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COMRISK
COMMON STRATEGIES TO REDUCE THE RISK OF
STORM FLOODS IN COASTAL LOWLANDS

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GUEST EDITOR: DR. JACOBUS HOFSTEDE

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COMRISK
Common Strategies to Reduce the Risk of Storm Floods in Coastal Lowlands: an Introduction

JACOBUS HOFSTEDE

Summary

Storm surges present a major natural hazard in the North Sea region. In this region, coastal lowlands occupy an area of about 40,000 km². More than 16 million people live here, and major economic activities take place. Without appropriate defence measures these lowlands may become flooded during severe storm surges. In order to achieve a sharing of knowledge and a sustainable approach on coastal risk management, the North Sea Coastal Management Group decided in 2002 to initiate a transnational project: "COMRISK – common strategies to reduce the risk of storm floods in coastal lowlands". The project was co-financed by the European Union under its INTERREG IIIB programme for the North Sea region. This paper introduces the project that ran from July 2002 till June 2005 as an example of international co-operation of coastal risk management authorities.

Zusammenfassung

Sturmfluten stellen eine wesentliche Naturgefahr in der Nordseeregion dar. In den etwa 40.000 km² großen Küstenniederungen leben über 16 Millionen Menschen und sind viele wirtschaftliche Aktivitäten konzentriert. Ohne Küstenschutzmaßnahmen könnten die Niederungen bei jeder extremen Sturmflut überschwemmt werden. Im Jahre 2002 initiierte die „North Sea Coastal Managers Group" ein transnationales Projekt: „COMRISK – gemeinsame Strategien zur Reduzierung der Risiken von Sturmfluten in Küstenniederungen" mit dem Ziel, mittels einem Austausch von Erfahrungen und Erkenntnissen nachhaltige Verfahren für das Management von Küstenrisiken aufzuzeigen. Das Projekt wurde von der Europäischen Union im Rahmen des INTERREG IIIB Programms für die Nordseeregion kofinanziert. In diesem Beitrag wird das vom Juli 2002 bis Juni 2005 laufende Projekt als Beispiel für eine internationale Zusammenarbeit von Küstenschutzverwaltungen vorgestellt.

Contents

Keywords

Coast, risk management, flood defence, international cooperation, storm surges, INTERREG

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1. Introduction

Storm surges present a major natural hazard in the North Sea region (NSR). In this region, coastal lowlands occupy an area of about 40,000 km^2 (Fig. 1). More than 16 million people live here, and major economic activities take place. Without appropriate countermeasures, these lowlands may become flooded during severe storm surges. To prevent this, national Governments spend several hundred million Euros per year on coastal defence or, rather, coastal risk management in the NSR. In future, with an accelerating sea level rise and changes in storminess (IPCC, 2001), the necessary budget to maintain present safety standards might increase significantly (CPSL, 2001; Office of Science and Technology, 2004). Apart perhaps from Bangladesh, in no other region in the world the potential losses (lives and assets) resulting from storm surges or, rather, coastal flooding are higher. The fact that this is not so much "in the peoples mind" may result from the success of coastal risk management. The last catastrophic storm floods occurred in 1953 in the Netherlands and England, and in 1962 in Germany. In all, more than 2,400 people lost their lives. After these catastrophes, national governments undertook huge efforts to improve the safety standards, in the Netherlands by the so-called "Deltawerken". The risk of coastal flooding was significantly reduced, but still existent. For example, in Hamburg storm surge water levels of up to 0.8 m higher than in 1962 have been observed, but no major damage occurred. As a result, people feel safe in coastal lowlands and may be tempted to ignore the latent hazards.

In the year 1996, on the initiative of the Danish Kystdirektoratet, leading national and regional coastal risk management authorities in the Netherlands, Belgium, the UK, Ger-

Fig. 1: Coastal flood-prone areas (green) in the southern North Sea region (Source: JORISSEN et al., 2001)

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many and Denmark started an informal network, the North Sea Coastal Managers Group (NSCMG). Basic idea was an improved international co-operation and co-ordination of transnational issues on coastal risk management, including the economics of beach nourishment, the improvement of public awareness and EU-regulations. Later, topics like coastal risk management strategies, climate change and research in coastal engineering, were introduced. Each year, small national delegations of senior public officers and managers meet in one of the member states to discuss common issues. From these meetings it became clear that, in order to achieve a sharing of knowledge and a balanced approach, a more comprehensive co-operation about coastal risk management throughout the NSR is desired. On the basis of these considerations, the idea for a NSCMG project: "COMRISK – Common strategies to reduce the risk of storm floods in coastal lowlands" was born.

Under the Community Initiative Program INTERREG IIIB the European Union co-finances (with 50 %) transnational projects for specific regions like the North Sea region. Program targets for the NSR are, amongst others: (1) improved compatibility of spatial planning and strategies at transnational level, (2) increased transnational co-operation through networks and studies, and (3) strengthen the cohesion and identity of the NSR through common approaches. One of the themes, under which projects may run, is called: "Risk management strategies for coastal areas prone to disasters and natural threats and for the North Sea". Hence, INTERREG IIIB constituted an optimal umbrella for the NSCMG to organise the project.

2. The project

COMRISK was an INTERREG IIIB project that ran from July 2002 to June 2005 with a total budget of 1.84 million Euros (50 % co-financing by the EU, 50 % national matching funds). The project was conducted by a consortium of seven public coastal risk management authorities in the NSR: Coastal Defence Division of the Schleswig-Holstein State Ministry of the Interior (GER, lead partner), Lower Saxony Water Management, Coastal Defence and Nature Protection Agency (GER), Coastal Authority of the Danish Ministry of Transport (DK), Coastal Waterways Division of the Belgian Ministry of the Flemish Community, Waterways and Maritime Affairs (B), Rijkswaterstaat National Institute for Coastal and Marine Management of the Dutch Ministry of Transport, Public Works and Water Management (NL), Rijkswaterstaat Road and Hydraulic Engineering Division of the Dutch Ministry of Transport, Public Works and Water Management (NL), and Centre for Risk and Forecasting of the Environment Agency of England and Wales (UK).

The overall impact that COMRISK wants to achieve is ensuring a sustainable, harmonious and balanced development in the coastal lowlands of the NSR. For this, an adequate and sustainable coastal risk management is a prerequisite. Risk is a combination of the probability (or frequency) of occurrence of a defined hazard (e.g., a storm flood) and the magnitude of the consequences (e.g., casualties, damages to properties) of the occurrence. Thus, COMRISK aimed at improved coastal risk management through a transfer and evaluation of knowledge and methods as well as pilot studies. The project was divided into two main parts, the umbrella project and nine subprojects. The umbrella project focused on an exchange of experience and on the co-ordination and integration of the subprojects. It had the following objectives: (1) to bring together coastal risk management experts from administration, science and private companies from around the North Sea and beyond, (2) to exchange experiences and studies of good practise on coastal risk management, (3) to evaluate and further develop

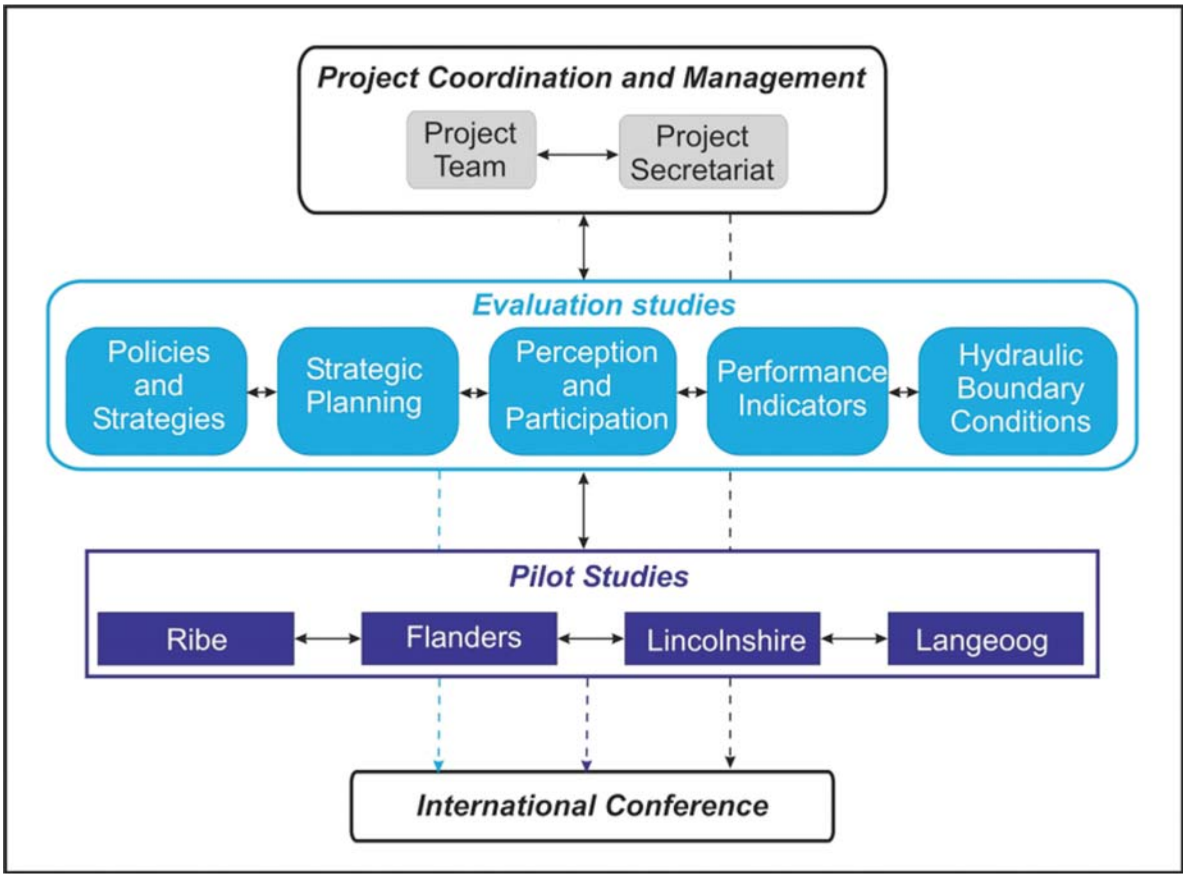

Fig. 2: COMRISK flow diagram

innovative integrated coastal risk management strategies, considering national regulations and responsibilities, (4) to initiate and support transnational co-operation on integrated coastal risk management (networking), and (5) to integrate coastal risk management into strategies for a sustainable management of the coastal zones in the North Sea Region (ICZM).

The project was divided into three phases. The first (starting-up) phase concentrated on the substantiation of the project structure (Fig. 2). During this phase, a project secretariat was established within the lead partners institute and a project manager: M. HAMANN (till December 2003), D. WITZKI (from April 2004) appointed. Further, a project team with representatives from the partner institutes was installed. It consisted of the following persons: T. VERWAEST (B), M. F. VAN NIELEN-KIEZEBRINK (NL), S. FRAIKIN (NL), A. WOLTERS (NL), C. LAUSTRUP (DK), T. PIONTKOWITZ (DK), I. MEADOWCROFT (UK), S. HAYMAN (UK), F. THORENZ (GER), H. BLUM (GER) and J. HOFSTEDE (GER, project leader). During the second (main) phase, the pilot and evaluation studies were conducted. Part of the work in these studies was carried out by subcontractors. In order to involve external experts as well as local authorities, 7 expert workshops were organised and 2 permanent contact groups established within pilot studies. Main activities during the last phase were the organisation of the final conference COMRISK2005 (see below), and the synthesis of the subprojects.

In all, about 30 organisations (partners, consultants, local administrations, etc.) were directly involved in the project. More than 40 individuals (project team, consultants and contact groups) actively contributed to the project outcomes, and about 150 more persons were involved through workshops, expert questionnaires, etc.

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2.1 The subprojects

The nine subprojects (five evaluation and four pilot studies, Fig. 2) contributed to the general project objectives (see above), each having one thematic or regional focus. The subprojects are described in detail in the following chapters of this volume. As an introduction, the main activities of the subprojects are described below.

In subproject one, the national and regional policies and strategies for coastal risk management were evaluated in terms of sustainability and with respect to their contexts. After an inventory of national policies and strategies, an evaluation in terms of their ability to promote a socio-economic and ecological sustainable development was conducted. The responsibility for this subproject is with the Rijkswaterstaat National Institute for Coastal and Marine Management of the Dutch Ministry of Transport, Public Works and Water Management.

Subproject two focused on common strategic planning tools for coastal risk management. On the basis of an inventory of non-technical strategic tools and techniques for planners and risk managers, an evaluation of different approaches taken in terms of their ability to answer the need of risk managers and strategic planners was conducted. The responsibility for this subproject is with the Centre for Risk and Forecasting of the Environment Agency of England and Wales.

In subproject three, a comparative assessment and evaluation of the present state of public perception and participation in coastal risk management in the participating countries was conducted. Further, a more general assessment and evaluation of methods for public participation in coastal risk management was carried out. The responsibility for this subproject is with the Coastal Defence Division of the Schleswig-Holstein State Ministry of the Interior.

In subproject four performance indicators for coastal risk management were investigated. After an inventory of currently applied technical and non-technical performance indicators in the NSR, an evaluation in terms of the ability of different approaches to answer the needs of risk managers and planners was carried out. The responsibility for this subproject lay is the Centre for Risk and Forecasting of the Environment Agency of England and Wales.

In subproject five, an inventory of presently applied hydraulic boundary conditions and safety standards (as a follow-up of an earlier NSCMG-study; JORISSEN *et al.*, 2001) was established. In a next step, for two case sites in the Netherlands, the different national and regional methods to achieve the hydraulic boundary conditions were tested. The responsibility for this subproject is with the Rijkswaterstaat Road and Hydraulic Engineering Division of the Dutch Ministry of Transport, Public Works and Water Management.

In the subprojects six, seven, eight and nine, state of the art risk analyses were conducted for several pilot areas (Flanders, Ribe, Lincshore and Langeoog) in the NSR. Based on integral inventories of physical and socio-economic conditions as well as existing coastal defence measures, risk assessments using newest techniques were carried out. The responsibility for these subprojects lay with the Coastal Waterways Division of the Belgian Ministry of the Flemish Community, Waterways and Maritime Affairs (Flanders), the Coastal Authority of the Danish Ministry of Transport (Ribe), the Centre for Risk and Forecasting of the Environment Agency of England and Wales (Lincshore), and the Lower Saxony Water Management, Coastal Defence and Nature Protection Agency (Langeoog).

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3. The final conference COMRISK2005

In April 2005, a three day international conference on coastal risk management "COMRISK2005" was organised in Kiel, Germany. The conference ran under the auspices of the North Sea Coastal Managers Group. In all, 85 representatives from science and administration participated in the conference (GER 37, NL 19, UK 11, B 9, DK 8, and USA 1). After welcoming addresses by the Schleswig-Holstein State Government, the North Sea Coastal Managers Group and the INTERREG IIIB Secretariat for the North Sea region, the conference theme was introduced to the audience in two key note presentations (see contributions OUMERACI and ALE in this volume). In six sessions, the results of the COMRISK subprojects were presented and discussed:

1) Hydraulic boundary conditions in the context of risk analysis
2) Risk analyses Flanders (B/NL) and Lincshore (UK).
3) Risk analyses Ribe (DK) and Langeoog (GER).
4) Managing coastal risk and performance.
5) Coastal risk perception and participation.
6) Coastal risk policies and strategies.

In two further sessions, researchers presented relevant project-external results. In a final session, several technical, managerial and policy level statements that were prepared by the organising COMRISK project team were presented and discussed (see contribution HOFSTEDE *et al*. in this volume). The conference ended with a boat excursion to the Probstei sea wall, the largest coastal risk management measure in the Baltic Sea.

Fig. 3: Discussion of project results during COMRISK2005

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4. Literature

CPSL: Final report of the trilateral working group on coastal protection and sea level rise. Wadden Sea Ecosystem, 13, Wilhelmshaven, 2001.

IPCC (Ed.): Climate Change 2001: Synthesis report – summary for policy makers. http://www.ipcc.ch, Geneva, 2001

JORISSEN, R., LITHJENS-VAN LOON, J. and LORENZO, A. M.: Flooding risk in coastal areas; an inventory of risks, safety levels and probabilistic techniques in five countries along the North Sea coast. Road and Hydraulic Engineering, Den Haag, 2001.

OFFICE OF SCIENCE AND TECHNOLOGY (Ed.): Foresight. Future Flooding, Executive Summary. www.foresight.gov.uk, London, 2004.

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Evaluation of Policies and Strategies for Coastal Risk Management COMRISK Subproject 1

MARINKA VAN NIELEN-KIEZEBRINK, JEROEN KLOOSTER

Summary

40.000 square kilometres in the southern North Sea Region is potentially affected by flooding. In this area 16 million people live and work. The governments of the countries involved manage this risk. Comparing them, both their actions and their goals have differences as well as similarities.

This paper presents the results of an evaluation study of policies and strategies in the countries bordering the southern North Sea.

For the assessment a comprehensive analytical framework is used. In the framework a distinction between context and policy is made. Policy largely depends on context elements such as the history of flooding, the cultural, socio-economic setting, institutional setting, public awareness. Within each country specific context there is however a certain degree of policy freedom. This implies that countries can learn from each other. The observed differences between the countries offer opportunities and challenges to exchange experiences and information. They might even adopt part of each other's policies, strategies, measures or instruments within the country specific context and could even lead to common strategies. Defining common strategies and policies does not necessarily have to lead to harmonisation of policies.

Although future harmonisation of policies and strategies should not be avoided when desirable and feasible, policy makers have to focus on further mutual understanding and mutual learning.

Zusammenfassung

40.000 Quadratkilometer in der südlichen Nordseeregion sind potentiell überflutungsgefährdet. In diesem Raum leben und arbeiten 16 Millionen Menschen. Die Regierungen der betroffenen Länder gehen mit diesem Risiko um. Einen Vergleich zeigt, dass ihre Maßnahmen und Ziele Ähnlichkeiten und Unterschiede aufweisen.

In diesem Beitrag werden die Resultate einer Evaluierungsstudie über die Politiken und Strategien in den Nordsee-Anrainerstaaten präsentiert.

Für die Untersuchung wurde ein umfassendes Analyseverfahren benutzt. Dieses Verfahren unterscheidet zwischen Kontext und Politik bzw. Strategie. Die Strategie ist zum größten Teil abhängig vom Kontext, zum Beispiel von der Überflutungsgeschichte, den kulturellen, sozialen, wirtschaftlichen und institutionellen Rahmen sowie dem Problembewusstsein. Innerhalb dieses Kontextes existiert jedoch ein gewisser politischer Handlungsspielraum. Somit können die Länder voneinander lernen. Die beobachteten Unterschiede zwischen den Ländern bieten Chancen und Herausforderungen für einen Austausch von Erfahrungen und Informationen. Dies könnte eine teilweise Übernahme von Strategien, Maßnahmen oder Instrumenten innerhalb des eigenen Kontextes beinhalten bis hin zu gemeinsamen Strategien. Gemeinsame Strategien und Politiken zu definieren muss nicht zwangsweise zu einer Harmonisierung der Politiken führen.

Obwohl künftige Harmonisierung von Politiken und Strategien nicht vermieden werden sollten wenn sie wünschenswert und machbar ist, sollte der Fokus auf dem Vorantreiben des gegenseitigen Verständnisses und dem Lernen voneinander liegen.

Keywords

Coast, risk management, flood defence, risk strategies

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Contents

1. Introduction

40.000 square kilometres in the southern North Sea Region is potentially affected by flooding (figure 1). In this area 16 million people live and work. The governments of the countries involved try to manage this risk. Both their actions and their goals have differences as well as similarities.

The concept of coastal flood risk management was derived from safety science theory (KIRWAN et al., 2002). Risk is a combination of the probability (or frequency) of occurrence of a defined hazard and the magnitude of the consequences of the occurrence. It is not necessarily a number.

Risk management is the process of implementing decisions about accepting or altering risk, based on an assessment of various costs and benefits. This also implies decisions about acceptable risk levels and appropriate measures.

In applying risk management to the field of coastal flood risk management the following steps are identified:

- Identification of the nature and extent of flood risks;
- Understanding and addressing the relevant public perceptions;
- Establishing goals and standards with respect to the flood risk;
- Establishing strategies and policies to achieve these goals;
- Finally minimizing the costs of achieving the goals, whilst ensuring the risk remains acceptable.

On behalf of the Rijkswaterstaat Dutch National Institute for Coastal and Marine Management / RIKZ, a consortium of KPMG Strategy Economics, Atos KPMG Consulting and TU Delft carried out an evaluation of policies and strategies for coastal risk management (KLOOSTER en VAN RAAK, 2004). This paper presents the results of this evaluation study.

For this evaluation the following specific objectives were formulated:

- An inventory of different levels (strategic, institutional, instrumental and operational) of coastal risk management in present national policies of the 5 countries in the North Sea region, involved in the COMRISK project.
- An assessment of the present national policies in terms of legal, social, technical, financial, socio-economic, ecological and managerial aspects (including the ICZM-principles for sustainability).

2. Methodology: context versus policies

The strategies and policies of the countries involved were identified, reviewed and compared within an analytical framework.

For the inventory national policy documents and a selection of documents of lower governments relevant to coastal, flood risk and water management were studied. In addition,

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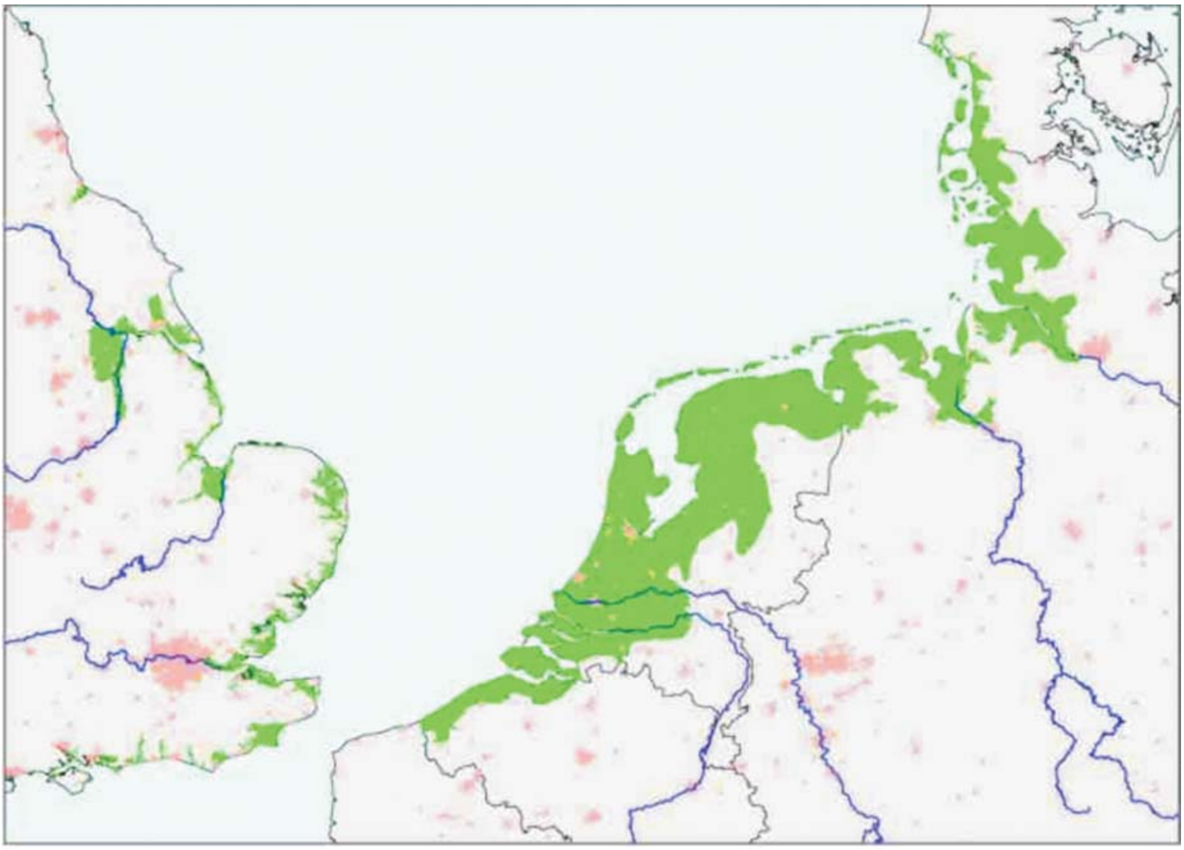

Fig. 1: Flood prone area in the North Sea region (source: JORISSEN et al., 2001)

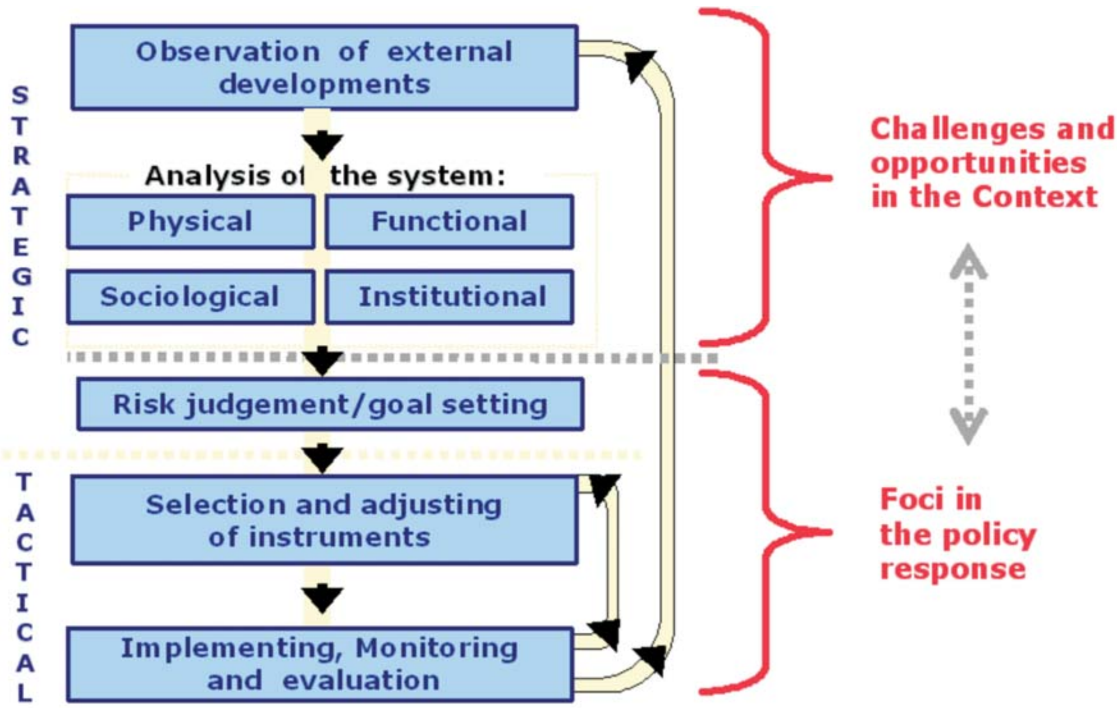

Fig. 2: Analytical framework

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earlier cross-country studies into North West European flood risk management and coastal management were studied. To fill specific information gaps and to find the motivation behind the policies, 25 interviews with coastal flood risk policy-makers and experts were held.

The analytical framework (figure 2) distinguishes between the *context* and *policy*. The *context* comprises the important challenges that governments in the regions face in relation to the management of the risk of flooding from the sea. Challenges can be threats to be confronted or avoided, but may also be opportunities to be explored and possibly exploited.

Governments develop *policies* to manage the risk of flooding within the country specific context but may not be able to influence the context directly. Depending on the socio-economic and socio-cultural setting, countries may adopt different forms of coastal risk management policies. For this reason we have refrained from taking one country as 'best practice' or to speak of *the* optimal coastal risk management process, as this will differ from country to country, to fit the particular context.

The key focal points within a policy can, however, be indicated. For this purpose the ICZM-criteria as formulated by the European Commission are used as a startingpoint. These principles offer various ways of good coastal zone management. The EU-ICZM principles however are formulated at quite a high and abstract level. Furthermore they relate to both the institutional structure and to the policy of coastal management. To make the ICZM principles more concrete, they are translated to possible focus points for coastal risk management.

The results of the assessments are discussed in the following sections and summarized in table 1, 2 and 3. The challenges in context and focuses in policies are indicated with dots in table 1 and 2. A black dot indicates a major challenge or focus and an open dot indicates significant challenges or focuses.

3. Challenges in the context

The challenges experienced by the governmensts in the 5 North Sea countries in relation to the risks of flooding from the sea are summarized in table 1.

All countries regard climate change and the corresponding sea level rise as major challenge (table 1). Keeping this in mind, the Dutch physical context is both in absolute and relative terms the most challenging, although it has some protective dunes, it has the largest and deepest floodprone areas (polders) of all countries. To make things even more urgent the Netherlands major cities are situated in flood-prone areas. The German coastline offers the least natural protection, but the hinterland has much smaller and less deep floodprone areas. The major city of Hamburg is partly situated in one of them. Also London is partially located in one of Englands floodprone areas. Development pressure is a major issue for the Netherlands and England, but less so in the other countries.

Ecological regulation is a complicating factor to policy-making, but in most cases not regarded as a major challenge to the existing policy. Policymakers in almost all regions are confronted with sensitive natural habitats at their coast, which brings limitations and conditions to coastal defences.

The common challenge for policy-makers in England, Flanders, the Netherlands and to a lesser extent Niedersachsen, is to raise the sense of urgency among their citizens to make them either support governmental action or take action themselves. In Schleswig-Holstein, citizens are also noted not to be very aware of the risk of flooding, but this has not lead to practical difficulties in implementing policy. Hamburg and Denmark in general feel that the demand and support for action is about right.

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Table 1: Challenges in the context

	England	Flanders	Nether-lands	Nieder-sachsen	Hamburg	Schlesw. Holstein	Den-mark
Challenges from external developments							
Relative sea level rise	●	●	●	●	●	●	●
Ecological regulation	○	○	○	○	○	○	○
Pressure for development	●	○	●		○		
Physical opportunities and threats							
Large amount of flood-prone area	○	○	●	○	○	○	
Deep flood-prone areas	○	○	●	○	○	○	
Natural coastline offers little protection	○		○	●		●	○
Challenges from the socio-economic functions							
Major cities threatened	○	○	●		○		
Designated nature areas	○	○	○	○	○	○	○
Challenges from societal perceptions							
Low sense of urgency citizens	○	●	●	○		*	
Challenges from the institutional context							
Limited staff capacity		●					
Limited budget	●	○	○	○	○	○	○
Limited relation to disaster management policy		○	*				
Limited relation to spatial planning policy		○	○				
Limited vertical integration	**		○				

● Major challenge ○ Challenge
* Limited relation, but not regarded as a problem;
** According to the local level, there is a policy vacuum

Limited budgets is a common challenge for policy makers in all countries. The challenge of integrating of policy across different fields and at different scales, is more ambiguous. In some cases policy integration is not strong, but often the primary policy-makers do not consider this as a major problem. The vertical integration in England has improved according to all interviewees, however at the local level a 'national policy vacuum' was reported by some.

4. Focus points in policies and strategies

Different countries focus on different aspects of policies and strategies in order to manage the risks of coastal flooding. These 'focus points' are summarized in table 2. The potential focus points are derived from the ICZM criteria. In some respects they also relate to the organisation of flood risk management.

With respect to goal-setting, England and the Netherlands have a multi-generation time horizon in common. Both countries have explored the long-term demands for coastal pro-

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Table 2: Focus points policies and strategies

	England	Flanders	Netherlands	Nieder sachsen	Hamburg	Schlesw. Holstein	Denmark
Goal-setting							
Taking into account the needs of many generations	●		●				
Economical costs and benefits taken into account	●		○	○	○	○	○
Ecological carrying capacity taken into account	●	○	○	○	○	○	○
Focus points in measures							
Allowing dynamics	●	○	○				○
Allowance of local tailor-made solutions	●	●	●		○		●
Variety of measures	●				○		●
Variety of methods to achieve measures	●		○		○		●
Monitoring and evaluation							
Performance monitoring of measures	○	●	●	●	●	●	●
Reconsideration at strategic level	●	○	○				

● Major focus ○ Some focus

tection. The other countries generally have limited themselves to study how – in the long run – the current level of protection could be maintained.

England has a strong focus on costs and benefits; for every project a benefit/cost ratio is calculated. In the Netherlands and Denmark current safety standards were set decades ago with much consideration to costs and benefits. These are currently being updated. Hamburg and Niedersachsen (in the Weser-Ems region) take some account of potential damages. However, since the dike design regulation does not allow for variable protection levels, this aspect cannot be directly incorporated in decision-making. Schleswig-Holstein however has incorporated this type of information in setting priorities in implementation of measures: locations with highest monetary or other value are first on the list. The way the ecological carrying capacity is taken into account is quite similar in all countries, as EU law regulates matters such as the Environmental Impact Assessments and the protection of habitats.

The allowance of dynamics of the coast is very much connected to erosion policy, which is outside the scope of this study. England allows largely for dynamics, including the setting back of dike lines. In Flanders, the Netherlands, Niedersachsen (for the islands) and Denmark some dynamics are allowed, though in general the currently protected areas will remain protected. In Germany a retreat policy for the main land might be followed in exceptional cases.

England has permissive legislation, like Denmark. National governments in these countries have the right to fund measures, if budgets allow, and if justified. They also give policy and procedural guidance to lower governments and operating authorities. However there is no legal duty to take action. Denmark and England thus place much emphasis on the initiative and freedom of the counties and boards, whereas the Niedersachsen high level policy is strictly prescribing and local policy-making is limited. The Schleswig-Holstein high level po-

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licy-maker leaves freedom to the water boards with regard to the secondary dikes. Hamburg is itself practically a local authority and also leaves freedom to industry areas to arrange their own protection measures. In the Netherlands and Flanders standards are set at the central level. However local 'tailoring' is receiving more and more attention. Alternatives to reach the safety standard are discussed with local communities and municipalities. The difference in the role of authorities in England and the Netherlands is well illustrated with fig. 2.

As pointed out, England, Denmark and to some lesser extent Hamburg use a variety of measures to manage the risk of flooding from the sea (see also table 3). Besides coastal protection these authorities also take acount of the possible consequences of flooding more explicitly than Flanders, the Netherlands and the other German states, which concentrate mostly on coastal defence. The Netherlands, though focused on coastal defence, is also more and more searching for more holistic approaches to managing coastal risks.

With respect to monitoring and evaluation all countries try to improve their actions by learning about their performance. However, only few countries are reconsidering their general set of goals and measures or have done so recently (England, Flanders and the Netherlands).

Fig. 3: Differences in the role of authorities in the Netherlands and England in relation to flood risk management as illustrated by public communications

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Table 3: Selection of instruments with respect to point of intervention.

Point of intervention	Instruments		England	Flanders	Netherlands	Niedersachsen	Hamburg	Schlesw.-Holstein	Denmark
Reduction of probability of flooding	Coastal flood protection	Primary sea defences	●	⬤	⬤	⬤	⬤	⬤	⬤
		Secondary sea defences			·	•	•	●	·
		Prepare for emergency strengthening	•	·	•	•	●	•	
Reduction of consequences of flooding	Avoid development in flood prone areas*		⬤		•	•	•	•	·
	Flood resistant building		●				·	·	•
	Crisis management	Forecasting and warning	⬤	●	●	●	⬤	●	⬤
		Evacuation and rescue operations	●	·	•	•	⬤	•	⬤
	Recovery	Prepare to restore land and infrastructure	•						•
Compensation		Redistribution of costs or damages	●	•	·	·	·	·	●

· Used limited, considered unimportant; • Used, considered of some importance

● Used, considered important; ⬤ Used, considered crucial

*) The Netherlands, Schleswig-Holstein, Niedersachsen en Flanders only have restrictions for building in the first (or first few) 100 m of dunes. Denmark applies a wider zone, related tot protection of the landscape.

5. Conclusions and recommendations

The concept of flood risk management – optimizing both the probablities and the consequences of flooding – is emerging in all five countries in the North Sea region, although in some countries more pronounced than others. In England and Denmark governments have chosen more points for intervention than for instance in the Netherlands and Germany, where focus is mainly on prevention of flooding. The actual translation of the concept of risk management into formalized policies and strategies has not happened in all countries and might face some serious obstacles. For example in Germany, where according to national regulations, every inhabitant has the right to the same level of protection against flooding. Harmonization on all aspects of coastal flood risk management does not seem to be feasable due to the differences in the contexts and approaches in the five countries, which are in some cases (the Netherlands, Germany) even laid down in national legislation. Definition of a common strategy however does not have to mean harmonization of policies. Although future harmonisation of policies and strategies should not be avoided when desirable and feasible,

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at the moment it is more appropoiate to focus on further mutual understanding and mutual learning. Elements that seem especially interesting in this respect include: public awareness in relation to responsibility of acting (government versus 'self acting' of individuals), insurance versus compensation, evacuation and crisis management.

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Strategic Planning in Coastal Risk Management COMRISK Subproject 2

Paul Sayers, Ian Meadowcroft

Summary

Strategic planning describes the planning framework to translate policy aims into practical decisions. The planning framework needs to reflect the policy in each case, so frameworks will differ. But there will also be common principles and common elements. Sub-project 2 in COMRISK aimed to understand the process of strategic planning, to explore how it can support flood risk assessment and management, and to identify common elements of strategic planning – and contrasting approaches – in North Sea coastal countries.

We identified the following elements in a risk-based strategic planning process: problem formulation; flood risk analysis; options generation and decision-making; implementation; and monitoring and review. The objectives for the plan will normally be determined by the policy aims (SP1) and through participative processes (SP3). Flood risk analysis will draw on analysis of the hydraulic boundary conditions (SP5). The 'options selection' and 'monitoring and review' stages will need to take account of the performance of risk management measures (SP4).

Finally, as in SP1, we note the importance of context in determining the best form of strategic planning. We find that the benefits are greatest where there are complex extensive flood plains and flood defence systems, where long term planning is needed, and where the solutions are potentially complex, relying on a suite of complementary risk management measures such as flood defence, warning and land use planning. In these circumstances a structured approach to strategic planning will have significant benefits in terms of flood risk management.

Zusammenfassung

Strategische Planung beschreibt den Rahmen für die Umsetzung der politischen Ziele in praktische Entscheidungen. Dieses Rahmenwerk soll die jeweilige Strategie reflektieren, weshalb sie unterschiedlich ausfallen werden. Andererseits werden gemeinsame Prinzipien und Elemente existieren. COMRISK Teilprojekt 2 zielte darauf ab, den strategischen Planungsprozess zu verstehen, zu untersuchen wie es Flutrisikomanagement unterstützen kann, und gemeinsame Elemente sowie unterschiedliche Ansätze in der strategischen Planung in den Nordsee-Anrainerstaaten zu identifizieren.

Die folgenden Elemente in einem risikobasierten Planungsprozess wurden ermittelt: Problemstellung; Flutrisikoanalyse; Variantenerstellung und Entscheidungsfindung; Umsetzung; Überwachung und Prüfung. Die Ziele eines Planes werden normalerweise bestimmt durch die politischen Ziele (Teilprojekt 1) und durch Beteiligungsverfahren (Teilprojekt 3). Die Elemente „Variantenauswahl" und „Überwachung und Prüfung" müssen die Leistung der Maßnahmen zum Risikomanagement berücksichtigen (Teilprojekt 4).

Letztendlich wird, wie in Teilprojekt 1, die Bedeutung des jeweiligen Kontexts bei der Ermittlung der optimalen strategischen Planung betont. Es wird gefolgert, dass die Vorteile der strategischen Planung dort am Größten sind, wo großräumige und komplexe Küstenniederungen betroffen sind die langfristige Planung benötigen und wo die Lösungen relativ komplex ausfallen werden (bestehend aus einem Mix von komplementäre Lösungen wie Hochwasserschutz, Flutwarnung und Raumplanung). In diesen Fällen wird ein strukturierter Ansatz wie strategische Planung signifikante Vorteile bezüglich eines Flutrisikomanagements aufweisen.

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Keywords

Coast, risk management, flood defence, strategic planning

Contents

1. Strategic planning as part of COMRISK

Strategic planning is the process for defining how policy aims are translated into action. Policy is produced with the intention of reducing undesirable outcomes and promoting desirable ones. Often, however, this is not straightforward reflecting the complexity of the flood system and the need to appraise and implement both structural and non-structural options in a logical manner. Particular difficulties arise when:

- problems are of a large-scale and solutions of a long-term nature are involved;
- works need to be implemented, monitored and adapted over a long time scale;
- there are process connections and interactions between different areas and options;
- the relationships between cause and effect is complex involving interconnected benefit areas and environment, social and economic impacts.

The process of strategic planning must therefore facilitate:

- the integration of short and long term actions
- the structured implementation of a combination of actions
- the translation of **Policy** to **practice**.

To develop an optimum ‚mix' of risk management measures and policies requires a good understanding of present and future risks; spatial distribution of flood risk, natural and man-made pressure on flood risk, and appraisal of flood risk management measures within a context of coastal zone and spatial planning policies.

The term 'strategic planning' is therefore used to mean the co-ordinated analysis, planning and decision-making to achieve flood management policy objectives.

2. Aims and outputs of sub-project 2

The subproject has the following specific objectives:

- To provide a non-technical overview of the strategic tools and techniques for planners and risk managers in each partner country.
- To evaluate these approaches in terms of their ability to answer the needs of managers and strategic planners.
- Provide recommendations to improve cross-border dissemination and application of common strategic and spatial planning methods.

A consultation workshop for sub-project 2 was held in Den Hague in the Netherlands at the offices of RIKZ on 17th and 18th of February 2004.

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Fig. 1: Workshop attendees – A site visit to a dune system in the Netherlands

The Workshop programme also included a visit to a number of flood defence structures, and areas where flood risk management poses particular challenges in the Netherlands. These provided excellent examples of the challenges and solutions to flood risk problems, and prompted much discussion.

Finally findings from the workshop and next steps were discussed and summarised.

3. An introduction to strategic planning

As outlined in Section 1, strategic planning the co-ordinated process of analysis, planning and decision-making to achieve flood management policy objectives. All of the partner countries, to some extent, have policies regarding the standard and sustainability of flood defences, flood warning systems and evacuation plans for areas with significant flood risk. Once policy has been established there is a range of different methods though which it can be implemented. The emphasis that each partner countries places on a particular option varies according their approach to risk and their perception of risk. Strategic planning is the process by which these various actions are identified, analysed and selected.

Planning relates to a specific spatial unit i.e. to a particular length of coastline and flood cell. It may include some or all of the following stages:

- **Problem formulation:** Establishing the policy aims, identifying the flood defence problem, establishing the spatial / temporal scale for the analysis. Key linkages in COMRISK: SP1 (Policies and Strategies)
- **Flood risk analysis:** Assessing flood risk for the present day, and in the future, generally including hazard identification, assessing probabilities and consequences of flooding, and presentation / communication of risk. Key linkages in COMRISK: SP4 (Performance Indicators), SP5 (Hydraulic Boundary Conditions)

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- **Options generation and appraisal, and decision-making:** Identifying options for future risk management, and assessing these options against specific criteria (including policy aims). Key linkages in COMRISK: SP1 (Policies and Strategies), SP3 (Perception and Participation).
- **Implementation (e.g. carrying out the flood management plan):** This may include conducting more detailed analysis, or improving or managing flood defences, developing flood warning and forecasting systems and communication with stakeholders. Key linkages in COMRISK: SP3 (Perception and Participation) and SP5 (Hydraulic Boundary Conditions)
- **Monitoring and review:** Evaluating the outcome in terms of risk reduction (usually using performance indicators). Key linkages in COMRISK: SP4 (Performance Indicators) and SP1 (Policies and Strategies)

This process is cyclic. The results of the monitoring / review feed back to refine and, if necessary, revise the problem formulation stage. The framework is also 'hierarchical'. For example, large scale plans may be made to establish the strategic aims for a length of coast, while more detailed plans for strategies and schemes will be made to realise those aims. Some stages will be more highly developed than others and this will differ between countries.

Once drafted a Strategy Plan provides broader benefit than simple a programme of actions. It also provides an effective framework for wide consultation in relation to the key flood and coastal defence issues for the study area. In turn, this enables the ownership of both problems and opportunities to be shared amongst all stakeholders (with a legitimate interest in these issues) facilitating the emergence of common goals.

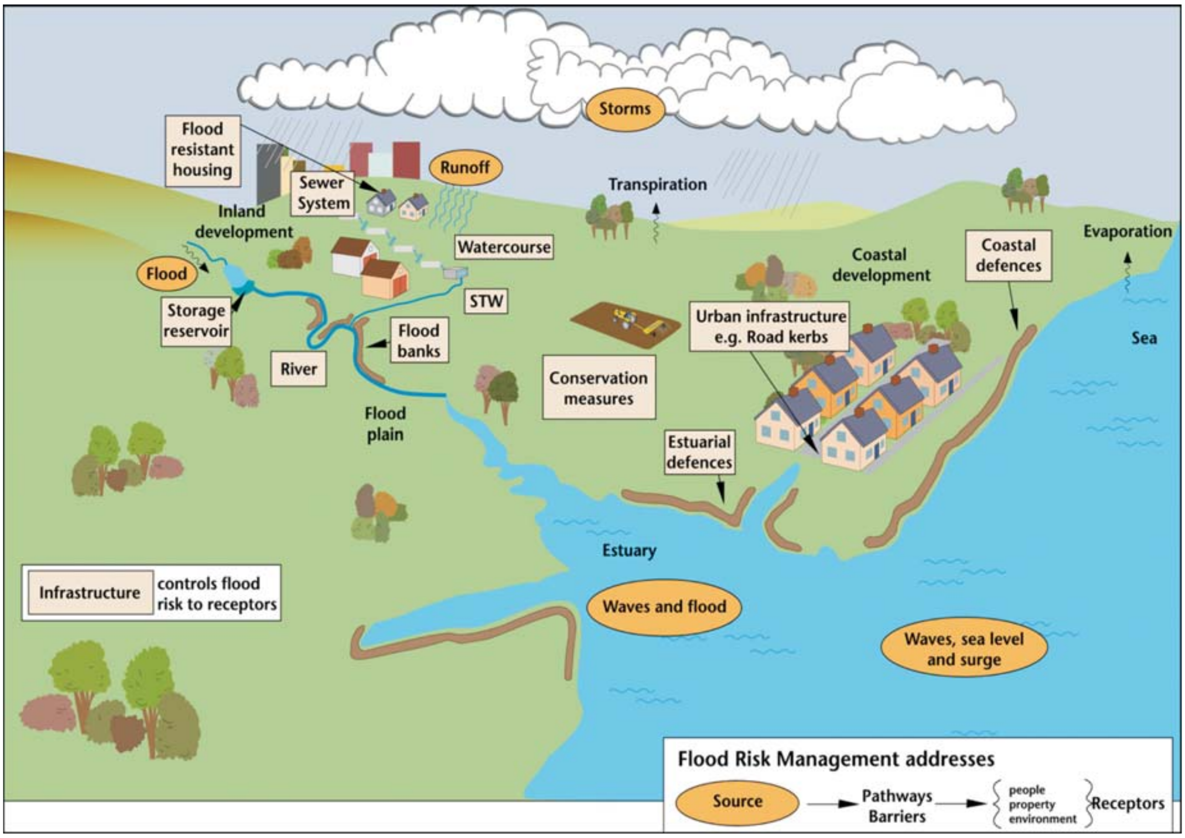

Fig. 2: The flooding system

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Strategic planning is about making choices and managing change in a structured way. Good management of flood risk requires many decisions to be made, often based on conflicting aims. For example, across all partner countries the flooding systems are complex and can be characterised as a variety of interacting elements and processes (see Fig. 2 and 3). Satisfying flood management objectives, alongside other social, economic and environmental aims, requires careful planning and Sub-Project 2 has been mainly concerned with the methods for achieving this.

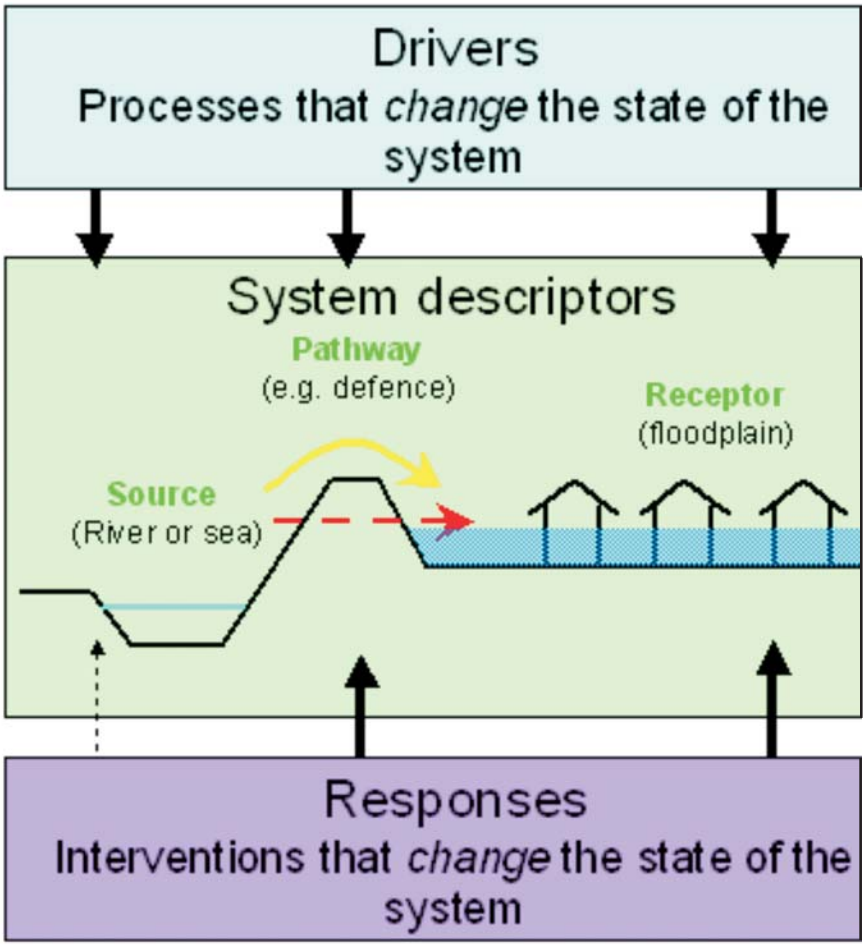

Fig. 3: The flood management system is continually modified by drivers and responses. Strategic planning aims to understand how these affect the flood risk in order to make better decisions to manage the risk

4. Strategic planning in the partner counties

Each partner country has adopted a particular approach to strategic planning for managing coastal flood risks. These different approaches are outlined in the sections below.

Belgium

Belgium has 65 km of coastline. The coastal lowlands of Belgium are focused in Flanders and are interconnected with the Dutch Region of Zeeuws-Vlaanderen. As such the floodplain behaves as a single flood cell, where if a defence breaches in either the Netherlands or Belgium significant inundation can be expected in both countries.

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Although sharing a common floodplain the responsibilities for coastal defence are divided between Belgium and the Netherlands at their respective national boundaries. Both countries have slightly different approaches to coastal management and notions of acceptable risks (translated through to a so-called safety standard).

Historically, a *resistance* based approach has been adopted. This has led to a focus on strengthening the flood and coastal defences themselves with direct translation of policy to action with only limited "strategic planning". For example, the main actions have been to:

- Strengthen the existing flood defences through a programme of raising and widening – prioritised according to structural reliability using methods developed in The Netherlands. The target safety standard was fixed at 1:1000 year return period.
- To "fix" the coastline at a pre-defined location and prevent through active intervention retreat – managed through monitoring (including yearly surveys using laser altimetry) and direct local action.

Previous strategic assessments identified many weak links in the defences; with sea dykes being too low in places and being of uncertain condition. Recent assessments found that, although the natural beach/dune systems generally performed well in terms of strength and height problems arose however, where infrastructure had been built directly within the beach/dune system. In terms of position, a comparison of detailed Digital Terrain Models (DTM) over a 20 year time period have been used to identify the extent of dune erosion. This analysis has highlighted significant losses.

Determining action based on these results has been difficult. In particular, there is a complex relationship between the flood defence needs and the broader process of planning via the Master Plan, including a lengthy process of Environmental Impact Assessment, building permits and other licenses. The 'Master Plan' should consider and evaluates not only flooding risks but different perspectives (e.g. ecology and tourism) and involves not only flooding experts but other administrations.

Following a major storm in 1990, a Strategic Investment Plan was developed to improve the defences and improve safety against flooding. The Strategic Investment Plan was designed mainly to guide coastal flood risk managers, prescribing a detailed set of actions both in regard to policies and specific defence schemes. It included a requirement for new schemes to allow for 30cm sea level rise due to climate change.

In the future Master Plans, the provision of new defences is likely to form only part of a broader strategy to manage future flood risk. This is likely to include contingency plans; flood warning systems; insurance systems; spatial planning decisions (relocation of activities, differentiation of safety standard); education and preparation of the public in addition to defence improvements.

The future aim is to continue to address flood risk issues in a more strategic and holistic way. Interestingly the broadening of goals and the move to flood risk management rather than flood defence is led by the civil engineers responsible for flood risk management. Budgetary constraints require a more flexible approach at a time when environmental and biodiversity objectives are coming to the fore in the general move to Integrated Coastal Zone Management (ICZM).

Netherlands – Overview of the present approach

After the severe flooding in 1953, the Delta commission initiated the development of an engineering led approach to flood management with an emphasis on the resistance of engineered defences. The required resistance of the defences was expressed through a 'safety standard' which in turn was enshrined in law. The current standards are shown in Fig. 4.

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In addition to setting safety standards, the law requires that the reliability of flood protection structures are reviewed about every 5 years (lower circle in the Figure 5). Recently a first round of assessment of the flood defences was performed. For the flood defences that did not perform adequately, plans are being made to improve them.

When works are carried out, the ability to adapt the defence in face of a climate change is built in. In particular, it is expected and accepted that the defence will need to be increased in height and width in the future and reservation of space for future adoption of the defence is enshrined within the spatial definitions of the defences.

The national budget for coastal defences is reviewed every year. Prioritisation of expenditure is based first on the safety case and then on consideration of the magnitude of possible (not probability of) consequences - represented by the capital value of assets in flood prone areas.

The reassessment of the potential impact of social, economic and technological developments on the flood risk in terms of expected damages or casualties would ideally take place about every 50 years (upper circle in Fig. 5). In response to this requirement, new methodologies are being developed that express safety levels in terms of a 'risk' i.e. taking account of both probability and consequences.

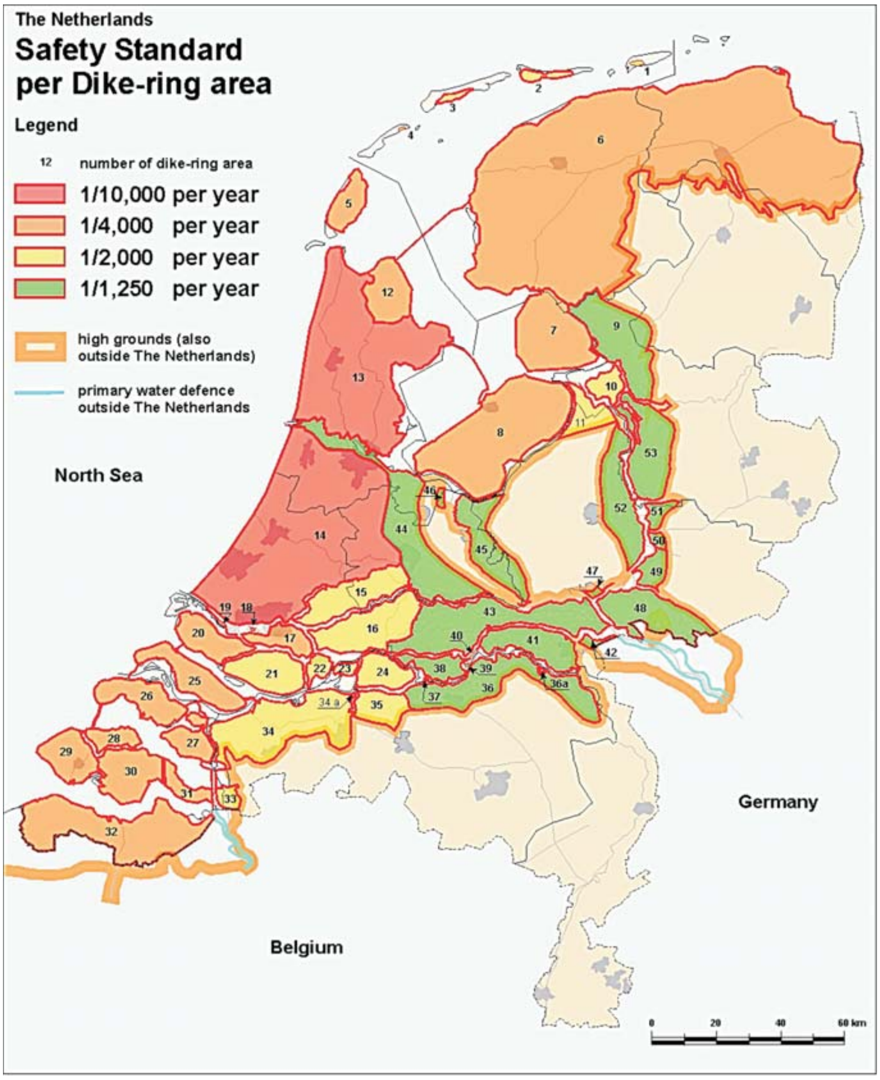

Fig. 4: Current safety standards in the Netherlands

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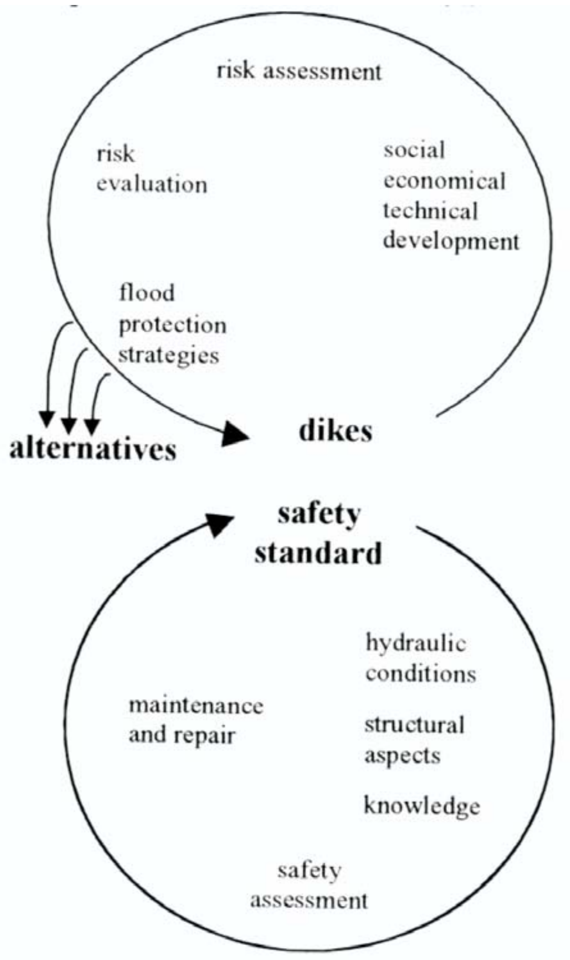

Fig. 5: Strategic planning process in the Netherlands

The new approach is being developed under a project entitled FLORIS commissioned by client the Netherlands Directorate General for water. Rijkswaterstaat is co-ordinating the project in close co-operation with the waterboards and provinces. The project has the following main goals:

- The assessment of the actual flood risk safety situation for the whole of the Netherlands by determining the *probability of flooding* associated with each of the 53 main dike rings which make up the country. Special attention is being paid to structures that have been identified as being weak spots in previous studies.
- The identification of the actual *weak spots* in the flood defence infrastructure.
- The assessment of the *consequences* of flooding and hence the determination of flood risk (probability x consequence), with a clear view on the uncertainties associated with this assessment.

Following the analysis of the flood risks, the FLORIS Project is also tasked with evaluating the physical measures required to improve the identified weak spots and determining the associated revised (reduced) probability of flooding for the relevant dike ring.

England and Wales

Three different scales of studies provide a framework for strategic planning in the UK (Fig. 5). At the broadest scale the UK coastline has been split up into 11 sediment cells and

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a series of sub-cells. Within each sediment cell longshore processes are largely considered self-contained.

The development of plans based on sediment cells signalled: a move away from administrative boundaries to process boundaries; a move towards regional management and shared responsibilities, and a recognition of the wider demands on the coastal zone.

The strategic planning process starts with the development of a Shoreline Management Plan (SMP) that are each between 50 and 150 Kilometres long and combine multiple local authorities and interested stakeholders through a series of Coastal Groups. Forty-nine have been completed so far. These studies consider time horizons of 20, 50 and 100 years and develop management policy identifying one of four policies of each Management Unit. The available policies are:

- Do nothing
- Hold the line
- Advance the line
- Retreat the line.

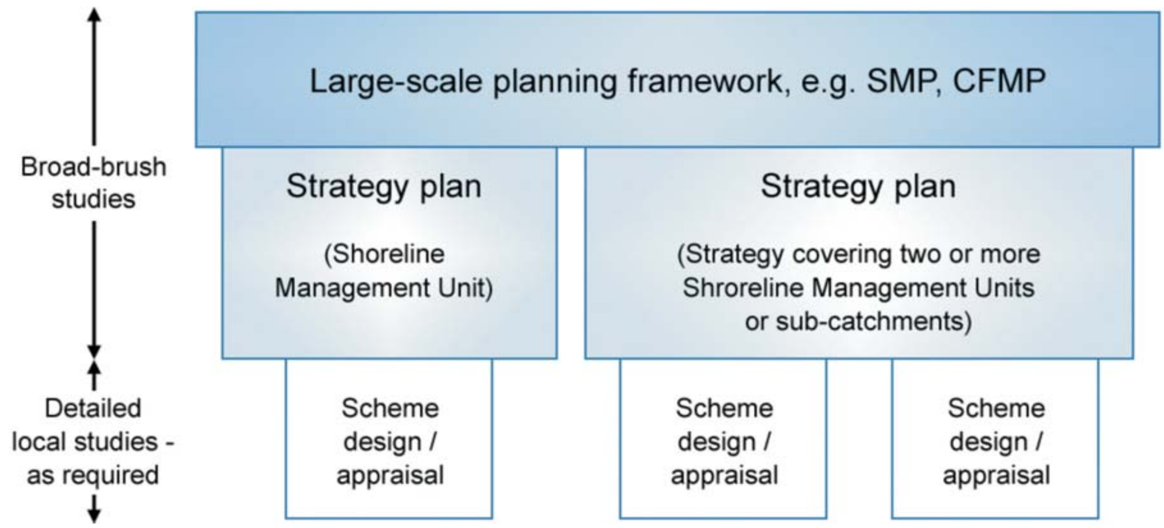

Fig. 6: Hierarchy of management plans in England and Wales

As shown in Fig. 6, Strategy Plans flow from the SMP process. These more detailed include more local analysis of defence performance, flood risk and the preferred programme of intervention options. As necessary local management plans are then developed to implement preferred options identified at higher levels.

The regional Shoreline Management Plans (SMP) and more local Strategy Plans are updated on a rolling five year programme. The results of the SMPs and Strategy studies are supplemented by national reviews of needs through bi-yearly review of budgets and flood risks by Defra as part of the UK Governments Comprehensive Spending Review.

The recently completed Foresight Flood and Coastal Defence study has taken a long-term look into the future in an attempt to inform policy direction and promote sustainable development.

The Foresight project produced a long-term (30–100 year) vision for the future of UK flood and coastal defence which is robust against a range of possible futures and can be used

as a basis to inform policy, and its delivery. This vision is challenging and independent and relies upon an integrated portfolio of measures and actions covering:
- Managing the rural landscape (e.g. run-off)
- Managing the urban fabric (e.g. sewer networks)
- Managing flood events (e.g. emergency responses)
- Managing flood losses (e.g. resilient buildings)
- Engineering and other large scale interventions.

