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

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

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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

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.

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.

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.

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 Kingdom (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

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

European Union: Recommendation of the European Parliament and of the Council concerning the implementation of Integrated Coastal Zone Management in Europe (2002/413/EC). Official Journal of the European Communities, 2002.

Office of Science and Technology (Ed.): Foresight. Future Flooding. Executive Summary. www.foresight.gov.uk, London, 2004.

Penning-rowsell, E., Johnson, C., Tunstall, S., Tapsell, S., Morris, J., Chatterton, J., Coker, A. and Green, C.: The benefits of flood and coastal defence: techniques and data for 2003. Flood Hazard Research Centre, Middlesex University, 2003.

Wet Op De Waterkering. Staatsblad van het Koninkrijk der Nederlanden, 1996, 8.

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.

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

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

	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

	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 m²) with high accuracy and topographical ter-restrial survey of significant breaklines
	Scale of data	micro		3p/10 m2	micro

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

IV Receptors, consequences of flooding		Ribe	Lincolnshire	Vlaanderen	Langeoog
Data	**Sources**	Bygnings- og Boligregistret, Flood Compensation Council, Danish Centre of Agricultural Research, Kort & Matrikel-styrelsen, Central Livestock register, Statistics Denmark		land use maps (20x20 m)	Resident register Langeoog, Business interviews, Field work, Tourism cata-log Langeoog, ALK (=Automatisierte Liegen-schaftskarte), Valuation guide-lines for buildings 2000, Insur-ance Companies, Municipality based motor vehicle specifica-tion, Internet / market analyse of used cars, Internal munici-pality investment specification, Advi-sory 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.