NLWKN

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für Wasserwirtschaft, Küsten- und Naturschutz
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COMRISK- Subproject 9 Pilot Study Langeoog

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1 Introduction

1.1 COMRISK project overview

The European INTERREG III B project COMRISK (Common strategies to reduce the risk of storm floods in coastal lowland) is carried out by national and regional coastal defence authorities in the North Sea Region (Belgium, The Netherlands, UK, Denmark and Germany).
Aim of the project is to improve risk management for flood-prone coastal areas in the North Sea Region by a joint treatment of relevant problems. The project is structured in 9 sub-projects consisting of 5 evaluation studies and 4 pilot studies. Lead partner is the Ministry of Interior Schleswig-Holstein, responsible for the over-all project management and one sub-project. Each study is led by one partner.
The evaluation studies aim mainly on a comparison and evaluation of the present assumptions, strategies and methodologies in the partner countries. Main objective of the pilot studies is to perform a state of art risk analyses for certain typical coastal flood units applying state of art methods.

The subprojects and responsible partners are listed in the following:

Evaluation studies

Sub-project 1: (policies and strategies) to improve national policies and strategies for coastal risk management

Sub-project 2: (strategic planning) to achieve common strategic planning tools for coastal risk management

Sub-project 3: (perception and participation) to achieve common methods to improve public perception of, and participation in coastal risk management

Sub-project 4: (performance) to achieve common approaches and indicators to establish the performance of risk management measures

Sub-project 5: (boundary conditions) to achieve common approaches to establish the hydraulic boundary conditions for technical measures

Pilot studies

Objective of the pilot studies is to achieve to perform a state of art risk analyses for certain coastal flood units within the following Sub-projects:

Sub-project 6: Flanders (Belgium)

Sub-project 7: Ribe, Wadden Sea (Denmark)

Sub-project 8: Lincolnshire (United Kingdom)

Sub-project 9: Langeoog (Germany)

The project is co-financed by the Community Initative Programme INTERREG IIIB North Sea Region by the European Union. Term of the project is from 2002 to 2005. The number of involved partners was extended in 2003 when the "Niedersächsische Landesbetrieb für Wasserwirtschaft und Küstenschutz (NLWK – Lower Saxony Water Management and Coastal Defence Agency) joined the project with subproject 9 (Risk assessment for the island Langeoog).

1.2 Objectives of subproject 9

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.
The following main issues shall be investigated within the suproject:

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

NLWK Performing contracted external experts working on special questions within this subproject. Their contributions are used as input for the following chapters of this report:

- chapter 4.1 – 4.4 "Microscale valuation analysis for the island Langeoog – Final report" by the University of Kiel – Department of Geography 2004
- chapter 4.5 / 5.2.2: "Scientific investigations for risk assessment of seawater breakthrough into the drinking water extraction area on Langeoog - Evaluation of the damage from the point of view of the drinking water supply", by the Oldenburgisch-Ostfriesischer Wassser-verband (OOWV) - Water Board of Oldenburg and East Frisia, 2004
- chapter 5.2.1: "Seawater break through on Langeoog and the consequences for drinking water resources - Estimating risks by using groundwater flow and transport modelling with Feflow" by the Technical University of Braunschweig - Institute for Environmental Geology, (IUG), 2004

1.3 Description of the study area Island of Langeoog

The island of Langeoog is located in the north-western part of 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 and lowlands on the southern side. Langeoogs total terrestrial area is 20 km². The area under investigation is located in the western part of Langeoog protected by a coastal defence system further described in chapter 3.1 and 4.1. The area covered by the village of Langeoog is approximately 1.5 km² .The number of inhabitants is 2019 as at June 30th 2004 (GEMEINDE LANGEOOG 2005).

Parts of the island as well as of the investigated area belong to Wadden Sea National Park of Lower Saxony (Nationalpark Niedersächsisches Wattenmeer). Only restricted access and restricted usage is permitted, to achieve certain nature conservation objectives such as natural dynamics and preservation of rare species.

Main economic factor on the island is tourism. In 2002 approximately 179,000 guests and 1,5 million overnight stays were registered (GEMEINDE LANGEOOG 2003).

Agriculture is of minor importance. Farms do not exist. South the village pasture areas are used for grazing of riding and working horses as well as grazing to achieve nature conservation goals.

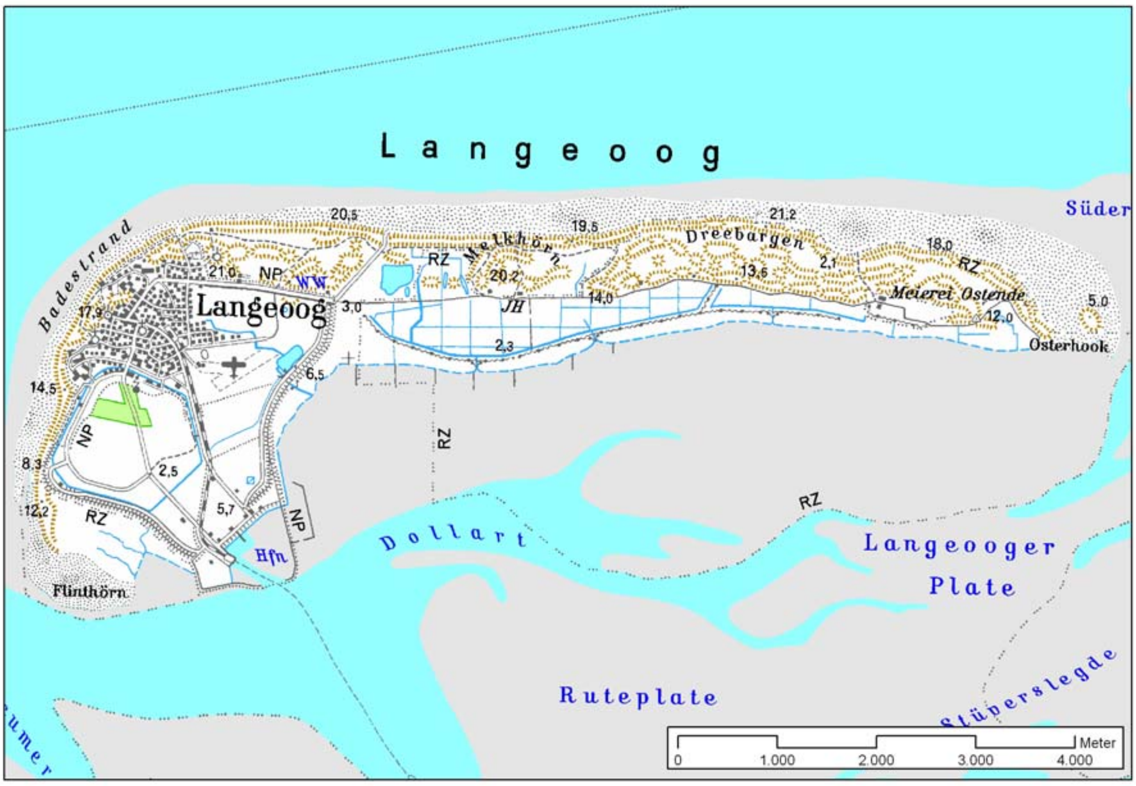
The island is connected with the mainland by a ferry line. The ferries operate in average 4 times a day in one direction. A small air field south-east the village offers an additional connection towards the mainland.

A road located on a 2 km long embankment and a railway connect the harbour in the south of the investigation area to the village of Langeoog..

Fresh water for the drinking water supply for the island is produced directly on the island. It is extracted from the fresh water lens exiting mainly in the dune areas. The main extraction area is located directly eastward the village of Langeoog in the southern part of the Pirolatal-Valley and the Heerenhus-Dunes. The water work is located in the Herrenhus dune area..

North the Pirola valley a considerable beach and dune erosion has been monitored beginning about 1970. This erosion endangers the functionality of the dune belt forming the flood protection for this part of the island and therefore for the fresh water lens and the village. Several coastal defence measurements were implemented in this area to counter negative impacts on safety of the dunes.

Map 1-1: Overview Germany with the location of the Eastfrisian Islands marked with red circle (from www.lib.utexas.edu)



Map 1-2: Langeoog overview – Topographic map 1:25000

1.4 Regulations for coastal defence in Lower Saxony

The lowlands of the Lower Saxony mainland coast and the Eastfriesian Islands off the coast are protected by coastal defences against storm surges. Legal basis for coastal defence is the Lower Saxony Dyke Act which defines coastal defence elements, general design rules, legal obligations and regulations. Main elements of the coastal defence system for the mainland coast are main dykes and storm surge barriers. On the islands a ring of main dykes and protective dunes guarantee flood protection. A general overview concerning the Lower Saxony design philosophy for coastal defences is provided in COMRISK subproject 5.
As stated in the Lower Saxony Dyke Act the design water level has to be calculated with a deterministic method which is based on the highest recorded surge level added to mean high tide, the maximum spring difference and the secular sea level rise. The design wave run-up for coastal defence structures is evaluated in a two stage procedure. Wave climate in front of the structures is mostly determined by numerical modelling with mathematical models as an input for wave run-up formulas, which take the spectral character of wave climate into account. The design width of protective dunes is calculated by time dependent 2-d mathematical cross shore models based on a design surge. (THORENZ et al. 2003)

2 Methodology

To obtain the subproject objectives defined in chapter 1.2 in the following a brief overview of the used methodology is given. Since terms in context of risk are often used in different senses, in important basis for this study are exact definitions of the terms used. Therefore relevant definitions are cited from final report of the COMRISK evaluation study subproject 3. (KAISER et al 2004):
Based on these definitions, the two basic elements conducting a risk analysis, the methodology of the hazard analysis and the vulnerability analysis are introduced. With a hazard analysis the treat of the flood-prone area due to flooding is evaluated. The expected loss of elements at risk is investigated within the vulnerability analysis. Figure 2-1 shows a flowchart of the distinct steps executed.

2.1 Definitions

The abstract term ’risk’ is frequently used in the field of coastal engineering, but in some cases with different meaning. In other fields, even in the context of risk and safety, there are completely different meanings. Thus, some definitions related to ‘risk’ are defined prior to further steps.
The definitions are cited from final report of the COMRISK evaluation study subproject 3. (KAISER et al 2004):

(Non) Accepted Risk:

A (not) accepted (subjective) risk is an empirically calculated description of a personal or collectively evaluated risk. A non-accepted risk is the result of a risk aversion, while an accepted results from a risk acceptance.

(Non) Acceptable Risk:

In contrast to the accepted risk, the (non) acceptable risk is a normative term, which describes basic ethical criteria for acceptability of risk.

Damages:

In order to separate it from loss expectancy, damages are defined as the real incurred consequences of an impact on the elements at risk from a specific extreme event in a specific area. The degree of loss can be expressed either as an absolute value (e.g. monetary value) or as a relative value on a scale between 0 (no damage) and 1 (total loss = 100 %)

Damage Analysis:

Damage analysis is the systematic, comprehensible and formal procedure to determine the real damages of the elements at risk caused by a specific event in a specific area. A damage analysis provides empirical information for the prognostic vulnerability analysis.

Damage Estimation:

Damage estimation is also a systematic, comprehensible and formal procedure and the sub-process of the vulnerability analysis. On the 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.

Damage Potential:

Damage potential is the quantitative or qualitative value of all elements at risk, which can suffer damages from a specific event in an area at risk.

Damage Potential Analysis:

Damage potential analysis or valuation analyses is a sub-process of the vulnerability analyses an the systematic, comprehensible and formal procedure to evaluate the damage potential respectively the (monetary) value of the elements at risk quantitatively or qualitatively which are potentially threatened by a specific event in a specific area.

Hazard:

Natural or man-made induced singular, sequential and combined events, conditions, processes or actions which can potentially cause damage or loss to the environment respectively the people and their property. If the threat comes from a natural source, it is called a natural hazard. Exposure is thereby the threat of a specific event, defined as the combination of hazard (intensity) and frequency (occurrence probability) of the phenomenon.

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 displayed as the combination of hazard (intensity) and frequency (probability) of a specific threat.

Probability:

The objective definition of probability (of an event) describes the number of cases, in which the event occurs, divided by the total number of events. Subjectively speaking it is the probability of the expectation degree or the confidence in a statement that an uncertain event will occur (KORTENHAUS&OUMERACI, 2002).

Risk:

Risk is the combination of vulnerability of the elements at risk in a specific area and the exposure by a specific event (intensity and occurrence probability). The term risk is often used as a basis for decisions in case of uncertainty. Risk has to be further distinguished:

Risk Analysis:

Risk analysis is the systematic, comprehensible and formal procedure to evaluate a numerical or qualitative value for the risk regarding the probability of occurrence and the dimension of the consequences in a defined system. Thereby the causes and consequences of a specific exposure are considered.

Risk Assessment:

Risk Assessment is a sub-process of the risk analyses. It is the systematic, comprehendible and formal method to link and quantify the possible consequences of an event (vulnerability) with the likelihood of the occurrence of a triggering event (exposure). The result of the risk assessment is the specific risk.

Risk Evaluation:

Risk evaluation is the individual or collective judgement of risk under the aspect of receiving information and the influence of personal, social and cultural parameters. The decision process is classified into two phases. During the perception phase risks are identified, analysed and verbalised. The judgement (evaluation) phase is characterised by the creation and valuation of alternatives and the decision of practices. The result of the risk evaluation is a numerical or qualitative risk level of the (non) accepted risk.

Risk Examination:

Risk examination is defined as the illustration and discussion of possibilities, experiences and explanations of methodical bases for analyses, evaluation and management of risks from natural hazards. In many cases the term risk management is only one segment of an integrated concept. Hence the neutral term risk examination appears to be more suitable.

Risk Management:

Risk management is defined as the use of methods for the designing, development and control of systems to prevent, reduce or spread risks. It comprises the articulation of goals and the construction of strategies which lead to a decision about the demand of practices and the implementation of concrete measures and the installation of a monitoring. Within natural hazard research, the term risk management is often equated with disaster management. In this connection, both prevention and recovery measures are developed for a specific exposure in a specific area. In many cases, the overall context of risk analysis, evaluation and management is called integrated “risk management”. In this study the value-free and purposely open term “risk examination” is used.

Risk Perception:

Risk perception is the sensual or rational, individual or collective perception process and the connected identification, analysis and verbalisation of risk. Influencing factors are the input and processing capacity of the percipient person as well as the situational, social und cultural framework. The perceived risk is the basis for the evaluation or judgement of the risk, whereas there is no exact separation of the perception and judgment processes.

Specific Risk:

Specific risk is the calculated probability of damage by a specific event in a specific event in a specific area and is computed by means of a risk assessment. The term can be also expressed as the product of exposure and vulnerability. If the specific risk is an objective factor, it is sceptical, since every risk analysis implies subjective assessments and valuations.

Vulnerability:

Vulnerability is the expected loss to the elements at risk in a specific area, as a possible consequence in the specific hazard situation. The degree of the damage expectancy can be expressed either as an absolute value (e.g. monetary value), as a relative value on a scale between 0 (no damage) and 1 (Total loss = 100 %) or descriptive in terns of vulnerability classes.

Vulnerability analysis:

Vulnerability analysis is defined as the systematic, comprehensible and formal procedure to estimate the possible damages to the elements at risk in a specific area threatened by specific events, conditions, processes or actions.

2.2 Hazard analysis

The danger of flooding, the negative impact of water on a risk element, is the focus of this hazard analysis. All risk elements like for example buildings, vehicles, life stocks within the investigation area are considered to be endangered. For specific scenarios the possibility of being affected i.e. by flooding of a polder area, is analysed.

Basis of the analysis is a description and systematisation of the coastal defence system consisting of dunes and dykes.

A statistical analysis is used to determine certain exceedance probabilities of surge water levels.

Where the coastal defence system consists of dunes, a two dimensional numerical model to simulate beach and dune erosion is used. 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 dykes, a deterministic calculation of failure is executed. The ProDeich model (KORTENHAUS / OUMERACI 2002) which contains functions for several failure modes for dykes is applied.

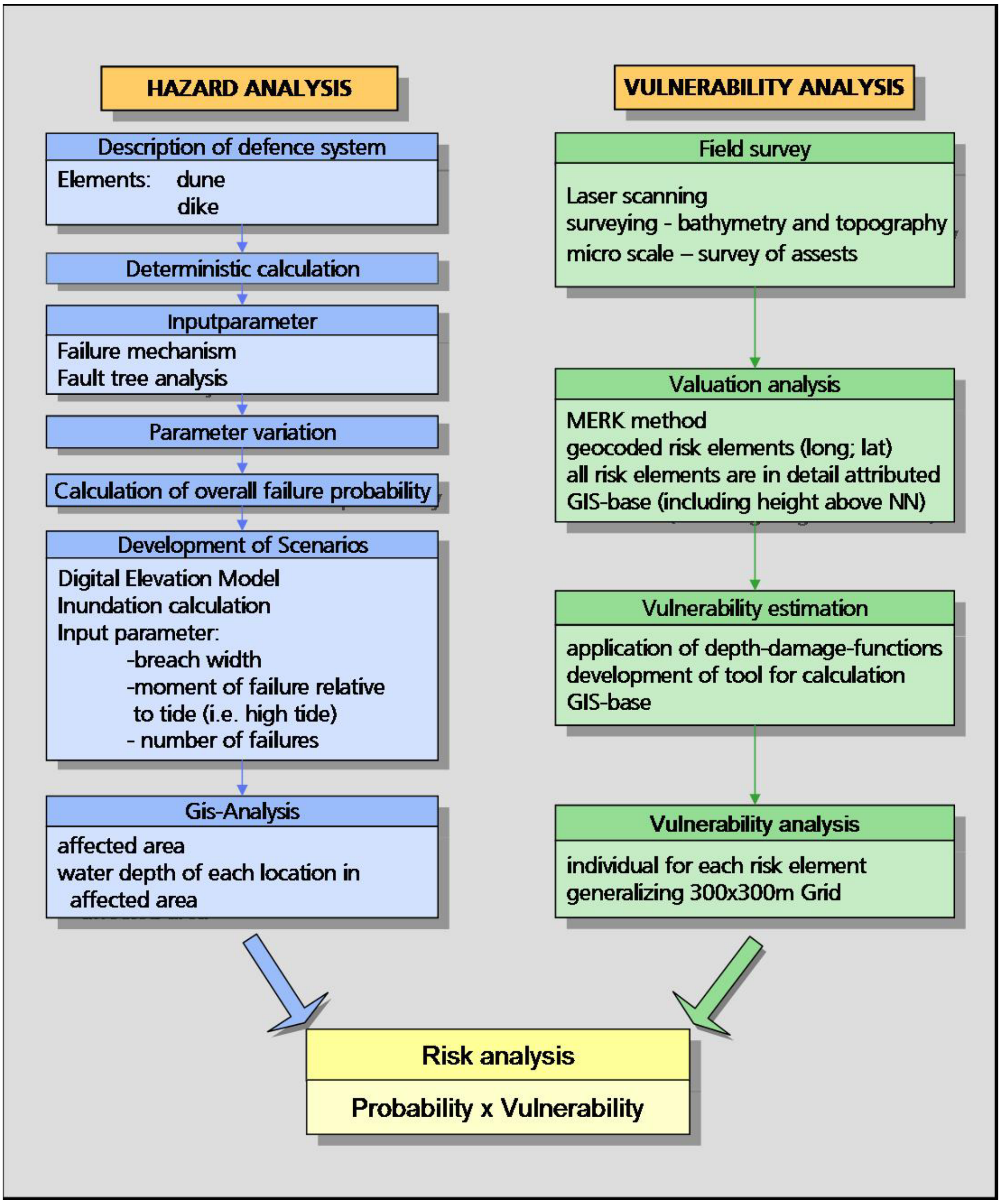


Figure 2-1: Flow diagram risk analysis

2.3 Vulnerability analysis

A valuation analysis and a vulnerability analysis for the protected area including the village Langeoog is executed on a micro scale level. These analysis-methods are based on the results of the MERK-project (REESE et al. 2003). With the MERK report a valuation and damage estimation approach is available, which is evaluated and documented. A micro scale approach is necessary to depict the situation for the relative small investigation area of Langeoog.

To determine the vulnerability, detailed information concerning water propagation and water depth are needed. Therefore hydraulic calculations of water inflow at detected failure locations are carried out. In combination with a GIS-based water level-approach and a high accuracy digital elevation model the water depth is determined for each element at risk.
The approach of depth-damage functions offers the opportunity to estimate the degree of expected damage for each element. In combination with the valuation analysis the expected damage can be expressed as a monetary value.

The effects on drinking water supply by a salt water intrusion in the fresh water lens due to partly flooding of the catchment area of the wells in case of a dune breach is analysed on basis of numerical simulations. The vulnerability for given scenarios is estimated by an expert statement of the water board OOWV on basis of salt concentration in the extracted freshwater of several wells determined by means of a numerical model.

3 Hazard analysis and failure probability

3.1 Description of the Langeoog coastal defence system

Simplifying the island can be divided in two parts: an inhabited western part protected against storm surges and an uninhabited eastern part. The demarcation is located at the western side of the Grosse Schlopp, a former wash over which is a remnant of the famous Christmas storm flood dated 1717 (“Weihnachtssturmflut”).