Germany – Overview of Present Approach

In German North Sea coastal regions, significant coastal flood prone areas exist (as illustrated in Fig. 8).

The approach to flood management varies between the regional governments. However all adopt a Master Planning approach covering all coastal flood and defence issues as the primary strategic planning document. In Schleswig-Holstein, for example, within the Master Plan the 10 most important issues are identified and actions discussed. In the case of flood defences, the actions undertaken reinforce the underpinning management paradigm of improving / maintaining the resistance afforded by the defences.

For example, in Lower Saxony the present approach to strategic planning is described in the Lower Saxony Dike Act and within the Master Plans for Coastal Defence for the districts of Weser-Ems from 1997 and Lower Saxony from 1973 (see www.nlwkn.de/ (Home/Wasserwirtschaft/Küstenschutz/ Generalplan Küstenschutz), in Krause (1999) and Thorenz et al. (2004).

As in the Netherlands there is a defined procedure for maintaining and improving dykes. According to the State Water Acts the flood and coastal defences must be inspected at least

Fig. 7: Flood prone coastal lowlands along the North Sea coast of Germany

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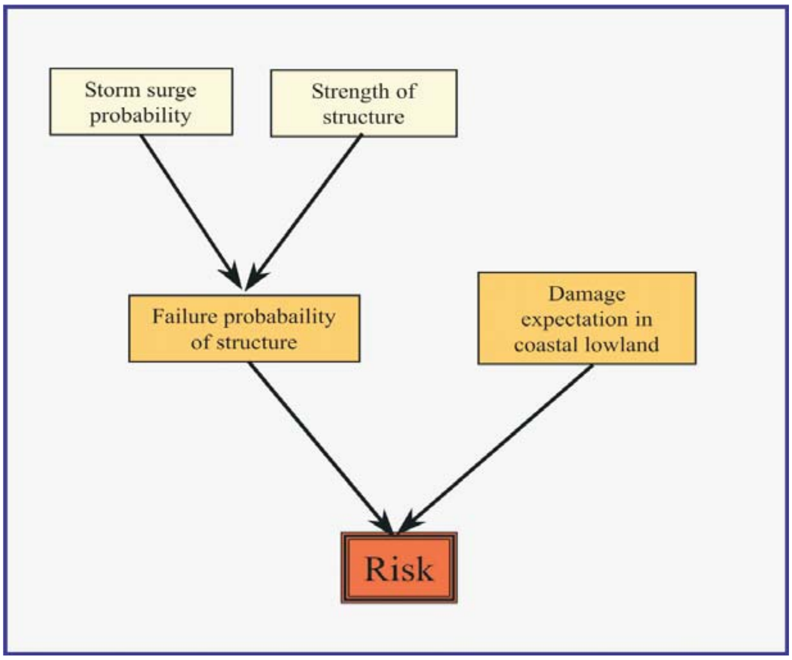

Fig. 8: Possible risk based management approach to flooding

once a year and once in 10 to 20 years detailed safety assessments should be carried out (the actual timing varies between States)

When works are carried out the ability to adapt the defence in face of a climate change is built in. In particular, it is expected and accepted that the defence will need to be increased in height in the future and adequate space is enshrined within the Master Plan to allow the dyke footprint to be expanded. For Lower Saxony, this regulation is laid down in the Lower Saxony Dike Act and a strip of land 50m wide is allocated to future dike widening.

The national budget for coastal defences is reviewed every year. Prioritisation of expenditure is based first on the safety case.

A new approach is under development, incorporating both probability and magnitude of damage (Fig. 8), although at present this is part of ongoing research and development and not implemented.

Denmark – Overview of current practice

Denmark has approx. 7,300km of coastline divided into 4 geomorphologic cells (as shown in fig. 9). The 7 administrative areas do not coincide with these and relate to more traditional governance boundaries. Flood prone areas in Denmark are protected by some 70km of dykes.

The policy background to the process of strategic planning is enshrined within the Coastal Protection Act that allows coastal protection where necessary, but promotes natural processes where possible. In particular:

- coastal/flood protection can be allowed only where significant assets are at stake
- nature preservation is of high priority especially the maintenance of natural coastal dynamics
- if old coastal/flood protection works are refurbished, the work must be minimal and redundant protection removed
- coastal/flood protection works must be technically optimised and fitted into the existing environment in a discreet way.

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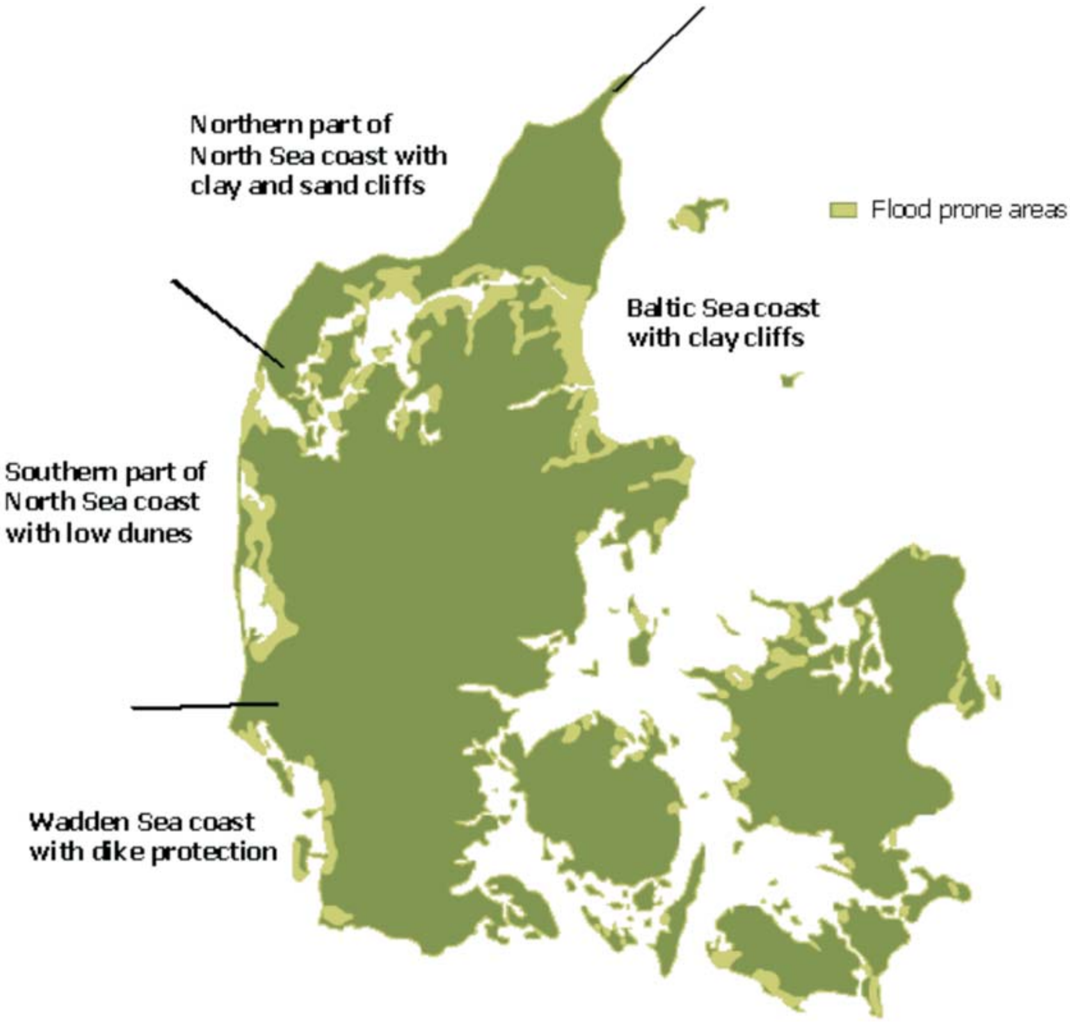

Fig. 9: Map of flood prone areas in Denmark

The main guidelines with respect to maintaining the performance of flood and coastal defences are focussed on finding the optimal technical solution to protect the value of the assets at stake whilst minimising disruption to the natural environment.

Visual inspection of the defences is required two times per year. Assessments of the defence profiles, extreme water levels and wave conditions are performed every five years. Coastal retreat and changes in dune width are monitored once per year and also five yearly evaluations of the hydraulic climate are made.

The approach to the planning of actions follows the basic process outlined below:

- defence inspections (2x per year, embedded in law)
- inspection and monitoring of forelands (by the Danish Veterinary and Food Administration)
- surveying of defence profiles (every 5 years in order to monitor consolidation)
- monitoring and evaluation of water levels (analysis of extreme water levels every 5 year)
- research and development programs. These focus among others on the efficiency of sand nourishment and on the natural variation of beach width, benefit/cost ratio.

This process delivers a prioritised programme of actions for the central part of the Danish North Sea coast based on risk. Two time horizons, 10 and 25 years into the future, are used to develop plans.

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5. Conclusions

Sub-Project 2 has reinforced the belief that across Europe there is common understanding of the meaning of strategic planning; as a process undertaken to determine an appropriate programme of measures to implement stated policy aims and objectives. More specially Strategic Planning is defined as follows:

- it a proactive rather than reactive process of analysis
- it considers a board range of options – both structural and non-structural such as:
  - all key consequences associated with action and in-action
  - regulation of urban development
  - structural intervention
  - improved public preparedness
  - better emergency responses
  - insurance / compensation
- it encourages co-operation between stakeholders (including NGOs, Governments and the public)
- it promotes long-term thinking and sustainability
- it provides an opportunity to undertake assessment of risks at the widest possible scale.

The process of Strategic Planning is, however, approached differently and has a different emphasis within each COMRISK partner country. In all Partner countries steps have been made towards this goal and tools are being developed to support (for example the RASP methods in the UK). These differences reflect different risk perceptions, society expectations and tradition. For example, throughout the continental European partners legislative instruments continue to provide the primary management tool, with prescribed safety standards (reflecting land use) and inspection intervals. Within England and Wales a more risk-based approach is adopted based on a more explicit trade-off of benefits and costs of action against the dis-benefits of in-action (with the exception of London where prescribed safety standards are provided by law). These differences are reflected in the way expenditure is prioritised. Within the context of a safety standards led approach prioritisation of expenditure is given little prominence within the strategic planning process and it is difficult (and often politically undesirable) to explicitly prioritise improvement to one defence over an other. The approach adopted in England and Wales, however, has a primary focus on prioritising actions in order of economic efficiency (taking account of both tangible and intangible benefits where possible).

Today across Europe, most countries are moving towards flood risk management based not just on predictions of the probabilities of defence overtopping under given events but also on prediction of the probability of an overall defence failure (e.g. dike breaching), the flooding consequences and their assessment in socio-economic terms. It will take time to establish a fully risk-based approach to strategic planning. This will need to consider a 'whole system' model of flooding including source, pathways and receptors, over the relevant planning timescale. It will also need to include a wide range of flood risk management options. While widely accepted as a key requirement for better flood risk management in the future, it is not yet fully reflected in present day practice.

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Risk Perception and Public Participation COMRISK Subproject 3

JACOBUS HOFSTEDE, GUNILLA KAISER, STEFAN REESE, HORST STERR

Summary

With more than 16 million inhabitants the potential losses and damages resulting from coastal flooding in the lowlands of the North Sea region are immense. The fact that this is not so much "in the peoples mind" may, at least in part, result from the success of coastal risk management during the last decades. People feel safe in coastal lowlands and are tempted to ignore or forget the latent risks. Perception of coastal risk, however, not only increases the acceptance for (costly) countermeasures but, also, reduces the reaction time in case of emergencies. One way to achieve awareness is public participation or rather, active involvement of the people in the planning process. COMRISK subproject three focussed on coastal risk perception and public participation in coastal risk management in the North Sea region. This paper describes the activities and outcomes of this subproject.

Zusammenfassung

Mit über 16 Millionen Einwohnern sind die potentiellen Verluste und Schäden im Falle einer Sturmflutkatastrophe in der Nordseeregion immens. Die Tatsache, dass dies nicht so im Bewusstsein jedes Einzelnen ist hängt, zumindest teilweise, mit den Erfolgen des Küstenschutzes in den letzten Jahrzehnten zusammen. Die Einwohner fühlen sich sicher in den Küstenniederungen und werden dazu verleitet, die Risiken zu ignorieren oder zu vergessen. Risikobewusstsein erhöht jedoch nicht nur die Akzeptanz für (teure) Maßnahmen, sondern reduziert auch die Reaktionszeit bei Überflutungen. Eine Methode, das Risikobewusstsein zu erhöhen ist Bürgerbeteiligung bzw. aktive Einbeziehung der Menschen in den Planungsprozess. Teilprojekt drei von COMRISK befasste sich mit der Wahrnehmung der Küstenrisiken und der Bürgerbeteiligung im Küstenschutz in der Nordseeregion. In diesem Beitrag werden die Aktivitäten und Ergebnisse dieses Teilprojektes beschrieben.

Keywords

Coast, risk management, flood defence, risk perception, public participation

Contents

1. Introduction

With more than 16 million inhabitants the potential losses and damages resulting from coastal flooding in the lowlands of the North Sea region are immense. The fact that this is not so much "in the peoples mind" may, at least in part, reflect the comprehensive coastal

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defence efforts that have been undertaken during the last decades. As a result, despite rising storm surge water levels, no catastrophic coastal flooding occurred in the North Sea region since 1962. The resulting lack of awareness of coastal risks in the population may, at least in some North Sea countries, have been "facilitated" by Government. They either indicated that coastal lowlands are safe or, vice versa, did not inform effectively about the remaining risks. In both ways, people are tempted to ignore or forget the latent (but existing) coastal risk.

Awareness of the risks and of the importance of coastal risk management in the population is crucial. It reduces the reaction time of each individual and, as a result, the consequences in case of emergencies. Further, it increases the acceptance for expensive countermeasures. This aspect becomes specific significance with respect to future climate change and its consequences. Assuming a sea level rise of one meter till 2100 AD, a trilateral expert group estimated that the necessary costs to maintain present safety standards in The Netherlands, Germany and Denmark might double (CPSL, 2001). It must be stressed, however, that one meter of sea level rise by the year 2100 constitutes the most pessimistic scenario with a low probability (IPCC 2001).

In order to guarantee an adequate level of risk awareness, it is necessary to (further) develop and more intensively apply respective instruments. One verified way to improve awareness is public participation or, rather, active involvement of the people in the planning process. The EU-demonstration projects on integrated coastal zone management showed that active involvement of the affected leads to increased engagement and acceptance of shared responsibilities (EUROPEAN UNION DG XI, 1999). In result, the long-term awareness of the risks of coastal flooding in the population may be improved.

COMRISK subproject 3 focussed on coastal risk perception and public participation in coastal risk management. In literature, a number of definitions for risk perception and participation exist. For this study, risk perception is defined as (MARKAU, 2003; REESE, 2003): "the sensual or rational, individual or collective perception process and the connected identification, analysis and verbalisation of risk". Participation is defined as (RENN and ZWICK, 1997): "forums of exchange that are organised for the purposes of facilitating communication between government, citizens, stakeholders and interest groups, and business regarding a specific decision or problem". The subproject had the following technical objectives: (1) assessment of the present state of coastal risk perception and public participation in coastal risk management in the five participating countries, (2) evaluation of methods to improve coastal risk perception and public participation in coastal risk management, and (3) establishment of recommendations. Responsible for this subproject was the Coastal Defence and Harbour Division of the Schleswig-Holstein State Ministry of the Interior. The main part of the work was conducted by the Department of Geography in association with the Research and Technology Centre West coast and the Disaster Research Unit (all of Kiel University). The technical report of Kiel University (KAISER et al., 2004) contains a comprehensive description of the methods applied and results achieved. The pilot study "school material" (see below) was executed by the Schleswig-Holstein Institute for Quality Assurance at Schools.

2. Methods

In order to achieve the technical objectives, the following activities were conducted. A classical desk top literature research was followed by an expert workshop. Further, a public opinion poll was conducted in five coastal localities (Fig. 1), and later a questionnaire was distributed to experts from administration and science. With respect to the evaluation of

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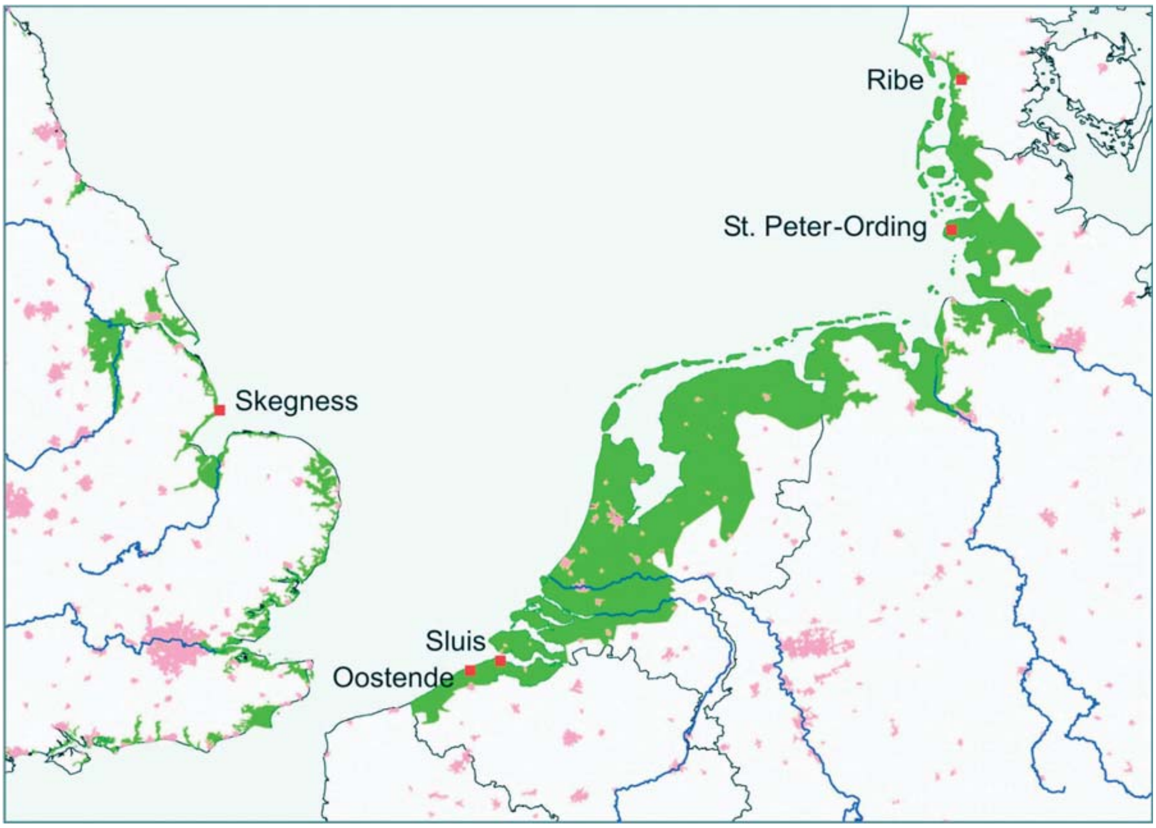

Fig. 1: Locations of the public opinion poll in the southern North Sea region

methods to improve coastal risk perception, one promising method, i.e. the establishment of school material, was tested in a pilot study.

As a start up event, an expert workshop was organised in order to discuss the chosen methodology to assess and evaluate coastal risk perception and public participation in coastal risk management. Further, the draft questionnaires for the public opinion poll and the expert survey that had been established by Kiel University on the basis of the literature research were elaborated. Finally, invited speakers from the United Kingdom, The Netherlands and Germany presented their project outcomes concerning the two subproject topics.

The public opinion poll about coastal risk perception and public participation was conducted as a mail survey. In order to increase the return rate, prepaid envelopes were distributed with the questionnaires, and a press release was mailed to the local newspapers announcing the inquiry. Further, the (German) questionnaire was translated into English, Dutch and Danish and, finally, additional information was given in a leaflet and a cover letter. Five coastal localities in the North Sea region were chosen for the inquiry in close coordination with the COMRISK project team (Fig. 1). In all, 2,000 questionnaires (i.e., 400 per locality) were distributed personally to randomly selected households. To have comparable samples in all localities, 1/3 of the questionnaires were distributed in the town centre, 1/3 directly behind the dike or dunes and 1/3 in areas further away from the sea. A map was included in the questionnaire where the people should mark where about they live in the area of investigation. In these maps, streets were eliminated to guarantee anonymity. The questionnaire contained twelve questions about risk perception, nine questions about participation and three questions concerning demographic data. The questions were multiple choice, ranking, as well as open questions.

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Apart from the public opinion poll, an expert survey about participation procedures in coastal risk management was conducted. In close coordination with the COMRISK project team, 121 experts from administration, science, consultants and stakeholders in the participating countries were selected. With respect to the high number of interviewees, the survey was conducted by electronic mail. The questionnaire included 12 questions concerning the evaluation of information tools, experience with and evaluation of participation procedures. The questions were multiple choice, ranking, as well as open questions. The questionnaire had a downloadable form and could be returned electronically or by mail.

From the literature research and the expert workshop it became clear that the perception of coastal risk may effectively and sustainable be enhanced by education. Students are susceptive for new information and can, thus, be influenced in their long-term behaviour or, rather, perception. This capability generally decreases with age. To test this hypothesis, a pilot study was conducted. On the basis of available data and information (raw and processed data, internal reports and documents, publications, diagrams and photographs, etc.) in the coastal defence administration of Schleswig-Holstein, pedagogues established appropriate school material for three class levels. The outputs are in German as only information from Schleswig-Holstein was edited. They are available in analogue (book) as well as in digital format (CD-ROM). As a next step, the established material was tested in school classes, seminars and advanced training courses for teachers by the pedagogues and the first author.

3. Results

3.1 Expert workshop

The workshop was attended by 32 experts from administration and science. Invited speakers from the United Kingdom, The Netherlands and Germany gave oral presentations about their research. From the discussion it appeared that people feel relatively safe in coastal lowlands, i.e. they have trust in the authorities (FLINTERMANN et al., 2003). However, a public survey in Lower Saxony showed that there is scepticism about the ability of the coastal defence system to cope with climate change. In this context, 30 to 50 % of the interviewed local residents support the reinforcement of coastal defence structures (PETERS & HEINRICHS 2003). Further, experts (from science and administration) and the society apparently define risk in different ways: the quantifiable technical risk applied by administration (e.g. return intervals, probability of breaching), on the one hand, and the subjectively perceived risk in the population (will my house be damaged?) on the other. To overcome this problem, risk should be translated into the language of the society, reference should be made to personal living surroundings and to personal consequences, and options for personal action should be presented. Another result was that people tend to ignore or disclaim the risk for personal or financial reasons. Society needs/demands targeted, understandable and regular information, e.g., by using local champions/celebrities (RIKZ and BWD, 2002; MCCUE, pers. Comm., 2003).

The discussion about the questionnaires that had been prepared by Kiel University resulted in a number of recommendations, like a preamble with references to the EU INTERREG IIIB program and to the COMRISK website, and the announcement of the public opinion poll in local press. These were considered in the surveys.

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3.2 Public opinion poll

Of the 2,000 questionnaires that were randomly distributed to private households, 411 (21 %) were returned. Most of the respondents (64 %) were male and (only) 7 % younger than 30 years. The highest return rate (28 %) was recorded for Oostende where a public discussion about a comprehensive coastal defence measure is underway. It is stressed here that the opinion polls in the selected localities are not representative for the whole country. Local situations, as described above for Oostende, prevent a generalization. Figs 2 to 5 display some selected results from the poll.

From the answers, it appeared that the awareness about the risk situation is not well developed. Although all selected households are situated within flood-prone areas, 30 % thought that their house could not be inundated during storm surges. For Sluis this ratio amounted to 10%, for Ribe to 68 % (Fig. 2). For Ribe this may be explained by the fact that Ribe town is situated some kilometers inland from the sea dike.

About 33% of the respondents estimated the risk of a coastal flooding event in their region to be high or very high (Fig. 3). This implies that a call for action or at least more

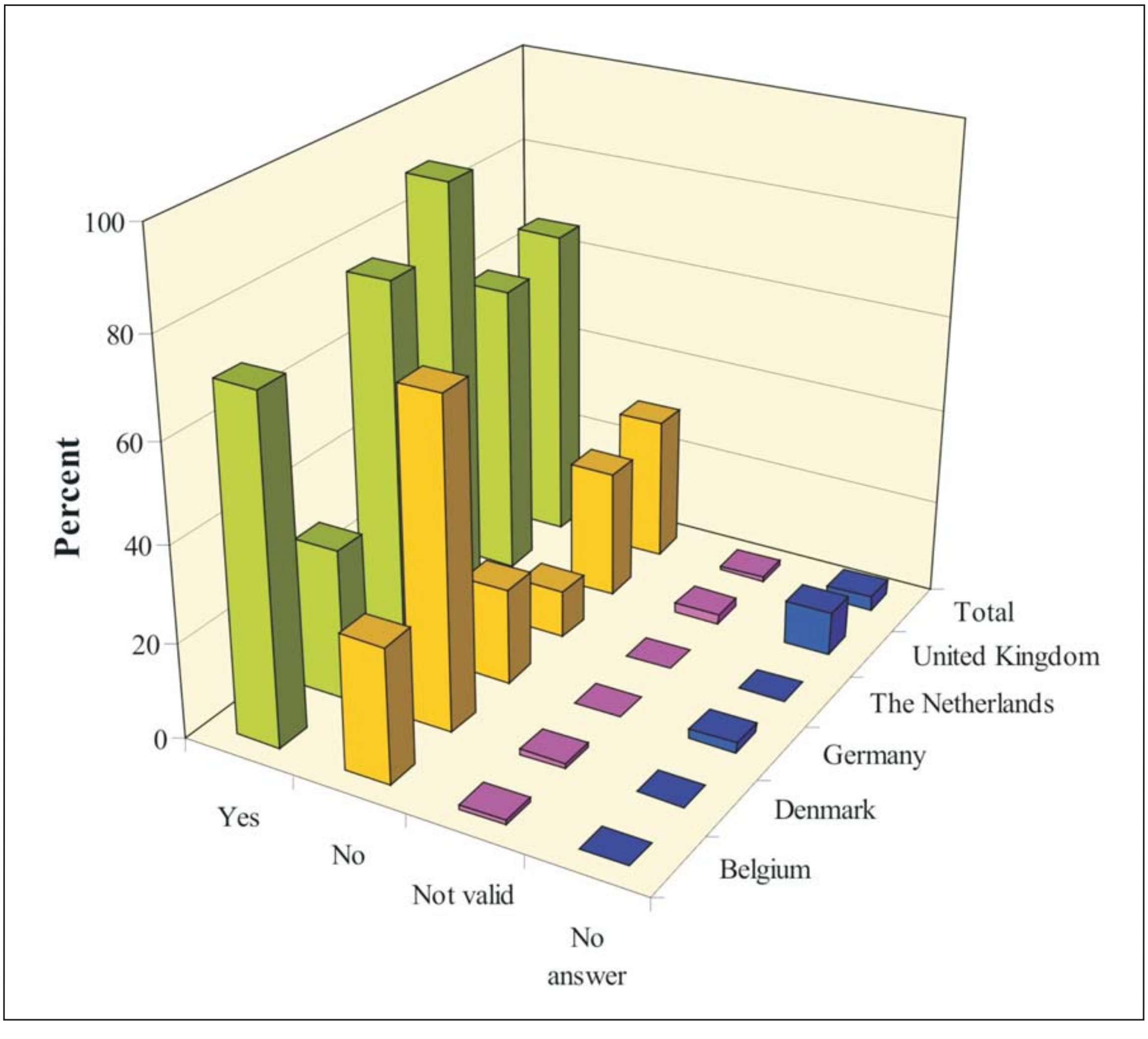

Fig. 2: Response to the question: could your dwelling be hit by the floodwater in case of a coastal flooding?

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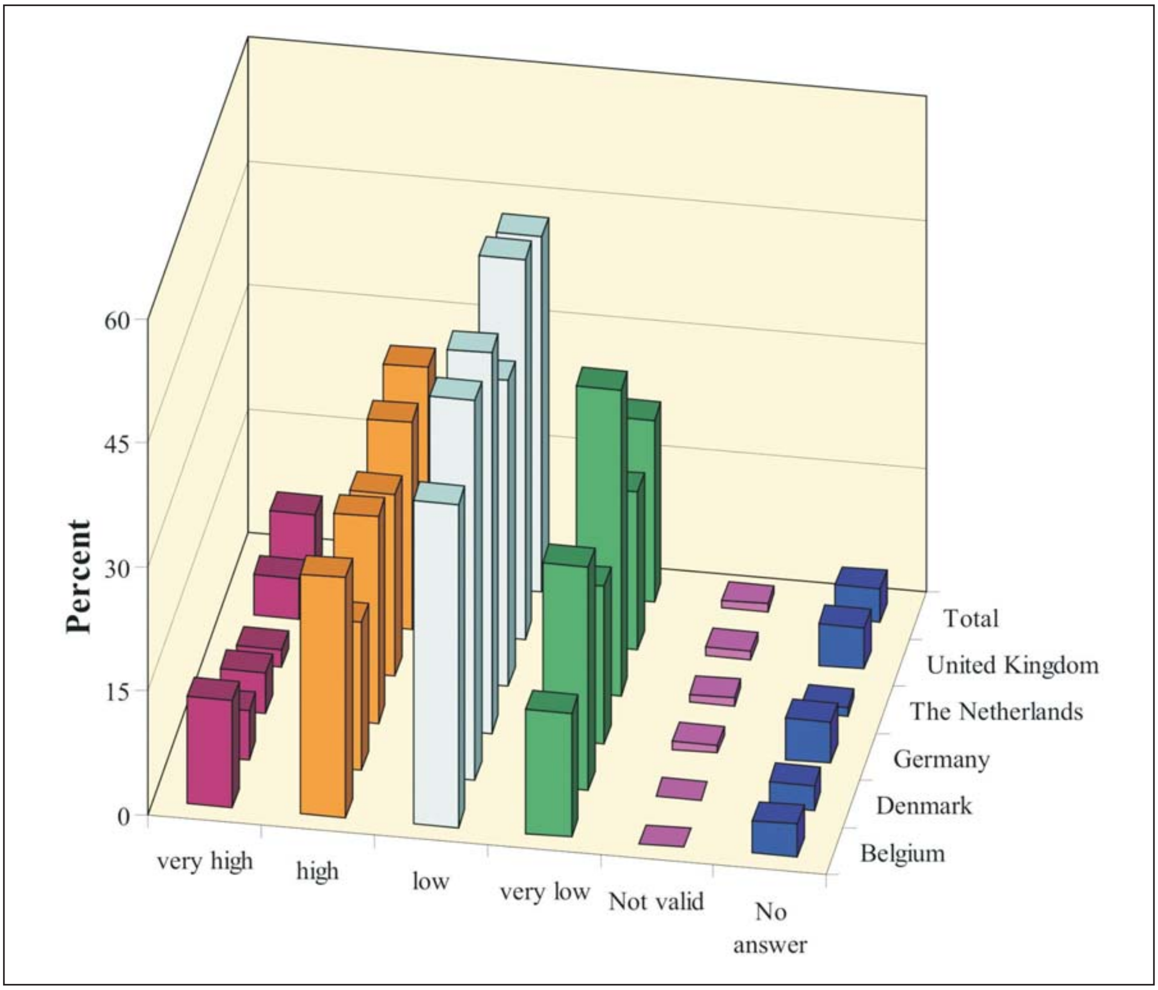

Fig. 3: Response to the question: how high do you estimate the probability of a coastal flooding?

information exists. Despite this high result, only 7 % had ever taken personal measures to be prepared for a future storm flood. There appears to be a discrepancy between the perception and the action of the people, as 90 % of the persons who estimate the probability of a storm flood as very high, had not taken any personal measures.

The answer to the question: "how well have you been informed about the basic risks of a storm flood by the responsible authorities", indicated an information deficit. Apart from Ribe, where 79 % seem to be satisfied with the information policy of the authorities, more than half of the respondents answered that they were informed poorly or very poorly (Fig. 4). Hence, a felt information deficit became apparent.

Apart from more information, the respondents demanded more active involvement in the process. However, if asked about concrete actions, (only) 6 % said they would be willing to sacrifice one working day, 9 % would work regularly as a volunteer, whereas about 50 % would visit an information event (Fig. 5).

In summary, some main results from the public survey on risk perception are: (1) risk perception is strongly influenced by personal experiences and the time that elapsed since than, (2) no correlation exists among personal experience and precautionary actions, (3) knowledge about the risk does not automatically imply knowledge about the consequences and precautionary actions, and (4) people are partly sensitive for climate change and sea level

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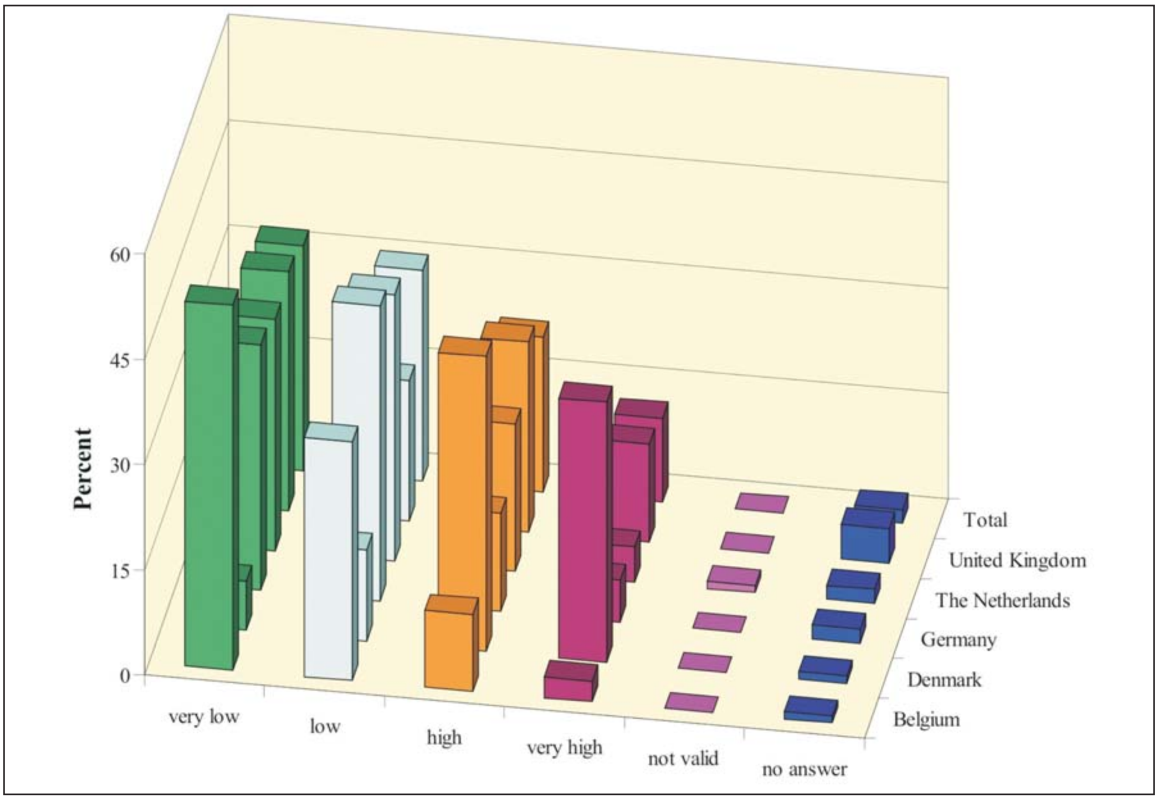

Fig. 4: Response to the question: how well have you been informed about the basic risks of a storm flood by the responsible authorities?

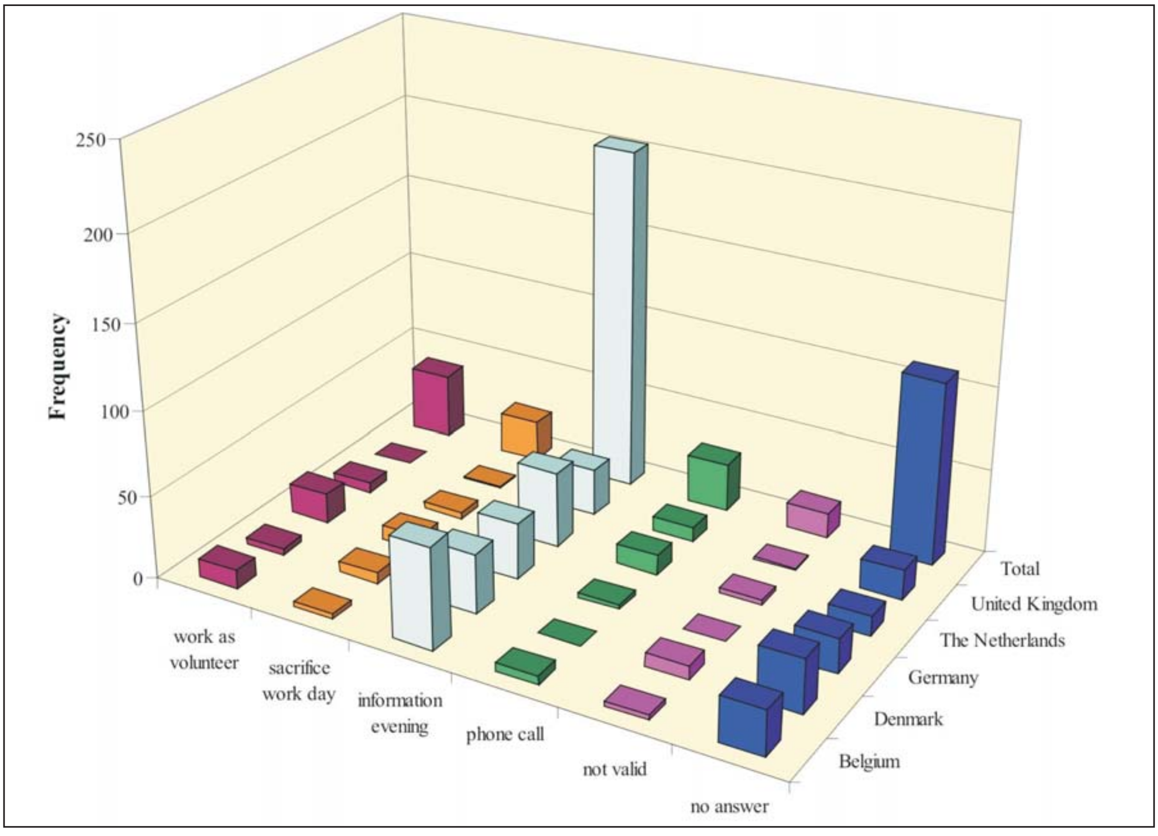

Fig. 5: Response to the question: if you want to represent your opinion in coastal defence planning, what would you like to do?

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rise but the majority has no adequate information about this issue. Main results from the public survey on participation are: (1) only 8 % have ever been involved in a participation procedure, they would do it again (positive experience), (2) active participation is demanded for, but only 6 % would sacrifice one working day, 50 % would attend an information event, and (3) the information supplied by administration about participation procedures does not reach the public to the desired extent, and (4) in result, people feel that they are not adequately informed and are sceptical about their possibilities to influence decisions.

3.3 Expert survey about public participation

From the 121 contacted experts, 42 (35%) returned the questionnaires. The highest return rate was recorded for Germany with 60%. The distribution of returned questionnaires was, however, very inhomogeneous among the countries. As a result, it was not possible to establish national differences. Some selected results are given below.

Out of a list of seven information tools and 13 participation tools, the respondents were asked to select those of significance for coastal risk management. From the list, press and local media were named by most respondents as an important information tool, the formal project approval procedure as a significant participation tool.

Further, the interviewees were asked to rank eight listed participation tools with respect to their capability to increase the acceptance of the measure (Fig. 6). The highest ranking was given to workshops, followed by round tables and project approval procedures. Participation through Internet received the lowest ranking.

About 85% of the experts believe that participation increases the acceptance of planned measures. At the same time, 76 % expect that participation causes problems for the involved administration. Some reasons listed are: (1) it is time-consuming, (2) it requires extra costs and man-power, (3) the outcomes must be considered in the plan (even if administration doubt the feasibility), and (4) it may be difficult to integrate all requests (someone will have to take the decision anyway).

From 10 possible instruments, the experts were asked to list those that are most qualified to sustainable inform people about coastal risks. Press and local radio were, again, named most frequently. Exhibitions and topic at school got high scores as well. The lowest score was given to phone-hotlines.

In summary, some main results from the expert survey on participation are: (1) information is as necessary and important as participation, (2) there exists no ideal information and participation tool, (3) active participation fosters the acceptance of the measures, but implies large efforts for administration, (4) good preparation and external (neutral) moderation increases the chances of success, (5) communication is the often the key problem, (6) controversial opinions exist under the respondents about formal participation, and (7) there exists a deficit in the integration of coastal flood defence and disaster management.

3.4 School material

In Schleswig-Holstein, coastal defence is a topic at school at different class levels (at the ages 9, 10, and 18). Pedagogues associated to the Schleswig-Holstein Institute for Quality assurance at Schools established school material (based on data and information from Schleswig-Holstein) for these class levels. The material was tested in school classes, at seminars and

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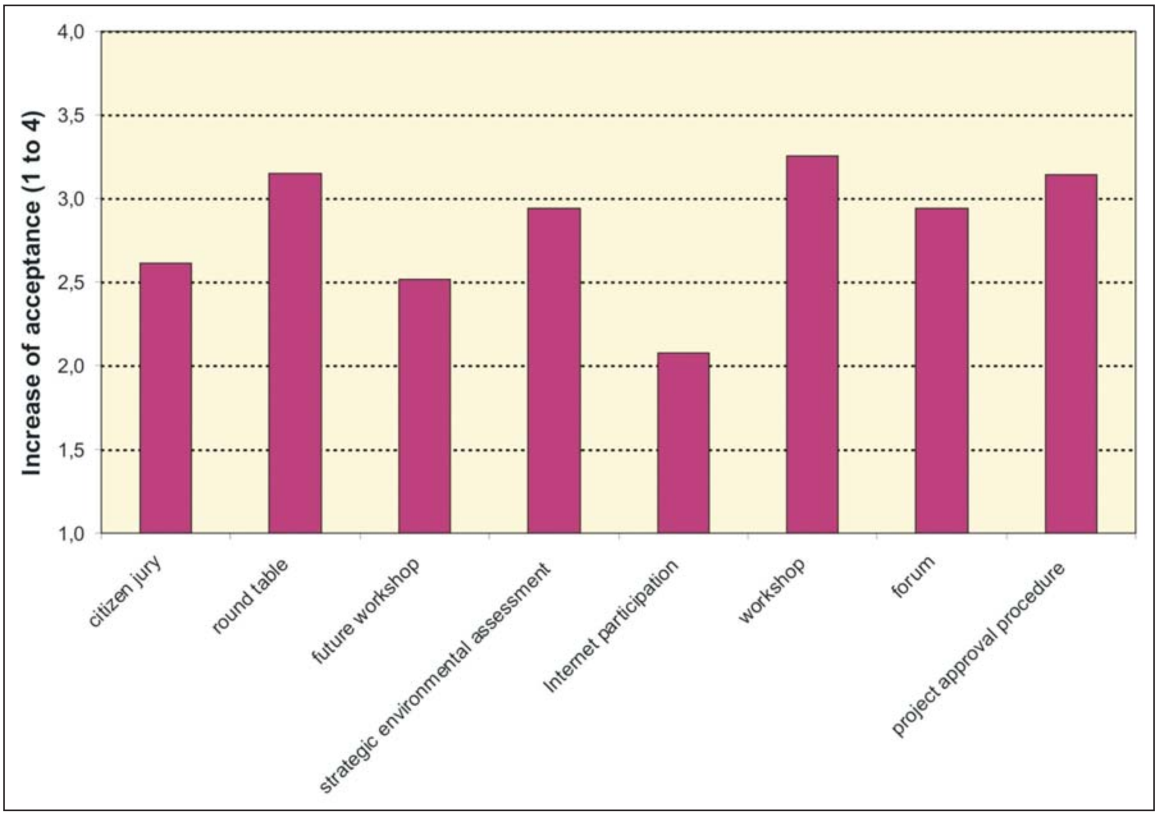

Fig. 6: Response to the question: how useful are the listed procedures for the acceptance of coastal defence measures? (1 = very low; 2 = low; 3 = high; 4 = very high)

in advanced training courses for teachers. Some main findings and experiences from lower grade (age 10) and high school graduates (age 18) that tested the material in a teaching unit are given below. The school material has been distributed (in book form and on CD-ROM) to all schools by the Schleswig-Holstein Institute for Quality Assurance at Schools.

For the lower grade (at age 10), the material was prepared in the form of "learning at stations". At nine stations, small groups worked independently (assisted as necessary by the teacher) on different topics. For example, they prepared a map showing the flood-prone lowlands along the North Sea coast of Schleswig-Holstein, and listened to an authentic flood warning that had been broadcasted by radio. At the beginning of the teaching unit, the pedagogue organised an excursion to a sea dike to experience the "state of knowledge and awareness" among the scholars. Most of the scholars were aware of the topic coastal defence (had visited a coastal location with sea dikes before), but could not clearly express the significance. With the stations, questions were delivered that needed to be solved by the scholars. From the answers and a final discussion it became clear that the scholars had gained a lot of information. Especially the written eyewitness account from a storm surge by peer kids living at small islands (Halligen) in the German sector of the Wadden Sea worked as a light bulb moment. In result, the knowledge about and the awareness for coastal risks could be raised substantially.

For the sixth form (at age 18), the material was provided in digital format and applying a simple version of a geographical information system (GIS). The GIS allowed for simulations, e.g., what would happen to Schleswig-Holstein without dikes. This option, especially, helped to demonstrate the coastal risks in Schleswig-Holstein. The fact that, without sea dikes,

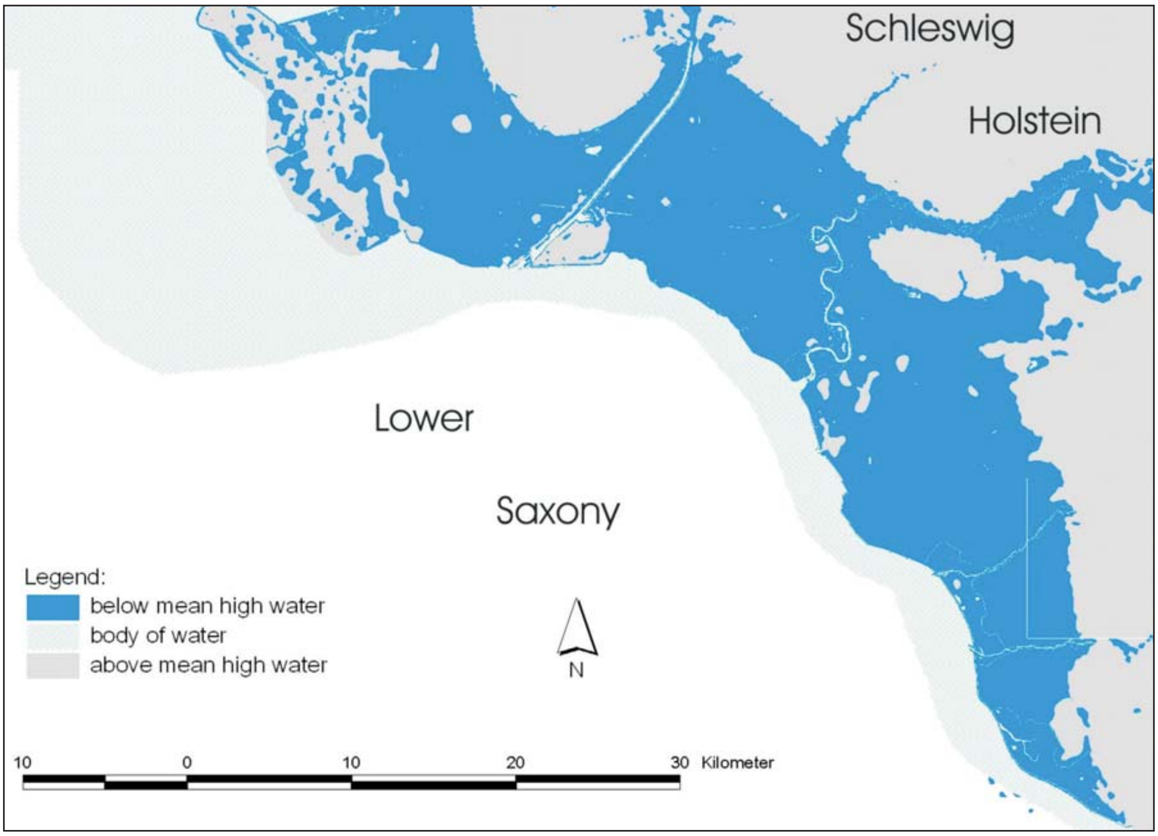

Fig. 7: Land area (dark blue) along the river Elbe in Schleswig-Holstein that would get under tidal influence without sea dikes

significant parts of Schleswig-Holstein like the marshes along the Elbe (Fig. 7) would come under daily tidal influence, struck up instantaneous awareness of the problem and resulted in a strong motivation to find out more. One of the provided options, the conduction of an external school survey on the basis of free software, turned out to be unfeasible. Schools which were not directly involved were reluctant to cooperate, which was interpreted by the high school graduates as lack of coastal risk awareness. An excursion to the coast (the test school was situated in one of the most coast remote locations in Schleswig-Holstein) opened the eyes of the students for the major tourist services and, therewith, the damage potentials that are situated directly along the shoreline. In conclusion, the material provided was seen as complete, allowing for a broad range of topics to be addressed. The application of new multi-media based techniques was motivating and resulted in a high creativity of the high school graduates. In the end, there was agreement among the students that the teaching unit had resulted in strong and sustainable coastal risk awareness. The teacher who tested the material now presents the unit on a regular (yearly) basis.

4. Discussion and recommendations

Although financial and time constraints do not allow for generalization of the results, the study seems to confirm the postulated deficit in coastal risk awareness in large parts of the coastal population. Although 33 % of the interviewees in the public opinion poll state that the risk of coastal flooding in their region is high to very high, they feel safe, have thrust

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in Government and/or tend to forget or disclaim the risk. Although situated in the lowland, 30 % believe that their houses could not be flooded when the sea dikes breach. Furthermore, 90 % of the people who estimate the chances of coastal flooding in their region to be very high had not taken any precautionary measures. This seems to indicate that the information flow towards the population is either insufficient, does not reach the recipients or is not taken seriously. There is an apparent deficit in risk communication. One of the reasons may be that the perception of risk differs among administration and science (the suppliers), and the population (the recipients). The information that sea dikes are able to withstand a certain water level with a certain (very low) probability of occurrence is too academic and may even give the false impression of absolute safety. To overcome this problem, risk should be translated into the language of the society, reference should be made to personal living surroundings and to personal consequences, and options for personal action should be presented. Background information about coastal risk management and about measures for personal precautionary actions should be distributed on a regularly basis.

In their answers, 62 % of the respondents to the public opinion poll indicated that the quality of the information about the risks of storm floods delivered by the responsible administration is low (30 %) to very low (32 %). The variance among the countries in the answers to this question was large. In Ribe, only 20 % of the respondents were not satisfied, whereas in Oostende this figure amounted to 86 %. These results should be viewed with special care. Although 80 % of the interviewees in Ribe were satisfied about the quality of information, 68 % of them indicated that their property could not be hit by a storm flood (although situated in a flood-prone area). In Oostende, a large coastal defence scheme is being planned that automatically leads to controversial discussions and discord among the affected population (despite extensive information campaigns and participation procedures). This general feeling of discontent is certainly reflected in the answers from Oostende. It may be concluded that the supposed degree of satisfaction among local residents is rather subjective and, at least in part, depending on external factors. To overcome this problem (at least in part), the information supplied should be neutral, objective, plain, targeted, comprehensive and understandable. Further, a mix of information tools should be used in combination.

An extensive number of participation procedures exist. KAISER et al. (2004) describe and evaluate 32 tools for information and participation. Some of these are formalized and mandatory like the project approval procedure. Most of the described tools, however, have a more informal character which implies, for example, that the results are not binding. Being mandatory, the project approval procedure is the best known tool to the experts from administration. A plan which needs to be approved is produced by a public or private initiator. The administration that is responsible for the approval has to take several steps to assure that all public and private affected institutions and persons can comment on the plan. It has to be published and laid out in affected communities, written comments have to be gathered and evaluated, and public hearings to decide on all objections have to be conducted. The expert survey delivered controversial results. Some experts feel that the project approval procedure is the optimal way to consider the desires of the affected. Others state that the procedure is rather reactive, i.e. people are only allowed to react on an existing plan. An active involvement of the affected in the development of their living surroundings (bottom-up principle) is not possible.

From the public survey it became apparent that people are sceptical whether their objections to plans are taken seriously. About 40 % of the respondents stated that the public has no influence. To overcome this scepticism, independent (external) persons might be used to moderate the process, and more information about the results and outcomes of the procedure

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should be provided. These results and outcomes should, of course, duly reflect the objections made during the procedure. In this respect, KAISER et al. (2004) recommend the administration to be positive and responsive, e.g., by respective training of staff. Furthermore, from the 92% of the respondents who said that they had never taken part in a participation procedure, 48% believed that such a procedure had never occurred in their region. From the expert surveys it became clear, however, that such procedures have been conducted in all locations (maybe several years ago). Apparently, the information about the procedure did not reach the public or was not noticed. More effective information tools like the involvement of (trustworthy) "local celebrities" and local press should be applied.

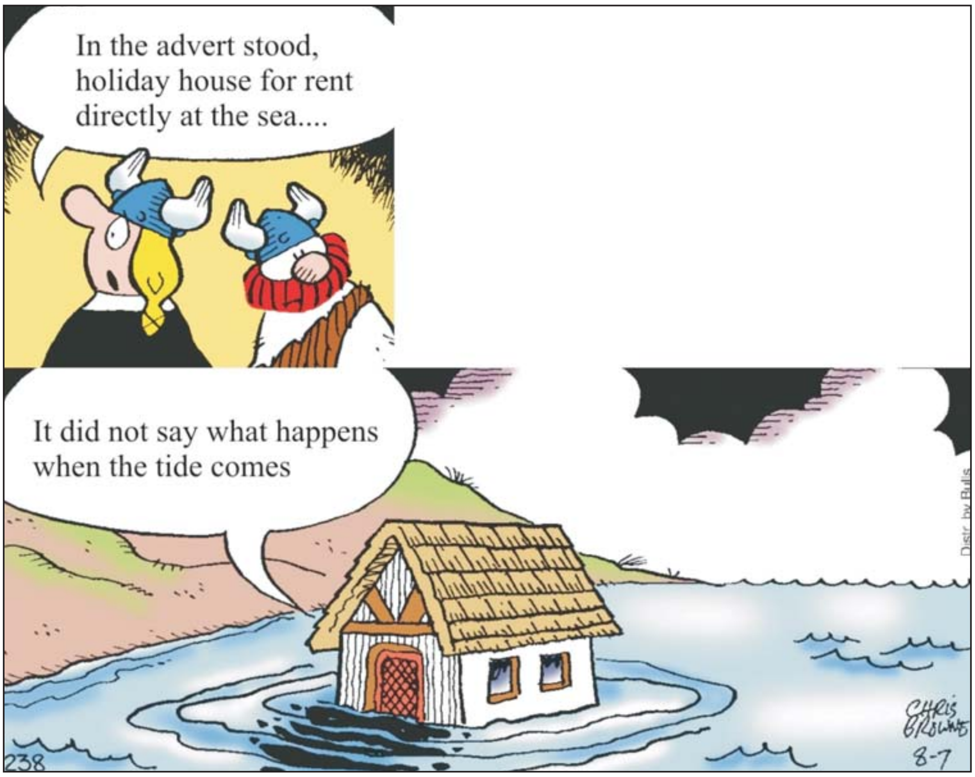

Fig. 8: Example of "vivid" information to explain the significance of coastal risk management to basic scholars (From the comic: "Haegar the Terrible"; with the courtesy of Bulls Press GmbH, Germany)

A promising tool to increase and maintain coastal risk awareness among the population in a sustainable (long-term) way is to include coastal risk management in the instruction topics at schools. The pilot study for Schleswig-Holstein demonstrated that students are, still, highly susceptible for praxis-oriented, tangible and vivid education (Fig. 8). As soon as they were convinced about the significance, they were highly motivated to increase their risk perception and their state of knowledge and awareness. It is recommended that the school material should be established in close cooperation among coastal risk administration and pedagogues to assure qualified and praxis-oriented education. Administration should deliver actual and praxis-related data and information, to be transferred into school material by qualified pedagogues applying multi-media based techniques. In order to remain modern, the material and applied techniques should be updated on a regular basis, e.g., conform the actualisations of respective coastal risk management master plans. In order to increase the application at schools, online advanced training courses for teachers should be provided for.

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The results and findings of this study, to the larger part, confirm and reflect previous national research projects. As a response to national and regional findings, comprehensive efforts are being undertaken by the respective administrations to overcome the information deficits and lack of active involvement that are experienced by the public. For example, in the United Kingdom extensive information campaigns have been or are being conducted to increase the awareness and preparedness, such as the distribution of a leaflet to all households in flood-prone areas, the maintenance of a comprehensive internet-presentation including a flood-warning system, and a national flood-phone. Investigations are underway to assess and communicate the risk of flooding, e.g. the national program "Veiligheid Nederland in Kaart - VNK" in The Netherlands, the RASP and Foresight-programmes in the UK, and the projects PRODEICH, MERK and KRIM in Germany. In the Netherlands, school material for different class levels and schools has been assembled in 2003 to commemorate the 1953 national storm flood catastrophe.

The added value of this study may be the conclusion that the observed deficits in all the North Sea countries and regions are highly comparable despite major differences in the physical, social, economic and cultural context (see contribution Kiezebrink, this volume). Every country and region has developed and implemented strategies to counteract the shortcomings. In consequence, the countries and regions can learn from each other.

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Performance of Flood Risk Management Measures COMRISK Subproject 4

JONATHAN SIMM, IAN MEADOWCROFT

Summary

In managing the risk of flooding in the southern North Sea Region, both physical defences (dikes and sea walls) and non-structural measures play a significant role, but their performance must be clearly understood, monitored and managed.

This paper presents the results of an comparative study of approaches to performance management in the countries bordering the southern North Sea, with a particular focus on performance indicators.

The paper introduces concepts of performance and performance evaluation in the context of flood management, building on a source- pathway-receptor conceptualisation. Flood risk assessments are promoted as providing an overall measure of the performance of the system of flood risk management measures.

In all countries performance of linear defences remains a key feature. In managing defence assets the concepts of defence fragility and a geographical, geometrical and structural hierarchy of performance assessment are found to be helpful. Reliability analysis is seen as a way forward to achieve a consistent estimate of defence failure probability.

The paper concludes that more work is required to develop better and more consistent performance indicators for NSR countries, distinguishing between output performance measures for organisations and outcome performance measures related to the actual reduction of flood risk.

Zusammenfassung

Beim Management der Risiken von Sturmfluten im südlichen Nordseeraum spielen sowohl technische Maßnahmen (Deiche) wie auch nicht-technische Maßnahmen eine signifikante Rolle. Ihre jeweiligen Leistungen sollten jedoch eindeutig verstanden, überwacht und gehandhabt werden.

In diesem Beitrag werden die Resultate einer vergleichenden Untersuchung über die jeweiligen Ansätze zum Umgang mit Leistung in den Nordsee-Anrainerstaaten mit einem Fokus auf die benutzten Leistungsindikatoren dargestellt.

Der Beitrag stellt Leistungskonzepte und deren Bewertung im Kontext des Flutmanagements vor, aufbauend auf dem sog. „Source-Pathway-Receptor-Prinzip“. Flutrisikoanalysen werden befürwortet als allgemeine Grundlage für die Leistungsbewertung von Maßnahmen des Flutrisikomanagements.

In allen Partnerländern ist die Leistung von linienhaften Schutzmaßnahmen Hauptaugenmerk. Die Untersuchung hat gezeigt, dass in der Pflege und Unterhaltung der Schutzmaßnahmen der Unterhaltungszustand sowie eine geographische, geometrische und strukturelle Hierarchie der Leistungsermittlung hilfreich sind. Sicherheitsanalysen stellen eine Verbesserung dar um eine konsistente Einschätzung der Versagenswahrscheinlichkeit von Schutzwerke zu ermitteln.

Es wird gefolgert, dass weitere Untersuchungen erforderlich sind um zu besseren und konsistenteren Leistungsindikatoren für die Nordsee-Anrainerstaaten zu gelangen. Dabei soll unterschieden werden zwischen Leistungsindikatoren für die Verwaltung und solchen für die tatsächliche Reduzierung der Risiken.

Keywords

Coast, risk management, flood defence, performance indicators

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Contents

1. Introduction: assessing performance of risk management measures as part of COMRISK

The risk of flooding in North Sea coastal lowlands may be managed by physical defences (eg embankments, sea walls, dunes), flood warning and response, and non-structural measures such as control of development in flood prone areas. The performance of these measures under a range of possible conditions including extreme storms needs to be understood in order to assess and manage risk. This report on the performance of risk management measures comprises the outcome of sub-project 4 of the COMRISK study (COMmon strategies to reduce the RISK of flooding in coastal lowlands).

An earlier study by the North Sea Coastal Managers Group showed that the quality and type of performance indicators varies considerably between member states. A more consistent approach to establishing the performance of flood risk management measures will improve flood risk management in coastal lowlands. Sub-project 4 (SP4) within COMRISK aims to support the development of best practice in the North Sea Region and contribute to improved flood risk assessment and management.

2. Aims and outputs of COMRISK sub-project 4

The aims of COMRISK Subproject 4 (SP4) – "Performance of risk management measures" were:

- to create an inventory of current performance indicators in the NSR including a technical review based on case studies
- to evaluate the ability of different approaches to answer the need of risk managers and planners
- to recommend international best practice and to improve cross-border dissemination and application of methods.

The anticipated outputs of SP4 were to include:

- an inventory of performance indicators used in the NSR, including data requirements, information content and usage for decision-making
- a meta-database of performance indicators
- to produce a comparative review of the set of performance indicators to establish common ground, and to identify gaps among the participating countries.

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3. Flood defence performance

Flooding from rivers, estuaries and the sea poses a threat to many millions of the citizens of Europe and remains the most widely distributed natural hazard in Europe leading to significant economic and social impacts. For example, the 1953 North Sea floods caused about 2500 deaths across the UK, Netherlands, Belgium and Germany and concentrations of fatalities in river floods are associated with flash floods, such as Vaison-la-Romaine (1992), and the mudflows at Sarno (1997). Over half of the population of the Netherlands lives below mean sea level; in the UK about 10 % of the population lives in areas of fluvial, tidal or coastal flood risk. The national scale of economic importance of flood and coastal defence activities has been documented for England and Wales (BURGESS et al, 2000) as preventing annual average damages of approximately 4 Billion, with the value of assets at risk of river and coastal flooding being about 300 Billion. In the Netherlands estimates of the possible damage due to flooding vary from 300 to 800 Billion. These and other floods in the past decade in many parts of Europe have focussed attention nationally and within the EU on the need to understand and manage flood risks. The potential for flood damage is also increasing from social and economic development bringing pressures on land use.

In the UK, the autumn of 2000 featured a number of extreme weather events over 25 days that were the wettest for 270 years. 10,000 properties were flooded costing the insurance industry over £1 billion. Various types of flooding occurred including fluvial, pluvial and coastal. The UK Government, the Environment Agency, stakeholders and the public all had to “heed the wake up call” to the risks and consequences of extreme flooding events. An analysis of the causes of the property flooding in 2000 showed that the source risks were split between four causes; overtopping of or breaching of river defences, lack of flood protection on rivers, exceedence of capacity in streams and ditches, and inadequate drainage.

The performance of local flood defence measures also came under closer scrutiny and interest rose dramatically in temporary protection systems and barriers and available measures to protect domestic property.

