support systems Return programmes

Table 5.2: Overview of measures in coastal risk and residual risk management

The category 'Prevention' includes the measures to be applied within coastal areas subject to flood risk. This category is involved with the options related to adjusting spatial planning arrangements in order to reduce the vulnerability of people and assets in the area or to provide space for water discharge and flood defence zones. Other (structural) options can include the selective protection or adaptation of specific locations or assets within the area and the possibilities for managed realignment. Awareness raising and risk communication are within the non-structural measures in this category.

The category 'Protection' includes the structural measures related to all forms of coastal protection systems, both with respect to flooding and coastal erosion, and including the measures aiming to reduce hydraulic loads. Non-structural measures relate to the inspection and monitoring of both the protection systems proper and the hydraulic boundary conditions affecting them.

Options within the category 'Crisis management' cover structural measures related to emergency repair of flood protection systems and providing evacuation routes and safe havens, as well as the related non-structural plans and procedures.

The category 'Recovery' includes all structural measures to restore the flooded area, its flood protection systems and its (infrastructure) facilities as well as the non-structural systems, funds and programmes required to support the restoration process.

5.4 Scaling issues and need for integrated planning

5.4.1 Scales and dimensions of coastal planning

Geographical and temporal scales

Coastal risk assessment typically involves a variety of spatial scales. From a local or regional perspective such scales are determined by the specific characteristics of flood prone areas and their flood protection systems; land use and related values; and the nature and extent of the coastal problems. From an overall planning perspective, coastal risks may need to be considered on larger geographical scales in order to take account of the interaction and interdependencies between coastal areas and to set priorities based on national objectives.

Figure 5.1 gives an overview of spatial and temporal scales associated with coastal flood and erosion risks. Obviously, the various planning scales to be considered should take account of the administrative levels involved in coastal management practices and decision making and the implementation of measures and strategies (see also chapter 4).

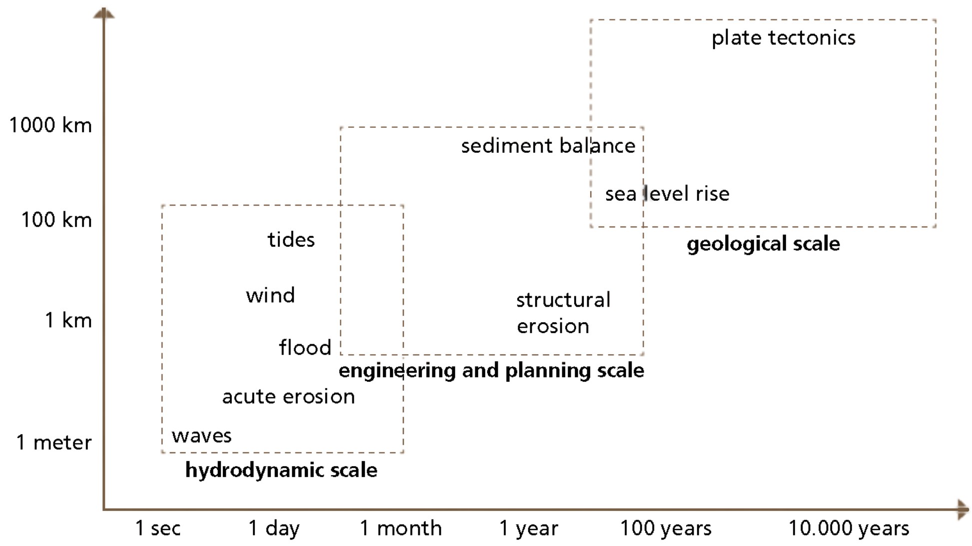


Figure 5.1: Example of temporal and spatial scales

The main drivers associated with future developments in coastal risks relate to hydraulic loads (including the impacts of climate change) and socio-economic and spatial developments in coastal zones. From the viewpoint of such developments, it is essential to consider the present and future coastal risks within a longer time perspective and on larger spatial scales, in addition to local and short term risk assessments. Local solutions to manage flood risk and erosion can give rise to detrimental effects elsewhere. Planning for future development in the coastal zone can take account of the risk and locate development to lower risk areas. The management of existing spatial development over time has to be considered and some difficult decisions may need to be taken to manage the risk such as relocating people and businesses or providing improved defences. This will have much wider issues with longer timescales and therefore will require a wider geographical base over a long planning period. For example, the Thames Estuary 2100 Strategy is looking at managing present and future development over the next 100 years. Other examples of master planning within the North Sea Region (such as the Netherlands Coastal Policy document and the Flanders master plan for coastal safety) consider a time horizon up to 2050.

Other dimensions in coastal planning

In addition to the aspects of space and time, the planning required for the management of coastal risks must link with other related planning processes regarding land use and spatial/infrastructure developments, involving a (large) number of stakeholders (actors) and interests. In order to facilitate this planning process there must be dialogue between engineers and scientists, land use planners, politicians and the affected public. This is another important dimension of integrated coastal planning.

The aim of integrated coastal planning is to provide clear policies that address current and future risk and in so doing, reduce the consequences of flooding and erosion and therefore benefit not just those living on the coast but the wider general public and governments. There is a continuous effort involved with the actual process of integrated coastal planning and decision making, policy and measure implementation, and the tasks related to operation and maintenance. These efforts and tasks take significant amounts of time due to the number of issues and actors involved and can only be achieved at considerable cost. Consequently, this may have important implications for the future planning of financial resources at all levels of responsibility, public, local and regional authority and national. The adoption of integrated planning procedures for managing coastal risk requires the continuity of the efforts and tasks involved and the required financial resources.

The above considerations effectively point towards the need for an integrated approach to coastal risk management ranging from the level of a long term and large scale coastal zone management plan to local and short term plans for building or maintaining specific coastal protection facilities. In this approach, the main aspects of integration would include different types of problems, developments, actors, solutions, and types and scales of planning.

5.4.2 Function and requirements of integrated planning

The specific output from ICZM planning would be an ICZM (master) plan that would provide the framework and guidelines for the long term management and protection of the coastal zone. Moreover, the master plan provides the basis for the development of local and short term plans with solutions for specific management problems and the implementation of such solutions, both in terms of institutional arrangements and management procedures (non-structural measures) and structural measures. The effects of the ICZM policies and measures would be subject to continuous or regular monitoring and evaluation, leading to updated assessments of coastal management problems and research requirements, which in turn may lead to adjustments to the ICZM (master) plan. This process is illustrated in figure 5.2.

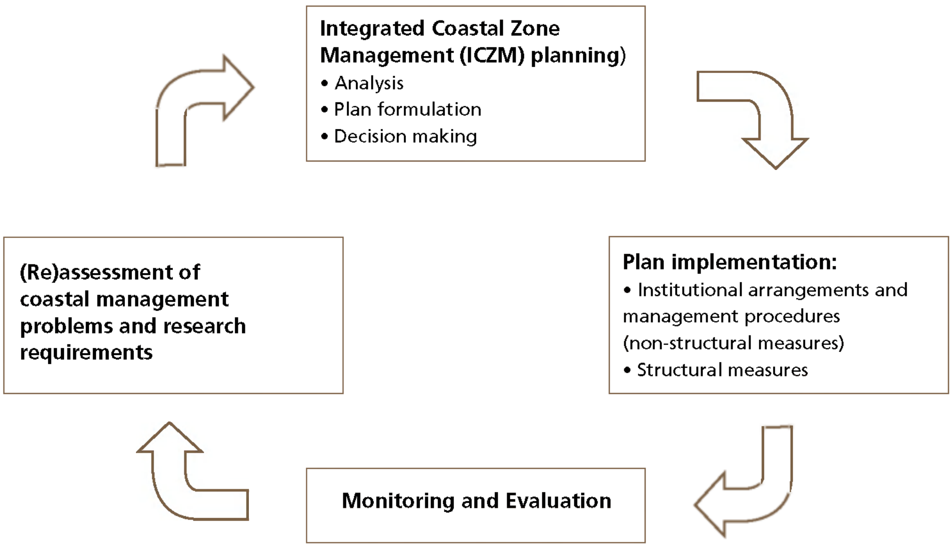


Figure 5.2: ICZM planning and implementation process

The development of an integrated coastal management plan requires the inputs from a variety of specialists within the fields of engineering, environment and planning. There is a need to work together to a common objective considering the various local coastal problems and risks within the context of the wider regional and national issues both within a short and long term development perspective. These planning efforts should not be limited to the development of a coastal zone management plan, but also be involved with its effective implementation.

In order to be an effective tool in managing coastal risk, an integrated coastal zone management plan must be in a form that is readily accessible to a broad audience, yet also be comprehensive in its coverage of the wide range of issues that are being addressed such as future development, flooding, erosion, etc. The following provides a general overview of the desired contents of an integrated coastal zone management plan. Obviously, the actual contents will depend on the nature, the scale and the specific problems of the area under consideration. Basically, the general contents could include:

- Statement of the strategic objectives and policy views underlying the integrated coastal management plan (who the plan is for and how it will be used).
- Delineation of the physical planning area, i.e. the coastal protection zone; the area seaward of the coastal protection zone including the related functions and values; and the area landward of the coastal protection zone (including the area and functions potentially affected by coastal risks and the area subject to potential measures to reduce coastal risks).
- The time horizon and projection years to be considered.
- The scenarios considered in the various future projections on hydraulic loads and developments within the physical planning area.
- The assessment of present and future coastal risks.
- The scope of possible measures to be considered in reducing coastal risks (in terms of prevention, protection, crisis management).
- The identification, analysis and evaluation (comparison) of measures and strategies to reduce coastal risks and selection of the preferred strategy.
- Implementation aspects of the measures/strategy to reduce coastal risks (e.g.: incorporation of the coastal master plan in related planning procedures; cooperation with relevant parties and stakeholders; technical, legal and financial aspects of measure implementation; management/maintenance of coastal protection measures).
- The timescale for the review of the plan.

Land use planning and coastal risk management varies from country to country as does the decision making process at both local and national level. There is nothing to say at this stage which is better, as the policies and procedures have developed over many years within different political and societal structures. There is however benefit from looking at the ways the North Sea countries are addressing the same problems in their coastal regions. The project Safecoast is to give strategic guidance to those with responsibility for or interested in coastal management and may provide both the catalyst and starting point for this to happen. The inputs of Safecoast and other sources to the development process of coastal management strategies will be described in further sections of this chapter.

5.5 Use of Safecoast results

Previous sections have emphasised the need for integrated planning for future coastal risk management. It is the specific aim of Safecoast to direct the integrated planning efforts, building on the knowledge and experiences gained in the North Sea Region countries and the specific results of the Safecoast project and other relevant sources. This section addresses the question how Safecoast results could support the planning and management process.

The Safecoast project focuses on the identification and management of risk in the coastal environment under climate change and future development scenarios. For this purpose, Safecoast has considered a number of specific actions aimed at understanding the drivers of coastal risks, carrying out risk assessments and preparing integrated plans for the future management of the coast, in a transparent and logical framework. From the perspective of potential measures and strategies to manage coastal risks, the emphasis of Safecoast is on the categories that have been identified in table 5.2 as 'Prevention' and 'Protection', including both structural and non-structural measures. The response to events as they occur either from flooding or erosion are by their very nature not planned and therefore are considered under the measure categories 'Crisis management' and 'Recovery'. These responses are addressed in other studies, such as the project Chain of Safety. From this perspective there is a clear link between the projects Safecoast and Chain of Safety, which can be seen as complementary: one dealing with the future planning to minimise risk; and the other with the residual risks and responses to events as they happen.

The various actions considered in Safecoast have addressed the following topics:

- Scenario development.
- Flood risk assessment methodology.
- Integrated risk assessment for the North Sea Region.
- Detailed risk assessments.
- Coastal protection master planning.
- Risk communication and awareness.
- Synthesis and ways forward for coastal risk management solutions.

Scenario development is involved with the future projection of hydraulic loads (including the aspects of climate change) and the relevant spatial and infrastructural developments, given a specification of the physical planning area and the time horizon (projection years) to be considered. The Safecoast findings on this topic were described in Chapter 3 of this report.

The next three of the above topics have addressed different parts of the methodological approach to the assessment of coastal risk (considering both flooding and coastal erosion). Safecoast considers a number of possibilities for methodological improvement. In addition, Safecoast has focused on the actual implementation of the coastal risk assessment methodology at different geographical scales, both from the perspective of a top down analysis for the North Sea Region and for a number of more detailed local pilot sites. These Safecoast results were described in Chapter 4 of the synthesis report.

The Safecoast activities on coastal protection master planning and risk communication and awareness have been directed towards the development of a coastal protection master plan for Flanders and the development of a communication strategy based on a practical example for the federal state of Schleswig-Holstein (the informed society: improve risk communication and awareness). These results have been summarised in following parts of this section.

The final topic considered in Safecoast involves the synthesis of Safecoast results and the focussed discussion on integrated coastal zone management solutions in the North Sea Region. One of the activities (Action 1) was to make a quick scan inventory of climate change adaptation within the various North Sea Region countries. These and other results of the Safecoast actions have been further developed in Chapter 5 of this report. The synthesis report as a whole is the final product of the Safecoast project.

5.5.1 Coastal protection master plan development for Flanders

The Safecoast action was executed by the Flanders Agency for Maritime and Coastal Services and is involved with the development of a master plan for the protection of the Flemish coast against erosion and flooding on a short term (10 years) and long term basis (time horizon 2050, see figure 5.3 for an overview of the Flanders coast). The total study envisaged will not be finished until mid 2009, meaning that the final results could not be made available within the timescale of the Safecoast project.

As part of the preparatory actions for the development of the Flanders coastal master plan an inventory and comparison was made of 6 different master plans for coastal safety from 4 countries along the North Sea (The Netherlands, Denmark, United Kingdom and Germany), in order to learn from the experience and know-how of the other surrounding countries in setting up the Flanders master plan. For this purpose, the plans were compared on the basis of a number of characteristic features regarding their scope, set-up and contents.

Development of Flanders master plan
The present study for developing the Flanders master plan considers the following steps:

- Safety assessment of existing coastal protection systems.
- Flood risk calculations in order to produce flood risk maps for the present and future (2050) situation.
- Identification and analysis of different measures and alternatives for controlling present and future flood risks.
- Societal Cost Benefit Analysis to evaluate alternative master plans.
- Environmental Impact Assessment for the overall master plan and local plans extracted from the master plan.
- Identification of requirements related to the legal framework.
- Risk Management of realisation of safety measures (budget, timing, etc.).
- Communication to relevant parties and stakeholders and the public at large.

The main activities conducted within the Safecoast action were aimed at the preparation of the above steps in terms of the specification of methodological approaches; further development of required analytical tools; and collection of relevant data. This has resulted in the drafting of a preparatory report describing the operational approach to the development of the master plan.

The preparation of the Master Plan is being undertaken by a taskforce comprising client authority and its contractors and a steering group of representatives of:

- Tourism;
- Agriculture;
- Integrated coastal zone management; and
- Marine and coastal environment.

There is also an advisory board made up of representatives of all the important stakeholders including the public.

