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Blum, Holger; Thorenz, Frank

Risk Assessment for the Island of Langeoog - COMRISK Subproject 9

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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

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 km^2; 7.7 km^2 are protected against storm surges by a ring of dunes and dikes. The village of Langeoog has an extent of 1.5 km^2 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.

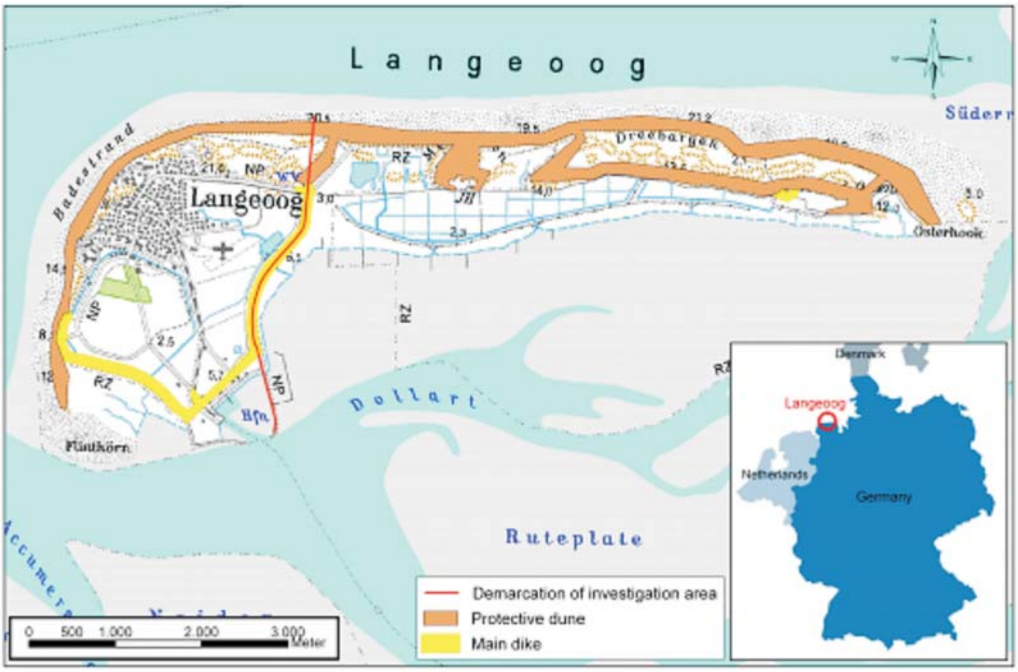