4. Definition of performance and performance evaluation

A useful definition of ‘performance’ is *‘The creation or achievement of something that can be valued against some stated aim or objective.’*

Evaluating performance is important so that:

- we can report on achievement
- we can learn from experience
- we can identify problems
- better links can be formed between the observed state and what we’re trying to achieve
- we can focus on what’s important - outcomes
- we can review the past and manage the future

In the case of flood and coastal erosion management, the objective is to reduce risk to the developed and natural environment. An essential aspect of the risk management process is ongoing monitoring of flood and coastal erosion risks. Monitoring takes place on a range of scales from local site-specific measurements to data that is assembled on a national basis by NSR countries. Performance Evaluation will then be able to contribute to ongoing risk monitoring by providing a periodic insight into the efficiency of investment in risk management actions and a periodic opportunity for reflection on the information being provided by ongoing monitoring activities.

Performance evaluation is applicable to all areas of significant investment in flood and coastal risk management, including:

- capital works of flood and coastal defence (design, procurement and implementation)
- operation and maintenance of flood and coastal defences
- major monitoring programmes
- flood forecasting and warning
- informing the statutory planning process in order to control development in flood risk areas
- policy development
- plan and strategy development
- research and development.

A useful way of thinking of these activities is as a hierarchy of processes, from high level policy and strategic processes to more detailed implementation and operation processes. The underlying concept is that of a tiered approach to risk-based decision-making with an interactive suite of tool, models and data addressing the national, catchment / coastal cell, and local (i.e. asset/defence management and river reach) levels.

Flood defence assets can also be thought of in a hierarchical way, with three main levels in the hierarchy:

- the geography of the defence asset – where it is, specifically its alignment
- the geometry of the defence asset – its overall physical shape, which is particularly important in limiting overtopping and flooding
- the structure of the defence asset – its physical condition which is important in terms of ensuring integrity under loading and avoidance of breach or erosion.

The advantage of this type of approach is that it has the potential to capture all of the diverse activities that contribute to flood and coastal management in one coherent picture. The majority of Performance Evaluation will focus on site-specific, detailed processes, but the results can also be aggregated to provide higher level measures of performance. Aggregation should take account of the criticality of low-level processes to the performance of higher level processes.

Performance evaluation involves collecting evidence about how a given flood or coastal management process is performing when compared with its objectives. The high level aim is likely to be associated with a desire to reduce flood or coastal erosion risk. This overall aim is then reflected in increasingly detailed and more specific objectives for subsidiary flood and coastal erosion management processes. (For example, a dike in a particular locality might have objectives set for it related to resisting overtopping and avoiding breaching.)

Performance Evaluation therefore involves consideration of both objectives and behaviour. Performance Objectives are statements of one or more target levels of behaviour of the process under consideration. Information on how the process behaves relative to the stated objectives can be obtained from measurable characteristics known as Performance Indicators. In the case of flood risk management these will have to take account (see Fig. 1) of:

- sources of flooding
- pathways for flooding
- receptors of flooding
- consequences of flooding

Thus the key steps in Performance Evaluation are:

1. Establish clear Performance Objectives for the process being evaluated.
2. Identify characteristics (Performance Indicators) of that process that can be used to measure how it is performing relative to objectives.

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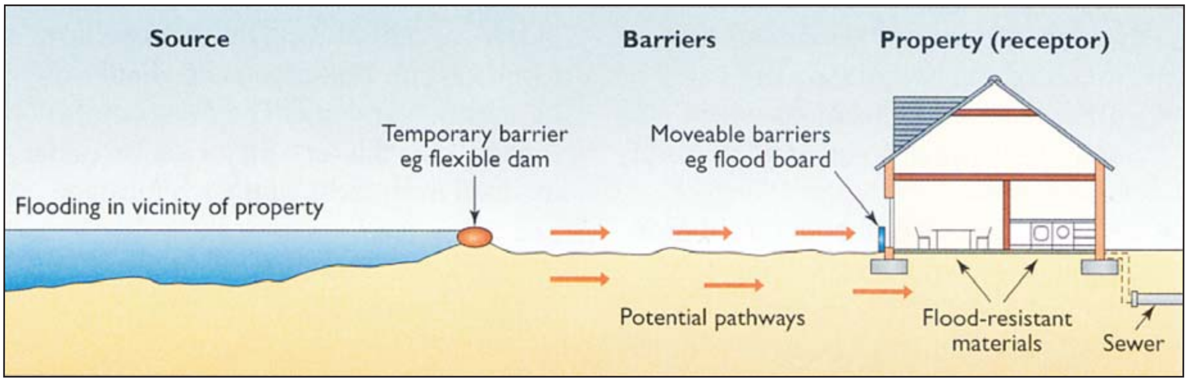

Fig. 1: Source / Pathway / Receptor / Consequence model for flood risk

3. On the basis of measurable evidence, establish how the process is performing compared with objectives.
4. Communicate the results of the evaluation as appropriate.
5. Decide what further action needs to be taken as a result.

In general Performance Indicators lie on a range from 'hard' to 'soft' measurements. Hard Performance Indicators have widely accepted methods and scales of measurement (such as weight and cost). Soft Performance Indicators cannot be precisely measured and are often expressed in linguistic terms (e.g. High, Medium or Low). Soft Performance Indicators are therefore inevitably less informative than hard Performance Indicators and the method of measurement (for example elicitation from experts or stakeholders) will tend to be more prone to bias. But there are important aspects of system performance that can only be measured in soft terms.

Performance Indicators may be directly informative in the format in which they are measured, or they may require some processing or analysis in order to be useful. Processing may, for example, involve summing or averaging several measurements.

5. Fragility curves

Often, in order to be useful, some analysis of the context or environment in which Performance Indicators were measured will be required. This will be essential for measurements of system (or more specifically defence structure) response to random loading. In order to obtain information about whether the response was satisfactory or not it is essential to analyse the loading conditions and to do so may require additional data collection or modelling (for example hindcasting). A convenient way of separating system response from the loading imposed upon it is to use a fragility function as a performance indicator. A fragility function (see example *fragility curve* in Fig. 2) is the defence response, P(D|*x*), *conditional upon a given loading condition, x*.|

There will usually be more than one performance indictor for any given process, but the number of Performance Indicators should be efficient and should as far as possible relate directly to objectives.

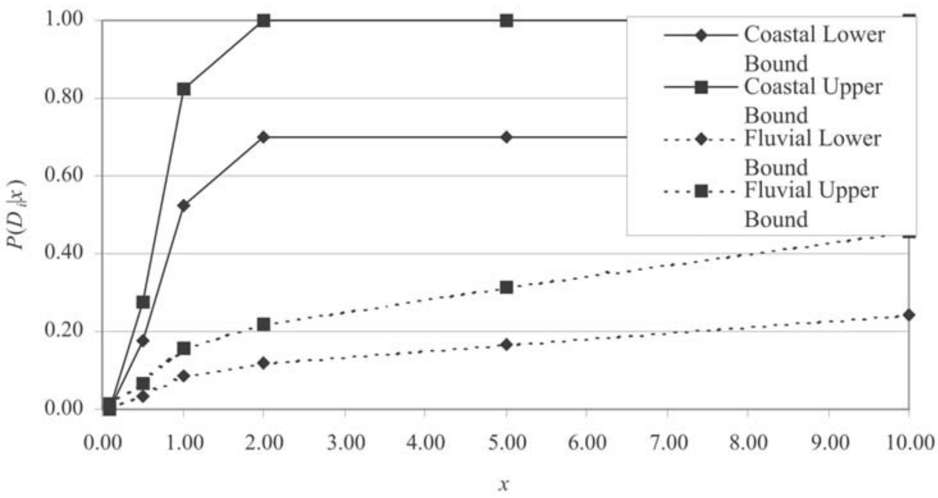

Fig. 2: Typical fragility curve

6. Defence asset condition assessment

Management of defence assets is a particularly important part of the overall performance management process described in the previous section. Performance-based defence asset management of the system must consider:

- the whole life cycle of systems (to secure the greatest return on investment)
- maintenance, renewal, and replacement options with the goal of optimising defence asset performance.

The objective must be to assess performance on a continuous basis and at appropriate times. Maintenance, renewal or replacement interventions are initiated to restore the original performance capability and to extend or re-initiate the residual life of the system or defence asset (Fig. 3). For such a process, it is essential that the monitoring involves a process of *con-*

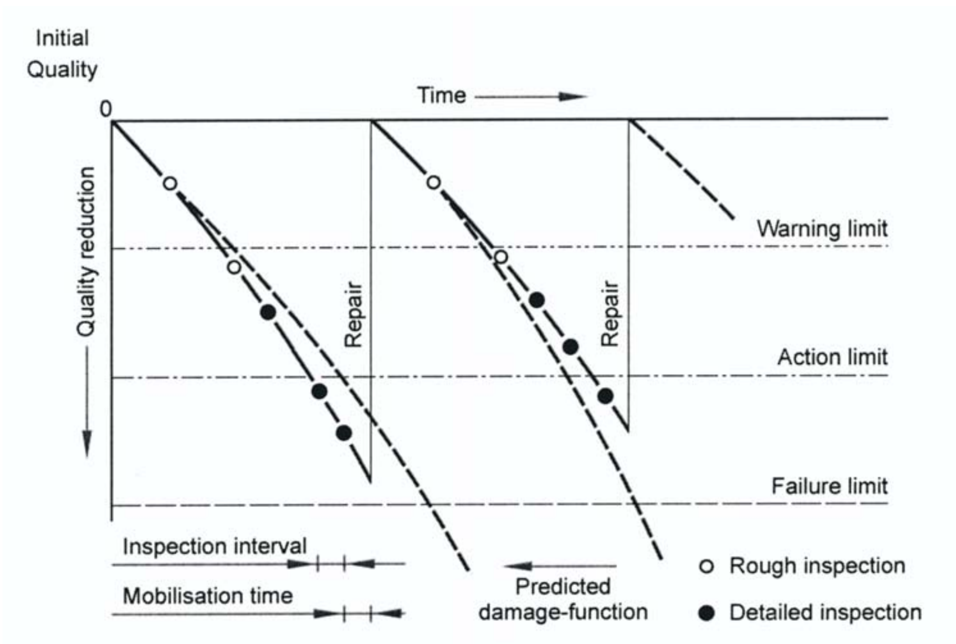

Fig. 3: Condition-based defence asset management (CIRIA/CUR, 1991)

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dition characterisation which is unambiguously related to performance levels and not just to a subjective assessment of structural condition.

Together, condition assessments and fragility curves can give an indication of the current and likely future ability of a structure to perform to its original design limits.

7. Performance Indicators used in NSR countries – similarities, differences and gaps

a. *Using assessments of future flood risk as a performance indicator.*

Most countries are considering a move from a safety standard approach towards flood risk assessment. This will be based not just on predictions of the probabilities of defence overtopping under given events but also on the flooding consequences and their assessment in socio-economic terms. However, so far only the United Kingdom and the Netherlands have made decisions to move towards this goal. Work still to be completed to enable such overall flood risk assessments to be carried out includes:

- obtaining appropriate data and/or setting up databases on defences and flood risk areas
- agreeing on national methodologies for flood risk assessment.

When such work is complete it should be possible to set up measures such as:

- **Effectiveness** of measures in reducing the economic value of national or regional assets at risk from flooding
- **Efficiency** of measures in reducing national or regional flood risk per Euro invested. This is the annual Benefit to Cost ratio for the national spend on flood risk management.

Such work will also enable the significance of a particular defence asset in providing flood risk reduction to be assessed.

b. *Geographic indicator of shoreline position.*

Most countries have some kind of objective in relation to the future shoreline position and are undertaking monitoring of that to identify whether the objective is being achieved or indeed is appropriate for the long term. The basic questions to be answered in terms of performance indicators are:

Where is the defence asset?
Is it moving, and at what rate?
Are these answers acceptable?

c. *Geometric indicators for shape and crest elevation of defences, including dunes*

The assessment of likely future loadings, whether an individual event or a more risk-based approach is a key condition for proper geometrical performance assessment. This includes predicting all sources risk, such as rainfall, river flow, wind, waves etc. This service includes:

- Development of design information for defences, based on data collection, analysis and prediction of river or sea conditions.
- Real time flood warning services for the public.

Given an understanding of the likely loadings, in most cases the performance indicator for defences is still set in rather deterministic terms as a maximum allowable overtopping rate (typically 2 l/s/m) not to be exceeded under a given design event.

In the future this will be modified as a more risk-based approach is adopted for linear defences, taken on a cell by cell basis. Key geometric performance indicators used to confirm acceptable performance include:

- Crest elevation. Both global settlement is assessed and also localised depressions which give rise to weak spots. In lower Saxony, for example, defences are designed for certain design conditions and crest levels are checked 20 years or more frequently
- Slope gradients (also used as a structural indicator of movement of defences)
- For sand dunes and beach systems, overall volumetric assessment of material within a defined geographical band is normally used

The basic questions to be answered can therefore be summarised as:

- What is the current level of risk associated with the defence asset?
- What is the geometry associated with that level of risk?
- Are these changing and at what rate?
- Are these answers acceptable?

Note that secondary defences are also important in some countries, designed to mitigate flooding should the main defences be overtopped. Performance objectives for such defences are quite variable.

d. *Structural indicators for the condition of the defences themselves and their vulnerability to breach under extreme loading.*

A wide range of approaches are adopted for assessing defence condition. These include

- Visual loss – exposure of clay
- Degree of clay deterioration/erosion
- Slope gradients. (In Germany, for example, a maximum slope of 1/3 is permitted)
- Piping and fissuring (tested by non – intrusive tests or by internal measurement)
- Assessments of safety factors against geotechnical failure

Whatever indicators are used, the basic questions to be answered are:

- What are the potential failure modes?
- What inspection, data collection and analysis are needed to assess these modes?
- What is the defence asset condition now and is it adequate for purpose?
- How quickly will the defence asset deteriorate?
- When will maintenance (or further inspection) be needed?

e. *Performance indicators for pumps and gates.*

More significant pump/gate assets have specific operations manuals setting detailed performance requirements. This may not be the case for smaller and/or older less significant assets. Where performance assessment guidance is provided, it usually requires answers to questions of the form:

- What is the pump/gate asset condition?
- What inspection, data collection and analysis is needed to facilitate assessment of pump/gate asset condition?
- How quickly will the pump/gate asset deteriorate and what is its future residual life?
- How frequently will inspection and/or maintenance be needed?

In most cases the overall performance requirements for barriers are:

- That their overtopping performance should be consistent with the associated linear defences
- That they should be closed properly and in time to defend against an extreme event.

In the case of pumps and culverts, the overall questions to be answered are more of the form:

- What flow capacity does the pump/gate asset provide?

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- Is the pump/gate asset actually available when needed?
- How reliable is the pump/gate asset when capacity is demanded of it?

f. *Objectives for reducing the consequences of flooding should it occur*

A wide range of objectives were noted here but include:

- Control of new property development in flood risk areas
- Educating and making the public aware of the possibility of flooding and its consequences.
- Flood proofing of properties by individual members of the public.
- Person and property emergency rescue. This includes the rescue of individuals, plus movement of valuable property to avoid damage.

The overall questions which the performance objectives and indicators need to be able to answer here is "What are the receptors and associated risk consequences and how have they changed?" For example, if flooding or coastal erosion occurs, then its impact will be affected by changes in:

- The degree of development in a flood risk area or area at risk from erosion.
- The ability to issue accurate flood or erosion risk warnings.
- The ability to respond to issued warnings, including moving flood prone people and goods out of the flood risk zone.
- The availability and speed with which temporary or demountable flood defences can be installed either as defences to individual properties or communities.

g. *Non-flood-risk objectives*

Most countries have other objectives other than flood risk reduction which they must also meet in the integrated management of their coastal zones. Some of these are legal requirements. They include:

- environmental acceptability, particularly in terms of reducing impacts on designated habitats, geological exposures, water quality, etc.
- contribution to public safety and reduction of social vulnerability
- amenity and tourism requirements
- sustainability objectives

The EU ICZM (Integrated Coastal Zone Management) Recommendation and the Water Framework Directive are expected to have a significant impact on such broader objectives

However, in these cases it is generally not possible to give clear expression for performance indicators. Rather the evaluation should be a more general one, examining the extent to which the original performance objectives have been met.

8. Appropriateness of performance indicators for needs of risk managers and planners

Most of the *outcome performance indicators* used by risk managers and planners in regard to flood risk reduction in the coastal regions of the North Sea seem to be appropriate for their purpose, particularly those which are focussed on the sources, pathways and receptors of flooding.

In most of the NSR countries there is some kind of national database in which flood risk management data is held. Generally this includes socio-economic and defence asset data and

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hydrodynamic data (perhaps real -time). In some cases there are also records of flood defence works and costs and information about planned works.

However, much of the raw data that are collected and stored in databases are, on the whole, not tailored to the needs of Performance Evaluation. Additional processing and / or data collection is generally needed to isolate specific performance indicators. Many of the databases were developed for other purposes and were now being adapted to meet the needs of risk and performance management; however, the information and even the structure of the databases is not necessarily ideal for this purpose.

Better performance indicators need to be developed to assess the social impacts of policy. Without such data and indicators, it is difficult to assess the impacts of a particular policy option on societal behaviour.

Some risk managers and planners also collect *output performance measures* (e.g. Defra High Level Targets in the United Kingdom.) These are mainly intended to monitor and audit the effectiveness and efficiency of the coastal management organisation in meeting operational targets. As such they do not refer directly to flood risk reduction and their role in assessing *outcome* performance is limited.

9. Concluding statements

1. Flood risk management (FRM) objectives come from national policy/law via strategic planning. *Outcome performance indicators* can be defined from FRM objectives.
2. Performance of linear defences (dikes) remains a key element of FRM; reliability analysis permits a consistent estimate of structure failure probability.
3. Whilst necessary, *output performance measures* of FRM organisations do not refer directly to flood risk reduction and their role in assessing *outcome* performance is limited.
4. More work is required to develop better and more consistent performance indicators in NSR countries, tailored to the policies and strategies being pursued.

10. Literature

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Hydraulic Boundary Conditions for Coastal Risk Management COMRISK Subproject 5

JOHANN DEKKER, AED WOLTERS, FRANK DEN HEIJER, SANDRA FRAIKIN

Summary

An inventory of the methods used to determine the hydraulic boundary conditions for the sea defences in the countries participating in the North Sea Coastal Managers Group was conducted. Based on the results of this inventory the various methods have been analysed and compared for a sea dike and a dune profile on the North Sea coast in The Netherlands. Though the general approach to determine the hydraulic boundary conditions is fairly similar, the differences in details of the methods can lead to crest heights that can vary several meters for the same return period. The approaches in the safety assessment of dune coasts are quite different, though a number of methods go back on the same research from the 1980-ies.

Due to these differences results of the various conducted risk-assessments are hardly comparable. The other way around, a common approach to risk assessment might thus lead to adaptations in safety-assessment methods in the various countries. On the other hand the knowledge questions, i.e. to reduce uncertainties in risk-analysis, are rather similar in the various countries. Joint research and further exchange of knowledge can and might lead to a convergence of the methods for risk assessment used in the various countries.

Zusammenfassung

Eine Bestandsaufnahme der Methoden zur Ermittlung der hydraulischen Randbedingungen für Küstenschutzbauwerke in den in der North Sea Coastal Managers Group vertretenen Ländern wurde durchgeführt. Basierend auf der Bestandsaufnahme wurden die verschiedenen Methoden vergleichend für einen Deich und eine Düne an der niederländischen Nordseeküste analysiert. Obwohl die Verfahren zur Bestimmung der Randbedingungen generell vergleichbar sind, können die Detailunterschiede in den angewandten Methoden zu Unterschieden von mehreren Metern in der resultierenden Deichhöhe für den gleichen Wiederkehrintervall führen. Die Verfahren zur Ermittlung der Sicherheitsstandards für Dünen variieren stark, obwohl mehrere Methoden auf die gleichen Forschungsergebnisse aus den frühen 1990ern beruhen.

Wegen dieser Unterschiede sind die Ergebnisse der durchgeführten Risikoanalysen kaum vergleichbar. Umgekehrt, ein gemeinsamer Ansatz zur Risikoanalyse kann zu Anpassungen bei den Ermittlungen der Sicherheitsstandards in den verschiedenen Ländern führen. Die Forschungsfragen hinsichtlich der Reduzierung der Unsicherheiten in Risikoanalysen sind in allen Ländern vergleichbar. Gemeinsame Forschung und weiterer Austausch von Erfahrungen können zu einer Harmonisierung der angewandten Ansätze zur Risikoanalyse in den Ländern führen.

Keywords

Coast, risk management, flood defence, hydraulic boundary conditions, dike design

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1. Introduction

In 1996 national and regional coastal defence authorities in the United Kingdom, Belgium, The Netherlands, Germany and Denmark initiated a high level network of co-operation, the North Sea Coastal Managers Group (NSCMG). It was realised that, in order to achieve a transfer of knowledge and a balanced approach, a more comprehensive trans-national co-operation about risk management throughout the North Sea Region is indispensable. The NSCMG initiated a study to make an inventory of the risks, adopted safety levels and used techniques with regard to flooding of coastal areas in five countries to improve communication on this subject between the partners (DWW, 2001).

This previous study covered many aspects of flood risk in coastal areas, ranging from policy aspects and safety levels adopted in the various countries to technical aspects of dike design. One of the conclusions of this study was that the structural aspect is closely related to the way hydraulic boundary conditions are assessed. It was recommended to study the total process of hydraulic conditions together with the structural aspect to allow better comparison of the safety standards and methods applied in the various countries. In such a study the scope should include the structural aspects of dikes and dunes.

In Subproject 5 the focus is on the more technical aspects related to the design and safety assessment of the sea defences. In this subproject the way that hydraulic boundary conditions for the sea defences are derived and used is compared. The Road and Hydraulic Engineering Division (DWW) of the Directorate-General of Public Works and Water Management (in short Rijkswaterstaat) is coordinator of this subproject. DWW contracted WL | Delft Hydraulics to assist in the inventory and comparison of the methods.

2. Approach

2.1 Inventory

Subproject 5 started in 2002 with an inventory of the methodologies adopted by the various partners to assess the hydraulic boundary conditions (water level and wave conditions) and the way these are used in the design and/or safety assessment of the sea defences. This inventory was based on the response on a questionnaire that was sent to the partners together with a description of the methodology in The Netherlands. The information received from the partners has been summarized in WL | Delft Hydraulics (2005).

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2.2 Analysis for selected locations

To get some more insight in possible reasons for the differences in the methodologies to determine the hydraulic boundary conditions, the results of the inventory have been brought a step further by comparing the results of the various methods. It would be interesting to see whether the heights of sea dikes in the six North Sea countries would be different if they were designed using the methodologies from other countries when adopting the same safety level.

Ideally all methods should be applied to a typical site in each of the partner countries. In this way differences due to different geography could be detected. This would mean 36 combinations of methods and sites, which was not feasible within the framework of the COMRISK project. The closest alternative was to apply all methods to a few selected sites. For practical reasons such as easy access to relevant data regarding water level, waves, wind and bathymetry, this was limited to sites in The Netherlands. Both a sea dike and a dune section have been considered. The following sites on the North Sea coast were selected:

– Petten sea defence, the sea dike near Petten,
– Dune coast at Callantsoog.

Both sites are in the province of North-Holland, north-northwest of Amsterdam. The location of these sites is shown in Fig. 1.

The Petten sea defence (Fig. 1, top right) is a sea dike with a crest at about 12.75 m above NAP (MSL). The lower part of the seaward side has a slope of 1:4.5, the upper part a slope of 1:3. Between those slopes is a 14 m wide berm at about 5.35 m above NAP. The inner slope is 1:3.

The dunes near Callantsoog consist of a single row with a width of about 100 m and a maximum height of about 20 m above NAP (Fig. 1, lower right).

Based on the information gathered through the questionnaires, the descriptions in earlier study (DWW, 2001) and other information (e.g. found on the website of the partners),

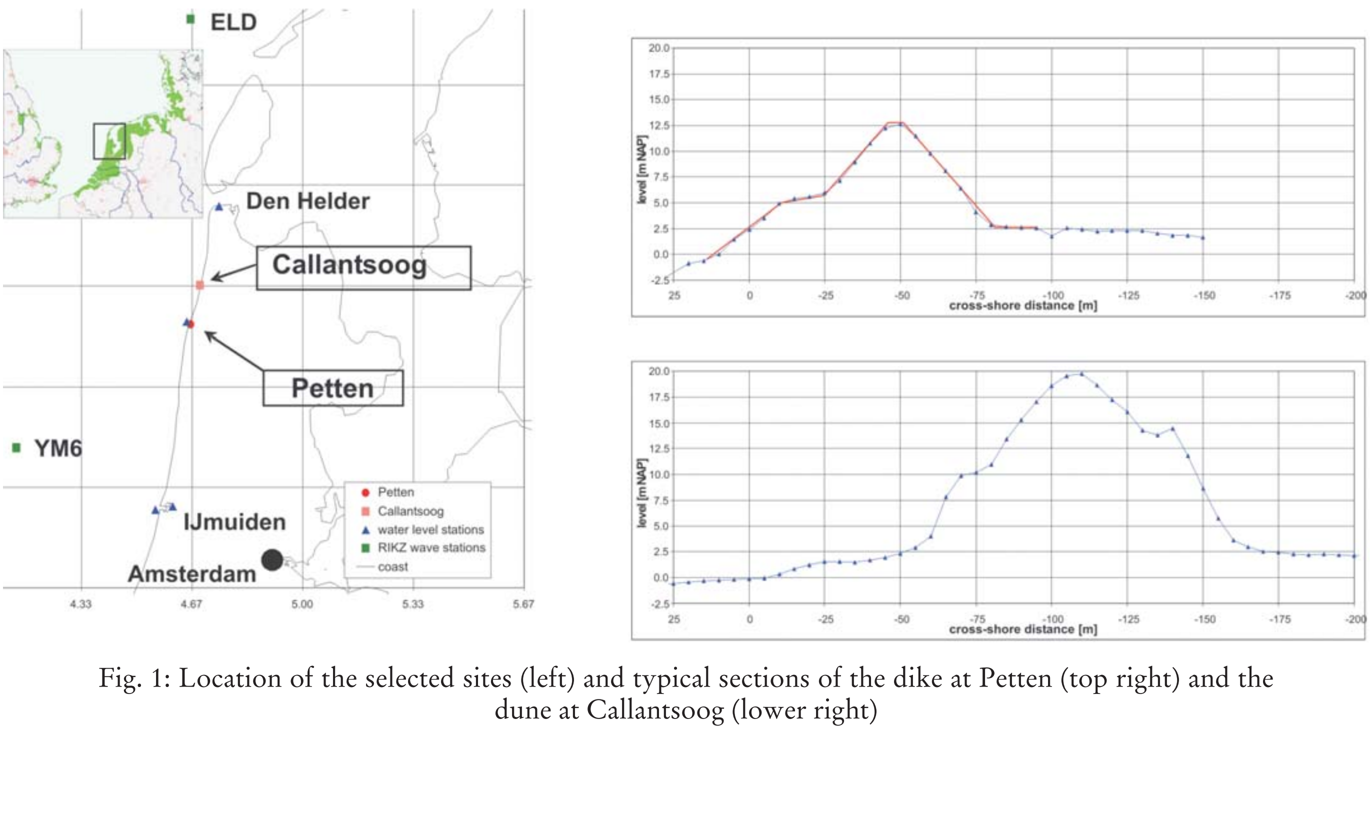

Fig. 1: Location of the selected sites (left) and typical sections of the dike at Petten (top right) and the dune at Callantsoog (lower right)

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the procedures used in the six countries are described and compared based on data for the selected sites of Petten and Callantsoog. The procedure to design or evaluate a sea dike generally consists of two steps: determination of the hydraulic boundary conditions at the toe of the dike and calculation of the required crest height. The safety assessment of sandy coasts involves similar steps, the main difference being that the wave conditions are usually required in deeper water. This study therefore compares first the way the hydraulic boundary conditions are derived. Water level and wave conditions are treated separately. Then the procedures to determine the required crest height are compared. This includes a comparison of formulae for wave run-up and overtopping. These are used to assess the required crest height for the Petten sea defence according to the various methods.

The comparison presented in this study is based on a deterministic approach. All countries are developing probabilistic techniques to support assessing the risk of flooding of coastal areas. Comparing these by application to a selected case was not feasible within the present study. However, aspects such as wave run-up and overtopping formulae and criteria for these factors are also key elements in probabilistic methods. Thus, the values given in this report can not be used for actual assessment of water levels, crest levels and so on, they are indicative values to study differences between approaches in the various countries. Risk assessment using probabilistic techniques has been conducted in some of the case studies treated in the COMRISK subprojects 6 to 9.

3. Hydraulic boundary conditions

3.1 Water levels

All countries have fairly extensive networks of water level stations. These are used as basis to determine extreme water levels required as input for design and safety assessment of the sea defences. The number of stations in the countries ranges from 3 in Belgium, which has a fairly short stretch of coast along the North Sea to about 40 in the United Kingdom and even more in Germany, which has a long coast line with various estuaries. National authorities gather the data and the available information goes for some stations back for more than 100 years.

Recent data are generally stored as 10-minute averages after a quality check. Before data are used to determine design conditions by extreme value analysis the historic data are corrected for trends in sea level and/or the tidal amplitude over period of observations. In this way each record can be considered to be representative for the present situation. In most of the countries the required water levels for design and safety assessment are determined using probabilistic methods. This can be based on extrapolation of observed water levels (e.g. Denmark and The Netherlands) or on extrapolation of measured surges that are combined with the tidal component (e.g. Belgium). In the United Kingdom each of these methods may be applied as the contractor carrying out the study can use his own methods. In Niedersachsen (Germany) a deterministic method is used, which combines the tide with the highest observed surge. Schleswig-Holstein (Germany) combines this deterministic method with the probabilistic approach by using the maximum of the two. Most countries increase the design level to account for factor such as local wind set-up and relative sea level rise.

The results of the various methods to assess the design water levels are summarised in Fig. 2. The most striking in this figure is of course the single value independent from the probability of occurrence following the method Niedersachsen. This is inherent to the design

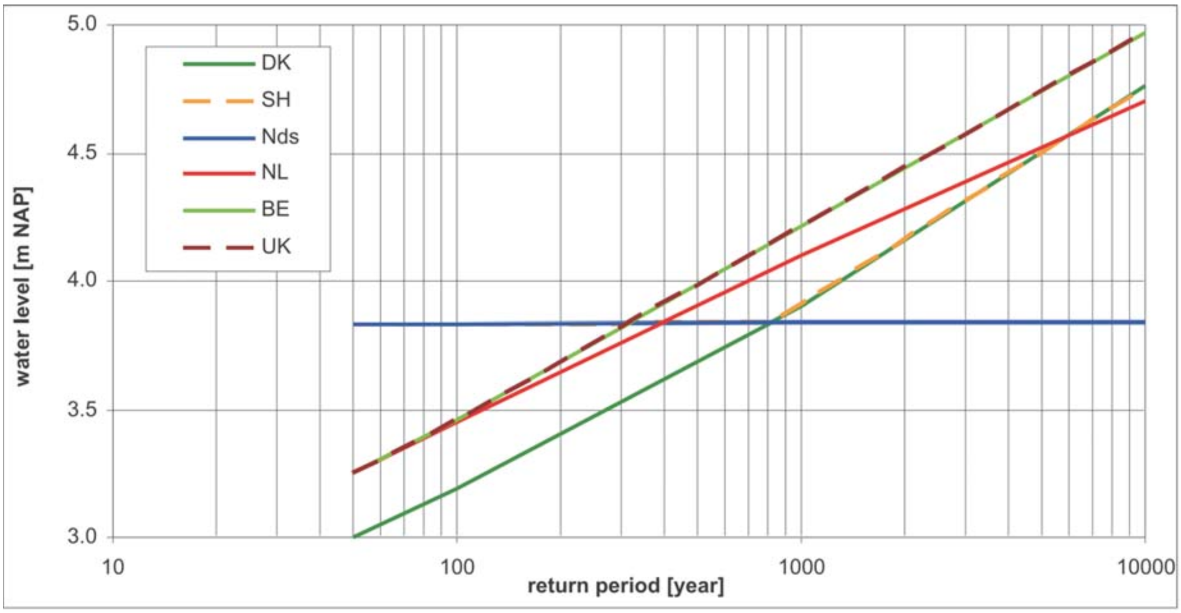

Fig. 2: Comparison of design water levels following different methods for Petten, The Netherlands

method *Einzelwert-Verfahren*, which "aims to avoid any exceedance" (quote from response to questionnaire; WL | Delft Hydraulics, 2005). It can be seen that the value for Petten following this method has a probability of occurrence between 1/400 (Dutch & Belgian method) and 1/800 (Danish method). In the comparison of methods for the Petten sea defence the results from the Belgian method have also been adopted for the United Kingdom.

It is further interesting to note that the water levels using the method of The Netherlands are for short return periods equal to those following the Belgian method, but for longer return periods closer to those from the Danish method. The differences between the results of these methods are in the order of 0.25 m, depending on the return period and method. For the longer return periods this is actually fairly small considering that the 95 %-confidence interval for the 1/10,000 year surge is in the order of 1 m. For the shorter return periods of 50 and 100 years, however, a better agreement was expected between the various methods. The difference for these return periods may be due to the use of not completely consistent data for the comparison (WL | Delft Hydraulics, 2005).

3.2 Wave conditions

Most countries use fairly similar methods to assess the wave conditions in the vicinity of the sea defences. Only Schleswig-Holstein has a quite different approach. Though deep water waves and wind are measured on a location off Sylt since 1984 (21 years) as a basis for sand nourishment, the nearshore design wave conditions are direct assessed by correlating with the still water level. The approach in the other countries is based on a statistical evaluation of deep water wave data (either from measurements or hindcast) combined with wave propagation modelling to determine the corresponding conditions near the coast. In The Netherlands and Belgium relatively long datasets of wave measurements in deep water are available (20-25 years), which allows extreme value analysis directly on the measured wave heights. In Denmark time series of 8 years are available for most of the wave gauges, while

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in the United Kingdom the available timeseries of wave measurements cover periods of 1 to 4 years. In these countries the wave measurements are combined with wind data that cover longer periods using hindcast techniques.

For this study the deep-water station Eierlandse Gat (ELD, see Fig. 1) is the reference relevant for the coast of Petten and Callantsoog. The official Dutch values extreme wave conditions for this station (RIKZ, 1995) have been compared with an independent analysis of the data. The resulting wave heights for the selected return periods are included Table 1. It can be seen that the difference in wave height is 0.3–0.5 m. As it appeared that this difference has no significant effect on the nearshore conditions near the Petten sea defence (the remaining difference is only 1–2 cm) other methods to assess the deep water wave conditions have not been tested. In the comparison the official values were used for the method of The Netherlands, the results of the independent analysis for all other methods.

Table 1: Extreme wave conditions at Eierlandse Gat adopted in the comparison

method	waves 1/50		waves 1/100		waves 1/1,000		waves 1/10,000	
	H_s [m]	T_m [s]	H_s [m]	T_m [s]	H_s [m]	T_m [s]	H_s [m]	T_m [s]
NL	8.05	9.5	8.37	9.7	9.24	10.2	10.00	10.6
other	7.52		7.82		8.80		9.72	

As mentioned above, all countries except Schleswig-Holstein use numerical models to determine the design wave conditions at the toe of the sea defences. Within the scope of the present comparison of methods it was not feasible to carry out wave propagation simulations with the various models used in the different countries. Instead, the wave conditions at the toe of the Petten sea defence were determined by interpolation in the results of a large number of wave runs with the model SWAN, that have been stored in a database. This database contains for a large number of locations the characteristic wave parameters (H_{m0}, T_p, T_{m02}, $T_{m\text{-}2\text{-}1}$, direction) of SWAN runs for 3 water levels, 14 wind directions and 5–7 combinations of wind speed and offshore wave conditions. Based on the derived water level and deep water wave height, the significant wave height H_{m0}, mean wave period T_{m02} and the peak wave period T_p near the Petten sea defence were determined by bilinear interpolation from the results for the wind and wave direction 285 °N, which is the most unfavourable direction in this location. The results are shown in Table 2. It appeared that the results were fairly insensitive to the deep water wave height and that the water level is in fact governing the nearshore wave conditions. This is illustrated by the results for Niedersachsen, for which the water level is the same for all return periods.

In Schleswig-Holstein the nearshore wave conditions are determined by correlation with the water level using the following relations:

$$H_{1/3} = (SWL - DZ) * Gr$$
$$T_z = a + b * H_{1/3}$$

where $H_{1/3}$ is the significant wave height and T_z is the mean zero-crossing wave period. The coefficients DZ, Gr, a and b are parameters determined based on measurements. For the present comparison these parameters have been derived based on measurements from the Petten site for the season 2003–2004 (RIKZ, 2004). The results are included in Table 2. It is remarkable that the wave heights are significantly higher than those based on the SWAN simulations.

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Table 2: Wave conditions at the toe of the Petten sea defence.

method	waves 1/50		waves 1/100		waves 1/1000		waves 1/10000	
	H_s [m]	T_{m02} [s]	H_s [m]	T_{m02} [s]	H_s [m]	T_{m02} [s]	H_s [m]	T_{m02} [s]
DK	2.61	6.56	2.74	6.66	3.19	6.93	3.69	7.15
SH	3.53	6.68	3.53	6.68	3.58	6.74	4.18	7.39
Nds	3.12	6.84	3.13	6.88	3.15	6.91	3.16	6.84
NL	2.78	6.71	2.91	6.80	3.31	6.97	3.66	7.11
B	2.76	6.64	2.90	6.75	3.37	7.03	3.80	7.22
UK	2.76	6.64	2.90	6.75	3.37	7.03	3.80	7.22

3.3 Wave periods

The database provides the spectral wave periods T_{m02}, $T_{m\text{-}2\text{-}1}$ and T_p whereas the datafiles from the field measurements at Petten that were available provide the wave periods T_{m02} and $T_{H1/3}$. The formulae for wave run-up and overtopping that are used in the various countries contain characteristic wave periods that are not directly available. These wave periods have therefore been determined by assuming a certain constant ratio between different wave periods.

The formula for wave run-up used in Denmark contains the wave period T_m (DWW, 2001), without providing the definition. ANDERSEN (1998) gives the same formula with $\hat{T}$, also without defining this parameter. Here the expression from DWW has been adopted, as this reference provides also values for the coefficients in the equation. The wave period T_m was approximated by $T_p/1.15$, similar to the relation adopted in DWW (2001).

In the overtopping formulae used in Schleswig-Holstein, Niedersachsen and the United Kingdom the mean wave period T_m is used. This is the mean period of the waves in time domain also known as the zero-crossing period T_z. This characteristic wave period is not available in the database. Energy balance models such as SWAN can only provide wave periods in the frequency domain such as T_p, T_{m-10}, T_{m01} and T_{m02}. For the present study relations between time-domain period T_m and the frequency domain periods T_p and T_{m01} have been derived from flume test on the Petten profile that were performed for a large range of conditions (WL | Delft Hydraulics, 1999). The ratio between T_m and T_p shows a fairly large range, but seems to depend on the ratio of H_{m0} over the water depth. Based on the results of tests for conditions similar to the extreme hydraulic conditions used in the comparison a ratio of $T_p/T_m = 1.45$ has been adopted in this study. As the ratio T_p/T_{m02} for the most relevant conditions in the database was around 2, the ratio T_m/T_{m02} was taken as 1.4.

The formulae for wave overtopping applied in The Netherlands and Belgium use the spectral mean period T_{m-10}. This period is not available within the database. The ratio between T_{m-10} and T_{m02} depends largely on the spectral shape. For the present comparison the ratio has been estimated based on the nearshore measurements at the Petten site. From graphs presenting T_{m02} and T_{m-10} for two storms in the season 2003–2004 (RIKZ, 2004) it can be seen that the ratio between the two is quite different before, at and after the peak of the storm. At the peak of the storm the ratio T_{m-10}/T_{m02} is about 1.6–1.7. Before the peak the ratio is smaller, after the peak, the ratio is larger. For the comparison of the various methods a ratio of 1.65 has been adopted. This value is rather large, but this is because the wave spectra at the toe are non-standard spectra.

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4. Approaches to dike evaluation/design

4.1 Comparison of methods

All partners determine the crest height from the design water level and the wave conditions near the sea defence. In the safety assessment of existing coastal defences additional margins are in some countries included for factors such as long waves, harbour resonance and trends in the sea level. In the design of new dike sections factors such as sea-level rise and the expected subsidence of the crest is taken into account.

The required height to account for waves is determined using a criterion either for wave run-up (DK, SH, Nds) or for wave overtopping (SH, NL, B, UK). For the wave run-up criteria, the run-up height follows directly from the formulas for wave run-up, which read in general form

$$Z_{n\%} = C\,\gamma_i\,\sqrt{H_s}\,T\tan\alpha \tag{1}$$

where $Z_{n\%}$ is the run-up level exceeded by n% of the waves, C is a coefficient, γ_i reduction factors for effects such as slope roughness, berms and angle of wave attack.

To allow comparison of the formulas for run-up and overtopping, the wave overtopping formulas have been rewritten to obtain a direct expression for the required crest level above the still water line. Where the general shape of the formulas for the overtopping rate is

$$q = c_1 \frac{\gamma_i H_s T}{\sqrt{\cot\alpha}} \exp\left(-c_2 \frac{R_c \cot\alpha}{\gamma_i \sqrt{H_s} T} \right) \tag{2}$$

with a maximum of

$$q = c_3 \sqrt{H_s^3} \exp\left(-c_4 \frac{R_c}{\gamma_i H_s} \right) \tag{3}$$

where q is the overtopping rate, R_c the crest height above the still water level and c_1, c_2, c_3 and c_4 are coefficients. Rewriting these equations, it follows that the crest level above the still water line as function of the criterion for the overtopping rate and the wave conditions is given by

$$R_c = -c_2 \gamma_i \frac{\sqrt{H_s} T}{\cot\alpha} \ln\left(c_1 \frac{q\sqrt{\cot\alpha}}{\gamma_i H_s T} \right) \tag{4}$$

with a maximum of

$$R_c = -c_4 \gamma_i H_s \ln\left(c_3 \frac{q}{\sqrt{H_s^3}} \right) \tag{5}$$

The expressions for the wave run-up and wave overtopping that are used in the different countries have been compared by calculating the required crest level above the still water line as function of the wave height. This comparison is carried out for a straight smooth 1:4 slope.

This is similar to the representative slope of the Petten sea defence under design conditions. The effects of berms, surface roughness, shallow foreshores or wave attack under an angle with the dike have not been considered.

The wave periods corresponding to the significant wave height have been calculated assuming JONSWAP type spectrum with •$_0$ = 3.3. (It should be noted that the spectral shape in shallow water close to the dike is usually significantly different due to breaking.) The peak wave period has been calculated using the relation $T_p = C\sqrt{H_s}$ in which C is 4.5 corresponding to a wave steepness of s_p = 0.03. Other wave period parameters (e.g. T_m and T_{m-10}) have been calculated from the peak period using the relations $T_m = T_{m02} = T_p/1.28634$ and $T_{m-10} = T_p/1.10706$.

For this combination of slope and wave conditions (steepness) the overtopping formulae for breaking waves are governing. The left panel of Fig. 3 shows that the required relative crest levels show a considerable scatter. The ratio between the highest and lowest value is in the order of 1.5, which means a difference in crest height of several meters for a significant wave height of 2–3 m. To compare the formula for non-breaking waves, the required crest levels were computed for a slope of 1:2.5. The right panel of Fig. 3 shows again the large spread in the crest level required to have the same amount of overtopping. It is interesting to note that the formulae used in Niedersachsen and The Netherlands give nearly the same results in this case. Note that in Belgium the formulae from The Netherlands are used.

One of the obvious observations from the figures above is that the shape of the curves for the relation $H_s - R_c$ for methods based on wave run-up is different to those based on wave overtopping. The curves based on wave run-up show a linear relation, whereas the curves for overtopping criteria show a non-linear relation: the required crest level is progressively increasing with the significant wave height.

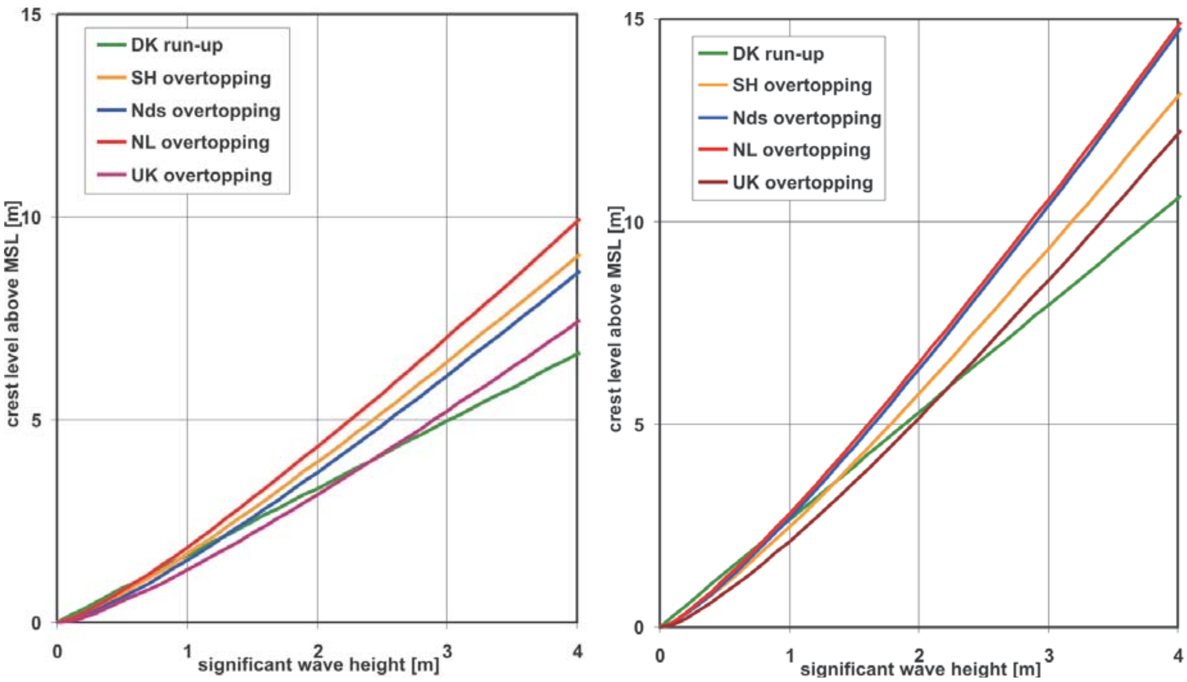


Fig. 3: Comparison of the crest level above MSL for breaking (left) and non-breaking (right) waves following different methods

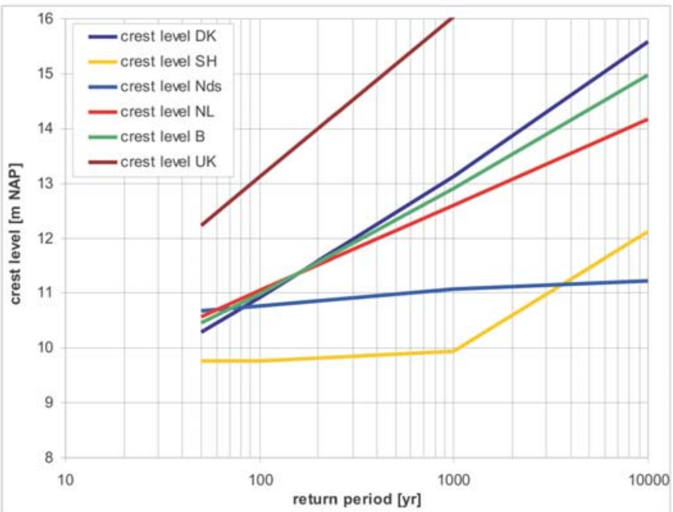
It is further interesting to note that the different countries make different distinctions in their criteria for wave overtopping. Denmark is the only country where the angle of the inner slope is an explicit factor in the allowable percentage of overtopping. Both Denmark and The Netherlands have further different criteria depending on the quality of the top layer of the inner slope for grass dikes, whereas other countries use a single criterion.

The required hydraulic boundary conditions for the various applied methods to assess the design height of the sea defences are the water level and the wave height and period at the toe of the sea dike. The wave height parameter can be H_s or H_{m0}; the difference between these two is usually not very large. For the wave period different characteristic parameters are being used of which the mean period T_m is mostly used (DK, SH, UK). Other characteristic periods that are used are the peak period T_p (Nds) and the spectral mean wave period T_{m-10} (NL, B and recently in Nds).

4.2 The height of the Petten sea defence

The formulae for wave run-up and overtopping were applied to the data for the Petten sea defence to assess the required height of this sea defence. Where the comparison of the various formulae in Section 4.1 was carried out without the effects of reduction factors for roughness, berm etc., it was ensured that the right corrections were included when applying the formulae to the Petten sea defence. It was found that these reduction factors are calculated differently in the various methods, especially the factors for the effect of a berm and for the effect of the angle of wave attack. The latter has no influence on this comparison as the waves are assumed to approach the coast perpendicularly.

The required crest levels according to the various methods are shown in left panel of Fig. 4. This comparison is based on the water levels, wave conditions, run-up or overtopping formula and associated criteria for run-up or the overtopping discharges as applied in the six countries. Note that for Niedersachsen accidentally overtopping has been considered instead of run-up.



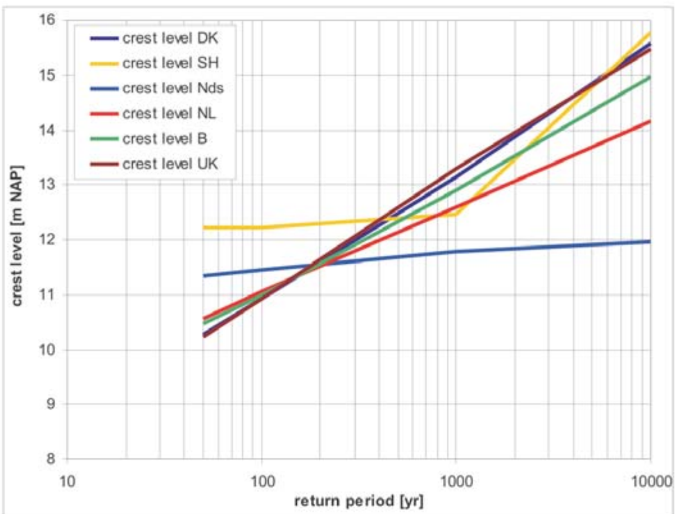


Fig. 4: Required crest level above NAP (·MSL) for the Petten sea defence following different methods; left panel: basic comparison, right panel: comparison of modified methods for SH, Nds and UK (see text)

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It can be seen that three methods give results that differ up to about 1m, three other methods show much larger differences. The fairly flat line for Niedersachsen is caused by the design water level, which is independent of the return period. Investigation of the large differences for Schleswig-Holstein, Niedersachsen and the UK showed that these could be traced back to a few specific factors that are discussed below.

For Schleswig-Holstein three factors cause a large part of the differences. The first factor is the reduction factor for a shallow foreshore that is applied in agreement with the original expression by Van der Meer (TAW, 1999). This factor (approx. 0.83), which causes the difference between the results for 50 and 100 year for Schleswig-Holstein and Niedersachsen, has not been included in the most recent formulae used in the Netherlands (TAW, 2002), as the use of another representative wave period (T_{m-10}) left insufficient evidence for retaining this factor. The Schleswig-Holstein expression for non-breaking waves includes further a reduction factor for a berm, a factor that is not included in the formulae for non-breaking waves from other countries. Finally, the formula for breaking waves contains a factor $1.25T_m$ to approximate the peak period T_a in the original expression of Van der Meer (TAW, 1999) on which the formula of Schleswig-Holstein is based. As mentioned above, this factor is more in the order of 1.45 for the considered conditions at Petten. The right panel of Fig. 4 shows the required crest level with these three modifications to the expressions of Schleswig-Holstein. It can be seen that the results are more in line with those of the other countries.

The expression for overtopping given in the EAK (2002) appears to contain the factor $\cot\alpha$ where several similar equations for the other countries have the square root of this factor on the same position (see Eq. 4). Using the square root leads to a higher crest level as shown in the right panel of Fig. 4.

For the United Kingdom the main cause of the differences seems to be the way the representative slope is calculated in the presence of a berm. Following the expression used in the United Kingdom this slope is around 3.2, whereas other methods lead to values around 4.0. This has a significant effect on the required crest level as can be seen in the right panel of Fig. 4, where the expressions from the United Kingdom have been combined with the Dutch equation for the effect of a berm. The line for the United Kingdom nearly coincides with the curve for Denmark.

Fig. 4 shows further that the methods of Denmark, The Netherlands and Belgium give fairly similar results for shorter return periods, but for the longer return periods the differences are increasingly larger. For the return period of 10,000 years the difference is up to 1.5 m. As the overtopping formulae are the same, the different results for the methods of Belgium and The Netherlands are entirely caused by the difference in water level: the 0.27 m higher water level leads to a 0.8 m higher required crest height (10,000 year return period).

The results of the various methods were further analysed by varying certain input parameters and criteria so that these are gradually the same for all methods. Using the same hydraulic input conditions (water level and waves) in the (modified) methods appears to lead to fairly small differences between the results (Fig. 5, left panel). Note that for each method the appropriate characteristic wave period has been used. These were all based on the same deep water conditions, the SWAN results in the database and the ratios between these characteristic periods mentioned in section 3.3.

Using both the same hydraulic boundary conditions and the same criteria for wave overtopping (2 l/s/m) and a comparable criterion for run-up (2 % run-up level) clearly increases the differences in the required crest level (Fig 5, right panel). It can be seen that increasing the overtopping criterion from 1 l/s/m to 2 l/s/m (Nds, NL, B methods) leads to crest heights that are lower by about 1 m. Given the fairly explicit statement in e.g. the German guidelines

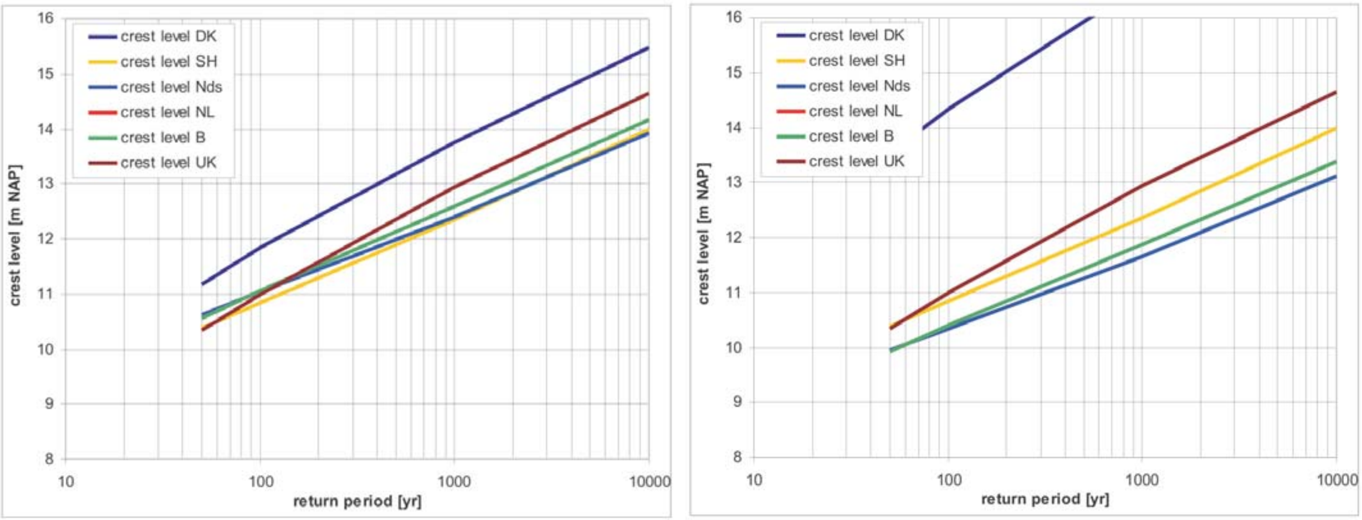

Fig. 5: Required crest levels above NAP with the same hydraulic boundary conditions (left panel) and with the same hydraulic boundary conditions and the same criteria (right panel)

(EAK, 2002) that "the criteria must be used with utmost care" and that "further research is required to complete" the information "and to specify the criteria with greater accuracy" this seems to be one of the larger gaps in present knowledge regarding sea dikes.

If the safety level adopted in the countries is also taken into consideration, the difference in crest level is even larger. The safety level adopted in Denmark is between 50 and 200 yr, in The Netherlands 2,000, 4,000 or 10,000 yr and in Belgium 1,000 yr. In the United Kingdom a cost-effective solution is determined without adopting a specific uniform safety level.

From the comparison and the analysis it appeared further that it is important that the formulae are used with the appropriate characteristic wave period. In the nearshore zone often adopted relations between the various characteristic wave periods based on a standard spectral shape such as a JONSWAP spectrum are not valid and their use may lead to erroneous results for the required crest height.

Testing the sensitivity of the crest height for the wave height and the wave period it appears that a 10 % different wave period has for the Petten sea defence a larger effect on the required crest height than a 10 % higher wave height. If wave propagation models are used to assess the conditions at the toe of the dike, it is therefore important that the model not only predicts the wave heights well; a correct prediction of the characteristic wave period is even more important. This means for generally applied wave models such as MIKE21 and SWAN that they must capable of accurately predicting the spectral shape in complex shallow water areas. It is known that e.g. SWAN has to be improved in this aspect.

5. Approaches to the safety assessment of dunes

5.1 Description of methods

Denmark uses a fairly simple criterion for the safety assessment of the dunes. These must have a minimum width of 40 m at a height of 5 m above MSL for unprotected dunes and 30 m for dunes protected by a revetment.

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In Schleswig-Holstein the sandy coasts are not included in the regular assessment of safety against flooding. This is due to the different concept adopted here. According to the coastal defence concept no dune erosion is allowed at all. Where necessary sand depots are created high on the beach which should be sufficient to prevent erosion of the actual dunes under design conditions. Calculations of the cross-shore transport are carried out to assess the required reserve of sand on the beach.

In Niedersachsen numerical simulations are used to determine the dune erosion during a design storm. Up to 2003 the model NEWDUNE was used. This model is comparable with the model EDUNE by KRIEBEL (1989), which is briefly described in (EAK, 2002). The NEWDUNE model was developed by Newe at LWI University of Braunschweig. NEWDUNE is based on an equilibrium profile. The transition slope in deeper water of 1:12.5 and the 1:1 slope of the dune above the zone of wave attack are taken after VELLINGA (1983). Since 2003/2004 the numerical model UNIBEST-DE (English version of DUROSTA; STEETZEL, 1993) is used in addition to the NEWDUNE model. The experience in Niedersachsen shows that both models give comparable results for design conditions, but that NEWDUNE overestimates the erosion for more regular events. After the numerical simulations are carried out the remaining dune width at a level of NN+8 m (approx. 8 m above MSL) is taken as an indicator for the strength of the considered dune profile. A width of 15 m remaining after a simulated storm surge event is judged to be sufficient.

The method to calculate dune erosion in The Netherlands (and also in Belgium) is based on an equilibrium profile after VELLINGA (1983) consisting of a dune front with a slope of 1:1 above the water line, a parabolic beach profile of to a depth of about $0.75H_{0,s}$ and a the transition to the original seabed on the seaward side with a slope of 1:12.5 (Fig. 6, top). This

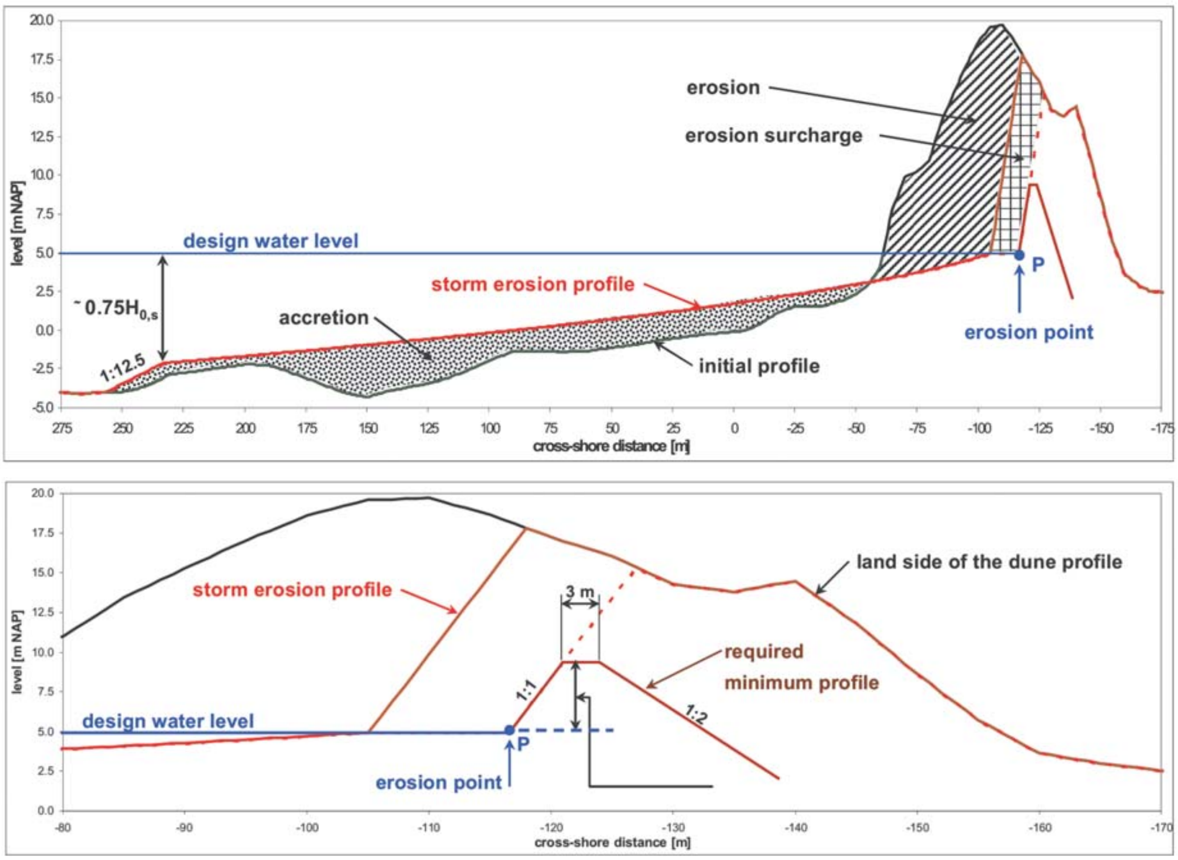

Fig. 6: Principles of the calculation of the profile after dune erosion in The Netherlands

equilibrium profile is fitted to the cross-section of the dune in such a way that the amount of erosion of the dune is equal to the amount of deposition below the water level. An additional amount of erosion equal to 25 % of the erosion above the still water level is added to account for the uncertainty in storm duration and the inaccuracy of the model. The remaining profile must have certain minimum dimensions (Fig. 6, bottom).

In the United Kingdom the dune erosion is considered to be part of the beach response to storms. Both numerical and physical models are used to predict the beach response to extreme conditions. A certain length of retreat implies failure.

Several countries use methods or criteria for dune erosion that are based on the method developed by VELLINGA (1983). This method has been derived for peak wave periods up to 12 s. A few years ago it was recognized in The Netherlands, based on much longer time series, that longer wave periods have to be taken into account for the design conditions. Recent small-scale flume tests have shown that the erosion is significantly more for longer wave periods. The method to determine dune erosion after VELLINGA (1983) is not valid for these longer periods. Further research and development of new procedures to calculate dune erosion more accurately for these conditions is therefore relevant.