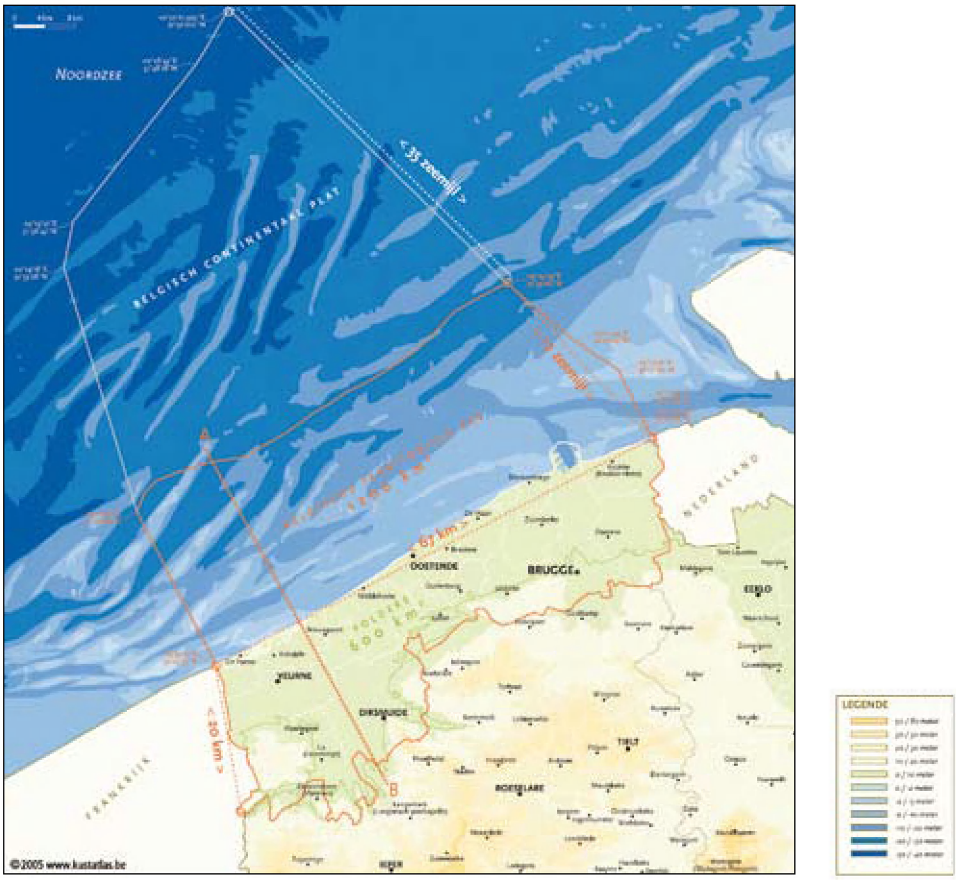


Figure 5.3: The Flanders coast (Source: www.kustatlas.be)

Comparison of master plans and implications for Flanders master plan

In Safecoast Action 4, a total of 6 master plans in 4 different countries were studied and compared in order to further define the set-up and desired contents of the Flanders master plan. These include the following countries and plans:

The Netherlands:

- Third Coastal Policy Document (VenW, 2000): long term perspective for the entire Dutch coast focusing on flood protection in relation to spatial developments.
- Strategic Vision for Dutch Coast 2050: integral vision for the long term coastal development and coastal protection of the provinces North and South Holland.

Denmark:

- West Coast 2002: coastal management plan for limited part of the coast regarding the short term collaboration of national, regional and local authorities on coastal defence.

United Kingdom:

- Making Space for Water (2004): master plan for controlling risks of flooding and coastal erosion focusing on sustainable strategy development.

Germany:

- Coastal protection master plans for Niedersachsen/Bremen (NLWKN, 2007) – and Schleswig-Holstein (MLUR, 2001): identification of required coastal protection measures to meet required safety standards.

Most of the above plans explicitly deal with the problem of coastal safety. Yet they are quite different as regards their scope, contents and level of detail as well as their starting points and specific approaches. This is not surprising, given the differences between these countries in the coastal situation and related planning procedures and in view of different historical perspectives. The analysis and comparison of the various master plans has resulted in a number of important observations regarding the requirements of setting up a coastal management master plan.

A first observation relates to the importance of clearly specifying the operational objectives underlying the development of the plan. This is particularly important in relation to the often long time horizons considered in the master plan. The absence of clearly stated, operational objectives in combination with long time horizons may lead to the development of abstract guidelines rather than clear tangible measures. It is also important to determine a long term strategic vision. However, this should be linked to a set of achievable measures over a shorter period of time. Hence, the master planning should provide results on different hierarchical levels, where strategic visions are actually translated into implementable, tangible measures for different sections of the coast, to which different priorities could be attached.

The various master plans differ with respect to their focus on specific types of measures. An important difference is the focus on hard measures (Germany) versus soft measures (Denmark), while other countries consider various types of measures. In the Dutch master plans, attention is paid to spatial planning policy in relation to safety objectives. In the master plan for the UK more attention is paid to risk management such as warning systems and emergency plans. This led to the conclusion that a rather broad scope of measures should be considered in the Flanders master plan.

Participation is an item stressed in several of the master plans studied. The purpose of involving both local authorities and pressure groups, and the inhabitants and the public at large is twofold. On the one hand, optimal use is made of the local know-how and skills of the local communities, taking into account their wishes and needs. On the other hand, the involvement of the local people in developing a plan for shared responsibility will guarantee a sound social basis for the plan, which is regarded an important aspect in the development of the Flanders master plan.

To some extent, most of the master plans for coastal safety make a link with integrated coastal zone management (ICZM). Although it is recognised that other interests may play an important role in the coastal zone, in all cases coast protection is given priority over all other interests. It is felt that the explicit consideration of the ICZM concept in the Flanders master plan would give it additional value.

Another aspect from the consideration of the master plans relates to the proper distribution of competences in relation to the implementation aspects of the master plan. Linking appropriate responsibilities to tangible actions will enhance the implementation of measures which is deemed an important issue.

Finally, it was found that other important links to be addressed within the master plan include:

- The legal basis for coastal protection.
- The financial basis for the implementation of the master plan.

Based on the above observations, the proposed contents of the Flanders integrated master plan includes the following aspects (see table 5.3):

0	Policy summary
1	Coastal zone description (physical-geographical and socio-economic description in the form of an actor analysis): current situation and developments to be expected
2	General problem assessment and description of rationale for further investment in coastal defence
3	Description of the planning process
4	Vision regarding the best way to handle the coastal defence within the Flemish context and objectives for the integrated coastal safety policy
5	Judicial and institutional aspects and competences regarding the coastal defence, with attention to the European context and trends
6	Survey of the measures taken (working, efficiency, way of execution) and of the alternatives studied
7	Consequences of carrying out the plan in terms of social benefits (damage prevented, environmental impacts, …) and social costs (investment costs, "side effects", …)
8	Survey of the major stakeholders' vision and the way to take into account their opinions
9	Positioning of the plan within the framework of an integrated coastal zone management (ICZM)
10	Preconditions regarding the realisation of the plan: financial; political; institutional; judicial
11	Time frame for phased execution (long-range plan) and indication of tasks to be carried out by the various parties responsible

Table 5.3: Proposed contents of the Flanders master plan for coastal safety

The results achieved in this Safecoast action are described in detail in the report: "Integrated master plan for Flanders future coastal safety", 2008

5.5.2 The informed society: improve risk communication and awareness

This Safecoast action was executed by the Federal State Ministries of Environment and Internal Affairs of Schleswig-Holstein (Germany). It encompasses the drafting of a communication strategy to provide information on the risks of storm floods and to simultaneously raise awareness among the general public and political decision-makers, as well as to raise the acceptance for (costly) coastal flood defence measures. The final objective was to reduce the flood risks of inhabitants of flood-prone areas. In order to achieve these targets, a communication strategy was developed and tested. The main activities in this process included:

- a primary analysis of communication activities in the partner countries;
- a desk top (literature) study;
- the production and on-site evaluation of a door-to-door circular and the development and testing of an exhibition.

A summary of the communication activities in the partner countries as described by Action 2 is given in table 5.4.

Country	Main communication activities
Germany	Hamburg and Cologne: communication media in these cities present practical courses of action, state the level of danger for citizens and describe appropriate behaviour in the event of a major incident, including 'storm flood instruction sheets', which give recommendations for actions to be taken during an emergency. In addition in Cologne there is a 'texting' service to mobile phones on water levels (when citizens type in the name of their street, they can see their level of exposure on a risk map).
The Netherlands	Three campaigns (with internet sites) currently exist in the Netherlands for the communication of the dangers of flooding: 'Nederland leeft met water', 'Denk vooruit' and the publication of provincial risk maps on the internet (risicokaart.nl). Risk communication takes place, but plans for disaster communication are still in development, so the recommendations for action remain rather general with a combination of a range of mass media: radio and television commercials, newsletters, advertising hoardings and information booklets, informative events and a comprehensive website round off the range of information.
United Kingdom	Environment Agency Floodline website with maps showing areas at risk from floods. An extensive internet presentation provides booklets, flyers, guidelines and school materials on the subject. Active provision of flood information is also carried out by the local councils.
Belgium	Informative internet site are available (kustatlas.be), containing information about the technical coastal defence measures, climate change and the potential threat of storm floods in Belgium. Recommendations for action in the event of emergency or preventative measures are not given.
Denmark	On the internet page of the Danish Coastal Authority (kyst.dk), the authority publishes information on the causes of flooding and on the public flood warning system in Southern and Northern Denmark. In addition, information is given on critical water levels. However, no booklets on flooding emergencies are available for download from the website and there are no recommendations found for action in the event of an incident.

Table 5.4: Summary of risk communication activities in the NSR

Based on the desk-top literature study and the primary analysis of activities in partner countries, a number of recommendations for the production of risk communication materials (in particular the door-to-door circular, see figure 5.4) were identified, as summarised below.

(1) The greater the extent to which people are potentially affected, the greater will be their perception of the risk and their readiness to take action:
- The circular should therefore focus on explaining how people are affected.
- People take preventative measures only when they are convinced that their measures will have some effect. Effectiveness should thus be stressed in the description of protective measures.

(2) Risks to which people have become familiar (e.g. by living on the coast for many years) are seen as less threatening:
- A circular should reawaken awareness of the risk.

(3) If people have made a conscious choice to live at the coast, this implies that they have accepted the risk of storm floods and flooding, and risk perception may therefore be weaker:
- A circular should describe the current risk situation and make specific reference to living on the coast.

(4) Motivation to undertake own damage prevention measures should be intensified:
- Images of disasters should only be used when the damage shown is not too great and when it still appears that the risk can be effectively managed.
- Role models (neighbours, celebrities) could facilitate communication on effective behaviour.

(5) The circular should inspire confidence and be trustworthy:
  - The publisher of the circular should briefly present its tasks and activities.

Following the above recommendations, a circular was drafted and distributed in four flood-prone pilot areas in Schleswig-Holstein. The “sustainability” of the circular (did the message get across) was then evaluated through a questionnaire. Relevant observations from this evaluation include:

- about 40% of the responders felt highly to very highly threatened;
- about 75% took the content of the circular seriously, and most of these thought the contents were useful to them;
- 14% of the responders answered that they have taken preventive actions after reading the circular;
- of those who did not take preventive measures, almost 40% said that they saw no need to take such actions.

Figure 5.4: Front of leaflet (circular) that was developed and used by Schleswig Holstein as part of Action 2: The informed society

Communication strategy

The results of the various activities were used to develop a communication strategy aiming to achieve the objectives of risk communication. For the communication strategy in Schleswig-Holstein relating to coastal defence and storm flood protection a targeted communication campaign was recommended, using a combination of communication media. The evaluation study showed that there are differences in the affected population concerning interest and the feeling of threat, and this must be taken into account by the communication strategy. The less interest and risk awareness present, the less an individual will be ready to spend large amounts of time searching for information. Further recommendations regarding the communication strategy include:

- There should be a raising of awareness of the population, especially in the Baltic Sea region, so that preventive measures can be implemented there more often.
- There should be regular communication about coastal and storm flood protection (e.g. once a year).
- Mass media such as radio, television and official publications are considered the most important ways of communicating. These should be made better use of when expanding communication activities.
- Future communication should especially involve information about catastrophe protection regarding local topics with reference to storm flood protection and preventive measures.
- In addition there should be a well conceived education campaign about the local effects of climate change, considering the uncertainty in the population.

With the media examined in the Safecoast action it is possible to create a targeted communication but in most cases communication goes in one direction only and cannot take into account and make use of the wishes, claims and knowledge of the public. By involving the public in decisions and recommendations, the needs of the public can be better taken account of and so increase the acceptance of measures over the long term. Sustainable development in coastal risk areas depends upon effective risk communication that creates awareness and sense of responsibility for the hazards. The results achieved in this Safecoast action are described in detail in the report: *"The informed society"*, 2008.

5.6 Developments on measure and strategy concepts

Coastal risk management has been undertaken in the North Sea countries for many hundreds of years. From an historical perspective, the development of policies and practices often followed as a result of severe floods or erosion. The time line in Annex 2 gives a brief overview of specific events and responses. The time line shows that up to the eighties of the last century, responses in terms of flood protection measures have mainly been triggered by major flooding events. The main responses have included the development of flood protection works and sand nourishment schemes. In some cases this has resulted in the development of major protection works involving huge investments and implementation times of several decades (Thames Barrier, Dutch Delta works). In the last decades there has been an increase in the attention to coastal risk management issues which has mainly been triggered by climate change and accelerated sea level rise. At the same time there is a broadening of the scope of possible solutions considered. These developments have also strongly reinforced the need and attention for integrated coastal risk management approaches.

Consequently, although much can be learnt from history, the most recent experiences against the background of socio-economic and spatial developments and climate change are more helpful in analysing what works and does not work and give a direction that future coastal risk management could take, learning from the recent past. Ongoing developments within the different North Sea countries, as well as results of recent studies, provide interesting sources of information and inspiration with regard to possible measures and strategies that might be considered in managing future coastal risks.

The following provides a selective overview of such developments, distinguishing between:

- Measure and strategy developments related to protection and prevention options.
- Planning and policy developments.
- Methodological developments.

5.6.1 Developments related to protection and prevention options

Relevant developments are considered within the following categories:

- Soft protection measures.
- Hard protection measures.
- Foreshore measures to reduce hydraulic loads.
- Establishing flood defence zones with multifunctional use.
- Measures to reduce risks in flood prone areas.

Soft protection measures

As part of a European wide perspective on coastal erosion, the *Eurosion* (2004) project recognised the need for sustainable development of coastal zones and the conservation of dynamic habitats. *Eurosion* defined coastal resilience as the inherent ability of the coast to accommodate changes induced by sea level rise, extreme events and occasional human impacts, whilst maintaining the functions fulfilled by the coastal system in the longer term. The concept of resilience is particularly important in the light of the predictions for climate change. Resilience depends on two key factors: sediments and space for coastal processes.

Measures proposed by the Eurosion project to adapt to coastal erosion included the designation and maintenance of strategic sediment 'reservoirs'. The main reservoirs considered would act as buffer zones directly protecting land from the sea, or aim to secure sufficient volume of sediment within active coastal sediment cells to allow the shore to keep pace with sea level rise. Different management modes could be applied to deal with the various reservoir types such as 'active conservation' or 'restrictive' (regarding activities that would decrease available sediment budgets). The concepts are currently being studied in EU research project Conscience and results are expected by the end of 2008.

All North Sea countries have, to different degrees, applied sand nourishments in the last decades in order to restore sediment budgets at critical locations (see Box 1 in chapter 2 of this report). In the Netherlands, sand nourishments to maintain sediment volumes within the active coastal zone have been applied as a structural measure since 1990 (presently amounting to 12 million m^3 per year). Recent evaluations have concluded that this is a successful policy to keep up with rising sea levels.

The further development of the understanding of these processes provides a promising basis for the future application of soft protection measures aiming to 'work with nature'. In addition, there are certain specific developments to favourably affect the sediment balance and/or the stability of soft protection systems. In this respect, the following examples can be mentioned:

- *Zandmotor* (sand motor): a possible method in the Netherlands, where a surplus of sand is added to a specific coastal section, after which waves and tides redistribute it to the necessary places. An experiment is foreseen at the South-Holland coast.