The western part of the island is protected against flooding due to storm surges by a coastal defence elements which form ring around this area. In the northern and the western part this ring consists of dune areas with various heights and extents. These dune areas are protected by law and no usage besides coastal defence actions is allowed. The dunes in the northern part are subject to temporary erosion processes of various durations that can cause dune regression. Hence soft coastal defence measures as beach nourishments and dune strengthenings are repeatedly executed to guarantee a certain safety level of the protective dune against breaching.

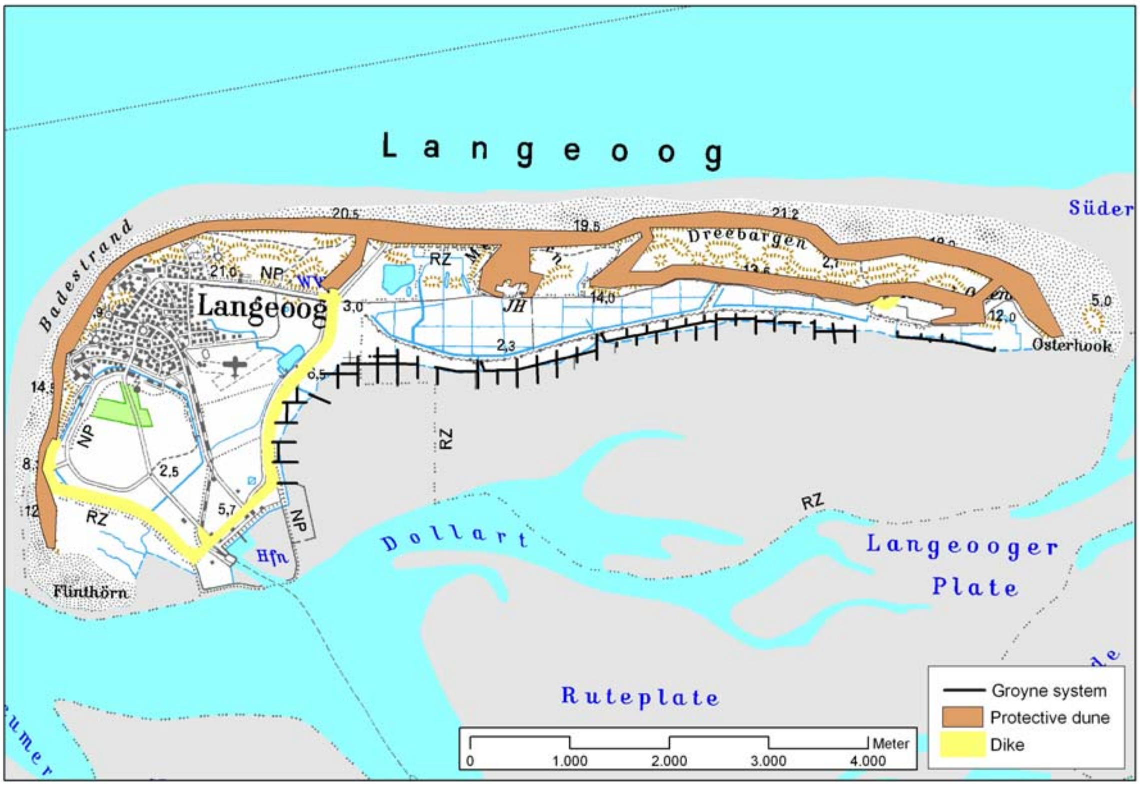
The eastern and southern part of the defence system consists of dykes that are connected to the dune areas. Within these dykes three lockable dyke openings for traffic use are located.

The protected area has a size of 7.7 km². Major parts show a height level below the legal design water level of NN + 5.1 m.

The investigation area is restricted to the inhabited western part of Langeoog.

Due to the existence of two completely different coastal defence elements within the coastal defence system two different methods are necessary to determine the probability of failure for dune areas and for dyke sections:

Besides the area under consideration several coastal protection elements that have no direct influence on the investigation exist. Map 3-1 shows the protective dune belt which extends from the western beach near Langeoog village)to the eastern end of the island. Additional, groyne fields protect the salt marshes on the wadden sea side of the island against erosion. In the eastern part a ring dyke in combination with dunes forms the defence system for a few houses. Mainly tourism use takes place there. This very small area is disconnected to the western part of the island and is supposed to have a relative small damage potential. Therefore it is considered to be negligible for this investigation.



Map 3-1: Overview Langeoog TK25 /TK 50 with elements of the coastal defence system indicated with colour

3.2 Input parameters for calculation

To perform a hazard analysis hydrological und morphological data are necessary to calculate the stress on the coastal defence structures.

Hydrological data like water level and wave height are major input parameters for the calculation (see chapter 3.3). As mentioned in chapter 2.2 statistics of extreme water level are used to derive the probability of water levels that might cause a failure of the coastal defence system. Thus an extreme value statistic is conducted in chapter 3.2.1 to determine an appropriated statistical distribution function. The results are extreme water levels for Langeoog which have high return periods (up to 10.000 years).

On basis of wave atlas' which are derived from numerical simulations of the Eastfrisian coastal area the input data for waves are selected. For specific subsections of the beach with comparable conditions where the application of failure model leads to a failure of the coastal defence the input values are compared with values determined by applying robust methods.

The morphological data are needed to calculate the sea state in front of the defence system, since the bathymetry influences the waves. Secondly, parts of the defence system, i.e. the dunes, are described by these data namely terrestrial beach and dune surveying as well as laser scanner (LIDAR) data.

To calculate the resistance of the coastal defence system elements by means of a numeric models it is necessary to describe these elements with parameters, e.g. geometry of the construction and material parameters.

A digital elevation model covering the complete investigation area is used to create cross profiles of the protective dunes with 10 m distance, additional to terrestrial surveyed profiles. An analysis of the dune volume and dune height based on this geometry data is conducted to derive potential weak spots of the dunes, see chaper 3.2.2.

For those parts of the coastal defence system represented by dykes the information on positioning, shape of construction, construction type and relevant soil parameters are mainly taken from the digital dyke register of Langeoog. Based on this information three dyke sections with comparable characteristics are detected. Within these sections representative cross profiles are derived, see chapter 3.2.3.

3.2.1 Hydraulic boundary conditions

At the island of Langeoog no tidal gauge that provides suitable data for statistical analysis of water levels exists.

The closest tideal gauge that offers suitable data is located at Norderney Island about 20 km westward of Langeoog). It is recording since 1896. The record files used in this study collects the monthly highest high water levels for the period 1896 to 2003. A second file contains the yearly mean high tide water levels. Mean tide level is calculated as 19-years arithmetic average. The yearly highest high tide is detected. The surge (including wind, astronomical and other influences) is determined by subtraction of the respective mean high tide. All values are given in cm above gauge reference level. All statistic calculations are executed with cm-values.

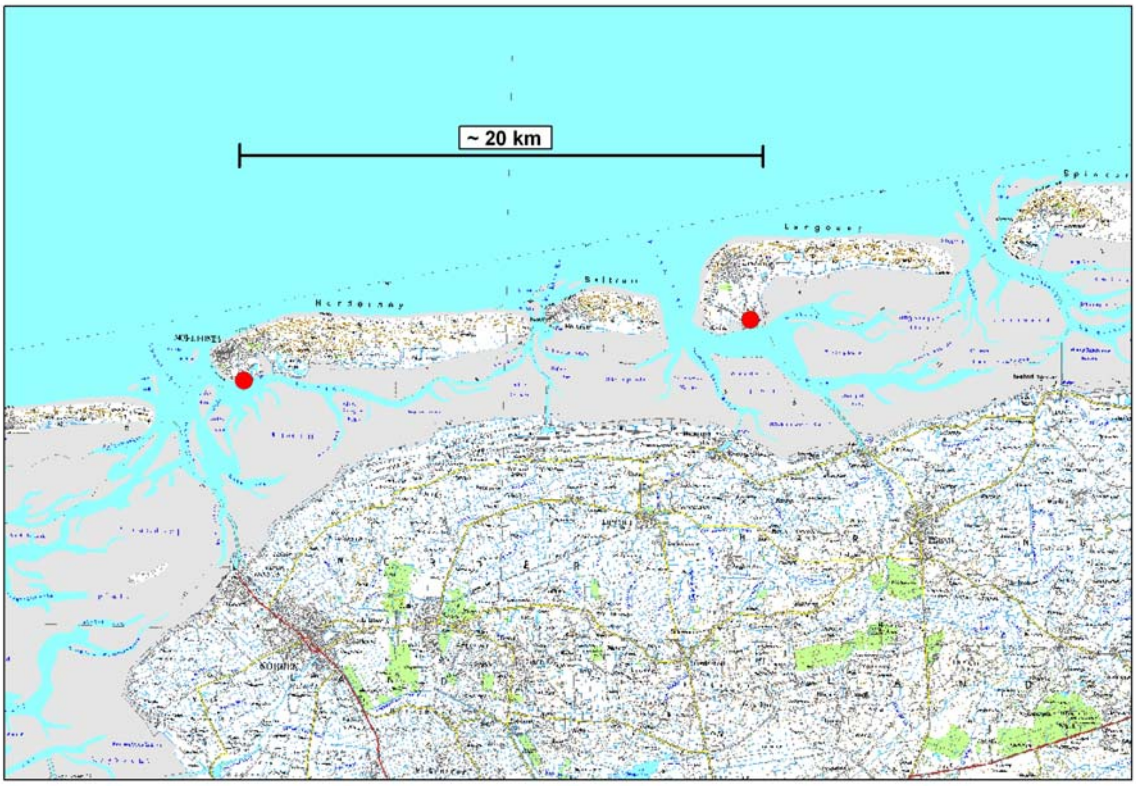
$h_{setup} = h_w - Mh_w$ equation 3-1

h_{setup} : set up caused by wind and other effects [cm]

$h_{w:}$ high water level [cm]

Mh_w Mean high water level [cm]

Note: In 2003 the gauge reference level is NN - 499 cm, mean high water level NN+1.20m (10-years average 1991/2000) and mean high water level NN+1.27 m (2003).



Map 3-2: Location of the tidal gauge stations Norderney and Langeoog

This extreme-event series includes the largest values of surge from the complete-duration series with each value selected from an equal time interval in the period of record. For the time interval is taken as one year, the series is an annual series.
This annual series of highest high tide and determined surge is shown in figure 3-2 Together with mean high tide water level

Due to a change in location of the gauging station the water level time series is not homogeneous and can not be corrected (TÖPPE / BROCKMANN, 1992). For this study in hand it is assumed that even if the influence on the surge is smaller than on the water level the surge time series is inhomogeneous too. This fact has to be taken into account when evaluating the results.

The transfer function to calculate the wind set up at Langeoog on the basis of gauge Norderney uses a comparison of two time series of Langeoog and Norderney with a period of 20 years. The yearly highest high tide event is selected and the wind set up of the same surge event at Langeoog and Norderney are compared. Figure 3-1 shows the height of the

wind set up and the differences in set up between Norderney and Langeoog. The statistics of the difference values results in a mean of 4.2 cm and standard deviation of 10.66 cm.
Since the islands have comparable boundary conditions in the German Bight (distance between the islands ~ 20 km, distance between the tidal inlet and the mainland coast approximately 6.5 km) it is as a simplification for this study assumed that in case of a severe storm surge at Norderney and at Langeoog the wind set up will be about the same size.

$h_{setup,\ Langeoog} = h_{setup,\ Norderney}$ equation 3-2

$h_{surge,\ Langeoog}$: set up caused by wind (and other effects) at Langeoog [cm]

$h_{surge,\ Nordrney}$: set up caused by wind (and other effects) at Norderney [cm]

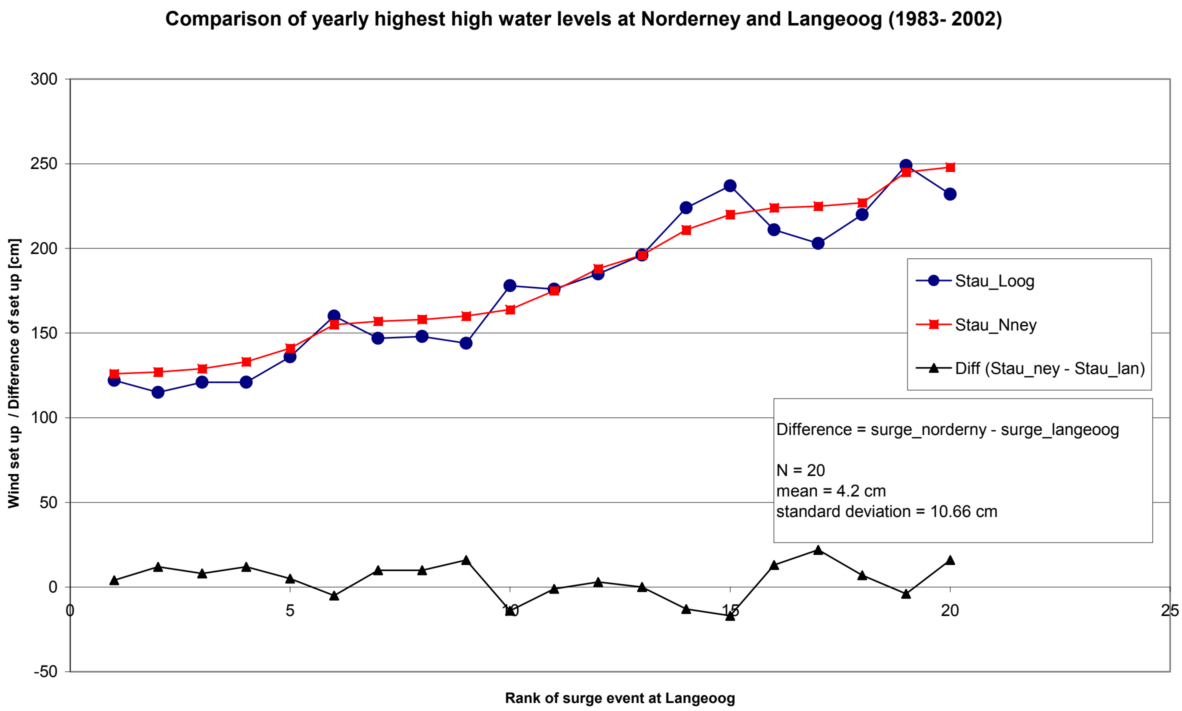


Figure 3-1: Comparison of yearly highest wind set up of gauge Norderney and Langeoog (time series 1983 - 2002)

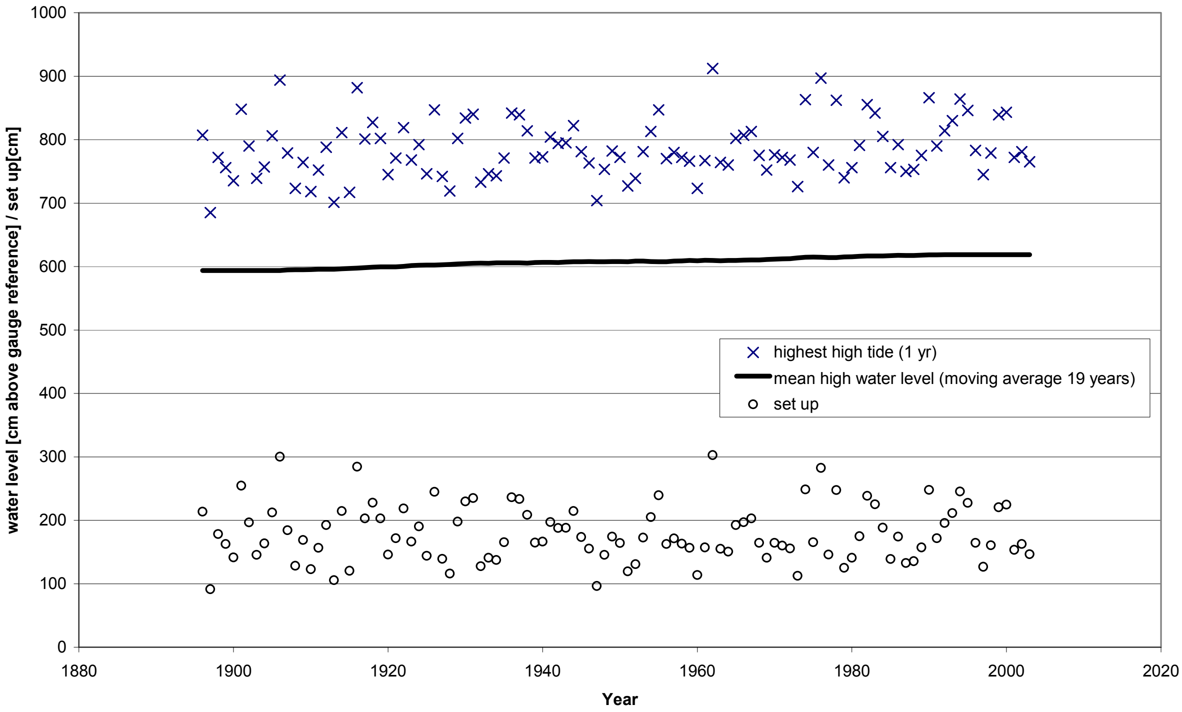


Figure 3-2: Highest high water level of a year for the period 1896 – 2003 at gauge Norderney, mean high water level and resulting set up of highest high water level

Plotting position

Various plotting formulas are documented in literature. Here the plotting formula according to GUMBEL (1958) is used.

$p_i = i / (n+1)$ equation 3-3

where

p_i: probability for the i^{th} value (plotting position)

i: ordered data; largest to smallest rank for maximum values

n: size of the data sample

The return period (T) is defined as

$T = 1/ p_i$ equation 3-4

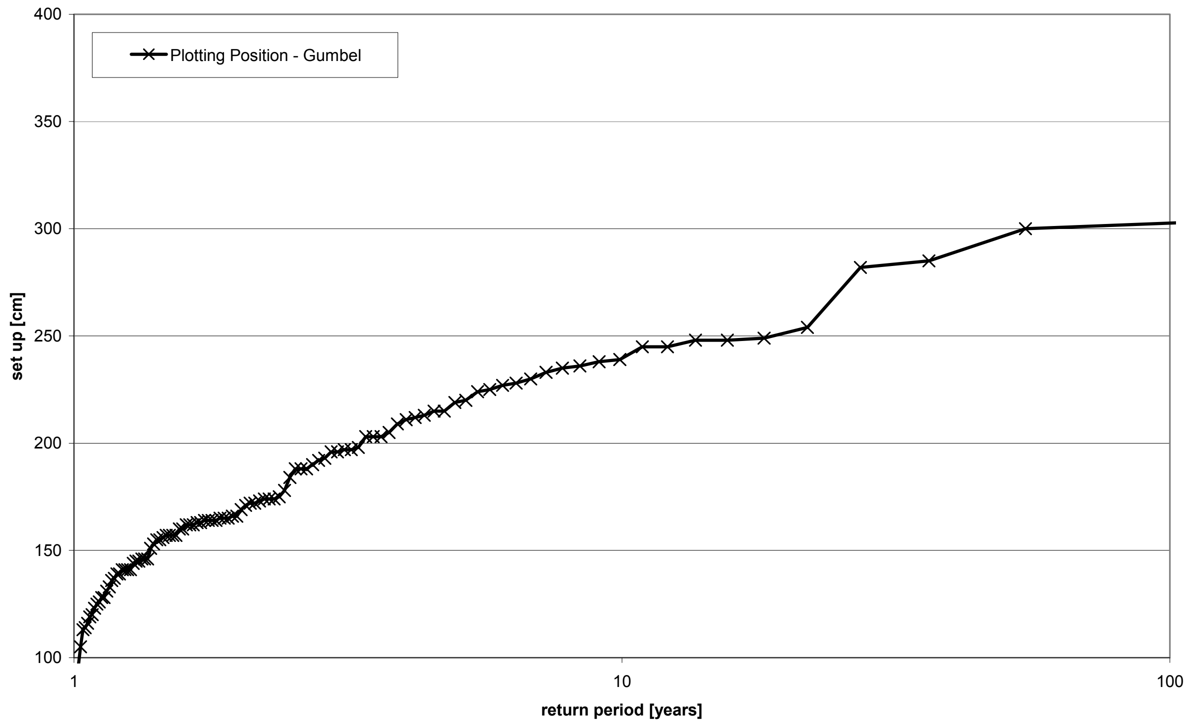


Figure 3-3: Plotting Position of set up values, N = 108

The following probability distribution functions are tested to find out which could be used for extrapolation of extreme values. To fit distribution functions to data the momentum method is used:

The applicability of following four extreme value distribution functions are compared:

- log-normal distribution (normal distribution with logarithmically transformed data)
- Pearson III
- Log Pearson III
- Gumbel / extreme value distribution Typ I (Extremal I)

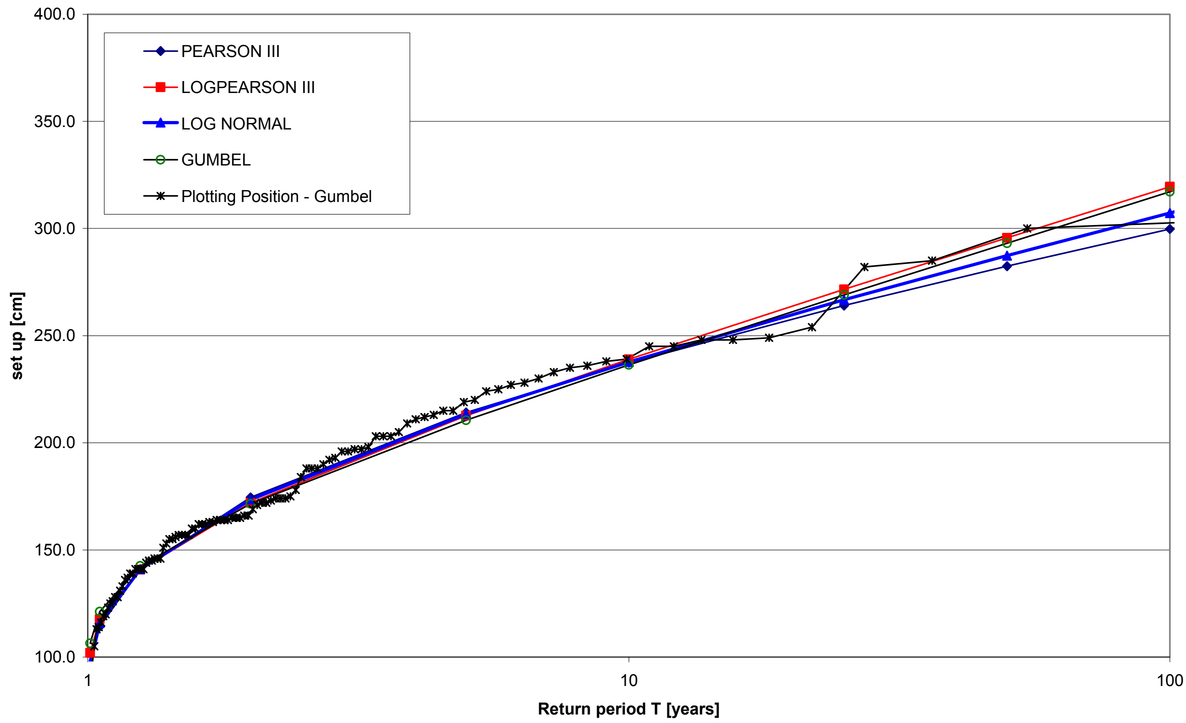


Figure 3-4: Plotting Position of set up values and various distribution functions

The extrapolation of extreme values is allowed in a range of three times the observation period [WANG/LE MEHAUTE (1983) after EAK 2002]. For specific surge time series of 108 years used in this study, this yields to 324 years). This period is indicated in figure 3-5 by the dotted line.