5.2 The strength of the Callantsoog dune profile

The methods to assess the strength of the dune profile from Denmark and The Netherlands have been compared for the selected profile at Callantsoog. The numerical method used in Niedersachsen was not available. The erosion according to the method of The Netherlands was computed using UCIT (Universal Coastal Intelligence Toolkit), a program developed at WL | Delft Hydraulics for coastal management applications. In UCIT the erosion can be calculated for a few selected return periods between 500 and 10,000 years. The result is shown in Fig. 7.

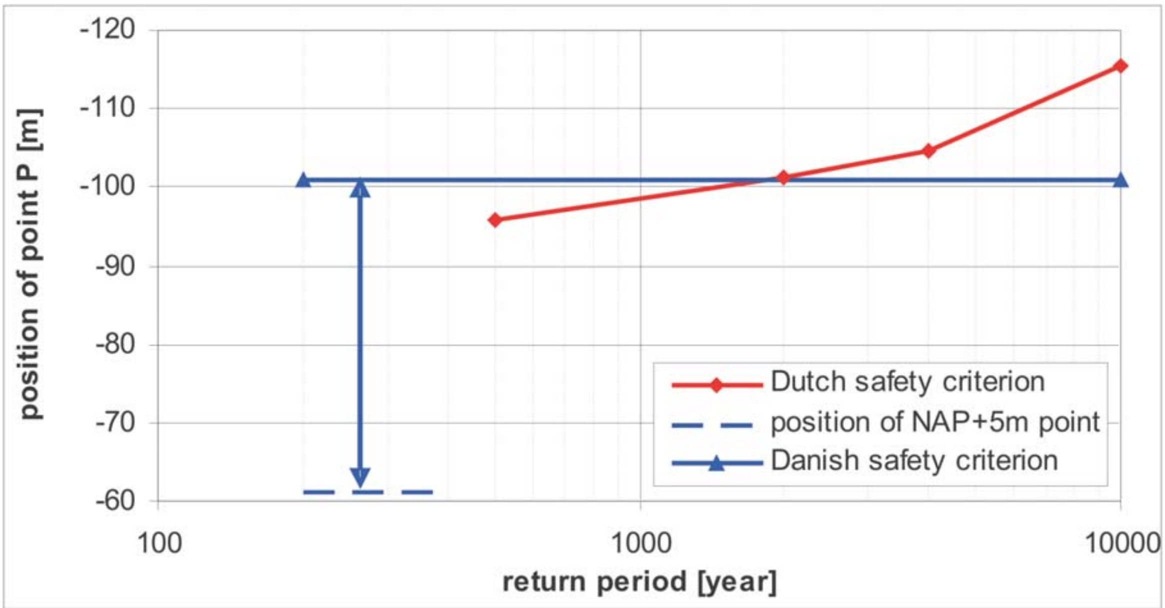

Fig. 7: Comparison of the Dutch and Danish safety criteria for dune erosion for the profile at Callantsoog

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As Denmark uses a safety levels in the order of 100 years and the probability of the deterministic design water level in Niedersachsen is in the order of 400–800 years, the criteria for dune erosion in these countries have been compared with the calculated erosion according to the original method in The Netherlands for a return period of 500 years (Fig. 8). It appears that the dune width at NAP+5 m is about 95 m, which is well above the Danish criterion of 40 m at a level of 5 m above MSL. The Danish criterion of 40 m is just equal to the calculated retreat of the dunefront following the Dutch method for a 2,000 year return period. This indicates that the criterion seems to be adequate for the safety levels usually adopted in Denmark, but that depends also on the height of the dune: for a dune with the same width but a lower height the retreat according to the Dutch method would be larger. For the safety level adopted in The Netherlands (10,000 years) the Danish criterion would be insufficient.

The indicator used in Niedersachsen, the remaining width at 8 m above MSL, is for the 500 year return period close to 50 m. This is well above the criterion of 15 m used that is applied in Niedersachsen. For the 10,000 year return period the remaining width at NAP + 8 m is about 30 m, still sufficient according to the criterion applied in Niedersachsen.

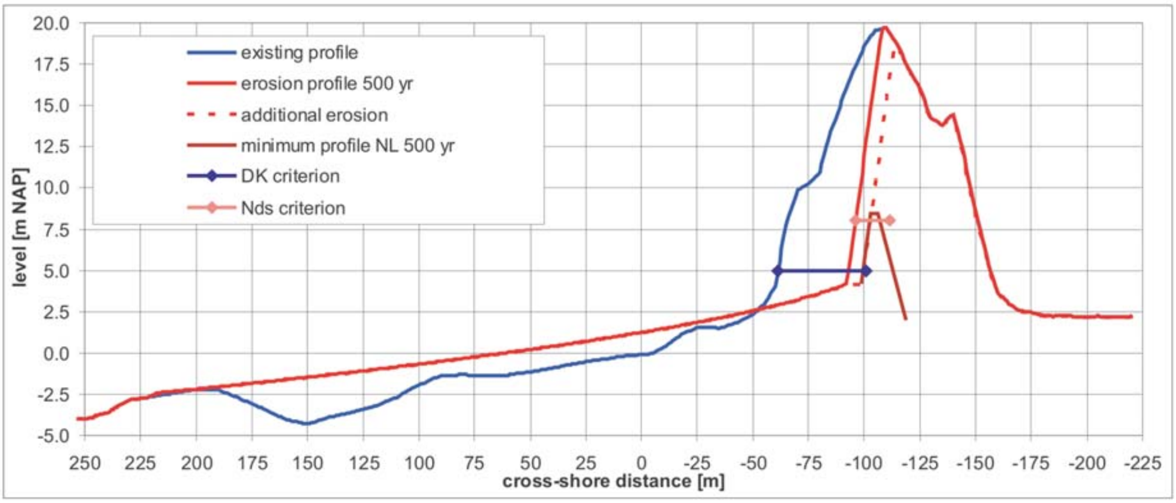

Fig. 8: Comparison of the calculated dune erosion for the Callantsoog dune profile according to the Dutch method with criteria for Denmark, Niedersachsen and The Netherlands (500 yr return period)

6. Discussion, conclusions and recommendations

6.1 Discussion

From the comparison of the various methods to assess the hydraulic boundary conditions and their use for safety assessment of the sea defences it can be concluded that the general approach in the North Sea countries is fairly similar. The boundary conditions are usually obtained by statistical evaluation and extrapolation of water levels and deep-water wave conditions followed by numerical modelling to obtain the wave conditions nearshore. The results are used in fairly similar expressions for run-up and overtopping. The differences are mostly in the details such as coefficients and some specific aspects of the applications.

Water levels at different return periods are usually based on extrapolation of long time-series of measured data. Remarkable here is the method used in Niedersachsen which leads to a single design level irrespective of the probability. This is not suitable in a risk-based approach. In the method used in Denmark to predict water levels for extreme events, different statistical distributions are used for different locations (Weibull and Log-Normal) depending on the quality of the fit.

The different methods to assess the design water levels lead to differences in the water level of 20–30 cm. For the shorter return periods, that are similar to the period of observations, this is more than might be expected. This may be caused by differences in the used data. For the longer return periods of 1,000 and 10,000 years the difference of 20–30 cm is not very large considering that the confidence interval which is in the order of 1m for these return periods. The fairly small difference in water level may have larger effects on the required crest level due to the effect that this difference has on the wave height near the toe of sea dikes and subsequently on the wave run-up and overtopping. For the Petten sea defence a difference in water level thus leads to a difference in crest height of 0.6–1.0 m.

The formulae to determine the required crest height of the dikes use the wave conditions at the toe of the structure as input parameter. These wave conditions are often limited by the local water depth. In the commonly adopted method to determine the wave conditions at the toe of the sea dikes using numerical models, the design water level and the applied model are factors determining for the nearshore wave conditions. In these depth-limited conditions the deep-water wave conditions has a negligible influence on the nearshore conditions. The quality of the input for the crest level calculation depends therefore largely on the ability of the model to predict the correct wave height and the required characteristic wave period.

From the comparison of the various methods to determine the required crest height of the Petten sea defence it is concluded that the different methods lead to crest heights that vary in the order of magnitude of meters for the same return period. This confirms the results of the earlier study (DWW, 2001). The largest differences are caused by the formulae used to calculate wave run-up and overtopping. If some specific factors in the formulae are modified and the same hydraulic boundary conditions are used, the remaining difference is still in the order of 1 m. but a difference of a few decimetres in the water level or a different overtopping criterion lead also to differences in crest height in the order of 1 m.

The countries use different overtopping criteria for their sea dikes. The guidelines used in Germany and the United Kingdom give rather vague ranges for the conditions were damage may occur. Denmark and The Netherlands give clear criteria, which depend on the condition of the toplayer of the dike. These criteria require a somewhat subjective judgement of the quality of the grass cover and sand/clay layer in which the grass grows. The choice of the overtopping criteria is therefore to some extent a subjective decision and can be a reason for differences, especially because the required crest level is fairly sensitive to the applied criterion. Increasing the allowable overtopping rate from 1 l/s/m to 2 l/s/m leads for Petten to a crest height that is 0.6–1.0 m lower; a more strict run-up criterion of 2 % instead of 10 % in the Danish method leads to a crest that is about 3 m higher.

Even if the dike fails to meet the given criterion for overtopping or run-up, the dike does not necessarily fail immediately. The structure still has a certain remaining strength. For the development of risk-based approaches it is necessary to obtain more insight into the criteria for overtopping and run-up and the remaining strength once these are exceeded.

The approaches to the safety assessment of sandy coasts are quite different and range from time-dependent simulation of dune erosion (Niedersachsen) via an equilibrium profile method (The Netherlands, Belgium) to a simple criterion for the required width of the dunes (Denmark), though the latter is also based on erosion estimates using an equilibrium profile. The fixed criterion for the dune width used in Denmark is not related to a probability of exceedance. This is not suitable in a risk-based approach of flooding.

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Several countries use methods or criteria for dune erosion that are based on the method developed by VELLINGA for wave periods up to 12 s (1983). Recent studies have shown that the erosion is significantly more for longer wave periods. Further research and development of new procedures to calculate dune erosion more accurately for these conditions is therefore relevant.

6.2 Conclusions and recommendations

Based on the comparison and analysis of the applied methods to determine the hydraulic boundary conditions and their use in the safety assessment of the sea defences the following general conclusions can be drawn:

- The methods used in the various countries to determine the required crest level lead to dike heights that can vary several meters for the same return period.
- Major factors for these differences in the crest height of sea dikes are:
  - The statistical methods to assess the design water level;
  - The quality of the prediction of the wave parameters at the toe of the dike;
  - The run-up and overtopping formulae including specific reduction factors and the way the representative slope is calculated for compound slopes and berms;
  - The strength criteria for overtopping and run-up.
- For the safety assessment of sandy coasts several countries use methods based on the work of VELLINGA (1983). The way in which this has been implemented in tools and criteria is quite different.
- Due to differences in methods adopted to determine the hydraulic boundary conditions and the strength criteria the results of risk assessments are hardly comparable. The other way around, a common approach to risk assessment might thus lead to adaptations in dike design in the various countries.

Based on the above conclusions the following general recommendations can be made:

- To further improve insight in the differences in the various methods to determine the hydraulic boundary conditions and in the strength formulations combined research, either in joint projects or by exchange of results, is recommended. On the longer term, this might lead to a convergence of the methods for risk assessment used in the various countries. Relevant aspects may include:
  - Statistical methods for determination of design water level for very long return periods;
  - Improving the quality of wave modelling tools by extensive validation for typical applications such as open coasts, estuaries and Wadden sea areas, including exchange of data for this purpose;
  - Development for better defined criteria for wave run-up / overtopping that leave less opportunity for subjective choices and that have a clear relation with the actual risk of failure and flooding.
- To obtain more insight into differences due to the geographical situation in each country, it is recommended to carry out a comparative risk analysis using a single method to derive hydraulic boundary conditions for a number of selected sites in the countries of the North Sea Coastal Managers Group.

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Risk Assessment for Flanders COMRISK Subproject 6

Toon Verwaest, Koen Trouw

Summary

The coastal lowlands of the Belgian region Vlaanderen and the Dutch region Zeeuws-Vlaanderen constitute one cross-border flood unit. If a dike breaches in the Dutch part of this flood unit, the water might well flow into Belgium and vice versa.

This paper presents the results of a case study of calculation of coastal flooding risk for a cross-border coastal flood unit from Zeebrugge in Belgium (Vlaanderen) to Breskens in the Netherlands (Zeeuws-Vlaanderen), abbreviated within the COMRISK project as the „Flanders“ case study area. The goal of the study was to investigate how good a flood risk assessment can be done with state of the art knowledge. The approach chosen was to do a case study with the available risk assessment methods and to evaluate the effects of the different sources of uncertainties by means of a sensitivity analysis.

Hydrometeorological boundary conditions characterising extreme storm events were analysed. The return period of an extreme storm resulting in serious flooding is of the order of magnitude of 1.000 years or more, whereas data of hydrometeorological characteristics of storms are limited to a series of less than 100 years. Therefore a very large uncertainty exists on the expected return period of extreme storm events causing serious flooding. The storm surge level of an extreme storm event is the most determining storm characteristic with respect to the associated flooding. Wave characteristics are also important, but found to be relatively well correlated with the storm surge level.

Different modes of failure of the sea defences were investigated. The most relevant in this case were erosion of beaches in front of sea defence structures followed by instabilities of parts of these structures due to wave attack and/or overtopping, followed by erosion of the core of these structures untill breaching. Dune erosion was also investigated. Where dunes still exist as the natural sea defences no breaching occured.

Flood modeling results were sensitive to the various estimates made for breach growth, in depth as well as in width. Stability of the secondary dikes existing in some parts of the coastal plain was assumed. With or without temporary blocking of the flooding propagation by secondary dikes the model results showed that the more distant parts of the coastal plain were not flooded.

As consequences of a flooding event direct economic damage and human casualties were caculated on a GIS-based approach. Thus significant consequences are not taken into account, e.g., damage to nature, psychological damage, damage to the economy outside the flooded area.

For a series of return periods (1,000 years, 4,000 years, 10,000 years and 40,000 years) expected values of the consequences were calculated. The annual risk was calculated as a sum of the probabilities times the consequences. The propagation of the different sources of uncertainties results in an uncertainty with a standard deviation of a factor 10 (order of magnitude) on the annual risk.

It is concluded that, on the one hand, further research is essential to reduce the very large uncertainty on the results. Research is most needed on the failure behaviour of the sea defences in the time domain (beach erosion, initiation of damage, breaching, breach growth...). On the other hand, the risk calculations that are feasible at present, with very limited accuracies, are nevertheless very useful for coastal defence management actions like informing the public, defining research priorities, comparing the relative importance of measures and defences, and elaborating contingency plans for possible scenarios of breaching of defences.

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Zusammenfassung

Die Küstenniederungen in der belgischen Region Vlaanderen und der niederländischen Region Zeeuws-Vlaanderen stellen einen grenzüberschreitenden Flutraum dar. Wenn ein Deich im niederländischen Teil bricht wird das Wasser auch in Belgien einströmen und vice versa.

In diesem Beitrag werden die Resultate einer Fallstudie zur Berechnung der Überflutungsrisiken für einen grenzüberschreitenden Flutraum von Zeebrugge in Belgien bis Breskens in den Niederlanden dargestellt, die sog. Fallstudie Flanders. Ziel war es zu untersuchen, inwieweit mit dem heutigen Kenntnisstand eine Risikoermittlung durchgeführt werden kann. Mit den heute verfügbaren Methoden wurde das Risiko ermittelt und die Auswirkungen der verschiedenen Quellen für Unsicherheiten mittels einer Sensitivitätsanalyse bewertet.

Hydrometeorologische Rahmenbedingungen für Extremereignisse wurden analysiert. Der Wiederkehrintervall für Extremereignisse die zu einer Überflutung führen liegt bei 1,000 Jahren und mehr, während die entsprechenden Datenbestände weniger als 100 Jahre lang sind. Daher existiert eine große Unsicherheit hinsichtlich der Wiederkehrintervalle für Überflutungsereignisse. Der Sturmwasserstand ist der bestimmende Parameter hinsichtlich der Überflutung. Auch Wellenparameter sind signifikant, aber korrelieren relativ gut zu den Sturmwasserständen.

Verschiedene Versagensmechanismen wurden untersucht. Der relevanteste Mechanismus war die Erosion der Strände vor Schutzwerken, gefolgt durch Erosion des Kernes dieser Schutzwerke bis zum Versagen (Durchbrechen). Dünenerosion wurde ebenfalls untersucht. Dort, wo Dünen als natürlicher Schutz noch vorhanden sind trat kein Versagen auf.

Die Resultate der Überflutungssimulation reagierten empfindlich auf die verschiedenen Annahmen für die Bruchentwicklung, sowohl in der Breite wie in der Tiefe. Die Standfestigkeit von vorhandenen zweiten Deichlinien wurde angenommen. Mit oder ohne zeitliche Blockierung der Flutwelle durch zweite Deichlinien zeigten die Simulationen, dass die küstenfernen Regionen nicht überflutet wurden.

Die aus einer Überflutung resultierenden direkten wirtschaftlichen Schäden und Menschenverluste wurden GIS-gestützt ermittelt. Signifikante Schadenskategorien wie Schäden an der Natur, psychologische Schäden und indirekte wirtschaftliche Schäden außerhalb des überfluteten Raumes wurden nicht berücksichtigt.

Für verschiedene Wiederkehrintervälle (1.000, 4.000, 10.000 und 40.000 Jahre) wurden die Werte ermittelt. Das jährliche Risiko wurde berechnet als das Produkt aus der Summe der Versagenswahrscheinlichkeiten und der Konsequenzen (Schäden). Die Fehlerfortpflanzung der verschiedenen Unsicherheitsfaktoren resultiert in einem Faktor 10 für die Standardabweichung (Größenordnung 10) für das jährliche Risiko.

Es wird gefolgert, dass weitere Forschung unabdingbar ist um die sehr großen Unsicherheiten zu reduzieren. Forschungsbedarf besteht insbesondere beim zeitlichen Versagensverhalten der Schutzwerke (Stranderosion, Schadensinitiierung am Bauwerk, Bruchentstehung und -Entwicklung). Trotzdem sind die Risikoermittlungen mit den bestehenden Unsicherheiten von großem Wert für Bestandteile eines Risikomanagements wie die Information der Öffentlichkeit, die Definition von Forschungsprioritäten, den Vergleich der (relativen) Bedeutung der einzelnen Maßnahmen und Schutzwerke, und für die Erstellung von Katastrophenplänen für verschiedene Bruchszenarien.

Keywords

Coast, risk management, flood defence, risk assessment, failure probabilities, vulnerability analyses, Flanders

Contents

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1. Introduction

The coastal lowlands of the Belgian region Vlaanderen and the Dutch region Zeeuws-Vlaanderen constitute a single cross-border coastal flood unit with a length along the coastline of 25 km and an landwardth width of 15 km (Fig. 1). If a dike breaches in the Dutch part of this flood unit, the water might well flow into Belgium and vice versa. For historical reasons, both countries have rather different coastal defence approaches and safety standards. These different approaches might result in unbalanced investments for coastal defence schemes in the two sections of the flood unit.

The responsibilities of Dutch and Belgian coastal defence administrations end at the respective national borders. In order to achieve common approaches, a cross-border project, including some form of transnational co-operation with the responsible local authorities like the "Zeeuws-Vlaanderen Water Board", became necessary. Within the INTERREG IIIB project COMRISK (EU-project – www.comrisk.org) and under the auspices of the North Sea Coastal Management Group, an international platform to implement such a cross-border pilot study is founded. The Coastal Division of the Flemish Community leads the subproject about the Flood Risk in the cross boundary area Vlaanderen-Zeeuws-Vlaanderen. The study is carried out by the consultant IMDC and subcontractors. A steering committee was established to guide and discuss the results. The committee consists of governmental organizations of Belgium (Coastal Division and Flanders Hydraulic Research) and the Netherlands (Rijkswaterstaat, the province and the polder board).

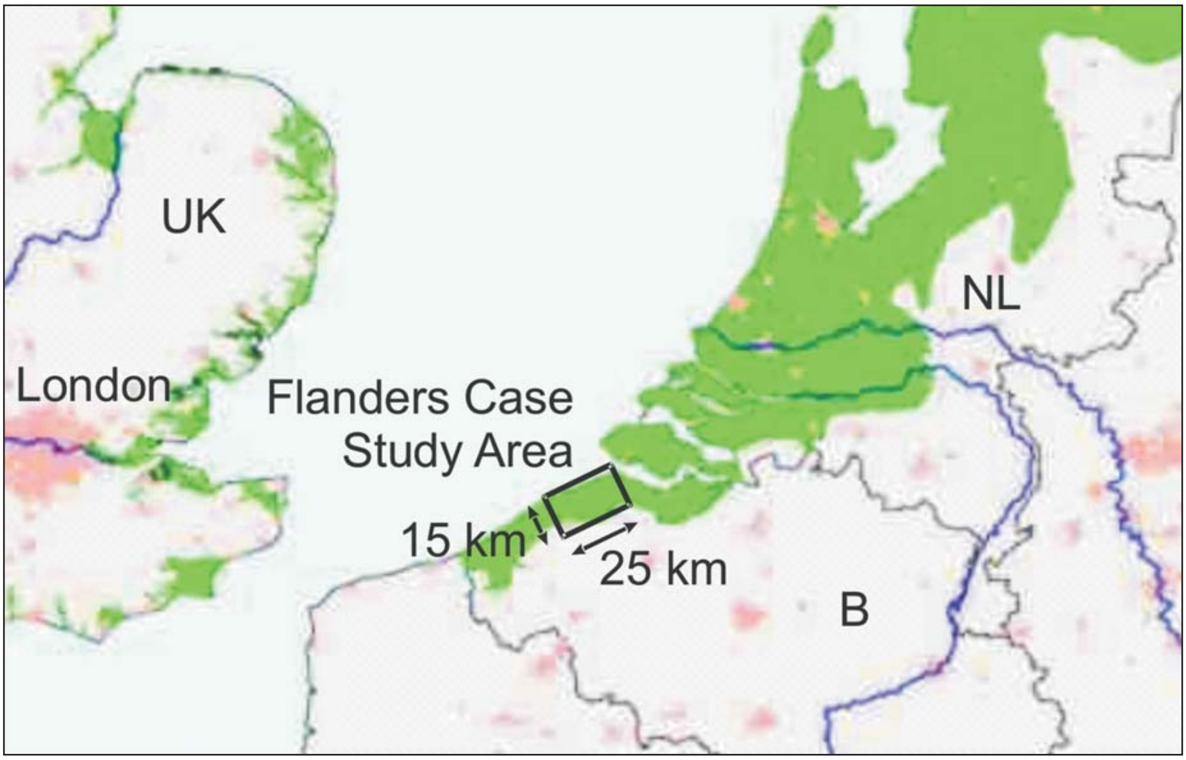

Fig. 1: Coastal flood unit from Zeebrugge in Belgium to Breskens in the Netherlands

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2. Risk assessment method

Future coastal flooding damage (e.g. in euro) for a certain area and within a specified time horizon, is an extremely stochastic quantity, mostly due to the fact that coastal flooding events are very rare in comparison to the time horizons considered in day to day coastal defence management practice. In this case the return period of a coastal flooding is of the order of magnitude of 1.000 years. Time horizons for specific coastal defence management measures are in the order of magnitude of 10 years (e.g. sand nourishment) to 100 years (e.g. dike construction). The risk for a certain area and within a specified time horizon is defined as the coastal flooding damage that can be expected *on average*, hypothetically considering manyfolds of futures within the specified time horizon that all have a certain probability of occuring. Because of very rare occurance of coastal flooding events, the risk is approximately linear with the considered time horizon. Therefore it is customary to divide the risk by the time horizon and thus calculating the annual risk (e.g in euro/year). Another way to explain the annual risk is as the product of the probability of occurrence of an event and the damages (or more general the consequences, comprising economical damages, casualties etcetera), integrated for all possible extreme events. Knowledge of the annual risk can be interesting for a number of reasons: as a basis for comparison between different areas in order to set priorities, to balance insurance premiums with damage compensations, to carry out a cost-benefit analysis to evaluate investments in coastal defence works (e.g. dikes/ beach nourishments), to elaborate contingency plans for possible scenarios of breaching of defences, to compare the relative importance of defences, to inform and sensitize the public about the importance of defences etcetera. But, for coastal defence management purposes one always has to keep in mind that risk and annual risk are only average quantities. One has to be aware when using risk calculation results not to forget the inherent extremely stochastic nature of coastal floodings. In addition to information about the risk, for coastal defence management one has to know about the return period of significant coastal flooding events. This characteristic is left out in the final results of a risk calculation, due to the very definition of risk itself as an average quantity, however intermediate results of a risk calculation can be used to give information about return periods.

The risk assessment method consisted of calculating the expected consequences for a limited number of representative storm events associated with a certain return period. Each of these representative storm events is taken to represent a cluster of possible storms, so that all clusters together represent all possible storm events. Hydrometeorological characteristics are assumed to be comparable for all storm events within the same cluster. The annual risk was calculated as a weighted sum of the probabilities times the consequences for the representative events. Thus the integration over all possible extreme events is discretised as a summation of a limited number of representative events. In this case study 4 representative events were defined, with characteristic return periods 1.000 years, 4.000 years, 10.000 years and 40.000 years. Expected values of the consequences were calculated for each of these. Risk is calculated as a summation for the 4 events of the product of damage and probability. By chosing this risk assessment method we assured that the results of the calculation provided information not only on the risk but also on the return periods of coastal flooding consequences.

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3. Inventory

3.1 Hydrometeorological boundary conditions

Seventy five years of measurements of water levels and twenty five years of deep water wave measurements at the Belgian coast are available. The return period of extreme storm events resulting in serious flooding is of the order of magnitude of 1.000 years or more, whereas data of hydrometeorological characteristics of storms are limited to a series of less than 100 years. Therefore a very large uncertainty exists on the expected return period of extreme storm events causing serious flooding. For example the standard deviation on the water level of 40 cm for the 1 in 10.000 year storm, corresponds with an order of magnitude of 10 in return period introducing a factor of 10 uncertainty on the calculated annual risk.

The storm surge level of an extreme storm event is the most determining storm characteristic with respect to the associated flooding. Wave characteristics are also important, but found to be relatively well correlated with the storm surge level.

3.1.1 Water level

Water level is the most important parameter and is modeled by sommation of surge and tide variations. Fig. 2 shows the variation of the water level, obtained as the sum of the astronomical tide and the storm surge.

The storm duration (and hence the duration of the simulations) was set at 45 hours, following an analysis of historical storms. A spring tide was taken as the water level, with a storm development superimposed. The maximum storm surge is the difference between the water level at the return period concerned and the maximum water level at the selected spring tide. The storm surge varies during the duration of the storm according to a square cosine function, with a surge of 0 m at the beginning and at the end of the storm.

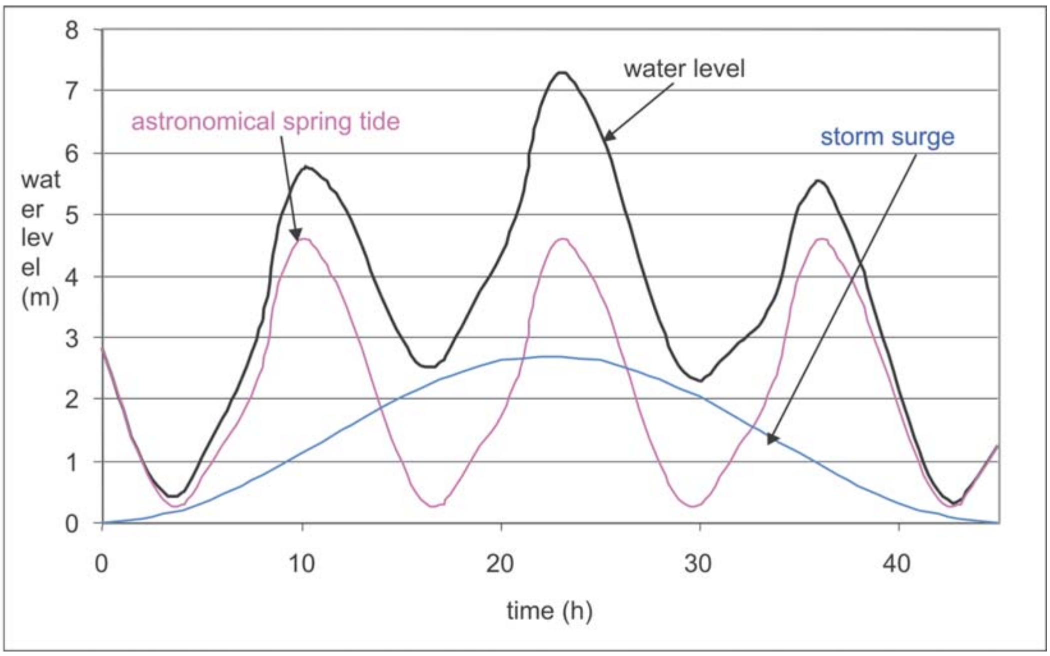

Fig. 2: Model for water level variation during extreme event

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3.1.2 Waves

Water level dependent statistics on wave heights and periods were established at measurement locations. These wave statistics have been transformed to nearshore wave characteristics using a calibrated numerical wave model (SWAN). The results of this consist of wave parameters at a line along the coast, with a water depth at about –5 m below low water, a position at which the bathymetry will not change considerably during storms.

The wave height variation in time is modeled with a square cosine function with the maximum in accordance with the maximum of the water level but with a period of 125 hours. For the peak period, it is assumed that the steepness of the wave remains constant with respect to the steepness at the storm maximum.

During a storm the beach in front of the dike will erode. Due to the lowering of the bed level, waves will travel more easily towards the toe of the dike, hence to know the wave height at the toe of the dike, it is important to calculate the erosion of the beach.

The erosion of the beach during the storm was determined with DUROSTA (STEETZEL, 1993). This is a time-dependent, one-dimensional model which determines the transformation of the wave height for a given bathymetry using an internal wave model. The most important parameters in the model are the hydrodynamic parameters and the grain diameter. The model takes the effect of hard structures such as sea dikes into account. The transformed waves cause a cross-shore transport of sand and a possible loss of sand at the sea side. After the storm, a new beach profile is obtained. For this profile, the hydrodynamic parameters are determined using the parameters at storm maximum as input. This is slightly conservative, since the profile is further evolved after the peak of the storm.

In principle, the wave height must be determined at the toe of the dike. However, most wave models (Swan, Endec, etc.) produce less reliable wave heights at very shallow water depths. Therefore the wave height at a distance of half a wave length from the toe of the dike is used. However, it is evident that the wave height can never exceed the water depth at the toe of the dike. This is therefore used as a limiting value.

The period to be entered in the overtopping calculations is Tm-1.0. In DUROSTA the period is assumed to have a constant value. Swan (1D) gives a better prediction of Tm-1.0. However, for Ostend an underestimate of 11 % was found compared to the measured values. It is not clear to what extent this underestimation is a function of the water depth. It is proposed to use the wave period obtained from Swan, augmented by 20 %, with a minimum of the deep water peak period divided by 1.1 (because the spectrum may be double peaked on shallow water).

Fig. 3 shows an example of the evolution of the beach profile during a storm. Without erosion, the waves are not able to reach the dike, but after erosion, the water depth at the toe is 1.5 m.

3.2 Information on the sea defences

Design drawings of the dikes were supplemented with recent beach profiles and dike crest surveys. In addition to existing geotechnical data, soundings and drillings were carried out along the Flemish dikes. Most of the dikes have a complex subsoil structure. The dikes often contain the historical sea defence, which has been breached and repaired on several occasions through time (past millennium). Also water level variations inside the dike are recorded, in order to predict the water level in the dike during an extreme storm.

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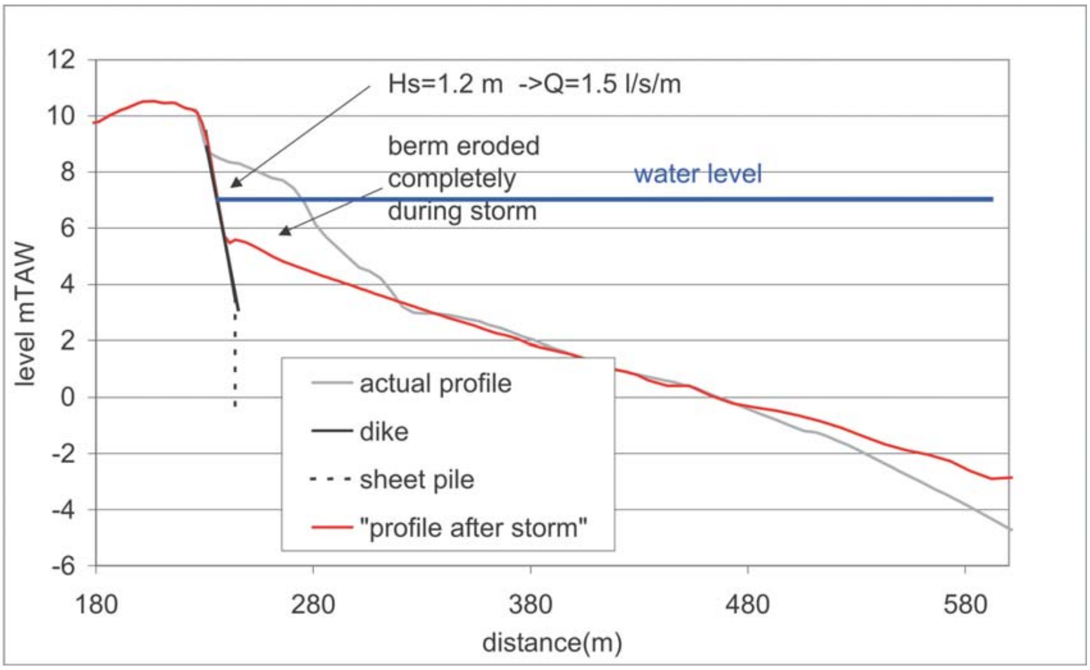

Fig. 3: Example of effect of beach erosion

Various data of beach and dune grain size are available from past measurement campaigns. The topography of the beaches and the dunes was taken from airborn laser altimetry measurements. Possible future changes of this topography (erosion / sedimentation) have not been taken into account.

4. Failure mechanisms

4.1 Dune breaching

To estimate the erosion risk of the dunes, the Vellinga approach was used (VELLINGA, 1986). An equilibrium profile is fitted to the existing (pre-storm) profile such that the eroded volume in the dune equals the volume deposited in front of the dune (e.g. Fig. 4). The Vellinga profile depends on the water level, the waves and the grain size. A breach is assumed to occur if the dune volume above the maximum water level is smaller than a critical volume.

4.2 Dike breaching

Dike breaching results from a cascade of mechanisms. Instabilities of parts of the dikes caused by wave attack and/or overtopping are followed by erosion of the core of these structures untill finally breaching.

4.2.1 Wave overtopping

Wave overtopping is calculated using the formula of VAN DER MEER (TAW, 2002). Wave overtopping is of importance if :

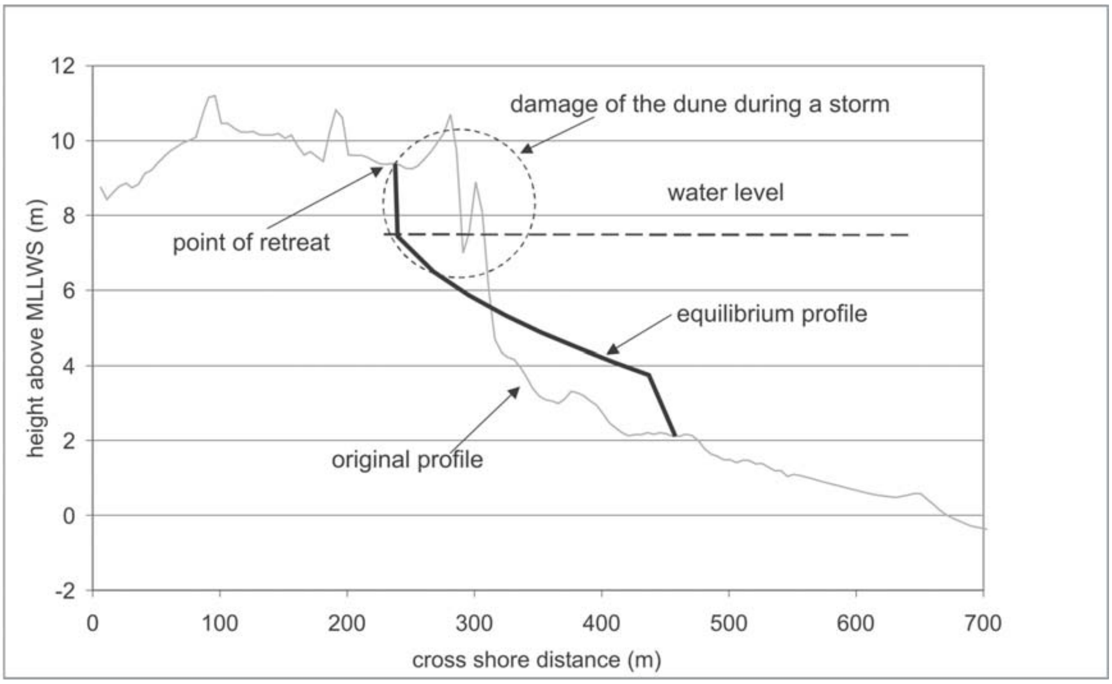

Fig. 4: Dune erosion with indication of original and equilibrium profile

a) the volume of overtopping water is too large, causing floodings in the inhabited area behind the dike, or
b) the overtopping rate causes erosion of the crest/inner slope of the dike, eventually resulting in breaching of the dike.

The water velocities over the dike caused by the overtopping are calculated with the formulae of SCHÜTTRUMPF (2003).

4.2.2 Macro stability outer slope

The macro stability of the front slope of the dikes has been tested by means of the SLOPE/W software (Geo-Slope, 2002). The method of Bishop has been used. In general, this method compares the moment of the resistance forces to the moment of the driving forces. The ratio of both moments is the safety coefficient. The resistance forces consist of the shear resistance of the soil, cohesion and the weight of a part of the structure and the soil. The loads consist of the other part of the structure and the soil that result in shear driving moment. To determine the weight of the structure and the soil, the level of the groundwater inside the dike (calculated with GEUZE and ABOTT, 1961 and verified with groundwater level measurements in the dike) is of uttermost importance. For a large number of predefined slip surfaces, the safety coefficient has been calculated. The smallest value of the safety coefficient, which should be larger than 1, corresponds to the most critical slip surface. The most critical situation occurs at low water after the highest high water.

4.2.3 Revetment

The revetment consists mostly of armed concrete (Belgium) and asphalt or stones (the Netherlands). The stability of the revetment is evaluated with the Duth safety assessment

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methods (TAW, 2004). The armed concrete does not contribute to failure, the asphalt or stones fail, but mostly they are covered with a layer of sand, which does not erode completely during a storm.

4.2.4 Erosion of the core untill breaching

To calculate the erosion process during overtopping the sand transport is calculated as the product of a flow rate and an average sand concentration. The assumed average sand concentration is 5 % (based on physical model results). The erosion of the dike body after failure of the outer slope revetment is based on the wave height at the toe of the dike.

4.2.5 Breach growth

Breach growth information was derived from literature data of historical breach formation. A breach grows quite fast in depth (1 to 2 hours). Widthways breach grow data between 0,5 m/hour and 82 m/hour were found. Taking into consideration the extreme hydrometeoconditions at sea, with waves and wind, a rather large value of 30 m/hour was chosen to be used in this case study as expected value. But it is also found by sensitivity analysis that the effect of this breach growth assumption is large.

5. Flood modelling

A two-dimensional hydrodynamic model (Mike21) was used for the flood modelling. The Digital Elevation Models of both Zeeuws-Vlaanderen and Vlaanderen were used for the altimetry. The Zeeuws-Vlaanderen model was available as a 5 m grid, the Vlaanderen model consisted of points with an average density of 3 per 10 m^2. These DEMs were further improved with land survey data of canal dikes inside the flood plain: these narrow elements are important for controlling the water levels and extend of the inundated area. The final modelling grid is rectangular with a grid size of 25 m. The water level at sea was used as a boundary condition. The roughness is taken uniformly over the entire terrain because sensitivity tests indicated that the roughness values don't significantly influence the extension of the flood area. Stability of the secondary dikes existing in some parts of the coastal plain was assumed. With or without temporary blocking of the flooding propagation by secondary dikes the model results showed that the more distant parts of the coastal plain were not flooded.

6. Consequences

To calculate the consequences of flooding, the method developed by Flanders Hydraulics Research is used for Vlaanderen, and the method of Rijkswaterstaat (Directorate General of public works and Water management, the Netherlands) is used for the Netherlands. The two methods are similar. Direct economic damage and human casualties are considered as the consequences of a flooding event. Thus significant consequences are not taken into account, e.g., damage to nature, psychological damage, damage to the economy outside the flooded area.

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The methods are based on a GIS-approach. The maximum damage per cell is determined on the basis of land-use maps and information obtained from the National Bureau of Statistics. The damage in the area is then calculated for each category of damage (housing, possessions, agriculture, industry) based on damage functions. Damage functions represent the development of the damage as a function of the depth of inundation, and replacement values or maximum damage values for these categories. This can be done for all potential damage categories. Combining the two sets of data produces the damage per cell. A similar method is used for casualties, with the difference that the maximum rise velocity (Vlaanderen) or the maximum horizontal velocity (the Netherlands) is also used as an input parameter.

7. Results and Conclusions

The calculated damages and casualties for the different representative events ar shown respectively in Table 1 and Table 2.

Table 1 : Direct economic damage

Return period	Vlaanderen (B)	Zeeuw-Vlaanderen (NL)	Total
1.000 years	0	5.000.000 euro	5.000.000 euro
4.000 years	80.000.000 euro	20.000.000 euro	100.000.000 euro
10.000 years	400.000.000 euro	30.000.000 euro	430.000.000 euro
40.000 years	700.000.000 euro	300.000.000 euro	1.000.000.000 euro

Table 2: Casualties

Return period	Vlaanderen (B)	Zeeuw-Vlaanderen (NL)	Total
1.000 years	0	4	4
4.000 years	0	6	6
10.000 years	2	8	10
40.000 years	4	24	28

Most damage is in the Flemish part. This is correlated with the relatively high wealth of the coastal community of Knokke-Heist. Most casualties are in the Dutch part. This can be explained by the high rise velocities caused by secondary dikes blocking the flood propagation for a while.

The annual risk was calculated from the numbers in Table 1 resulting in a relatively small value of 100.000 à 200.000 euro/year. However the propagation of the different sources of uncertainties results in an uncertainty with a standard deviation of a factor 10 (order of magnitude) on the annual risk.

It is concluded that, on the one hand, further research is essential to reduce the very large uncertainty on the risk results. Research is most needed on the failure behaviour of the sea defences in the time domain (beach erosion, initiation of damage, breaching, breach growth ...). On the other hand, the risk calculations that are feasible at present, with very limited accuracies, are nevertheless very useful for coastal defence management actions like

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informing the public, defining research priorities, comparing the relative importance of measures and defences, and elaborating contingency plans for possible scenarios of breaching of defences.

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Risk Assessment for the Ribe Area
COMRISK Subproject 7

THORSTEN PIONTKOWITZ, ANDREAS KORTENHAUS, HOCINE OUMERACI

Summary

Within COMRISK subproject SP7, a risk assessment of the coastal defence system in Ribe/Denmark has been performed based on the state-of-the-art of flood risk analysis methods. The flood risk has been defined as the product of the flooding probability and the expected consequences of flooding. This paper describes the detailed hazard analysis by which the overall flooding probability of the Ribe defence system has been achieved. Results of sensitivity analyses regarding the assessment of uncertainties for input parameters and models used, the consideration of other special constructions such as one sluice and three outlets as well as an approach of dividing the defence system into 'homogenous' sections with respect to governing load and resistance parameters are also described.

Furthermore, the paper provides information about the vulnerability analysis, which has been performed to evaluate the consequences in case of flooding. Relevant damage categories, comprising vulnerable assets or non-material values, have been selected and valued together with the derivation of depth-damage functions for each damage category. Seven breach and inundation scenarios have been defined to assess the range of expected damage due to flooding in the flood prone area. Finally, risk values have been assessed.

Zusammenfassung

Innerhalb des siebten Teilprojekts von COMRISK wurde eine Risikoanalyse des Hochwasser- und Küstenschutzsystems (HuK-System) in Ribe/Dänemark durchgeführt. Das Überflutungsrisiko wurde hierbei definiert als das Produkt aus Versagenswahrscheinlichkeit des HuK-Systems und dem zu erwartenden potenziellen Schaden im Falle einer Überflutung. Dieser Beitrag beschreibt zunächst die detaillierte Gefahrenanalyse mit der die Gesamtversagenswahrscheinlichkeit des HuK-Systems in Ribe ermittelt wurde. Die Ergebnisse einer Sensitivitätsanalyse bezüglich der Abschätzung von Unsicherheiten der Eingangsparameter und Modelle, die Berücksichtigung von Sonderbauwerken (eine Schleuse und drei Auslässe), sowie die Einteilung des HuK-Systems in ‚homogene' Abschnitte abhängig von maßgebenden Belastungs- und Widerstandsparametern werden ebenfalls beschrieben.

Zusätzlich wird die Vulnerabilitätsanalyse beschrieben, die durchgeführt wurde um die bedrohten Werte und die potenzielle Schädigung im Untersuchungsgebiet abzuschätzen. Hierzu wurden maßgebende Schadenskategorien, die Vermögensobjekte oder nicht materielle Werte umfassten, ausgewählt und Schadensfunktionen für jede Schadenskategorie hergeleitet. Sieben Versagens- und Überflutungsszenarien wurden definiert, um die Größenordnung des durch Überflutung verursachten potenziellen Schadens ermitteln zu können. Abschließend wurden szenarienabhängige Risiken bestimmt und beurteilt.

Keywords

Coast, risk management, flood defence, risk assessment, failure probabilities, vulnerability analyses, Ribe

Contents

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1. Introduction

More than 16 million people, corresponding to approx. 20 % of the total population in the North Sea region, live in coastal lowlands. Major economic activities, such as the seaports of Rotterdam, London and Hamburg or the tourist industry, have been increasingly concentrated in coastal regions over the last centuries. In addition, storm surges have increased over the last decades, both in frequency and intensity, increasing the hazard to the coastal regions. This has led to an increase of vulnerability to natural hazards within these regions.

Defence structures (e.g. sea dikes) to protect the flood prone areas have been designed by means of purely deterministic approaches or based on experience. Due to decreasing resources and increasing costs it is more and more desirable to optimise the cost-benefit-ratio for these structures (OUMERACI, 2004). Within the COMRISK subproject SP7, a risk assessment of the coastal defence system in Ribe/Denmark has been performed based on the state-of-the-art of flood risk analysis methods. The overall flooding risk has been defined as the product of the flooding probability P_f and the expected consequences of flooding E(D).

The study has been performed in two major steps which comprises (I) the hazard analysis (calculation of the overall flooding probability) and the (II) the vulnerability analysis evaluating the expected consequences of flooding. Latter has been performed by the Danish Coastal Authority (DCA), being responsible for subproject SP7. The hazard analysis has been carried out together with the Leichtweiß-Institute for Hydraulic Engineering at the Technical University Braunschweig, Germany.

The overall aim of this paper is to describe the risk analysis of the Ribe area. For this purpose, the defence system and its components, the input parameters and their uncertainties as well as the limit state equations (LSE) and the probabilistic calculations will be described. Damage categories applied within the vulnerability analysis will be listed and their valuation will be explained together with the derivation of the depth-damage functions for each damage category. Seven breach and inundation scenarios are defined to assess the range of expected damage due to flooding in the flood prone area. Finally, the overall results will be critically discussed and remarks for future developments will be given.

2. Coastal Defence System in Ribe

The Ribe defence system is located about 50 km north of the German-Danish border at the Wadden Sea coast protecting approximately 95 km^2 low-lying flat marsh land surrounding Ribe town. Ribe is the oldest town in Denmark with about 9000 inhabitants. Three streams and a large river, Ribe Å, cross the flat marshland on their way towards their mouths

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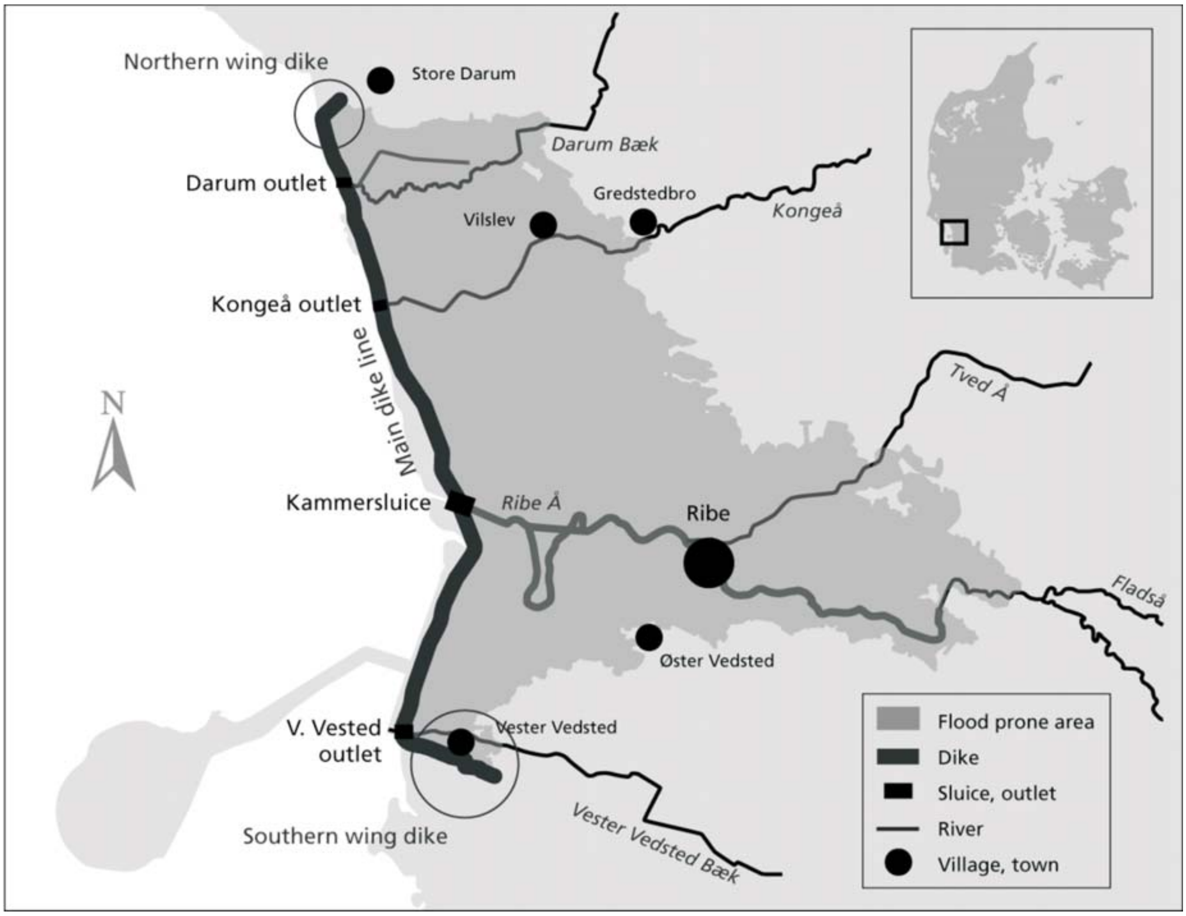

Fig. 1: Map of the Ribe flood defence system

(see Fig. 1). The river flows through Ribe town and passes a sluice shortly before reaching its mouth. The three streams pass the defence line through three outlets.

In this way, the 15.3 km long defence line consists of a main dike structure, a sluice and three outlets. The main dike is characterised by a sand core and a clay/grass cover. The standard profile shows a 1:10 seaward slope and a crown height of 6.88 m DVR90. The standard cross section and the key geometric parameters are shown in Fig. 2. The dike structure, the sluice and outlets are described in more detail in OUMERACI et al. (2004) and DANISH COASTAL AUTHORITY (2004).

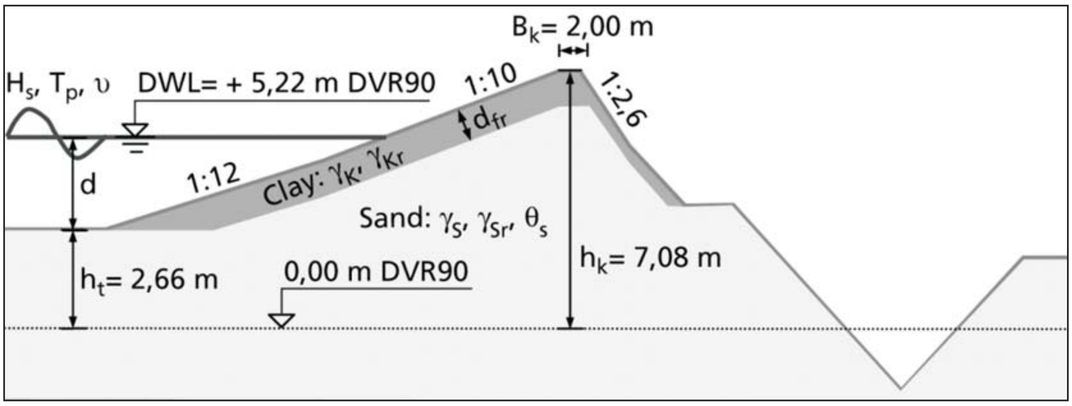

Fig. 2: Standard cross-section of the main dike in Ribe (km 6,644 as an example)

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3. Hazard analysis

For the deterministic and probabilistic calculations within the hazard analysis, the model by Kortenhaus (2003) for sea dikes has been used. It comprises 25 failure mechanisms with a total number of 87 input parameters. The input parameters were grouped into parameters describing (I) the geometry of the structure, (II) the hydromechanic boundary conditions, and (III) the geotechnical properties of the structure.

3.1 Input parameters

I. Geometrical parameters

Topographic measurements were available for six cross sections along the main dike line which were regarded as the weakest points of the main dike. Thus, it was concluded that analysing these profiles would account for the potential weak spots of the dike.

The crest heights of the main dike were taken from available measurements performed in different years. The dimensions and constructional details of the sluice and the outlets were taken from technical drawings which were made available by the DCA.

II. Hydraulic boundary conditions

The design water level for all cross sections, the sluice and the outlets is a pre-described value which was determined from measurements at the Danish coast. It is defined as h_w = 5.22 m for a 200-year return period.

The input parameters for wave height and wave periods resulted from a study performed by Danish Hydraulic Institute (DHI). The offshore input parameters for this study were given by DCA so that 21 simulations with different input parameters were performed. The results of these runs are given as wave heights H_{m0} and wave periods T_m for specific points along the coastline (100 m distance) for water depths corresponding to 50 m and 300 m distance to the toe of the dike, respectively.

Angles of wave attack were based on instructions given by the DCA and corresponded to the most unfavourable conditions for the specific cross sections. The duration of design storm surge was assumed to be constant as t_s = 6.5 h.

III. Geotechnical parameters

All geotechnical parameters like the shear strength of the clay were predefined by the DCA. This information was based on geotechnical investigations which were performed close to the six cross sections during reinforcement works in 1980.

3.2 Deterministic calculations

3.2.1 Limit state equations

For deterministic calculations of the dike sections a total number of 23 failure mechanisms were considered. Due to the lack of stone revetments at the Ribe main dike all failure mechanisms associated with stone revetments were not considered for the calculations. Fig. 3 gives an overview of failure mechanisms of a sea dike considered in the method by KORTENHAUS (2003).

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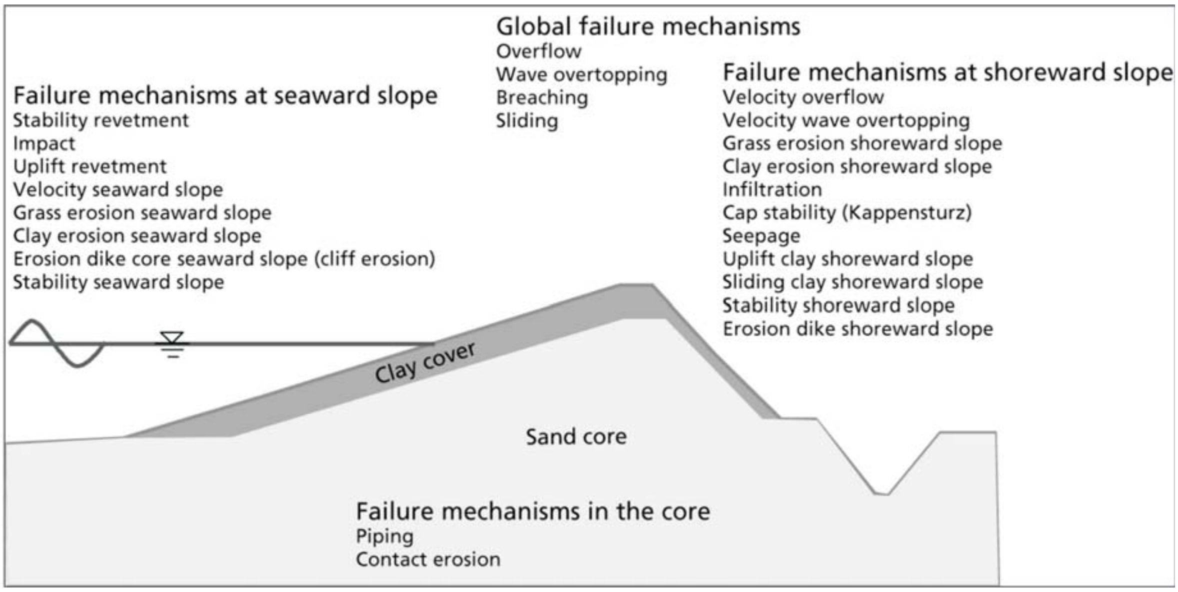

Fig. 3: Overview of failure mechanisms of a sea dike considered in the method after KORTENHAUS (2003)

For deterministic calculations of the sluice, the failure mechanisms described in KORTENHAUS (2003) could not be used. Therefore, OUMERACI et al. (2004) have formulated further limit state equations (LSE) describing e.g. the stability of the gates, piping underneath the sluice, wave overtopping over the gates and human error.

The failure mechanisms for the Ribe outlets are a combination of the failure mechanisms for the sluice and those for the dike sections. This combination was chosen since the outlets are partly sluices (walls, gates, etc.) but also show the characteristics of a dike (slope, grass cover, crest, etc.). Details of this approach are described in OUMERACI et al. (2004).

3.2.2 Calculation of dike sections

A deterministic calculation for all failure mechanisms described in section 3.2.1 was performed for all six dike sections showing that the failure mode "erosion of grass cover at the seaward side" will lead to failure for all cross sections. This means that for a design water level of $h_w = 5.22$ m and a storm surge duration of $t_s = 6.5$ h the grass cover both at the seaward and shoreward side of the dike will fail.

3.2.3 Calculations for sluice and outlets

The results of the deterministic calculation of the sluice and the outlets showed that there is failure for the LSE "wave overtopping" under design conditions. Consequently, there is also a total failure (inundation of flood prone areas) for the sluice and the outlets. The safety coefficients for wave overtopping and overflow are significantly lower as compared to the dike cross sections. A reason for this observation is that the seaward slope is much steeper in the case of the outlets. Furthermore, the water depth in front of the structures is significantly larger (up to 5.0 m) than in front of the dikes, thus allowing higher waves to occur at the structures.

3.3 Uncertainty of input parameters

Uncertainties indicate the variation of parameters around their mean values. They can be estimated using either a full statistical distribution or a mean value and a standard deviation assuming a Normal distribution. For some parameters, which were considered to be important for the failure mechanisms (a sensitivity analysis was performed beforehand), the uncertainties were evaluated in more detail (water level, dike height, wave height and wave period, geotechnical parameters, model uncertainties). Tab. 1 shows the results of the uncertainty evaluations used in this study.

Tab. 1: Overview of uncertainties of most relevant parameters

Parameter	Uncertainty	Restriction	Remarks
Crown heigh hk	Sdev = 0,10 m	–	Uncertainty in measurements
Water level hw	Sdev = 0,47 m	–	Extreme statistics from available measurements
Wave heigh Hs	CoV	Hs = 0,55*d	Breaker criterin, d = local water depth
Wave period Tp	CoV = 0,20	Tp = (Hs/0,0938)^0.5	Restriction by wave steepness

3.4 Probabilistic calculations

In a first step, the failure probability P_f of each mechanism was determined. Level II (FORM) or Level III (Monte Carlo Simulation) calculations were performed depending on the complexity of the limit state equations. The calculated failure probability is given as P_f/year. Failure probabilities smaller than $P_f = 1 \cdot 10^{-10}$ were taken as Pf · 0 and were ignored for subsequent calculations.

To calculate the temporal dependencies of the failure mechanisms, a scenario approach proposed by KORTENHAUS (2003) was used. In the scenario approach, the chronology of time-dependent failure mechanisms was achieved by defining "scenario blocks", which comprise several individual failure mechanisms in logical and temporal order.

3.4.1 Calculation of dike sections

In Tab. 2 an overview of all results for the probabilistic calculation of all dike cross sections and all individual failure mechanisms is given. The failure probability for breaching is extremely high since the LSE does not consider the temporal development of the erosion process. The same missing temporal dependency accounts for the failure mechanism 'grass erosion seaward slope'. The very high failure probability does not have a significant importance for the overall failure probability since it only represents the start of the erosion process at the seaward slope.

Therefore, in the following the results of the calculation for a scenario approach (inc. temporal relations between failure mech.) and the related fault tree analysis will be discussed.

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A simplified 'scenario fault tree' for dike cross section km 8,422, ignoring all branches in the fault tree with $P_f < 10^{-10}$, is shown in Fig. 4. The failure probabilities for the scenarios were calculated using the Level III approach (Monte-Carlo simulation). The results are summarised in Tab. 3.