- Passive drainage experiments: a method to enhance the natural supply and fixation of sediment in the beach area by applying passive (vertical) drainage. The sediment is retained in the beach area increasing the width and volume of the beach and enhancing natural dune formation. Both in the Netherlands *(Ecobeach)* as in Denmark *(Sic)* the system is currently being tested. In Denmark, an evaluation is expected this year.
- Experiments with salt marsh recharge in the Crouch estuary (e.g. the 'mud nourishment' as described in Box 1 in chapter 2), as part of a *Comcoast* pilot.
- Emerging sediment management concepts in the Elbe estuary *(Tideelbe)*
- Ideas for use of dredged sediments in newly created dwelling mounds in the Netherlands *(Terpen van Baggerspecie).*

Hard protection measures

With respect to improving flood defences to perform better under extreme conditions of water levels and waves, various initiatives have emerged in the North Sea region. The project *Comcoast* (2007) has provided several innovative solutions regarding dike design, for example:

- The overtopping resistant dike: making the flood defence resistant to wave overtopping and ensuring that any water that is washed over the top can be temporarily stored and drained away.
- Sandy cover: a layer of sand is placed on top of the inner dike slope. The sand will be washed away during extreme overtopping events, but this will not threaten the stability of the dike if the thickness of the sand layer is sufficient.

In the project *Erograss* (2008) attention is given to the performance of grass cover layers on dikes. Grass cover layers have attracted more interest since the mid-eighties as one type of revetment for flood defence structures. In recent years, this grass cover revetment is being considered as a constructional component that has to be designed and managed.

The Dutch project *Inside* has developed several ground and soil techniques to stabilise sub soils and to anchor dike bodies into the subsoil. Other possible measures include the application of steel nails; expanding columns or stabilised ground columns.

Foreshore measures to reduce hydraulic loads

In the German coastal states joint foreland management concepts have been created in the past decade, as foreshore measures to reduce hydraulic loads on dikes. Foreshore recharge and salt marsh management to restore the coastline by coastal nourishment of eroded foreshores was also identified as a promising measure in the project *Comcoast.*

In the past decades, partly driven by a Dutch innovation programme (WINN) many ideas for the Dutch coast have been developed, ranging from seaward options such as a concept of a parallel floating breakwater or advancing the line by further land reclamation or islands near the Dutch coast. Figure 5.5 shows

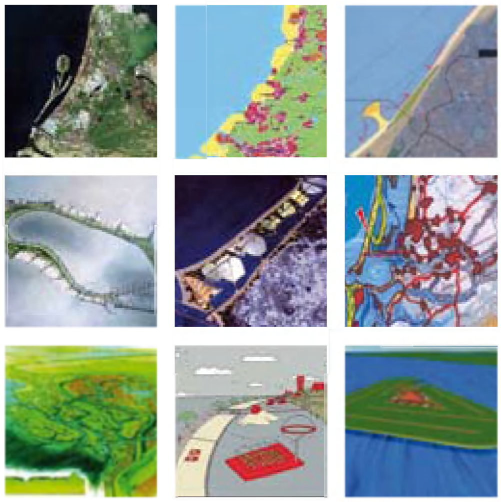


Figure 5.5: Mosaic of recent and less recent ideas related to seaward options and artificial islands along the Dutch shore

a mosaic of recent and less recent ideas for Dutch coastal development. Another ongoing study investigates the possibilities of artificial (longshore, deepwater) reefs near Scheveningen to reduce wave height and period during storm surges.

Establishing flood defence zones with multifunctional use

Various recent projects have developed concepts and investigated possibilities for creating a gradual transition within flood defence zones from sea to land, allowing for a multifunctional use of the transition zone that will generate benefits for the wider coastal community and the environment.

Landward options of this concept, which have been referred to as 'managed realignment' and 'regulated tidal exchange' were considered, among others, in the project *Comcoast* and the *Branch* project. These options might involve breaching of existing coastal defences, such as a sea wall or an embankment, and allowing the land behind to be flooded by the incoming tide. The new intertidal zone is then left to be colonised by natural vegetation and to natural siltation processes. As a result, the intertidal area may keep (more or less) pace with sea-level rise and land subsidence, providing a buffer zone to disperse wave energy during storm events, to reduce erosion rates and to provide an important habitat for coastal flora and fauna. In addition, there would be opportunities for adapted economic use (aquaculture, salt-resistant crops); adjusted (flood proof) buildings; and recreational use. On the landward side of this zone, protection measures may have to be taken beforehand to reduce the risk of flooding of adjacent low-lying areas. A seaward application of this principle would be to build a dike in front of the existing flood defence, creating a brackish transition zone on the seaward side of the primary defence system.

Selective applications of these principles have taken place in estuarine locations of several North Sea countries (Germany, the Netherlands), mainly from the perspective of nature conservation. In England, managed realignment is more commonly implemented and is seen as a relatively cheap and environmentally friendly option, of which the application is likely to increase in future. On the densely populated open North Sea coasts of Germany, Belgium and the Netherlands, the possible applications will be very limited. However, the project Comcoast has shown that there may be interesting possibilities in combining this management principle with flood defences that are resistant to wave overtopping combined with a wider defence zone where considered feasible.

Measures to reduce risks in flood prone areas

Potentially promising options to be considered include the possibilities of creating dike compartments by using secondary dike lines or defences situated landward of a primary sea dike. These secondary dikes are widespread along the Dutch and German mainland coast, often resulting from repeated land reclamations (see section 2.3). The potential of these measures was explicitly considered in the Safecoast German pilot sites on flood risk assessment (see Section 4.4.4).

Other promising developments relate to the possible application of flood resistant adaptations to buildings or local sites in flood areas that are not (sufficiently) protected by flood defences. These options are sometimes referred to as 'dry proofing' (e.g. buildings on poles, floating houses, dwelling mounds, local protection) and 'wet proofing' (reduce damage by making buildings water proof). An example is the recently developed quarter 'Hafencity' in Hamburg (Germany) where residents live on the third flood or above, while lower floors are adapted to avoid flood damage (see figure 5.6).

In addition, there is general recognition of the need and importance of spatial planning options to reduce the vulnerability of flood prone areas. These developments are further addressed in the following section.

5.6.2 Planning and policy developments

In all North Sea countries there is an increasing attention towards long term planning for coastal protection and management in view of climate change. Increased planning efforts are taking place in the development of various national, regional and local plans. Belgium has recently started the development of an integrated master plan for the future coastal safety of the Flanders region, of which the set-up was developed as part of Safecoast.

In Germany, master plans for coastal defence have recently been developed for all four coastal states. In the England and Wales (UK), regional, long term policy frameworks to reduce coastal risk are being developed in Shoreline Management Plans. Other master planning projects deal with developing long-term strategic plans for areas of specific importance, such as the project Thames Estuary 2100.

In the Netherlands, long term policies on coastal management and flood protection policies have been developed during many years according to the guidelines set out by a Delta Committee (1953-1960, following the 1953 flood disaster). Recently, a new Delta Committee was established to give advice on the long term sustainable development and protection of the Dutch coast that will be the basis for policy development for the next decades.

In Denmark, the focus of future planning is mainly on the consequences of climate change for coastal erosion. For this purpose, a national coastal erosion atlas is being developed that will provide guidance to regional and local assessments aiming to identify long-term adaptation measures.

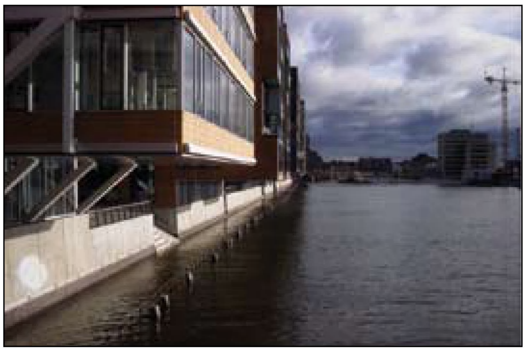


Figure 5.6: Incorporating flood risks in the planning and construction design (Source: HPA)

In most North Sea countries there is a strong tendency to further integrate planning for coastal risk management with spatial planning. In the UK the strategic directions for this integration have been set out in the policy document 'Making Space for Water' aiming to implement a cross-Government holistic approach to managing flood and coastal erosion risks (led by Defra). The link with spatial planning is also emphasised in the development process for the coastal protection master plan for the Flanders region. The Government of the Netherlands has launched the Programme Adaptation Space and Climate (ARK) in order to identify spatial adaptation measures needed to counter the impacts of climate change from a broad perspective. A programme aiming to reduce flood risk from rivers by providing more space for natural river beds in the Netherlands is also being implemented.

Within the European context, several projects have focused on the spatial planning challenges of climate adaptation. These include, for example the *Branch* project (2007), the *Espace* project (phase 1, 2007) and the *Response* project (2007).

There is a varying, but increasing emphasis in North Sea countries to consider cost-benefit considerations in planning of coastal risk management at various planning levels. In the Flanders master plan development the execution of a social cost-benefit analysis of alternative strategies for coastal protection was identified as a key issue. In the UK the need to balance flood risks and opportunities in all stages of the planning process was reinforced in the recently adopted Planning Policy Statement 25 (PPS 25). The PPS 25 emphasises the need to reduce existing flood risks by re-creating and safeguarding functional flood plains, without completely banning developments in flood risk areas. Moreover it focuses on the requirements at the various planning levels to ensure that decisions are made at the most appropriate level in a timely fashion. The future management of flood risks in the Netherlands is currently being considered in a policy exploration (WV21, Flood Safety 21th Century) which makes explicit trade-offs of costs and benefits of flood protection levels in order to determine desired flood protection levels in a long-term development perspective.

5.6.3 Methodological developments

Methods for coastal risk and especially flood risk assessment are commonly applied in the North Sea countries. Applications and experiences in Safecoast have shown that there are ongoing developments in the further expansion and improvement of available methods. Specific areas of attention in the ongoing methodological improvements include:

- Methods to determine hydraulic boundary conditions.
- Detailed assessments of failure mechanisms.
- Methods to establish integrated flood risk for flood prone areas.
- Assessment of long term 'optimal' protection levels.

In most countries, continuous efforts are made to improve and expand the information on hydraulic boundary conditions (hydraulic loads) based on monitoring data, physical and numerical modelling. In the Netherlands, new sets of hydraulic boundary conditions (including water levels and wave characteristics) for the entire coast are established every five years, based on the latest available data, insights and methodology.

Ongoing research efforts aim to improve the understanding of specific mechanisms involved in coastal erosion processes and the failure of flood protection systems. Examples include the further development of probabilistic modelling of soft cliff erosion and control in the UK; the analysis on strength and failure mechanisms of flood defences in the Netherlands; and developments on breach growth modelling in Flanders.

Specific flood prone areas may be subject to flood risk from different hydraulic regimes and be protected by a variety of natural and man-made flood defence systems with different physical dimensions. Methodological developments are taking place in various countries to better understand the behaviour of different parts of the flood protection system in order to predict the most likely failure scenarios and to identify the weakest links in the protection system. In the project Floris (VNK) in the Netherlands, a methodology is being developed and tested to determine the overall flooding probability of flood prone areas based on a composition of all contributing failure probabilities (across all parts of the flood protection system and their specific failure mechanisms). Other important developments relate to the assessment of flooding events by means of flood mapping. The need for flood mapping was emphasised in the European Flood Directive. Developments and exchange of knowledge and information on this subject is facilitated by the European Exchange Circle on Flood Mapping (EXCIMAP). It recently published a guidance document and an atlas with examples of risk maps that are used in the EU member states.

Other methodological developments are involved with the assessment of costs and benefits of flood protection systems in order to support decisions for desired flood protection levels and the preferred protection strategies to achieve these. Presently, in the Netherlands, a methodology is being developed and tested to determine 'optimal' flood protection levels by comparing the long term costs and benefits of flood protection, taking into account a projection of climate change and invested capital values (driven by economic growth). The outcomes of such a scenario driven optimization process, might provide a basis for the future differentiation of safety standards across flood prone areas.

Coastal monitoring, research and knowledge distribution are essential for sharing, testing and developing ideas and concepts for the future. The main objective of EU projects like Safecoast is to support and stimulate this process. Others projects and initiatives such as Encora and Floodsite are considered to be good examples for the continuation of international knowledge exchange. A list of relevant EU projects may be found in Chapter 1 of this report or online at www.safecoast.org.

5.7 Suggestions for strategy development

Considering the long term and large-scale aspects of coastal risks, it was concluded that the development of coastal risk management strategies should be based on a hierarchical planning approach, ranging from a top down national (master) planning level to the analysis of individual flood prone areas and the consideration of specific strategies and measures within these areas.

According to these views, the suggestions for strategy development are considered at two different levels, i.e. the strategic, master planning level of coastal risk management and the approach to the development of a coastal protection plan for specific flood prone areas.

5.7.1 Master planning for coastal risk management

The development of an integrated coastal zone master plan should provide the boundary conditions for developing specific protection plans for the various coastal regions subject to coastal risk, within a long term national planning perspective. Emerging from the needs and experiences of the North Sea countries, the following functions should be included in the strategic master plan:

- The master plan should distinguish between coastal areas with different 'protection' status based on physical characteristics; land use and associated economic and ecological values; types and extent of problems; historical/cultural background; protection possibilities and effectiveness in relation to coastal dynamics; etc.
- Within the conditions set by the master plan it is to assume that a protection status given would be warranted for, at least, a considerable amount of time. Moreover, clarity should be provided on the legal status of designated areas and the parties responsible for the further development and implementation of coastal management strategies.
- The master plan should formulate the general set of rules and policy measures that would apply to the entire coastal area subject to coastal risk (such as: certain restrictions in land use regulation; early warning systems; evacuation plans; disaster mitigation).
- For each designated coastal area with a desired protection status, there would be some area specific 'optimal mix' of measures. Within the boundary conditions established in the master plan, this is to be further explored and elaborated on at the level of the designated coastal areas.
- The master plan should warrant the continuity of coastal risk management policies, the protection measures and the related operational procedures (i.e. in terms of financing; institutional arrangements; legal rights/obligations; and operational responsibilities).
- The integrated planning approach developed in the master plan should facilitate the necessary communication between coastal defence managers, contingency planners and crisis managers.

The process of master planning in relation to regional/local plan development and implementation is shown in figure 5.7. As described above, the integrated master plan defines the scope for the development of management and protection strategies for designated flood prone areas, given the long term scenario specification on socio-economic, spatial and infrastructural developments and climate change. These strategies will be formulated in terms of a coastal protection or shoreline management plan for each designated coastal area. The phase of plan implementation is the realisation of the structural and non-structural measures defined in the plan which is followed by a phase of (continuous) monitoring of coastal developments and related problems. Based on the monitoring results, both the regional/local plans and the master plan are evaluated and reviewed, which may give rise to adjustment of the plans.