Fig. 1: Langeoog overview – Topographic map 1:50000

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

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

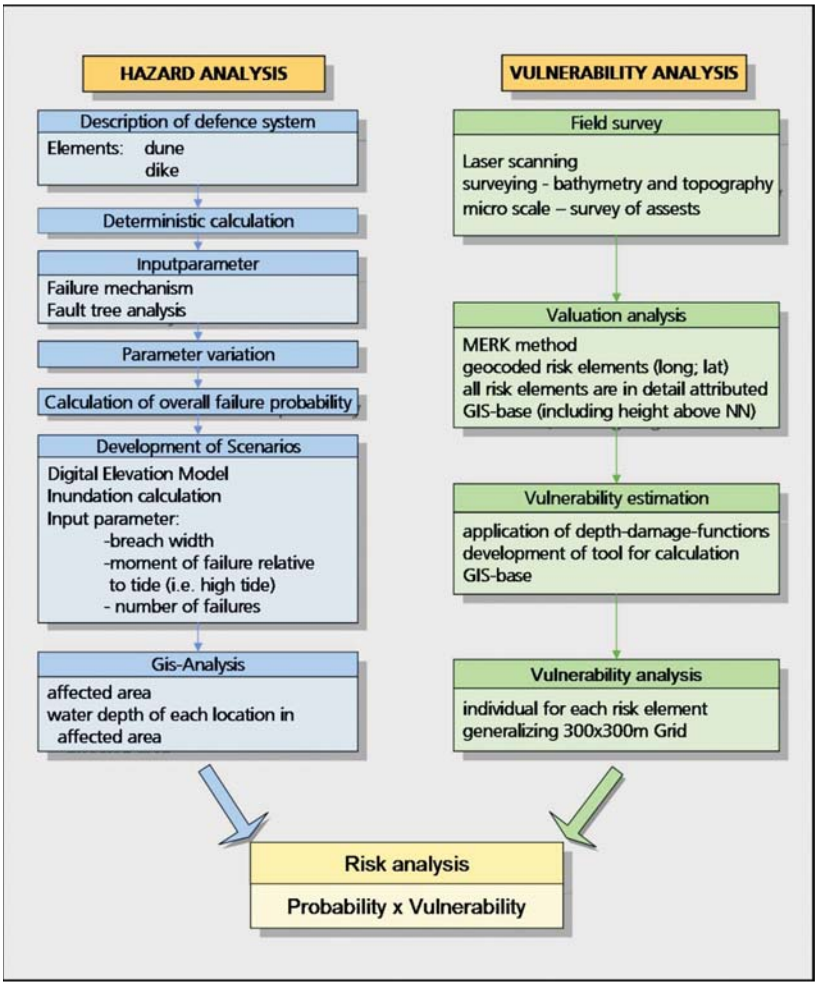

Fig. 2: Flow diagram risk analysis

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

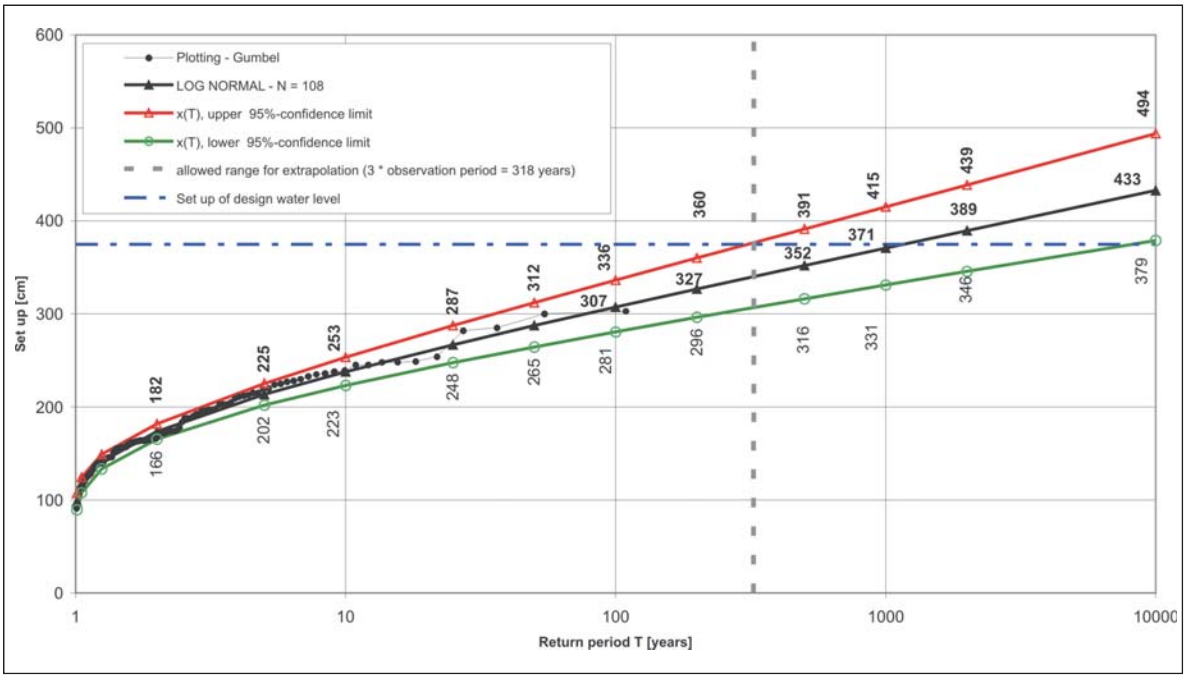

Fig. 3: Extrapolation of set up based on Log-Normal distribution

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

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”