At this first step of hazard analysis an assumption concerning the water level which will lead to a failure of the system is used to estimate the range of extrapolation. Assuming that the coastal defence system will withstand a water level that remains under the legal design water level of NN+5.1 m, the extrapolation of extreme water levels has to cover a least this value of NN+5.1m. A set up of 3.75m is necessary to reach this legal design water level. Figure 3-6 shows obviously that extrapolations up to return periods of approximately T = 1,000 years are required to yield the legal design water level calculated.

Since extrapolating water levels with a lower exceedance probability than 1/324 per year is statistically critical, the 95%-confidence interval is calculated to indicate the increasing range of likely values. The width of the confidence interval gives some idea about how uncertain the unknown parameter should be considered. “A very wide interval may indicate that more data should be collected before anything very definite can be said about the parameter.” (Easton/McColl)

Table 3-1 and Figure 3-5 gives an overview on the wide spread of intervals.

The confidence interval of 95% is calculated for all distributions. The formula and the coefficients of skewness are calculated according to MANIAK (1997).

Distribution	PEARSON III	LOGPEARSON III	GUMBEL	LOG NORMAL
return period T [years]				
x(T) = set- up [cm]				
1.0101	95.2	102.0	106.4	98.0
1.0526	114.1	117.7	121.2	115.8
1.25	141.0	140.8	142.6	141.1
2	174.6	172.0	171.5	173.5
5	214.2	212.7	210.5	213.4
10	237.3	239.0	236.3	237.7
25	264.1	271.6	269.0	266.8
50	282.4	295.6	293.2	287.4
100	299.7	319.5	317.2	307.2
200	316.2	343.6	341.1	326.7
500	337.0	375.5	372.7	351.8
1000	352.1	400.4	396.5	370.7
2000	366.7	425.6	420.4	389.4
10000	399.5	486.3	475.8	432.6
x(T), upper 95%-confidence limit [cm]				
1.0101	109.2	111.2	118.6	107.3
1.0526	126.5	126.4	131.1	124.5
1.25	151.0	148.8	150.1	149.0
2	183.0	180.3	179.3	181.8
5	223.8	224.4	223.6	225.4
10	248.7	254.5	254.0	253.3
25	278.2	292.9	292.7	287.5
50	298.6	321.8	321.6	312.2
100	317.9	351.0	350.3	336.3
200	336.4	380.6	378.9	360.2
500	359.7	420.6	416.7	391.4
1000	376.7	452.0	445.3	415.0
2000	393.3	484.2	473.9	438.6
10000	430.3	562.6	540.3	493.7
95% - confidence interval width- absolute [cm]				
1.0101	28.0	17.8	24.4	17.7
1.0526	24.7	16.8	19.9	16.7
1.25	20.0	15.6	15.1	15.4
2	17.0	16.2	15.5	16.3
5	19.2	22.9	26.1	23.3
10	22.8	30.1	35.2	30.2
25	28.2	41.1	47.5	39.9
50	32.3	50.3	56.9	47.7
100	36.4	60.1	66.2	55.7
200	40.4	70.5	75.6	63.9
500	45.6	85.3	88.1	75.1
1000	49.4	97.4	97.6	83.9
2000	53.1	110.1	107.1	92.9
10000	61.6	142.4	129.1	114.7

Table 3-1: Extrapolated set-up [cm] and corresponding 95%-confidence intervals (upper limit and confidence interval width)

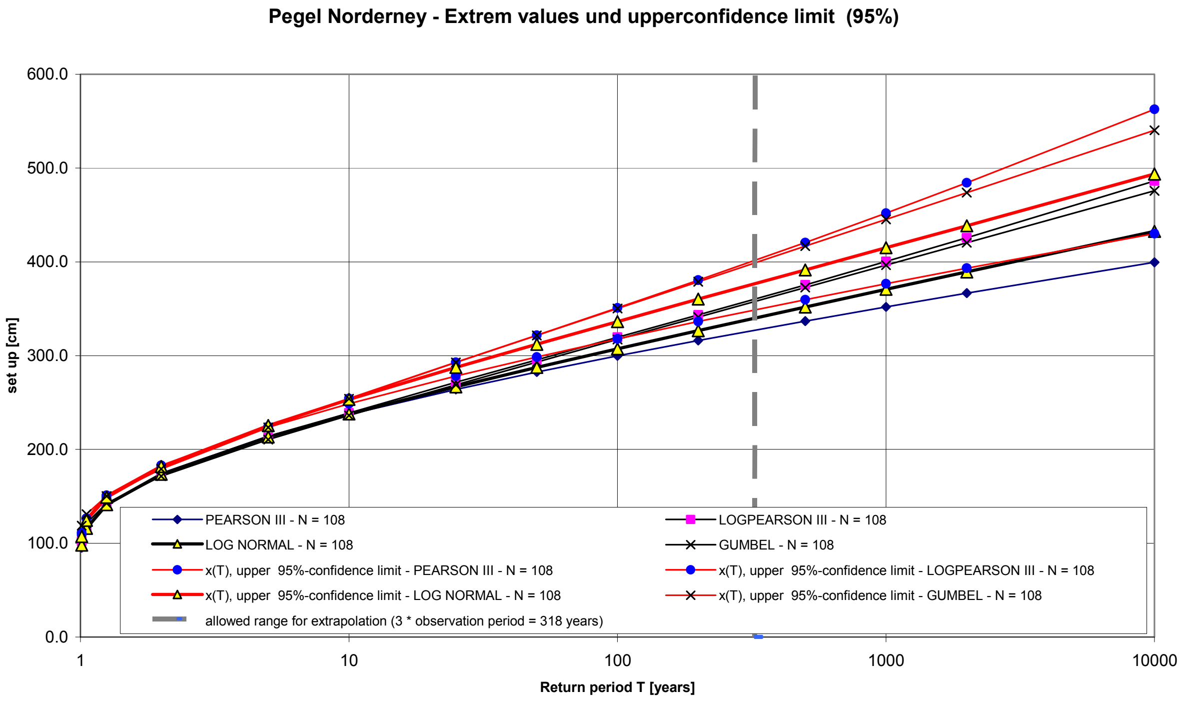


Figure 3-5: Extrapolated extreme set-up values and corresponding upper 95%-confidence limits

Chi-square tests for distributions on different levels are done to evaluate the fitting of the distributions. Since the test is sensitive to the choice of the classes different class-width were tested. The expected frequency should be at least five, a class-width 52 cm (5 classes) is chosen. The distributions passed the test on different significance level α see table 3-2

5 classes	**Pearson**	**Log Pearson**	**Gumbel**	**Log Normal**
Degree of freedom	1	1	2	2
Chi²	1.23	2.29	2.054	0.714
significance level α #)	20%	10%	30%	50%

#) significance level α - tabular value from BRONSTEIN (1989)

Table 3-2: Results of Chi²-tests

All in all the Log-Normal-Distribution provides the best adjustment to the surge series. It offers the best comparative values, i.e the spread of the confidence interval relative and absolute to mean. Therefore the Log-Normal-Distribution is chosen for the further calculations. The range of the confidence interval should be considered when extreme events with very low exceedance probability are discussed.

The mean high water level at gauge station Langeoog is NN+135 cm (Mean value time series 1991 – 2000). Table 3-1 presents the resulting values of set up for various exceedance probabilities of surge level based on the Log-Normal-Distribution and the related 95%-confidence intervals. The set up values of the Log-Normal-Distribution are plotted in figure 3-6. The set up level that is necessary to yield the design high water level (NN +5.10 m) is marked as well as the range of three times the observation period (dotted line).

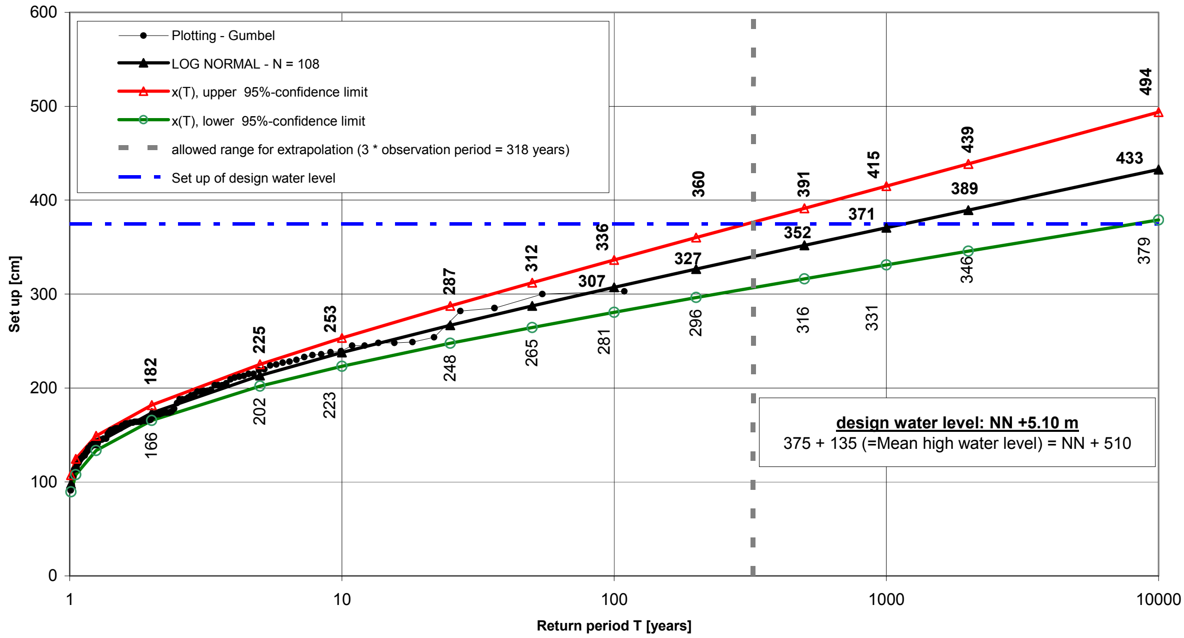


Figure 3-6: Extreme value of set up at Langeoog and 95% confidance interval of distribution function (Log Normal)

Due to physical limits, for example limited fetch length or storm duration, an extrapolation can not be arbitrarily extended (EAK 2002). An investigation concerning the physical possibility of the surge water levels determined by means of statistic extrapolation as described above is not part of this study.

Wave conditions

At the Eastfrisian coastline storms with northwestern or western directions cause high surges. The wind speed causing a design storm surge according to present design criteria or even a higher surge at the island of Langeoog is deemed to be a top level storm with wind speed of at least ~30 m/s.

Since the dune erosion model uses an implemented 1d-wave propagation model the input parameter is the deep water condition at the beginning of the cross profile simulated, so called x0-position.

For the use in the dune erosion model (see chapter 3.3.1) the wave height is calculated additionally by means of a relation between wind set up and wave height, according to STEETZEL (1993).

The wave period is derived from a wave height / wave period function based on a functional relation implemented in the program

According to STEETZEL (1993) the used relation to calculate the wave period is based on a constant wave steepness S:

$S = H_s / L$ equation 3-5

Where:

Hs: wave height [m]

L: wave length [m]

For the deep water wave length this yields:

$$T_p = \sqrt{\frac{2 * \pi * H_S}{g * \hat{S}}}$$ equation 3-6a

For a wave steepness of S = 0.035 (being a typical North Sea condition)

this yields:

$T_p = 4.28 *(Hs)^{0.5}$ equation 3-6b

The wave height values are compared with simpler approaches as the formula NIEMEYER (1979)

$$H_{1/3} = 0{,}35 \cdot \left(\frac{U_{(3h)}^2}{g} \right)^{0{,}66}$$ equation 3-7

For defined parameters combinations of water level, wind speed and wind direction the wave atlas “Seegangsatlas” from MAI (2002) delivers wave heights Hs and wave periods Tm for the north and northwest beaches. The mapped sea states are limited to defined water levels up to 5.0 m and wind speeds of 28 m/s and 32 m/s.

	Hs [m]	**Tp [s]**	**Tm [s]**
UNIBEST-De / Steetzel (1993)			
NN+5.06m	7.8	11.9	
NN+5.24m	7.9	12.0	
NN+5.68m	8.1	12.2	
Niemeyer (1979)			
U3h = 28m/s	6.3		
U3h = 30m/s	6.9		
U3h = 32m/s	7.5		
Seegangsatlas 2002			
Wind from 330°, Water level = NN+5m at location R=3395000 / H=5965000			
u = 28 m/s	4.5		7.4
u = 32 m/s	4.6		7.5

Table 3-3: Wave conditions for the dune erosion simulation as input at the position X0

The wave height Hs used for further calculations of dune erosion at the north and north- west orientated beach sections is based on the comparison a medium value of 7.0 m. The wave period is 11.3 s estimated by using the functional relation implemented in UNIBEST-de, see above equation 3-6.

All dyke 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 dyke lead to moderate / slight wave conditions.

For no measured wave climate are available the sea state conditions are roughly estimated based on the wave atlas of Wangerooge (MAI / DAEMRICH 2004). As this wave atlas covers with its wide area model, which is used to calculate the boundary conditions for the detailed model of Wangerooge, the southern and the south-eastern region of the Langeoog investigation area of this project In spite of a SWAN numerical simulation taking a spectral spreading into account, the limitations of diffraction still exists. Due to this numerical model limitation of SWAN (see above) and the fact that the results of a wide area model (MAI / DAEMRICH 2004) are calculated for a water level below the statistic derived water level (chapter 3-1) a set of possible higher values (Hs and Tp) are additionally considered. This second calculation is run with wave heights and period added a margin of corresponding 0.5 m and 0.5 – 1.0 s.

Location	**Estimated figure based on MAI 2004**		**Increased value - uncerteinties due to model restrictions**	
	Hs [m]	Tp [s]	Hs [m]	Tp [s]
Flinthörn	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

Table 3-4: Used wave conditions in front of the dyke sections (ProDeich calculation)

3.2.2 Dune sections

Data basis for determination of the dune, beach and foreshore conditions are three different kinds of data:

- Terrestrial beach and dune surveying campaigns using DGPS – units. And additional to these standard profile surveys conducted at least twice a year topographical surveys of the dune face and other significant terrain points and lines.
- Airborne laserscanning data (LIDAR), partly filtered to detect and remove the influence of vegetation. One laser scanning campaign was followed by a terrestrical surveying campaign to measure the topographical issues like break lines and single heights point.
- Sonar data of the beach and foreshore area. The measures were conducted with single beam sonar in defined profiles orthogonal to the dune face and in a orthogonal raster.

Survey method/Year	**DGPS-terrestrial**	**LIDAR**	**Topography**	**Sonar**
1999	Beach&Dune NLWK	Total area of Langeoog island		
2000	Beach&Dune NLWK			North western beach – firm
2001	Beach&Dune NLWK	Dune belt in North of Pirola valley		BSH North western beach – firm
2002	Beach&Dune NLWK	Dune belt in North of Pirola valley	Breaklines of topography – covering village and protective dune areas – LGN	North western beach – firm
2003	Beach&Dune NLWK	Dune belt in North of Pirola valley		
Beach&Dune = terrestrial survey of defined beach and dune profiles and survey of dune face (top and foot) BSH = Bundesamt für Seeschifffahrt und Hydrographie				

Table 3-5: Used Survey data

The sonar data within the intersecting area of the two measure campaigns are compared. This intersecting area of the beach is defined by the terrestrial survey measuring down to approximately NN-1.5m and the sonar campaign carried out at high tide reaching up to approximately NN+0m. This comparison shows a mean error of approximately 0.2 m and a good fitting to previous sonar data sets of this area for a depth below NN – 6 m.

Since the extents of the LIDAR campaigns later than 1999 are restricted to the erosion problem zone in the north of the Pirola valley, the dune belt at the North western and western beaches is modelled in DEM by using the LIDAR data of 1999 corrected with the breaklines and annual beach and dune survey data. Thus the dune situation of 2003 can be modelled in a DEM and be used for further analysis.

Additional DGPS surveying of selected street axis in and around the village of Langeoog were carried out collect high accuracy data. These datum have an high accuracy of position and heights which are better than 0.01m (position) and better than 0.03 m (height).These datum are used to evaluate the accuracy of the digital elevation model (DEM) constructed of LIDAR data and topographical issues. The analysis yields to an accuracy better than 8 cm for the LIDAR points close to those points measured in the control axis. Even, the differences between the generated 1x1m Grid and these control points of the axis are smaller than 8 cm.

Finally, a second DEM with a GRID size of 2x2m is derived to reduce the necessary calculation efforts. This GRID is used for illustrational propose and flood path analysis, see chapter 5.1.1.

Method used to derive dune cross profiles for failure analysis

The aim is to divide the 4.5 km of protective dunes in several defined dune sections and to analyse each of these sections to detect the weakest profile. Defining the section is done by criteria that will provide comparable parameters within one section. The weakest profile is choosen to represent the section.

The following criteria are applied:

1. Orientation of the dune face (wave attack)
2. Structure of the dune belt, e.g. presents or absents of valleys behind the dune
3. Potential flood paths leading towards the protected area

Within these sections every 10m a cross profile is derived from the DEM by means of a GIS. These cross profiles are analyzed by calculating two characteristics:

- The heights of the (first) dune belt and
- The volume of the (total) dune belt above NN+4m.

On the island of Langeoog the dune foot of eroding dunes, i.e. the upper point of the dry beach and the seaward boundary of the eroded dune is on the long term located at a level of approximately NN + 3 m (ERCHINGER 1986). Since in this analysis also non-eroded dune belts are dealt with, the level is set to NN+4m to reduce the influence of primary dune or high beaches in front of the protective dune belt. Otherwise the analysis-routine will add the volume of these beach situations as a dune volume of the dune belt.

The profile attributed with the lowest heights and volume figures is assumed to be the weakest profile within a section. It is assumed deemed that the failure of the protective dune under extreme conditions within one storm surge will occur at this weak point.