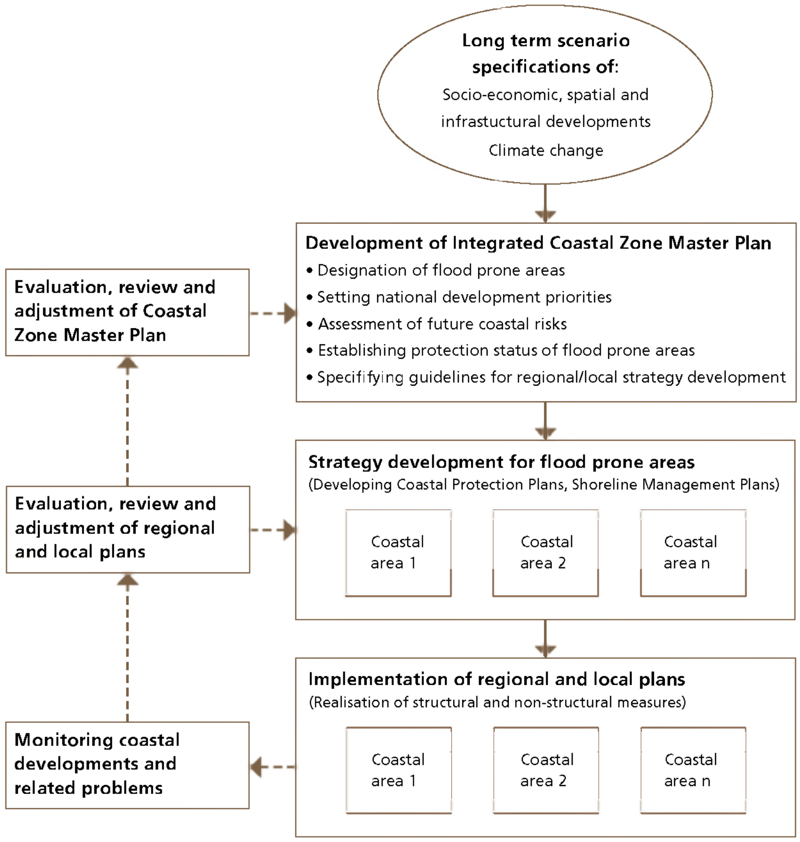


Figure 5.7: Coastal zone master planning and regional/local plan development

It is recognised that integrated coastal management is still in its infancy. To progress it in such a way that management of the coast can be undertaken in a sustainable way the current thinking has to be taken forward. It should address and develop the points above and others that will be identified by particular circumstances either physical or institutional.

From the experiences gained in the various Safecoast actions it is concluded that presently there are no generally applied formats and approaches to the development of coastal management master plans. Therefore, in view of future needs to deal with the impacts of climate change there is scope for common developments in the North Sea Region regarding planning approaches to manage coastal risks. Important common aspects may include: scenario development; coastal risk assessment methodology; and the need for integrated and tiered planning approaches of coastal regions, linking short and long term time horizons and different geographical scales.

In particular, based on Safecoast experiences it is concluded that scenario specifications used in national and regional studies underlying policy formulation and decision making are generally incomplete, only partly reflecting the important drivers of coastal problems and related uncertainties. In this respect there is a general need for the development of adequate and consistent scenarios to properly deal with these long term uncertainty aspects.

5.7.2 Strategy development for specific flood prone areas

Given the boundary conditions established within the master plan, specific coastal protection strategies, based on an 'optimal' mix of measures are to be determined for each designated coastal region. This involves further choices to be made from available management concepts and related potential measures. The choice of strategy will depend on a great many different factors, such as resource availability, current flood risk, predicted flood risk, land uses, etc.

In general, the development of coastal protection strategies involves the following steps:
(1) Specification of detailed regional scenarios.
(2) Problem assessment and identification of promising measures.
(3) Analysis and evaluation of alternative strategies.

(1) Specification of detailed regional scenarios
Regional scenarios should be developed within the more general global and national trends as considered in the master plan. These scenarios should provide more specific and detailed information with respect to:
- the regional translation of the various aspects of climate change (to be included in the regional specification of hydraulic loads);
- spatial and infrastructural developments based on specific regional development potential; existing plans; and specified development priorities;
- already planned developments in flood protection systems.

The regional scenarios are to reflect the main scope of possible developments and should capture the major uncertainties in developments driving future risks and the possible effects of measures and strategies to reduce these risks.

(2) Problem assessment and identification of promising measures
The problem assessment refers to establishing the extent of future coastal risks and carrying out a flood risk assessment for the relevant regional scenarios as specified in the previous step. This will provide the required insights in the development of future risks and the underlying causes, providing a basis for the identification of possible measures and strategies to cope with future challenges.

In addition to the application and upgrading of more traditional forms of hard and soft coastal protection measures (such as dikes, sea walls, barriers and different forms of sand nourishment) the managing of future coastal risks should be aimed at a broader scope of potentially promising adaptation measures. Such options might include measures to reduce hydraulic loads, measures to establish flood defence zones with multifunctional use and measures to reduce the vulnerability of flood prone areas, according to the examples provided in section 5.6.

The feasibility of measures to be considered depends on a great many factors related to the natural and socio-economic characteristics of the coastal area, the existing flood protection system and the coastal management context (as affected by political, institutional and cultural conditions). Within the directives provided by the master plan, a screening exercise should be performed to identify possible measures that are more plausible or promising than others, given the specific characteristics and conditions pertaining to the coastal area considered.

(3) Analysis and evaluation of alternative strategies
Alternative strategies regarding the protection and management of the coastal area should be based on various combinations of promising measures, each strategy representing a logical and coherent mix of measures. The analysis of strategies involves the assessment of the relevant impacts (in terms of societal costs and benefits) of the alternative protection and management strategies. In order to deal with the various (large) uncertainties, the impacts of possible strategies need to be considered for different regional scenarios. The evaluation of strategies should be based on a comparison of strategies across these scenarios. The evaluation should not so much aim at selecting the 'best' strategy within a specific scenario, but rather to identify the most 'robust' strategy, showing an acceptable performance (in terms of meeting required objectives or achieving anticipated benefits) across all relevant scenarios. *Hence, the primary aim of the evaluation would be to minimise the risk of selecting a wrong strategy.*

Illustrative example of strategy development process
In order to illustrate some of the above principles, table 5.5 provides an example of strategy development for a hypothetical coastal area. The illustration is based on a comparison of two different management principles, i.e. the principle of (1) 'hold the line' (maintaining a fixed coastline) and (2) 'establishing multifunctional flood defence zones' where the characteristics of the coastline and the coastal defence zone would be allowed to change. Within each of these two management principles, two possibilities are considered which leads to four different strategies as follows:
1.a Hold the line – 'soft' protection.
1.b Hold the line – 'hard' protection.
2.a Establishing multifunctional flood defence zones – landward.
2.b Establishing multifunctional flood defence zones – seaward.

The main measures (options) that logically follow from the strategy formulation are shown in table 5.5 in the row with the heading 'primary measures'. For the 'hold the line' strategy, in addition to more traditional options under the sub-heading 'traditional', more recent developments have been indicated under the sub-heading 'new'. This distinction (traditional versus new) is not relevant for the primary measures under 'establishing multifunctional flood defence zones'.

In addition to the primary measures, other measures may be considered. In table 5.5 such measures have been considered within the categories: measures to reduce hydraulic loads and measures to reduce risks in flood prone areas. The table suggests that certain specific measures within these categories would more logically 'fit' the different strategy concepts than others (e.g. additional 'hard' measures would better fit the concept of 'hard' than 'soft' protection). However, in this respect there is certainly no general rule, and the merit of each measure should be judged within each specific situation. With respect to the measure 'awareness raising' (through coastal risk education and communication) it is suggested that this should be generally considered as a 'no regret' measure fitting all strategies.

In the last two rows of table 5.5 a number of natural and societal conditions have been indicated that, if they apply to the coastal region considered, would favour the strategies considered (one but last row) or would not favour these strategies (last row). These, and other conditions pertaining to the coastal regions could be used in the process to identify promising measures and strategies.

The illustrations in table 5.5 just provide an example of a structured process that might be applied in actual situations for the identification of promising coastal protection and management strategies. This process would consider the full scope and potential of measures historically applied and other possible measures following from more recent developments. It is emphasised that this is merely an example. Obviously, different strategies and mixes of measures could and would apply, depending on specific local circumstances and the political, historical and cultural context.

Measures	**Example strategies**			
	1. "Hold the line"		2. "Establishing multifunctional flood defence zones"	
	a. Soft protection	b. Hard protection	a. Landward	b. Seaward
Primary measures	*'Traditional':* Beach and dune nourishment *'New':* Maintain sand budgets in active sediment cells Passive drainage Sand motor	*'Traditional':* Build/reinforce dikes, sea walls, barriers, boulevards *'New':* New techniques to stabilise sub soils and anchor dike bodies 'Overtopping' dike concept	Creating a designated landward flood defence zone subject to temporary and controlled inundation Development of adjusted (economic) use, natural values or recreational functions in landward defence zone	Foreland protection before primary defence zone creating a brackish transition zone subject to temporary inundation Development of adjusted (economic) use, natural values or recreational functions in seaward defence zone
Measures to reduce hydraulic loads		Foreshore recharge Parallel floating breakwater Artificial deepwater longshore reefs	Foreshore recharge	
Measures to reduce risks in flood prone area	Adaptation of buildings (dry and wet proofing) Use of dwelling mounds Spatial planning	Dike compartments Local protection of structures Spatial planning	Adaptation of buildings (dry and wet proofing) Use of dwelling mounds	Adaptation of buildings (dry and wet proofing) Use of dwelling mounds
	Awareness raising: coastal risk education and communication			
Natural and societal conditions in favour of strategy	Soft existing protection High values in flood prone area Fixed safety standards	Hard existing protection High values in flood prone area Fixed safety standards	Relatively low values and low spatial development pressure in flood prone area Non fixed or low safety standards High appreciation of natural/recreational values	Non fixed or limited safety standards Need to maintain existing land use and functions High appreciation of natural/recreational values
Natural and societal conditions not in favour of strategy	Limitations in sediment availability High erosion rates	Possible impacts on adjacent coastal areas Financial limitations	Lack of acceptability of local stakeholders (Large) size of flood prone area	High erosion rates Possible impacts on adjacent coastal areas Financial limitations

Table 5.5: Illustration of coastal protection strategy development

In view of the above considerations on coastal protection strategy development and the wide scope of potential measures, it is expected that the present anticipated impacts of climate change could largely be effectively counteracted. Given the dynamic nature of coastal systems, there is a substantial degree of natural adaptation which may at least to a certain extent keep up with predicted sea level rise, if sufficient sediment availability can be ensured.
Consequently, many of the North Sea flood prone areas (but not all) can probably be kept safe at an acceptable cost by increasing normal practices as the sea level rises (e.g. strengthening, widening and heightened of existing defences or increasing sand nourishments to compensate for extra erosion).

In addition, in order to cope with future threats, there is the possibility to broaden the scope of possible measures to be considered. Several new ideas and concepts have emerged and are developing in different North Sea countries, extending the options for future coastal protection and management. Important trends relate to 'working with nature' and 'increasing resilience', following integrated policy goals and seeking to combine the various functions of the coastal zone. Other options aim to reduce or divert the (growth of) economic value within vulnerable areas (flood or erosion prone) by strategic spatial planning or to provide selective protection. However, it is essential to consider these options in their specific context. What can be worthwhile in one place could be inappropriate in another. Translation of coastal management concepts from one country to the other should therefore be treated with utmost care.

Undertaking the Safecoast project has also been valuable in gaining a better understanding of our European neighbours. Even so, mutual learning and understanding has not been limited to the science or issues related to coasts and risks. Although intangible, it is generally felt that it is these types of projects that bring us closer to the aims of the European cohesion policy.

Figure 5.8: Keeping focused at the first Safecoast workshop in Den Haag (NL)

6 MAIN FINDINGS AND RECOMMENDATIONS

6.1 Main findings and observations

6.2 Recommendations

6 MAIN FINDINGS AND RECOMMENDATIONS

This chapter summarises the main findings, observations and recommendations of the overall Safecoast project, based on results from studies in Safecoast and the wider orientation executed in the Safecoast synthesis process. Main findings and observations are considered within different themes, as follows:

- ***"Today"****: Coastal risk management in the present situation*
- ***"Tomorrow"****: Developments driving future coastal risks*
- ***"Next steps"****: Strategies to adapt to future coastal risks*
- ***"How"****: Risk assessment to support decision making*

Based on the Safecoast conclusions, further recommendations are provided to support and improve future coastal risk management practices and the continuation of the cooperation between North Sea countries.

6.1 Main findings and observations

"Today": Coastal risk management in the present situation

- **The North Sea coastal flood plains show a large variety in both the probability of and vulnerability to flooding.** There is a large variation in types of coastal areas, land forms, land use and emphasis on certain risk management approaches in the North Sea countries. Shaped by the forces of nature and human presence, coasts are different everywhere. Also, there is strong disparity between well-developed coastal areas and peripheral rural coastal communities. Safecoast has studied and mapped this variation more closely.

- **Despite the variety in societal attitudes and approaches towards flood risk in the North Sea countries, there are large similarities in coastal risk management strategies.** A precautionary approach based on safety standards (embedded in law or not) for a certain design water level is dominant in Denmark, Germany, the Netherlands and Belgium. In England however, the strategic objective is not to solely minimise flood losses but to maximise the sustainability of the system. Of all North Sea countries, the risk-based approach is furthest embedded in England. Following initiatives taken on European level, all countries have adopted the principles of Integrated Coastal Zone Management (ICZM). In practice the consideration of precautionary, robust and risk-based management approaches in the various countries often leads to similar management choices: context, more than attitude, therefore appears to define strategy.

- **Historically, a large variety of coastal risk management measures has been implemented.** In the periods after the coastal flood disasters in the 20th century (in particular those in 1953 and 1962) measures have focused on the improvement of flood defence systems (e.g. shortening of coastlines, stronger dikes, sea walls and barriers). In the past decades, the scope of policy options is broadening to include various options related to 'working with natural processes' such as coastal nourishments, salt marsh / foreland management (e.g. at the mainland coast of the Wadden Sea) and the upcoming use of managed retreat strategies where feasible and viable (such as in Essex, England). In Safecoast, a historical timeline and maps were produced to provide an overview of the various (inter)national policies and instruments applied.

- **In all North Sea countries and regions, annual government spending of coastal flood and erosion management is below 0.1% of their GDP** *(nominal Gross Domestic Product)*. While some countries get close to this number, in other countries this expenditure may be reasonably lower than 0.1% of GDP. In the countries and regions funding is organised differently, given the specific administrative and geo-political situation. For instance, in Germany 70% of the costs for coastal defence investments are shared by the federal government, whereas in Southern Denmark dikes are funded by means of local and private ownership. In the Netherlands, all costs for strengthening flood defence measures are paid by the national government. Also in England, the majority of flood and coastal erosion expenditure comes from the central government.

- **At present, coastal flood risk management is influenced by societal concern for climate change in many North Sea countries.** As a result, in most of the North Sea countries a rise of government spending on coastal flood and erosion risk management can be observed. At the same time, due to the absence of recent coastal flood disasters there is a risk of decreasing societal awareness and support for protection measures in specific, flood prone areas. This stresses the need and importance of risk communication and awareness raising to ensure the continuity and support of required coastal risk management strategies.

“Tomorrow”: Developments driving future coastal risks

- **The most important drivers of future coastal risks are related to spatial (socio-economic) developments and climate change.** From the viewpoint of coastal risk assessment these are considered as (more or less) autonomous developments, which are subject to major variation and uncertainty. The assessment of such developments is not an exact science. Scenario analysis is considered the most important tool to make the effects of these uncertainties explicit in the assessment of future coastal risks. Another important aspect in risk assessment relates to future protection levels offered by the coastal defence system, following from decisions to be made by coastal risk management authorities, based on anticipated future risks.

- **For the North Sea region as a whole, further increase of spatial pressure due to socio-economic development in coastal flood prone areas is expected.** For example, based on existing development scenarios, the Hamburg (harbour) area, London and Thames Gateway and Central Holland are considered to be growing socio-economic hotspots. A Safecoast case study (part of Action 1) on Central Holland shows an increase of economic value by 30-40% by 2030. Large parts of these areas are situated in low-lying areas, historically reclaimed from the sea or from lakes. In other areas the demand for other functions, such as tourism and nature is also considerable and influences flood risk management decisions. A generally expected demographic trend is that population levels will slowly rise and stabilise by 2050. In some places the trend of an ageing population is stronger in coastal areas, such as in Flanders and in parts of the English coast.