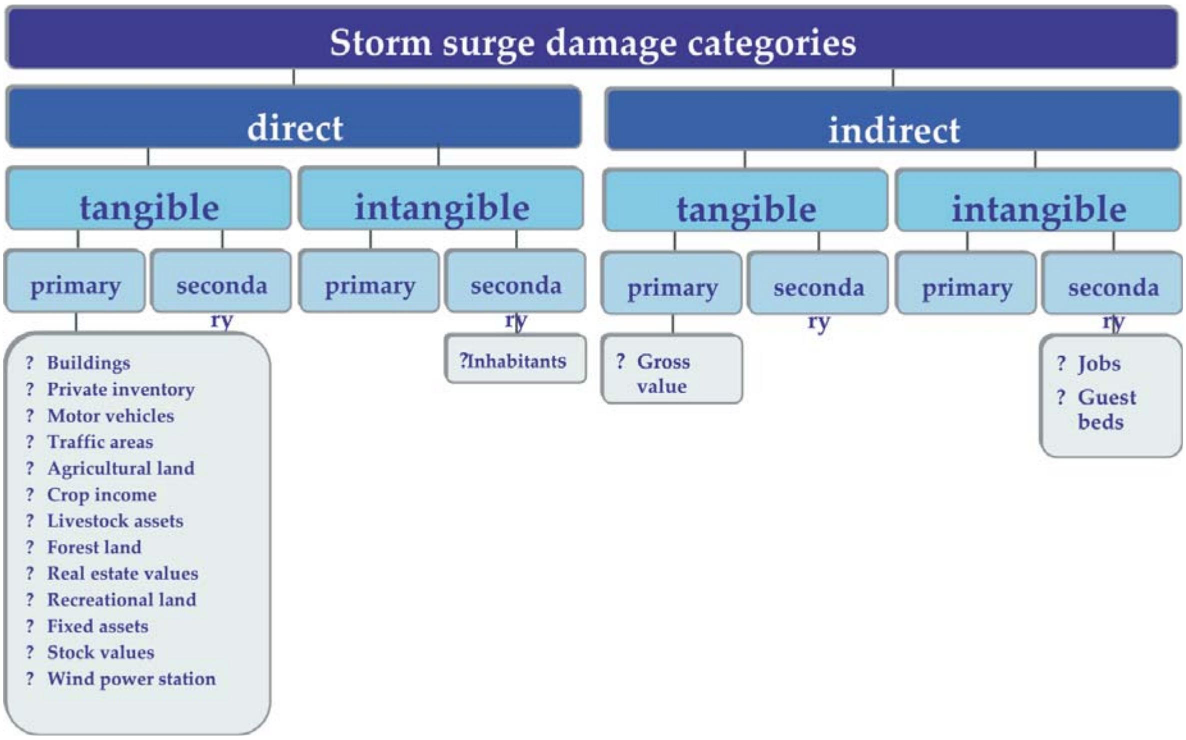

Fig. 4: Damage categories of the valuation analysis (from: UNIVERSITY OF KIEL 2004)