Tab. 2: Overview of failure probabilities for all failure modes of all dike cross sections

No.	Failure mechanism	Dike section					
		3156	6644	8422	9400	10 403	14 499
	Global failure mechanisms						
1	Overflow	1,0E-06	2,0E-07	2,3E-06	1,0E-0,6	3,4E-06	5,0E-07
2	Wave overtopping	3,0E-05	0,0E-06	4,1E-05	3,5E-05	6,6E-05	9,0E-06
3	Breaching	4,3E-02	1,8E-02	7,4E-02	4,2E-02	8,9E-02	3,6E-02
4	Sliding	3,4E-07	3,3E-07	4,1E-07	3,3E-07	3,5E-07	3,4E-07
	Failure mechanisms at the seaward slope of the dike						
6	Impact	8,0E-06	5,0E-06	2,0E-06	4,0E-06	7,0E-06	8,0E-06
8	Velocity seaward slope	2,2E-02	1,8E-02	3,4E-02	1,9E-02	3,4E-02	3,2E-02
9	Crass erosion seaward slope	2,9E-01	2,4E-01	6,8E-01	2,6E-01	3,3E-01	3,0E-01
10	Clay erosion seaward slope	1,3E-05	5,6E-05	3,6E-05	1,3E-05	3,7E-05	4,6E-05
11	Erosion dike core seaward slope	1,7E-05	7,6E-05	4,8E-04	1,1E-04	3,2E-04	5,6E-04
12	Stability seaward slope	0,0	0,0	0,0	0,0	0,0	0,0
	Failure mechanisms at the shoreward slope of the dike						
13	Velocity overflow	2,0E-06	3,0E-06	3,0E-06	2,0E-06	2,0E-06	0,0E+00
14	Velocity wave overtopping	2,6E-05	3,3E-05	1,4E-04	1,2E-05	1,9E-04	2,2E-05
15	Grass erosion shoreward slope	1,6E-04	1,0E-04	5,7E-04	8,5E-05	6,9E-04	1,2E-04
16	Clay erosion shoreward slope	6,3E-05	1,6E-05	6,6E-05	2,3E-05	7,6E-05	1,7E-05
17	Infiltration	0,0	8,0E-06	2,1E-04	1,0E-06	0,0E+00	1,6E-04
18	Kappensturz	1,4E-02	1,1E-02	7,6E-03	2,3E-02	4,1E-03	1,4E-02
19	Seepage	1,0E-06	1,0E-06	1,0E-06	2,0E-06	0,0E+00	1,0E-06
20	Uplift clay on shoreward slope	1,0E-06	2,0E-06	1,0E-06	1,0E-06	0,0E-06	0,0+00
21	Sliding clay shoreward slope	4,1E-04	5,4E-04	1,4E-04	1,3E-03	1,4E-03	2,4E-04
22	Stability shoreward slope	0,0	0,0	9,6E-05	0,0	0,0	0,0
23	Erosion dike shoreward slope	0,0	0,0	3,2E-05	3,0E-06	7,0E-06	0,0
	Failure mechanisms in the dike						
24	Piping	9,6E-07	2,0E-06	2,0E-06	6,8E-07	1,1E-06	5,4E-7
25	Matrix erosion	2,5E-01	1,4E-01	2,7E-02	2,6E-02	3,8E-03	2,8E-04
	Overall failure	3,1E-05	9,2E-06	4,3E-05	3,6E-05	6,9E-05	9,5E-06

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Tab. 3: Failure probability of scenarios for all dike cross sections of the Ribe sea defence

No.	Individual mechanisms (see Tab. 4–7 for def.)	Dike cross section 3156	6644	8422	9400	10403	14499
Sc 1	9+10+11+3	3,0E-06	6,0E-06	3,5E-05	1,4E-05	3,4E-05	7,0E-06
Sc 2	11+3	3,0E-05	2,6E-04	1,1E-03	6,9E-05	4,9E-04	7,7E-04
Sc 3	15+16+18+3	0	0	0	0	0	0
Sc 4	17+21+18+3	0	0	0	0	0	0
Sc 5	19+20+21+18+3	0	0	0	0	0	0
Sc 6	15+16+23+3	0	0	1,5E-05	0	4,0E-06	0
Sc 7	17+21+23+3	0	0	0	0	0	0
Sc 8	19+20+21+23+3	0	0	0	0	0	0
Sc 9	23+3	0	0	3,8E-05	0	9,0E-06	0
Sc 10	19+24+23+3	0	0	0	0	0	0
Sc 11	19+25+23+3	0	0	0	0	0	0
	Overall failure	3,10E-05	9,6E-06	4,50E-05	3,70E-05	7,10E-05	1,00E-05

For most of the scenarios the overall failure probability resulted in $P_f \cdot 0$. Scenario I comprises the grass erosion, the clay erosion, the cliff erosion and the breaching of the dike and Scenario I + II (cliff erosion and breaching) result in failure probabilities larger than $P_f = 1 \cdot 10^{-10}$. For cross section km 8,422, Scenario I gives $P_f = 3.5 \cdot 10^{-5}$. In comparison to the traditional fault tree approach where temporal relations of the failure modes are not considered sufficiently, the failure probability for the seaward side of the dike was $P_f \sim 5 \cdot 10^{-8}$, i.e. three orders of magnitude smaller.

The increased failure probability for the seaward slope including the grass erosion now comes much closer to the failure probability for wave overtopping so that the erosion process gets increasingly important for dikes investigated here.

Overall, the flooding probabilities using the scenario approach results in 3–5 % higher values for four cross sections (6644, 8422, 9400 and 10409). All other cross sections do not seem to be affected by the use of a scenario approach. This result is only valid for the Ribe case since the failure probability for wave overtopping is rather high in this case.

The influence of mean values of some key input parameters on the failure probability of individual mechanisms, scenarios and the overall flooding probability has been investigated. An increase, for example, of the mean water level hw by 0.50 m yields an increase of the failure probability for wave overtopping by a factor of 10 and a reduction by 0.50 m results in a lower failure probability by a factor of 10. The overall flooding probability is changed by the same order of magnitude. Moreover, the influence of mean values of further parameters on the failure probability for wave overtopping was investigated in detail (wave overtopping was selected since it has the largest influence on the overall flooding probability). In this connection, the key parameters, which affect the failure probability for wave overtopping and the overall flooding probability most, were determined as the water level and the wave period. Uncertainties for both parameters should therefore be evaluated very carefully.

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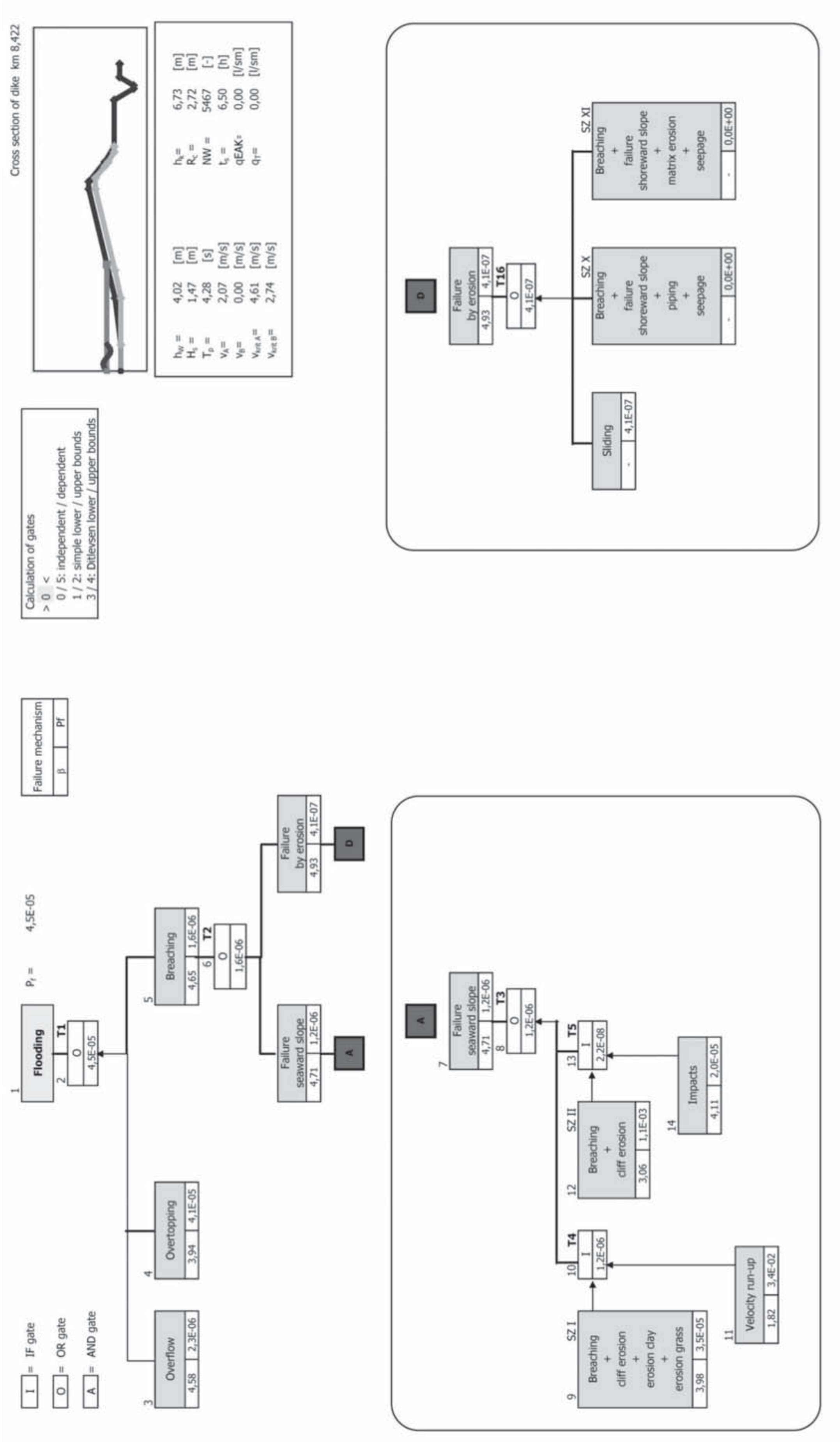

Fig. 4: Simplified scenario fault tree for dike cross section km 8,422

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3.4.2 Calculation of the Ribe sluice and outlets

The failure probability of the Ribe sluice and the outlets was calculated using the Monte-Carlo method. The results are shown in Tab. 4.

The failure probabilities for the outlets are all in the range of Pf · $5\cdot10^{-1}$, which means that flooding occurs once every 2 years, approximately.

Calculations showed, that the key failure mechanism for all structures is wave overtopping where a tolerable wave overtopping rate of q_{tol} = 20 l/(sm) has been assumed. Variations of the tolerable overtopping rates (q_{tol} = 100 l/(sm), 200 l/(sm) and 515 l/(sm) where the latter corresponds to the overtopping rate for zero free-board as the maximum possible value were performed to study its influence on the results.

Increasing the tolerable wave overtopping rate to 100 l/(sm) and 200 l/(sm) results in a decrease of the failure probability for wave overtopping by a factor of about 10 and 100 for all outlets and the sluice, respectively. If the tolerable wave overtopping rate is set to 515 l/(sm), the failure probability for wave overtopping will be in the range of 10^{-4} for the sluice and 10^{-5} or 10^{-6} for the outlets.

Tab. 4: Results of probabilistic calculations for the sluice and the three outlets (selected failure mechanisms)

No.	Failure mechanisms	Kammer sluice	V.Vedsted	Outlets Konge Å	Darum
1	Overflow	5,3 E-02	1,5E-04	2,5E-04	7,9E-05
2	Wave overtopping	6,1E-01	5,6E-01	4,7E-01	4,9E-01
3	Hydraulic heave	1,0E-10	1,0E-10	1,0E-10	1,0E-10
4	Gates not closed	1,2E-03	1,0E-04	1,0E-04	1,0E-04
	Overall failure	6,3E-01	5,6E-01	4,7E-01	4,9E-01

3.5 Failure probability of flood defence system

In order to determine the overall flooding probability of the Ribe defence system, a division into several dike sections was made. The division into several dike sections assumed for one section very small variation of the input parameters for either the stress or the resistance of the limit state equations. The crown height hk of the dike and the peak wave period T_p were finally selected as the key criteria for the division of the defence system into 'homogenous' dike sections.

In all, 15 sections were defined as shown in Fig. 5. Four sections were defined to be close to section km 6,644, two sections close to km 14,499 whereas all other sections differ from each other. Section 4 in Fig. 5 could not be assigned to one of the investigated cross-sections since the crest height h_k = 7.53 m was significantly higher than for the other sections. This section was ignored for the subsequent probabilistic calculation. The sluice and the three outlets were defined as separate sections.

The failure probabilities of all sections (dike sections, sluice outlets) were linked to each other by means of a fault tree with just one OR gate, which was used to calculate the overall flooding probability of the hinterland.

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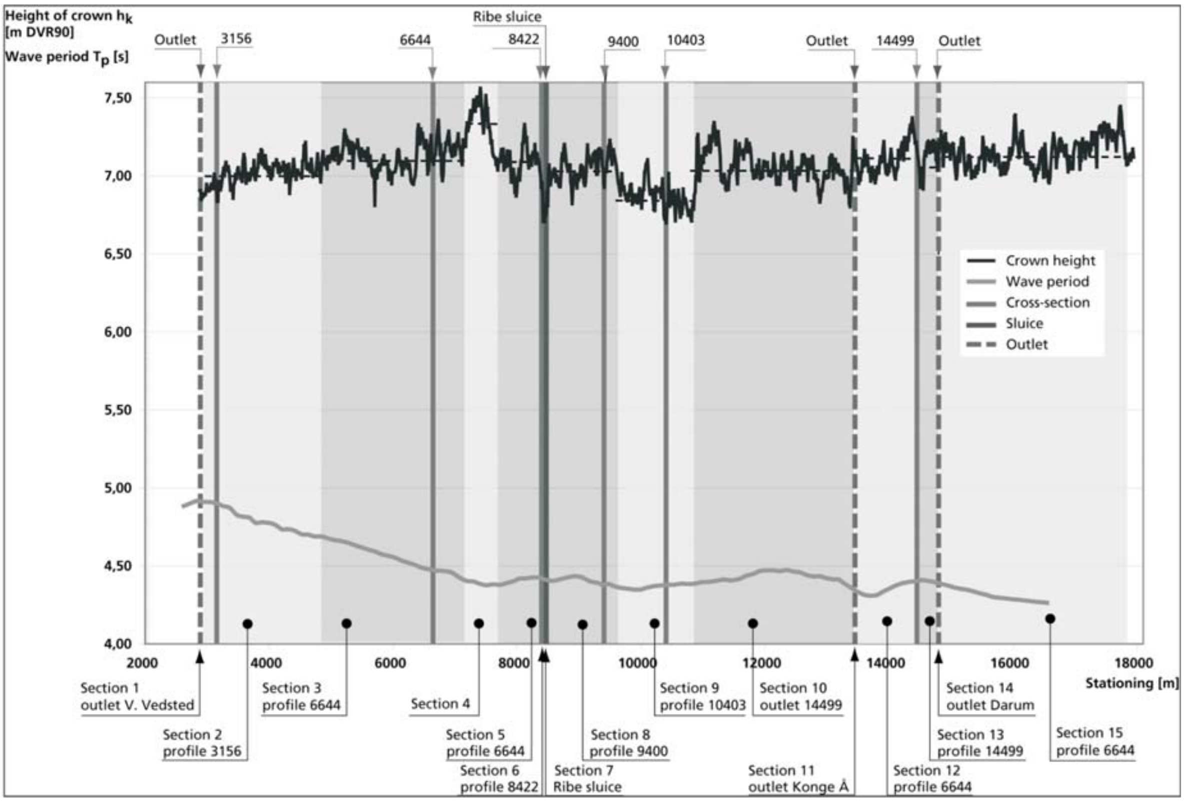

Fig. 5: Division of the Ribe flood defence system into representative sections

The fault tree calculations including all sections resulted in an overall flooding probability of $P_f = 9.5 \cdot 10^{-1}$. This result was considered to be much too high since it solely depends on the failure probabilities of the sluice and the outlets which are mainly governed by wave overtopping. Due to small inflow volumes during wave overtopping (limited stretch of sluice/outlets), a second calculation ignoring sluice and the outlets resulted in an overall flooding probability of $P_f = 2.5 \cdot 10^{-4}$.

Despite the fact that the sluice and the outlets are very narrow structures, calculations showed that the sluice and the outlets are the weakest elements in the defence line. An example calculation showed that flooding from wave overtopping over the sluice would result in a water level in the flood prone area of less than 1 mm only. However, structural failure of the sluice or one of the outlets would cause major flooding of the hinterland. It is therefore essential to investigate the sluice and the outlets in more detail to finally determine the overall flooding probability. For the time being it is recommended to use a flooding probability of $P_f = 2.5 \cdot 10^{-4}$ for the flood defence system in Ribe.

4. Vulnerability analysis

As cartographic basis for the vulnerability analysis, altitude data in a grid net of 25x25 metres was used to generate a topographical map of the flood-prone area, being delimited by the 5.0 m DVR90 altitude line. The altitude data was supplemented by altitude data from road surveys. Fig. 6 presents the topography of the Ribe flood-prone area, showing low-lying delta areas surrounding the watercourses far into the hinterland.

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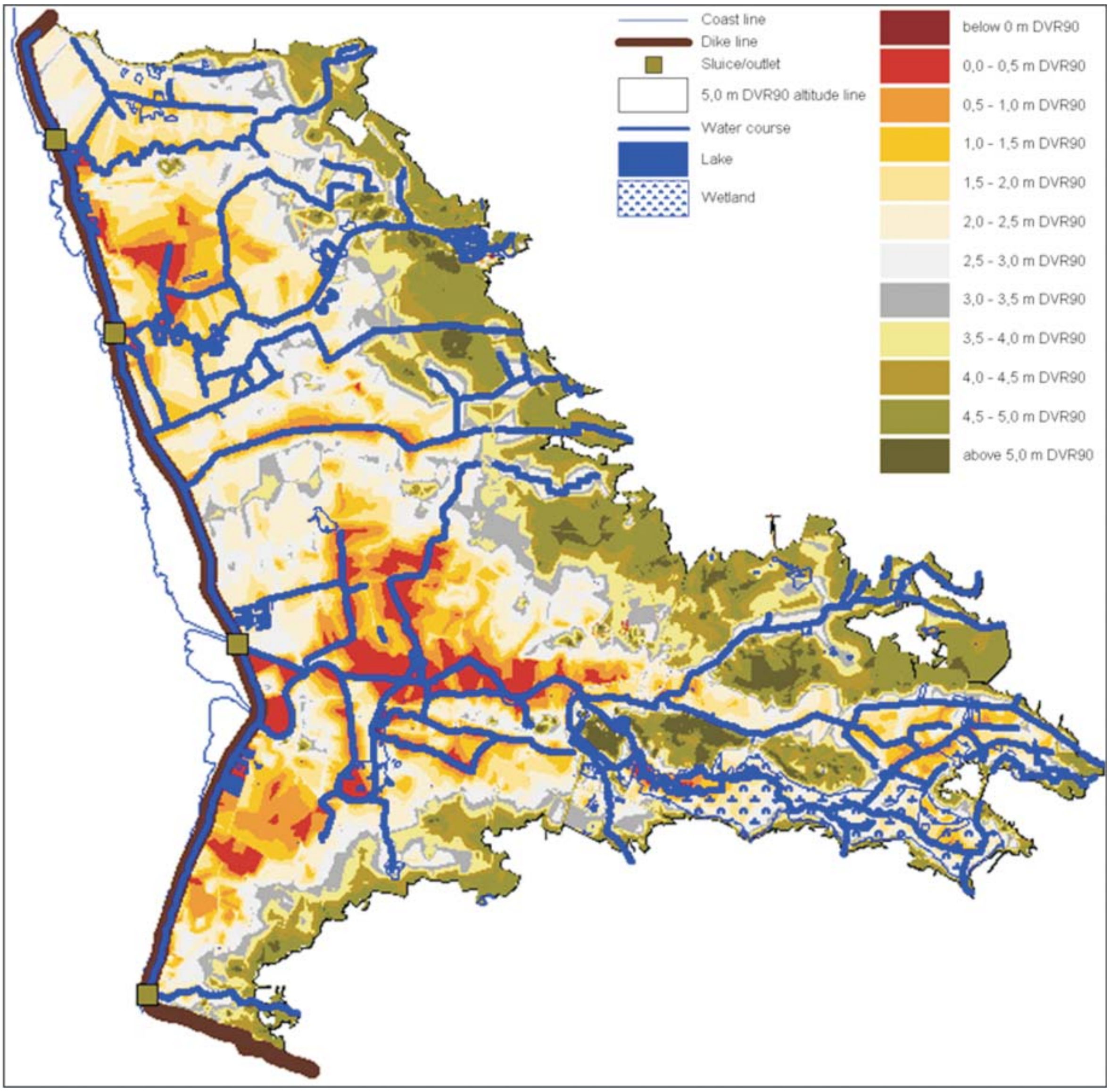

Fig. 6: Topography of the Ribe flood-prone area

4.1 Damage categories and data sources

Within the flood-prone area of Ribe six categories of direct, tangible damage were selected (buildings, movable property, agricultural acreage, livestock, electric installations, traffic system). Additionally, four damage categories (inhabitants, employees, vehicles, tourism) subject to intangible, direct/indirect damage were considered in a descriptive form. Typically, data was available at national registers, such as the Building and Housing register or the Central Livestock register. In other cases, data was provided by research centres or the responsible county. The request of data from national registers or public administrations about the damage categories showed however clear differences in data quality and format. This fact complicated the procedure of geocoding each risk element by means of a GIS software application.

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4.2 Valuation analysis

The valuation analysis showed the location of most of the assets on high ground around the low-lying delta area of Ribe River. For example, only 7 % of the accumulated property value is located below 2.5 m DVR90. About 45 % of the accumulated property value is placed below 4.0 m DVR90 and about 30 % of the total property value is located between 4.5 and 5.0 m DVR90. Fig. 6 illustrates the total property value of buildings distributed over ten altitude intervals.

This distribution of assets over altitude has been characteristic for most of the damage categories. However, a differentiation of the total profit of all kinds of crop over altitude showed an almost linear distribution, which differed remarkably from the other damage categories.

4.3 Damage analysis and inundation scenarios

To determine the possible damage for each damage category, seven breach and overtopping scenarios were defined. In five scenarios inundation occurs due to one or more dike breaches, whereas two scenarios consider wave overtopping and the structural failure of both gates of the sluice, respectively. The seven scenarios are defined as follows (sections as referred to in Fig. 5):

Sc1: one dike breach in section 6

Sc2: one dike breach in section 2

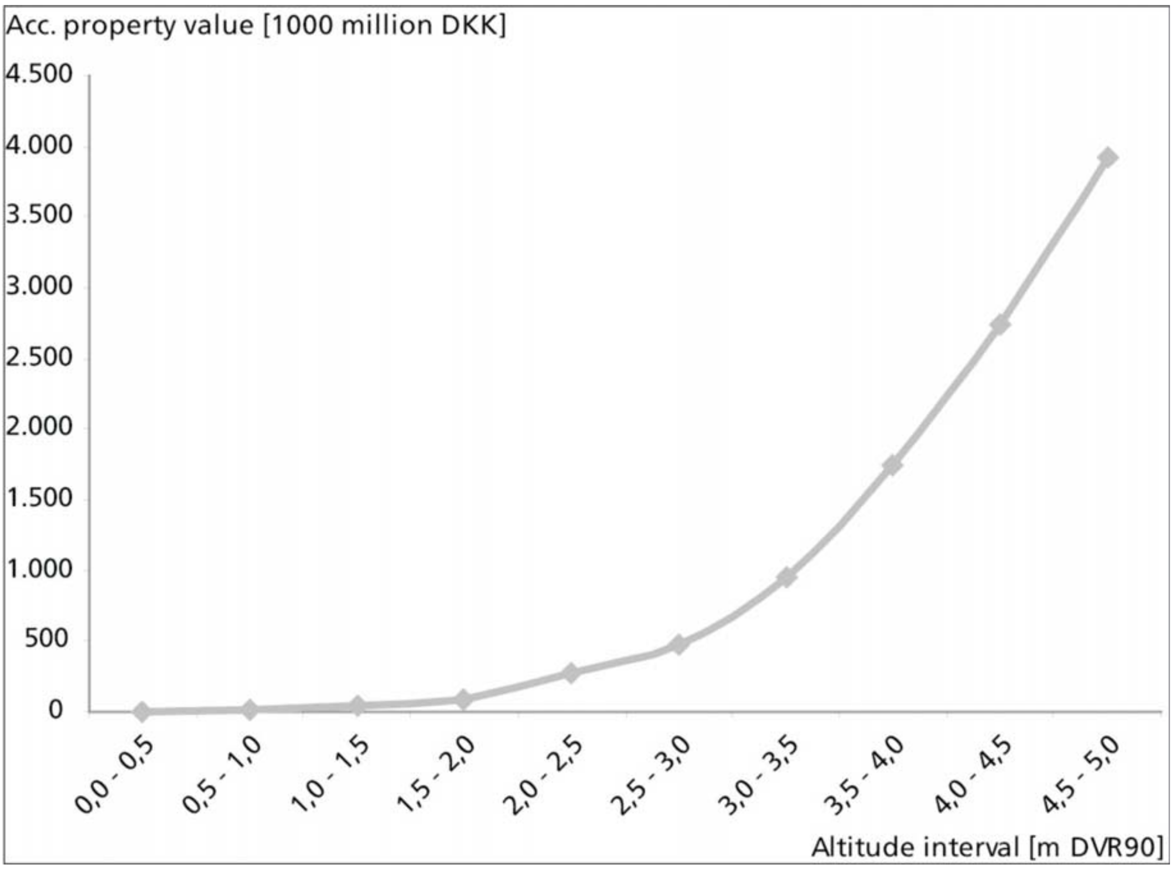

Fig. 7: Total property value distributed over altitude intervals

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Sc3: one dike breach in section 9
Sc4: wave overtopping in section 9
Sc5: three dike breaches in sections 2, 6, and 9
Sc6: four dike breaches in sections 2, 6, 8, and 9
Sc7: failure of both gates at the sluice

Depth-damage functions were derived for each damage category where the damage depends on the inundation depth. In case of depth-independent damage, damage factors were derived to quantify the damage.

For buildings and movable property depth-damage functions could be derived from data about compensation payments regarding real flood damage to buildings and movable property in Denmark. The assessment of flood damage to agricultural acreage was performed by external experts. Their assessment comprised damage factors for different kinds of crop and inundation periods of 5, 14 and 28 days.

Based on the seven scenarios, inflow volumes between 0.5 and 127 million m3 were calculated. Input parameters, such as a standardised storm surge hydrograph, the failure probability of defence system sections, the time-dependent development of a dike breach as well as an assumed time of failure during storm surge were considered in the calculations of the inflow volumes. Based on these input parameters, the flood-prone area is differently inundated depending on the location and the number of failure events.

Due to differences in inundation behaviour, damage within each scenario varies between 1.15 and 424.5 million DKK (56.9 million Đ). Only the scenarios Sc5 and Sc6 resulted in damage exceeding 100 million DKK (13.4 million Đ). The scenarios Sc1, Sc2 and Sc7 showed comparable inundation behaviour and resulted in the same total damage for all three scenarios. Tab. 5 gives the final results of the calculated damage for the seven scenarios.

Tab. 5: The calculated damage for all inundation scenarios (‘trafic system’ and ‘elec. installations’ have been grouped together as ‘infrastructure’

Risk element	Sc1/Sc2/Sc7	Sc3	Sc4	Sc5	Sc6
Buildings	DKK 4.937.000	DKK 0	DKK 0	DKK 54.179.000	DKK 203.555.00
	€ 662.685	€ 0	€ 0	€ 7.272.349	€ 27.322.819
Movable proberty	DKK 4.640.000	DKK 0	DKK 0	DKK 37.538.000	DKK 146.905.000
	€ 622.819	€ 0	€ 0	€ 5.038.658	€ 19.718.792
Agricultural acreages	DKK 2.208.000	DKK 933.000	DKK 211.000	DKK 7.098.000	DKK 9.489.000
January	€ 296.376	€ 125.235	€ 28.322	€ 952.752	€ 1.273.691
Livestock	DKK 0	DKK 0	DKK 0	DKK 1.232.500	DKK 7.978.000
	€ 0	€	€ 0	€ 165.436	€ 1.070.872
Infra-structure	DKK 7.226.000	DKK 844.000	DKK 942.500	DKK 22.862.000	DKK 56.554.000
	€ 969.933	€ 113.289	€ 126.510	€ 3.068.725	€ 7.591.141
Total	DKK 19.011.00	DKK 1.777.000	DKK 1.153.500	DKK 122.909.500	DKK 424.481.000
	€ 2.551.812	€ 238.523	€ 154.832	€ 16.497.919	€ 56.977.315

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5. Risk assessment

Finally, risk values were calculated varying between 300 DKK/year and 110.000 DKK/year. In this connection, the risk values calculated for scenarios Sc3 and Sc4 represent the lower bound of risk values for the Ribe flood defence system. On the other hand, the upper bound is represented by the risk value based on scenario Sc6.

The risk assessment made clear that the range of risk values depends on the inundation scenarios and the damage, which was determined on the basis of the inundation extension and depth. The determination of these factors required several assumptions, such as the location and number of failure events, the time of failure, the water level at the time of failure and a standardised storm surge hydrograph.

The aforementioned assumptions were not analysed within the damage analysis, as, for example, the location and number of dike breaches was chosen mainly on the basis of the overall failure probabilities calculated for the dike sections of the defence system.

6. Concluding remarks

The aim of this study was to analyse the overall risk of the flood-prone area in Ribe/Denmark. A hazard analysis has been performed as part of determining the flooding probability. The probabilistic calculations resulted in a failure probability of $P_f = 1 \cdot 10^{-5}$ to $P_f = 1 \cdot 10^{-6}$ for the dike sections. Similar values were obtained when scenario fault trees were used because the overall flooding probability is primarily governed by the failure probability of wave overtopping. The failure probability of the sluice and the outlets were in the range of $Pf = 1 \cdot 10^{-1}$ which was mainly due to the high failure probability for wave overtopping.

In order to determine the overall flooding probability, the defence system was divided into 15 sections. The division was based on two selection criteria, the structure type and the input parameters. Regarding the latter the wave period Tp and the crest height hk were most relevant. The fault tree calculations only considering the dike sections (without sluice and outlets) resulted in $P_f = 2.5 \cdot 10^{-4}$. However, this simple approach of dividing a defence system into sections has to be further developed in future, prompted by the following objectives:

- The variation of the relevant input parameters along the defence system (length effect) has to be considered. Wave attack on the seaward slope may vary locally because of changing the foreshore geometry. Furthermore, a varying crest height due to consolidation of different magnitude along the defence system may influence the probability of wave overtopping.
- The variation of input parameters along the defence system has to be considered in the probabilistic calculations in order to obtain a more accurate overall flooding probability of the defence system. In this respect, spatial and temporal correlations between different defence structures (dike, sluice, foreshore etc.) within one defence system have to be considered.
- Moreover, an improved approach of considering the parameter variation and dependencies (length effect) will give reliability-based indications of the location of failure (dike breach) along the defence line, which will be crucial in the process of defining inundation scenarios.

Due to the high failure probability of the sluice and the outlets, it was concluded that the sluice and the outlets represent the weak points of the Ribe flood defence system. Nevertheless, calculations showed that the limit-state equations and the uncertainty of the input parameters concerning sluices and outlets require further investigations. This goes

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along with a more accurate estimation of the real wave height and wave period in front of sluices and outlets.Within the vulnerability analysis only few damage categories have been considered. For some damage categories the tangible property was difficult to assess. However, the vulnerability analysis showed that the total damage calculated within each scenario strongly depends on the definition of the scenarios, the considered damage categories, the determination of the inundation behaviour and the derived depth-damage functions. Therefore, further investigations on the following topics should be carried out:

- criteria for the definition of inundation scenarios;
- damage categories, which have not been considered in this study;
- determination of the inundation process, e.g. by using numerical modelling;
- understanding of the breaching process of a clay-covered dike and the flood inundation process;
- further development of the depth-damage functions and their verification by real data.

Despite these further investigations, the assessment of the inundation propagation and thus the dimension of the damage are only assessable to a certain degree of accuracy. However, to calculate the flood risk and to assess the importance of the flood defence system as a defence structure for the inhabitants and their assets, a vulnerability analysis is indispensable.

The presented risk analysis procedure has been considered as starting point of reliability-based design of flood defence systems. This study has shown that it is indeed possible to consider more stochastic parameters when analysing the safety of a flood defence system. Despite the fact that many questions are still open and problems regarding the feasibility remain unsolved, the risk analysis procedure has resulted in a considerable increase in information about the Ribe flood defence system and the protected hinterland, which certainly will contribute to improve the decision-making regarding future flood defence systems in the area.

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Risk Assessment for the Lincolnshire Coastal Flood Unit COMRISK Subproject 8

ELISE POBJOY, PETER FLOYD, STEVE HAYMAN

Summary

The North Sea countries (Belgium, Denmark, Germany, Great Britain and The Netherlands) have a number of different policies towards the assessment and management of flood risk. COMRISK aims to establish a transfer and evaluation of knowledge and methods through focussed subject and pilot studies. The UK Subproject Pilot Study examines Lincshore; a major UK coastal defence scheme between Mablethorpe and Skegness where nearly 9 million m^3 of beach material has been placed since 1994.

The Lincshore defence strategy is based on the maintenance of a design beach profile. By taking a simplified relationship between the design minimum berm width and the level of storm resistance (and, hence probability of flooding), it has been possible to show how risk-based approaches based on risks to people, risks to assets (mainly property damage) and risks to both people and assets can be developed.

There are numerous ways in which the effects of flooding can be 'measured'. Within the UK, great reliance is placed upon extensive modelling to generate flood depths which, in turn, are used to generate estimates of losses in monetary terms. In this case study, the much simpler approach of simply counting people in flood compartments close to the defences yielded similar minimum berm width requirements.

Broader examination has been made of flooding from one of the coastal zones to demonstrate how a desk-top tool could be generated to assist in the identification of optimal areas for the placement of recharge during the decision making process. Analysis to examine the effects of a range of profile variations on the resulting overtopping volumes and consequent flood areas, depths and hence damages has been used to generate a limited range of data and look-up tables for interpolation. Limitations, issues encountered and recommendations for development of similar approaches in the future have been identified.

Zusammenfassung

Die Nordsee-Anrainerstaaten (Belgien, Dänemark, Deutschland, Vereinigtes Königreich und Die Niederlanden) nutzen unterschiedliche Strategien zur Ermittlung und Handhabung von Flutrisiken. COMRISK bezweckt einen Austausch und die Bewertung von Kenntnissen und Methoden durch thematische und Fallstudien. Die Fallstudie Lincolnshire (England) untersucht ein umfassendes Küstenschutzschema zwischen Mabletorpe und Skegness, wo seit 1994 fast neun Millionen m^3 Strandmaterial aufgespült wurde.

Die Lincshore Küstenschutzstrategie basiert auf einem definierten Strandprofil. Anhand eines einfachen Ansatzes zwischen der minimal erforderlichen Strandbreite im Bemessungsfall und dem Grad des Sturmwiderstandes (und, in der Konsequenz, die Überflutungswahrscheinlichkeit), war es möglich zu zeigen wie risikobasierte Ansätze (Risiko für Menschen, Risiko für Sachwerte und in Kombination) entwickelt werden können.

Viele Ansätze zur Ermittlung der Konsequenzen von Überflutungen existieren. Im Vereinigten Königreich liegt großes Vertrauen in dem Modellieren der Überflutungshöhen als Basis für die Berechnung der monetären Schäden. In dieser Fallstudie konnte durch einfaches Zählen der Einwohner hinter den Schutzwerken eine vergleichbare benötigte Minimalbreite des Strandprofils ermittelt werden.

Für eine der Niederungen wurde eine vertiefte Untersuchung der Überflutung durchgeführt um aufzuzeigen, wie eine „desk-top" Module zur Optimierung der Standortsuche für Sandaufspülungen entwickelt werden kann. Die Auswirkungen verschiedener Strandprofile auf die Überlaufmengen und resultierende Überflutungsflächen, -Tiefen und -Schäden wurden als Grundlage

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für die Erstellung von Nachschlagetabellen für Interpolation analysiert. Schließlich wurden die Grenzen der Methodik und die behandelten Themen aufgezeigt sowie Empfehlungen für die Entwicklung ähnlicher Ansätze in der Zukunft definiert.

Keywords

Coast, risk management, flood defence, risk assessment, failure probabilities, vulnerability analyses, Lincolnshire

Contents

1. Introduction

In the UK, the Environment Agency has permissive powers to maintain the coastal defences that provide protection to 24 km of the Lincolnshire coastline between Mablethorpe and Skegness, referred to as the 'Lincshore' coastline. Lincshore is the pilot study for Great Britain under Subproject 8 and has been undertaken jointly by Halcrow and Risk and Policy Analysts (RPA) for the Environment Agency.

The Lincshore coastal defences provide flood protection to the low-lying coastal plain, which extends up to 15 km inland and has a recorded history of flooding back to the 13th century. The coastal plain covers approximately 35,000 ha of both urban and agricultural land, and includes over 27,500 residential and 3,500 commercial properties. The coastal frontage is heavily used for recreation and tourism with major tourist resorts at Mablethorpe and Skegness. Fishing contributes to the local economy and, further inland, land-use is dominated by isolated rural communities within agricultural holdings. There are a number of conservation and heritage sites protected by the defences on both the Lincshore frontage and the adjacent coast.

Fig. 1: Location of the study area

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Historically, the natural sand dunes have formed the coastal defences along the Lincshore coastline, supplemented by concrete revetments and seawalls around residential areas. In 1953 extreme surge tide levels and severe wave action caused erosion and breaching of the natural dunes and erosion of the rear of hard defences, resulting in their collapse. This led to 12 major breaches with floodwater spreading several kilometres inland, causing the loss of over 40 lives and major property damage.

Fig. 2: Flooding in Lincshore during the 1953 storm surge

Following 1953, many of the seawalls were rebuilt and have required maintenance, repair and upgrading ever since. During subsequent storm surges, breaking waves still reached the seawalls, leading to significant overtopping and damage (although no major flood event), which highlighted the flood risks and need for a detailed review of the Lincshore coastal defences.

UK defence systems are planned within a ‚hierarchy', cascading from National policy, through large-scale plans, to strategies, and down to individual schemes. The Lincolnshire Shoreline Management Plan (SMP) sets out the high-level policy for the coastline taking into account coastal processes, human influence, land-use and other environmental matters. For the Lincshore coastline the preferred policy is to 'hold the line'.

In 1991, the first Lincshore Sea Defence Strategy was commissioned. The strategy concluded that holding the line through beach nourishment and maintenance of seawalls and promontories was the preferred long-term defence strategy from technical, environmental and economic considerations. The strategy was reviewed in 1997 and again in 2003/2004 in light of the coast's performance and updated guidance, and in both instances it was concluded that beach nourishment to provide a 1 in 200 standard of defence should continue as the preferred coastal defence option (referred to as Option 6b in the latest 2003 Strategy Review).

2. Sources of Risk

At any particular location, the likelihood of flooding will depend on:

- The presence and form of the coastal defences;
- The beach profile and nearshore bathymetry;
- the nearshore wave climate, which in turn is dependent on tidal and meteorological conditions and offshore wind and wave conditions.

The near-shore wave climate also affects the movement of beach material. Sediment movement along the Lincshore frontage is primarily governed by cross-shore processes, which tend to dominate during storm conditions. However, the beach material is also subject to some longshore movement, effectively acting as a loss from one length of coastline, but a gain to that downdrift.

Coast Defence Structures

The coastal defence structures along the Lincshore coast have been developed over many years and hence have a number of different profiles. The flood defences consist mainly of beaches, groynes, dune systems, seawalls and promontories (Chapel Point, Vickers Point & Ingoldmells Point). Structural details of the seawall were taken from the Anglian Sea Defence Survey (Mott, 1999) which contained photographs, profile sections and descriptive details of both visual and analytical information for each structure surveyed.

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Beach Profile/Sea Bed Conditions

For most of its length, the Lincolnshire coast is characterised by a narrow steep beach with little sand, backed by seawalls or revetments. The beaches comprise sand of variable thickness and consistency, overlying clay, which is subject to erosion when exposed. The available recharge material has a coarser grain size than the original insitu beach material; in 2001 the mean grain size sampled on the beach was 0.4 mm.

Significant Wave Heights

In the latest Strategy Review, the offshore wave data were obtained from the UK Met Office for a point located near Dowsing Light for the period 1991–2001. Analysis of this data gave a 1:100 year offshore wave height of 5.82 m. Differences were observed between the analysis of historic vessel observed records (prior to 1991) and the more recent (lower) Met Office predictions. Therefore this remains a potential source of some uncertainty, but the impact is mitigated by the minimal resulting difference in nearshore wave heights.

Tidal Conditions

The mean tidal range for Lincolnshire coast is 4.4m, around a mean sea level of 0.26m OD (4.01m CD). A joint analysis of water level and wave height extremes was undertaken for the assessment of defences in the Strategy Review using hourly measured water levels from Immingham.

Sea Level Rise (SLR) has been included as a constant increase over the appraisal period. For the Lincshore coastline, situated in the Environment Agency Anglian region, a value of SLR of 6mm/yr was used in accordance with the latest DEFRA Guidance. Secondary impacts such as changes in wave heights due to an increase in water depths have been examined in a sensitivity analysis.

Near-shore Wave Climate

The near-shore wave climate is typified by waves from the north-east. Waves were propagated inshore using Halcrow's in-house mathematical model, which is based on a new formulation of the mild slope equation for water waves, allowing for refraction, diffraction, breaking and bottom friction. The coastline was divided into seven zones, broadly based upon the management units defined in the SMP (Posford Duvivier, 1996) and the offshore wave heights were transformed to inshore points within each of the zones. Wave heights are slightly larger towards the southern part of the coast. The results of the joint probability analysis for zone 2 are shown in the table below. Despite the different in offshore wave conditions it should be noted that the wave heights in the table below are comparable with those derived in the 1990 Strategic Approach Study:

Zone	Return Period	Water Level, WL(mOD)	Future Water Level, WL+300mm (mOD)	Significant Wave Height, Hs (m)	Zero Crossing Tz (s)
2	1 in 1	3.35	3.65	2.80	7.75
	1 in 10	4.00	4.30	3.20	8.29
	1 in 20	4.15	4.45	3.50	8.67
	1 in 50	4.40	4.70	3.50	8.67
	1 in 100	4.50	4.80	3.70	8.91
	1 in 200	4.65	4.95	4.00	9.27
	1 in 300	4.79	5.09	4.07	9.35
	1 in 500	5.00	5.30	4.10	9.38

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3. Risk Pathways

Flood Events

As already indicated, coastal flooding is caused by seawater overwhelming the defences. In practice, this can occur either by seawater coming over the top of the defence; and/or through a breach (i.e. failure) of the defences. The subsequent extent and severity of the resultant flooding will be governed by numerous factors including the nature and timing of the flooding. (Eg, there are likely to be far fewer people at risk in the static caravan parks in winter when storms are more likely).

Failure and Inundation Mechanisms

Different modes of failure (overtopping, undermining, face or toe erosion, overturning, piping, reduction in bearing capacity) were evaluated. The most prevalent structural failure mechanism for the seawalls was due to extreme overtopping of the structure. Overtopping of structures only leads to a breach once certain defined limiting values for discharge rates have been exceeded. Guidance for critical overtopping discharges for serviceability and ultimate limit states (CIRIA/CUR, 1991) were used as the means to assess breach failure.

Overtopping analysis was undertaken under a number of return periods to enable a robust assessment of the limits of the current standard of defence. Discharge quantities for overtopping of the initial return wall (OT1) and the rear of the embankment (OT3) were calculated directly from the overtopping modelling package. Overtopping of the intermediate splash wall (OT2) was calculated by means of a reduction co-efficient, determined as a function of the crest width and potential presence of a splash wall.

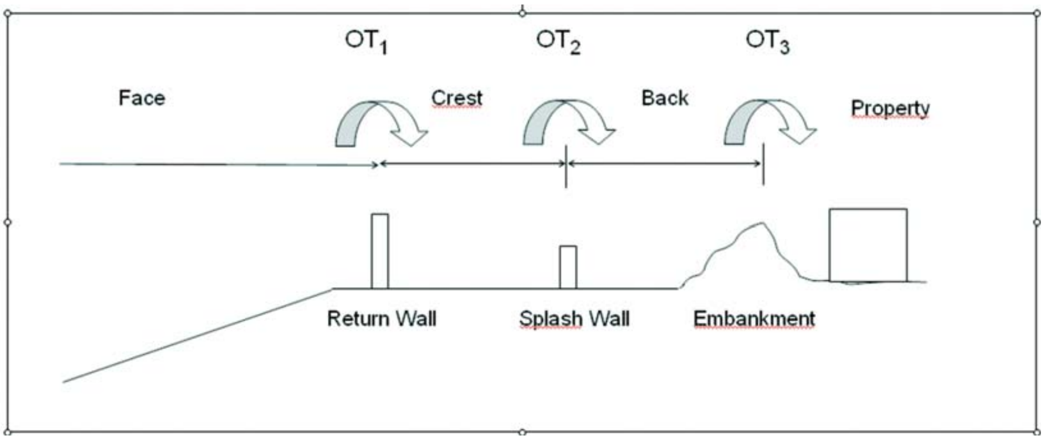

Fig. 3: Overtopping analyses of the defences

The discharges from the overtopping analysis were reviewed against a number of sources, including visual reference information of overtopping events for location, quantity and damage sustained to the defences. The results of the overtopping discharge assessment of the existing structures were compared against the critical overtopping limits to provide an assessment of the integrity and standard of each of the defences.

Flood Propagation

A dynamic method was used for flood propagation prediction, which takes account of the tidal range at the site and spreads the flood volume over consecutive tides by the application of hydrodynamic modelling. A digital terrain model (DTM) of the frontage was

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developed based on Ordnance Survey profile data (made up of nationwide photogrammetry estimates and random spot heights), LIDAR data (1 km coastal strip), and Agricultural spot height co-ordinates and levels from Lindsey Marsh Drainage Board. From the DTM and OS profile information the location and level of the reservoir boundaries were defined and converted into ISIS spill lengths, across which flow would take place between adjacent reservoirs. Over 100 reservoirs and 700 spill units were established for the flood model for the coastline to reproduce the hydraulic characteristics of the flood area.

The 1953 documented flood event was used to calibrate the model. The 12 breach locations and extents were included in the flood model as well as the 1953 surge water levels as a tidal head boundary. Model calibration (breach widths, secondary defences etc) was then undertaken to reflect the 1953 flood limits.

Where either OT1 or OT2 exceeded the defined overtopping limits, the structure was deemed to have failed, and for each length failed, a breach width of 100 m (determined through a sensitivity analysis of breach widths) was entered into the model. OT3 was modelled as an inflow into the model over the peak of the tide.

Assets have been defined for each reservoir and the economic 'benefits' associated with the provision of standards of defence are dominated by the damages avoided to residential properties and industrial/commercial properties incurred through flooding. The capital value of residential assets at risk over the entire Lincshore frontage was over £ 2 billion.

Movement of Beach Materials

In recent decades, wide accreting sandy beaches have been present both to the north of Mablethorpe and to the south of Skegness (Posford Duvivier, 1991 and Halcrow, 2003). Between these locations, the beaches have a history of erosion. Prior to beach recharge, the main supply of material for these accreting beaches was considered to be off-shore banks with a limited littoral movement (north to south) of 130,000 m^3/year (Posford Duvivier, 1991). Recent coastal process modelling for the site suggests a southerly longshore movement with rates of around 100,000 and 250,000 m3/yr in the northern and southern parts respectively.

Design Principle

The basic design principle is based around the provision of sufficient beach width to protect the seawall. The design beach profiles for different levels of protection have been established by increasing the width of the profile until the overtopping discharge falls below the acceptable overtopping limits. The volume of overtopping of the chosen design profile is that which would be expected once the profile had eroded after a storm event; this is calculated by extrapolating the overtopping between beach and clay profiles in proportion to (the eroded) volume change. The design berm width was then increased to account for annual erosion losses, and the cross shore modelling of the beaches determined a need for an average 8m increase in the berm width to account for the 300 mm increase in water level due to SLR over the strategy period of 50 years.

Using the October 2002 beach profiles as a baseline, digital terrain modelling was undertaken to determine the volume of material required to build up the beaches to the minimum profile widths for the 100 year design, the 200 year design and the 300 year design.

Overtopping Assessment

The overtopping modelling results show that overtopping rates increase with decreasing berm width. However, as separate models were used to predict beach draw-down and then overtopping rates were based on the eroded beach profile, no simple linear correlation was derived between the starting beach profile and overtopping rates.

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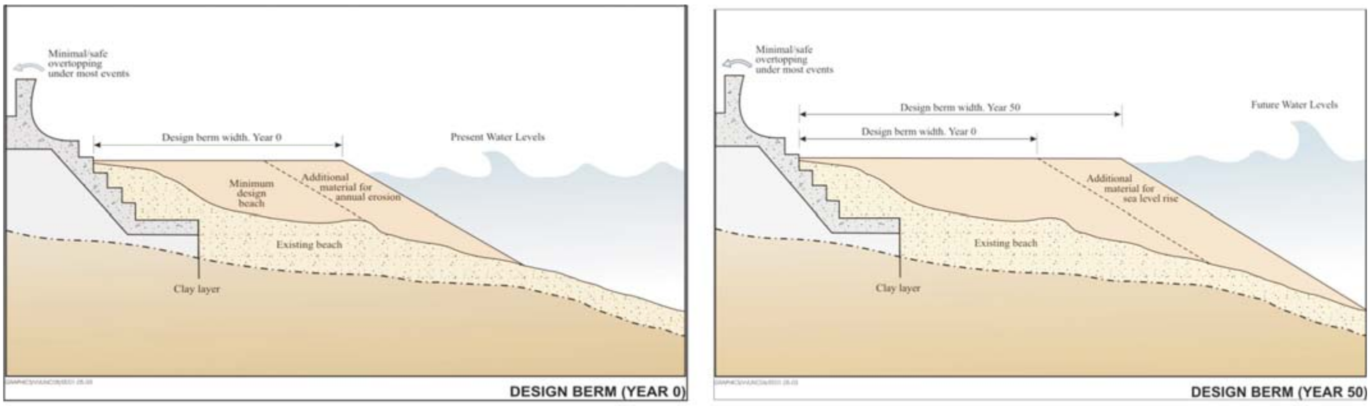

Fig. 4: Design berm without and with additional material for sea level rise

4. Beach Performance

Nourishment of the Lincshore frontage has been ongoing since 1994. Over the ten year period, 1994-2003, nearly 9 million m^3 of beach material has been placed on the Lincolnshire coast between Mablethorpe and Skegness. Photographs demonstrate that the beach is now significantly wider than it was in 1994.

Beach Profiles

One of the key features of Lincshore is that use has been made of material with a mixture of grain sizes. This has led to 'natural' grading on the beach with medium sand found on the upper beach, very coarse sand on the middle beach and fine/medium sands on the lower beach (BLOTT & PYE, 2001). A number of data sets on the grain sizes exist, with samples taken over a number of transects by various parties at differing times and for a variety of purposes. Correlation between the observed beach profiles and equilibrium beach profiles (based on DEAN 1991) derived using certain of the data sets suggested that the profiles may be a direct consequence of the grain size distribution of the material used for beach nourishment and renourishment. However, this analysis did not fit all the available (different) data sets.

Net Movement of Material

Budgetary constraints for recharge activities mean that the beach still has a substantial shortfall from the original 1991 design profile. It has been recognised that the annual recharge is an ongoing commitment, ie it is addressing a shortfall in the sediment budget due to historic defence measures that have reduced feed to the frontage, and to address climate change in the longer term.

Considerable resources have been devoted to the collection and analysis of data over the last 15 years, and whilst it is accepted that there will always be a degree of uncertainty in predicting material losses from a renourished beach, it has proved difficult to conclusively relate the observed rate of loss to the rate of renourishment. Between Maplethorpe and Skegness the mean nourishment rate has been 0.785 million m^3/year and (net) losses from the upper/middle beach (excluding Gibraltar Point), have averaged 0.598 million m^3/year. These losses are predominantly cross-shore. However, despite one anomalous year of data, general trends can be extrapolated and the degree of uncertainty is within the sensitivities examined in the Strategy Review.

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5. Defence Option Assessment

Within the UK, options for flood and coastal defence schemes and strategies are subjected to a formal appraisal process, including an environmental, technical and economic assessment (as set out by DEFRA) to ensure that the optimal defence option and standard is selected. For the Lincolnshire coastline the required indicative standards of protection for the land usage can only achieved by 'do something' options.

Beach Management Options

The preferred Strategy defence option (Option 6b) entails annual beach recharge quantities of around 0.3 million m3 following the initial capital recharge campaign. There are a variety of methods which could be used to determine where this material could practically be best placed.

For each length of beach (as characterised by the beach profile), it is possible to estimate either the shortfall in beach volume between the current and design profile, or the present standard of defence (as 'probability of critical overtopping'). Those profiles with the greatest shortfall of material or lower standard of defence could be given priority for beach recharge. However, this would not account (explicitly) for the associated risks.

Alternative approaches could be based on risks to either people or assets situated behind the defences, or even a combination of the two. The management options for material emplacement outlined in the previous sub-sections are summarised below.

Summary of Management Options for Material Emplacement

Option	*Simple?*	*Relevant?*	*Risks to People Considered?*	*Risks to Assets Considered?*
Vol. differences – original design	Yes	No	No	No
Volume differences – latest design	Yes	Yes	No	No
Maintain standards of defence	Yes	Yes	No	No
Risk-based approach				
(with focus on risks to people)	No	Yes	Yes	No
(with focus on risks to assets)	No?	Yes	No	Yes
Combined risk-based approach	No	Yes	Yes	Yes

Risk-Based Approach

At a particular location, the risk to people behind the defences is a function of the standard of defence, the presence of people behind the defences and their vulnerability to flooding (eg flood depth and velocity and nature of buildings). Consideration of a range of flood events (at a particular location) would enable the baseline risk of death to a hypothetical individual stood outside for 24 hours a day to be determined and be presented graphically in the form of a series of 'risk contours'. These contours should then be passed through a logic gate to confirm the probability that someone would be present at each location in order to provide the 'real' risk. Those areas with the highest 'real' risk could then be given priority for beach recharge.

Similarly, the risk to assets behind the defences is a function of the standard of defence, the presence of assets behind the defences and damage-depth relationships. This is a similar approach to that taken in determining average annual damages (AADs). It should be noted that taking the AAD values effectively takes account of the flood reservoir location since the damages are associated with the flood level predicted in each of the flood reservoirs.

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Damages (for a range of extreme events) should be considered on a profile by profile basis.

Within each flood reservoir, the assets were detailed and the associated monetary damages determined under a range of storm events. The risks to both people and property obviously decrease with distance from the coast. For Option 6b, the AAD figures indicate that over half of the total calculated damages occur in flood reservoirs which are located immediately behind the defences. Furthermore, 95 % of the damages are associated with the 61 flood reservoirs which, at their closest, are within two kilometres of the defences. It therefore appeared reasonable to develop a simplified risk-based approach based on those 61 flood reservoirs.

Flood risks to an individual are, primarily, a function of depth and velocity, both of which are related to location. The overall risk is also a function of the total number of people. Determining the precise levels of risk to particular people in particular locations is a complex task and is beyond the scope of this study. However, a simple function was formulated based on numbers of people and location. A simple risk score was assigned to each flood reservoir under consideration. For risk to people this was based on its proximity to the defences and the number of people at risk. For risk to assets, risk was assigned based on the level of damage.

Risk Scores for Flood Reservoirs (based on Risks to People)

Boundary of Flood Reservoir	Number of People within Flood Reservoir People at Risk = Nr of residential + industrial/commercial properties x 2.5					
	up to 10	>10	>30	>100	>300	>1000
Adjacent to Defences	0	1	2	3	4	5
Within 2 km of Defences	0	0.5	1	1.5	2	2.5

Risk Scores for Flood Reservoirs (based on Risks to Assets)

Level of Damage	Predicted Annual Average Damage (AAD)					
	up to £3k	>£3k	>£10k	>£30k	>£100k	>£300k
Risk Score	0	1	2	3	4	5

From these risk values, a relationship to the design berm was determined:

$$\text{Berm Width} = 6 \times \text{Risk Score} + 5$$

At each location along the Lincolnshire coastline, breaching or overtopping of defences could affect more than one flood reservoir. The flood reservoirs were 'mapped' against each of the profile numbers in order to develop a means of providing sufficient berm width for all the flood reservoirs that could be affected from a single stretch of coastline. It was found that the berm width requirements are dominated by the risks associated with flood reservoirs which are immediately behind the defences.

A comparison of the result can be seen below. There was a strong correlation between the results from both approaches which indicates a strong correlation between the derived

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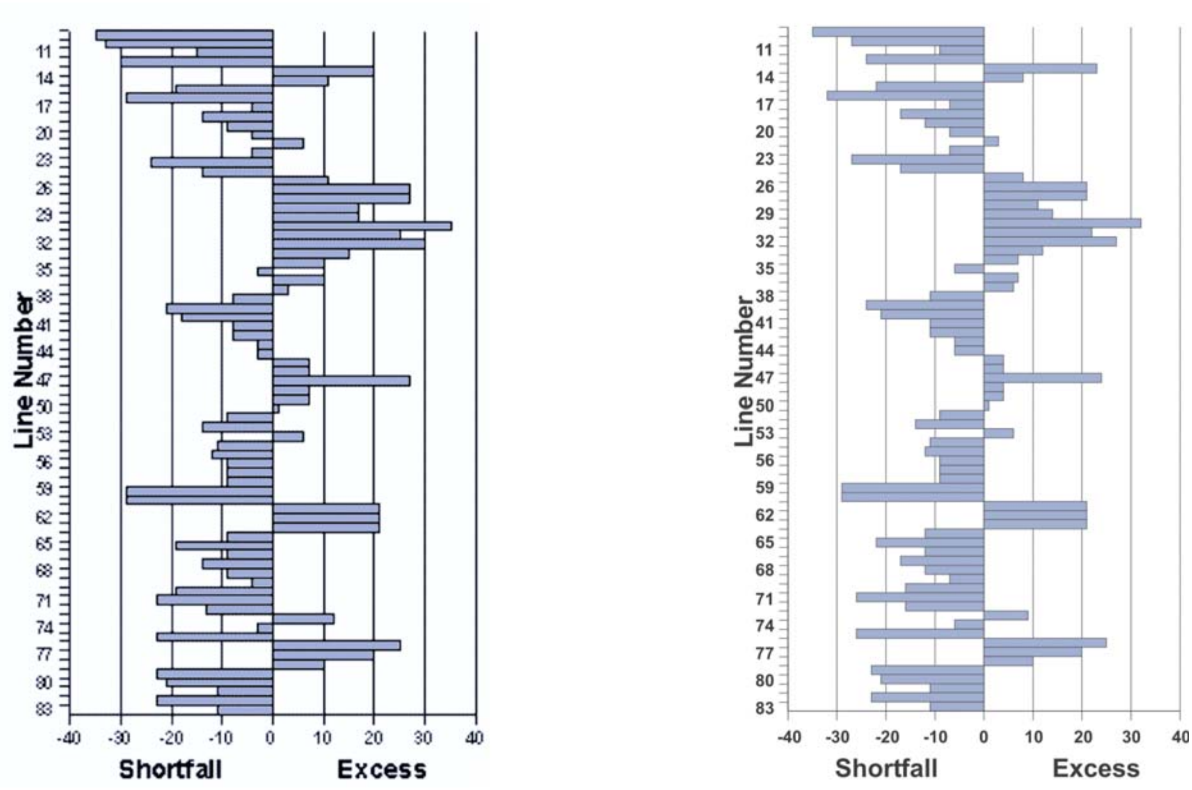

Fig. 5: Comparison of berm widths based on risks to people (left), and to assets (right)

risk scores. ie, as might have been expected, in areas with relatively high annual average damages there will also be a relatively high level of risk (as both are a function of the numbers of people/assets at risk and the floodwater depth).

Comparison of the overall minimum berm widths with actual berm widths would enable the areas requiring additional recharge material to be identified. A combined approach could be based on simply averaging the minimum berm widths for each flood reservoir.

6. Desk-top Tool

A desk-top tool has been developed to assist in the identification of optimal areas for the placement of limited recharge. The tool examines the flooding associated with Zone 2 (selected as being representative of average conditions along the frontage).

The steps for using the tool are as follows:

- Import latest survey results (or historic surveys held within the spreadsheet can be used)
- Working through the zone, beach profiles are presented, and by inspection, the user selects an appropriate toe level for each. Toe levels are collated into a table of results.
- Once all profile information has been collated, the programme interpolates from a look-up table to determine overtopping volumes for each reservoir and whether a breach is likely to have occurred.
- The programme then uses a second look-up table to relate the derived overtopping volume or breach scenario to a consequential value of damages caused by this flooding. These damages are related to the damages anticipated with the design profile in place, and hence the value of damages avoided calculated.

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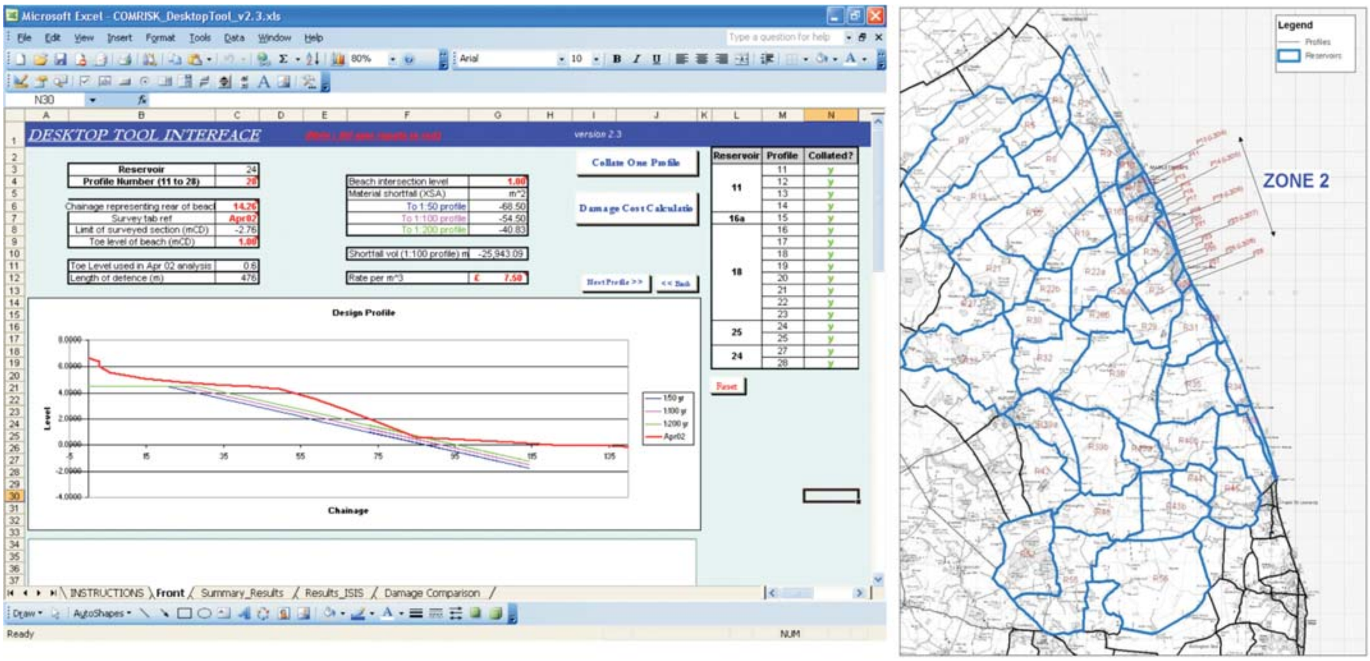

Fig. 6: Screen shot of desk-top tool to assist in identifying optimal locations for recharges (left), and locations of the profiles in the screen shot (right)

- From the design profile for the different standards of defence (1:50, 1:100, 1:200) and the beach survey levels, a table of shortfall volumes to different design standards is calculated.
- From the shortfall volumes and the value of damages avoided, a cost:benefit comparison for recharging to different standards of defence throughout each reservoir is derived. This can then be examined in light of any budgetary constraints in order to determine the optimal economic solution for the placement of material.

7. Key Findings

Lincshore is a major UK coastal defence scheme which has involved the emplacement of nearly 9 million cubic metres of material upon the beach between Mablethorpe and Skegness since 1994. There has been extensive work over a period of time on beach monitoring, modelling of flood events and comprehensive evaluations of the costs and benefits of various options for maintaining appropriate standards of defence.

Risk-Based Approaches

Lincshore is based on the maintenance of a design beach volume to protect a hard defence line. The latest design incorporates a minimum berm width to provide, in effect, the required level of storm resistance (and, thus, reduce the probability of flooding). However, the strong temporal variability in the beach response and influence of coastal geomorphology, storm sequencing and persistence make it difficult to identify a simple relationship between design berm widths and probabilities of flooding, which has proved to be an obstacle to the development of a 'calibrated' example of a risk-based approach for the Lincolnshire coastline.

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Nevertheless, on the simplified assumption that the probability of flooding is directly proportional to the berm width, risk-based approaches have been developed based on risks to people, risks to assets (mainly property damage) and risks to both people and assets. The results from all three approaches were very similar and could provide an alternative (simplified) basis on which to allocate beach material along the coastline.

Desk-Top Tool Development

A number of points or note came out of the development of the desk-top tool:

Uncertainty in Analysis

The tool uses a combined assessment of drawdown and overtopping to determine an overtopping volume for the eroded beach profile. The degree of accuracy of the overtopping calculations is generally appreciated to be order of magnitude, hence the validity of comparison with a single critical overtopping value to assess whether or not a breach has occurred is questionable. Calibration with real events would help to improve confidence, but (fortunately) there is limited data on breach failure scenarios. This does, however, mean that the prediction of circumstances when breach and overtopping failure would occur is uncertain, and a full system model of flood risk is required to enable testing of a wide range of combinations of beach state and forcing conditions to assess the sensitivity of management assumptions to the underpinning analysis and assumptions.