- **General trends in spatial (socio-economic) developments may be appropriate for long-term, macro-level risk assessments but more detailed information is required in developing coastal management strategies for specific areas.** Safecoast has mapped a possibly plausible spatial development scenario for the North Sea region, based on existing national planning strategies. In addition, and as part of tiered flood risk assessment, there is a need to consider more detailed spatial development scenarios based on specific spatial plans. The translation to lower assessment levels should be done with utmost care as there may be profound implications for how scenarios are characterised at a regional and local scale, limiting their reproducibility and credibility. While the impacts of climate change would require the consideration of long time horizons, planning horizons of spatial plans commonly do not exceed 30 years. The matching of these different temporal scales represents a major challenge in spatial scenario development.

- **With respect to the development of climate change there is a reasonable consensus on the average order of magnitude of sea level rise** (5 to 6 mm per year, following the IPCC). However, a Safecoast study (Action 1) concluded that the translation from scientific based climate change scenarios in the various countries and the assumptions actually applied in coastal risk management lack consistency and transparency. Moreover, the actual scenario applications are generally limited to sea level rise and do not incorporate assumptions for future changes in storminess or tidal characteristics. The main reasons for that are the lack of scientific knowledge and the complexity of dealing with these different climate change aspects in a long term policy making context.

- **From analyses conducted within Safecoast it follows that overall vulnerability and flood risk could substantially increase in the coming 50-100 years.**
  - Safecoast Action 3A assessed the increase in flood risk for the North Sea region up to 2050, assuming the present coastal defence system would not change. The increase in risk follows from the combined effects of an increase in consequence (due to socio-economic developments) and an increase in flooding probability (due to climate change). Even without taking account of possible increases in urban areas and based on a fixed price level (2007), consequences would increase by a factor of 1.3 to 1.5. At locations where present flooding probability is relatively high, increases in flooding probability may be of the same order of magnitude. The increase in flood risk is most marked in the Thames and Humber estuaries, West Flanders/Antwerp, Central Holland, and coastal flood prone areas of Hamburg and Bremen.
  - The results of the more specific cases studies on flood risk assessment that were carried out in Actions 3B and 5B provide more detailed results on the potential increase in flooding vulnerability and flood risk of particular flood prone areas.
  - Coastal erosion is a primary driver for coastal flood risks in certain areas. Without countermeasures, gradual coastline retreat puts pressure on inflexible coastal defence structures such as revetments or sea walls. Climate change will exacerbate this trend. Coastal erosion is also an important process to be managed in dune areas that form natural protection of flood prone areas. The results of Safecoast Action 5A on Danish coastal erosion have emphasised the need to include the results of local erosion assessments in decision-making regarding long term adaptation measures.
  - Estuaries in Belgium, Germany, The Netherlands and England may be particularly vulnerable. Flood risks become increasingly high in estuaries when coastal storm surges coincide with high river discharges in winter (an example being the Thames flood in 1928). In addition, a rise of sea level influences sediment dynamics which may lead to ‘drowning’ of salt marshes, affecting hydraulic loads on flood defences (for instance in the Wadden Sea).

Next steps": Strategies to adapt to future coastal risks

- **Under presently assumed trends in climate change, most of the North Sea flood prone areas can probably be kept safe at acceptable levels and acceptable cost by continuing and upgrading current practices.** In principle, the probability of flooding could be reduced to any desired small number, assuming funding and capacity are without limits. A Safecoast quick scan (Action 6) concluded that most of the increasing risk in the foreseeable future could probably be counteracted by increasing and upgrading current practices, providing climate change developments would be within presently assumed trends. Such practices would include the strengthening, widening and heightening of existing defences or increasing sand nourishments to compensate for extra erosion, but would also have to consider a further broadening of possible protection and prevention measures. In addition, more conscious and transparent decisions are needed regarding the determination and allocation of 'acceptable' coastal risks. These can only emerge from public and political debate supported with the best possible knowledge provided by scientific communities.

- **The concept of integrated coastal zone management (ICZM) should provide the basis for developing specific integrated master plans for the various coastal regions subject to coastal risk.** The ICZM principles as adopted in the EU recommendation of 2002 are considered to be essential. Master plans should address the continuity of coastal risk management policies, provision of protection measures and the related operational procedures (i.e. in terms of balancing interests; financing; institutional arrangements; legal rights/obligations; and operational responsibilities). These aspects and possibilities have been further considered in Safecoast Action 4 on the development of a coastal protection master plan for Flanders. Moreover, the integrated planning approach should facilitate the necessary cooperation between coastal managers, land use planners and crisis managers and seek community participation at an early stage. Emerging climate adaptation policies should explicitly encourage this.

- **When considering possible alternative measures and options to manage coastal risks the risk management cycle or 'safety chain' must be considered in its full potential.** The safety chain should be addressed as a framework for categorisation and incentive for integration, rather than a principle for prioritisation. In spite of different terminology used in Europe, there is a lot of similarity in the meaning of the categories and types of measures considered. The EU Floods Directive is considered an important tool for the further harmonisation and integration of solutions and approaches regarding flood risk management. Within Safecoast, measure categories were defined by the following key expressions: (1) Prevention; (2) Protection; (3) Crisis management; and (4) Recovery. The focus in Safecoast has been primarily on the first two categories.

- **Within the measure categories 'Protection' and 'Prevention', many new ideas and concepts have emerged and are being developed in different North Sea countries.** Examples of observed trends related to such new ideas and innovative concepts include:
  - The development of various **sediment management principles** regarding the designation and maintenance of strategic sediment 'reservoirs' ('sand motor', passive drainage, salt marsh recharge). Such reservoirs would act as buffer zones directly protecting land from the sea, or aiming to secure sufficient sediment volumes within active coastal sediment cells to allow the shore to keep pace with sea level rise.
  - Ongoing **improvement of flood defences** by researching new techniques that reduce the probability of failure. Examples are given in EU projects like Comcoast and Erograss.

- A growing interest in creating more optimal **dike compartments** from the viewpoint of flood risk and/or the use or completion of secondary dike lines to enhance flood safety (for instance in the Netherlands and parts of Germany).
- Emerging concepts towards the use of **wider flood defence zones** and the redesign and re-allocation of space surrounding existing flood defences, to seek additions to and alternatives for continuous dike strengthening and to better combine functions such as safety, nature and tourism (as illustrated by Comcoast).
- Further implementation and discussion of seaward options to **reduce hydraulic loads** on flood defences (management of salt marshes as part of flood protection, wave energy reduction by artificial reefs and even islands, or increased coastal nourishments such as in Denmark, The Netherlands and Flanders).
- An increase of various **forms of managed retreat**, especially in estuarine and salt marsh environments, however currently mainly used for purposes other than flood risk management (e.g. habitat restoration and nature compensation) and sometimes lacking local public support, such as in the Western Scheldt estuary.
- Increasing incentives to better incorporate flood and erosion risks and vulnerability into the spatial planning process to **avoid or manage unsustainable developments**, e.g. discussions on revising coastal and flood risk planning policies in England, but also in other countries.
- Selective use of **flood proofing** methods for local areas/structures/properties, especially in developed, but non-protected areas, such as in the Hamburg harbour area.
- Increasing efforts and discussion in the North Sea region to **better allocate risks** (e.g. insurance) and to promote **risk awareness** and **preparedness** (communication campaigns (as covered in Safecoast Action 2), early warning, evacuation, self-help and flood risk mapping) and enhancing public support for proposed measures.

• **It is essential to consider the possible implementation of the various concepts that have emerged or are emerging in different North Sea countries in their specific context.** What can be worthwhile in one place could be inappropriate in another. Translation of coastal management concepts from one country to the other should therefore be treated with utmost care. However, in most North Sea countries there seem to be emerging trends relating to 'working with nature' and 'increasing resilience', following integrated policy goals and seeking to combine the various functions of the coastal zone.

• **Flood risk communication and education is an important means to enhance coastal risk awareness and public support for measures.** Flood risk communication needs to be sincere, straightforward and aimed at all levels but with particular emphasis on the local level to target those at risk. In particular, awareness raising and communication should be aimed at reinforcing the potential for personal self-help before and during floods. In project Safecoast, a communication campaign in Schleswig-Holstein was performed and evaluated. The results obtained from an inventory of communication activities and experiences in North Sea countries and from a literature study, have emphasised the desire of people to be provided with guidelines on appropriate behaviour in crisis situations. Awareness of risks and believe in the effectiveness of possible measures is an important requirement to raise the interest and enhance the participation of people in this respect.

“How”: Risk assessment to support decision making

- **In the North Sea region, there is an increased use of risk assessment methods to support coastal policy and management decisions.** In England, risk assessments are embedded in the appraisal process of management options with guidance from the government. In the other North Sea countries, risk assessments currently have different purposes, such as creating support for existing precautionary approaches, increasing the knowledge base for risk management (e.g. failure of flood defences) and risk communication. For example in the Netherlands, a running national project (FLORIS 2) aims to provide the knowledge base for identifying critical weak spots in the flood protection system of flood prone areas based on an integrated flood risk assessment. Moreover, the knowledge base for flood risk assessment was also improved by EU project FLOODsite.

- **There is a need for risk assessments to be executed at different geographical and temporal scales.** The review of applications of risk assessment methodologies in Safecoast have emphasised the need to distinguish between different geographical and temporal scales in risk assessment in relation to specific planning objectives and phases. Different purposes require a different level of detail. In this respect, a distinction is to be made in a number of different, tiered assessment levels that could include:
  - The trans-national level, to identify the most vulnerable areas, e.g. in support of the implementation of the EU Floods Directive (as covered in Safecoast Action 3A).
  - The national/regional level or any level of competent administration, to substantiate or prioritise funding or planning decisions (as covered in Safecoast Action 4 on the development of the Flanders coastal protection master plan).
  - The local or regional level of specific flood prone areas to identify, design and evaluate possible measures (as covered in Safecoast Action 5B on the case studies in Lower Saxony).

In addition, it is observed that the planning for coastal risk management strongly interacts with other planning processes such as land use and spatial/infrastructural developments, involving many stakeholders and interests.

- **There is a large degree of commonality in flood risk assessment methods and approaches applied in the various North Sea countries.** Although the various countries in the North Sea Region all have developed their own approaches in dealing with flood risk assessment, the general method and approach is basically the same. Differences may pertain to specific methods and assumptions used, the emphasis put on various steps in the assessments, and the level of detail considered. The overall agreement and common aspects of the approach provide ample scope for joined methodological development and further exchange of knowledge and experiences.

- **Within Safecoast, part of the focus of the project was related to the application of risk assessment methods in specific case studies. The experiences from these applications have contributed to the international learning process by:**
  - Identifying shortcomings and problems related to data availability and accessibility.
  - Providing ideas for further methodological improvement.
  - Gaining new insights in the sensitivity of modelling parameters and assumptions.
  - Providing recommendations for the use and interpretation of modelling results, in particular in view of the major uncertainties involved in coastal risk assessment.

6.2 Recommendations

By continuing, intensifying and expanding current management practices it is expected that most of the North Sea flood prone areas could be kept safe at acceptable risk levels and at acceptable costs, under presently assumed trends in climate change. In achieving this, the findings of Safecoast effectively point towards the need for a more *integrated* approach to coastal risk management, where the main aspects of integration would include: different types of problems, developments, stakeholders, solutions, and types and scales of planning. The adoption of integrated planning procedures for managing coastal risk should not be underestimated and will require considerable effort and cooperation from all parties involved, as well as the necessary financial resources.

Recommendations following these main findings are categorised for different target groups related to coastal policy makers and managers and the various research communities.

Policy and management

- **Make use of the full potential of measures considered within the risk management cycle or 'safety chain'.** In addition to present management practices, a wide scope of potential measures should be considered to reduce coastal risks, building on experiences obtained in the various North Sea countries. This broad orientation on potential measures should stimulate innovation and help manage future coastal risks, taking into account the specific circumstances in coastal regions.

- **Clearly define national and regional coastal risk management goals in a broad and long-term perspective.** Coastal risk management and other planning objectives and existing trade-offs (e.g. related to economic development, flood risk and nature conservation) should be made explicit and discussed with the affected public. A clear understanding and communication of the trade-offs involved should warrant the development of sustainable solutions, balancing the interests of all stakeholders including the public at large. This requires an honest and open communication and participation process with affected communities.

- **Increase the focus of coastal planning procedures at the participation of local communities and authorities.** The purpose of this local participation is twofold. On the one hand, optimal use is made of the know-how and skills of local communities, taking into account their wishes and needs. On the other hand, the involvement and shared responsibility of local parties in the coastal risk management planning process will guarantee a sound social basis for the management plans to be developed. In Safecoast, this was put into practice in Action 5B, where the Lower Saxony flood risk assessment and simulation was discussed with a local contact group.

- **Continue the international cooperation and learning process.** Safecoast findings have confirmed the similarities in coastal problems and possible solutions, and the commonality in methodological approaches, among the various North Sea countries. As experience grows in coastal risk management there will be emerging options relating to policy and implementation to reduce risk and promote sustainable solutions. The North Sea countries should therefore continue to learn from each other by cooperation and knowledge sharing. They should also join in the research and monitoring of the dynamics of the North Sea and its climate and improve the knowledge base for all steps involved in flood and erosion risk assessments. Moreover, they should improve conditions and arrangements for international data availability, data accessibility, and knowledge / information exchange.

Research communities

- **Further develop the integrated planning approach to manage coastal risks.** Important common aspects for further research include the integrated development of: scenario specification procedures; coastal risk assessment methodology; and the hierarchical planning approach for coastal risk management, linking short and long term time horizons and different geographical scales. A multidisciplinary approach is therefore important.

- **Improve the knowledge base on the aspects and impacts of climate change.** In addition to sea level rise, further developments should also be involved with other aspects of climate change such as wind speed and direction, storm surges and altered wave behaviour. The focus should be on the need and possibilities to explicitly include these aspects in policy and management scenarios to provide reliable estimates of the impacts to be expected under projected climate change scenarios. This may lead to a joint development of methodological procedures to include other climate change impacts in coastal risk assessment.

- **Continue the exchange of knowledge for development and further improvement of risk assessment methodologies.** The preparation and execution of case studies on risk assessment in Safecoast have yielded a variety of detailed suggestions for the improvement and further application of risk assessment methods. In chapter 4 of this synthesis report, specific recommendations with respect to these improvements and applications are provided in the context of the various case studies.

- **Reduce and better manage uncertainty in coastal flood and erosion risk assessments.** Further research should aim to understand and identify methods to explicitly include uncertainty in all decisions relating to coastal management. Major uncertainties are related to 1) natural and human induced variability and 2) knowledge uncertainty. Scenario analysis should be applied to manage uncertainty by making the effects of uncertainties explicit and transparent. This does not take away the uncertainties but provides a basis to 'minimise' the risk of making wrong decisions.

  Among the most important uncertainties found in Safecoast case studies are:
  - The magnitude and direction of economic and spatial developments (driving the possible extent of flooding consequences in terms of damages and casualties);
  - The occurrence and development of hydraulic loads (in relation to climate change);
  - The location and nature of possible failure of flood defences;
  - The extent, duration and gravity of flooding events.