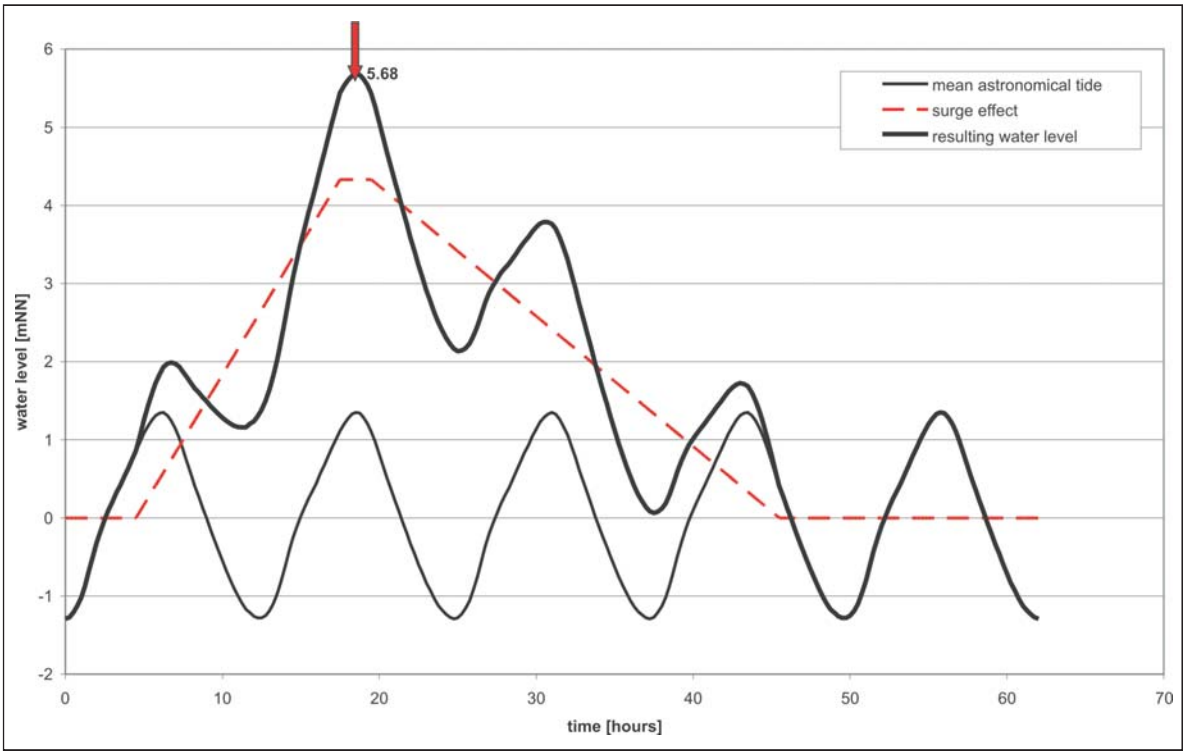

Fig. 5: Hydrograph of the storm surge at Langeoog

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.

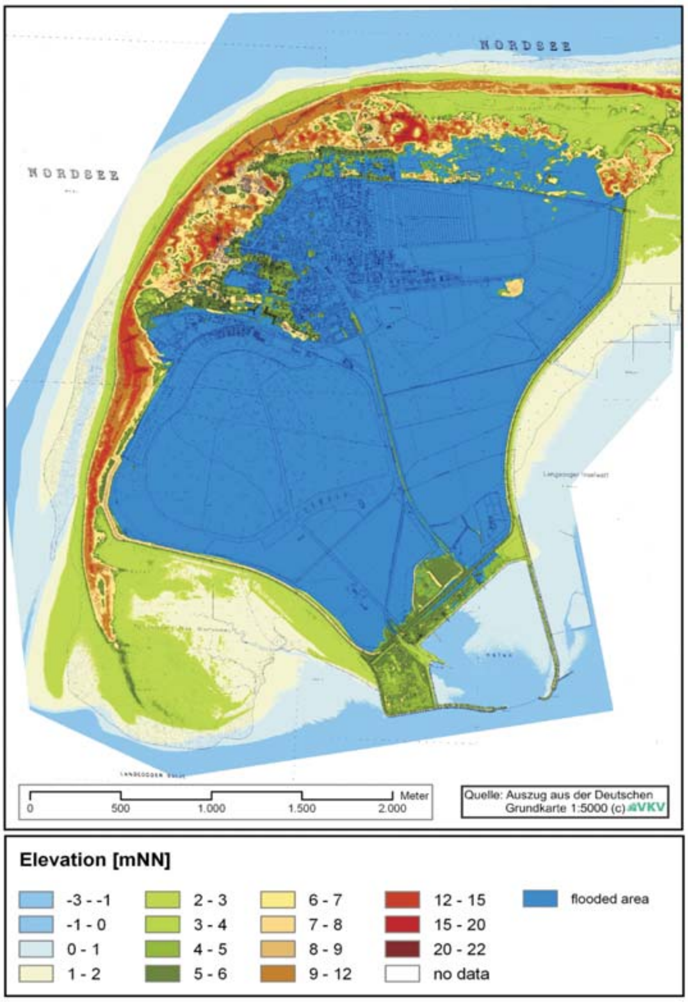

Fig. 6: Flooded area scenario "Hafendeich"