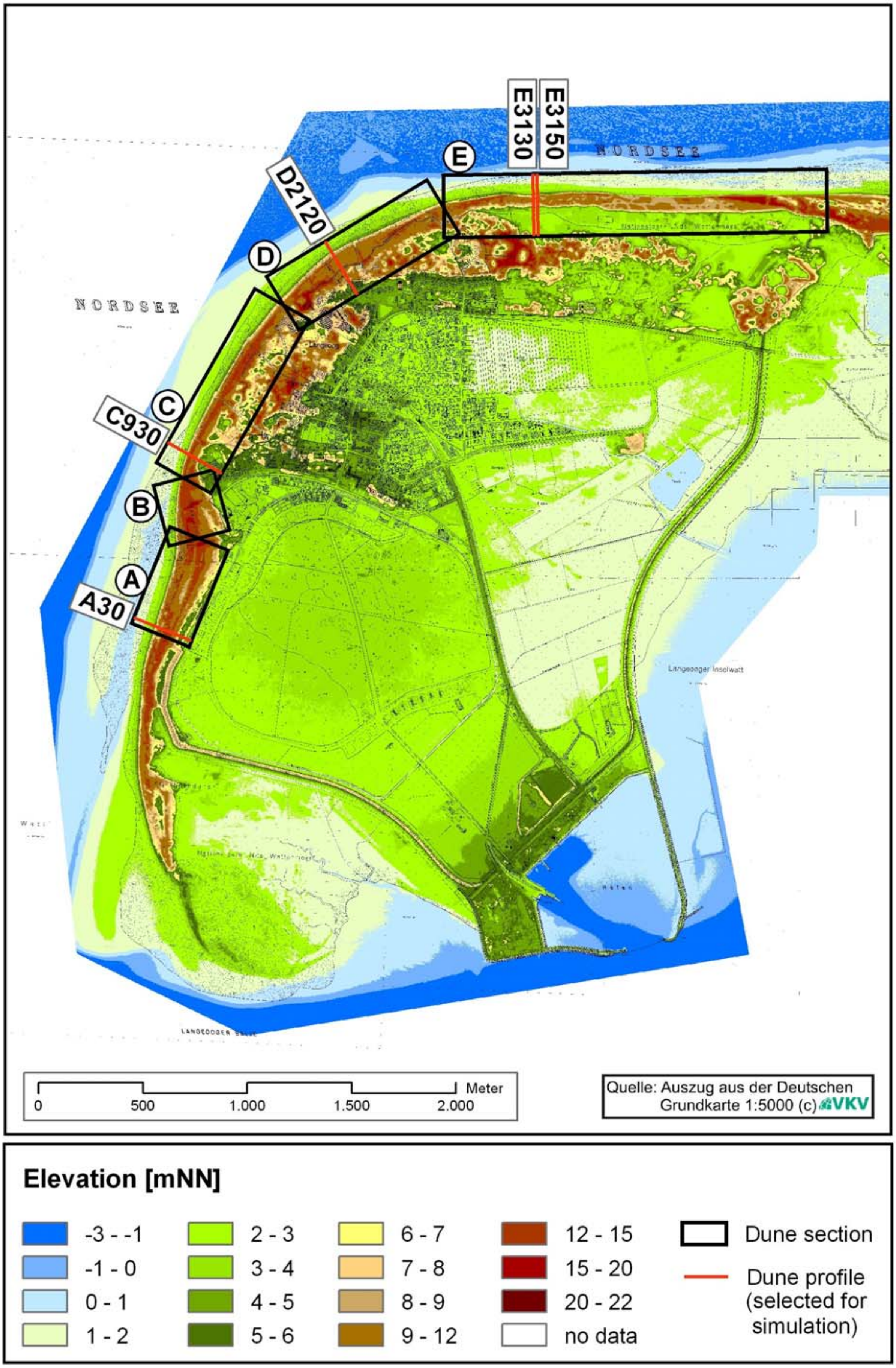
Five sections are defined and the weakest profiles are analysed in numeric simulation program (see map 3-3).

For the great heights and volumes of all dune profiles in section B, no profile is selected. In section E two profiles with similar volume but different dune shape are selected.
Map 3-3 shows the dune sections, labelled A – E, and the weakest profiles of the corresponding section.
A synthetic cross profile based on the smallest cross profile, i.e. E3130, is constructed to take the possible morphological changes into account. The results of this profile will be used to estimate the influence of negative changes of foreshore and beach, e.g. loss of sediment and resulting smaller beach, on the dune erosion. The pessimistic synthetic profile E3130 is generated by lowering the bottom of beach and foreshore in between the levels of NN – 4 m and NN + 4m by -0.5m.

Table 3- 6 contains the parameters dune heights and the volume above NN+4m.
The plots of the weakest cross profiles are attached to Appendix A.

Cross profile	dune volume above NN + 4m	dune height
	[m³/m]	[mNN]
A 30	809.11	14.75
C 930	542.58	12.88
D 2120	1052.82	11.87
E 3130	253.82	10.09
E 3150	253.35	9.63

Table 3-6: Selected profiles and corresponding characteristics



Map 3-3: Digital elevation model, defined dune sections and analysed critical profiles

3.2.3 Dyke sections

The dyke register "Deichbuch Langeoog (2004)" is used as a basis to point out the weakest point or sub-section within a dyke section. Wherein a section is defined by:

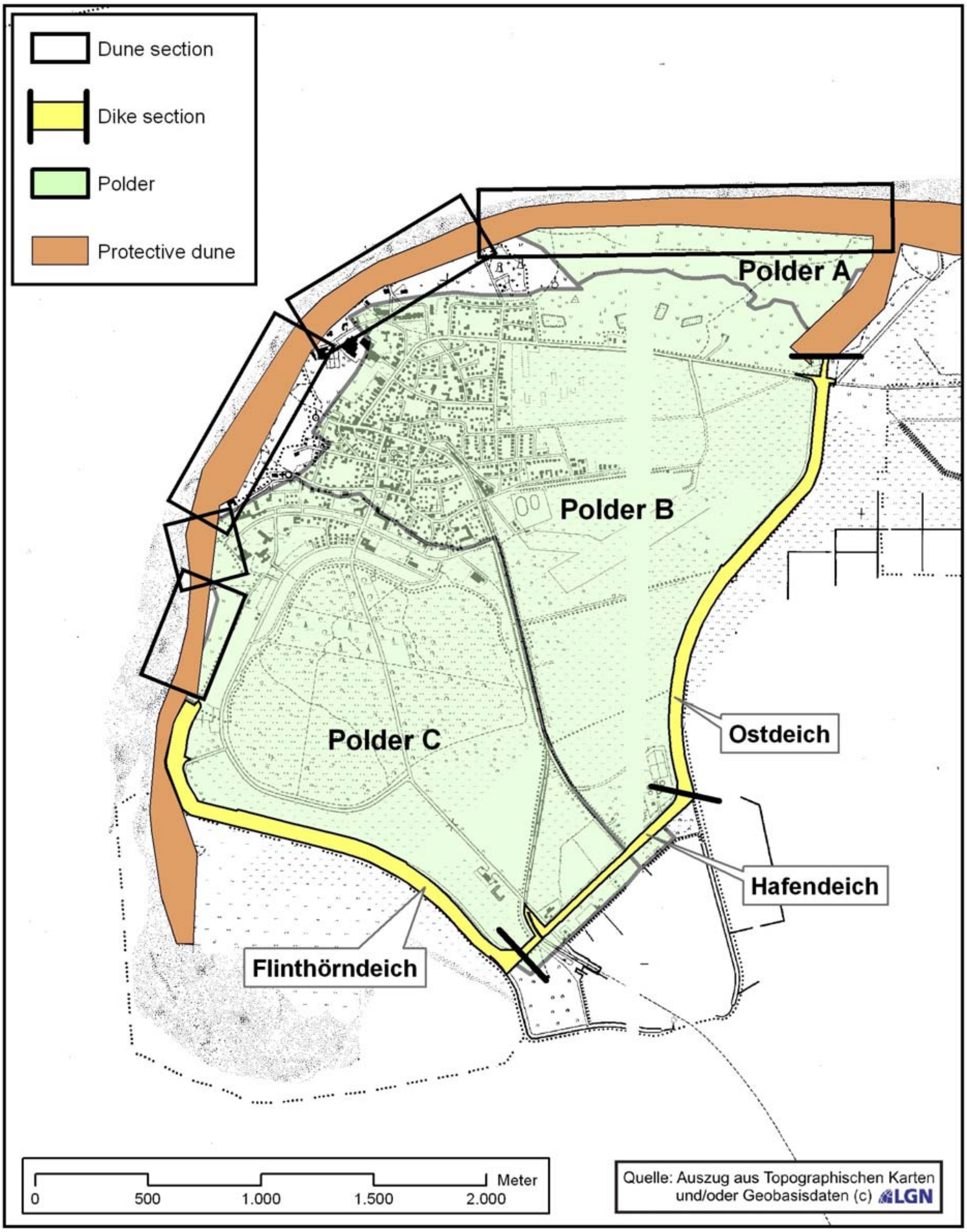
a) comparable hydraulic boundaries conditions and
b) comparable cross direction profile (volume/m), steep slope.

Three sub-sections are detected in the general design and boundary conditions.

- Flinthörndeich: 0+000 to 2+500 km
- Hafendeich (as part of the Flinthörndeich): 2+150 to 2+500 km, in the following stated as Hafendeich
- Ostdeich: 2+500 to 5+196 km

The weakest points are detected at the following positions [Dyke positioning based on Dyke register 2004]
Flinthörndeich : between 1+900 km and 2+070 km
Hafendeich: between 2+200 km and 2+700 km
Ostdeich: between 2+950 and 3+220 km

Map 3-4 shows the locations of the three main dykes on Langeoog island.



Map 3-4: Dyke sections in the western part of Langeoog

Three openings are situated in the dykes. All of them can be closed in case of a severe storm surge with flood gates or girders. Technical details of the openings are:

name of opening	width of opening	level of threshold	Top edge of gate/girder
	[m]	[m above NN]	[m above NN]
Rail way opening	4.00	3.74	5.51
Harbour road (Störtebeckerstrasse)	8.30	4.91	5.58
Road opening Willrath Dreesen Str.	6.00	5.00	5.93

Table 3-7: Details of dyke openings in Hafendeich and Ostdeich

Figure 3-7: Photo of dyke opening "Road opening Willrath Dreesen Strasse"

Figure 3-8: Photo of dyke opening “Harbour road (Störtebeckerstrasse)”

Figure 3-9: Photo of dyke opening “Rail way opening”

The necessity of closing the openings at a specific water level differs among these openings and depends on the threshold level of the construction and is laid down in emergency plans. The decision to close the openings is based on forecast values provided by storm surge forecasts.

Relative high uncertainties appear in the deterministic calculation of the dyke safety, especially soil mechanic parameters of the dyke sections are often analysed for different purposes. Reports describing the soil parameters are often written for planning proposes, construction scheme realized may be not in accordance with the planning. Some differences between mapped cross profiles and the results of the actual conducted survey during the dyke register investigation seem to corroborate this problem.

3.3 Deterministic calculation

One conclusion in KORTENHAUS et al. (2002) is that the most relevant parameters for the design of a sea dyke are the water level and some sea state parameters like storm duration, wave period and wave height.

A deterministic, instead of a probabilistic, approach is used because of :

- lack of a probabilistic tool for revetments like the used construction of Flinthörndeich or Hafendeich
- lack of probabilistic tools for dune erosion modelling
- lack of data (statistics of hydraulic boundary conditions)

3.3.1 Calculation of dune erosion

The calculation of dune erosion was performed with the numerical model UNIBEST-DE distributed by Delft Hydraulics, which computes the cross-shore profile development of sandy beaches, including the dune front, during storm conditions (DELFT HYDRAULICS 1995). Besides large wave attack these conditions are characterized by a considerable raise of the water level in a storm surge. The model is verified with data from physical models as well as from nature.

UNIBEST-DE, originally based on the DUROSTA-model, is a time dependent, two dimensional model which computes the sediment concentration and horizontal velocity in breaking waves. The local wave conditions are computed from the deep water wave characteristics using an energy decay method. Cross- shore profile changes are computed using a mass balance equation, taken into account the erosion of the dune. Seawalls and other structures in the cross-shore profile can be incorporated in the model. In this way the generation of a scour hole is taken into account. Erosion above the structure is also modelled by UNIBEST-DE. Gradients in longshore sediment transport can be incorporated in the model. This makes the model suitable for curved coasts or coasts where tidal influences are important.

In UNIBEST-DE the following physical processes are incorporated:

- mixing of sediment in breaking waves;
- changes in concentration profile due to varying wave conditions;
- settling of sediment, including hindered settling, space/time lagging;
- time average velocity below the wave through, consisting of a uniform,
- linear and logarithmic contribution;
- mass flux above the wave through;
- sediment transport above and below the wave through, resolution from the vertical integrated concentration and the vertical averaged velocity;
- sediment transport resulting from the beach slope;
- erosion of the dunes, due to wave run-up- and raise of water level.

The parameters to derive the shape of the surge are taken from GÖNNERT (2003). It is necessary to adapt these parameters to water levels from 1000 years up to 10.000 years return period. The overall possible storm surge duration in the model is approximately 3 tides.
The hydrograph curve of a certain storm surge is determined as an estimation due to lack of data concerning very seldom events by addition of a mean tidal hydrograph curve and a shape of the surge (i.e. wind and astronomic influence) according to GÖNNERT (2003) with an increase rate of 3 hours/meter [h/m] and a decrease rate of 6 h/m. A duration of highest surge which is deemed to be constant of 2 hours. This level of highest surge begins and ends one hour before and after high tide respectively (see chapter 5.1.3).

Failure definition for dune sections is

$R/S<1$ equation 3-7

Where: R = Resistance

S = Stress

$R = w_{d8} - U$ equation 3-8a

$S = r_{d8}$ equation 3-8b

w_{d8} = dune width at level of NN + 8 m [m]

U = surcharge of 15 m to take uncertainties into account

r_{d8} = regression due to erosion calculated with the dune erosion model at level of NN + 8 m [m]

To take model and data uncertainties as well as potential effects of longshore transport into account a surcharge has to be determined. This calculation is done in analogy with JORRISON (2001) and yields an average surcharge value for the present dune situation of 15 m (beach and shape of the dunes) (NLWK 2002). This means that a remaining dune width at level NN+8m smaller or equal than 15 m is deemed to be a failure of the dune.

3.3.2 Calculation of dyke failure

The computer model ProDeich has been developed during a project, the ProDeich project 'Probabilistische Bemessungsmethoden für Seedeichen', at the Leichtweiss at the University of Braunschweig (KORTENHAUS / OUMERACI 2002, KORTENHAUS 2003). The model allows the calculation of the failure probability of sea and estuary dykes. One part of the model is a program based on a MS Excel interface and a program code in Visual Basic that enables a deterministic failure calculation of dykes using 25 failure mechanisms and 87 input parameters and the visualisation of the fault tree (see Kortenhaus, 2003).

In the traditional deterministic calculation failure is defined by

$R/S < 1$ equation 3-9

Where R is the resistance of the structure and S is the stress resulting from the different loads on the structure.

Figure 3-10 presents an overview of the failure mechanisms of a sea dyke which are considered in the ProDeich model.

The failure mechanisms are divided into the following four groups:

- Global failure mechanisms result in a direct failure on the cross-section;
- Failure mechanisms on the seaward slope lead to failure of the seaward slope and subsequently to breaching;
- Failure mechanisms on the shoreward slope lead to failure of the shoreward slope and then to breaching (`'Kappensturz' is not included since it is a separate branch in the fault tree);
- Failure mechanisms in the dyke core describe mechanisms which lead to inner erosion of the core and thus provide the basis for breaching of the dyke.

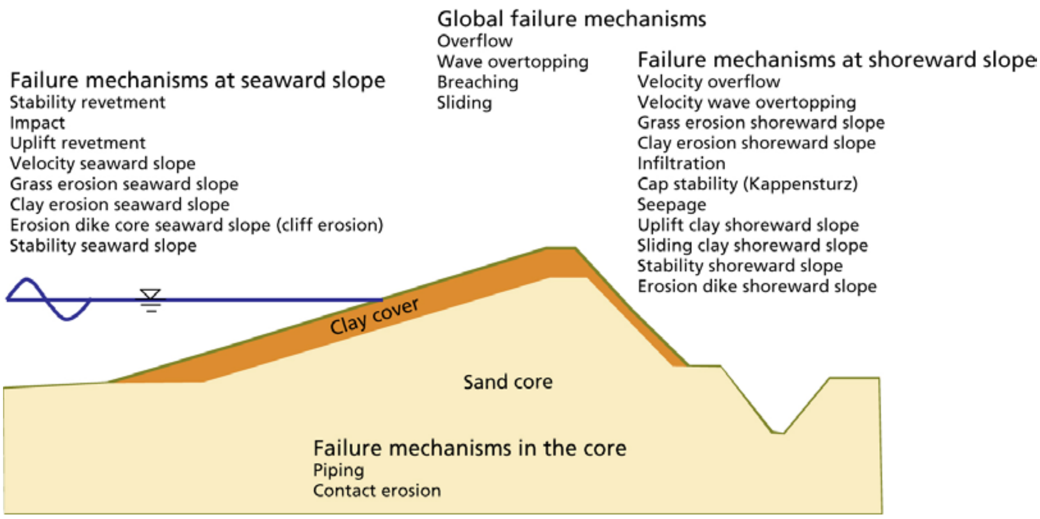


Figure 3-10: Failure mechanisms in ProDeich (from Kystedirektoratet 2004)

For limit state equations and more detailed descriptions of the failure mechanisms, see Kortenhaus (2003). The connections between each failure mechanism are considered by means of a fault tree (see Figure 3-11). In the fault tree, additional possible failure mechanisms are provided which are not considered in this study due to lack of models, shortage of data or an estimated extremely low failure probability. These failure mechanisms are e. g. vandalism, explosion, sabotage, ship collision, liquefaction and damage by debris.

Due to the lack of a revetment type that is implemented in ProDeich, all failure mechanisms for revetments are not considered in the calculations either. Due to the construction type of the Hafendeich which consists of a paved crown, all failure mechanisms for sliding are not considered either. The total number of input parameters is therefore reduced to **75**. All gates in the fault tree will be calculated according to Kortenhaus (2003) and are schematically shown in Figure 3-11.

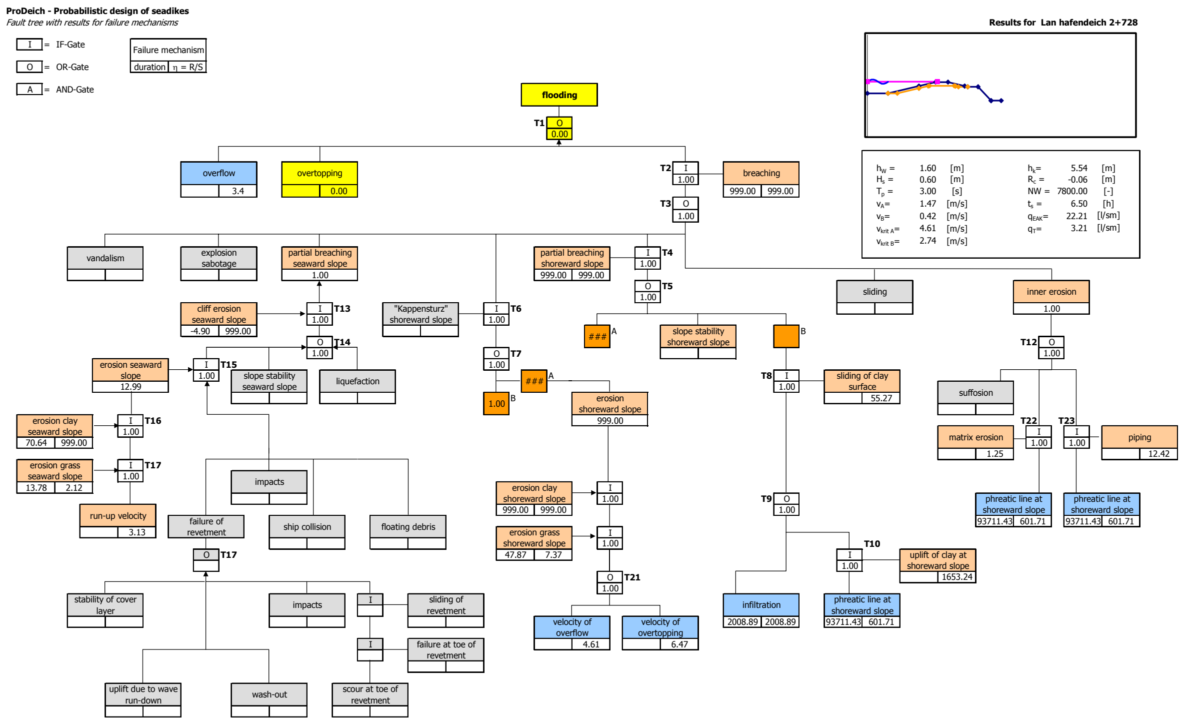


Figure 3-11: Fault tree for the Hafendeich – failure due to overtopping

The calculations of the limit state equations and the failure probabilities have been performed by software programmed in 'Pascal'. MS Excel extended with VBA routines has been used to check the calculation results of the limit state equations, to calculate the limit state equations in the fault tree as well as to display the results. The software has been developed at the Leichtweiss Institute and details are provided in Kortenhaus (2003). (Kystedirektoratet 2004)

The failure mechanisms of the locks of the dyke openings have not been assessed due to a lack of methods.