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2	"The informed society", 2008
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3B	"Comparison between different flood risk methodologies", 2008
4	"Integrated master plan for Flanders future coastal safety", 2008
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ANNEX 1

GLOSSARY OF TERMS

ANNEX 2

HISTORICAL TIMELINE

ANNEX 3

MAPS

ANNEX 1

GLOSSARY OF TERMS

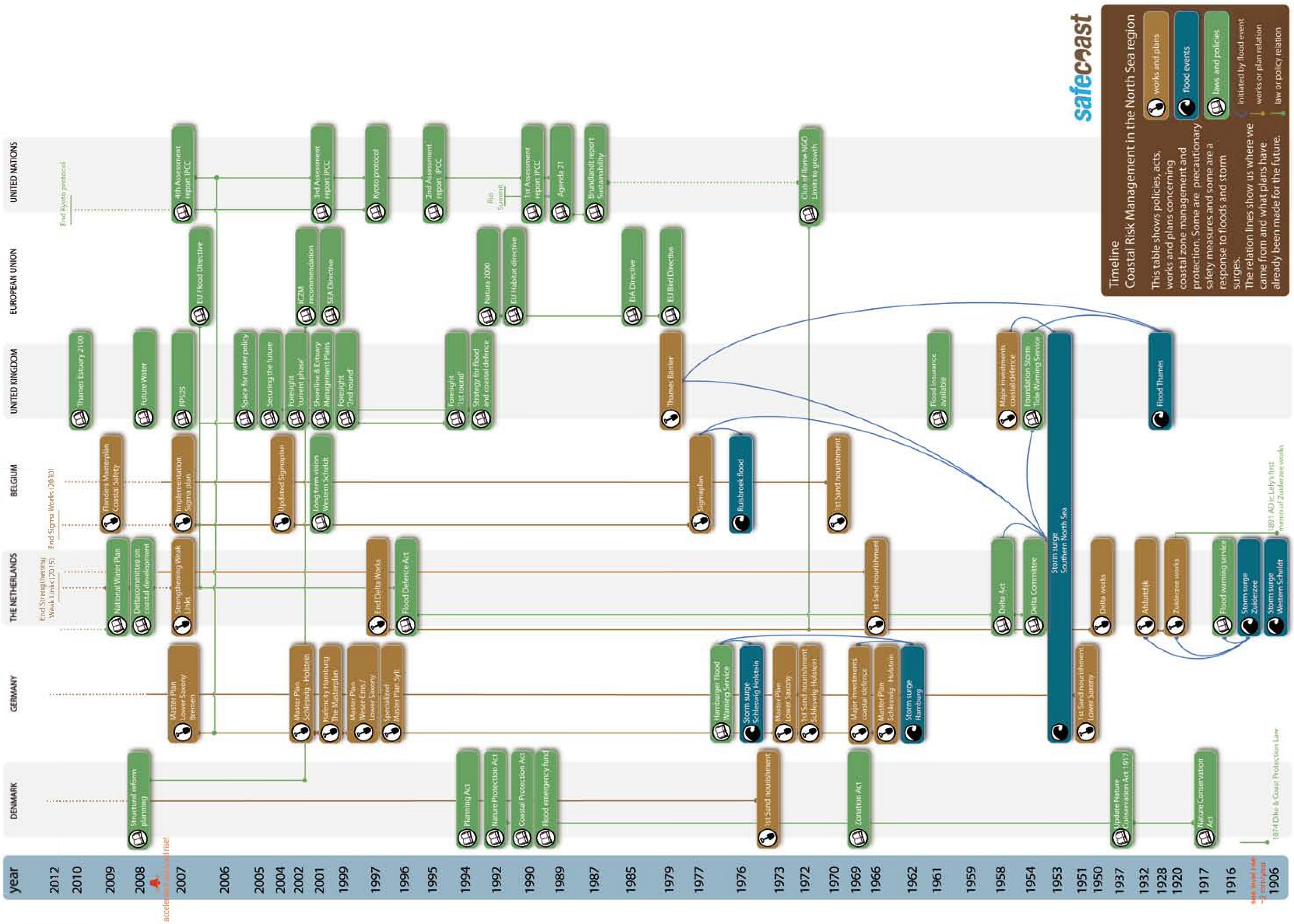
Breach growth modelling	This refers to analyses which are performed on the way defences fail or 'breach'. For example, the rate at which the breach grows with time may be modelled.
CBA	Cost Benefit Analysis. An economic appraisal involving the comparison of present value benefits with costs.
Climate change	Gradual alteration over time in the prevailing weather conditi-ons. In particular, this refers to the assumed long term changes in weather patterns and conditions due to human activities such as the burning of fossil fuels.
Climate change adaptation measure or adaptive strategy	In Safecoast, this refers to an action taken to deal with the effects of climate change. For example, strengthening a flood defence or increasing the amount of sand nourishment given to a beach.
Coastal accretion	Process where sediment is deposited so the depth of water covering an area becomes shallower.
Coastal erosion	A process where material is worn away from the coast due to an imbalance in the supply and removal of matter. This covers the loss of natural or constructed defences such as sand dunes and sea walls, as well as land and intertidal areas. 'Cliff retreat' refers to the erosion of cliffs.
Coastal nourishment	The process of artificially adding sediment to a beach. The sediment may have been sourced from offshore dredging.
Coastal squeeze	Coastal squeeze occurs when coastal defences prevent vegetation migrating landwards in response to sea level rise. The result is a loss of coastal habitats.
Coastal zone	The area of land along the coastline which may be influenced by coastal processes such as flooding and erosion.
Contingency planner	Person or organisation who decides what course of action needs to be taken should a possible but not very likely event happen.
Crisis management	The organisation of ways of dealing with large-scale problems or disasters.

Demographic values	Information on a population covering size, distribution etc.
Digital Elevation Model (DEM)	A digital portrayal of the ground surface topography, often produced using remote sensing techniques.
DPSIR	Driver-Pressure-State-Impacts-Response is a framework for assessing and managing the state of the environment and associated problems.
Driver	A factor which may affect or change the state of a system. For example, sea level rise could be seen as a driver for coastal flooding.
Elevation data	Measurements giving height or altitude.
Failure mechanism	(In relation to a flood defence system) This term refers to the way in which the defence is overcome. For example, by wave overtopping or the erosion of the outer slopes.
Fragility curve	A graph which gives the relationship between the load on a flood defence and the probability of the system failing.
GIS	Geographical Information System
Hydraulic boundary conditions	These are the characteristics e.g. waves, levels and currents of a water body which are used when modelling.
Hydraulic pressure	(In relation to flooding in Safecoast) When performing an analysis, hydraulic pressure refers to the water levels and wave characteristics (height and forces).
Hydrograph	A graph of time plotted against discharge for a river or other flow of water.
IPCC	Intergovernmental Panel on Climate Change
Isostatic rise (or tectonic rebound)	This refers to the slow uplifting of Earth's surface which is occurring in some areas. This uplift is a delayed reaction resulting from the removal of a load i.e. the melting and subsequent loss of a glacier.
Managed realignment	The process of actively overseeing and establishing a new defence line which is further inland. This may be part of attempts to recreate lost habitats such as salt marsh.

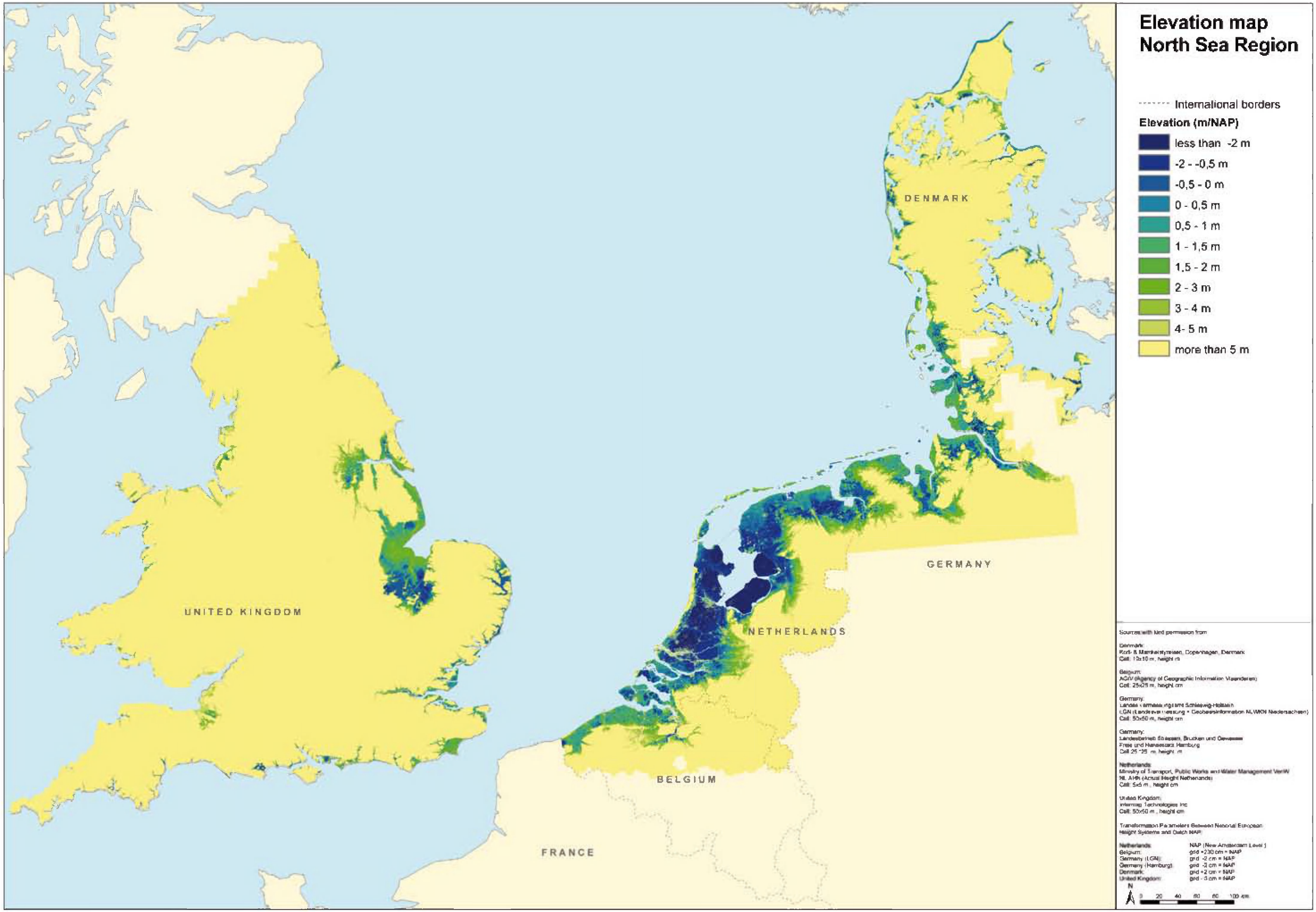
No regrets (or measures of no regret)	This phrase describes actions which mitigate the impacts of climate change and bring short-term benefits, but do not involve long-term consequences.
Parameter	A factor which is fed into equations or models to ensure its influence on the outcome is taken into account. For example relative sea level rise and wind speed are amongst those parameters used to produce a climate change scenario. When determining the probabililty of flooding, parameters such as water level and the condition of coastal protection are considered.
Precautionary principle (or measures)	This is when actions are taken to avoid possible damage or other detrimental impacts, even though there may not be conclusive evidence that such negative consequences would occur.
Return period	The time within which a flood of a certain magnitude is expected. For example, a 1 in 50 flood would have a 0.02 chance of occurring each year.
Risk	(In relation to Safecoast) A dynamic concept given as the probability of flooding or erosion occurring multiplied by the consequences.
Risk assessment	The process of identifying the risks involved in a project or situation and the ways to mitigate or remove them.
Risk or crisis communication	The transmission of information about the level and extent of risk. This affects the extent of risk awareness.
Risk management	In relation to coastal flooding and erosion, risk management refers to the process of planning for and dealing with possible negative events and their consequences.
Scenario (climate scenario or emissions scenario)	A set of assumptions forming a situation which is used in modelling to predict what might happen in reality. For example, the impacts of climate change can be investigated by considering different greenhouse gas emission levels, each of which could be classed as a scenario.
Scenario analysis	The use of different scenarios or situations as inputs to a system or model to determine what outcomes may result from particular actions or happenings. In Safecoast, scenario analysis is used to bring possible changes in variables like sea level into decision-making. This can help show what the impacts from future changes might be.

Scouring	A form of erosion caused by the movement of water against a surface e.g. the base of a cliff.
Sea level rise	The rise in sea level due to global warming leading to thermal expansion and melting of ice. Isostatic adjustment may be having an additional effect in some areas.
Sediment cell	A length of coastline which generally does not import or export significant amounts of sediment, with the result that it can be analysed separately to adjacent cells.
Sensitivity analysis	A process undertaken to determine how vulnerable the results of a project or model are to changes in methods or particular data inputs. For example sensitivity analysis could be used to test the amount of influence sea level rise has on the extent of flooding in a particular area.
Socio-economic values	Data on a society or population in a particular area which often covers the way the society is organised, its politics and economic arrangements.
Spatial planning	The way in which distribution of development and habitation is controlled through land use planning from the local to the international level.
Spring tide	A tide which shows the biggest difference between high and low water levels. It occurs when there is a full moon or a new moon.
Storm surge (or tidal surge)	A surge is when meteorological effects such as the wind or changes in atmospheric pressure lead to the movement of water. A storm surge is rather like a wave which is higher than an ordinary tide (or typical sea level) and is caused by the wind blowing across the water's surface.
Strategic flood risk management	The combination of plans and arrangements which covers how flood risk should be dealt with. This may be referred to as strategic planning.
Tectonic movements	Movement of the plates making up the Earth's surface.
Tidal gauge	A device used to measure sea level and quantify the height of tsunamis and storm surges.
Urbanisation	Process where an area, which may previously have been rural, is developed and becomes a built-up environment.

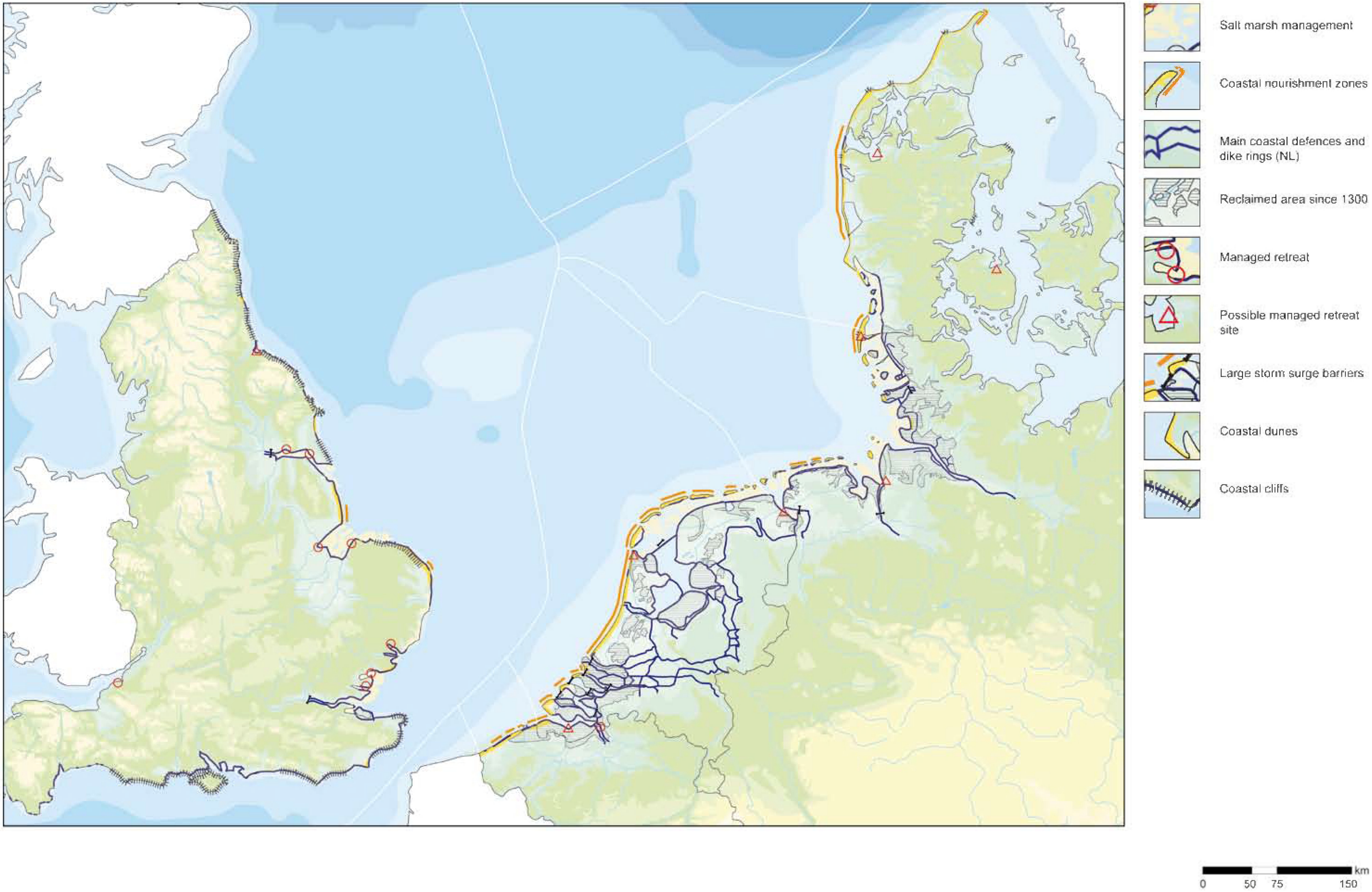
Annex 2: Historical timeline



Annex 3.1: Elevation map North Sea region



Annex 3.2: Coastal risk management measures



Description

This map gives a simplified representation of the coastal risk management measures of the countries around the North Sea. The coastal defences are plotted against the natural background. There is a brief description of each country's protection measures.