Potential for Changes to the System

The analysis used is founded on an assessment of the response of the beach defence system for the current wind and wave climate and existing bathymetric levels, with beach gradings based on the current understanding of available recharge sources. The tool does not allow for these parameters to be varied, nor does it account for whether erosion rates at this location are likely to be high, medium, low or what would happen to the material if placed there in the near or more distant future. As described, the coastal system is very complex and material can remain stored in offshore banks for some time, making assessment of movement trends difficult. However, as the purpose of the tool is for short-term management decisions, this is not viewed as a major constraint.

Reservoirs with Damages

The majority of the damages from breaches and/or flooding in Zone 2 occur within a limited number of reservoirs, located adjacent to the coast and which cover the urban areas of Mablethorpe and Sutton on Sea.

Look-up Tables

The look-up tables used in the desk-top tool are based on coarse interpolation between a limited number of model runs to generate data for a range of toe levels, overtopping volumes, flood lmits and damages. To get a comprehensive table of the full range of beach profiles, forcing conditions, breach/non-breach scenarios, flood pathways and relative overtopping contributions form adjacent coastal reservoirs to determine independent and in-combination events for the entire coastline would require a vast amount of modelling.

Data Management System

Examination and review of the scheme has been ongoing for the last 15 years. An efficient data management system is vital to collate the vast amounts of data associated with a project spanning over this length of time. Any database system should permit comments to

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be added pertaining to the source, reliability and methodology adopted and enable identification of any issues to be noted as records are collated and any assessments of the raw data or trends are undertaken.

Recommendations

There are numerous ways in which the effects of flooding can be 'measured'. Within the UK, great reliance is placed upon extensive modelling to generate flood depths which, in turn, are used to generate estimates of losses in monetary terms. In this instance, the much simpler approach of counting people in flood compartments close to the defences yielded similar minimum berm width requirements. Consideration should therefore be given to the ability of the appraisal method to deliver the required results in an efficient manner.

A desktop tool has been developed which enables a strategic approach to recharging the beach and allows the sensitivity of flood risk to beach condition in each coastal cell to be tested to identify trends. Such a tool could be useful for Flood managers to provide short-term management decision support as a relative measure of qualitative benefits of alternative recharge locations when there are budgetary constraints. However, it does not consider longer term impacts of the wider geomorphology of the system and therefore does not replace the deterministic assessment of failure required to put forward the longer-term business case for the recharge works.

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Risk Assessment for the Island of Langeoog COMRISK Subproject 9

HOLGER BLUM, FRANK THORENZ

Summary

A risk analysis based on available data and methods is conducted for the flood prone areas of the Island of Langeoog protected by coastal defences. By executing a hazard analysis the danger of flooding due to failure of a coastal defence element is determined. A statistical analysis is used to determine the surge water levels for certain occurrence probabilities. Deterministic failure calculations of the coastal defence system are executed considering various failure modes. A vulnerability analysis for the area protected by a coastal defence system including the village Langeoog is executed on a micro scale level. Elements at risk like buildings, vehicles, life stocks within the investigation area are considered to be endangered. The results of the valuation, the estimated damages and the specific risk based on flooding scenarios are presented. The influence of uncertainties of major input data, assumptions and chosen scenarios on the estimated damage and the calculated risk are exemplarily determined and discussed. Based on the results of risk calculation possible measures to reduce the risk of Langeoog are recommended.

Zusammenfassung

Für die sturmflutgefährdeten Gebiete der Insel Langeoog, die durch Küstenschutzanlagen geschützt sind, wird eine Risikoanalyse auf der Basis verfügbarer Daten und Methoden durchgeführt. In einer Gefährdungsanalyse wird die von einer Flutung im Falle des Versagens einer Küstenschutzanlage ausgehende Gefährdung geschützter Werte bestimmt. Hierfür liefert eine Extremwertanalyse der Wasserstände für bestimmte Überschreitenswahrscheinlichkeiten die Sturmflutwasserstände. Bei der Ermittlung des Versagen der Elemente des Küstenschutzsystems wurden verschiedene Versagensmechanismen berücksichtigt. Eine Vulnerabilitätsanalyse für den vom Küstenschutzsystem geschützten Bereich der Insel, inklusive der Ortslage, erfolgt über einen mikroskaligen Ansatz. Die Ergebnisse der Bewertung, der Schadenschätzung und das spezifische Risiko basierend auf Szenarien werden dargestellt. Der Einfluss von Unsicherheiten der Eingangsdaten, Annahmen und gewählten Szenarien auf die Größe des spezifischen Risikos werden über exemplarische Sensitivitätsstudien ermittelt und diskutiert. Abschließend erfolgt eine Empfehlung von möglichen Maßnahmen zur Reduzierung des Risikos.

Keywords

Coast, risk management, flood defence, risk assessment, failure probabilities, vulnerability analyses, Langeoog

Contents

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1. Introduction

The island of Langeoog is one of seven inhabited sandy barrier islands located in front of the Lower Saxony mainland coast in the southern German Bight. It is characterized by dune areas in the north and lowlands in the south. Langeoog covers a terrestrial area of 20 km²; 7.7 km² are protected against storm surges by a ring of dunes and dikes. The village of Langeoog has an extent of 1.5 km² and is inhabited by approximately 2000 persons constantly living on the island. The most important economic factor is tourism. The drinking water supply is based completely on the fresh water lens in the dune areas protected by the coastal defence system.

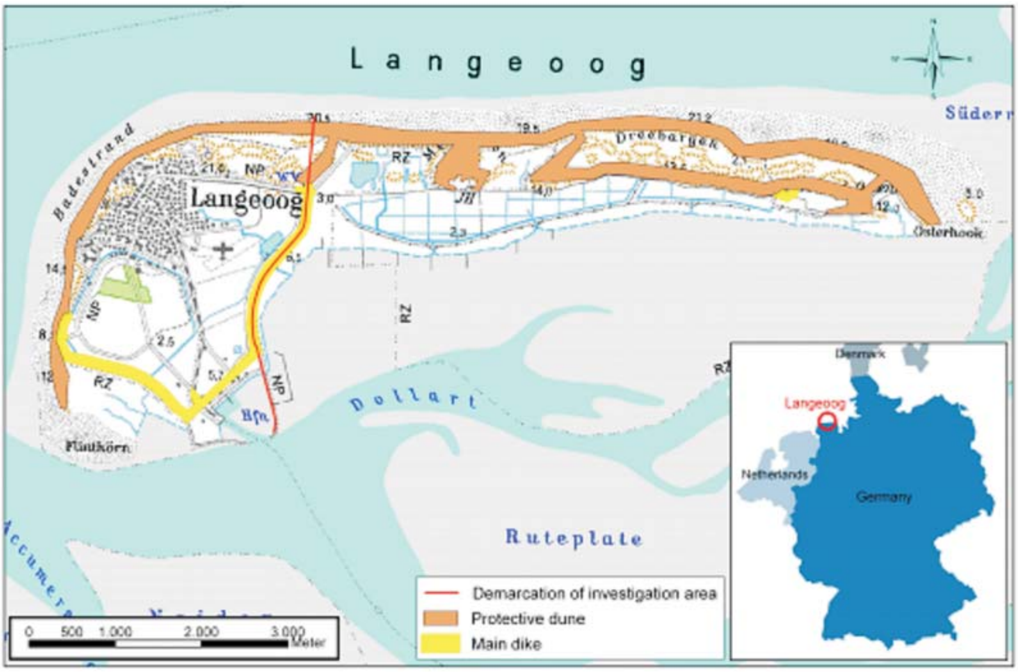

Fig. 1: Langeoog overview – Topographic map 1:50000

2. Objectives

The situation of an island concerning coastal defence and risk management issues differs significantly from the situation on the mainland coast. The coastal defence elements form a protective ring for flood-proned areas. Hence a failure of one element might lead to a flooding of the whole area, see Fig. 1.

The following main issues shall be investigated within the subproject:

- an inventory of the existing coastal defence measures as well as of physical and socio-economic conditions in the Langeoog flood unit
- a state of the art risk assessment ,
- recommendations for measures to reduce the risk of flooding i.e. to increase the safety standard

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3. Methods

Fig. 2 gives an overview of the various steps used in the study [NLWKN 2005] to come up with a risk analysis. A hazard- and a vulnerability analysis are used to gather the information needed for a risk calculation. In the following the two analysis and their main subprocesses are described.

3.1 Hazard analysis

The hazard analysis is the methodical, comprehensible and formal procedure to evaluate the threat of specific events, conditions, processes or actions in a specific area. It is determined as a combination of hazard (intensity) and frequency (probability) of a specific threat.

3.1.1 Extreme value analysis on water level

An extreme value analysis on data of Norderney gauge station is conducted based on water level set up caused by storm surges for a time series of 108 years. The momentum

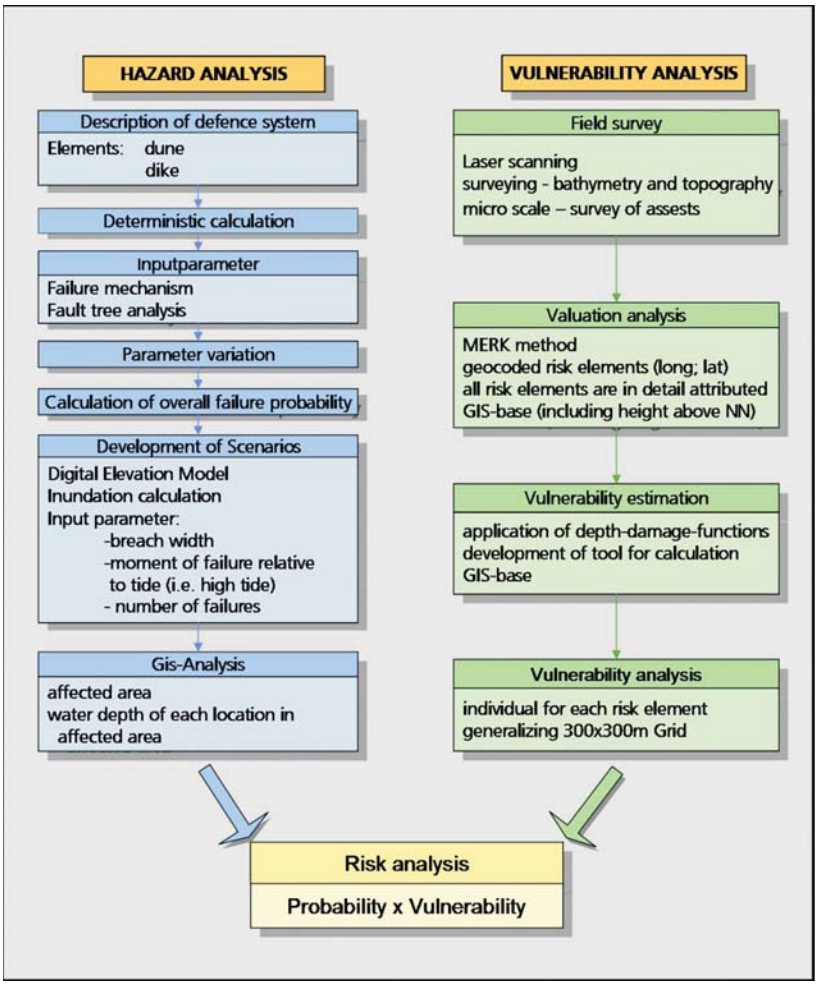

Fig. 2: Flow diagram risk analysis

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method is applied on four statistical distribution functions to determine the best fitting distribution and the associated parameters. A transfer function yields the extreme storm surge water levels at Langeoog.

Since a failure of the coastal defence system is expected for water levels that are at least equal to or higher than the design water level of NN + 5.10 m, an extrapolation of the statistical distribution up to the return period of T = 10,000 years is calculated.

This extrapolation interval is significantly higher than the recommended extrapolation interval of three times the time series duration (WANG / LE MEHAUTE 1983 after EAK 2002) which yields 324 years in this case. Confidence intervals are determined for all investigated distribution functions. The Chi-Squared Test is conducted to assess the fitting quality of the distribution functions. Results of the Chi-Squared Test and the width of the 95%-confidence interval showed the Log-Normal distribution function best fitting. Therefore this function is applied for calculating the water levels related to certain return periods used in the further investigation.

The chosen Log-Normal distribution yields a water level of NN + 5.68 m for a 1/10,000 years storm surge event which is nearly 0.6 m higher than the legal design water level at present. The 95 %-confidence interval shows a margin of 1.14 m. The return period of the present legal design water level is determined to approximately 1,000 years, see Fig. 3.

3.1.2 Failure calculation

The calculation of failure for the coastal defence system was conducted by means of numerical models: ProDeich (KORTENHAUS & OUMERACI 2002) and UNIBEST-DE (STEETZEL 1993, Delft Hydraulics 1995) are used to determine the damages to the dike and dune, respectively. The failure is calculated with a deterministic approach by determining the surge height leading to a failure of the coastal defence section, e.g. by overtopping, or an under-run

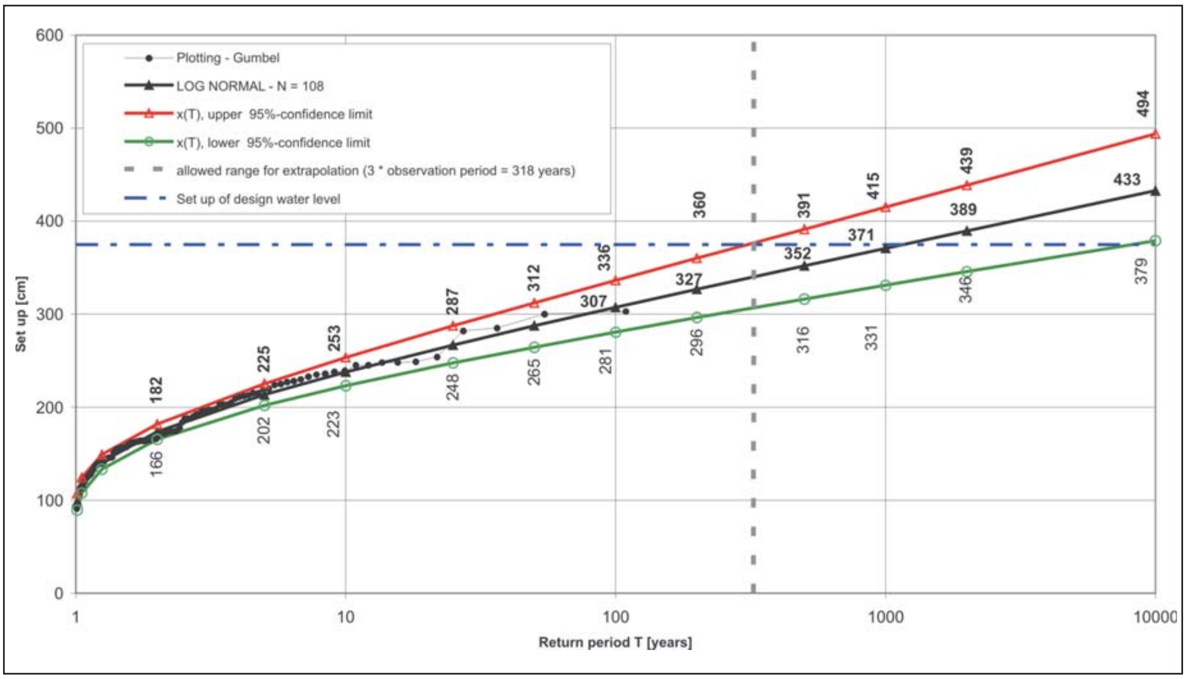

Fig. 3: Extrapolation of set up based on Log-Normal distribution

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of a minimum dune width. UNIBEST-DE is a profile based time dependent numerical model to simulate beach and dune erosion. The model provides among others the potential erosion volume and the post-storm beach and dune shape. For the parts of the coastal defence system consisting of dikes, the ProDeich model and the VBA-based deterministic tool for calculating the fault tree are applied which contains functions for several failure modes for dikes.

Additionally to the storm surge level input data are needed to run the numerical models. These data describe the geometry and characteristic of the defence elements and the wave conditions. Cross profiles based on a terrestrial survey and derived from a digital elevation model are integrated into comparable sections. The weakest profile represents the section and is used for the hazard analysis. Six dune cross profiles and three dike profiles are selected.

The significant wave height used as input data for calculations of dune erosion at the north and north-west orientated beach sections is based on the comparison between wave atlas data (MAI 2002) and the results of rough calculation formulars (NIEMEYER 1979). A medium value of Hs 7.0 m is used. The wave period Tp of 11.3 s is estimated by using the functional relation between Hs and Tp implemented in UNIBEST-DE. These figures are used for all surge levels higher than the present legal design water level.

All dike sections are located in lee-situations, sheltered against undamped wave attack: The Flinthörndeich by a dune area, the Hafendeich by harbour breakwaters and due to its southeast orientation. The eastward orientation of the Ostdeich and the relative shallow water of the Wadden Sea area in front of the dike lead to moderate / slight wave conditions. Since a measured wave climate is not available the sea state conditions are roughly estimated based on the wave atlas of Wangerooge (MAI & DAEMRICH 2004). This wave atlas covers also the southern and the south-eastern region of the Langeoog investigation area of this project as a peripheral area. Due to this and limited applicability of the used wave model SWAN in Wadden Sea areas, non implementation of diffraction (WL|Delft 2005) and the fact that the wave climate is calculated for a water level below the statistic derived water level (chapter 3.1.1) a set of possible higher values (Hs and Tp) are additionally considered (Tab. 1). This second calculation is run with wave heights and periods added a margin of corresponding 0.5 m and 0.5 – 1.0 s.

The hydrograph used in the dune erosion simulation is identical to the hydrograph described in chapter 3.22 (see Fig. 5).

The hazard analysis concerning the dune sections and dikes under investigation taken the assumptions above into account yields the following:

- Failure of the dune belt occurs in the north of the Pirola valley at a storm surge water level of NN + 5.68 m with a return period of 10,000 years.
- The Hafendeich, a mild sloped dike with a crest height of NN + 5.60 m, fails as well at the storm surge water level with a return period of 10,000 years due to overtopping.

Tab. 1: Used wave conditions for ProDeich calculations

Lokation	Estimated figure based on MAI & DAEMRICH (2004)		Increased value-uncertainties due to model restrictious	
	H_s [m]	T_p [m]	H_s [m]	T_p [m]
Flinthorn	1.0	3.5	1.5	4.5
Hafendeich	0.6	3.0	1.0	3.5
Ostdeich	0.5	3.0	1.0	3.5

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3.2 Vulnerability analysis

The vulnerability analysis is characterised by three sub-processes: The valuation analysis and the simulation of flooding which is mainly based on the failure scenario and the results of the hazard analysis. The third sub-process is the damage estimation.

3.2.1 Valuation analysis

The valuation analysis is the systematic, comprehensible and formal procedure to evaluate the damage potential, expressed as the (monetary) value of the elements at risk quantitatively or qualitatively which are potentially threatened by a specific event in a specific area.

For the valuation analysis the MERK-method (REESE et al. 2003), a micro scale approach is used that allows identifying and mapping of elements at risk on the level of separate buildings. By means of extensive field work, damage potentials within the investigation area of Langeoog are mapped and analyzed (UNIVERSITY OF KIEL 2004). The field work provides the essential information about the buildings, the land use and infrastructure facilities to determine the damage potential. The building data contain the following information: Number of storeys, structure of the building (e.g. terraced house), use of the attic storey, equipment, age of the building and use of the single storeys and if necessary of the basement. More than 2200 elements are identified as risk objects, e.g. houses and adjoining buildings.

All elements and land uses are classified and valuated. The information is transferred into a geographic information system (GIS) and linked with the height information derived from a digital elevation model. The elements are classified into three intangible categories, i.e. guest beds, jobs and inhabitants, and nine tangible, that means monetarily assessable, categories. These categories are: Buildings, building inventory (household effects), real estate values, vehicles, land use (traffic areas, agricultural land, forest land, recreational land), livestock assets, gross value added, fixed assets and stock value, see Fig. 4.

The total of all values up to a level of NN + 19.5 m amounts to · 1,115.89 million. Up to a level of NN + 5.5 m which can be regarded as the flood prone zone the total value amounts to · 931.52 million. Four of nine damage categories, namely buildings, inventory of buildings, real estate and fixed assets, contain 92.8 % of the surveyed potential flood prone values.

3.2.2 Simulation

As basis for a flooding simulation two scenarios both showing an occurrence probability of 10^{-4} $years^{-1}$ are defined: "Dune Pirola valley" for the dune area and "Hafendeich" for the dikes. In these scenarios major boundary conditions have to be assumed such as constant breach width and time of breaching. The breach width is set to 20 m in the dune belt and 100 m in the dike.

The hydrograph of the storm surge (Fig. 5) is determined using increase and decrease rates of the wind set-up according to GÖNNERT (2003) and the mean tidal hydrograph of Langeoog.

The flow through the breach into the protected area and through a cascade of reservoirs is calculated using a broad crested weir equation implemented in a MS Excel spreadsheet based tool. Parameters of the flooded area are derived of a digital elevation model by means of GIS analysis. The inflow volume and corresponding water level of the scenario "Hafendeich"

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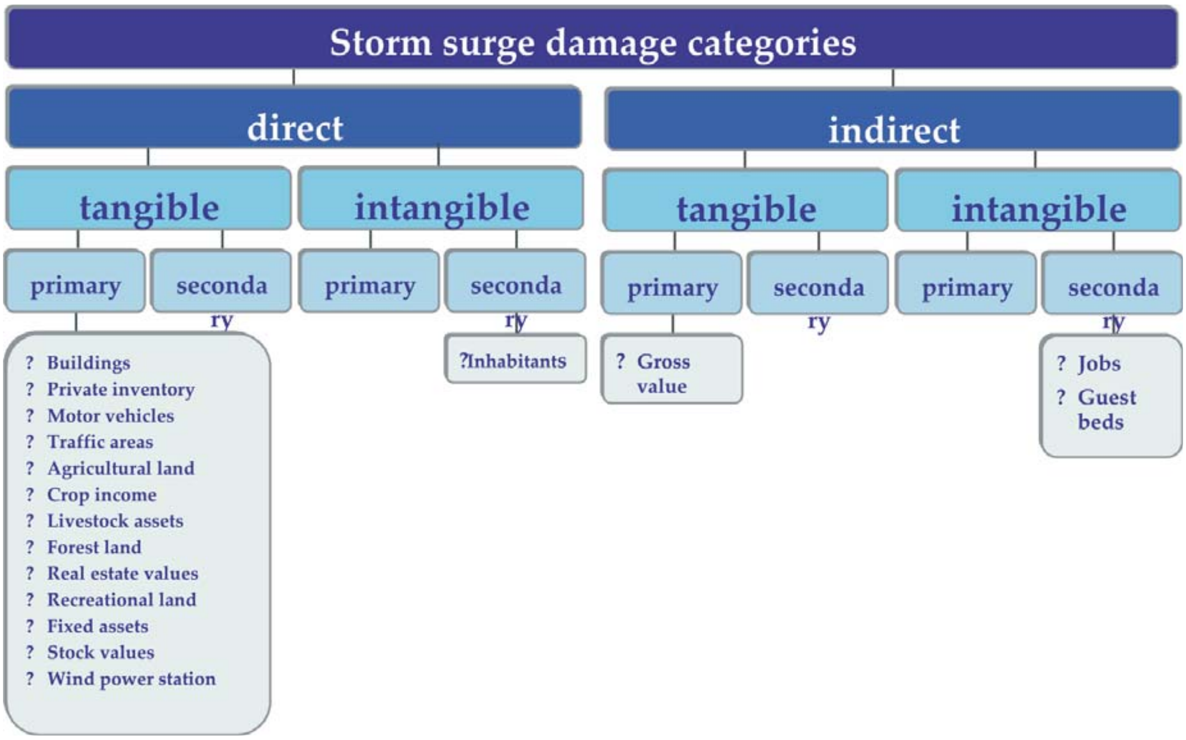

Fig. 4: Damage categories of the valuation analysis (from: UNIVERSITY OF KIEL 2004)

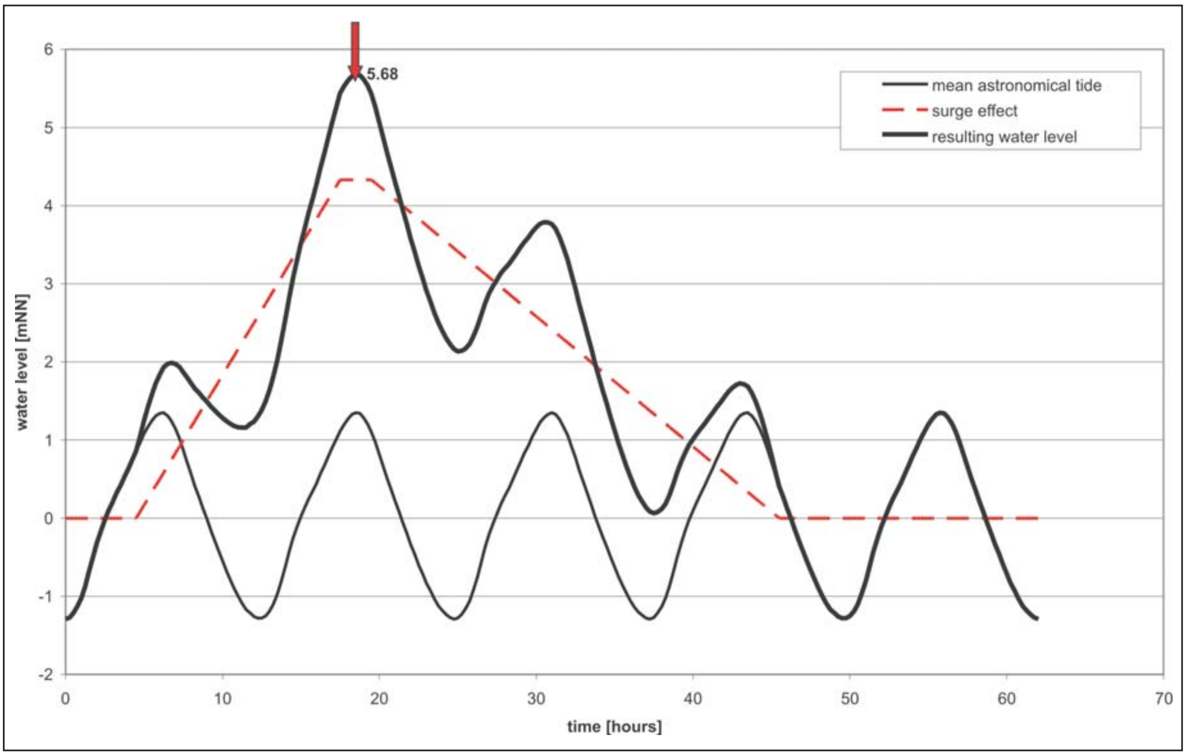

Fig. 5: Hydrograph of the storm surge at Langeoog

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comes to approximately 8 million m^3 leading to flood water levels of NN + 4.9 m in the south western area of Langeoog and NN + 4.27 m in the central parts of the village (Fig. 6). The flooding simulation of the scenario "Dune Pirola valley" is limited to the dune valley south of the dune belt because of its relevance for estimation of damage to the fresh water lens and drinking water supply.

3.2.3 Damage estimation

The damage estimation is a systematic, comprehensible and formal procedure. On basis of the damage potential and under consideration of the general conditions of specific events, conditions, processes or actions the damage expectancy of the elements at risk in a specific area is quantitatively or qualitatively evaluated.

Based on the results of the hazard analysis and of the simulation of flooding, the specific estimated damage to every risk element in the investigation area is determined by means of depth-damage functions. The depth-damage functions are used to determine the degree of damage for specific risk elements. These functions describe the dependence between the degree of damage and the water level which causes this damage. The applied functions are taken from the MERK-report.

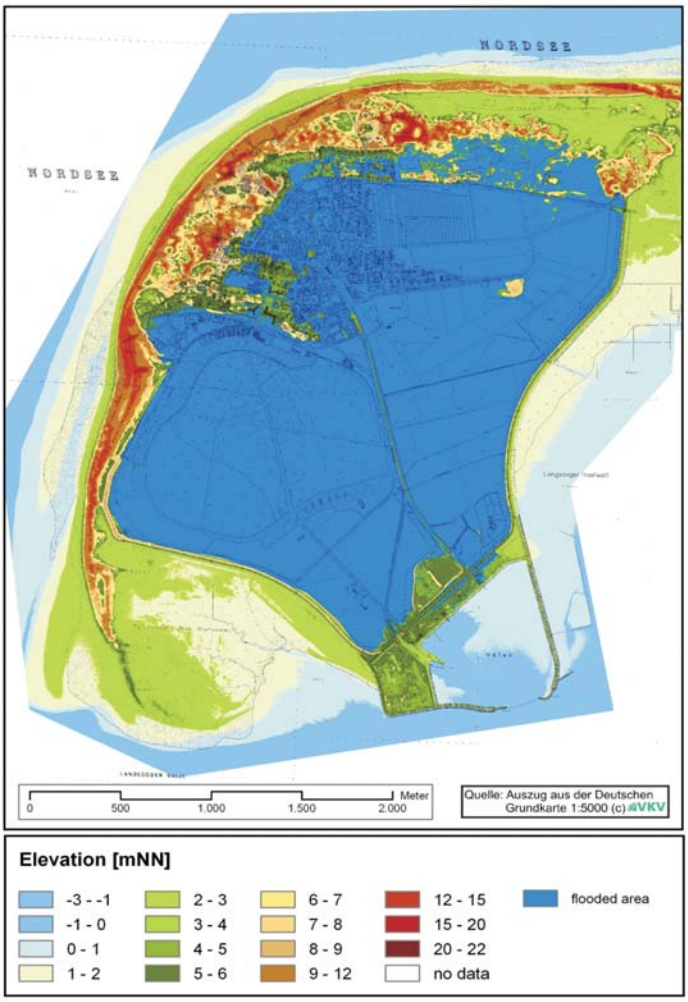

Fig. 6: Flooded area scenario "Hafendeich"

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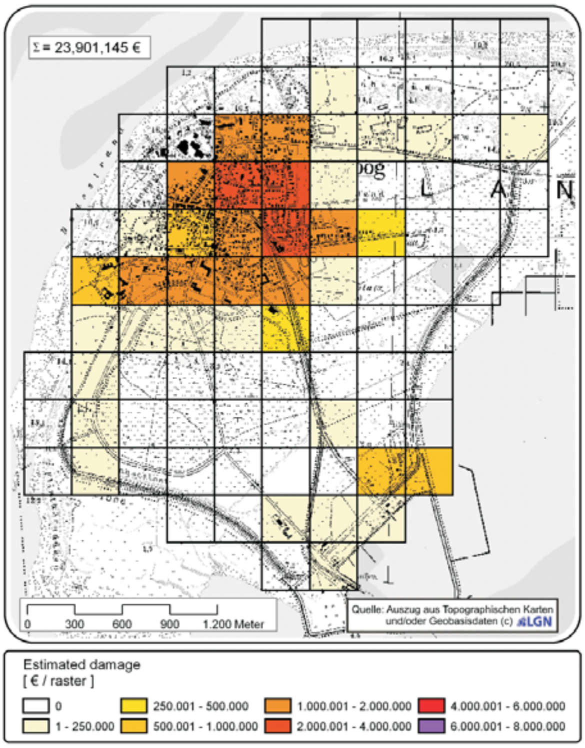

Fig. 7: Damage to buildings ("Hafendeich")

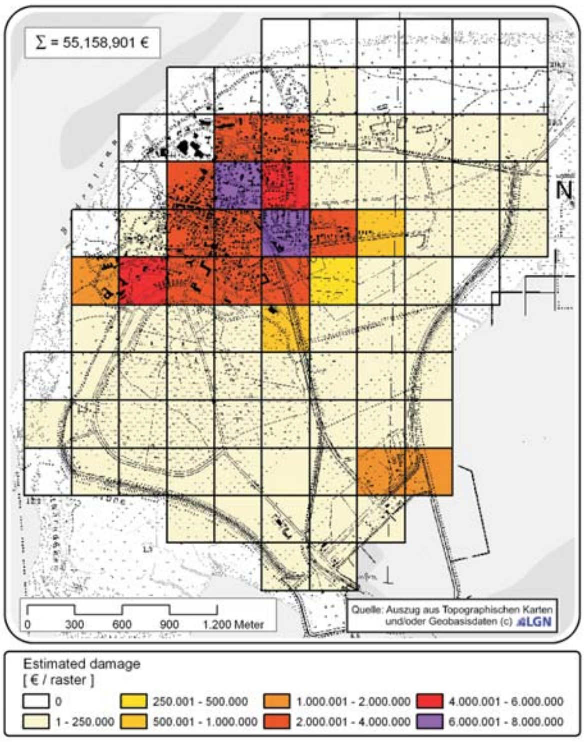

Fig. 8: Total estimated damage ("Hafendeich")

The scenario "Hafendeich" yields estimated damages of · 55.16 million. Taking into account all registered inhabitants, i.e. permanent and secondary residence, 2229 persons are affected and 214 inhabitants should be evacuated. Fig. 7 and 8 show the spatial distribution of damages using a generalizing 300 x 300 m evaluation grid.

The damages to buildings show the major part of the total estimated damages followed by the damages to private inventory and fixed assets. The accumulate damage of these three categories amounts to · 49.5 million which is about 83.4 % of the total estimated damage in the scenario, see Fig. 9.

In comparison with the tourism resorts investigated in the MERK report the estimated damage figures of the scenario "Hafendeich" show nearly the same ratio and ranking of the major damage categories, i.e. buildings, private inventory, fixed assets and damages to traffic and recreational used areas. Tab. 2 shows the total sum of estimated damages, the number of affected inhabitants and the ratio of the damage categories in relation to the total. Additionally, the ranking of the first four categories by their contribution to the total damage is shown in brackets.

Since all damage estimations are influenced by scenario assumptions, a variation of the breach width and of the calculated flood water level in the polders is conducted to show the influence of accuracy of flood simulation which depends on the used numeric model and the accuracy of the model topography: A variation of breach width in scenario Hafendeich from 80 m to 120 m influences the water level in all polders up to a range of 0.32 m.

The variation of the water level within the flooded area for this scenario is executed with constant values within the interval -0.5 m to 0.5 m by steps of 0.1 m. Changes in the total amount of estimated damage (elements at risk) of -28 % and 32 % show the strong dependency of estimated damage from flooding water level (cp. Fig. 10). For all categories an increasing water level leads to rising estimated damages. The strong increase in damages

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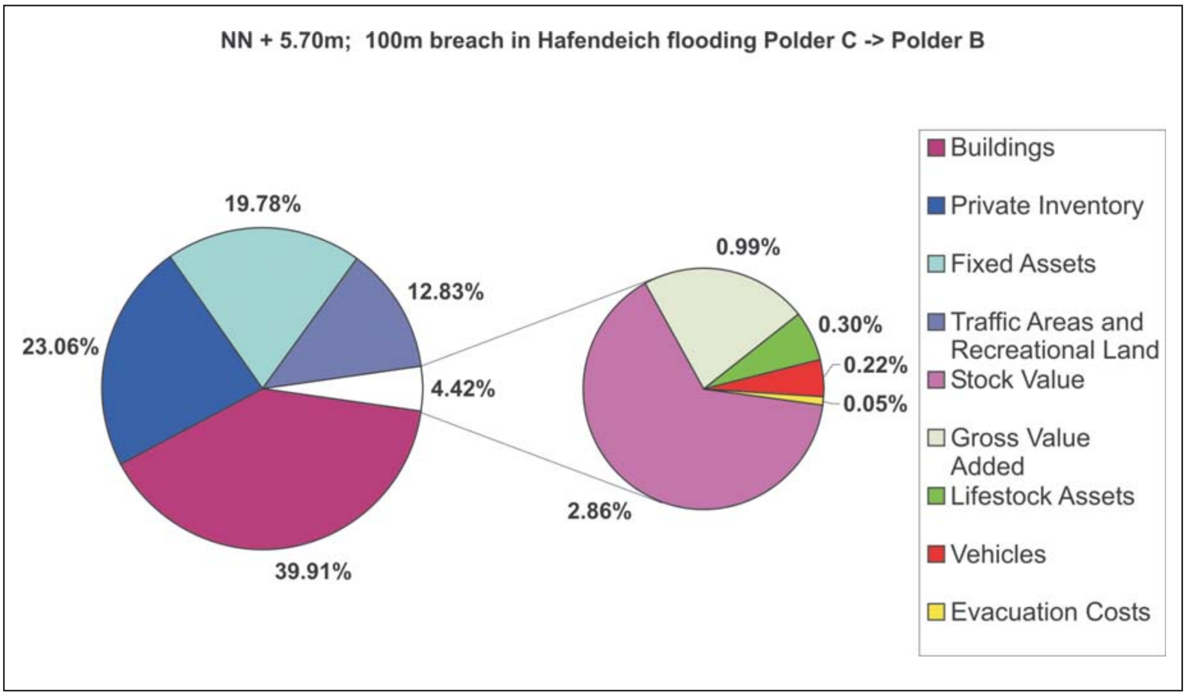

Fig. 9: Ratio of damage categories to total damage in scenario "Hafendeich"

Tab. 2: Comparison of estimated damage between „Hafendeich"
scenario and scenarios in the MERK report

	COMRISK	MERK			
	Langeoog-Hafendeich	Timmendorfer Strand TS-1	Timmendorfer Strand TS-2	St. Peter-Ording SPO-1	St. Peter-Ording SPO-2
Total [Mio *]	55.16	47.95	116.99	0.88	69.2
Affected inhabitants [persons]	2229	476	1987	1271	1954
Rate of total estimated damage [%]					
Buildings	39.9 (1)	57.9 (1)	57.5 (1)	16.7 (3)	40.6 (1)
Private inventory	23.1 (2)	8.6 (4)	13.7 (3)	17.6 (2)	22.0 (2)
Fixed assets	19.8 (3)	16.8 (2)	15.1 (2)	5.5 (4)	21.9 (3)
Damages to traffic areas and recreational land	12.8 (4)	0.9	1.6	58.3 (1)	6.3 (4)
Stock value	2.9	1.3	1.0	0.9	1.6
Gross value added	1.0	11.7 (3)	8.8 (4)	0.9	4.7
Lifestock assets	0.3	0.0	0.0	0.0	1.1
Vehicles	0.2	2.8	2.0	0.1	0.59
Evacuation costs	0.05	0.15	0.25	0.1	0.42

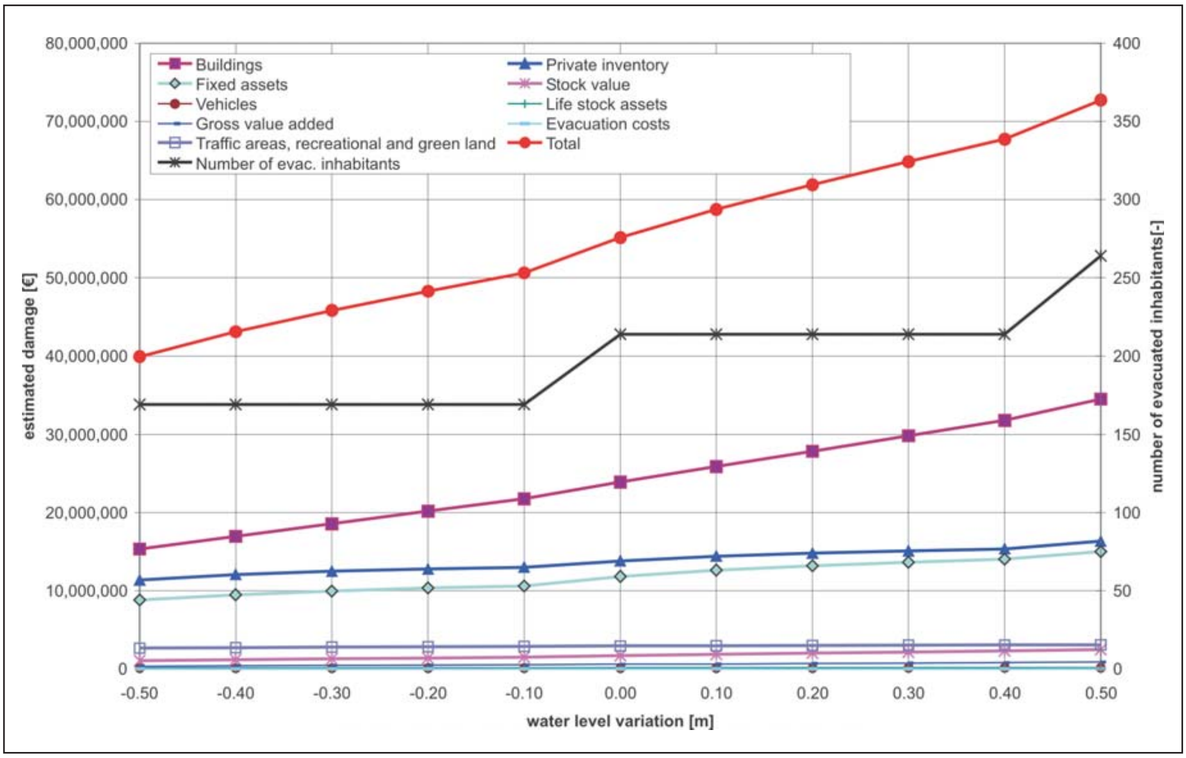

Fig. 10: Estimated damages by categories for variations of the flood water level of scenario "Hafendeich"

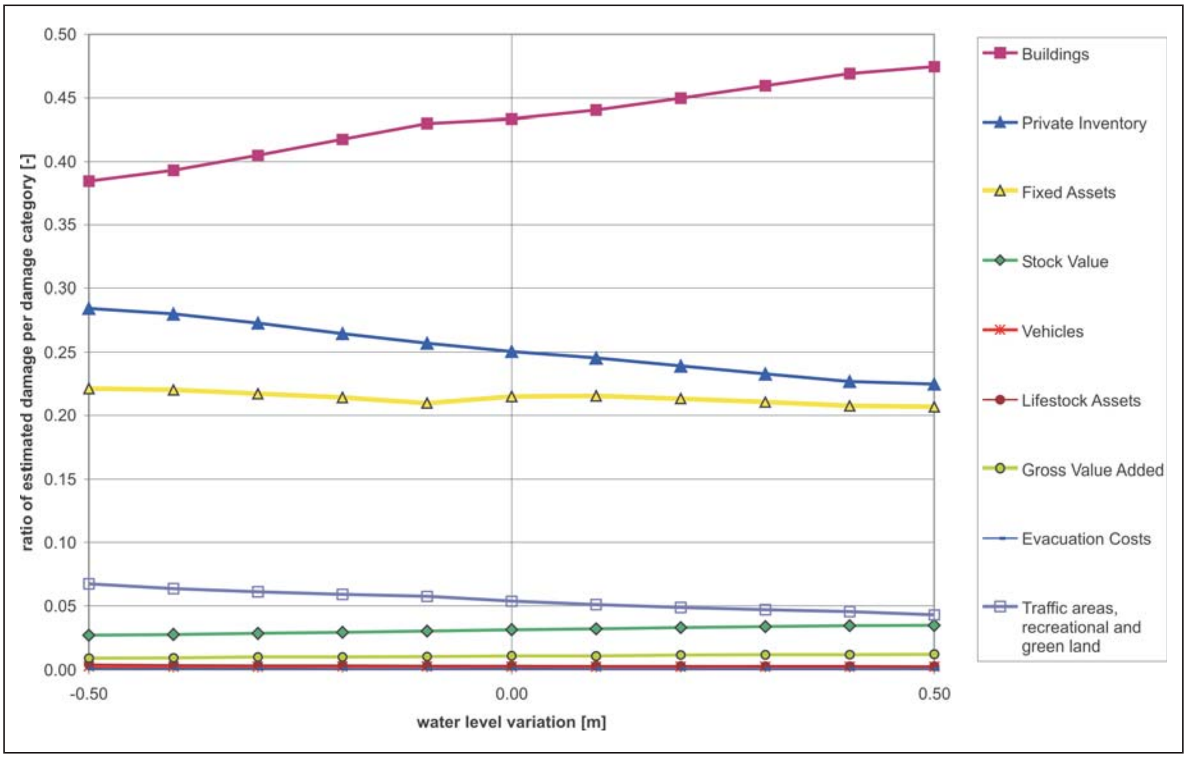

Fig. 11: Ratio of categories for variations of water level (based on "Hafendeich")

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to buildings is remarkable. This increase is absolute and relative higher than the increases of the other categories. This is shown in Fig. 11 where the ratios of the categories in relation to the total estimated damage are compared. For a water level variation of +0.5 m the ratio of the category "damage to buildings" results in 47 % of the total estimated damage. This underlines the fact that damages to buildings are a major aspect in hazard analysis using the MERK-approach.

In addition to the MERK-method used for valuation and damage estimation in scenario "Hafendeich", the impact of the scenario "Dune" on the drinking water supply and on the fresh water lens due to saltwater intrusion after a flooding of the wells field is exemplarily simulated by means of the numerical groundwater model FEFLOW (IUG 2004) under certain boundary conditions. The main results of the simulations are that a complete destabilisation of the freshwater lens in the investigated cases is not expected. In one scenario which is the calculated worst case 10 of 16 wells might be affected by heightened chloride concentration in the groundwater. The drinking water supply for inhabitants and guests which is based completely on the freshwater lens might be partly continued with the remaining unaffected wells. Additional technical measures are expected to be necessary. More detailed simulations are regarded to be necessary to improve the outcomes concerning the risk calculation due to a complex groundwater situation.

3.3 Risk calculation

The risk is defined as a product of vulnerability multiplied by the probability of failure of the coastal defence system according to KORTENHAUS et al. (2002). In the context of this study the probability of failure for the coastal defence elements is assumed to be equal to the occurence probability of the surge water level leading to failure of the coastal defence element based on a deterministic calculation. This is determined to 1/10.000 years.

The risk calculation for the area under consideration yields 5500 ·/year. Based on this calculated risk figure three different risk zones are mapped by grid cells of 300 x 300 m to illustrate the relative risk distribution within the investigated area. Considering the margin of estimated damage due to the variation of flood water level by –/+ 0.5 m within the polders the risk figure varies from approximately 4000 ·/year up to 7300 ·/year. Taking the wide range of the confidence interval (cp. 3.1.1, fig. 3) into account, it becomes clear that risk figures calculated with the methods described above could differ significantly.

4. Conclusions and recommendations

The implementation of risk based methods in this study shows a different approach to investigate the functionality of coastal defences compared to the present one applied in Lower Saxony. On basis of certain boundary conditions and assumptions, necessary to conduct this study, differences in reliability of the different types of coastal defences can be monitored.

The study provides hints on potential weak points in the coastal defence system of Langeoog offered by a risk analysis. Therefore this approach provides an additional decision making tool for pointing out priorities for future reinforcements of the coastal defences. Additionally it should be stressed that by application of standard design procedures the criteria for safe constructions are fulfilled at present.

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The assumption of scenarios and the execution of parameter variations in case of lack of data or methods provided important additional knowledge concerning the uncertainty margin of calculated risk figures. Due to a lack of input data and methods several assumptions were necessary to conduct this study:

- For statistical analysis of hydraulic boundary conditions reliable data on wave climate were not available. The time series for water levels allows only a limited extrapolation of the distribution function with relatively high uncertainties concerning long return periods, for example a confidance interval range of 1.14 m for a 1 in 10,000 years event.
- Definition of the failure mode for dune erosion and some input parameters for the Pro-Deich tool, e.g. geotechnical parameters.
- Scenario definitions to determine the resulting flooding caused by a failure of a coastal defence system. The number of failures, i.e. breaches at the same time or same event, their location and dimension are deemed to be the most important parameters.
- Flooding simulation of the three considered sub-areas is conduced based on a GIS description of the flooded area. The discharge is calculated assuming a cascade of reservoirs. This leads to a relative rough scale of the model compared with the valuation scale. Thus it results in uncertainties of calculated water depths at the threatened objects.
- Uncertainties and limitations are implied in the MERK-method, for example the evacuation rate, the limited number of valuated risk element categories. The last mentioned limitation includes the fact that most of the intangible risk element categories are not considered.

To improve the accuracy of the risk assessment the following aspects should be taken into account:

- Improving the data of hydraulic boundary conditions especially wave climate statistics and of statistics for extreme values
- Enhancement and determination of boundary conditions for dune erosion calculation
- Further investigation of failure mechanisms on different types of dikes (e.g. revetments and geotextile enforcements) and implementation of other constructions like dike locks to improve the limit state equations of the ProDeich model and assessment of the uncertainties
- Gathering of detailed soil parameters of the coastal defence elements
- Application of a numerical simulation model to calculate the flooding based on a 1D2D-approach taking the process of time dependent flood propagation into account. This will lead to reduced uncertainties concerning the flood water level in the polders.
- More detailed insights in the breaching process of sea dikes and dunes which are clay covered and/or protected by a revetment and in the breaching process of dune belts.
- Further investigation on depth – damage functions especially evacuation rates and costs of cleaning and re-establishing on a site specific basis should be carried out.

The application of a risk analysis shows additional potentials of minimizing the risk in case of failure of the coastal defence system. Measures within the protected area seem to be useful to minimize flood propagation and therewith estimated damage due to flooding. From the technical point of view following aspects should be focussed on:

Potential weak points in protective dunes:

Additional investigations concerning the effects of morphological changes on the erosion of beach and nearshore are necessary to define more exact boundary conditions for dune erosion processes. Whether the definition of a certain minimum beach profile or a more complex statistical time dependent approach for the beach evolution is appropriate, needs

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further investigation. Furthermore the period under consideration, for example one surge or a winter season with several storm events, is supposed to have significant effects on the calculation of safety for the dunes as coastal defences.

Weak points of dike openings:

Especially the railway opening located in the harbour area with only single safety, no redundancy and a low laying threshold was monitored to be a potential weak point of the dike ring. A malfunction or human error, i.e. a forgotten closure in case of emergency, may lead to total failure of the system. The storm surge forecast service and the adherent alarm chain at present do take these points into account. But further investigations and enhancements of methods are needed for a more detailed determination of failure probability, especially concerning the factor 'human error'.

Flow paths and technical prevention measures:

The reduction of flood propagation and/or the closure of potential flow paths in the protected area by technical means seem to be an additional way to minimize the risk in the investigated area. More detailed investigations on flood propagation by means of advanced models and a more detailed topography including technical constructions provide a basis to develop appropriate measures for reducing the negative impacts of flooding. An examination of the dewatering system of the polders and the village will help to detect flow paths which might be activated in case of flooding. This demands the application of appropriate software tools.

Potential measures in the investigation area to block flow paths are the closure of a gap in the Heerenhus dunes south of the Pirola valley which would build an effective barrier to prevent parts of the drinking water supply and the village from flooding in case of breaching of the dunes north the Pirola valley. The heightening of street levels might significantly reduce the overflow volume from one polder to another.

Contingency plans:

Detailed height information of the area under investigation provides an improved basis for the catastrophe management authorities to monitor the most endangered areas and the potential escape routes. A more detailed flooding determination in case of failure of the coastal defences at certain locations will provide further valuable information.

5. Outlook

The project outcomes provide substantial information concerning the feasibility of conducting a risk analysis, showing potentials and lacks. Data and methods produced in this study can be used as a support for decision making providing additional insights for future defence planning, detecting weak spots in the defence system and priority settings for reinforcement of costal defences. Furthermore the project delivers an important input for catastrophe management to improve contingency plans.

Open questions concerning methods and data reliability in hazard and in vulnerability analysis have been elaborated and showed the need for further investigations. To enhance the accuracy of risk analysis a focus should be on the accuracy of data and methods like hydrological and morphological conditions, failure modes for technical constructions and valuation methods. For the latter intangible damage categories like human health, damages to ecological and cultural value are not taken into account in this study due to a lack of

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methods. For further improving of risk analysis procedures and evaluation whether and how to consider these aspects might be useful.

The conducted analysis provides a detailed insight in the flood prone area and hints that prevention measures to reduce the effects of failure of the coastal defences might be suitable to reduce the risk to a certain level. This exemplarily shows the intensive links between coastal defence planning on one hand and spatial as well as land utilisation planning on the other and the need for common procedures.

The approaches for risk calculation applied in the four pilot studies of the COMRISK project, promoted by an intensive exchange of experiences between the partners, showed different boundary conditions and methods to proceed within the involved countries. This provides further evaluation of partner experiences in order to develop improved approaches of risk analysis for flood prone coastal lowlands in the North Sea region. Taking future developments in flood prone areas like effects of climate change into account, a worthy contribution for implementation of the ICZM Recommendation can be expected. Therefore a project initiative is launched within the Interreg IIIb North Sea program called SAFE-COAST (Sustainable Coastal Risk Management in 2050).

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COMRISK
Common Strategies to Reduce the Risk of Storm Floods In Coastal Lowlands: a Synthesis

JACOBUS HOFSTEDE, HOLGER BLUM, SANDRA FRAIKIN, STEVE HAYMAN, CHRISTIAN LAUSTRUP, MARINKA VAN NIELEN-KIEZEBRINK, IAN MEADOWCROFT, THORSTEN PIONTKOWITZ, FRANK THORENZ, TOON VERWAEST, ARD WOLTERS

Summary

Seven national and regional coastal risk management authorities from the North Sea countries conducted the INTERREG IIIB project "COMRISK – common strategies to reduce the risk of storm floods in coastal lowlands". COMRISK aimed at improved coastal risk management in the North Sea region (NSR) through a transfer and evaluation of knowledge and methods as well as pilot studies. Nine subprojects with specific thematic and regional foci and the final conference COMRISK2005 all contributed to this aim. This paper synthesizes the main findings of the project, describes its "main messages", and gives an outlook for further work.

Zusammenfassung

Sieben nationale und regionale Küstenschutzbehörden aus den Nordsee-Anrainerstaaten führten das INTERREG IIIB Projekt „COMRISK – gemeinsame Strategien zur Reduzierung der Risiken von Sturmfluten in Küstenniederungen" durch. COMRISK zielte mittels Austausch und Evaluierung von Kenntnissen und Methoden wie auch durch Pilotstudien auf ein verbessertes Risikomanagement in den Küstenniederungen des Nordseeraumes ab. Neun Teilprojekte mit spezifischen thematischen und regionalen Schwerpunkten und die Schlusskonferenz COMRISK2005 trugen zu dieser übergeordneten Zielstellung bei. In diesem Beitrag werden die Projektergebnisse in einer Synthese zusammengeführt, die wichtigsten Botschaften erläutert, und ein Ausblick auf künftige Arbeiten gegeben.

Keywords

Coast, risk management, flood defence, international cooperation, INTERREG

Contents

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1. Introduction

Since 1996, leading public managers and officers from national and regional administrations in Denmark, Germany, The Netherlands, Belgium and the United Kingdom confer on transnational aspects of coastal risk management in the so-called North Sea Coastal Managers Group (NSCMG). It became clear that, despite major differences in the physical, socio-economic, cultural and institutional setting, the challenges that national and regional administrations face in safeguarding societies against storm surges are very similar throughout the North Sea region. In order to achieve a sharing of knowledge and more balanced and sustainable approaches, a comprehensive and comparative assessment and evaluation of national and regional coastal risk management practices was agreed upon. These considerations led to the initiation of the project "COMRISK – common strategies to reduce the risk of storm floods in coastal lowlands". Seven public coastal risk management institutions from the member states co-operated in the project. It was implemented under the Community Initiative Programme INTERREG IIIB of the European Union that co-finances (with 50 %) transnational projects for specific regions. In all, about 30 organisations (project partners, consultants, local administrations, etc.) were directly involved in the project. More than 40 individuals (project team, consultants and contact groups) actively contributed to the project outcomes, and about 150 more persons were involved through workshops, expert questionnaires, etc. One positive impact that COMRISK achieved is that these individuals and institutions are able to benefit, in their daily work, from this transnational sharing of information and knowledge.

Risk is a combination of the probability (or frequency) of occurrence of a defined hazard and the magnitude of the consequences of the occurrence. Coastal risk management constitutes of a range of topics that vary from strategic like national risk policies to more technical, for example, the dimensions and performance of flood defence schemes. The themes that were assessed and analyzed in the COMRISK subprojects one to five were: (1) policies and strategies, (2) strategic planning, (3) perception and participation, (4) performance indicators, and (5) hydraulic boundary conditions. For each of the topics, in a first step the national and/or regional state of the art was assessed and put into the context. In a next step, a comparison was conducted that focussed on challenges and opportunities in the national and regional practices. Finally, if appropriate, recommendations were established. In the COMRISK subprojects six to nine, risk analyses were conducted for four case sites: Flanders (B/NL), Ribe (DK), Lincshore (UK) and Langeoog (GER). These studies followed a broadly similar approach although each had distinct aims and objectives. In each case, as a first step, the physical and socio-economic conditions were characterized, and an inventory of existing flood and coastal defence measures was established. With these data, risk assessments using newest probabilistic techniques were then carried out. Finally, recommendations concerning the application and/or improvement of the risk assessment techniques were established. The subprojects are described in detail in the previous chapters of this volume. This paper synthesizes the main findings of the subprojects, present the key messages to emerge, and gives an outlook for further work.

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2. Project synthesis

2.1 Differences in the contexts

From all subprojects it became clear that the national and regional settings in the North Sea countries, i.e., the physical, socio-economic, cultural and institutional context, are extremely diverse. For example, the scale of flooding and the affected population size differ substantially between The Netherlands and Denmark. This variance in the context explains most of the observed differences in the implemented policies and strategies for coastal risk management. However, within the varying settings there is certain freedom of policy choices. It is recommended that this freedom should be used to increase the number of risk management options and, therewith, the robustness of the policy. For example, apart from focussing on technical solutions, non-structural options like flood warning systems, self-help (where the affected take preparatory actions themselves), insurance/compensation, and control of development in flood-prone areas might be included into the policies and strategies. It is interesting to note that the technical solutions applied in the North Sea countries such as sea dikes and sand nourishments are very similar (although the design criteria vary substantially, see below).

The COMRISK project has identified many areas of common interest to those developing flood risk management strategies and policies in the partner countries. Continued co-operation and collaboration is needed to ensure that these common interests are fully exploited. Harmonization on all aspects of coastal flood risk management seems not feasible due to the differences in the contexts and approaches in the five countries. Definition of a common strategy however does not have to mean harmonization of policies. Although future harmonisation of policies and strategies should not be avoided when desirable and feasible, at the moment it is more appropriate to focus on further mutual understanding and mutual learning.

2.2 Communication of risks

Our study found that coastal risk perception, or the awareness of coastal risks, is relatively underdeveloped, despite major efforts of the responsible administrations. This indicates that the information flow from the responsible administration towards the population is either insufficient, does not reach the recipients or is not taken seriously. There, still, is an apparent deficit in risk communication. One of the reasons may be the different definitions that experts (from science and administration) and the society apply. Experts talk in terms of quantifiable technical risk such as return intervals, probability of breaching and so on. These may not match the way risk is perceived by the population – will my house be damaged? Hence, it is recommended that risk should be translated into the language of the society. Instead of communicating safety standards (which may give a false impression of absolute safety), reference should be made to personal living surroundings and to personal consequences. Further, options for personal action (self-help) should be presented.

Moreover, people indicate that they are not adequately informed about the risks of storm floods and are sceptical about their ability to influence planning decisions. To increase the quality of information, it should be neutral, objective, plain, targeted, comprehensive and understandable. Further, a mix of information tools should be used in combination. To overcome the scepticism about the possibilities to influence planning decisions, the involvement of external facilitators can be helpful.

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2.3 Strategic planning: safety standards versus risk based approaches

Strategic planning is carried out in all North Sea countries in order to determine an appropriate programme of measures to implement stated policy aims and objectives. However, the process of Strategic Planning is approached differently within each COMRISK partner country. These differences reflect different risk perceptions, societal expectations and cultural traditions. For example, throughout the continental European partners legislative instruments provide the primary planning tools. Defence measures are designed to withstand a storm water level with a specified probability of occurrence. The German states and Belgium presently define one safety standard for all their major coastal flood defence schemes, whereas in Denmark and The Netherlands some socio-economic considerations lead to regionally variable safety standards. For example, in the densely populated province of South-Holland, a 1:10,000 year storm water level should be stopped, whereas in the province of Friesland the safety standard is the 1:4,000 year water level (WET OP DE WATERKERING, 1996).

As an alternative to safety, a risk-based approach can be applied to establish a basis for consistent and transparent decision-making with respect to defence measures. Risk may be defined here as the multiplication of the probability of occurrence of a defined event (e.g. dike breaching) and the magnitude of the consequences of the event (i.e., the damages resulting from the flooding). With this concept, instead of one water level that should be resisted, a pre-defined acceptable risk is allowed for. Adapting risk criteria would imply that defence schemes are designed according to the protected values. In result, the financial means may be invested more effectively. In order to arrive at the same acceptable risk, the sea dike in front of a heavily utilized polder would need to be higher (i.e., the probability of breaching lower) than the dike in front of a polder with a low population density.

Within England and Wales a risk-based approach is adopted based on analyses of the benefits and costs of action compared with the consequences of doing nothing. A guideline for assessing the benefits is provided in the so called "Multi-Coloured Manual" (PENNING-ROWSELL et al., 2003). In Denmark and The Netherlands regionally varying safety standards reflect some risk considerations (see above). In Germany, this risk-based approach is not adopted because it leads to disagreements with the affected population as it can negatively affect equal opportunities.

The differences among the safety and risk based approaches are, amongst others, reflected in the way expenditure is prioritised. Within the context of a safety standards approach for example, prioritisation of expenditure is given little prominence within the strategic planning process and it is difficult (and may be politically undesirable) to prioritise improvement of one defence over an other. The approach adopted in England and Wales, however, has a primary focus on prioritising actions in order of economic efficiency.

A fully risk based approach would require acceptable risk criteria to be defined. The societal definition of an acceptable risk is highly complex as it varies strongly depending on, for example, age, sex, lifestyle, etc. Therefore, this problem should be solved within a coherent, transparent, adaptive and widely accepted framework for tolerable flood risk assessment. This would also need to consider questions of values, equities and affordability. A starting point for the development of such a framework may be the so-called ALARP- or ALARA-concepts which are widely accepted across many disciplines (see contributions OUMERACI and ALE in this Volume). Public discussion has an important role to play in establishing an appropriate approach and leads to better acceptance of the decision.

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2.4 Monitoring of performance

Associated with the setting of safety or risk standards is the performance of the structural and non-structural measures that implement those standards. In all countries performance indicators are applied in monitoring programmes for structural schemes. For example, for sea dikes a maximum allowable overtopping rate (typically 2 l/s/m) not to be exceeded under a given design event is defined and monitored. Most countries are moving towards flood risk assessment based not just on predictions of the probabilities of defence overtopping under given events but also on prediction of the probability of an overall defence failure (e.g. dike breaching), the flooding consequences and their assessment in socio-economic terms (see above). It is possible to evaluate measures based on their effectiveness in reducing the economic risk from flooding, and their efficiency in reducing national or regional flood risk per Euro invested. This is the basis of the national appraisal of flood and coastal risk management expenditure in England and Wales.

Our study found that most of the outcome performance indicators used by coastal risk managers in the North Sea countries are appropriate for their purpose. In many cases these focus on specific parts of the flooding system. In risk management terms it is convenient to think in terms of the sources, pathways and receptors of flooding. Sources relate to the extreme loads such as sea levels and wave heights. Pathways or barriers relate to the flood defence and inundation routes through which flood water reaches the receptors - these are the people, property and environments which can be harmed by flooding. During the study, it was convenient to categorise performance measures in this way and this provided a good framework to compare indicators in different countries.