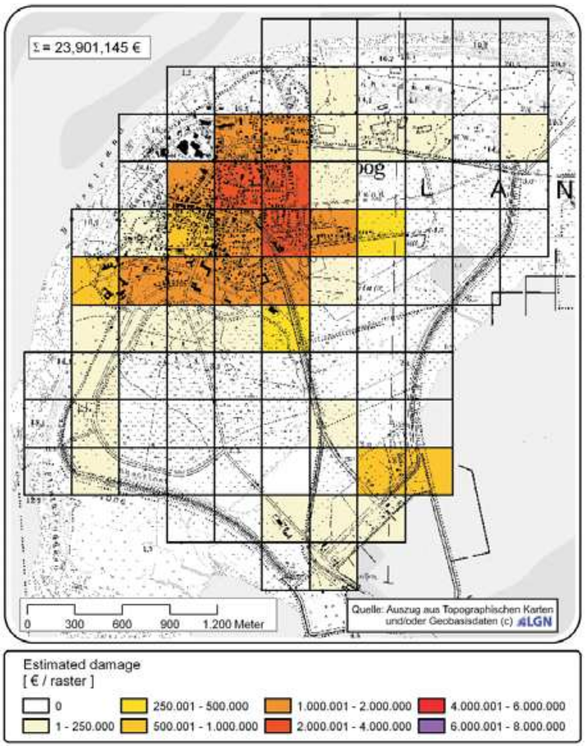

Fig. 7: Damage to buildings (“Hafendeich”)

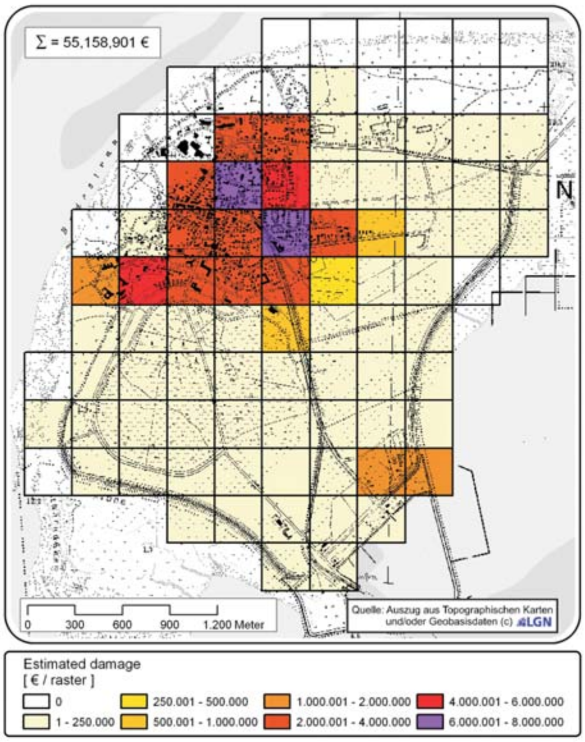

Fig. 8: Total estimated damage (“Hafendeich”)