The Belgian coast is partly fixed by sea defences, and partly protected by 'soft' coastal risk management measures. The southern section of the coast is protected by dunes, which are regularly reinforced. The central section, in the region of Ostend and Knokke, is defended by a seawall in combination with sand replenishment and raising of the beach level. Slight land accretion takes place in the south, and slight erosion in the north, with the fixed coast near Ostend as the transition point.

The south-western flank of Jutland in Denmark forms a part of the Wadden Sea coast. The marine dynamics mean that the positions of the three Wadden Islands of Rømø, Mandø and Fanø are subject to change. To the north of the Skallingen archipelago, the Danish coast is characterised by a narrow strip of dunes indented by inlets. Behind these lie the Jutland Fjords. Further north are the larger waters of Nissum Breding and Limfjorden. The Danish coastline is largely in retreat: sand is being eroded and carried away. It is deposited just beyond the most northerly point on the eastern side, flanking the Kattegat.

The German North Sea coast is primarily a coastline of mudflats. The Wadden Islands form a natural row of dunes, and represent the first line of defence of the hinterland. This hinterland is protected by a double row of seawalls, relics of the era of land reclamation. To the north of the Helgoländer Bucht, the orientation of the coast changes to north-south. It is dissected by a number of rivers. Storm surge defences prevent high water levels from encroaching further into the rivers.

The UK North Sea coastline is varied. Hard and, particularly, soft rocky coastlines alternate with marshy coasts and dunes. A number of rivers and estuaries cut through the coastline. Wetland areas – some of them drained – are to be found at many low-lying locations. The vulnerable points in the coast are provided with defences in the form of hard defences or earth embankments. The standard of protection varies with higher standards being provided to the urban areas. The area also contains a number of internationally recognised conservation areas, many of them fresh water grazing marsh and reed beds which are under threat from rising sea levels.

The Dutch coast is made up of three types: Wadden Sea, more level sandy coastline and artificially surfaced delta. The western section of the Wadden Sea is found at the north of the Netherlands. The Wadden Islands form a natural line of dunes, and the mainland is protected by seawalls. The western coast of the Netherlands is made up of a strip of dunes, with seawalls at several locations. In the south is the Zeeland delta area of the rivers Rhine, Meuse and Scheldt. Following the flood disaster of 1953, a number of seawalls were built in this area, and large sections of the estuaries were closed off from the sea. The hinterland and its rivers are protected by dikes. The entire coast is given extra reinforcement through sand nourishment on beaches or on the foreshore.

The Belgian, Dutch, German Danish and East and South East England coasts are subject to erosion. This is connected with the sinking elevation of the land, high waves caused by strong currents, and soft sediments. The low elevation of the Netherlands in particular, and also of a considerable part of the Belgian and German coasts, increases the danger of flooding. The estuary of the river Scheldt, with its inland location, is an example of a sensitive area where the sea can have a great influence on both the Belgian and the Dutch hinterland.

Method and assumptions

Steps:

1) Background layer: basic North Sea region map with elevation contourlines.
2) Inventory and analysis of relevant sources aimed at known and planned coastal protection and managed retreat sites of importance for flood defence.
3) Identifying different types of coastal protection measures (main coastal defences, large storm surge barriers, secondary coastal defence, management zones).
4) Identifying coastal protection measures in low-lying areas.
5) Re-sketch and re-drawing sources into a qualitative trans-national impression map.

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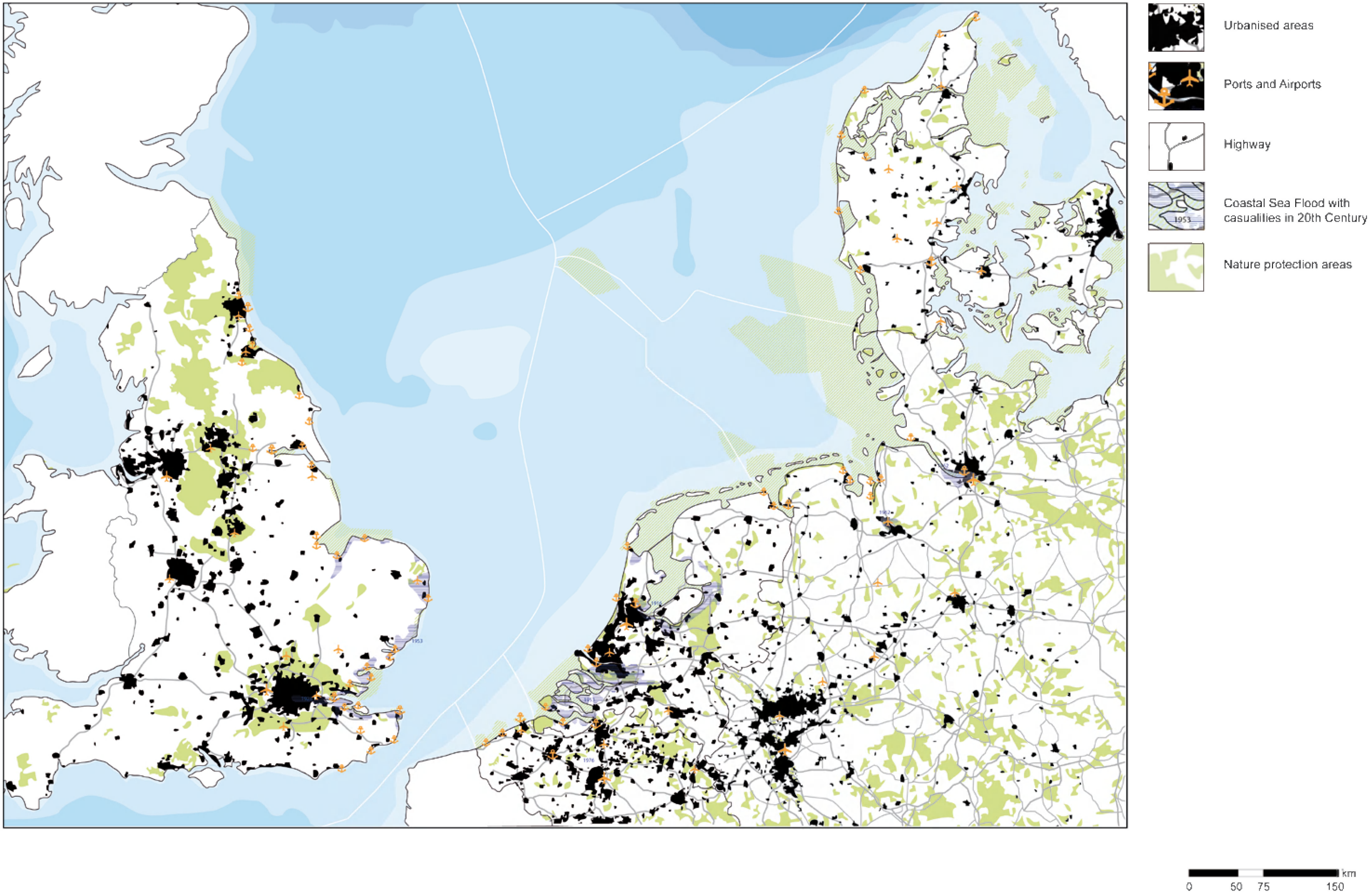
Annex 3.3: People and environment



Annex 3.3: People and environment

Description

This map shows the distribution and intensity of land use in relation to elevation above sea level in various countries surrounding the North Sea. Occupation, networks and natural areas are shown against the natural background.

The central urban zone of north-western Europe, from central Britain to the Rhine Valley, with its associated network of trans-European connections, reveals the pattern of urbanisation. These are the zones where people live, work and relax. The Dutch 'Randstad' conurbation, the 'Flemish Diamond' in Belgium and the German Rhine-Ruhr Area are now part of one of the most densely populated regions in the world. This is in contrast with Denmark and the northern areas of Germany and Britain. The most densely populated regions lie in the lowlands, which are typified by delta areas and polders. The Netherlands lies partly below sea level.

A dense urban network and a highly concentrated population have repercussions for their environment. A natural or rural fringe area is important for the preservation the quality of the living environment and the landscape. Around the 'Randstad', the 'Flemish Diamond' and London, such areas have a firm status. The dense green network bordering the urban agglomerations can be clearly seen on the map.

A wide range and scale of economic activity takes place within these extensive urban agglomerations. Transport, both of people and goods, is of major importance, and takes shape in substantial mainports. The numerous harbours on the rivers and the North Sea itself are a reflection of the economic importance of water in the North Sea countries. Harbours are crucial to a city or country's national and international trading position, and also offer employment opportunities.

Method and assumptions

Steps:

1) Background layer: basic North Sea region map.

2) Inventory and analysis of relevant sources aimed at urbanised area's, upper-regional motorway system, mainports and nature protection areas > app. 20km2. Airports with less then 2 millions passengers per year have been disregarded. As well as ports without ferry boat- and/or shortsea shipping connection. Protected green areas originate from the European directive Natura 2000, protected. national landscapes, parks, greenbelts etc designated by national governments.

3) Identifying key sources for map aimed at inter-regional and (inter)national significance (urban patterns, transport transport network, large regional and (inter)national mainports, nature area's protected by governments).

4) Re-sketch and re-drawing sources into a qualitative trans-national impression map.