3.4 Failure probability of the coastal defence system

3.4.1 Dune failure

The investigated dune situation of spring 2003 shows significant differences between the dune sections A – E concerning the resistance against dune erosion. According with the input parameters used for classifying the sections the results for the profiles of sections A and D represent a sufficient dune situation after all calculated storm surges. In section C a sufficient remaining dune width at a level of NN + 8 m is calculated for the profile C930. In section E, the dune belt in the north of the Pirola valley, the results for the two investigated cross profiles vary in a range of about 6 m. The simulated storm flood with a tidal water level of NN+ 5.68 m leads to erosions depth of about 20 m. Depending on the initial dune shape which differs between E3130 and E3150 these dune erosions result in a failure of the dune for the profile E3130 whereas the remaining dune profile of E3150 is judged as sufficient. Table 3-8 shows the initial and the remaining dune width at the level of NN + 8 m for the investigated storm surge levels of NN + 5.06 m, NN +5.24 m and NN + 5.68 m corresponding with the return periods of 10^3 , $2*10^3$ and 10^4 years.

Additionally, the eroded dune volume above NN + 4 m, the calculated safety according to equation 3- 7 and the failure assessment of the profile are specified.

Cross profile	Return period	Initial width at NN +8 m	Erosion at level NN + 8	remaining width at NN + 8 m	Loss of material above NN+4m	remaining dune height	Safety eta = R/S	Safety eta = R/S
[-]	[years]	[m]	[m]	[m]	[m]	[mNN]	[-]	[-]
A30	1,000	101	8	93	55	14.60	10.75	Safe
	2,000	101	11	90	65	14.60	7.82	Safe
	10,000	101	17	84	88	14.60	5.06	Safe
C930	1,000	52	11	41	78	12.90	3.36	Safe
	2,000	52	13	39	91	12.90	2.85	Safe
	10,000	52	17	35	120	12.80	2.18	Safe
D2120	1,000	140	3	137	48	11.40	41.67	Safe
	2,000	140	5	135	61	11.40	25.00	Safe
	10,000	140	10	130	85	11.40	12.50	Safe
E3130	1,000	34	11	23	71	10.00	1.73	Safe
	2,000	34	14	20	84	10.00	1.36	Safe
	10,000	34	20	14	111	9.70	0.95	Failure
E3150	1,000	40	11	29	73	9.30	2.27	Safe
	2,000	40	13	27	84	9.00	1.92	Safe
	10,000	40	21	19	112	8.70	1.19	Safe
E3130_syn	1,000	34	16	18	101	10.00	1.19	Safe
	2,000	34	18	16	112	9.90	1.06	Safe
	10,000	34	25	9	144	8.90	0.76	Failure

Table 3-8: Results of the numerical simulation of dune erosion

3.4.2 Dyke failure

The results of the deterministic ProDeich calculations are shown by fault tree plots in Appendix A. The results clearly show that overtopping is the only global failure that occurs. Table 3-9 shows the safety coefficient eta = R/S for the investigated profiles.

Waterlevel Exceedance Probability	NN + 5.06 m 1/1.000 years		NN + 5.24 m 1/2.000 years		NN + 5.68 m 1/10.000 years	
Wave condition	estimated	increased	estimated	increased	estimated	increased
Flinthörn	4.70	2.43	4.24	2.15	3.11	1.55
Hafendeich	53.48	32.76	25.36	15.65	0.00	0.00
Ostdeich	13.65	5.33	12.26	4.79	8.87	3.46

note: Wave conditions cp. chapter 4.2.1 (estimated = Mai et al. 2004)

Table 3-9: Deterministic ProDeich result on safety against Overtopping (eta = R/S)

Overtopping of the Hafendeich will lead to a failure of the dyke for storm surge levels with a return period of 10.000 years.

The Overflow and/or overtopping volume over the (closed!) dyke opening for water level between NN+5.51m and NN+5.68m is relative small compared to the overflow at the dyke section. It is assumed that the gate of the dyke opening will not fail due to overflow before the dyke does. Therefore the return period for this event is assumed to be identical to the return period of overtopping the Hafendeich which is $T = 1 * 10^4$ years.

It is assumed that the large overtopping and overflow volume will lead to a structural failure of the Hafendeich, at least the locations of the dyke openings will be starting points for the structural failure. Since a point in time of failure or a specific position in a dyke section can not be deduced from the results calculated in ProDeich, it is assumed that further applications of the failure, e.g. in the damage estimation are best done by scenarios.

3.5 Remarks on results

It should be stressed that the uncertainties of wind set-up statistics will influence the results of the calculation of failure probability significantly. The absolute width of the confidence interval of the log-normal distribution as the best fitting distribution function is 84 cm for a returen period of T=1000 years, 93 cm for T = 2000 years and 115 cm for T = 10 000 years.

The actual dune width is mainly influenced by morphological processes. Negative combinations of beach and near-shore development have been observed in the past.
To investigate such morphological situations and their effect on failure probability of the dune, a unfavourable synthetic cross profile is simulated for dune section E3130 and the results of the simulation of this profile show clearly the strong influence of the morphological situation on the dune safety.
Another important aspect while assessing the safety of a dune is the fact, that just one surge event for this calculation is taken into account. Additional surges and morphological changes of the beach and foreshore leading to further dune erosion are likely to occur during one winter season. Especially on an island like Langeoog it would be an extremely difficult task to re-establish the dune corpus during wintertime. Therefore a requirement for elaboration of methods how to execute safety calculations for dune areas can be monitored.

Discussion of results Hafendeich failure versus dune failure
Morphological changes may lead to a situation of smaller dune belt and higher loads on the dunes due to changed boundary condition. This may result in significant differences in failure probability between dune and dyke section as described above.

Due to the high dynamic processes in the foreshore and beach in the north of the Pirola valley significant changes of this coastal defence system element, the dune belt, can take place in a shorter period than changes of the dyke sections. Therefore even an equal failure probability has to be assessed different considering the time scale of possible changes. It becomes clear that a monitoring program with a high resolution of time and space to detect changes is an important and necessary part for coastal management plans.

Due to human error such as “forgetting to close the gate” failure of dyke openings for railway and street (Deichscharte) in the harbour area may lead to a flooding event. This may occur in case of storm surge water levels above NN+3,74m and/or NN+4.91m which is level of bedplate of dyke opening for the railway and road, respectively. Due to a lack of technical evaluation methods these failure mechanisms were not taken into account. But are are considered to be in important factor to increase the probability of failure.

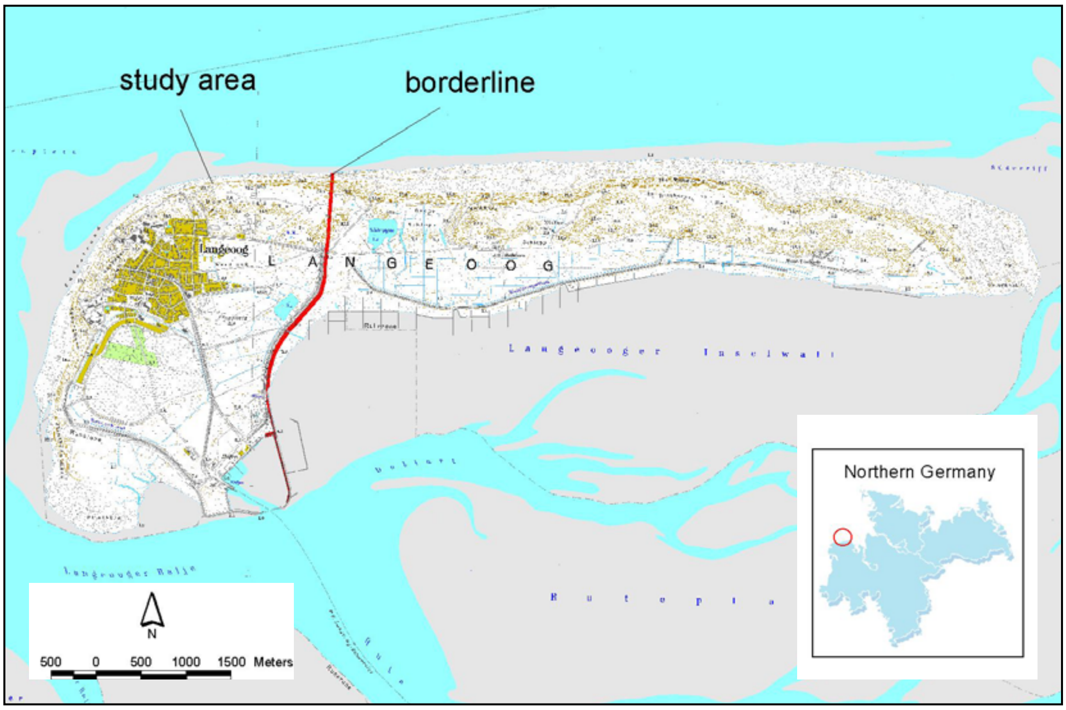
Since no point in time of failure, no specific position dyke section with comparable parameters it is assumed that further application of the failure is best done by scenarios.

4 Valuation analysis

The valuation analysis was carried out by the Department of geography at the University of Kiel (2004).Main results of this study are described below.

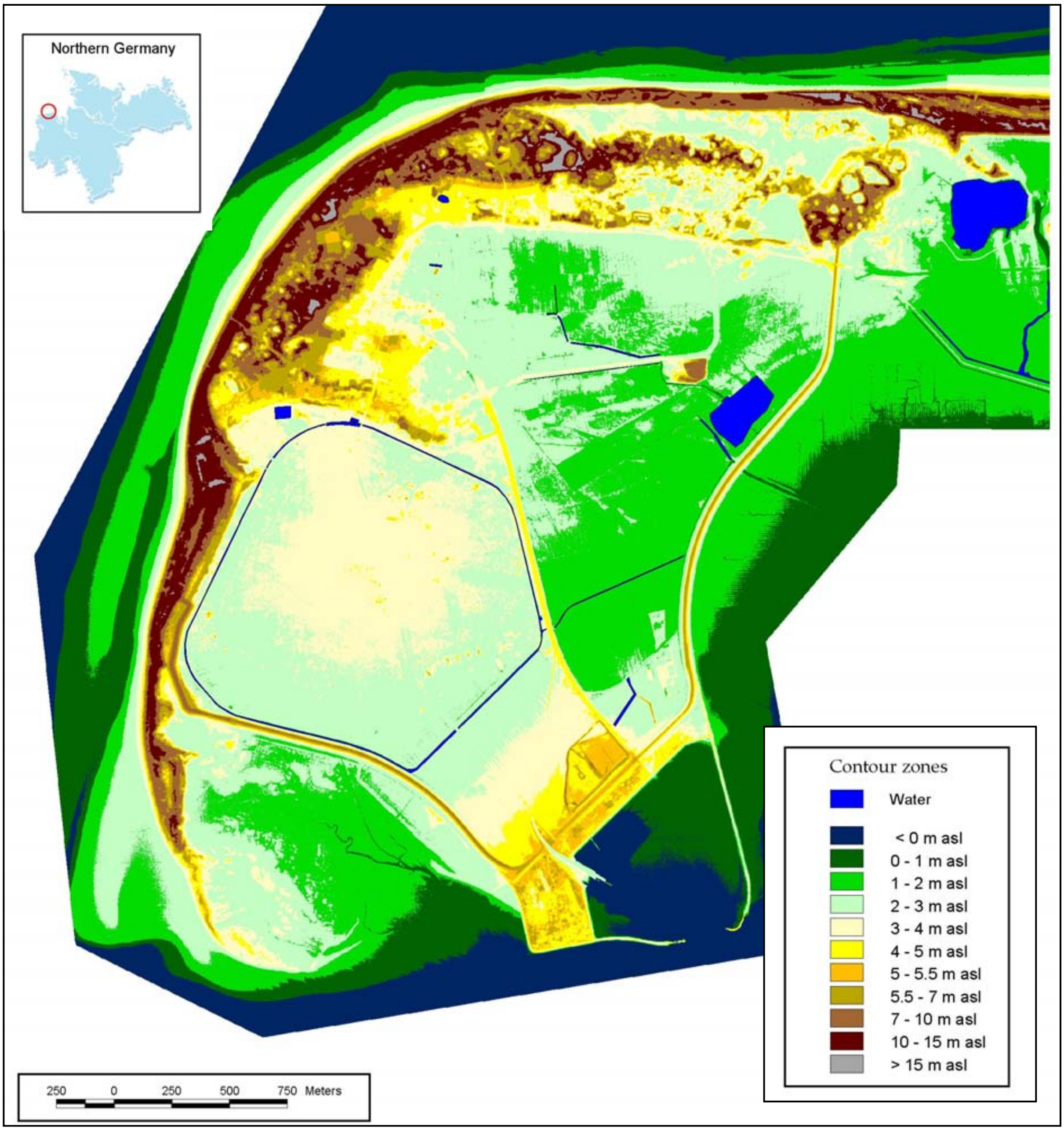
4.1 System demarcation

As the closer study area the western part of Langeoog is defined. This region includes i.a. the site of Langeoog (Map 4-1;).



Map 4-1: Study/ working area of the Langeoog Island

The topology of this western part of the island is displayed in map 4-1.



Map 4-2: Hypsometric map of the western part of Langeoog Island (from UNIVERSITY OF KIEL 2004)

Map 4-1 shows that Langeoog is protected against the North Sea to the west and the north by a coherent dune system. The hinterland of the island however lies comparatively low and is therefore protected against flooding by a ring dyke.

Figure 4-1 and table 4-1 illustrate the distribution of the height zones up to 5.5 m above sea level for the western part of Langeoog.

The largest proportion of about 40% of the total study area lies at the height zone between 2 and 3 m.

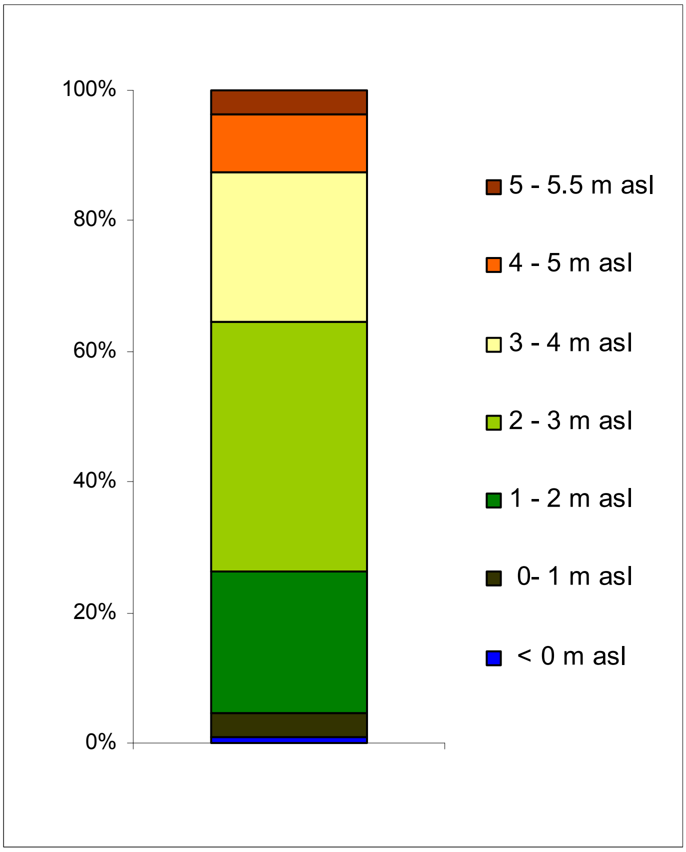


Figure 4-1:
Percentage height distribution of the western part of the Langeoog Island; up to NN+5.5 m (from UNIVERSITY OF KIEL 2004)

Table 4-1:
Height distribution of the western part of the Langeoog Island; up to NN+5.5 m (from UNIVERSITY OF KIEL 2004)

Area (ha)	***Height (mNN)***	***%***
28.30	***5 - 5.5***	3.67
31.50	***4.5 - 5***	4.08
36.31	***4 - 4.5***	4.71
56.96	***3.5 - 4***	7.39
121.31	***3 - 3.5***	15.74
135.99	***2.5 - 3***	17.64
157.25	***2 - 2.5***	20.40
135.16	***1.5 - 2***	17.53
32.59	***1 - 1.5***	4.22
17.71	***0 .5 - 1***	2.29
11.32	***0 - 0.5***	1.47
6.19	***< 0***	0.80
770.66	***Total***	100.00

4.2 Structure of valuation project

The assessment of the damage potential requires several procedures and different sources of information. The project structure is represented in figure 4-2.

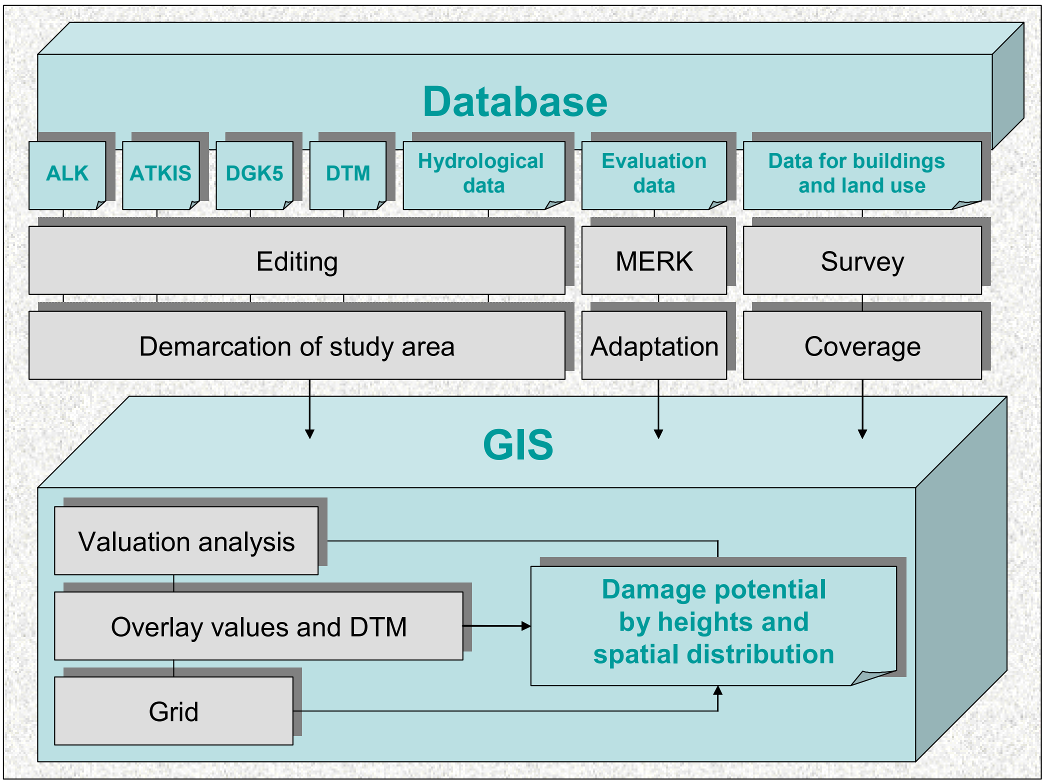


Figure 4-2: Project structure for the valuation of the damage potential (from University of Kiel 2004)

Processing, modification and actualisation of the digital data

Different digital cartographic bases were provided by the contractor (ALK, DGK5, ATKIS, TK25, TK50). These had to be adapted both to the requirements of the valuation analysis and to the size of the working area (e.g. by classification of different land uses). Besides, the valuation data and procedures, which were generated in the project MERK, had to be updated and adapted to the specific regional conditions.

Demarcation of the study area

The contractor NLWK defined the western part of the island Langeoog as the closer study area. It includes mainly the site of Langeoog village, which is protected, as described in chapter 4.1, on the one hand by preliminary dunes and on the other hand by a ring dyke. The area within the limits of the dyke and the dune is classified by the coastal defence authority as the flood-prone area. Hence the cartographic information had to be restricted on this area (cp. Chapter 4.1).

Field work

The field work provided the essential information about the buildings, the land use and infrastructure facilities for the determination of 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.

GIS and data integration

Subsequently all data are transformed in the GIS and linked with the cartographic bases.

Valuation analysis

On the basis of the methodology, developed in the project MERK, the different damage categories are evaluated. Guest beds, jobs and inhabitants are only recorded quantitatively (intangible values). The other objects are defined as tangible values and can be assessed monetarily:

- Buildings
- Building inventory (household effects)
- Real estate values
- Motor vehicles
- Traffic areas
- Agricultural land
- Livestock assets
- Forest land
- Recreational land
- Gross value added
- Fixed assets
- Stock value

Combination of the damage potential with the height information

As the height of the objects at risk have a significant influence of the damage expectation in case of flooding, the values of the single objects are linked with the heights of the study area. For that purpose the single layers (e.g. land use, infrastructure, use of the buildings, etc.) are overlaid with the hypsometric map of the island. Therefore height zones with an equidistance of 0.5 m were generated out of the original grid.