In most of the NSR countries there is some kind of national or regional database in which coastal risk management data is held. Generally this includes socio-economic data as well as hydro- and geomorphologic data. In some cases there are also records of flood defence works and costs and information about planned works. However, much of the raw data that are collected and stored in databases are, on the whole, not tailored to the needs of Performance Evaluation. Additional processing and/or data collection is generally needed to isolate specific performance indicators. Many of the databases were developed for other purposes and were now being adapted to meet the needs of risk and performance management. For this purpose, however, the information and even the structure of the databases are not necessarily ideal.

2.5 Methods to determine hydraulic boundary conditions

An inventory of the methods used to determine the hydraulic boundary conditions for designing or assessing the safety of sea defences was conducted. Based on the results of this inventory the various methods have been analysed and compared for a sea dike and a dune profile on the North Sea coast in The Netherlands. Though the general approach to determine the hydraulic boundary conditions is fairly similar, the differences in details of the methods can lead to crest heights that can vary several meters for the same return period. Major factors for these differences in the crest height of sea dikes are the statistical methods to assess the design water level, the quality of the prediction of the nearshore wave parameters and the various parameters in run-up and overtopping formulae. The approaches in the safety assessment of dune coasts are quite different, though a number of methods go back on the same research from the 1980-ies.

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Due to these differences, results of the various risk-assessments that were conducted in COMRISK are hardly comparable. Thus, a common approach to risk assessment might lead to adaptations in safety-assessment methods in the various countries. On the other hand the knowledge questions, i.e. to reduce uncertainties in risk-analysis, are rather similar in the various countries. Joint research and further exchange of knowledge can and might lead to a convergence of the methods for risk assessment used in the various countries.

2.6 Risk assessment

In COMRISK subprojects six to nine risk assessments were conducted for four case sites. Each site had distinct physical and socio-economic characteristics. A scheduler overview of the conducted risk assessments in the four study areas is given at the end of this paper. It becomes clear, that each subproject applied different techniques and models to assess the risk. In consequence, the outcomes of the subprojects cannot be compared directly. Three basic aspects were considered in all projects, the extreme loads (sources), failure mechanisms and the flooding process (pathways), and the potential damages (receptors). One basic message from the case studies is that, for all three aspects, the uncertainties are large. The probability distributions of most of the failure mechanisms like the erosion of the grass cover on sea dikes are still not known precisely and, thus, have to be assumed. Further, major differences in the calculated risk result from the unknown breach development (e.g., one breach or several breaches, final breach width). This strongly influences the flooding (e.g., speed, flood height and extension) and, therefore, the degree of damage. As a final example, in some cases little is known about the actual damage that appears in dependency of the height and duration of the flooding (the so called depth-damage-curves). If summed up, all these uncertainties result in risk values that may vary several orders of magnitude, depending upon the assumptions that were made. From a technical point of view, using probabilistic techniques, it may be appropriate to address and consider these kinds of uncertainties. This certainly represents a challenge for coastal flood risk managers. It is clear that complexity and level of detail of risk analysis should be appropriate to the flooding system, the level of uncertainty, and the needs of decision-makers. The analysis should not be over-complicated. The project also concluded that uncertainties must be understood and managed to make better decisions. Managing uncertainty includes the whole process of identifying sources of uncertainty, modelling their effects, communicating uncertainties and allowing decision-makers to account them. Further research and guidance is needed to assess and reduce uncertainty, and to make sure that decision-makers are fully aware of uncertainties in data, information and knowledge.

At the same time, the risk assessments as applied in the project brought a number of significant improvements. The sensitivity analyses of the failure mechanisms gave new insights in the respective relevance of each single failure mode as well as the failure development, i.e. "weak spots" could be detected. Further, the vulnerability analyses substantially increased the information and knowledge about the flood-prone areas, as "hazard areas" could be identified. The established data and information may be used as a decision supporting tool, i.e., as arguments for appropriate defence schemes. Further, they may be used for informing the public and as a basis for contingency plans. It is recommended to continue the research on risk analysis, especially on reducing and handling the uncertainties, and harmonizing the different approaches that were tested in the subprojects six to nine.

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3. Conclusions

Based upon the COMRISK investigations and results, the international project team established technical, managerial and policy level statements. These were presented and, partly controversially, discussed during the final session of the conference COMRISK2005. Discussions during the course of the Conference included opportunity for delegates to challenge or support the initial set of statements. This peer review of a broad group of coastal flood risk experts and policy makers provided a unique opportunity to tune and refine the statements. Taking this into account, the project team‘s overall conclusions are as follows:

- Risk, being probability and consequences of flooding, should provide the basis for flood management decisions.
- Concerning the large uncertainties that exist in assessing coastal risks, it is concluded that these must be understood and managed to make better decisions. Managing uncertainty includes the whole process of identifying sources of uncertainty, modelling their effects, communicating uncertainties and allowing decision-makers to account them. Further research and guidance is needed to assess and reduce uncertainty, and to make sure that decision-makers are fully aware of uncertainties in data, information and knowledge.
- With respect to the uncertainties, the conducted level of risk analysis should be appropriate to the flooding system, the level of uncertainty, and the needs of decision-makers. The analysis should not be over-complicated.
- It is concluded that common methods for risk assessments should be established. It is, however, recognised that risk-based criteria depend on the physical and socio-economic contexts which differ strongly among the countries. Hence, common criteria are not recommended.
- People living in flood-prone areas tend to ignore or disclaim the risks of flooding. In this respect, it was agreed that the right information should be provided to the right people at the right time to raise awareness without raising alarm.
- More risk based performance indicators are needed in order to translate policy aims into flood risk objectives, and to evaluate changes in flood risk.
- Uncertainties are not a barrier to good policy making. Policies should take proper account of uncertainty, and risk assessments should identify and report on all relevant uncertainties.
- Finally, it is concluded that harmonization on all aspects of coastal flood risk management seems not feasible due to the differences in the contexts and approaches in the five countries. Definition of a common strategy however does not have to mean harmonization of policies. Although future harmonisation of policies and strategies should not be avoided when desirable and feasible, at the moment it is more appropriate to focus on further mutual understanding and mutual learning. The COMRISK project has identified many areas of common interest to those developing flood risk management strategies and policies in the partner countries. Continued co-operation and collaboration is needed to ensure that these common interests are fully exploited.

4. Outlook

More than 16 million Europeans who live in about 40,000 km^2 of coastal lowlands in the North Sea region as well as major economic activities depend upon a sustainable coastal risk management. In future, as demonstrated by the FORESIGHT program in the United King-

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dom (OFFICE OF SCIENCE AND TECHNOLOGY, 2004), the coastal risks will increase substantially. Both the protected values and the natural coastal hazards in the coastal lowlands will rise due to utilization pressure and climate change (IPCC, 2001). In COMRISK, the present state of national and regional coastal risk management was established and recommendations for improvements made. Possible future developments were not directly considered. This topic will be addressed in a follow-up project SAFECOAST. This INTERREG IIIB project starts in July 2005 and broadens the scope of COMRISK in two ways. Firstly, the activities will be based on a time horizon 2050, applying physical and socio-economic scenarios. Secondly, the criteria of Integrated Coastal Zone Management will be addressed in an own subproject (EUROPEAN UNION, 2002). For this, the COMRISK partnership has been extended with some new partners. Major issues, as extracted from COMRISK, will be the testing of a more standardized method to assess the coastal risks, and the establishment of appropriate information material. Apart from COMRISK, SAFECOAST will be based on the policy recommendations as established in the EUROSION project. The EUROSION project was initiated in 2001 by the European Parliament with a view to evaluate the social, economical and ecological impact of coastal erosion on European coasts and assess the need for action (www.eurosion.org).

With COMRISK, for the first time, an interregional project of national and regional coastal risk management authorities in the North Sea region has looked for transnational improvements. With this study, almost 200 directly and indirectly involved individuals and about 30 public and private institutions that work on coastal risk management in the North Sea region have actually benefited from this transnational sharing of information and knowledge. In the long-term, this will lead to a quality improvement and harmonisation of coastal risk management in the North Sea region.

5. Literature

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I General		Ribe	Lincolnshire	Vlaanderen	Langeoog
Aim of study		To perform a risk analysis of the flood defence system located in Ribe/Denmark	To quantify flood risk associated with different beach recharge options in order to select the optimum recharge strategy	safety methodology - integrated coastal planning studies	Risk analysis at a state of the art level and to evaluate the applicability
General discription of study area	**Geographical**	The Ribe defence system is located approximately 50 km north of the German-Danish border. The area is mainly characterised by a large rural area of former marshland and by an urban area (Ribe town), which is located 5-6 km from the sea. Ribe town is the oldest town in Denmark and is protected by an 18,4 km long sea dike. The dike has a constant profile over its total length and is interrupted by one sluice (Kammer sluice) and three smaller outlets.	Located on the Esat coast of England north of The Wash, The 24km of the ‚Lincshore' coastal defences provide flood protection to the low-lying coastal flood plain which extends up to 15km inland. The area has a history of flooding as far back as the 13th century, and was flooded in 1953 following breaching of the defences.	Zeebrugge (Flanders - Breskens (Netherlands, mouth of the Scheldt) = 30 km coastline	Wadden sea island - The island of Langeoog is located in the north-western part Germany. It is one of seven inhabited sandy barrier islands in front of the Lower Saxony mainland coast. The island is characterized by dune areas at the northern side of the island and lowlands on the southern side. The coastal defence system consists of dune belts and dikes. The investigation area is focussed on the western part of the island, covering the village and major infrastructures / facilities.
	Area measure	95 km^2	350 km^2	500 km^2	7,7 km^2
	Nr. of inhabitants	9.000	55.000	150.000	~2.150
	Any other		27.500 residential properties, 3.500 commercial properties, recreation, tourism, agriculture, fishing, and numerous environmental and conservation sites		The main economic factor on the island is tourism. In 2002 approxi-mately 179.000 guests and 1,5 million overnight stays were registered.

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II Sources of flood risk (Hydraulic boundary conditions)		Ribe	Lincolnshire	Vlaanderen	Langeoog
Basic data	**Water levels**	Measured water level at the Kammer sluice comprising a time series of 85 years	Harmonic Tidal predictions, plus hourly measured water levels (Immingham) used for Joint Probability analysis. Sea Level Rise was standard Anglian Region allowance of 6mm/yr.	75 year tidal measements in Ostend	Tidal water level gauge station at the island of Norderney com-prising a time series of 108 years
	Wave heights	Offshore wave rider (online data) and three offline wave rider in the tidal channels	UK Met Office European Wave Model, prediction point located at Dowsng Light for period of 1991 - 2001. Other sources dating back to 1970.	20 year wave measurements at different stations 30 km in front of the coast	No measurements available
Data processing	**Water levels**	Extreme value statistics - Log Normal distribution	Joint Probability - weibull fit	astronomical tide - POT analysis on the storm surges (general extreme value dis-tribution) - combining with deterministic distribution of astronomical HW	Extrem value analysis of water level „set ups“- time series and extrapolati-on based on a Log Normal distribution function. Estimation of function para-me-ters by momentum method.
	Wave heights	Composition of time series for the off-shore wave rider	Joint Probability - weibull fit	making one composed time series at deep water - POT analysis	
Nearshore conditions	**Water levels**	Measured water level at the Kammer sluice comprising a time series of 85 years	Neashore conditions same as offshore	storm surges are fairly uni-form along the coast - cor-rections with the variation of HW at spring along the coast	Tidal water level gauge station at the island of Norderney com-prising a time series of 108 years and tranfer functi-on

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II Sources of flood risk (Hydraulic boundary conditions)		Ribe	Lincolnshire	Vlaanderen	Langeoog
Nearshore conditions	**Wave modelling**	Numerical modelling of wave parameters along the Danish Wadden Sea coastline based on MIKE 21 OSW3G by DHI (1998). The numerical modelling resulted in wave heights and the wave periods for specific points with a distance of 100 m in between alongshore as well as a distance to the dike toe of 50 m and 300 m respectively	Halcrow model MWAV_REG including wave refraction, diffraction, breaking and bottom friction. Inshore conditions assessed at 7 zones along the frontage. Separate study to examine how wave height changes with beach slope due to shoaling.	SWAN modelling - Mike 21 Boussinesq model for Zwin	SWAN Seegangsatlas Langeogg (MAI 2002) and Wangerooge (MAI 2004)
Design criteria	**frequency of exceedance**	1/200	Risk assessed over a range of storm events: 1:1, 1:20, 1:200, 1:500	1 in 1.000 for Flanders, 1 in 4.000 for Zeeuws-Vlaanderen	Not used for design of dykes in Lower Saxony
	overtopping formula	Schüttrumpf & Oumeraci (2001), based on Van der Meer (1998)	Halcrow SEAWALL package based on HR Wallingford Report SR261. Method based on Owen, 1980.	van der Meer	Not used for design of dykes in Lower Saxony
	overtopping criterium	Admissible overflow rate 20 l/sm	From 2 l/s/m to 200 l/s/m depending on cross section and protection	1 l/s/m	Not used for design of dykes in Lower Saxony
	formula for dune erosion	No dune	Dunes not applicable. Beach profiles and berm widths carried out using COSMOS 2D	Dutch safety assessment procedure (Vellinga)	DURSOSTA (UNIBEST-DE)
	criterium for dune erosion	No dune	Overtopping rates assessed from eroded beach profiles	id.	Critical dune width

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III Pathways and failure mechanisms for inundation		Ribe	Lincolnshire	Vlaanderen	Langeoog
Failure mechanisms (based on Fundamentals on Water defences) considered/most relevant (C/R) ?	**Overflow**	C(onsidered)	Not relevant	C/Not relevant	C
	Wave overtopping	C/R(elevant)	C	C/R	C/R
	Sliding clay inner slope	C	Not relevant	C/R	C
	Shearing	C	Not relevant		C
	Sliding outer slope	C/R	Not relevant	C/R	[C] 1 section (2 sections consists of dike with revetment)
	Micro instability	C	Not relevant	C/R	C
	Piping	C	Not relevant	C/R	C
	Erosion (grass + clay) inner slope	C	C	C/R	[C] 1 section (2 sections consist of dike with revetment)
	Erosion (grass + clay) outer slope	C/R		C/R	Not relevant
	Erosion first bank	Not relevant	C		Not relevant
	Settlement	C			Not considered
	Drifting ice	Not considered	Not relevant		Not considered
	Collision	Not considered	Not relevant	C/R	Not considered
	Dune erosion	Not relevant	Not relevant	C/R	C/R
	Revetment stability	Not relevant	Not relevant	C/R	Not relevant
	Revetment uplift	Not relevant	Not relevant	Erosion inner slope due to overtopping	Not relevant
	Any other	Failure mechanisms at inner slope and in the core	Beach erosion (especially narrowing and lowering of berm width)	checking all possible failure mechanism + possible cascade of failure mechanisms until breach occurs. Different return periods + sensitivity analysis	C

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	III Pathways and failure mechanisms for inundation	Ribe	Lincolnshire	Vlaanderen	Langeoog
Method/ Model		6 dike profiles available, probabilistic calculations by means of the ProDeich model		40 dune sections - 80 dike sections, distance between sections about 200 m	Deterministic; ProDeich
Schematization	General	Set-up of a detailed fault tree for the 6 dike profiles, the sluice and the 3 outlets (combination of concrete construction and dike core on top) based on the ProDeich model, considering 23 failure mechanisms and about 80 input parameters	Beach level and berm width affects wave incidence at coastline. Wave overtopping of the sea defence (wave return wall and embankment behind) is the key factor in determining failure. Overtopping and breaching used to drive flood inundaiton model. Calculations carried out on 113 lines to assess breach probability. Flood depth and frequency and consequences assessed for over 100 ‚reservoirs' or cells. Analysis used to optimise beach nourishment in order to obtain greatest reduction in risk.	profiles: DTM (Flanders) - „Jarkus“ profiles Netherl - grain size measurements - drawings of dike, sonding and drilling data - water level measurements in the dike	5 dune profiles selected from 4 com-parable dune belt sections + 3 dike profiles representing dike sections
	Data sources	X-section measurements of the 6 X-section, 2 measurements of the crown height in L-direction, wave modelling, former geotechnical investigations	Beach surveys, wave modelling, tide gauges, hydraulic and structural analysis, topographic and land use mapping		X-section measurements: terrestrial DGPS surveying measure, extracted from LIDAR (Laserscanner data) based high accuracy digital elevation model; physiographic description of X-section
	Scale of data (micro, meso, macro)	micro X-direction / micro L-direction		micro X-direction / meso L-direction	micro X-direction / meso L-direction

	III Pathways and failure mechanisms for inundation	Ribe	Lincolnshire	Vlaanderen	Langeoog
Inundation mechanisms	**Mechanisms considered**	5 simplified dike breach scenarios, 1 overtopping scenario, 1 scenario considering the failure of the sluice gates	ISIS model of inundation of flood plain ‚reservoirs‘ or cells. Water level in each cell assumed horizontal. Spillage between cells. Model verified by comparison with 1953 floods.	scenarios + simplified breaching	Dike breach scenario assuming: width and depth of breach (constant over the time), time of failure related to hydro-graph of the tidal high water.
	Representative inundation mechanism	Calculated still water level = inundation depth	Unsteady flow model to represent inundation including effects of tide	flow of water through the gap	Calculated still water level = inunda-tion depth (based on DEM)
	Inundation model(s) used	GIS-based calculation of the inundation volume, no numerical model	ISIS	MIKE 21 / Mike Flood	GIS-based calculation
	Data sources	Topographical data by Kort & Matrikel-styrelsen (Copenhagen)		DTM + inner dikes	Digital Elevation Model (DEM) based on LIDAR data (~1 point per m^2) with high accuracy and topographical ter-restrial survey of significant breaklines
	Scale of data	micro		3p/10 m2	micro

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IV Receptors, consequences of flooding	Ribe	Lincolnshire	Vlaanderen	Langeoog
Damage functions	• Buildings, movable property: de-pending on historic compensation payments • Crops: damage factor depending on the month of occurrence and the inundation duration • Infrastructure: damage factor/ damage function depending on the inundation depth	Damage to residential and commercial property and agricultural land assessed using standard methods (Flood Hazard Research Centre.). Flood probability and damage assessed over a range of storm events with return period up to 500 years. Processed to estimate Annual Average Damage (£ per year). Numbers of people at risk in each ‚reservoir' based on property counts.	Relative damage, depending on water depths	MERK-method: Depending on flood water level, water propagation and flood duration (assumed)
Direct tangibles considered	Buildings Electric installations Agricultural land Movable property Traffic system (roads, railways) Livestock	Residential commercial properties, caravans, agricultural land	buildings/furniture industry, agriculture (various crops, cattle), infrastructure, road/ railway recreation, vehicles	Buildings, Building inventory, Vehi-cles, Traffic areas, Agricultural land, Livestock assets, Recreational land, Gross value added, Fixed assets, Stock value, Real estate values
Direct intangibles considered	Inhabitants, vehicle (only in a descriptive form)	People at risk	casualties	affected inhabitants, evacuated inhabi-tants
Indirect tangibles considered			production losses (function of direct tangibe damage)	Gross value added, evacuation costs for inhabitants
Indirect intangible considered	Employees, tourism capacity (only in a descriptive form)			Affected guest beds, damage to the drinking water supply

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IV Receptors, consequences of flooding		Ribe	Lincolnshire	Vlaanderen	Langeoog
Data	**Sources**	Bygnings- og Boligregistret, Flood Compensation Council, Danish Centre of Agricultural Research, Kort & Matrikelstyrelsen, Central Livestock register, Statistics Denmark		land use maps (20x20 m)	Resident register Langeoog, Business interviews, Field work, Tourism cata-log Langeoog, ALK (=Automatisierte Liegenschaftskarte), Valuation guidelines for buildings 2000, Insurance Companies, Municipality based motor vehicle specification, Internet / market analyse of used cars, Internal munici-pality investment specification, Advisory committee for real estate values State Office of Statistics, Official soil consultant - Local Tax Office Witt-mund, Deutsche Bank (annual ac-counts of West German companies)
	Scale	Micro		meso	mirco scale

V Outcomes		Ribe	Lincolnshire	Vlaanderen	Langeoog
Probability of failure flood defence system		2,5E-04 (1:4.000 yr.) (without considering the Kammer sluice and the three outlets)	Risk scores‘ based on people at risk and economic damage used to estimate beach berm width required. Current failure probability at isolated sections calculated to be 0,02 (1:50-year).	location of breaching for some return periods	1/10.000 years
Total costs of consequences		depends on the particular inundation scenario, varies between MĐ 0,15-57	To do-nothing over next 50 years: £1,088 million. 1:50-year storm (1953) at present day, predicted to cause £60 million of damage.	yes	55.000.000 Đ (40.000.000 / 73.00.000 Đ : variation of flood water level by -/+ 0.5m)
Resulting flood risk		40 - 14.200 Đ/year	If current beach levels maintained - £7 million/yr If improvements made - £1 million/yr	+/- : not enough return periods	5.500 Đ/year (4.000 Đ/year up to 7.300 Đ/year)
Sensitivity analysis	**Yes/No**	Different inundation scenarios		yes	Parameter variation of hydraulic input parameters used in damage estimation
	Parameters considered	Nummer of dike breaches and their location		grain size, water level, wave height, position of clay core,	water level, breach width

General remarks	The study made clear that the range of risk values depends on the inundation scenarios and the damage, which has been determined on the basis of the inundation extension and depth. The determination of these factors required, however, several assumptions, e.g. the location and number of dike breaches. The reliability of these assumptions was not analysed within the study.	Study concluded that, whilst fully quantified analysis of damages is required to develop a business case for intervention, practical tools to consider where intervention measures provide greatest value in terms of risk reduction can rely on much coarser analysis of the geographical distribution of people. A method for considering how short-term changes to defence performance can influence flood risk has been developed.		The range of estimated damage strongly depends on the inundation scenarios and the used depth-damage functions. The inundation parameters which have strong influence on the result of the vulnerability analysis are the inundation extension and the flood water depth. The determination of these figure requires several assumpti-ons, especially the location and (num-ber and) width of dyke breaches. The reliability of these assumptions is not analysed within the study.

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Integrated Risk-Based Design and Management of Coastal Flood Defences

HOCINE OUMERACI

Summary

The main obstacles encountered in the practical implementation of a sustainable protection against coastal floods and the peculiarities of coastal systems and processes are first discussed from the view point of the deficiencies in scientific knowledge, predictability and modelling tools.

The main requirements for a new design and management concept for sustainable flood defences are then derived, leading to an integrated probabilistic risk analysis (PRA)-based conceptual framework for the design and safety assessment of coastal flood defences. This concept is based on the risk source-pathway-receptor model, including (i) the prediction of flood risk, (ii) the assessment of tolerable flood risks and the risk analysis and (iii) the management of residual risk as an integral part of the overall design process. The scientific and modelling challenges within each component of the integrated concept (risk sources, risk pathways, risk receptors) are systematically addressed, also including the assessment of risk acceptances

Zusammenfassung

Zunächst werden die Hauptschwierigkeiten bei der praktischen Implementierung eines nachhaltigen Hochwasserschutzes im Küstenraum sowie die Besonderheiten der küstenbezogenen Systeme und Prozesse aus der Sicht der Defizite im Wissensstand, der Vorhersagbarkeit und der operationellen Modelle aufgezeigt.

Die Formulierung der Hauptanforderungen an ein neues Konzept für die Bemessung nachhaltiger Hochwasserschutzwerke führt zu einem integrierten probabilistischen und risikobasierten Konzept für die Bemessung neuer und die Sicherheitsprüfung vorhandener Hochwasserschutzwerke. Das Konzept basiert auf dem Modell „Risikoquellen-Risikowege und Risikoauswege“ mit drei Hauptkomponenten: (i) Vorhersage der Flutgefährdung und der Vulnerabilität der geschützten bzw. zu schützenden Gebiete (berechnetes Flutrisiko); (ii) Evaluierung der tolerablen Flutrisiken und Risikoanalyse; (iii) Management der Flutrisiken als integraler Bestandteil des gesamten Konzeptes für die Bemessung bzw. Sicherheitsüberprüfung. Die Diskussion der wissenschaftlich/technischen Herausforderungen hinsichtlich der Risikoquellen, Risikowege und Risikoempfänger bilden den Hauptteil des Beitrages, wobei auch auf den wichtigen, noch offenen Aspekt der Riskoakzeptanz eingegangen wird.

Keywords

Coast, risk management, flood defence, probabilistic risk analysis, risk source-pathway-receptor model

Contents

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1. Design of Flood Defences in the Context of Sustainable Development and Protection of Coastal Zones

Coastal zones, including estuaries, represent unique and vital transition areas between the marine and terrestrial environment and are therefore favoured as valuable habitats by both humans and wild life. In fact, almost 40 % of the world population are concentrated within a 100 km wide coastal strip, including 65 % of the large cities with more than 2.5 million inhabitants (OUMERACI, 2000). Worldwide, coastal, river and flash floods are responsible for more than 50 % of the fatalities and for about 30 % of the economic losses caused by all natural disasters. Moreover, the increasing storm surge activities which are observed since many decades will certainly continue to increase in terms of frequency, duration and intensity. This may lead to the increase of the probability of flood hazards.

On the other hand, the still increasing socio-economic pressure on the use of coastal zones with the subsequent increase of the needs for more infrastructures (industry, transportation, amenities, housing, etc.) has led to an increasing conversion of these vital zones to a built environment, and thus to a vulnerability increase. Subsequently, flood risks which consist of both flood hazard probability and vulnerability are expected to dramatically increase if no appropriate countermeasures are undertaken.

It is obvious, that appropriate solutions to mitigate coastal flood risks can only be found within the general context of sustainable development and protection of coastal zones. Some of the challenges towards the development of future models which are implied by the application of the sustainability principles to flood protection are briefly mentioned in Fig. 1.

The search for appropriate solutions meeting the sustainability principles becomes even more difficult due to some peculiarities and conundrums of the coastal system which may be summarized as follows (Fig. 1):

1) Although coastal zones occupy only 6 % of the total surface of our planet, the value of the coastal ecosystems represent almost 40 % of the value of all marine and terrestrial ecosystems (OUMERACI, 2000). This would suggest that conservation and preservation of coastal ecosystems should have a higher priority than the socio-economic use of coastal zones which is generally associated with an increasing need for more infrastructure and coastal defence structures. This will particularly require integrated methodology tools to achieve a proper balance between socio-economic needs and environmental integrity.
2) The coastal processes (hydrological, hydrodynamical, morphological and ecological) and their interactions are highly complex and stochastic. They are essentially non-linear, dynamic and three dimensional with a high level of spatial and temporal variability. They occur at a very broad range of space and time scales and are very sensitive to climate variability and human inferences. These will particularly require models with a high level of

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integration of the diverse physical, ecological and socio-economic issues and interactions over a broad range of scales. Moreover, these models should account for the high temporal/spatial variability of the processes, for possible 3D-effects and the inherent stochastic variability of the influencing parameters and processes.

3) The use and protection of coastal zones, including prioritization, will always be subject to changes (moving target in both time and space!) as well as to conflicts and compromises. This will require adaptive tools/models to account for the evolving socio-economic demands and the evolving impact of human interventions on the apparently natural processes. Account should also be made for the sudden dramatic changes which might result from decadal to centennial/millennial slow changes and accumulations.
4) The knowledge, data and models used at any stage of decision making (design, operation, management) are never complete, permanently evolving and always subject to large uncertainties from diverse sources. Therefore explicit account should be made for these uncertainties, including the inherently low level of predictability of the modelling tools, the inherent stochastic variability of the input parameters as well as the human and organisation errors.

Given these peculiarities and the requirements implied by the sustainability principles it is obvious that a protection against flooding which fulfils both socio-economic efficiency and environmental integrity at longer term can only be achieved by within an integrated design and management framework which is based on probabilistic risk analysis (Fig. 1).

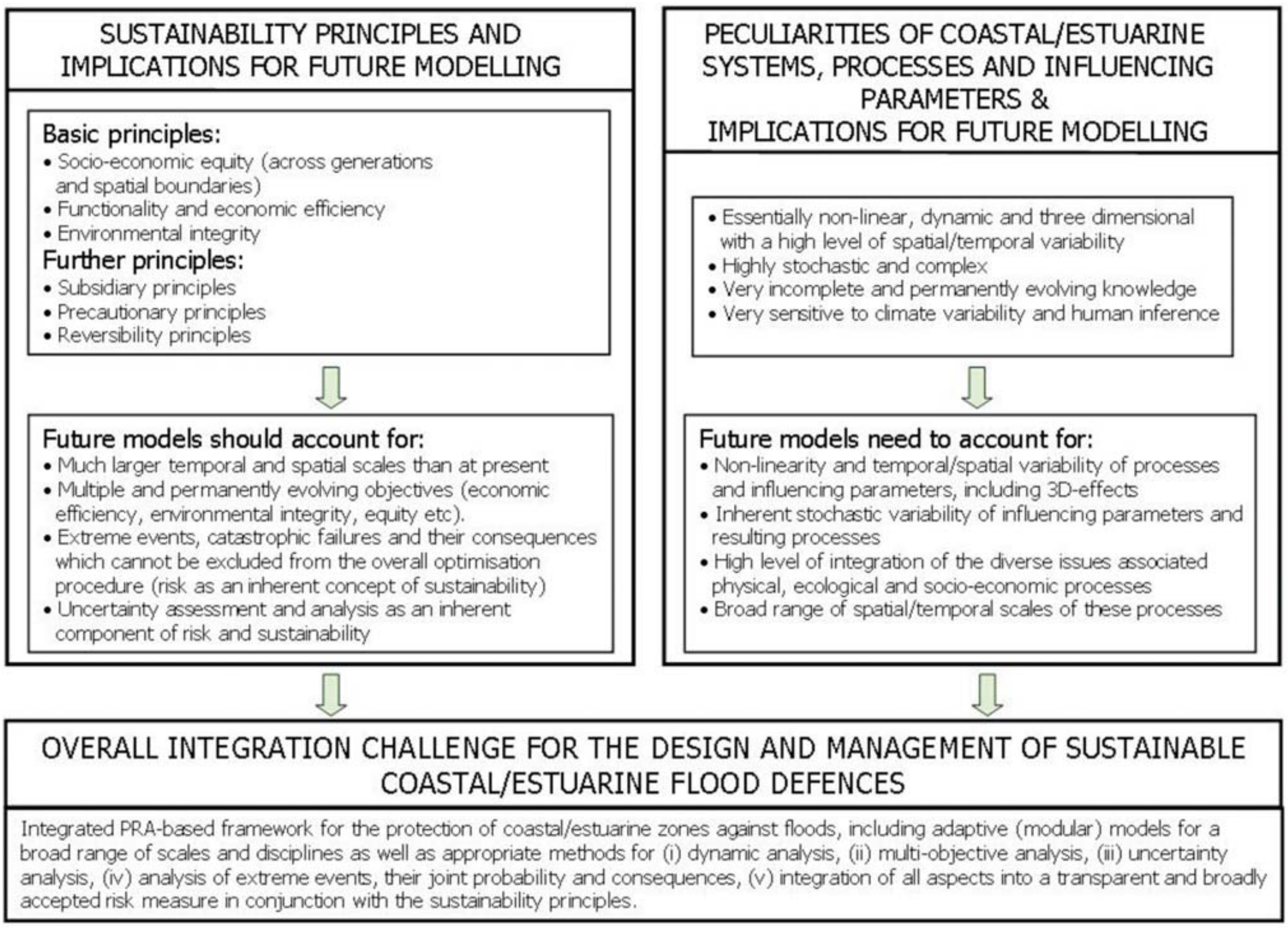

Fig. 1: Research and modelling challenges for the design of sustainable of coastal flood defences

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2. PRA-Based Integrated Concept for the Design of Sustainable Coastal Flood Defences

Beside the general motivations mentioned in the introductory section, the necessity of a more rational and integrated design approach, fulfilling the sustainability requirements will be briefly outlined before starting with the description of the suggested design concept.

2.1 Necessity of New Design Concept

The protection against floods and the design of coastal flood defences have a long tradition worldwide. In spite of the wide variety of design methods and safety standards adopted in each country, the design criteria for flood defences structures are still essentially based on the so-called design water levels associated with exceedance frequencies which are specified by design standards and regulations. The specified exceedance frequency is implicitly interpreted as a probability of failure of the defence which is again equated to a flooding probability. Such approaches are too simplistic as:

1) they may lead to too high and expensive defence structures, because the structure must not necessarily fail when the design water level is exceeded;
2) they may result in an incorrect safety assessment, because the defence structure may also fail, even if the design water level will not be exceeded. The adopted safety coefficients are often arbitrary, lacking rationality and transparency;
3) they do not only ignore totally or partially the failure mechanisms likely to lead to flooding, but also the vulnerability of the flood-prone areas. Only in few countries such as in the Netherlands, the vulnerability is implicitly considered by allocating different exceedance frequencies, depending on the vulnerability of the flood-prone areas.

2.2 Basic Requirements for the New Design Concept

In order to substantially help moving the design of sustainable flood defences from an academic debate into the realm of concrete work, performance and return, a new design concept in line with a sustainable flood protection is urgently needed, including all the necessary methods and modelling tools, which should at least fulfil the following requirements:

1) To ensure that the prospective design approach and associated tools are consistent and transparent enough for a wide acceptance in practice, they should be based on a sound knowledge of all relevant processes and interactions at any stage – from the sources to the receptors of the flood risk –, including all constraints, possible changes and their predictions. Therefore, the prospective design approach/tools should possibly be based on *process-oriented* research.
2) To account explicitly in the design process for all uncertainties, including those associated with the prediction over a brad range of scales under the constraints of evolving socio-economic demands and human inferences as well as under the constraints of the more uncertain climate variability and its local implication, *reliability analysis and reliability-based tools* are necessarily required.
3) To offer more choices and transparency in the design process and to bridge the gap between technician and non-technical decision makers, the reliability analysis must be extended to *risk analysis*. The flood risk being defined as a combination of the probability

of the flood hazard (risk sources and risk pathways) and the vulnerability of the flood areas (risk receptors), the risk analysis should preferably be carried out according to the *risk source-pathway-receptor approach*, thus allowing to act on both risk components (hazard and vulnerability) to reduce flood risk.

4) To reduce flood risk, a proper balance of all options (retreat, accommodation and protection) and measures (structural and organisational; prior, during and after flood event) is required. Therefore, *risk management* must be an *integral part of the design* of new flood defences and of the safety assessment of existing defences.
5) To ensure that all processes and conflicting interests, which may affect one or both risk components (hazard and vulnerability), are properly assessed and accounted for, an *integrated approach* is required.
6) To help developing unified safety concepts and thresholds between sustainable and non-sustainable flood protection schemes, an appropriate measure for acceptable vulnerabilities and risks should be developed which also allows a comparison with tolerable values in other sectors such as transportation, chemical industry, nuclear power plants, etc. This will also be particularly important in the case of risk analysis associated with multi-hazards. Therefore, a *transparent framework for the assessment of acceptable flood risk with appropriate methodologies/modelling tools* and with clear implications for regulatory actions should be an integral part of the new design concept.
7) To make the new design concept broadly applicable at various levels, the entire approach for a detailed design level should be simplified for a feasibility and a preliminary design level, including the associated requirements for the data and the modelling tools to be used. *(Tiered approach).*

A possible design concept which can fulfil most of the aforementioned requirements is suggested in Fig. 2. This concept is based on risk-source-pathway-receptor approach, including four major steps:

1) *Prediction of flood risk:* It consists of the predicted flooding probability which is obtained from the risk sources and the risk pathways and of the predicted potential damages and losses which require a sufficient knowledge of the vulnerability of the flood-prone areas, including their temporal variability and uncertainties.
2) *Evaluation of the tolerable flood risk:* It consists of the tolerable damages and losses and of the tolerable probability of their occurrence. Both require a very good knowledge of the socio-economic/ecological resilience and of the risk perception/communication in the flood-prone areas which depend on a large variety of aspects, including individual, societal, political and legal issues. The variability of these aspects and the uncertainties associated with their assessment should be properly accounted for.
3) *Evaluation of the residual risk* through comparison of the predicted and acceptable flood risk. An appropriate measure for the level of residual risk should be developed which clearly describes the penalty associated with both underdesign and overdesign. This of course will have clear implications for future safety factors to be adopted in the design standards and regulations.
4) *Management of the residual risk* through structural and non-structural measures before, during and after the flood event. One of the key features of this design concept is the incorporation of the risk management as an integral part of the entire design process. In fact, no optimisation over the life-cycle of the flood defences is possible without the knowledge of the residual risk and its management.

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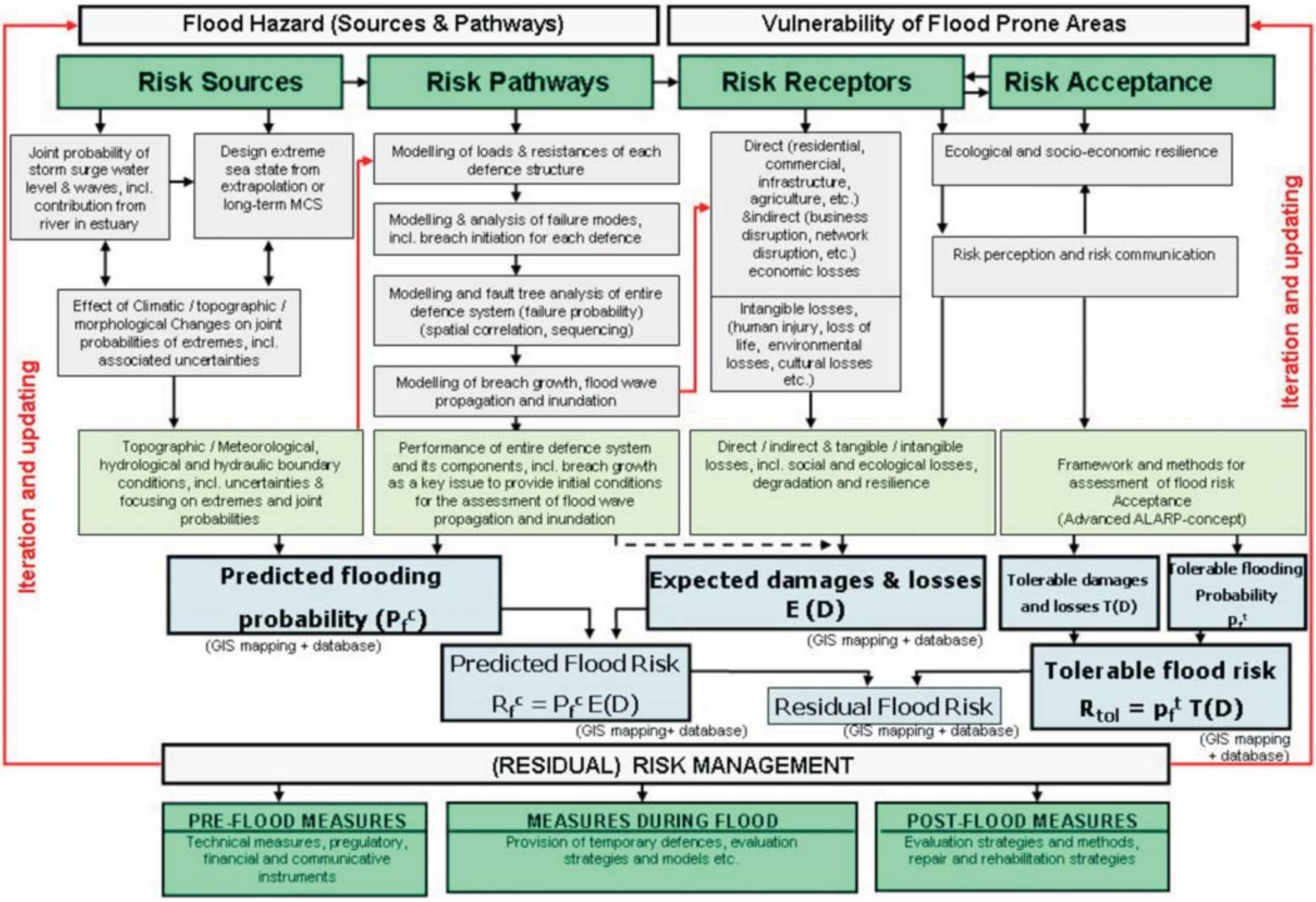

Fig. 2: Integrated PRA-based concept for the design of sustainable coastal flood defences

The practical implication of these four major steps require, however, a scientific knowledge, methodologies and modelling tools which are not yet sufficiently available and which therefore need to be developed. The research challenges associated with the risk sources, pathways, receptors and acceptance are discussed in Section 3 below.

3. Scientific, Modelling and Further Challenges

3.1 Challenges Associated with Risk Sources

The "risk sources" essentially provide the hydraulic boundary conditions which are required to assess the design loads and the probability of failure of the flood defence components. These are generally dependent on the prevailing tidal, meteorological and topographic conditions.

On coastlines with shallow shelf areas (e.g. North Sea) a combination of high tides storm surges, wind waves and mutual interactions generally represent the major sources of coastal flood risks:

$$\eta_{WL} = \overline{\eta}_{MSL} + \eta_{tide} + \eta_{surge} + \eta_{waves} + \eta_{topo} + \eta_{inter} \quad (3.1)$$

The resulting water level (η_{WL}), which is temporarily and spatially variable, may be considered a resulting sea state.

The mean sea level component $\overline{\eta}_{MSL}$ essentially varies over long time periods as a result of climate changes (10–25 cm in past century) and is therefore subject to very large uncertainty. For a given climate change scenario the effect of changes in water depth due to MSL-rise on the tidal, surge and wave components can be quantified with some confidence for a well-defended (not morphologically very active) coast.

The astronomically generated tidal component η_{tide} is rather deterministic and much easier to quantify. The same applies for topographic effects on tides.

Much more difficult to determine is, however, the meteorologically induced surge component η_{surge} (BODE & HARDY, 1997). Although simultaneous computation of the tidal and surge components are now routine in present 2D and 3D baratropic storm surge models (SSM) which seem to hindcast water levels with acceptable accuracy, there is still a serious lack in the understanding/modelling of the processes involved in the interaction of the surge and wave components η_{waves}. In fact, the latter is still calculated separately (RESIO & CARDONE, 1999).

The wind wave and wind wave-induced component η_{waves} is calculated by high resolution wave models, including wave transformation over and by rather simple topographic features. Methods also exist to estimate the joint probability of wave heights and wave periods, but higher resolution models for wave transformation over a more complex topography, including the effects on the joint statistics of wave heights, periods and directions are urgently needed.

The contribution of the topography-induced effects η_{topo} to the resulting sea state η_{WL} is generally considered by means of models for the transformation of the tidal, surge and wind waves. Although morphological models are available to predict the topographic changes during storms, the susceptibility of sea bed and coastal features to progressive changes (e.g. migration of sand bank) and to sudden changes (e.g. breaching of barriers islands) is still not properly considered in the long-term simulations of sea state. Coupled surge, wind-wave and morphological models over a broad range of scales represent an ideal alternative for this purpose and are thus to be kept in perspective. Meanwhile, considerable improvements of the assessment of the extreme design sea state may be achieved through the joint run of existing models.

The contribution η_{inter} of the mutual interactions between the various components still remains the most unknown, despite the now routine linking of tidal and surge components in present operational storm surge models and despite the substantial progress in recent research on the physics of air-sea interactions and on the coupling of surge and wind-wave models. The coupling will certainly take a long way to be implemented in operational prediction models. Meanwhile, rather pragmatic approaches for the assessment of the joint probability of extreme water levels and waves for coastal engineering design emerged (HAWKES et al, 2002; DE VALK et al, 2001). These approaches certainly represent an important step toward the practical implementation of the PRA-design concept in Fig. 2, although much more remains to be done. In further research focus should rather be put on those approaches in which the critical step of extrapolation of the multivariate input data to extreme values is undertaken at the earliest and prior to any transformation, i.e. at the level of the offshore or regional climate. This is in fact more generic than extrapolation at the level of local nearshore climate or structure variables. In fact, the extrapolations offshore can be used for any type of sea defences at any location and for any structure function. This is also potentially more accurate as structure variables and nearshore climate are subject to much mort constraints

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which may result in anomalies in the tails of the distribution function. In contrast, tails of offshore climate are generally smoother and easier to extrapolate. Substantial improvement of the predicted extremes is achieved through Monte Carlo simulations of large samples of wave height, wave period and water level, using fitted distribution and by incorporating additional non-simultaneous data (HAWKES et al, 2002).

Within the particular context of such joint probability approaches the greatest research challenges are directed towards the following aspects:

1) Assessment of the uncertainties associated with transformation of the multivariate distributions functions through a sequence of models up to the failure probability function, including their explicit incorporation in the latter. This is particularly important, because it is much more difficult than transforming data.
2) Physical justification of the extrapolation of the fitted distribution to high extremes.
3) Introduction of the time factor, including the temporal dependence between successive variables and their time dependence. This is particularly important for failure tree analysis as well as for many failure modes which depend on the entire load history during a storm or which are caused by stepwise deterioration (e.g. dune regression, dike breaching).

Within the context of Eq. (3.1) the greatest challenge is to overcome the difficulties toward a complete understanding and modelling of all components, possibly also including contributions from other sources (e.g, from river discharges). These difficulties essentially arise from the very large differences in scales of the temporal (and spatial) variability associated with the formative components, of which the last two in Eq. (3.1) are present over a very broad range of scales (up to millennia). Particular challenges worth to be mentioned are:

1) Investigation of the effect of the increasingly high non-stationarity of the climate signals suggesting that the assumption is no longer defensible and that long-term changes in the distribution models are very likely even for time scales in the decadal range. This is particularly crucial for very vulnerable flood-prone areas where design return period of 103–104 years and design life time of 100 years are not uncommon.
   While sensitivity studies might indeed provide a first useful insight into the effect of climate changes on the extreme distributions, the systematic deviation from the fitted distribution, suggesting further population in the extreme distributions, can only be quantified through long hindcast simulation and a joint run of storm surge models, wave models and morphological models forced by (a) routine meteorological and other data which will provide the "natural" variability and (b) data including the results from a high resolution regional climate model which will provide the effects of climate changes. First attempts in this direction recently started to emerge, but without any consideration of the morphological changes. The effect on the tidal range was found negligibly small (FLATHER & WILLIAMS, 2000). The runs with the climate effect on extreme wind and extreme surge level estimates from observational records were found to dramatically deviate from the fitted distribution (VAN DEN BRINK et al, 2003; VAN DEN BRINK et al, 2004).
2) Improvement of the physical understanding of the relative contributions of the components in Eq. (3.1) and the underlying formative factors, including the range of their variability, their limits compatible with the physical laws and within the context of the geophysical and anthropogenic processes. Rather than mainly focusing on more sophisticated distribution models which will doubtfully be useful, this should have the highest research priority, because the results will build the basis for a physically sound combinatorial approach. The latter will enable the extreme joint probabilities to be obtained from the simulation of a large number of physically possible and unusual combinations of the constitutive factors and components compatible with the geophysical and anthropogenic context rather than

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only from curve fitting and extrapolation without any explicit and complete account of the physical causes of observed records and of the possible changes of the climatic, morphological and other conditions circumscribing the potential of extreme sea states. It is in fact rather surprising that extrapolations to 103, 104 and even 105 years events determined in this manner are still accepted – even in regulatory documents – although it is widely known that decisions based on wrong numbers resulting from sophisticated mathematical analyses (extreme value theory and multivariate analysis) represent themselves an additional hazard which may substantially contribute to increase the flood damages and losses.

3.2 Challenges Associated with Risk Pathways

The main goal of the risk pathways is to predict flooding probability EMBED Equation. DSMT4 P_f^c which results from the failure of one or more components of the entire defence system (Fig. 2). This will particularly require reliable methods and models to predict:

1) the loading and resistance parameters of the defence components
2) the associated failures, including their interdependence and contribution to the initiation of the top failure event (e.g. breaching, flooding)
3) the breach growth, the subsequent flood propagation and the damaging effects
4) the overall performance (failure probability) of the flood defence system which may become very complicated, depending on the number, configuration and degree of interdependence of the defence components.

Among the R & D challenges associated with these four issues the following are worth to be mentioned.

3.2.1 Wave Overtopping, Breach Initiation and Growth from Landward Side

Except in the case of particular (moveable) defence structures such as storm surge barriers where flood may occur as a result of malfunctions due to human and organisation errors (OUMERACI et al., 2001) disastrous floods generally result from the breaching of flood defences. Keeping in mind that most sea dike breaches in the past (e.g. storm surge of 1953 in The Netherlands and 1962 in Germany) were initiated from the landward side by wave overtopping (SCHÜTTRUMPF & OUMERACI, 2004a) the highest research priority with respect to wave loading should be directed towards a proper modelling of wave overtopping, possibly in combination with overflow (OUMERACI et al, 1999).

The available empirical/analytical wave overtopping formulae (e.g. SCHÜTTRUMPF & OUMERACI, 2004b) and numerical models (e.g. HUBBARD & DODD, 2002) are restricted to a 2D-situation, including a number of further limitations which make their application in limit state equations for the failure modes associated with breach initiation questionable. Fig. 3 illustrates the 3D-structure of the overtopping flow with a complex tongue shape. Not only the 3D-modelling of such a single overtopping event is required (Fig. 3), but also the sequencing and distribution of the overtopping tongues along the defence (Fig. 4). For the inception of the erosion on the rear slope (Fig. 6a) it is also important to know, whether the overtopping tongue falls on a water free slope or on the water layer of the previous overtopping tongue (Fig. 4). Moreover, the effect of the incipient erosion on the crest and rear slope on the overtopping flow distribution may also become significant (Fig. 5). In this case, the

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Fig. 3: Three-dimensional structure of overtopping flow

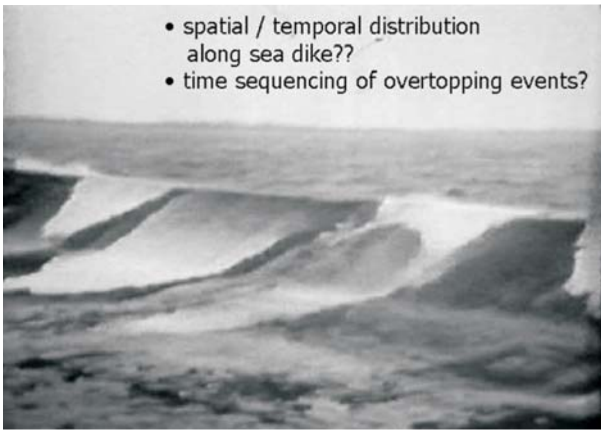

Fig. 4: Distribution of wave overtopping flow along a sea dike

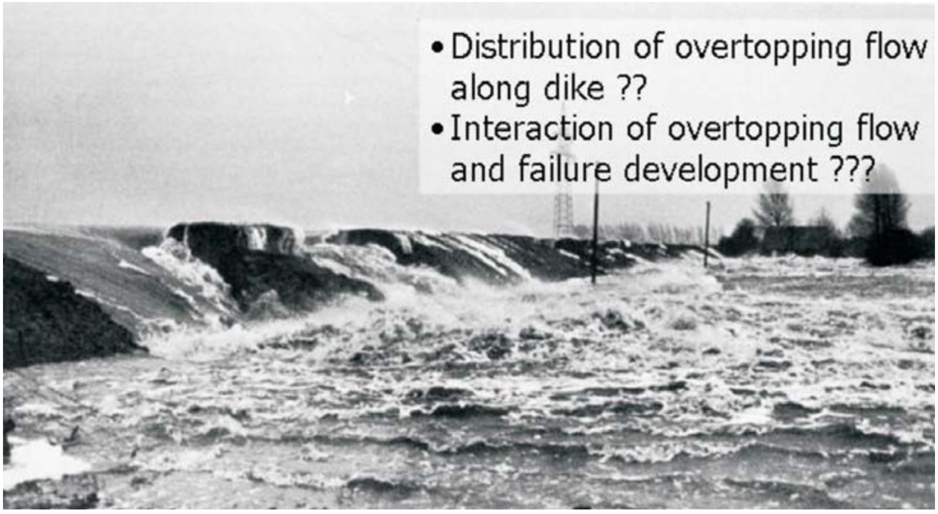

Fig. 5: Wave overtopping and erosion along an estuary dike

interaction between the flow and the development of the erosion should also be modelled, if a reliable prediction of breach initiation has to be achieved.

Furthermore, the prediction of breach development induced by wave overtopping still represents an unsolved problem, although the initial conditions at the defence line constitute one of the greatest uncertainties in flood propagation models and thus in the assessment of the warning time and the damaging effects.

The large experience available in dam engineering with dam-break flood wave models (Morris & Hassan, 2002) cannot be simply extrapolated to coastal flood defences, due to several reasons such as (i) the initial conditions of the flood wave which interacts with the breach growth, (ii) the limited breach width along the defence line and (iii) the 3D-character of the flood wave in a coastal plain. Therefore, substantially new knowledge towards the physical understanding and proper modelling of the breaching process must be generated before embarking into the detailed modelling of flood propagation and its damaging effects on typical obstacles in the protected areas.

Due to the very strong interaction between the expected extreme hydrodynamic conditions (high water levels, strong currents and high storm waves) and soil strength parameters (large Shield's parameter, variable shear strength, etc.) associated with very high erosion and

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transport rate during the breaching process, serious scale effects would be expected, if common small-scale models are used. On the other hand, it will not be possible to achieve the required understanding of the physical processes by using only field experiments for which the control of the forcing functions (water levels, currents and waves) and the boundary conditions cannot be controlled. Therefore, hydraulic model tests at almost full-scale in a large wave facility remains the sole alternative. Based on the experimental results, generic models of the development of the breach initiated by wave overtopping (Fig. 6c,d) must be developed from a structural and hydro-geotechnical engineering perspective for a class of typical flood defences, including homogenous and non-homogeneous earth structures.

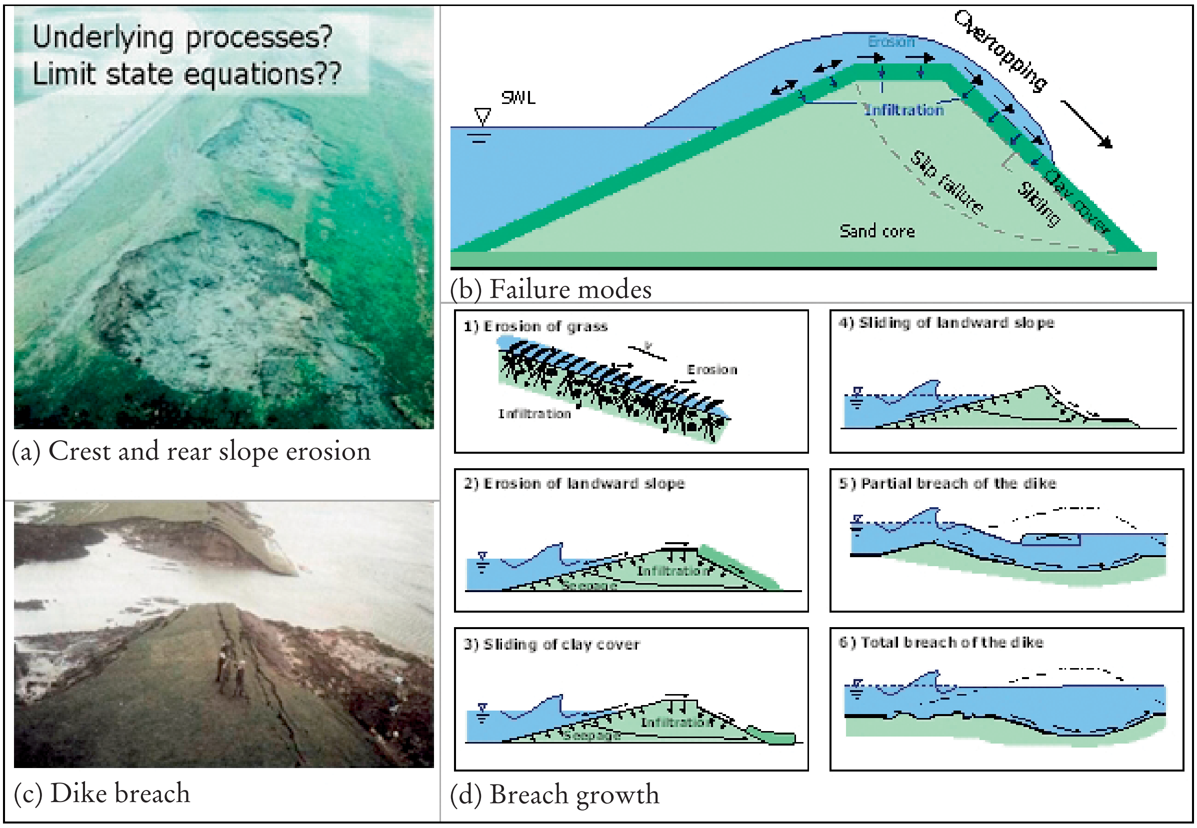

Fig. 6: Development of breach initiated from landward side by wave overtopping

3.2.2 Wave Impact, Breach Initiation and Growth from Seaward Side

A breach may also be initiated from the seaward side by various mechanisms, depending on the type of slope revetment. For most of the revetments and particularly for clay-covers of sea dikes as widely used in The Netherlands, Germany, Denmark, etc., the most common failure mode consists in erosion holes induced by breaching wave impacts along the dike (Fig. 7a,b).

It is therefore needed to develop a better understanding of the propagation of the impact pressure through cracks/voids (Fig. 7a) in the revetment into the dike core (Bruce et al,

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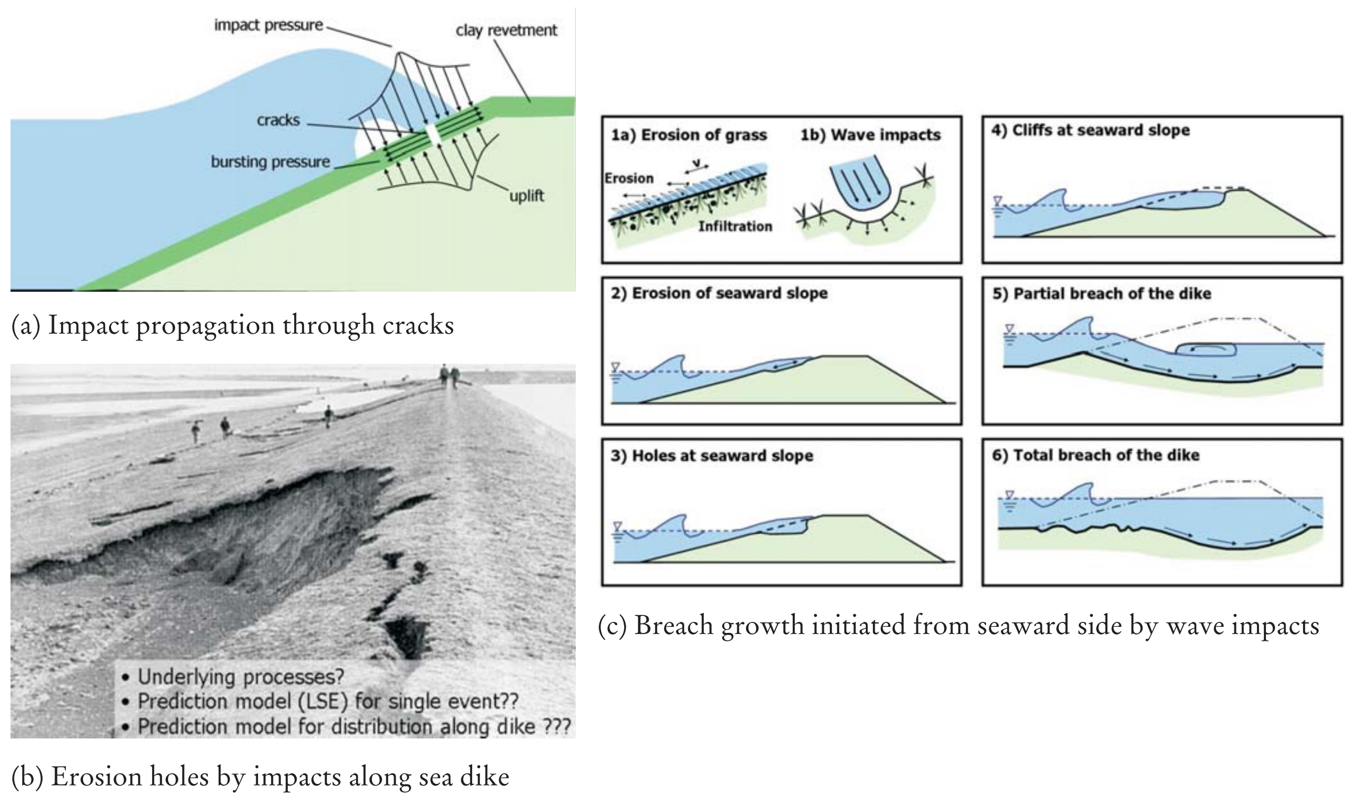


(a) Impact propagation through cracks

(b) Erosion holes by impacts along sea dike

(c) Breach growth initiated from seaward side by wave impacts

Fig. 7: Erosion holes induced by wave impacts along a sea dike

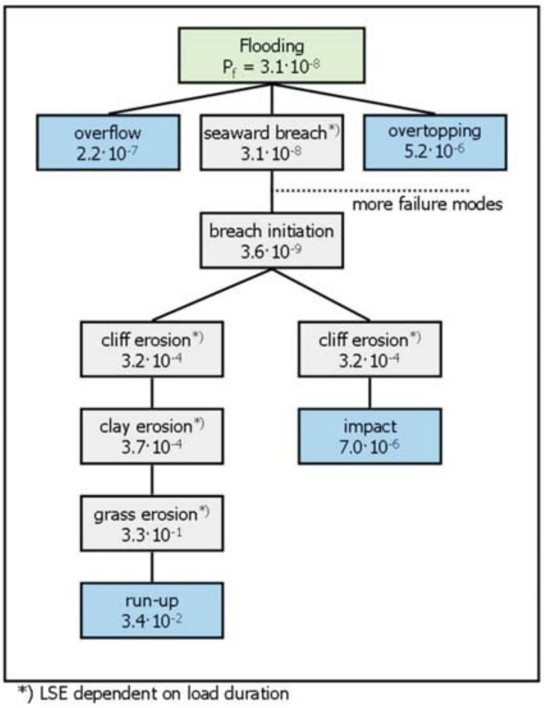
2000) and of the mechanisms by which the revetment is "blown out" by the pressure pulses. Generic limit state equations can then be developed for these failure mechanisms and a set of typical defences and revetments. There is also a crucial need to develop a prediction model for the distribution of the holes along the defence and to understand under which conditions theses holes may lead to breach initiation (Fig. 7b in the back). Since the breach will develop differently from the case shown in Fig. 6d, generic models are required for the development of the breach induced from the seaward side by wave impacts for a class of typical flood defences and revetments (Fig. 7c).

3.2.3 Advanced Fault Tree Analysis

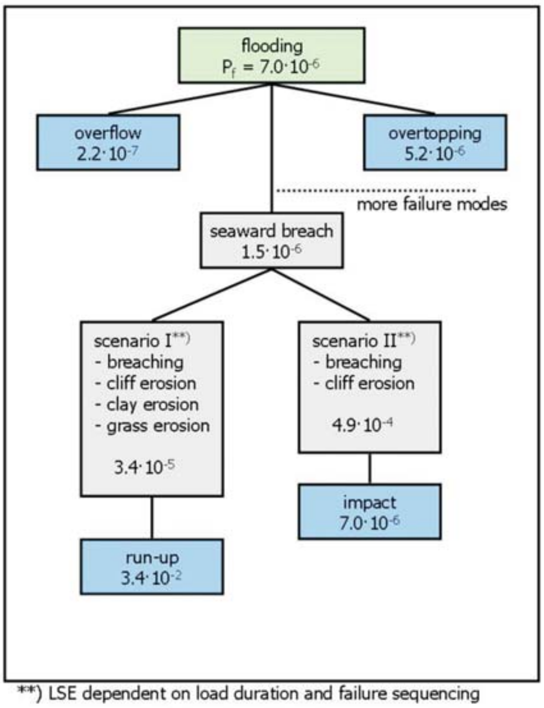
Conventional fault trees describe the occurrence probability of a specific failure mode (top event) and all the ways in which that top event can be reached; i.e. the relative contributions of prior failure modes to the probability of the top event. Particularly for the cases where the load and resistance parameters are time dependent, the time duration of the failure mechanisms as well as their time sequencing and actual links which are not taken into account by conventional failure tree analysis may be crucial for the outcome. Kortenhaus (2003) performed a fault tree analysis, including 25 failure modes of a sea dike with flooding as a top event, by comparatively applying a conventional approach and a so-called "scenario approach". In the latter, time sequencing of the time dependent failure modes is achieved by building "scenario blocks" in the fault tree. A "scenario block" consists of a combination of those non-discrete failure modes which strongly depends on the time duration and on each other (e.g. progressive erosion and breach initiation). As expected the annual probability of the top event obtained by an improved fault tree including "scenario blocks" was more than two orders of magnitude higher than that obtained from a conventional fault tree (Kortenhaus, 2003). A more recent case study for a North Sea dike performed by Kortenhaus (2004) has shown that the difference between the two approaches may indeed reach two orders of magnitude with respect to the probability of the top event or even three orders of magnitude with respect to the probability of the failure immediately following the "scenario blocks" (see simplified fault trees in Fig. 8).