Map 1: People and environment

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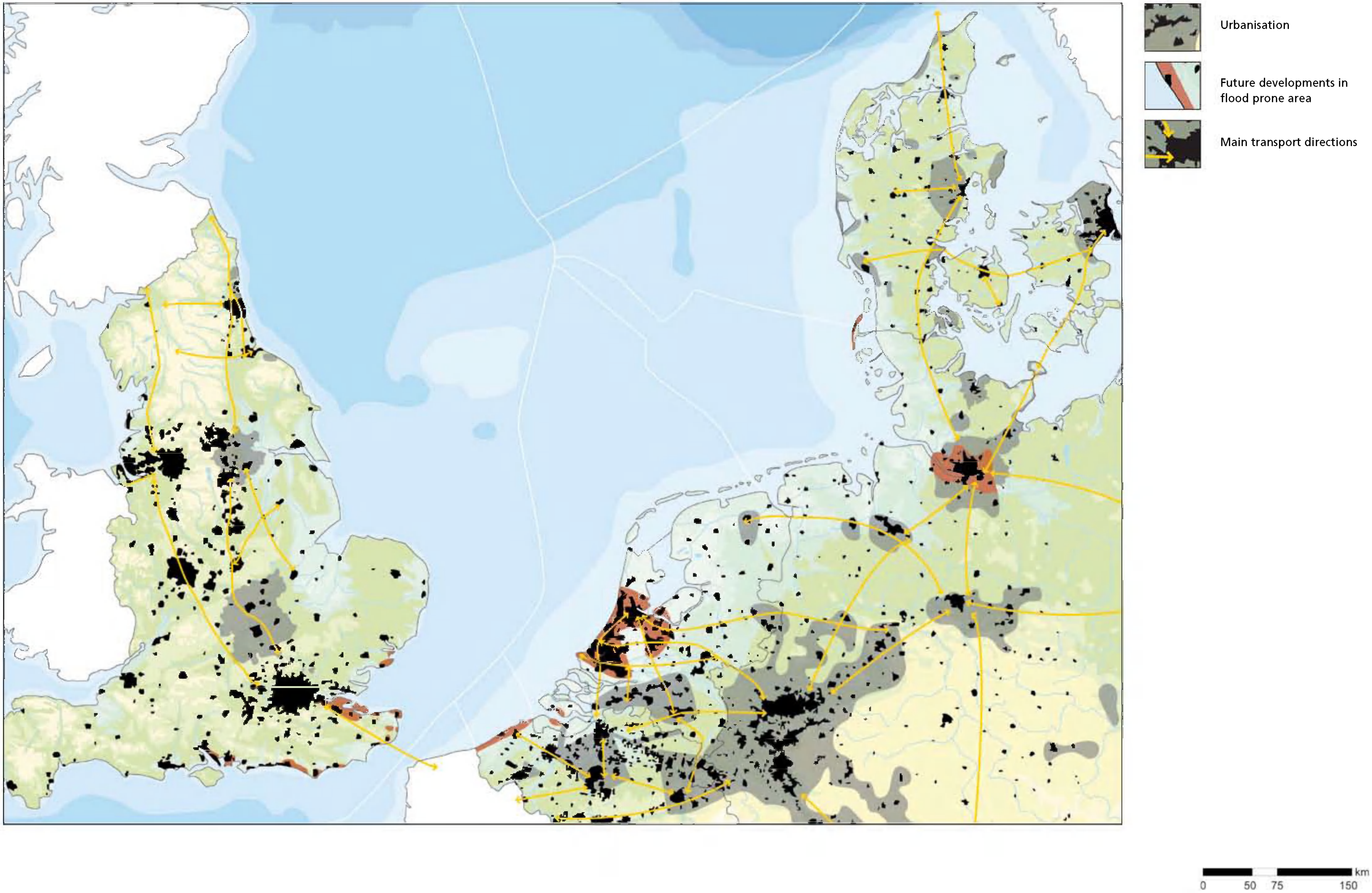
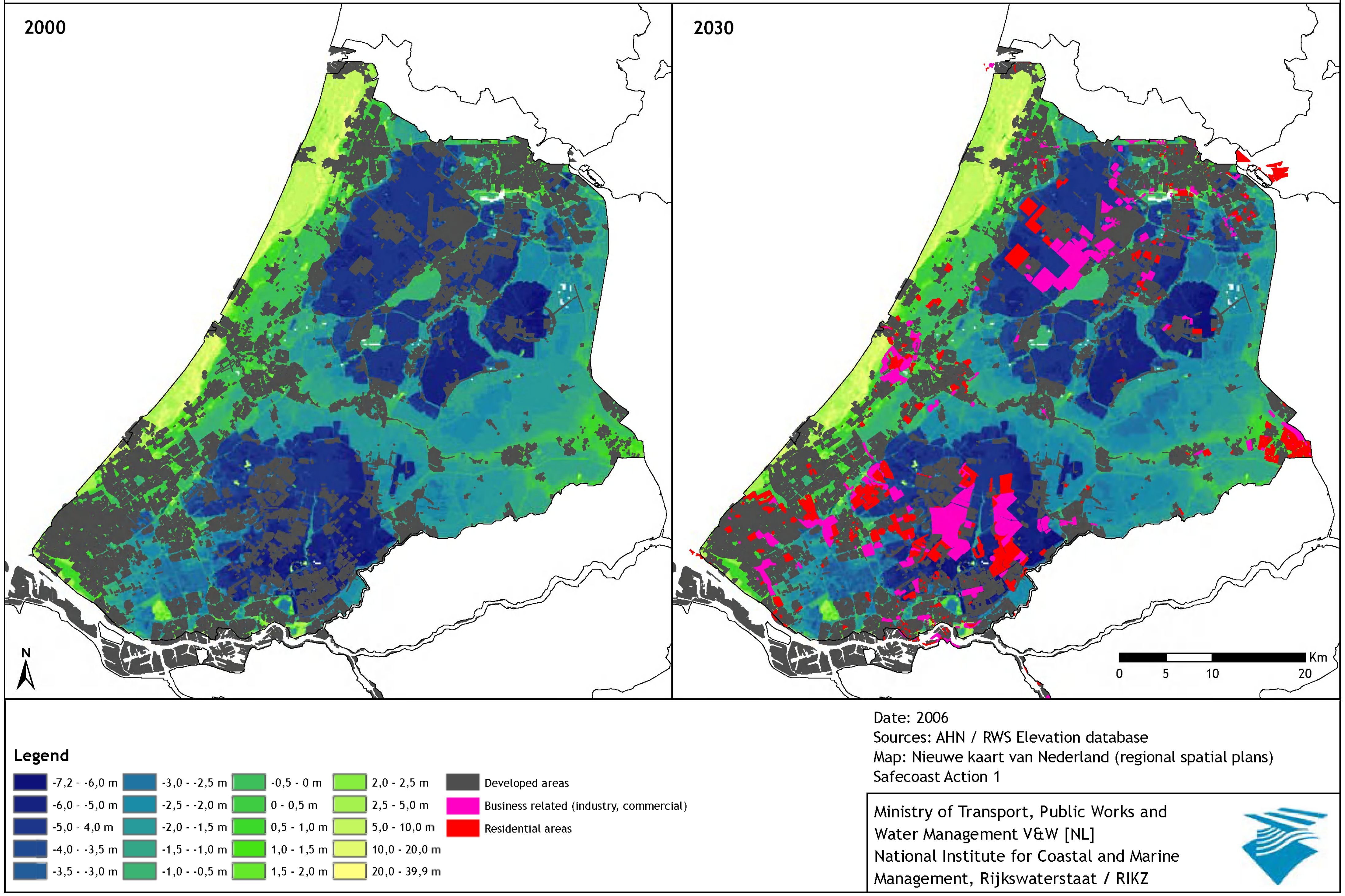
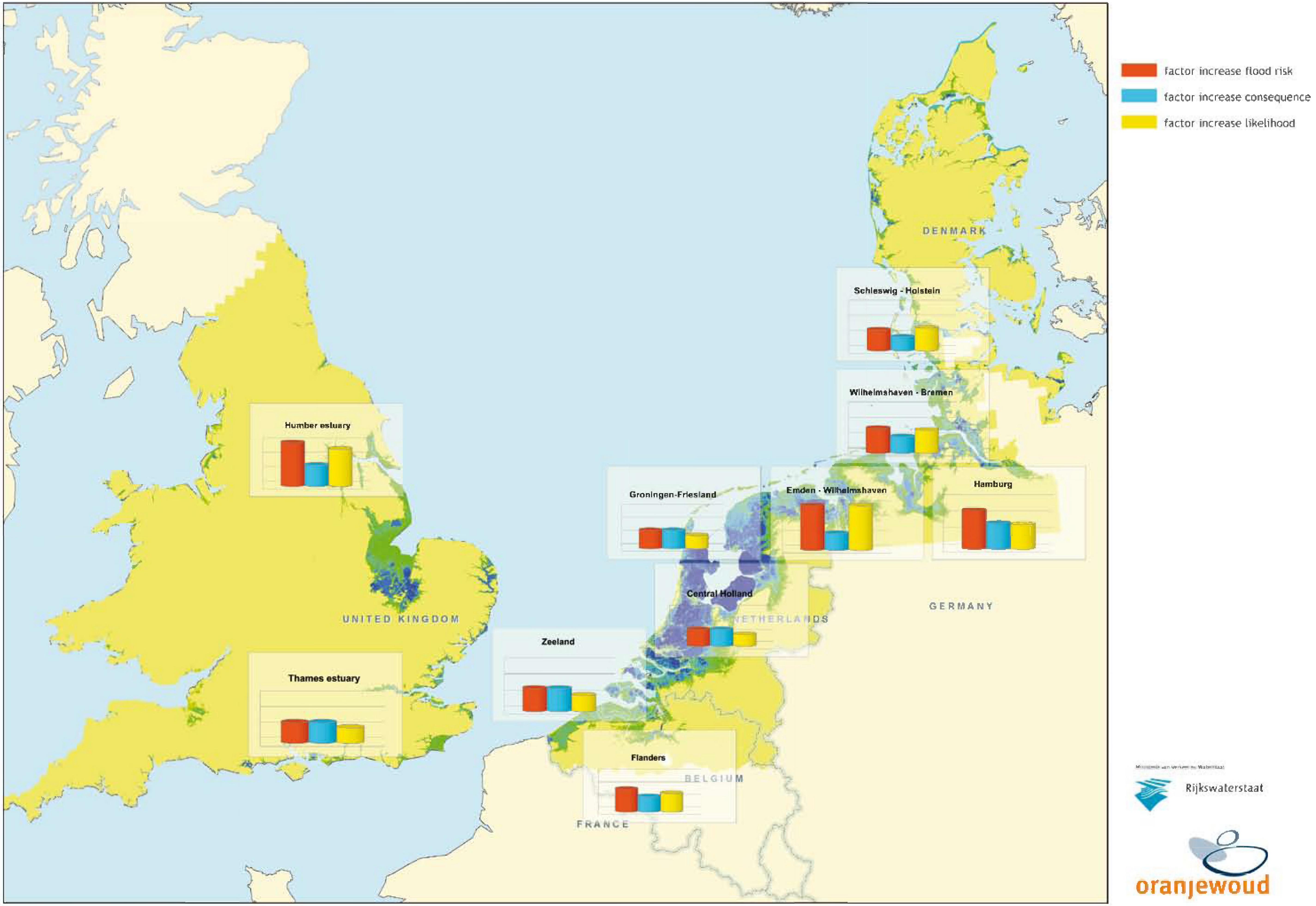
Annex 3.4: Spatial scenario impression 2050

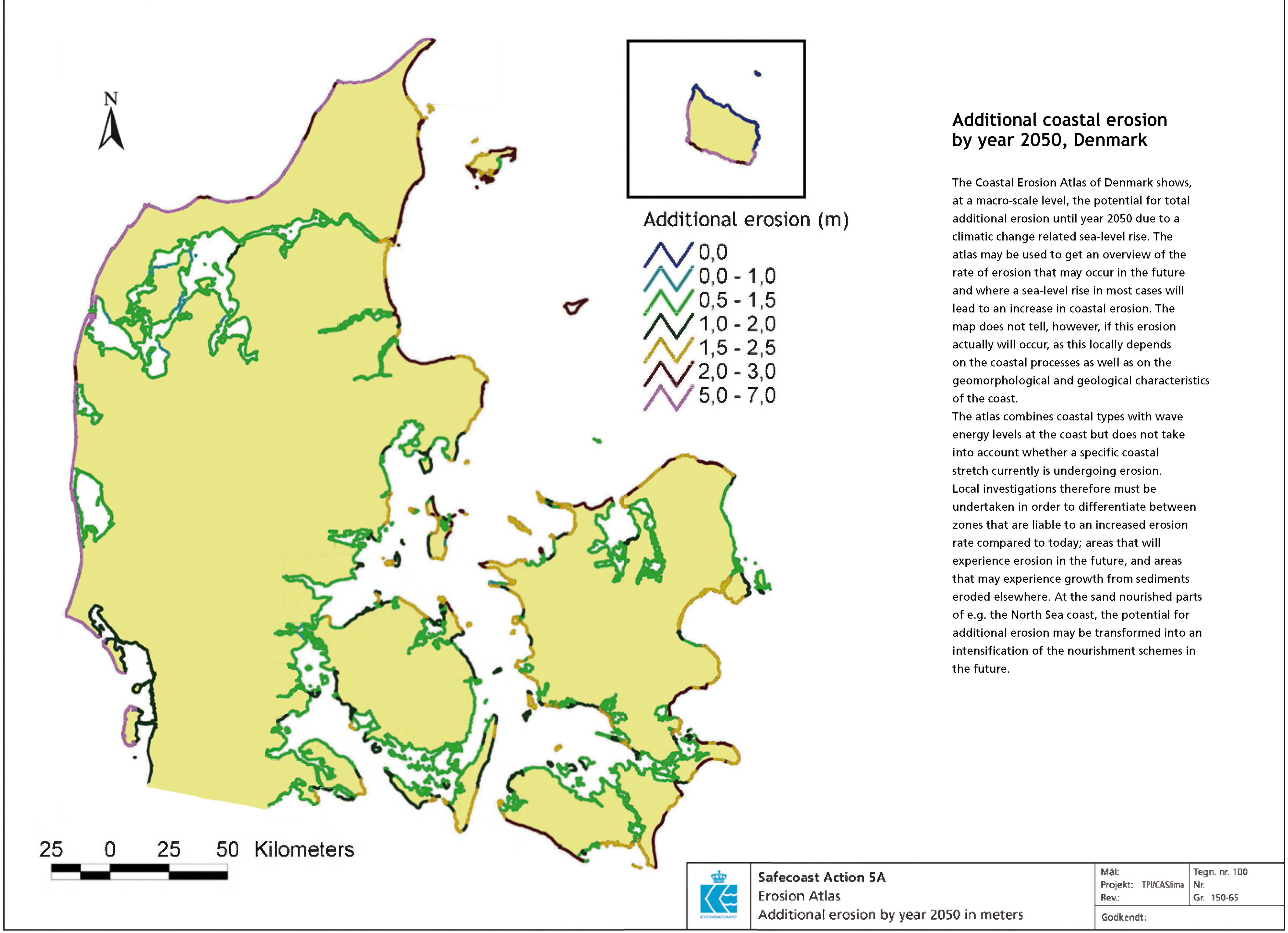


Elevation and spatial planning dike ring 14 (Central-Holland) for 2000 and 2030



Annex 3.6: Flood risk trends North Sea region



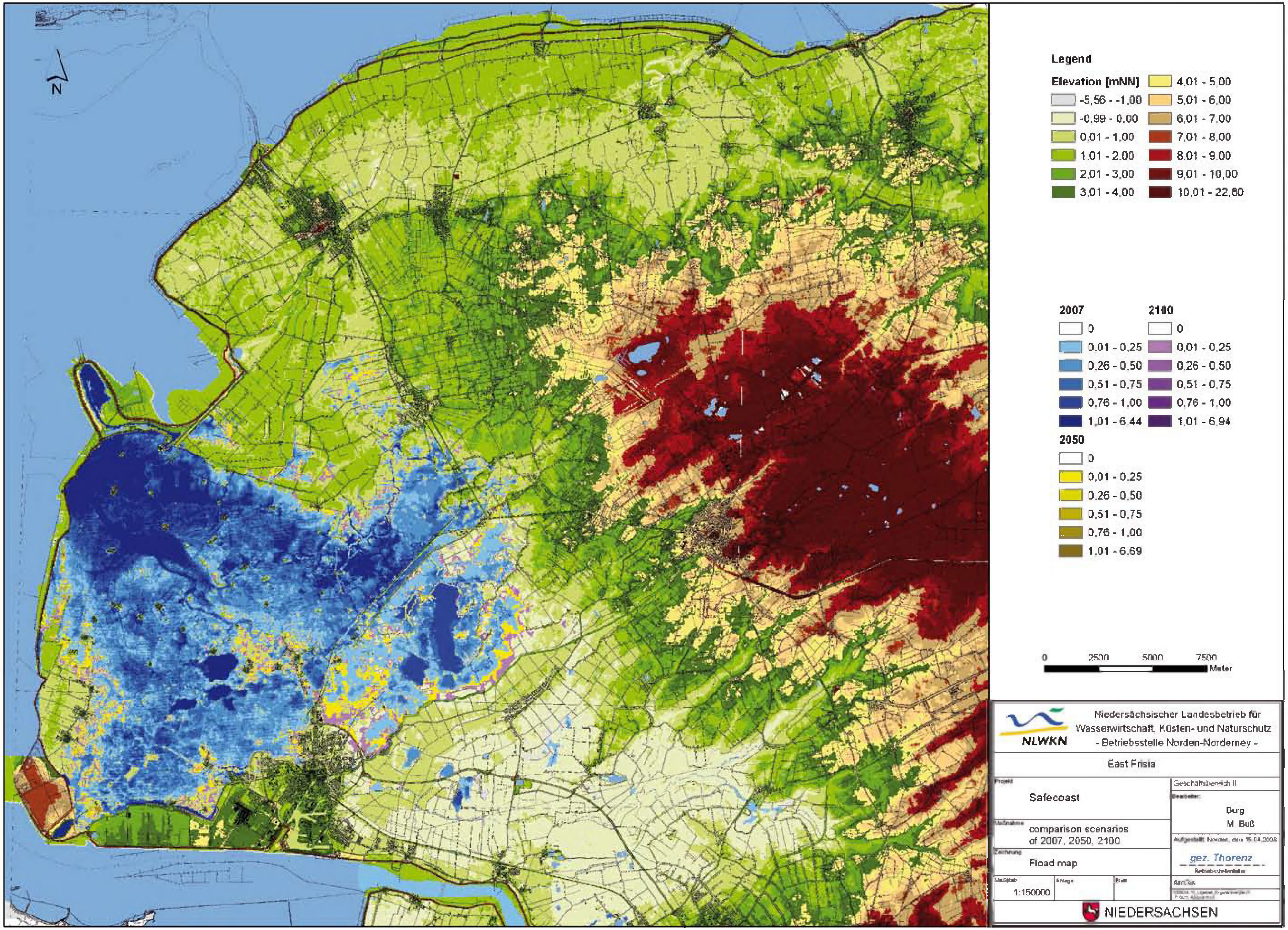


Additional coastal erosion by year 2050, Denmark

The Coastal Erosion Atlas of Denmark shows, at a macro-scale level, the potential for total additional erosion until year 2050 due to a climatic change related sea-level rise. The atlas may be used to get an overview of the rate of erosion that may occur in the future and where a sea-level rise in most cases will lead to an increase in coastal erosion. The map does not tell, however, if this erosion actually will occur, as this locally depends on the coastal processes as well as on the geomorphological and geological characteristics of the coast.

The atlas combines coastal types with wave energy levels at the coast but does not take into account whether a specific coastal stretch currently is undergoing erosion. Local investigations therefore must be undertaken in order to differentiate between zones that are liable to an increased erosion rate compared to today; areas that will experience erosion in the future, and areas that may experience growth from sediments eroded elsewhere. At the sand nourished parts of e.g. the North Sea coast, the potential for additional erosion may be transformed into an intensification of the nourishment schemes in the future.

Annex 3.8: Example of a flood simulation Lower Saxony



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