Generation of the spatial distribution of the damage potential

Apart from the absolute damage potential as well as the knowledge of the vertical distribution the spatial distribution of the assets is of prime importance especially for future risk management.

A grid with a resolution of 300 x 300 m was therefore projected onto the study area (analogous to the methodology of the MERK-project) and overlaid with the spatial information of the damage potential.

A concentration-dependent colour for the individual grid squares enables to display the spatial distribution of either the single categories or the total assets.

Valuation analysis determines and quantifies the material and non-material goods of a well defined study area. Often the term damage potential analysis is used analogously, which however isn’t a standardised term in the technical literature. Thus this term is often used in connection with the assessment of the damage expectation.

The damage potential in this study is equivalent to the values, which are threatened in their integrity by a certain hazard. Due to the complexity of the structure of the values within the specific area, it is nearly impossible to identify and assess all elements at risk within the scope of a vulnerability analysis, respectively a valuation analysis. The impact on the ecosystem for instance or the consequences for special values such as significant historic elements are hard to determine and thus not the subject of the appraisal at hand.

The majority of the elements at risk can be determined quantitatively as monetary values. Other elements such as inhabitants can only be assessed in terms of numbers. Ecological assets, on the other hand, are difficult to determine, e.g. by analysis of the willingness to pay or travel expenses. According to the differences, the elements at risk have to be evaluated with the available resources and with the maximum possible scale and preciseness.

Microscale valuation analyses require detailed, object-orientated information about the vulnerable structures. The selection of the categories relevant for the investigation requires first of all an identification of the objects, which can potentially suffer damages by a certain hazard.

Direct losses are caused by the immediate effect of the event such as building collapse, while *indirect loss* are normally long-term, respectively consequential damages, such as the disruption of economic and social activities. Indirect damages arise mainly through the second–order consequences of disaster and thus cannot be easily attributed to the event directly. In addition direct and indirect losses can be classified into tangible and intangible effects. Tangible effects are those for which it is possible to assign fairly reliable monetary values. Indirect effects, although real, cannot be satisfactorily assessed in monetary terms and can thus be determined only descriptively.

4.3 Methodology of valuation

In the course of this project the focus was on the evaluation of mainly direct, tangible and partly intangible values. Figure 4-3 illustrates the different value resp. damage categories, found to be relevant on Langeoog. According to this, the majority of the elements can be assigned to direct, tangible and primary damages.

Physical damages to public and private properties can be evaluated and are an important base for the determination of the vulnerability. Primary personal injuries and direct, intangible damages are of priority in risk handling.

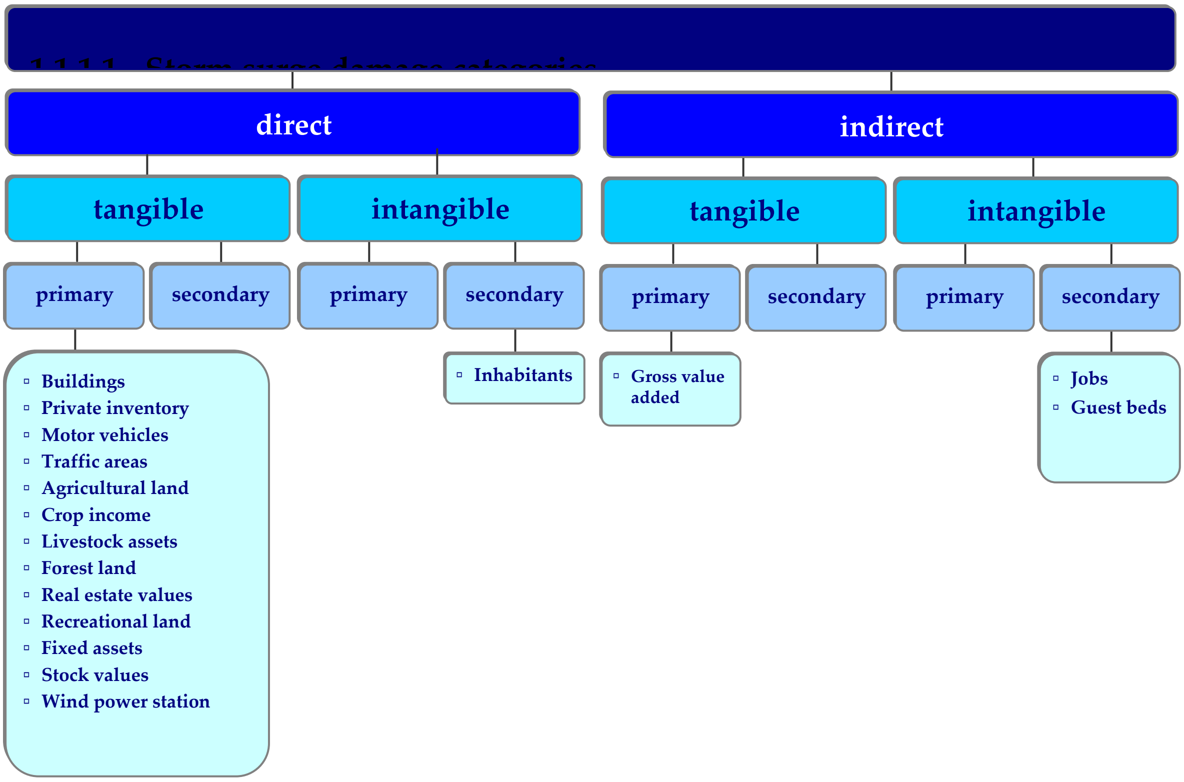


Figure 4-3: Storm surge damage categories within the Langeoog project

Thus also the coastal defence planning is oriented at the safety of the inhabitants i.e. their protection in the flood prone areas. Even though several approaches exist (cp. NOWITZKI, 1997) to evaluate human life as a monetary value, in this project the population at risk is considered as intangible due to ethical reasons. Hence only the number of inhabitants is considered as relevant.

In the category of tangible indirect values, the losses of the value added in case of business interruptions are considered. Jobs and guest beds at risk, as part of the indirect, intangible objects, are only assessed according to their quantity.

Regarding the monetary valuation of the assets the study distinguished between two different approaches. The gross coverage principle describes the replacement value and the net principle describes the current value. Dependent on the particular category, this study uses both concepts and can be characterised as an insurance approach.

In Germany storm surge risks are presently considered as not insurable. But it is nevertheless of importance, which kinds of losses may be covered by weather-related insurances in the future and how the damages turn out to be.

What kind of costs can be covered by insurances in case of loss? While householders' insurance refunds the replacement value in case of loss, the current market value is the base for loss adjustment of an automobile insurance. Accordingly, both the net and gross coverage principle is applied.

When going through a microscale valuation analysis, serious problems may arise, regarding uniform reference levels, reference date and source, through the object-related data requirements. Moreover the data availability on the object level could be very restricted by data security. Consequently the valuation analysis had to be based on various sources, reference dates and levels of aggregation (Tab. 4-3).

An important information base for the study at hand was the field work conducted in the investigation area. Besides the survey of land use, the specific structure of each building, as well as the number of storeys, age and use of the building was collected on the basis of the *Automated Real Estate Cadastral Map* (ALK). However in this routine the information of the ALK proved insufficient for several demands. Some essential information for the valuation analysis such as number of storeys and use of the building are not available from the ALK and in addition the data set is partly incorrect. In particular addresses were thus attributed incorrectly. Numerous land uses and other usage information didn't correspond with the reality. The lack of correct and up-to-date information on buildings caused problems during the inventory of buildings and land.

Damage category	Source	Reference date	Indicator
Inhabitants	• Resident register Langeoog	• 10/ 2003	• Number of people
Jobs	• Business interviews, Field work	• 9 - 10/ 2003	• Number of employees
Guest beds/ Tourism capacity	• Tourism catalog Langeoog, Field work	• 2003 bzw. 9/ 2003	• Number of beds
Buildings	• ALK • Field work • Valuation guidelines 2000	• 10/ 2002 • 9/ 2003 • 12/ 2001	• Base of the building in m^2 • Number of storeys, age, condition • Value in Euro
Private Inventory	• ALK • Field work • Insurances	• 10/ 2002 • 9/ 2003 • 9/ 2003	• Living area in m^2 • Use of the building • Value in Euro/m^2 living area
Motor vehicles	• Municipality based motor vehicle specification • Internet / market analyse of used cars	• 11/ 2003 • 12/ 2003	• Number of motor vehicles by type • Value in Euro / vehicle
Traffic areas	• ALK • Field work • Internal municipality investment specification	• 10/ 2002 • 9/ 2003 • 11/ 2003	• Area in m^2 • Street-/Road length in m & Type of traffic area • Construction costs in Euro/m resp. Euro/m^2
Agricultural land	• ALK Advisory committee for real estate values at Cadastral office Aurich	• 10/ 2002 • 1/ 2004	• Land use in m^2 • Value in Euro/m^2
Livestock assets	• Field work • Lower Saxony State Office of Statistics • ZMP	• 9/ 2003 • 1999 • diverse	• Agricultural farms • Number of farms with livestock • Livestock by species • Value in Euro/exempl. resp. Kg
Forest land	• ALK • Official soil consultant - Local Tax Office Wittmund	• 10/ 2002 • 10/2003	• Forest land in m^2 • Value in Euro/m^2
Real estate values	Advisory Committee for Real Estate Values at Cadastral Office Wittmund	• 1/ 2003	• Standard land value in Euro/m^2
Recreational land	• ALK • Field work • Specialist interviews	• 10/ 2002 • 9/ 2003 • 10/ 2000	• Area in m^2 • Type • Construction costs in Euro/m^2 resp. /facility
Gross value added	• Lower Saxony State Office of Statistics	• 2001	• Value added per employee
Fixed assets	• ALK • Field work • Spezialist interviews (production facilities, factory insurance)	• 10/ 2002 • 9/ 2003 • 12/ 2000	• Base of the building in m^2 • Area of business enterprise in m^2 • Value in Euro/m^2
Stock value	• ALK • Field work • Deutsche Bank (annual accounts of West German companies) • Internet	• 10/ 2002 • 9/ 2003 • 1996 • diverse	• Base of the building in m^2 • Area of business enterprise in m^2 • Value in Euro/m^2 business area • Value in Euro/m^2 business area

Table 4-3: Data base for the valuation analysis (from University of Kiel 2004)

Therefore the ALK data could only be used as cartographic base for the survey, but after an updating routine they were usable for the valuation of the different land use outside the residential areas as well. The time-consuming microscale data survey provides very detailed information about the elements at risk and enables an accurate spatial mapping of all the objects, such as the number of inhabitants. For the valuation of the inhabitants at risk the internal statistic of the municipality could be used.

While the economic data was derived from expert and company interviews, additional information was received through extensive internet inquiries.

Yet, it should be clear that the assessment of the damage potential is always a snapshot of the survey at a specific date.

Short-term changes such as the variation of the land use within a season can be considered, but only with an enormous effort. In the future an iterative valuation analysis, at least for certain parts would be reasonable and eligible, especially in the scope of a risk monitoring.

The GIS plays an important role at the valuation analysis as a technical instrument. By overlaying the corresponding information layers an analysis regarding the spatial distribution of the values could be carried out. The illustration of the damage potential was realized using a grid. The size of each cell is 300 x 300 m, but it can be modified according to the assets considered and the required resolution.

Below the specific categories and the relevant assessment methodologies of the valuation are presented:

Inhabitants

The valuation of the inhabitants at risk was conducted on the base of the building of the ALK and by means of the municipality internal register of the population (GEMEINDE LANGEOOG, 2003b). The surveying and mapping and the ALK enabled an accurate assignment of the streets and street numbers to each single houses.

On the basis of the survey results and the mentioned register the inhabitants of the flood-prone area could be identified. Since the secondary residence is of importance in tourist municipalities both the main and auxiliary abodes were surveyed. The recorded number of inhabitants at risk is consistent with the maximum population within the potential flooding area. No reliable information is available about the time variability of the population such as absence of the people or seasonal concentration differences.

Employees / Jobs

Employees in this context are defined as the manpower resources within the study area. Thus this definition is different from the one given in the national statistical records i.e. such

as persons employed liable to social security and economically active population. The number of employees is the key parameter for the evaluation of the gross value added and consequently requires a detailed assessment.
The valuation of the employees is based on mean values depending on the economic category, developed within the MERK-project.

The mean values were updated and adjusted to the local conditions by additional interviews of subjective selected local firms from Langeoog Island. This information as well as the surveyed and mapped economic category and the companies' surface area provided the base for the valuation of the employees.

Guest beds/ tourism capacity

The official statistics on tourism are unsuitable for the determination of the number of guest beds at risk, since there are only companies included with more than 8 beds. In many places private providers have a significant share in the total number of tourist accommodations. Because they often have less than 9 beds, statistical data alone will yield an underestimation of the total tourism capacity.
Hence an analysis of the local accommodation catalogue and of the online pages of private providers was necessary (KURVERWALTUNG LANGEOOG 2003). In connection with the information of the field mapping it was possible to allocate the beds spatially to the houses in the potential flooding area.
The surveying and mapping produced a much higher number of tourist buildings than the local accommodation catalogue. This can be attributed to the fact, that not all accommodations are registered in the catalogue. According to the size of the houses and the type of business an average number of beds was assigned to these non-registered accommodations.

Buildings

The building assets were computed according to the *Valuation Guidelines and Manufacturing Costs 2000* (BMV 2001). This allowed the calculation of the replacement value for different types of buildings by considering the height of each storey, base surface and age of the building. While the relevant building parameters were collected in the course of the field work, the surface area was taken from the digital data basis ALK. As far as basements existed and were visible, they were considered on surveying.
Different correction factors had to be included in the computation due to significant regional variations of the manufacturing costs. These factors consider the size of the city as well as the different regional construction costs within the federal territory.

Apart from the valuation of the main buildings the replacement costs of the annex structures such as garages or summer houses were also assessed.

Official manufacturing costs don't give much information about the value of these objects, so that additional data was extracted from an internet inquiry (MULTI-GARAGEN, 2000; HEIMWERKER.DE 2000). Outside facilities have been assessed in consultation with the regional insurance company *Provinzial Brandkasse Kiel* in the amount of 3% of the total building value (KÄHLER 2000).
The value of the properties was determined separately in the scope of the real estate valuation.

Private Inventory
The determination of the inventory assets was conducted according to the rating of household insurances. The PROVINZIAL BRANDKASSE (2000) estimated the private inventory of their clients by a flat-rate value of approx. 700 €/m^2 living area. This value has to be enhanced in case of high-quality houses and reduced for low-value buildings and annexes. The living area of each building could be computed from the gross base surface using a particular factor (KLAGGES / ARETZ 2000).
The inventory assets of business enterprises were determined separately in the framework of the valuation of the fixed assets.

Motor vehicles
The motor vehicle assets are estimated on the basis of information of the municipality of Langeoog. Stock data of automobiles and number of powered two-wheelers, commercial cars and trailers were used. As the island of Langeoog is car-free, only three passenger cars were identified within the study area.
By the internet based analysis of the second-hand passenger car market in the context of the MERK project, mean values have been derived and applied for Langeoog (ANNONCEN AVIS, 2000; MOBILE.DE, 2000).
Besides regular cars, electric trolleys and other commercial cars were assessed. Their values were estimated through an internet based analysis. The transfer to the assets found in the study area took place via the business enterprises. The respective economic category and the size of each company were also considered.

Traffic areas
The traffic areas include both line elements such as streets, railroads, cycle tracks and footpaths and spatial objects such as parking areas.

The information about length and extent of the traffic structures were extracted from the Geographical Information System. Subsequently these objects were evaluated by average construction costs of different types of elements.

Agricultural land

The ALK offers information about agricultural land use. This information was verified with the results of the survey and the land use plan of Langeoog and finally transferred into the GIS.
The values of the agricultural areas could be evaluated on the basis of average prices, derived from sales of agricultural land by official soil consultants. Here, different land values classified by the type and quality of the soils were considered.

Lifestock assets

In the context of this category all productive livestock is evaluated. The stock figures were taken from the official state statistics of Lower Saxony (NIEDERSÄCHSISCHES LANDESAMT FÜR STATISTIK 2001) and verified by field surveying. The assessment of the assets is based on producer and wholesale prices of the ZMP (2003). Farms with stock rearing have been attributed with municipality-based mean values. These farms were identified in the course of the surveying and mapping.

Forest land

Forest areas were identified via the ALK and from the land use plan of Langeoog and were updated by the field work. Information regarding the monetary valuation was provided by the official soil consultants. The monetary value of the forest land was then assessed on the basis of different hectare prices depending on the type of forest.

Real estate values in residential areas

For assessment of property values in residential areas all lots were summarized which show housing. This comprises the surface areas of buildings as well as real estate sites without buildings.
These areas had not been included in course of the mapping of the building assets and thus had to be evaluated separately. As valuation basis standard land values released by the Advisory Committee for Real Estate Values at the Cadastral Office Wittmund were used.

The determination of these standard values was based upon a compilation of purchase prices. The main basis for these are the prices of undeveloped real estate areas, i.e. their values without unusual or special conditions on the real estate market. Standard land values are determined from the value, which would result, if properties were undeveloped.

They refer to building land before preparation regarding their development status. While the standard land values are usually classified either as construction sites, multiple storey construction sites or industrial building land, this study selected only a mean value, because a correct attribution to one of these areas was not feasible from the cartographic base at hand.

Recreational land

The surfaces of the tennis courts, sports fields, miniature golf, playgrounds and campgrounds are summarized under the term recreational areas.
Due to the different infrastructure of these areas their valuation had to be made individually. For the only campground in the east of the island the standard land value was used for the monetary valuation. Information about the construction costs of the other recreational areas were received from expert interviews. Thereby both prices based on square meters and total values for the whole equipment were considered.

Gross value added

For the economic damage categories the limited microscale data availability allowed only a rough estimation of the potential values at risk in the study areas.
In national economic terms gross value added is defined as the manufactured goods and performed work given. In the national accounting the added value is taken as the difference between output value and intermediate inputs (SCHREIBER 2000). The gross value added can serve as a size for the possible losses of production in case of flooding accordingly. It is indicated for a full financial year.
Since information about the gross value added was not available on municipality level, we had to revert to more aggregated data, in order to estimate the added value approximatively.
The Lower Saxony State Office of Statistics publishes the average gross value added at manufacturing prices per employee for different economic sectors for the district Wittmund. Depending on the economic category an average gross value added can be assigned to the employees of each business of Langeoog Island.

Fixed assets

According to SCHREIBER (2000) the fixed assets comprise all the assets designed for permanent or perennial use. Thereby material, immaterial and financial fixed assets are distinguished. It is assumed that financial assets and parts of the immaterial fixed assets are normally not vulnerable against flooding. Hence in the context of this study only the material fixed assets of the local businesses will be determined and can consequently be defined as the equipment assets. In the scope of the valuation analysis all non-private used buildings are considered. Expert interviews with different equipment providing companies as well as factory insurance companies and potentially affected businesses provided information about the fixed assets, respectively the equipment assets. Square meter based prices were assigned to the individual companies according to the type of business. The surface area of each company was also included.

Stock value

The stock value is defined as part of the floating assets, which is in stock for production and sale. It includes raw, auxiliary and operating materials, semi-finished and finished products (SCHREIBER 2000). During the valuation the problem occurred, that statistical data is only available on regional level and is not differentiated according to economic sectors. The *Deutsche Bundesbank* which publishes the annual financial statements of West German companies differentiates according to economic sectors (DEUTSCHE BUNDESBANK 1999). Furthermore, numerous firms submit their annual financial statements to the public, so that percentage ratios from fixed assets to stock value can be derived from this detailed listings of the tangible fixed assets and the stock value. Thus, on the basis of the determined equipment assets the stock value of each business could be assessed within the study area.

Wind power station

There are no wind power stations on Langeoog.

4.4 Results of the valuation analysis

The results of the valuation analysis for the investigation area Langeoog Island are represented below. According to the requirements of the contractor the damage potential is only represented for the terrain heights up to 5.5 m above sea level. Judging from historical storm surges and taking the sea level rise into account, this height zone can be classified as the flood prone area.

In order to complete the results and present an overview of the total area, the values of the zones above 5.5 m asl are illustrated additionally. 83.5% of the total values are located in areas up to 5.5 m above sea level. The results up to the 5 m contour line allow a comparison with the damage potential of the areas analysed within the MERK-project.