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

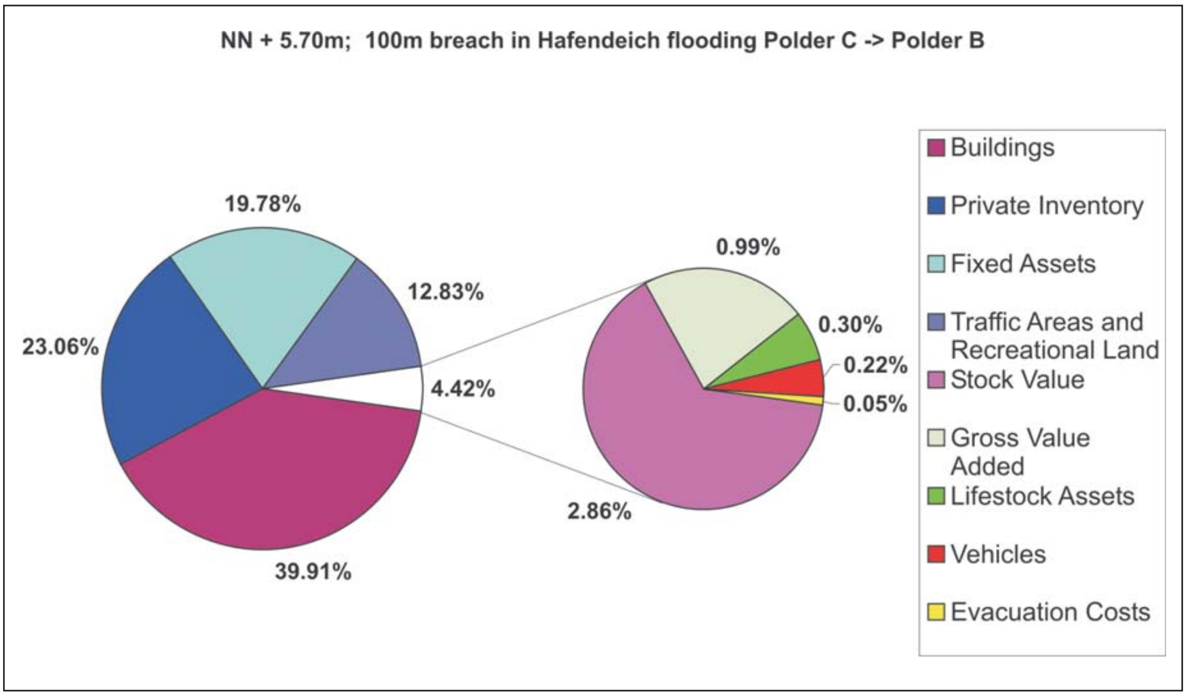

Fig. 9: Ratio of damage categories to total damage in scenario "Hafendeich"