Moreover, fault trees must also include the key failure modes which are not or hardly amenable to common limit state equations (e.g. failures of moveable barriers due to human and organisation errors). "Quantification" of the failure probability by elicitation of expert opinions or/and simulations may considerably improve confidence (COOKE, 1991; OUMERACI et al., 2001).

To further reduce the drawbacks of conventional fault tree analysis which is time consuming and rather subjective as the outcome is strongly dependent on the expertise and skills of the analyst, innovative methodologies and techniques are urgently needed. These should particularly help moving this conventional analysis from an art to science, from a fragile and very sensitive tool to a more robust and widely affordable approach for practitioners. Complementarily the research should also be directed towards examining the feasibility of integrated system dynamic models and GIS-approaches to obtain a modelling framework capable of coping with space and time dependent processes (see Section 3.2.4 below).



a) Conventional fault tree analysis



b) Fault tree analysis with "scenario" approach

Fig. 8: Fault tree analysis: conventional vs. "scenario" approach

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3.2.4 Failure Probability of Entire Defence Line and Phased Defence Systems

In practice, a flood defence rarely consists of a single or homogenous structure over its entire length. Generic methodologies and techniques are still lacking for the definition of "homogenous" segments of the defence line with respect to the load and resistance parameters as well as for the specification of the degree of interdependence of adjacent segments with respect to various mechanisms (structural support offered to adjacent segments, simultaneous hydraulic load effects, flood propagation, etc.). The same holds true for the modelling of the performance (probability of failure) of the entire defence line. The occurrence of a breach along a certain defence segment may be stochastically independent, but the breach along the nearby segment may strongly depend on the breach which occurred along the adjacent segment (Fig. 9).

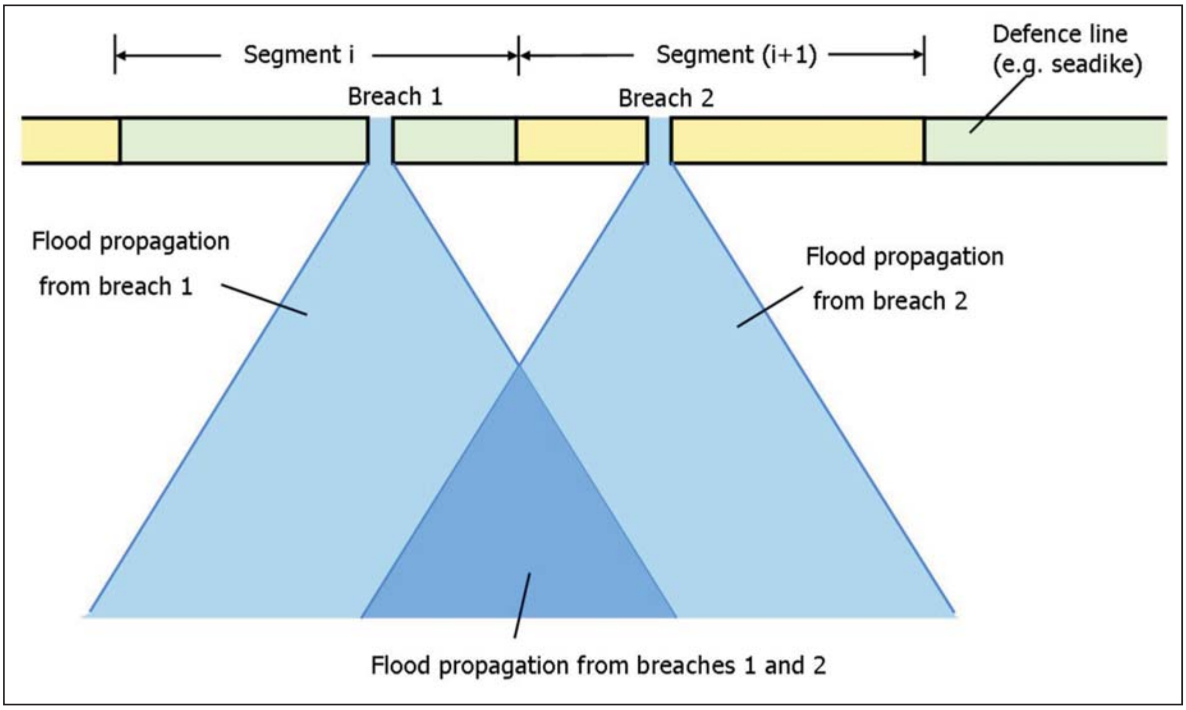

Fig. 9: Distribution of breaches along a defence line

Moreover, the time sequencing of both breaches will have a significant effect on the flood propagation and thus on the subsequent damages in the protected area. Therefore, the prediction of the defence performance must be conducted in close connection with the risk receptor analysis (Fig. 11).

Beside the "segmentation" and the modelling of the performance of the entire defence line, specification of the degree of a phased defence system and modelling of the performance of the entire defence system represent a further and much greater research challenge. Examples of such coastal flood systems as commonly applied in Germany are given in Fig. 10, showing for instance that the performance of the main defence line strongly depends on the high foreshore or dune fronting it.

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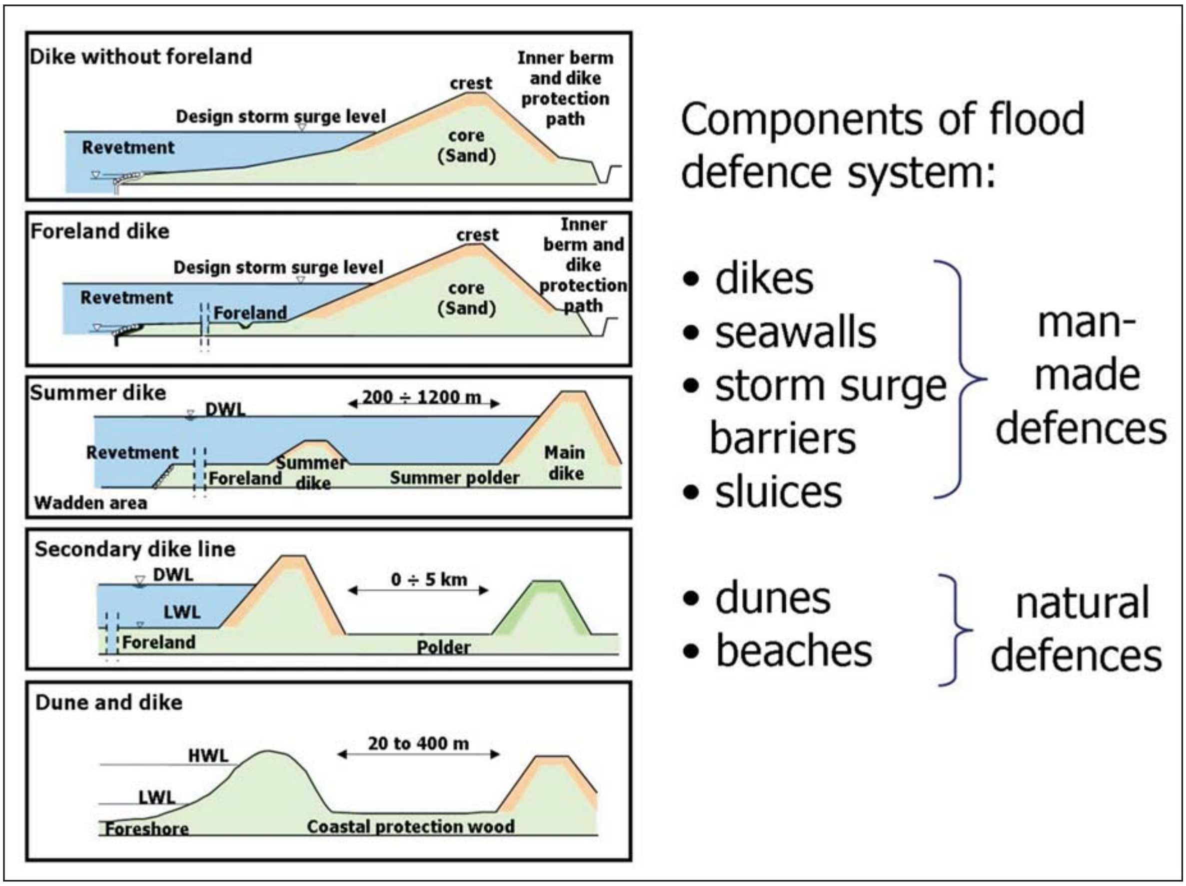

Fig. 10: Example of coastal flood defence systems in Germany (North Sea and Baltic Sea)

The degree of spatial correlation between the defence components will also depend upon the respective along and across shore distance between the components and how they are tied to each other in plan view (links, bonds, etc.). Therefore, due consideration of both cross sectional and along shore (plan view) representations of the defence components is required to formulate appropriate correlation functions. Keeping in mind the research challenges associated with advanced fault trees mentioned in Section 3.2.3, the simplified flow chart in Fig. 11 is tentatively suggested to illustrate the degree of complexity and the range of difficulties of the problems associated with the prediction of the performance of entire and complex defence systems. These difficulties are also well illustrated by a case study (BUIJS et al, 2003) which represents one of the first serious attempts in this direction. That and further case studies show that the performance of an entire defence system is too complex to be addressed by conventional approaches and modelling. Therefore, an appropriate modelling framework is needed which is capable to cope with the complex failure mechanisms in time and space, including all interactions between the component of the defence system and integrating the expected damages directly caused by flood propagation. Such a framework might be obtained by coupling system dynamic models to cope with the time dependent processes and GIS-based approaches to cope with spatial modelling. Cellular automata have also been suggested, but they are appropriate for discrete event simulations rather than for continuous time simulations.

Such a modelling framework will also enable to simulate the performance of the entire defence system over the intended design life time and thus to account explicitly for the long-

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term change of the failure probabilities which would necessarily result from the long-term changes of the load and resistance parameters. This issue is particularly crucial for probability discounting as optimisation can only be achieved by considering life-cycle costs.

3.3 Challenges Associated with Risk Receptors

The prime objective of the risk receptor analysis is to predict the expected damages and losses which will result form the predicted flood event (Fig. 2) This will require a consistent methodology with the necessary models and predictive/analytical tools for the vulnerability at multiple levels of the receptors, including the resilience of the ecological and social systems. Among the variety of candidate research issues the following research and modelling challenges may be mentioned: (i) physics of direct damages caused by flood propagation, (ii) loss of life and human injuries, (iii) environmental and cultural damages induced by inundation, (iv) integration of all expected flood losses.

3.3.1 Physics of Direct Damages Caused by Flood Propagation

The research efforts should primarily be directed towards modelling the interaction between breach growth and flood propagation from one or more breaches (Fig. 9), but also towards the damaging effects of the flood wave on a variety of a set of typical obstacles and topographic features, including scour, erosion, sedimentation and infiltration. As a result, a set of high resolution models (including modelling of turbulence and fluid-sediment-structure interactions) for the prediction of direct physical damages should be obtained.

3.3.2 Loss of Life and Human Injuries

Besides the socio-economic and ecological importance of the flood-prone area, the safety of flood defences primarily depends on the number of people at risk. Among the so-called intangible losses, human injuries and loss of life are, however, the most difficult to predict and to valuate.

The difficulties associated with the prediction essentially arise from the fact that the probability of drowning/injuries is not only a function of the flood propagation and inundation characteristics (depth, discharge, rising rate, etc.) but also of the warning, evacuation and further risk reducing measures. Therefore, appropriate models are urgently needed for the prediction of loss of life and human injuries by simulating the hydraulic conditions of the flood together with the associated risk reduction measures, including the explicit account for all other influencing factors such as reaction time, infrastructure capacity, traffic management, etc. A first step in this direction has been undertaken by JONKMAN et al. (2003). The lack of appropriate data for validation will, however, constitute a crucial bottleneck. In fact, the international flood disaster database (www.cred.be) is not appropriate for the detailed assessment of loss of life given certain flood and risk management circumstances. Although the valuation of human life is questionable from the ethical view point, the problem is often formulated in terms of the amount society is willing to pay for saving life. Values between 1 to 10 million US$, depending on considerations associated with aversion of risk, have been reported.

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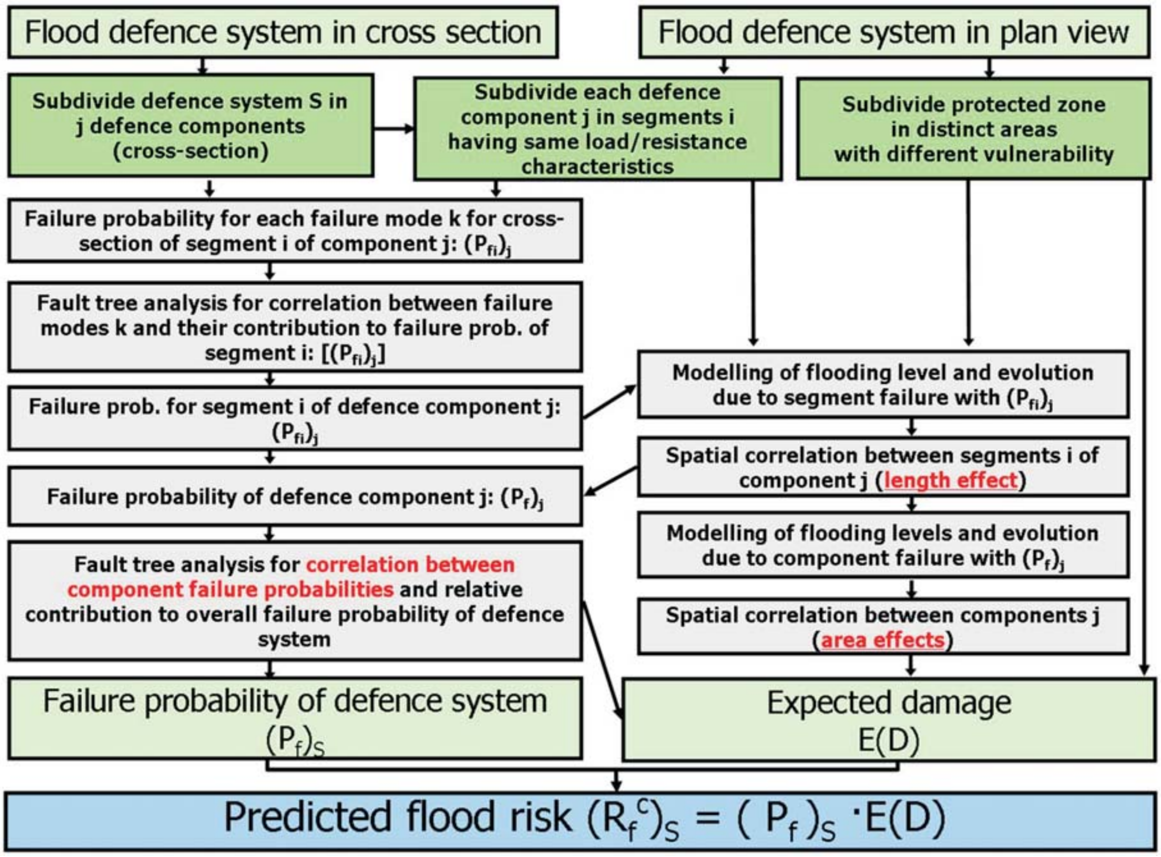

Fig. 11: Performance of entire flood system and integration methodology for flood risk prediction

Various methods to predict and to valuate intangible losses are available in the literature. A systematic review and analysis will help to derive the approaches which are most appropriate for coastal flood and the need for improvement/new development.

3.3.3 Environmental and Cultural Damages Induced by Inundation

Quantitative assessment of the damages caused by flood propagation and inundation in terms of degradation of natural resources such as ground/ground water contamination, loss of ecosystem integrity and functioning (including ecosystem services and goods such as organic matter production, nutrient cycling, physical structuring, biodiversity and loss of visual amenity). A key research challenge is the development of reliable methodologies/tools to assess the degree of degradation and the resilience of the damaged ecosystem. The damage to historic buildings and further cultural goods may also represent a substantial part of the flood damages and must therefore also be assessed.

3.3.4 Integration of Expected Flood Losses

To quantify and integrate the expected flood losses from various sources, new methodologies/techniques must be developed which are widely accepted by decision-makers, po-

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liticians and public at large. Tangible direct/indirect economic losses are generally tractable with common CBA-techniques. The key challenges are rather the methods (i) to evaluate the so-called intangible losses such as human injuries, loss of life, environmental and cultural losses, social and psychological impacts and (ii) to integrate these with the more tangible economic losses in order to get a complete overall picture of the vulnerability which is then fully quantified on a sound and transparent basis. In fact, previous experience has shown that common CBA-techniques supplemented by Utility Analysis and Life Quality Methods are often not very appropriate.

3.4 Challenges Associated with Risk Acceptance

The prime goal of the risk acceptance analysis is to assess the acceptable flood risk which may be considered as target flood risk R^t_f. This target risk and its comparison with the predicted flood risk R^c_f are required to develop an appropriate measure of the residual flood risk (Oumeraci, 2001), which can be used for design, safety assessment and decision-making on the most appropriate risk reduction measures. Due to the socio-cultural, legal, political and socio-economic dimensions of the issue, the assessment of acceptable flood risk certainly represents one of the most complex, most difficult and most important steps in any risk-based design and safety assessment. Therefore, this problem can only be solved within a coherent, transparent, adaptive and widely accepted framework for tolerable flood risk assessment. A good starting point for the development of such a framework is the so-called ALARP-concept (As Low As Reasonably Practicable) which is widely accepted across many disciplines (Fig. 12).

The key research challenges will be (Figs. 12 & 13):

1) *to define the lower and upper bound of the ALARP-zone for flood risks*. To achieve a wide consensus in accordance with the acceptable risks in other sectors (e.g. dam engineering, offshore engineering, nuclear power plants, transportation, etc.) it is indispensable that the prospective assessment methodologies and modelling tools are robust, coherent and transparent, enabling a comparison with the risk tolerated in other sectors. For this purpose, it would be useful to assess the acceptable probability of the flood hazard P^t_f and the acceptable vulnerability T(D) separately. This might also be important from the legal point of view. In fact, from the human rights perspective the responsible authorities have to reduce the vulnerability to an acceptable level, but not necessarily the flood risk.
2) *to explicitly account for risk aversion*. Weight factors have often been suggested, but more consistent methods are required to account for differences in acceptance/penalisation of certain risks as compared to others and to help achieving a better consensus on acceptable risks across many sectors and disciplines.
3) *to explicitly account for uncertainties in both components of the acceptable flood risk*. This is particularly important for high risks near the upper bound of the ALARP-zone where large uncertainties might shift the assessed acceptable risk outside the ALARP-zone (Fig. 12 right)

A tentative generic flow diagram which may also be used for the assessment of acceptable flood risks is roughly outlined in Fig. 13 to show that for the various steps, use can be made of techniques/tools already available in Cost Benefit Analysis (CBA), Reliability and Multi-Criteria Decision Theory, but also to point out that a number of further improvements and new developments are still needed.

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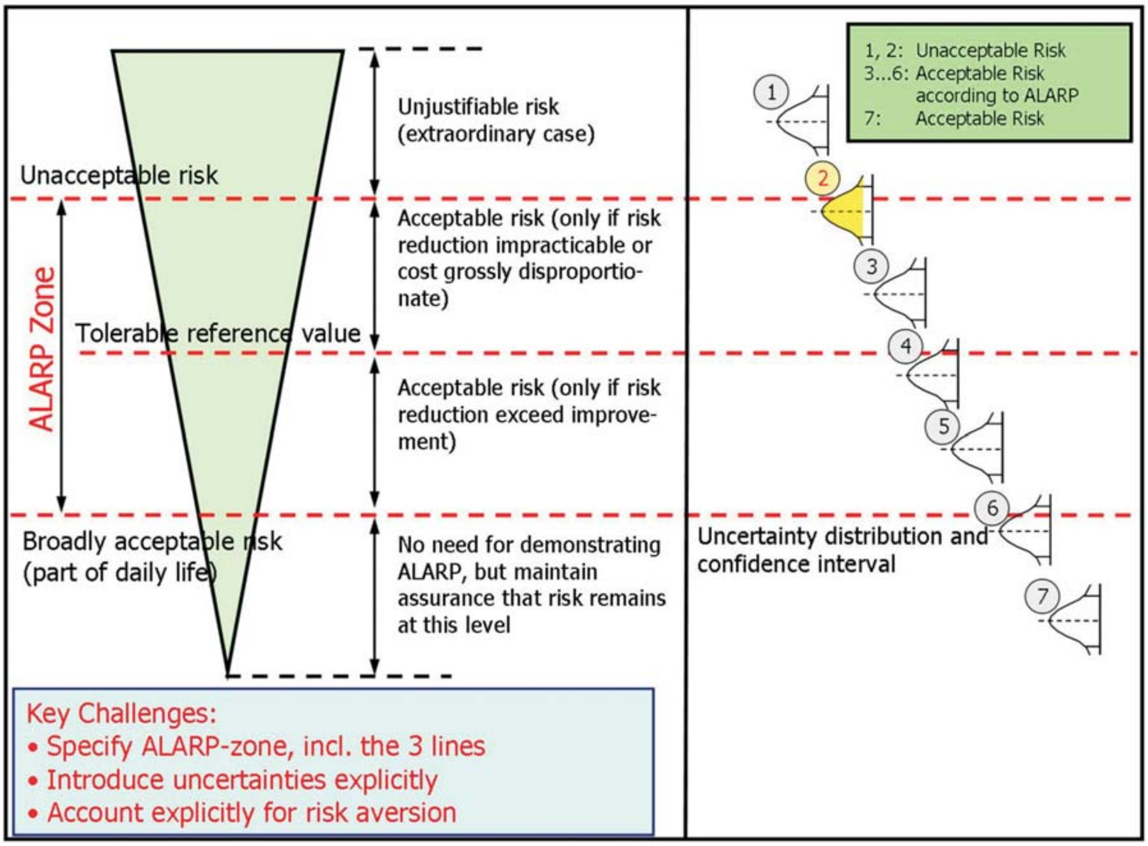

Fig. 12: Key challenge towards an advanced ALARP-concept for acceptable flood risk assessment

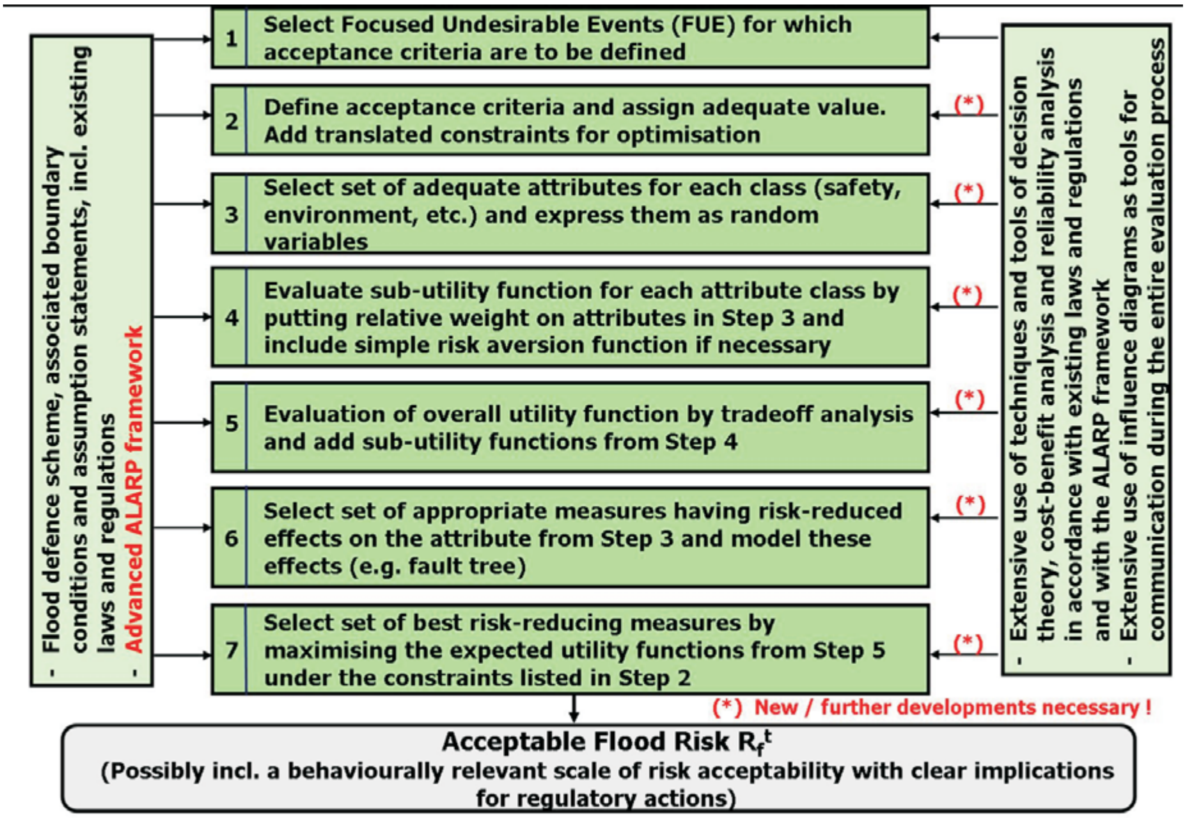

Fig. 13: Tentative flow diagram for a framework of acceptable flood risk assessment

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4. Concluding Remarks

Keeping in mind that one of the key features of the proposed PRA-based design framework is the focus on the improved understanding/modelling of the underlying processes which may lead to disastrous floods (e.g. joint probabilities of risk sources, breach initiation, breach growth, subsequent flood propagation and damages), including the explicit account of all uncertainties at every design stages, the following key research challenges may be stressed:

1) To overcome the major problems encountered in *risk source prediction* (Fig. 14), a consistent modelling strategy with proper models and uncertainty analyses is required to predict the effects of climate/geophysical/morphological interdecadal changes on the joint probability distributions of storm surge water levels and waves, including joint design extremes. For the long-term, coupling of improved climate/storm surge/wind waves/morphological models must be kept in perspective. Meanwhile, substantial improvements might be achieved by the joint run of these models in their available or improved versions. This will at least provide the physical insight needed for instance to justify/improve the extrapolation to high extremes.
2) Most of the problems associated with *risk pathway analysis* are due to the lack of consistent modelling strategies, proper models and integration methodologies. With respect to the loading issue, the modelling of wave overtopping and wave impact, including their temporal/special distribution along the defence lines represents the greatest challenge. A further challenge is the modelling of the interactions between the various failure modes

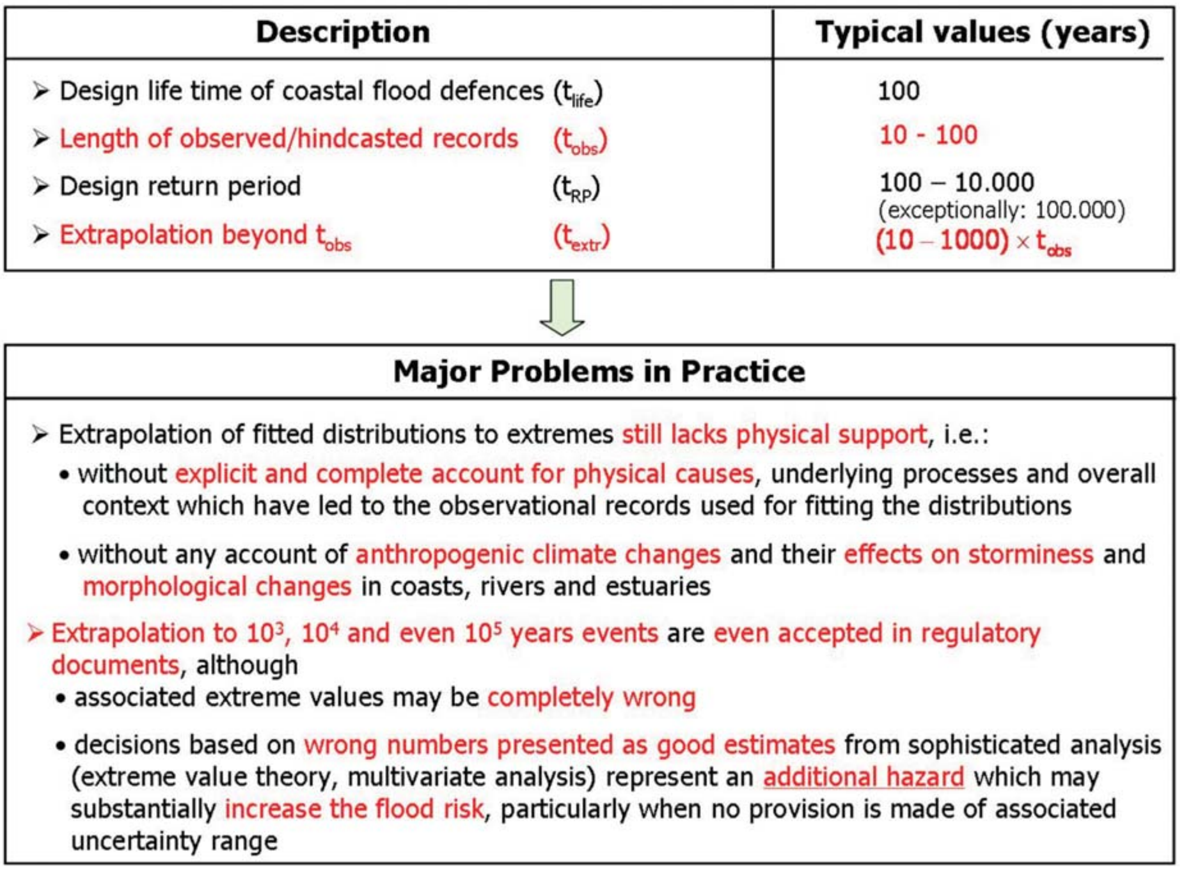

Fig. 14: Practical problems associated with risk source prediction

and of all the ways leading to breach initiation from both landward and seaward side by wave overtopping and wave impact, respectively. Generic models for the prediction of breaches, their growth and their temporal/spatial distribution along the defence components, including the effect of breach growth on flood propagation for a set of typical defence components and systems. Advanced fault trees or other alternative tools will be needed to account for the time duration, the time sequencing and the actual links of the failure mechanisms within each defence component and within more complex defence systems.

3) Most difficulties encountered in the *vulnerability analysis and risk acceptance assessment* primarily arise from the high degree of complexity and multi-disciplinarity of the various processes/issues involved. Therefore, research should be oriented towards developing consistent methods and models to predict and valuate the intangible flood losses, more coherent methodologies to integrate tangible and intangible losses, direct and indirect costs, but also a robust and transparent framework with the required modelling and analysis tools for the assessment of acceptable flood risks.

Besides all these challenges which are primarily associated with modelling and integration methodologies the greatest challenge will be to simplify as much as reasonably practicable (e.g. without loosing any important issue!), so that the prospective design and safety assessment approach will be comprehensible and affordable by practitioners and further prospective end users. Many of these challenges are expected to be met within the next five years by the recently initiated EU-Integrated Project "FLOODsite" on river, flash and coastal/estuarine flood management (SAMUELS et al, 2004), including 36 leading institutions from 13 EU-countries (www.floodsite.net). This synergetic transnational partnership and collaboration will substantially contribute to forge the transition to a more integrated design and safety assessment of flood defences, which includes risk management as an integral part of the design process and which is based on an interdisciplinary sound ground to meet the sustainability requirements.

Acknowledgements

The concept and ideas presented in this paper were developed over years during the course of the EU-Project PROVERBS (MAS3-CT95-0041) and other research projects supported by the European Community, the German Research Council (DFG) and the Federal Ministry for Science, Education, Research and Technology (BMBF/Germany). The author gratefully acknowledges these supports as well as the contributions of co-workers and other partners to these research projects.

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Risk is of all Time

BEN J. M. ALE

Summary

Risk is everywhere and always has been. Although these risks seem new, industrial risk, environmental risk and health risk have been around since the origin of mankind. Men always have been trying to minimise these risk and manage them where possible. The risks of modern technological society can be managed with the means this society has developed. But today just as always the decision to reduce risk is political. Risk reduction policies are difficult to maintain over prolonged periods of time. This holds especially for high consequence low probability events. The absence of occurrences over long periods of time reinforces the illusion that these events are impossible and will not happen. Until disaster strikes again!

Zusammenfassung

Risiko ist, und war immer, allgegenwärtig. Obwohl diese Risiken neu erscheinen, existieren industrielle, Umwelt- und Gesundheitsrisiken seit Anfang der Menschheit. Der Mensch hat immer versucht, diese Risiken zu minimieren und managen wo immer möglich. Mit den Risiken der modernen technologischen Gesellschaft kann mit den entwickelten Verfahren umgegangen werden. Heute wie in der Vergangenheit ist die Entscheidung zur Risikominimierung eine politische. Strategien zur Risikominimierung sind schwer über längere Zeiträume zu handhaben. Dies trifft insbesondere zu für sehr folgenschwere aber nur sehr seltene Ereignisse. Das Ausbleiben von solchen Ereignissen über längere Zeiträume stärkt die Illusion, dass sie nicht möglich sind und nicht eintreten werden. Bis zur nächsten Katastrophe!

Keywords

Risk, risk management, risk perception, bowtie models

Contents

1. Introduction

It is said that the present society is a risk society (BECK, 1986). And indeed some risks are new. And because of the global connectivity of our societies, many risks are shared by all. That does not take away though, that may ancient risks have had a similar standing in the society in which they where dominant. They formed a threat to the whole – known – world and all – known – societies were exposed.

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Between 1347 and 1350 the plague or the Black Death wiped out one third of the population of Europe (CENTRAAL BUREAU VOOR DE STATISTIEK, 2004). In the 17th century the average life expectancy was 25 years and to become 45 was an exception.

Also what now is called industrial risk has roots in the early centuries. Already Plinius described illnesses among slaves (RAMAZZINI, 1700). In 1472 Dr U. Ellenbog from Augsburg wrote an eight page note on the hazards of silver, mercury and vapours of lead (ROSEN, 1976). Ailments of the lungs found in miners were described extensively by Georg Bauer (AGRICOLA, 1556). In the seventeenth century a significant part of the crew of ships sailing the East and West Indies never made it home. As recent as 1918 the Spanish flue killed 170,000 people in the Netherlands alone.

The Netherlands has a long history of having to deal with the threat of floods. In the middle ages several groups, such as Hugenotes and Jews, fled to the Netherlands because they were oppressed by their government. These people literally stepped down from the Central European Plane into the Low Lands, the swamp that is the Netherlands. The only authorities that were accepted for a long time were the „waterboards". These were deemed necessary to manage the flood defences. The oldest waterboards were those of Schieland (1273), Rijnland (1286), and Delfland (1319). Now with 478 people per km2 one of the densest populated area's in the world and housing a harbour of Rotterdam, Schiphol Airport and a third of the refinery capacity of Europe managing the risks of resulting from the close proximity of people and industry has become just as important an activity as managing the risks of flooding.

Attempts to avoid unnecessary risk also has been part of human activities from as long as history is written. Those who had something to loose surrounded themselves and their possessions with walls, castles, guards and armies. If you had enough money you went outside of the city to escape the plague. And societies have put people into power in order to protect them from a long time ago.

This does not take away that worldwide and in absolute numbers the number of disasters and the associated costs increase. At the same time the population of the earth increases, suggesting that people more and more live in less and less suitable locations (OECD, 2003).

This raises the question why risk management looks so different today and why we have so much difficulty getting to an organised policy on risk, whether we are in public office, in government or in private enterprise. For this we first look at the evolution of risk especially in the 20th century. We look at the development of risk perception research and findings and then we look at methodologies to understand the genesis of accidents and strategies to eliminate them or reduce the probability.

2. Industrial risk

In the Netherlands some large scale accidents with explosives materials occurred as well. In 1654 the centre of Delft was demolished by the explosion of a powder tower. This explosion, which could be heard 80 km away, created the "horse market", which still exists as an open space (Fig. 1).

In 1807 a similar explosion took place. Now a barge laden with black powder exploded in the centre of Leiden. The van der Werf park today is still witness of this event. 150 people were killed among who 50 children, whose school was demolished by the blast. This explosion led to an imperial decree by Napoleon. The emperor stated that from then on a permit was needed for having an industrial facility. Three classes of industry were designated:

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Fig. 1: The big thunder of Delft in 1654

- Industries that were considered too dangerous to be inside a city. The authorities would indicate a location.
- Industries for which location inside a city could be considered if it could be demonstrated that there was no danger for the community.
- Industries that always could be located inside city limits.

In addition Napoleon stated that objections of future neighbours should be noted and addressed by the authority that made a decision. As the explosion in Leiden involved a ship, similar measures were taken with regards to the transportation of explosives and other dangerous materials. Interestingly the safety regulations in France can be traced back to the same imperial decree.

3. Risk management

The origin of modern risk management lies in the industrial accidents after World War II. In 1966 a fire in a storage facility for LPG in Feyzin, France killed 18 and wounded 81. This accident led to re-emphasis on design rules for bottom valves on pressure vessels. In the realm of physical planning no actions from the French or the European authorities seemed to have resulted from that accident.

Ten years later a number of similar accidents occurred: Flixborough (1974, 28 dead), Beek (1975, 14 dead) and Los Alfaques (1978, 216 dead). These accidents showed that the Feyzin accident was not a unique freak accident. Apparently LPG and other flammable substances could pose a serious threat to the workforce and to the surroundings.

In 1979 Prime-Minister van Agt, just as his predecessors, wrote a letter to parliament about the development of environmental policies as integral part of the nation's policies. In

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Tab. 1: Zoning around LP G station

Distance to tank and/or fillingpoint (m)	Allowed building	
	Houses	Offices
0 – 25	none	none
25 – 50	max 2	max 10 people
50 – 100	max 8	max 30 people
100 – 150	max 15	max 60 people
> 150	no limit	no limit

this letter he introduced "External Safety" as separate from occupational safety. The Prime-Minister introduced and announced three elements of a new policy:

- appointment of the minister of environment as co-ordinator for hazardous materials,
- founding of a new separate policy body dealing with external safety, and
- announcement of new legislation covering external safety.

At the same time a major change in the energy market appeared imminent. This among other lead to a major market push for LPG as motor fuel. In 1978 a tank car exploded in a tank station. Although nobody was hurt in this accident, it became apparent that the population around the stations should be limited. The chief inspector for the environment decided not to wait for legislation. He issued an instruction for his inspectors to not approve a permit unless the conditions for distances and population densities as indicated in the Table 1 were satisfied (HIMH, 1981). This was the first explicit zoning measure around a hazardous activity.

A further potential increase in the transport of LPG through the Netherlands resulted from the desire to use LPG as feedstock for the production of ethylene. A committee was charged with developing a policy. A study was commissioned into the safety of the whole chain from import to final use. It became apparent that a policy aimed at insuring that no accident ever would harm the population would not be compatible with the limited space in the Netherlands. The committee decided that there should be a level of risk below which it is neither desirable nor economical to strive for further reduction. This statement implied that the level of risk should be established and that acceptability limits should be set.

At the same time authorities in the Rijnmond area started to be worried about the safety of the population around the large petro-chemical complexes in the area. Taking the Canvey Island study as an example (HSE CANVEY, 1978; HSE CANVEY, 1981), the Rijnmond authority embarked on a study to establish whether quantification of risk was feasible and would give results that would be useful in decision-making. The results (CREMER and WARNER, 1981) were promising with regards to the usefulness of the results. The quantification of risk as a routine exercise was judged not to be feasible unless information technology could be used to take away the burden of the many complicated calculations and reduce the time needed.

The Rijnmond Authority together with the ministry of environment embarked on the venture towards an automated method for quantification of risk. Now, twenty plus years later the process still is not fully automated. Such a level of automation no longer is desired either. But the techniques developed since together with the rapid development of computational capability has lead to workable systems with reasonable return times.

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3.1 Risk matrices

The division of risk in three bands introduced by Napoleon can be found back in the risk matrices that are used frequently to support and structure decision making (Fig. 2). In these matrices the two dimensions of risk: probability and consequences are separated out and plotted against each other. Any combination of consequence and probability is a point in this two dimensional space. Alternatively the risk profile of any activity can be plotted as a so-called complementary cumulative distribution curve (CCDC). In such a curve the probability of exceeding certain consequences are given as a function of these consequences.

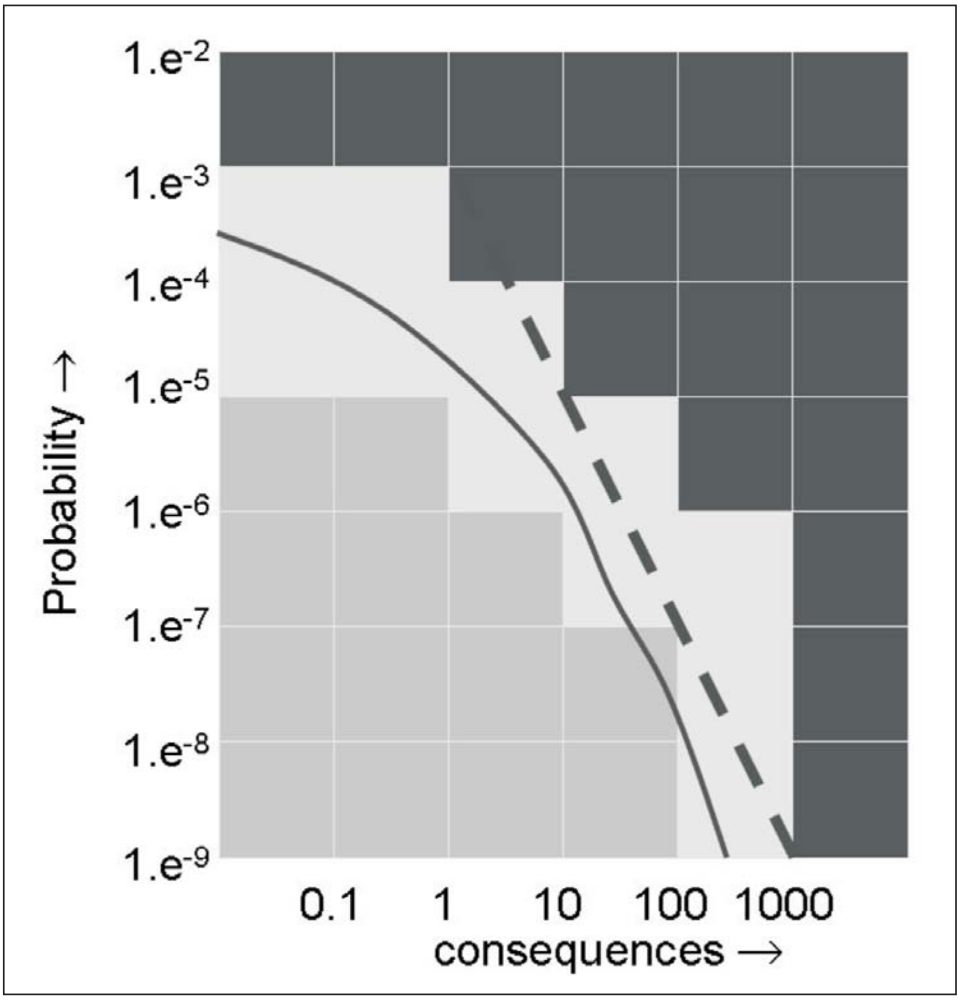

Fig. 2: Risk matrix

The plot area can be divided into three areas: acceptable, conditionally acceptable and unacceptable. Whenever the risk is not in the acceptable area measures have to be taken or at last contemplated. Of particular interest is the region in the lower right hand corner of the matrix where those risks are located of which the consequences cannot be borne. These risks have to be transferred e.g. by insurance, or have to be eliminated – regardless how low the probability - as the consequences would lead to ruin.

In practice any consequence proves to be acceptable when the probability is sufficiently remote and the advantages to be gained by embarking the risky activity are sufficiently large.

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Therefore the red or unacceptable area is seldom demarcated by a vertical line. Rather the limit is some sort of sloping line as depicted by the dotted line in the figure.

The use of risk matrices is not restricted any more to the chemical industry. Many applications are found in finance and insurance industries (MACARTHY et al., 2004).

3.2 Criteria

Having decided that risk quantification is the way to go the inseparable counterpart had to be developed as well. Questions to be answered included were what to do with the results, and how to make sure the analyses would actually be made and used in decision making. Regional and local authorities as well as industry asked for guidance regarding the acceptability of risk. The bases for this guidance was found in documents and decisions taken earlier.

An important base line was found in decisions made regarding the sea defences of the Netherlands. In 1953 a large part of the south west of the Netherlands was flooded as a result of a combination of heavy storms, high tides and insufficient strength and maintenance of the diking system. Almost two thousand people lost their lives and the material damage was enormous especially because the Netherlands was still recovering from World War II. The Netherlands embarked on a project to strengthen the sea defences, including a drastic shortening of the coastline by damming off all but one of the major estuaries of the Rhine/Maas delta. The design criteria were determined on the basis of a proposal of the so-called "Delta Committee" who proposed that the dikes should be so high that the sea would only reach the top once every 10,000 years (DELTA COMMISSIE, 1960). The probability of the dike collapsing is a factor of 10 lower. The probability of drowning is another factor of 10 lower, so that the recommendation of the Delta Committee implies an individual risk of drowning in the areas at risk of 1 in a million per year. This recommendation was subsequently converted into law.

This value of risk was reaffirmed when a decision had to be taken about the construction of the closure of the Oosterschelde estuary. For reasons of preserving the ecosystems the design was changed from a closed solid dam, to a movable barrier. This barrier should give the same protection as the dams. In this manner Dutch parliament had a history of debating safety in terms of probabilistic expectations, which came in handy when industrial risk had to be discussed.

The value of 1 in a million per year corresponds to about 1 % of the probability of being killed on the road in the mid 80-ties. This became the maximum acceptable addition to the risk of death for any individual resulting from industrial accidents.

For societal risk the anchor point was found in the "interim viewpoint" regarding LPG points of sale mentioned above. When combined with value already chosen for individual risk this led to the point 10 people killed at a frequency of 1 in 100,000 per year. As societal risk usually is depicted as an FN curve having the frequency of exceeding N victims as a function of N, the limit had to be given the same form. Thus the slope of the limit line had to be determined. It was decided to incorporate the apparent aversion against large disasters in de the national limit by having the slope steeper than –1. Several values circulated in literature at the time, ranging from –1.2 to –2 (FARMER, 1967; MELEIS and ERDMAN, 1972; TURKENBURG, 1974; WILSON, 1975, OKRENT, 1981; RABASH, 1985; SMETS, 1985; HUBERT et al., 1990). In the end it was decided to adopt a slope of –2 for the limit line. In order to bind the decision space at the lower end of the risk spectrum limits of negligibility were set for individual risk and societal risk alike at 1% of value of the acceptability limit. The

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resulting complex of limit values was laid down in a policy document called "premises for risk management".

The accident in Bhopal, where some 3000 people were killed as a result of a release of methyl isocyanate, helped to promote the adoption of European legislation. The SEVESO directive, named after a small village in Italy where dioxine was relaesed in an accident, became the vehicle to implement these policies into law in the Netherlands just as in many other members of the EU. The "Hazards of Major Accidents Decree" demanded that top tier establishments would submit a safety report, in which a quantified risk analysis performed according to the set standards, would be presented. This information then subsequently could be used by local planners for zoning decision and by the emergency services for disaster abatement planning.

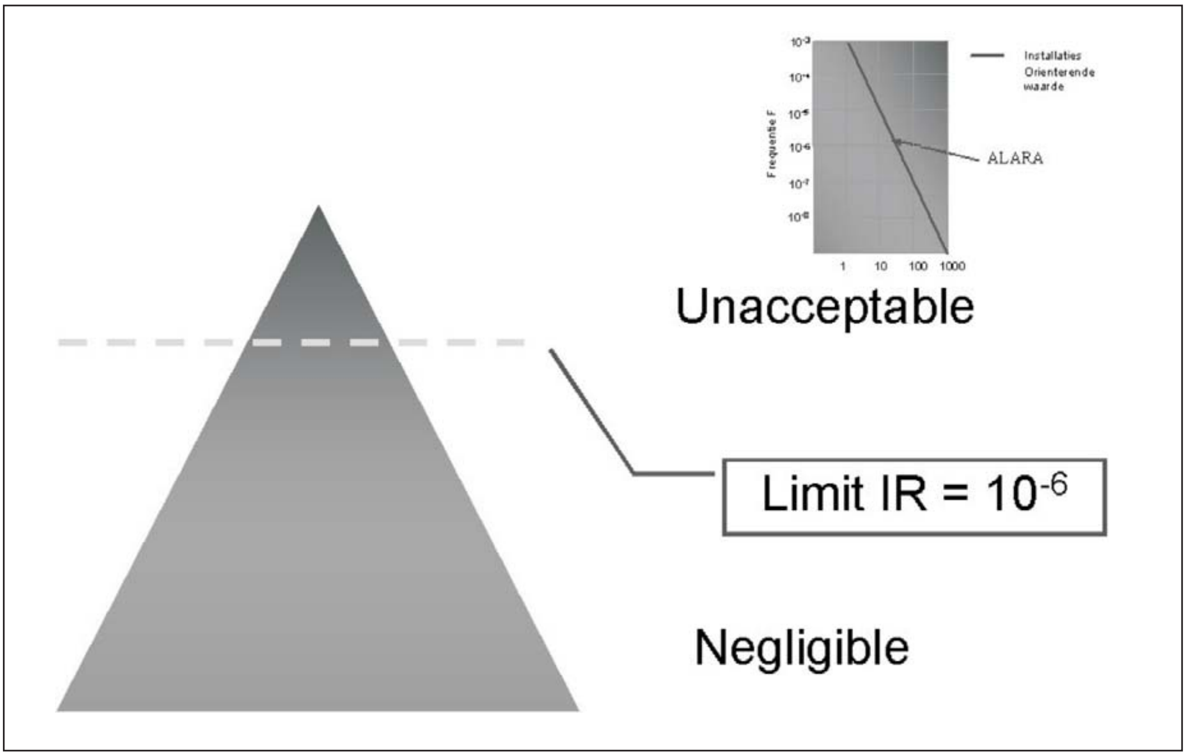

Fig. 3: Risk triangle and criteria

On 13 may 2000 an explosion occurred in a fireworks storage and trading facility in Enschede, the Netherlands. Twenty-two people were killed and some 900 injured. The material damage was approximately 400 MEuro. This lead to a further re-enforcement of the policy in the Decree on External Safety of Establishments (BEVI), in which the risk limits were again specified (Fig. 3).

4. Perception

A major factor influencing the people's reaction to potentially hazardous activities is what generally is described as risk perception.

In part these perceptions are driven by the way, by which information is processed by our brain. One of the features is that information that strengthens existing ideas is more rea-

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dily absorbed than information to the contrary. In Table 2 the mortality of various activities is given. The numbers are applicable for the Netherlands. From the table it can be seen that the probability of any Dutchman to be killed by an accident in a chemical plant not being an employee is 6 orders of magnitude smaller than the probability of dying of a smoking induced illness (if he or she is a smoker).

Tab. 2: Probabilities of death and probabilities of winning lotteries

Activity	Winning a lottery	Probabilty (/yr)
Smoking		$5*10^{-3}$
Traffic		$8*10^{-5}$
Lightning		$5*10^{-7}$
Bee-Sting		$2*10^{-7}$
Flood		$1*10^{-7}$
	Staatsloterij	$1*10^{-7}$
	Bankgiroloterij	$4*10^{-8}$
	Lotto	$2*10^{-8}$
Falling Aircraft		$2*10^{-8}$
	Postcodeloterij	$1*10^{-8}$
Chemical Industry		$6*10^{-9}$
	Sponsorloterij	$3*10^{-12}$

On the basis of these numbers a decision maker has a fair point when assuming that the probability of him being confronted with a disaster in the chemical industry is remote and hardly probable. Especially when one notes that the present Netherlands are only some 200 years old

In the table also the probabilities are given of winning the main prize for five of the nation's lotteries. One can see that winning the „sponsorlottery" is three orders of magnitude smaller than being the victim of a chemical accident. Nevertheless these lottery tickets are readily sold and there regularly is a winner. Apparently the probability of winning this lottery is considered by many remote but possible, or even probable. This difference in appreciation of the numerical information is closely related to the psycho-social theories of risk perception. According go these theories there are many factors shaping the perception of risky activities (VLEK, 1996; SLOVIC, 1999; SJOBERG, 2000). The top 10 of the most listed are:

- Extent and probability of damage
- Catastrophic potential
- Involuntariness
- Non-equity
- Uncontrollability
- Lack of confidence
- New technology
- Non-clarity about advantages
- Familiarity with the victims
- Harmful intent

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Combining these factors with the mortality discussed above reinforces that people are more willing to accept a certain small loss than an uncertain large loss. And because the probability of a large disaster is small, long periods of time may elapse after one disaster before another strike. In this period the notion that improbable equals impossible is steadily reinforced and thus the impetus that exists shortly after a disaster to do something about it disappears.

As the factors that influence the judgement of a risky activity are different for differing activities it cannot be expected that a single set of risk criteria is applicable to all activities. Nevertheless a policy may look more organized as the set of applicable criteria is small.

On the other hand it is argued that these factors make it impossible to set general standards, as every situation and every activity is different. In a more extreme stance it is argued that risk is a social construct rather than something that in principle can be determined scientifically. In this view there are so many subjective choices made in risk analyses that they cannot be called objective science at all (van Asselt, 2000). Scientists are just other lay-people. There judgement is influenced by the same factors, but in addition they let their science influence by their political judgements. It is no surprises that the more objectivist risk analysts argue that scientific judgements and political judgements are not the same thing and that objective quantification of risk is a scientific exercise. Indeed such objectivity is necessary to make cost benefit based decisions. In such argumentation the value of the risk should be as objective as the – monetary – value of potential risk reducing measures (Tengs et al., 1995).

Any policy should conform to general principles of justice and democracy, be it setting a speed limit or a limit on risk. The results should be predictable for the stakeholders and for the public and execution should be measurable against objective standards. This holds even when arguments are formulated in more qualitative terms such as “As Low As Reasonably Achievable” or “gross disproportionality”. It should always be borne in mind that any stakeholder in any regulatory system can resort to getting a dispute settled in court.

How valid the arguments may be, they nevertheless are of great help to stakeholders that have no interest in having risks limited by a government policy in the short run. And as the last accident disappears in past history the pressure to be firm on risk dissolves.

4.1 Bow-ties

Whenever a strategy or policy is defined that asks for reduction of risk, an analysis has to be made of what would be the optimal place to interfere with the causal chain from cause to accident and consequences in order to obtain the desired reduction. Bowtie models are tools for integrating broad classes of cause-consequence models. The familiar fault and tree-event tree models are ‘bowtied’ in this way; indeed, attaching the fault tree’s ‘top event’ with the event tree’s ‘initiating event’ originally suggested the bowtie metaphor. The bowtie may be conceived as a ‘lens’ for focusing on causal chains and ‘projecting’ these onto the space of consequences. These consequences will ultimately be factored into decision problems for risk management. Hence the bowtie’s consequence side forms an interface with the decision models. Decisions taken will reflect backwards to causes. This structure not only has proven a worthwhile concept in accident prediction, it also has proven its worth in analysing past accidents and suggesting improvements to prevent further re-occurrence (Groeneweg, 1998) (Fig. 4).

The selection of the centre of the bow-tie is crucial for the analysis. Any event can be

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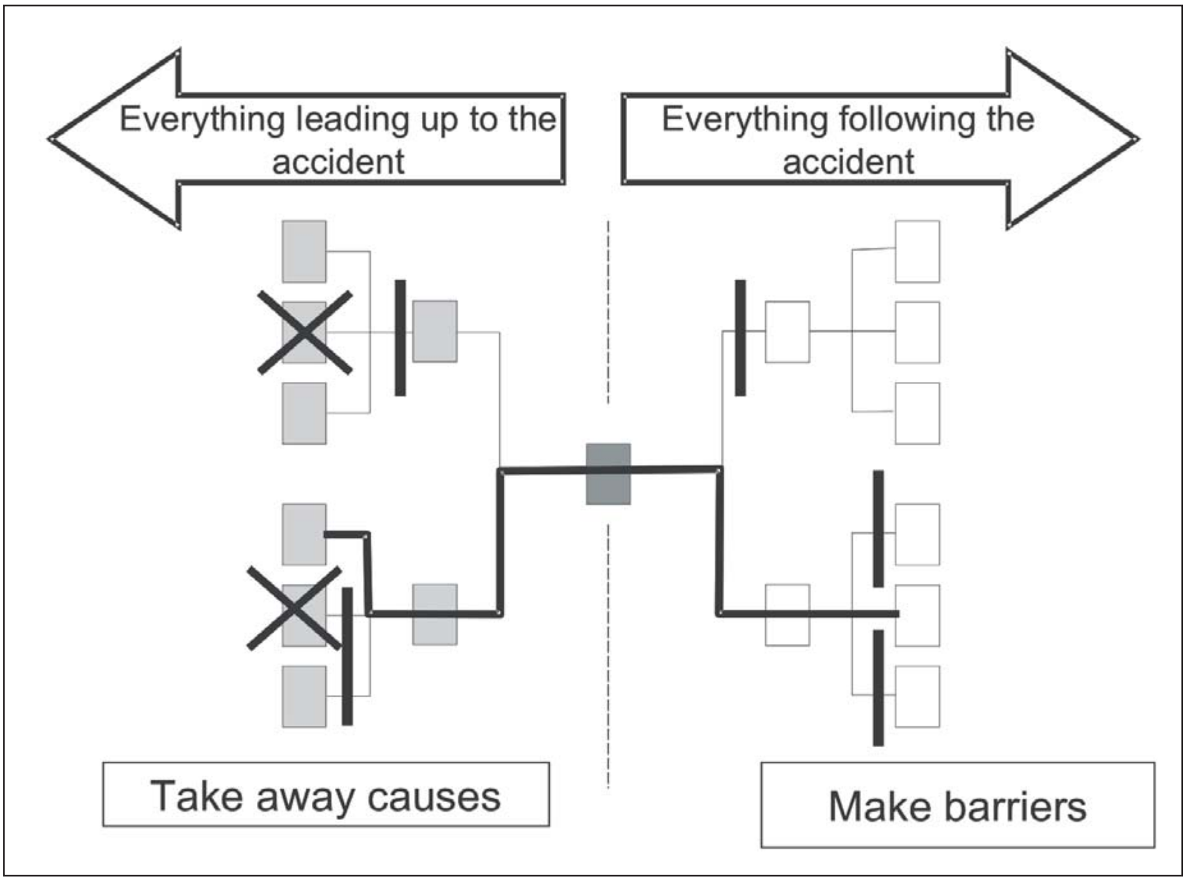

Fig. 4: Bow-tie and Murphy's law

taken as this centre. The causes and consequences of this event form the bow-tie and form a slice out of all the things that happen in this world.. Any event can be considered a cause and any event can be considered a consequence. Events can therefore serve as causes and as consequences in many bow-ties, each with its own centre. However: once the centre is chosen, no other events will be visible in the bow-tie than those which are in the causal chains running through the centre.

This could raise some interesting questions. What has to be considered as the centre event of a – lethal – accident of a parachute jumper. The moment that his parachute did not open, the moment that his parachute was packed in the wrong way or the moment that the reserve parachute failed to open. Any of these three approaches leads to a valid bow-tie, and to a valid quantification of his risk of falling, but the analysis will be much more detailed on some aspects and much less detailed on others depending on the choice of the centre event. As a result the options for remedial action will be different.

4.2 Events as barriers

When the a certain consequence is deemed unacceptable or when the probability of a certain outcome is deemed too high, measures have to be taken to either take away the causes or block the progression from cause to accident. The classical way of presenting this and handling this in a mathematical way is to combine the path originating from a cause with

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a path from a safeguard into an „AND“-gate, which means that the cause and the failure of the safeguard have to occur simultaneously to result in the consequence. This concept however proved to be difficult to grasp for decision makers. Therefore these safeguards are often depicted as barriers in the path from cause to consequence (Figure 5), an idea originally developed by Haddon, who introduced the barrier concept in 1973 (HADDON, 1973). The number of barriers in the path then could form the basis for a layer of protection analysis (LOPA). In any case this way of presenting layers of protection proves to be helpful for decisionmakers. When in an analysis a path is detected that does not have any barriers in it, it constitutes a – latent – deficiency in the system that according to Murphy‘s law will sooner or later lead to ruin.

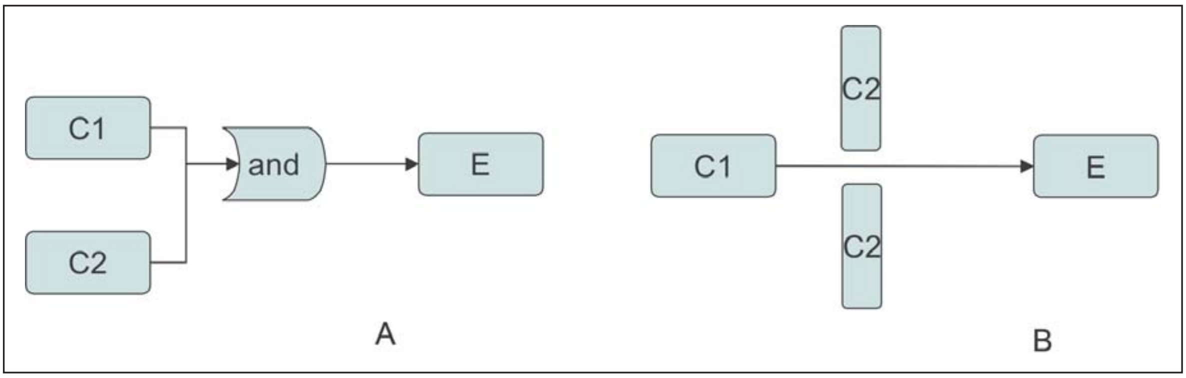

Fig. 5: And-gate representation (A) and barrier representation (B) of the same causal configuration

5. Concluding remarks

Modern times are not necessarily more risky than earlier times. There have been many threats to humanity that indeed wiped out significant portions of the known population. Life expectancy has not been as high as it is today, at least in the „first“ world. There are some new risks and may be contrary to historic times it is now known for sure that the known world is all the world there is. But the historic people thought the same.

All over history it has been difficult to maintain risk containment or risk management strategies for prolonged periods of time. For low probability large consequence type risks this is to a significant extent inherent to the way the human brain processes information. Every day a disaster does not happen the idea gets reinforced that it cannot happen at all.

Nevertheless there are many good methods to systematically deal with risks and many are part of the policy of governments. Due to the dense population and the intensive use of space in the Netherlands, the Dutch authorities have an advanced position in governmental risk management, which combines the sue of quantitative analytical methods with set criteria and rules for justifying risk taking by authorities.

Risk analysts have a role to play in the discussion about risks. They are in a position to point out that the absence so far of an accident does not mean its impossibility. And they should do so in the interest of the innocent bystanders, who are the people of who the lives, health and property are at stake.

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