Total values up to 19.5 m above sea level: 1,115,894,800 Euro

Total values up to 5.5 m asl: 931,522,000 Euro

Total values up to 5.0 m asl: 864,209,900 Euro

83.5% of the total values are located up to 5.5 m asl

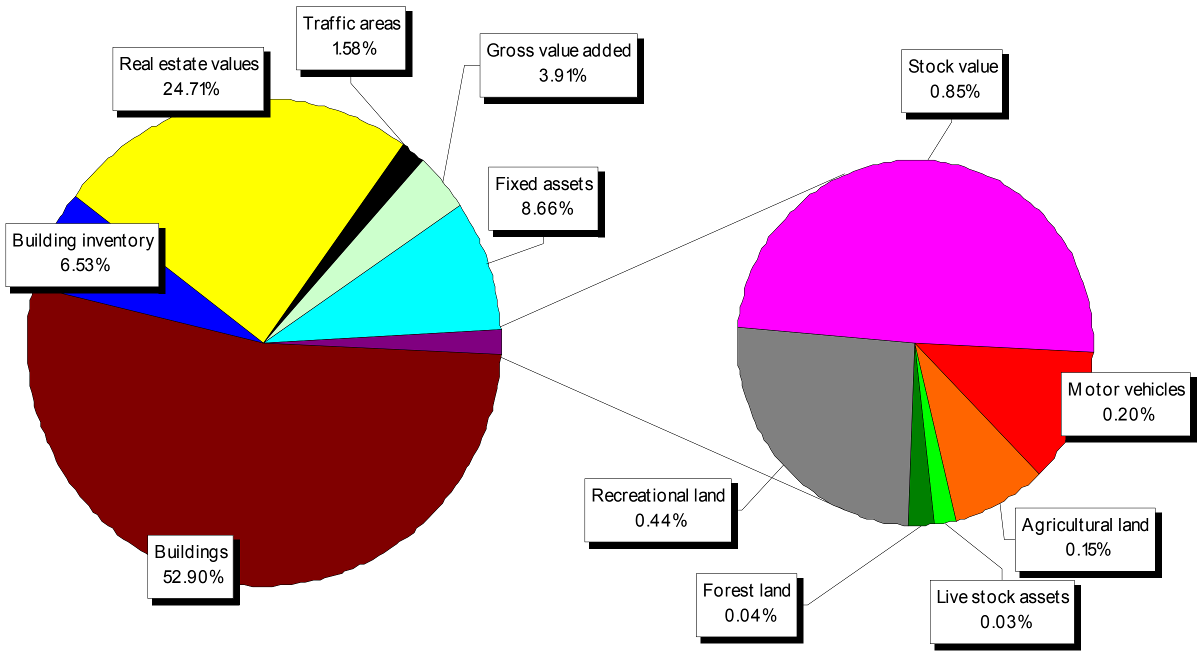


Figure 4-4: Distribution of the damage potential separated by each category

4.5 Pirola valley – relevance for drinking water supply

Importance of the Pirola valley for the drinking water supply on Langeoog

Under the dune areas of the island a freshwater lens is located. Most of the necessary amount of water for sufficient drinking water supply is won directly eastward the village of Langeoog by vertical filter wells from this lens. Due to the natural spreading of the dunes as well as the different use restrictions existing in the area (spatial planning, pollution or nature protection), the extraction area is limited to the range of the Herrenhus dunes. Since there is no drinking water pipeline to the mainland, the drinking water supply is solely based on the freshwater lens. The OOWV (Water Board of Oldenburg and Eastfrisia) is responsible for the drinking water supply on the island Langeoog since 1992.

The development of the chloride contents in the production wells during the early 90th showed, that the freshwater lens was strongly stressed. This required an expansion of the extraction. The aim was to extend the extraction to a larger area in order to reduce the punctual load of the freshwater lens. Extensive investigations considering the different groups of interest (tourism, nature protection, coastal protection, water management) come to the result, that only the adjacent Pirola valley was suitable for an extension of the extraction. Since the Pirola valley is situated in the central catchment area of the production wells, it plays an important part in the long-term protection of drinking water extraction.

The valley is sheldered against salt water intrusion due to storm surges by a dune row on its northern side.

Direct damage to the well field equipment

In case of flooding all production wells, whose buildings (well-shaft, electrical installation) would come directly into contact with the seawater, would be temporarily closed to protect the plants as well as to avoid a possible pollution during flooding.

The measures of the restarting extraction depend on the extent of the damage. Assuming that the well-shaft is flooded, the costs of cleaning, disinfection of the extraction well, pumping test, renewal of the electrical installation are estimated up to a height of 25.000 € for each well. Some of the wells are not secured against lift. Thereby the costs of the building of a new well-shaft could increase around approx. 20,000 € for each well.

According to this statement on direct, tangible damage potentials (OOWV 2004) it is likely that some direct damages to the wells and the well equipment (pumps, construction of pumping station) will occur in a case of flooding.

The damage potential on the well fields is estimated to a maximal amount of 45.000 € per affected well. There are 16 production wells situated in the Pirola valley and the adjacent valley. The maximum damage potential is therewith calculated to 720.000€.

Indirect damage to drinking water supply

According to the MERK study there is no approach available at present to take the hazard of dune breaching, flooding of the wells and the damage to the ground water lens into account. A damage to the freshwater lens in the area of Pirola valley by flooding will be indirect and intangible since the freshwater lens is not monetary valued.

On the other hand a significant impact by intrusion of saltwater into the freshwater lens can be expected (IUG 2004). Drinking water supply of the inhabitants might significantly be affected in case of a dune breach. This can cause negative effects for their living conditions and as well for the important economical factor tourism on the island. Due to the lack of evaluations criterions for this intangible damages and the high importance of a sufficient drinking water supply for the island this study aims on potential measures to reduce the intrusion of salt water in the fresh water lens.

An additional indirect but tangible damage could be a reduced supply due to negative effects on the water quality (e.g. high chloride value) or the production equipment (e.g. damage electrical installation). This would lead to a decreased amount of water sold by OOWV (decrease of receipts) and may lead to costly emergency measures to guarantee the drinking water supply.

5 Vulnerability analysis

The aim of this analysis is to determine on basis of a micro scale evaluation, i.e for each individual tangible element at risk, the damages due to a given flooding scenario. In a second step the results are generalised and mapped in raster-plots.

The results are evaluated and parameter variations are conducted to show the influence of particular intermediate results on the estimated total amount of damage.

5.1 Inundation scenarios

The hazard analysis in chapter 3 resulted in a probability of failure for specific sections of the coastal defence system. The probability of failure “flooding of the protected area” is calculated in chapter 3. The location of a failure within the coastal defence system is qualified to this section by definition.

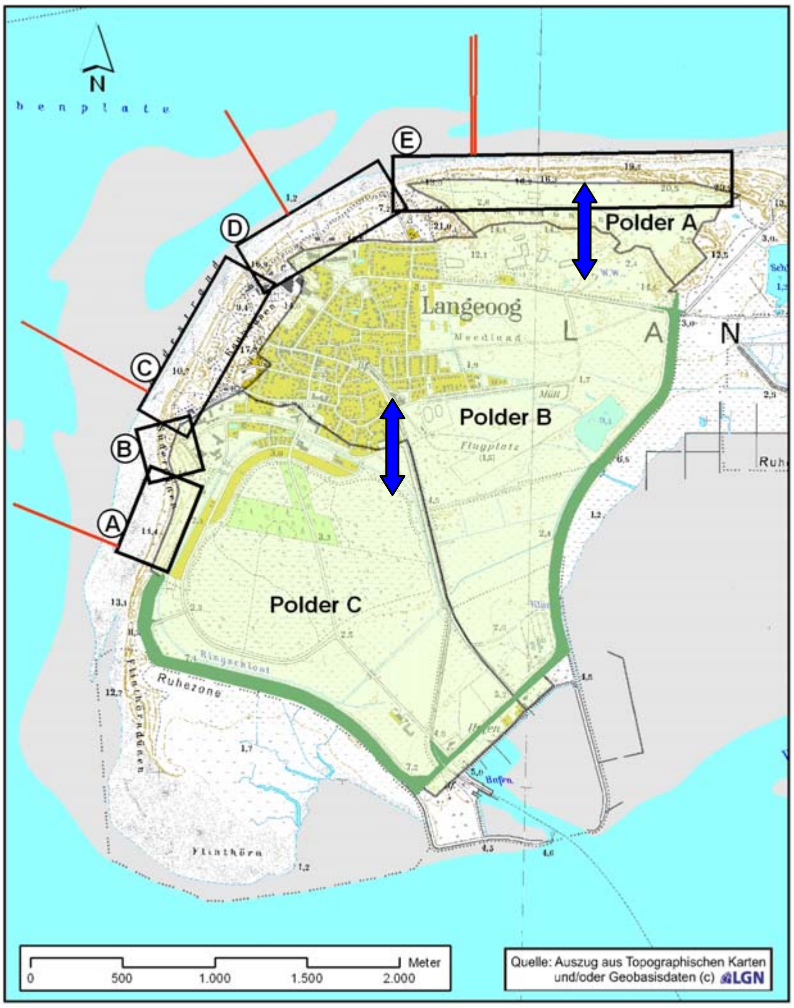
Starting here, this chapter describes the necessary steps to an inundation result which allows determining flood water levels at risk elements.

5.1.1 Identification of sub-areas

The topography of the investigation area is analysed to determine sub-areas, see map -1. As tool for the analyses a GIS in combination with a DEM was used. These sub-areas are defined by the existence of boundaries that prevent an overflow from one sub-area to the adjacent for distinct water levels. In the following these sub-areas are called polders.

Polder A: Pirola valley
Polder B: Polder in the East (town and airfield)
Polder C: Polder in the Southwest

The location of these polders is plotted in map 5-1.



Map 5-1: Determined polder (sub-areas) and potential flow paths underlaid by a topographic map

These polders are defined by two topographic boundaries:

a) a road embankment from the harbour area to dune range in south-western part of the built-up area of Langeoog between polders B and C and
b) a closed dune range south of Pirola valley between polders A and B

Figure 5-1 presents 8 maps illustrating the potential flooded area for certain water levels. The blue coloured areas indicate the inundated surface. This sequence of flooded areas indicates clearly the three sub-areas.

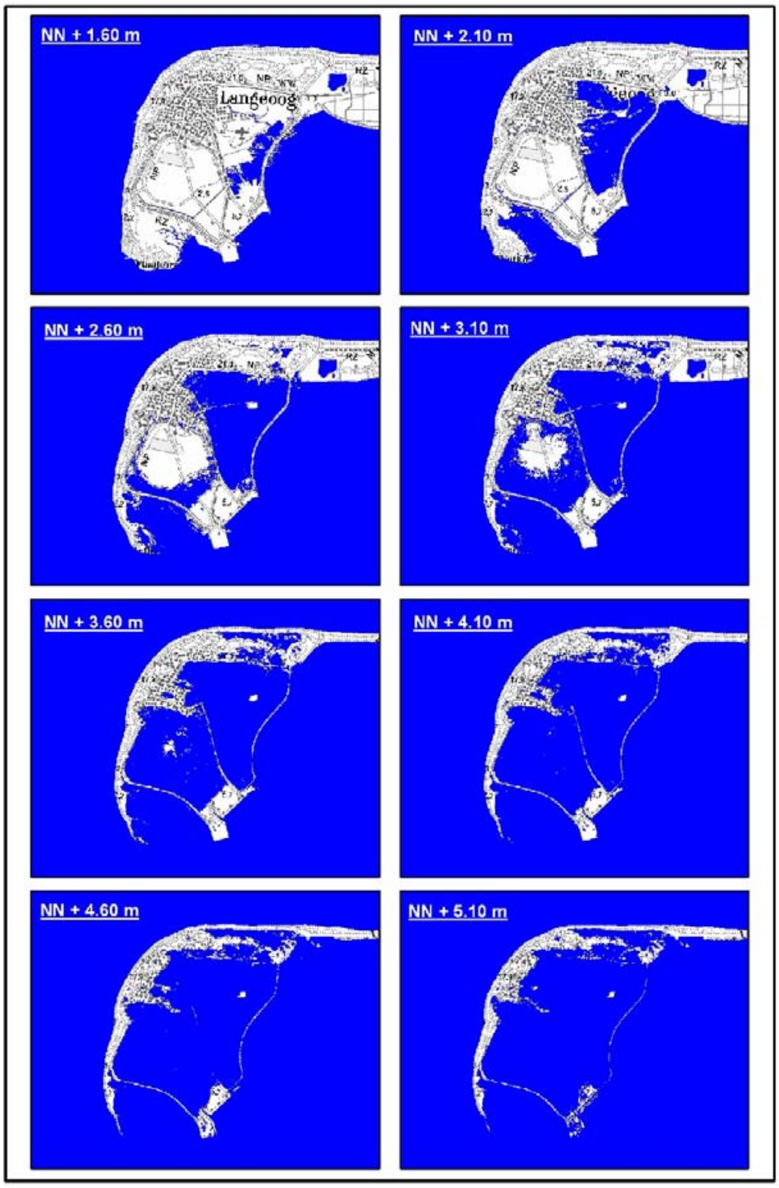


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Figure 5-1: Isohypsen DEM Langeoog, blue coloured area indicates potential flooded area in case of equivalent water level [mNN]

Interdependency of polders by flow paths

A connection between sub-areas via hydraulic effective flow paths is given at two locations. These locations are marked by arrows in Map 5-1.

- **Location “A-B”**: A foot path is crossing the dune area south of Pirola valley through a small gap in the dune belt.
- **Location “B-C”**: A low laying area with some buildings located in the northern part of Polder C which lays between the northern end of the road embankment and a higher dune range in the northern part of the polder C.

Hydraulic characteristics of location “A-B”:

- The highest point of the dune gap where this foot path crosses the dune crest has a level of approximately NN + 3.0 m, The nearest surrounding dunes have heights of about NN+ 5m to NN+ 6 m. A cross section is given in figure 5-2.
- Since the hydraulic cross section for water levels up to NN+4m is small compared to the potential inflow cross sections of Polder B (dyke breach, point “B-C”), it is only taken into account for the calculation of the dewatering the Polder A into Polder B (numerical simulation of salt water intrusion).
- The flow is calculated with the POLENI-formula (see chapter 5.1.3) based on the assumption that the gap works like a weir with a round crest.

Hydraulic characteristics of location “B-C”:

- above a water level of NN + 3.6 m up to NN + 4.6 m the connection between road embankment and higher dune range in the northern part of the polder C, is overflowed in a section with a length of approximately 120 m.
- above a water level of NN + 4.6 m the road embankment (village to harbour) is overflowed on a length of approximately 500m. A water level extending NN+4.8 m will overflow the road embankment on a length of approximately 1.3 km.
- The flow is calculated with the POLENI-formula (see chapter 5.1.3) based on the assumption that the embankment works like a weir with a round crest.

In this simple inundation model the openings in the road embankment are neglected.

Due to the topography there is no common boarder line between the sub-areas A and C. Therefore no direct inflow from A to C or vice versa Is expected.

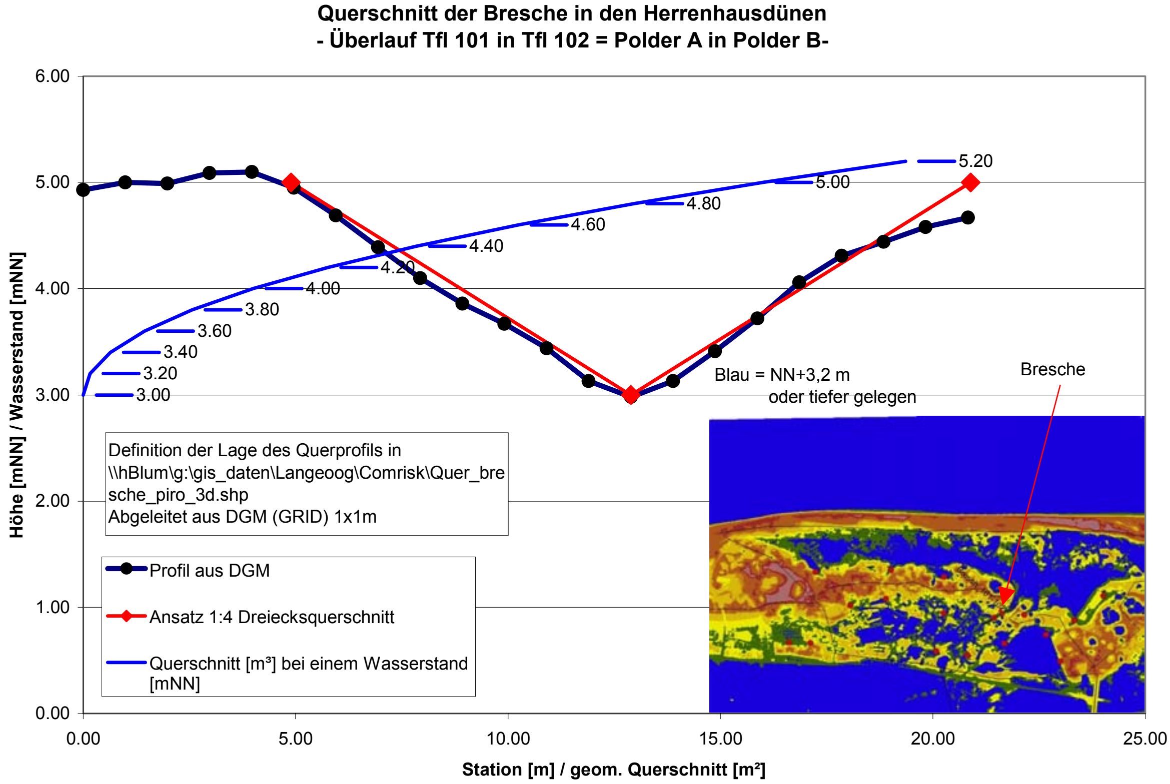


Figure 5-2: Flow path A-B through the dune belt in south of Piola valley – cross section based on DEM (laser scanning with high-resolution) and hydraulic cross-section [m²]

Spatial distribution of assets in sub-areas

The spatial distribution of assets situated in these sub-areas shows a clear allocation of major categories to single sub-areas.

sub-area A: drinking water supply (ground water as fresh water reservoir, operational equipment of wells) is situated in Pirola valley

sub-area B: major part of village of Langeoog, airfield and hangar, railway depot

sub-area C: some buildings close to western beach, forest areas, harbour buildings, railway, minor part of village of Langeoog

Spatial assignment of sub-areas and sub-sections of the coastal defence system protecting those sub-areas

A failure of the following coastal defence section will primarily affect the nearest or adjacent Polder.

- Dunes area in the North of Pirola valley Profiles (3130 /3150): sub-area A
- Flinthoern dyke: sub-area B
- Harbour dyke: sub-area B
- East dyke: sub-area C

5.1.2 Breaching

Hydrograph - shape of tidal curve and surge

For all failure locations the same hydrograph as described in chapter 3.3.1 is used. Figure 5-3 shows the storm flood water level and a marker indicating the time of failure.

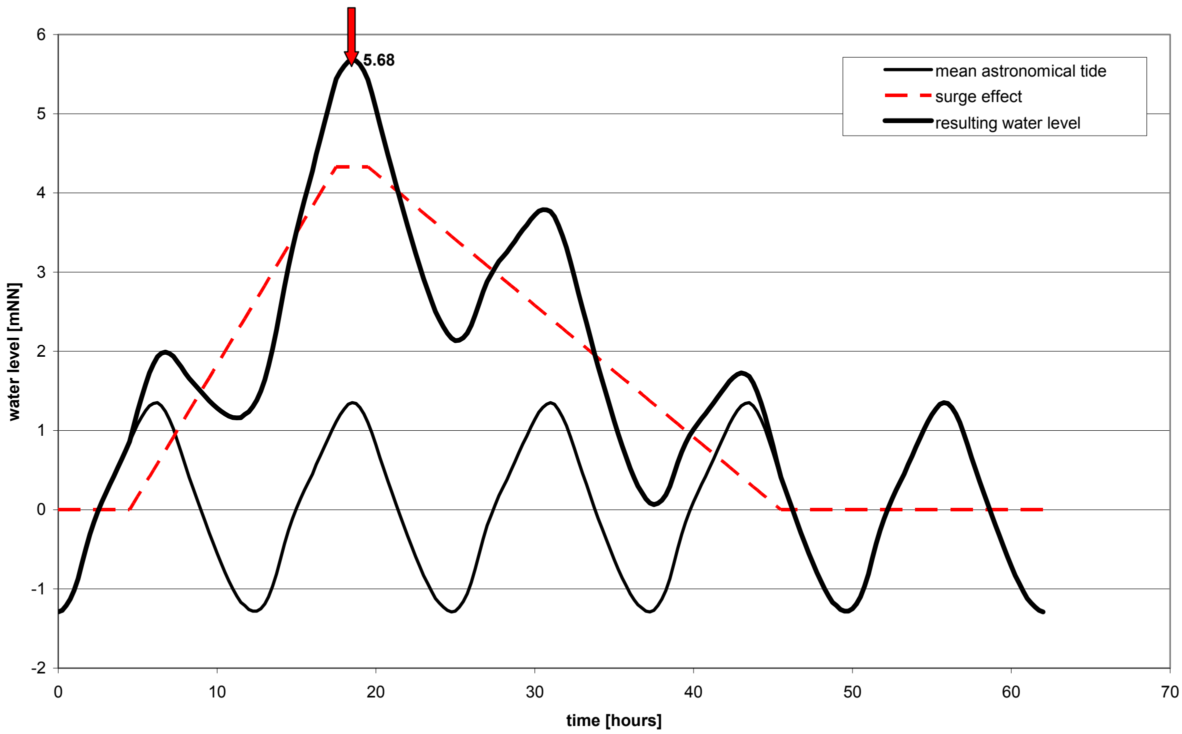


Figure 5-3: Hydrograph for water level with a probability of exceedance p = 10^{-4} $years^{-1}$

Time of failure during storm surge

Besides the highest water level the shape of the hydrograph in relation to the time of failure of the defence system is an important factor for the development of the polder flooding. If a

failure occurs during the falling of water level (after high tide) it is not clear whether the remaining time is sufficient to flood an accompanying sub-area.
Due to the used deterministic approach (chap. 3.3) it is seen as requirement that the highest water level had occurred before a failure of the structure is possible. To simplify the calculation the time of failure is assumed to be the time of highest tidal water level. See figure 5-3.