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

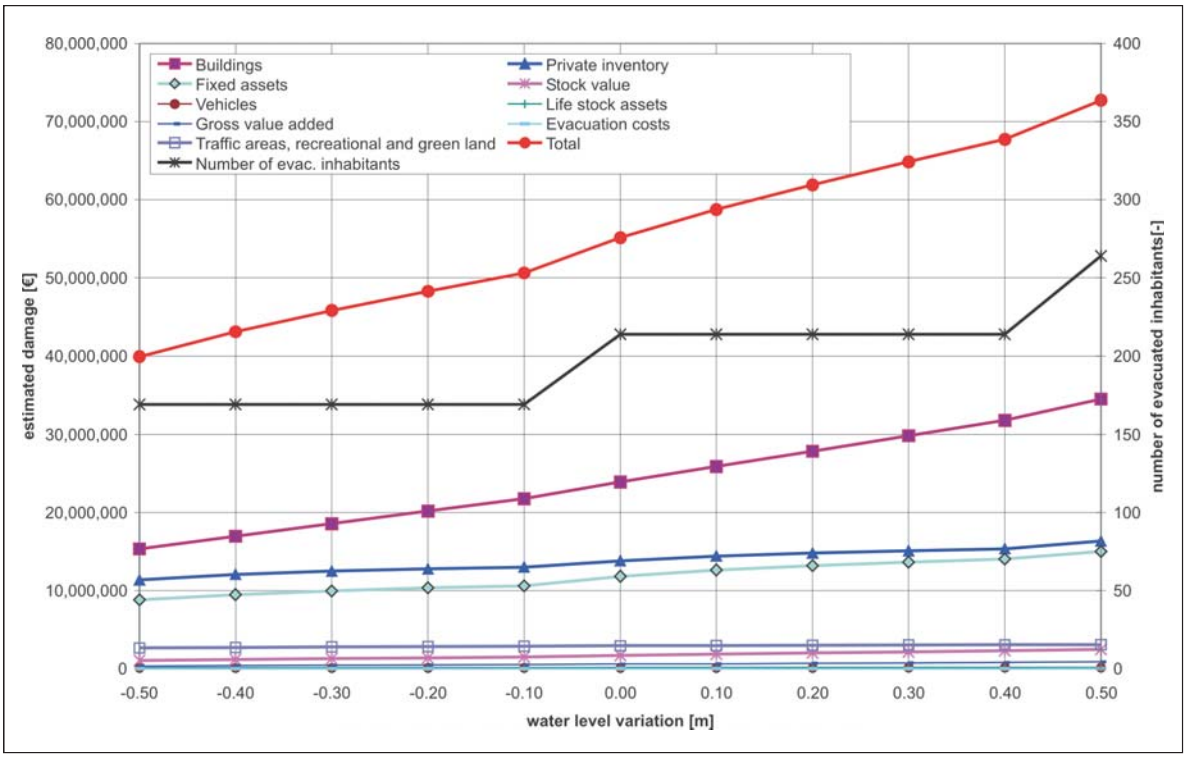

Fig. 10: Estimated damages by categories for variations of the flood water level of scenario "Hafendeich"

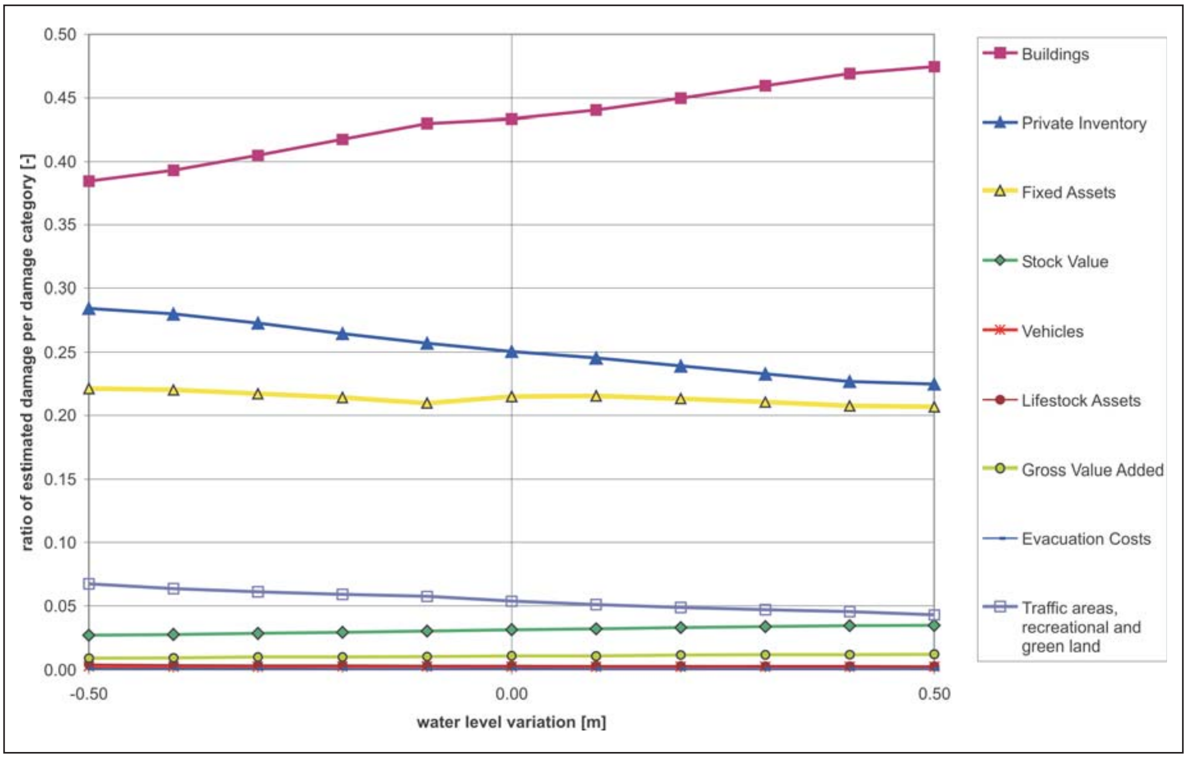

Fig. 11: Ratio of categories for variations of water level (based on "Hafendeich")

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.

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 ProDeich 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 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 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 SAFECOAST (Sustainable Coastal Risk Management in 2050).

6. Literature

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