Breach dimension - width and depth

Whether failure of the coastal defence element occurs or not is calculated in chapter 3. First a distinction between a breach in a dune and a breach in a dyke is drawn:

The erosion process of dunes is a shore line parallel forwarding of the dune face that leads to a simultaneous reduction of dune width (shore profile) and in case of failure to an idealistically simultaneous breaching of the dune. The following inflow, with as the case may be high velocity, will enlarge this breach in the dune. These processes of breaching and subsequently widening and deepening are neither investigated nor described in models.
The used method is based on the assumption of a constant width and depth of the breach.

Concerning dykes the breaching of a sand dyke is investigated. VISSER (1998) offers a method to quantify the width and its development in time. Since the harbour dyke is constructed with a heavy revetment on the outer slope, the method of VISSER can not be applicated. To point out the influence of breach width a variation of different width is used to compare the resultant differences in water level in sense of a sensivity study (see chapter 5.4.2). Based on a literature review a constant breach width of 100 m is used as a starting point for calculation.
For the dune areas the GIS analysis shows that 20 m is a dimension in which a uniform dune shape can be surveyed.

Location and positioning of a breach in the defence system sub-section

Hence the spatial assignment of sub-areas and sub-sections of coastal defence system is clearly defined (chapter 3.2) and the dimensions (length) of coastal defence sub-sections is quite small, the position of a certain breach within a sub-section has negligible influence on the calculated water level with in the flooded polder areas or on the damage estimation.

5.1.3 Hydraulic calculation

It is assumed that the water level of the North Sea outside a dyke or dune breach will be uninfluenced by the volume streaming into the polder. The used tidal curve is described in chapter 5.1.2.

The inflow though the breach and the flow though potential flow path between the polders are calculated based on the POLENI - overflow formula. This calculation approach for a breach is a variation to FÜHRBÖTER (1987). The time dependency of water levels and flow volumina is taken into account by defining of discrete time intervals of five minutes, in which constant conditions are assumed. The water level in the polders is determined by means of volume-level functions. This functional relation between retaining volume and resulting water level is determined by volume analysis of the digital elevation model (DEM). On basis of the inside water levels for each polder the potential flow path and if applicable the direction of flow is determined. The calculation is conducted by means of MS Excel spreadsheets.

The area affected by inundation is derived by a surface analysis based on calculated maximum water levels in the GIS, as well.

These calculated water levels within the three sub-areas are assigned to each element at risk (e.g. a building) located in the study area. The individual height information for the investigated elements at risk (in mNN) and this water level (in mNN) are used to fill in the additional attribute ‘flood level at/in the individual element’. This attribute is an important variable for the damage estimation in the used method of (see chapter 5.3).

5.2 Damage to drinking water supply and freshwater lens

For a risk assessment that takes the protection of the drinking water supply into account, effects of flooding on a drinking water extraction site are of great importance.
To answer the questions whether the freshwater lens is affected, a numerical simulation is carried out by the University of Braunschweig - Institute for Environmental Geology (IUG) in 2004.

5.2.1 Simulation of saltwater intrusion in the fresh water lens

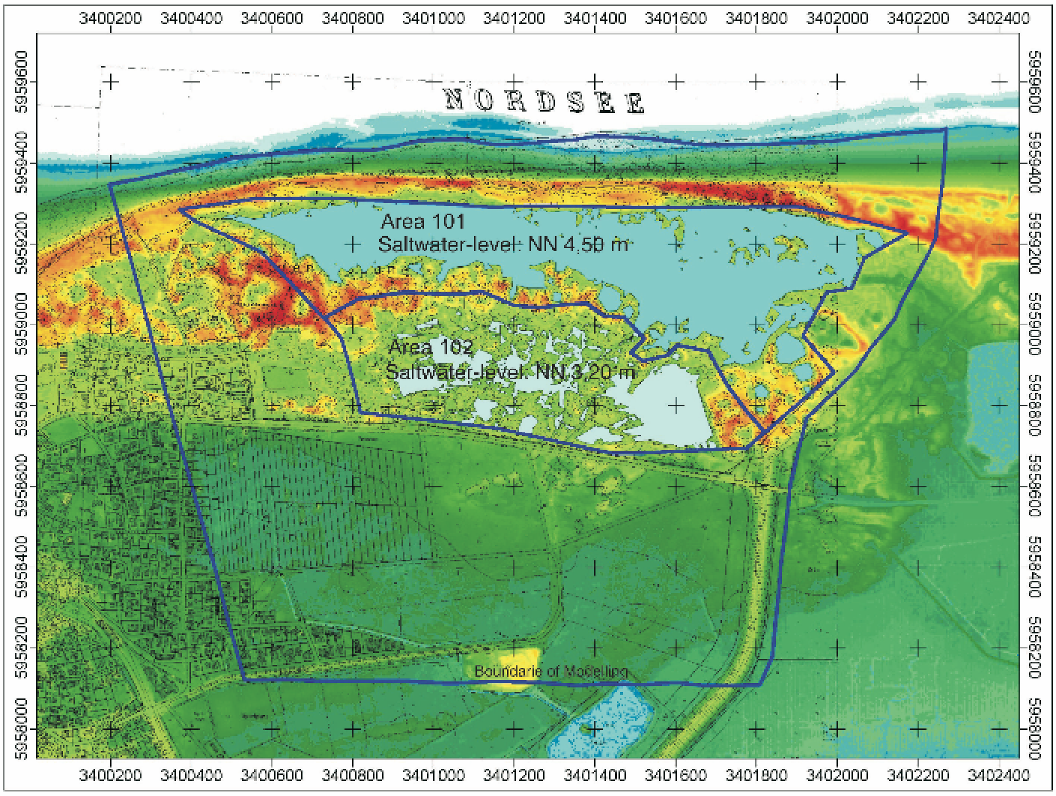
The Pirola Valley is very important for the water supply on the island because it is the area of groundwater recharge by seepage infiltration of rainwater. After a break through of the dune belt caused by a storm flood, the drinking water supply is threatened by seepage infiltration of saltwater. A defined threshold of chloride concentration in drinking water should not be exceeded for longer periods.
The used numerical model is FEFLOW which is a finite element simulation package for 3D and 2D density-dependent flow, mass and heat transport processes in ground water (WATERLOO HYDROGEOLOGIC 2005).
Main task of numeric modelling with the program is to estimate the dimension of impact on the water supply after a break through. There are no measurements of this case because a break through of the dune range did not occur during the last century.

The simulation scheme is derived from a flooding simulation analogous to flooding of polder C-B, described in chapter 5.1.3. In this scenario the North Sea floods the Pirola Valley through a 50 m breach in the dune belt. After a few hours, the North Sea water level decreases and the saltwater drains off the valley. A barrier beach, which remains after the break through of the dunes, prevents a total drain off due to the topography of the valley.
The area threatened by flooding can be divided into two parts. The central Pirola Valley / polder A (area code 101) is connected to a smaller valley (area code 102) in the southern part of the Herrenhus dunes which is part of the polder B (see chapter 5.1). Both valleys are orientated in East-West direction. A connection between these two valleys is given by a small valley in north-south direction and could be easily damned up by a dyke. It will be a further scenario to calculate the protection function of such a dyke.

The detailed specifications of the scenarios are given in table 5-1. It should be stressed that the possibility of additional storm surge during the winter season that may re-flood the valley due to the breached dune belt is not taken into account. Cause of the limited accessibility and limited possibility of construction works in the winter season a sufficient closure of a breach can be protracted until spring.

Scenario I	Break through, sea water remains at a water level of 4,50 m NN (absolute altitude) in the the central Pirola Tal (area 101) and 3,20 m NN in the southern part (102). Because of a drain off into the lowlands of the Meedlands (wadden sea side of the island), there is a lower water level in area 102 than in 101. **Time table** 1. After break through seawater level at 4,50 m NN 2. After 2 hours seawater level at 4,00 m NN 3. After 4 hours seawater level at 3,50 m NN 4. After 6 hours seawater level at 3,00 m NN, holds out for 48 hours
Scenario II	Area 102 is protected by a dyke.

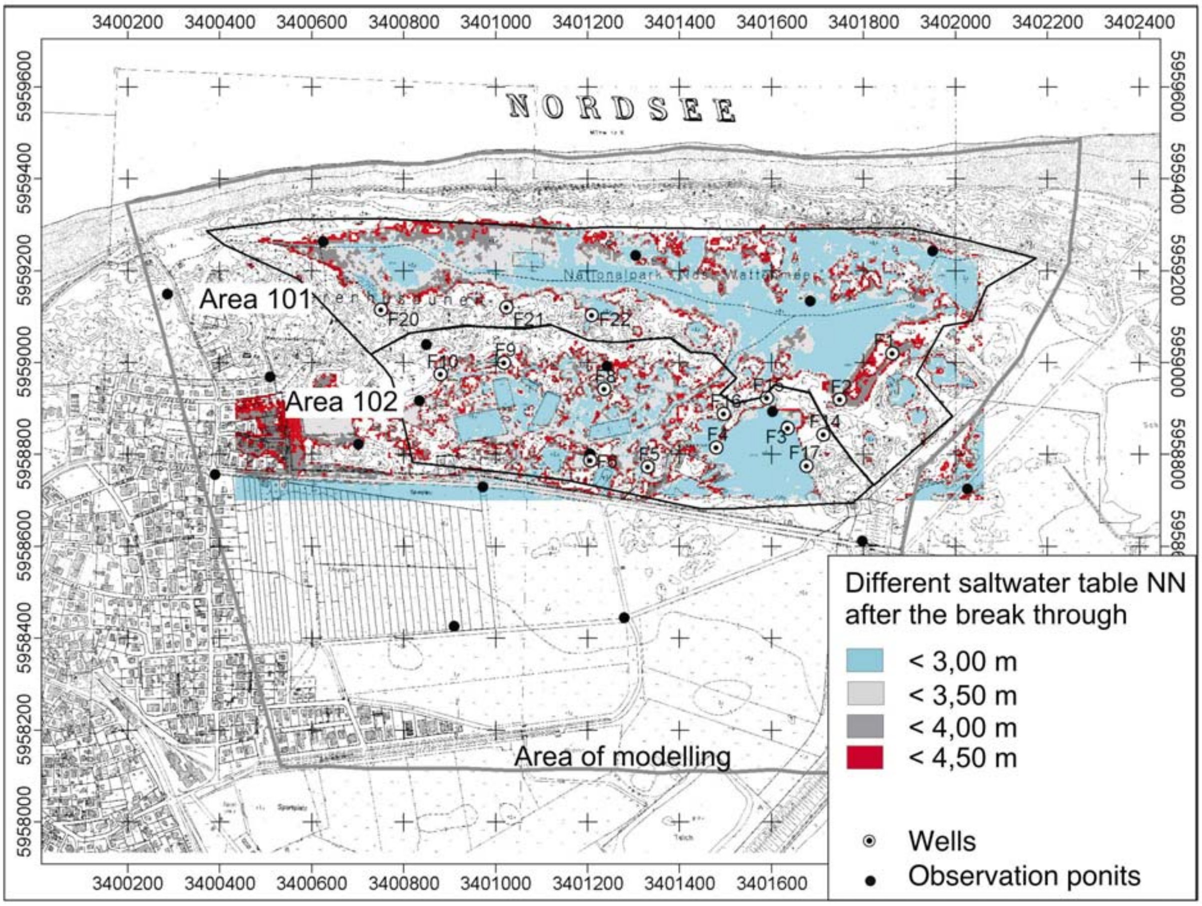
Table 5-1: Detailed specifications of the flooding scenarios of the Pirola valley



Map 5-2: Model area on Langeoog, area 101 (Central Pirola valley) and area 102 (Southern part); blue signature = flooded area after break through (Fig. 1 from IUG, 2004)

The amount of infiltrated seawater within the aquifer can be calculated by the the volume of the pores of the unsaturated zone. The seepage velocity ranges between 0.36 m/h and 0.5 m/h (field measurements and calculated values), so the unsaturated zone will be filled quickly. The thickness of the unsaturated zone is calculated by the average distance from the surface down to the groundwater table.

The simulated flooding of the Priola valley occurs in different phases. The phases after the break through of the dune belt are a result of the drain off of saltwater back into North Sea and the effect of man-made arrangements (mainly pumping).



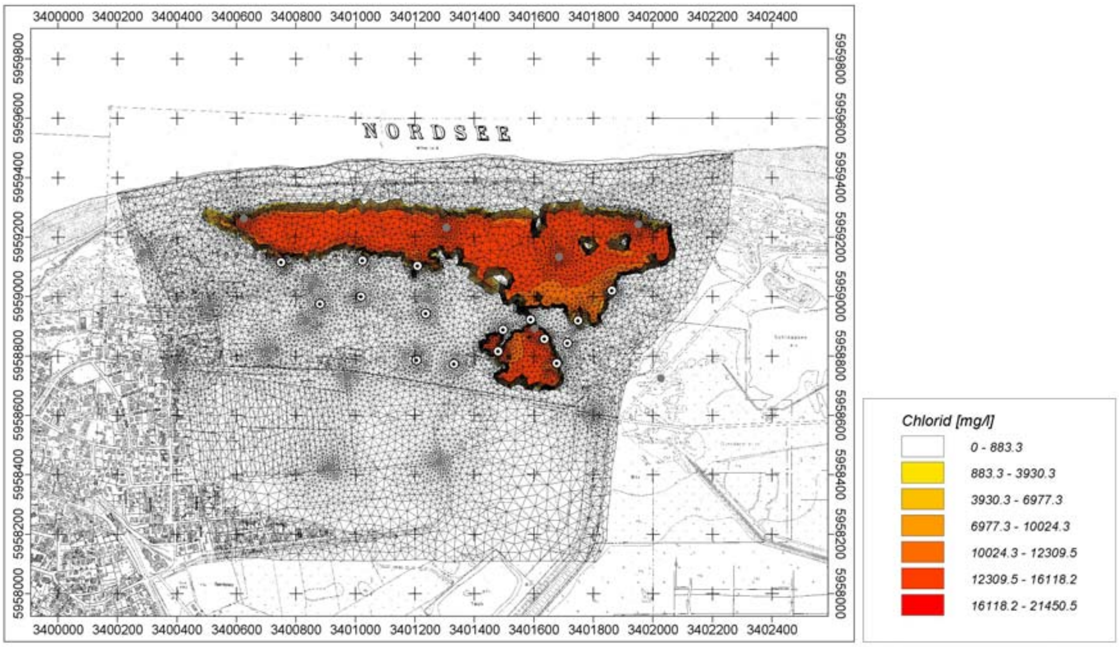
Map 5-3: Phases of flooding defined by NLWK, Norden. (Fig. 6 from IUG, 2004)

Because of a drain off into the lowlands of the Meedlands (wadden sea side of the island), there is a lower initial water level after the break through in area 102 (3.5 m NN) than in 101 (4.5 m NN). The flooded area is marked in map 5-2.

The scenario includes the assumption, that all saltwater above surface will be removed by pumping during 48 hours. In this period the unsaturated zone is completely filled with saltwater. A volume of 148 057 m³ saltwater is infiltrated into the freshwater lense.

As a final step the activities of the pumping wells have been integrated into the simulation. As a worst case scenario all pumping wells are active at the same time with a pumping rate of 8 m³/h. Normally only a few pumping wells are active at the same time. A useful arrangement from the OOWV is to change the active wells after a while so the groundwater withdrawal is evenly spread. Upcoming effects of saltwater are minimised as a result of this management.

The distribution of saltwater at the surface after 48 hours is shown in map 5-4. The saltwater within the subsoil is demonstrated in the 3D picture (Fig. 5-4).



Map 5-4: Area 101 seawater-level: NN 4.50 [m], Area 102 seawater-level: NN 3,20 [m]. Time: 48 h after the event. (Fig. 7 from IUG, 2004)

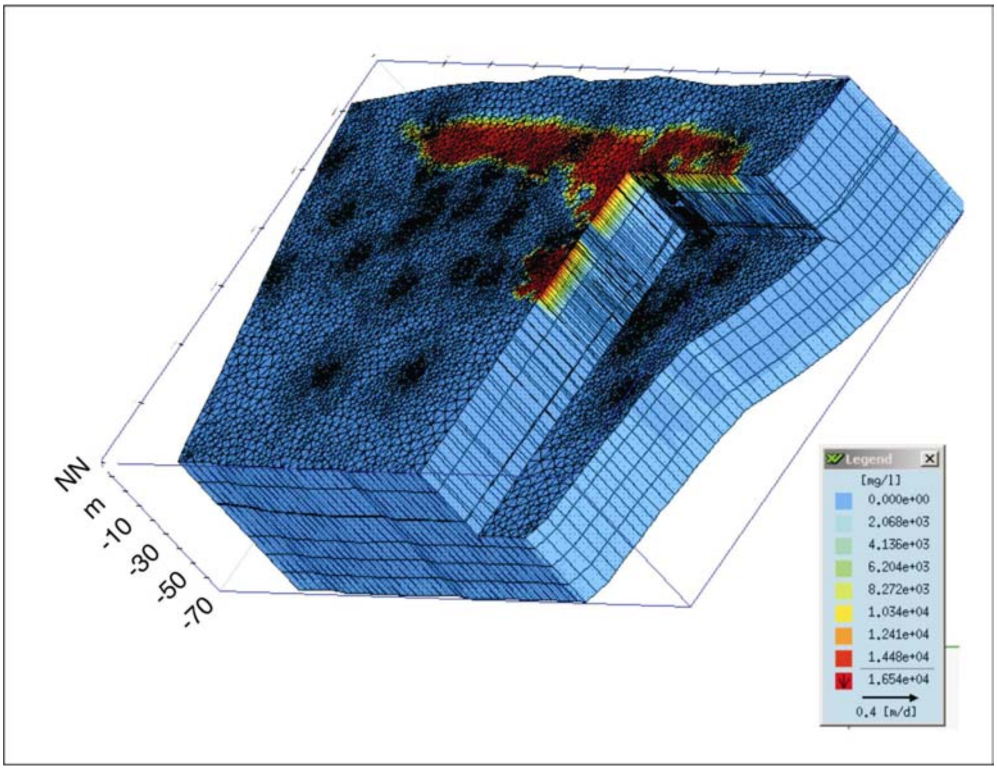
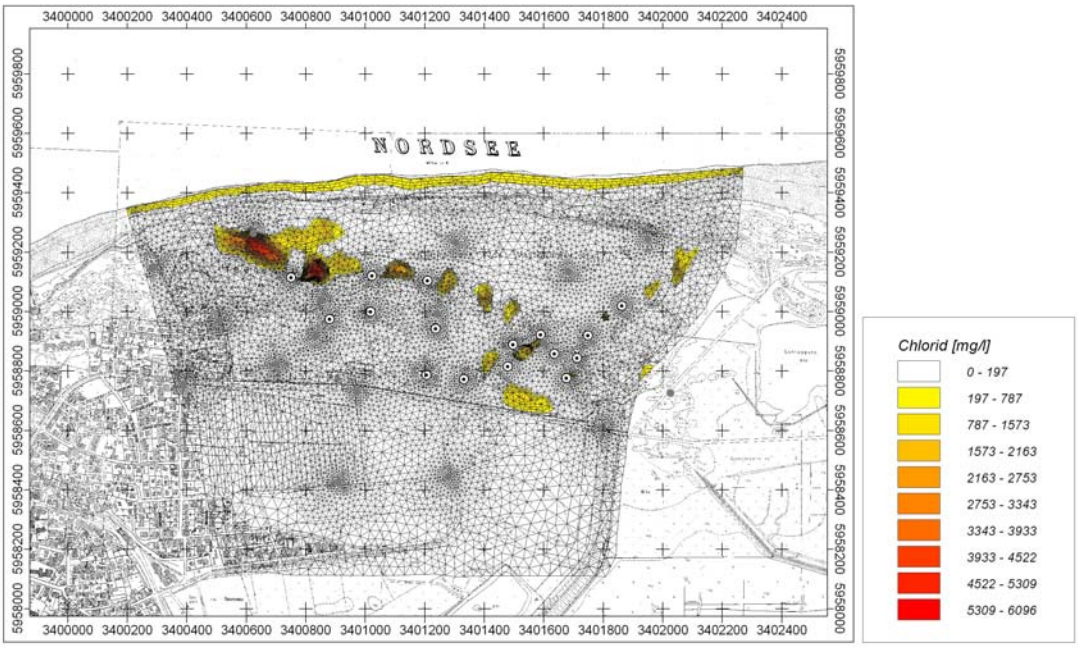


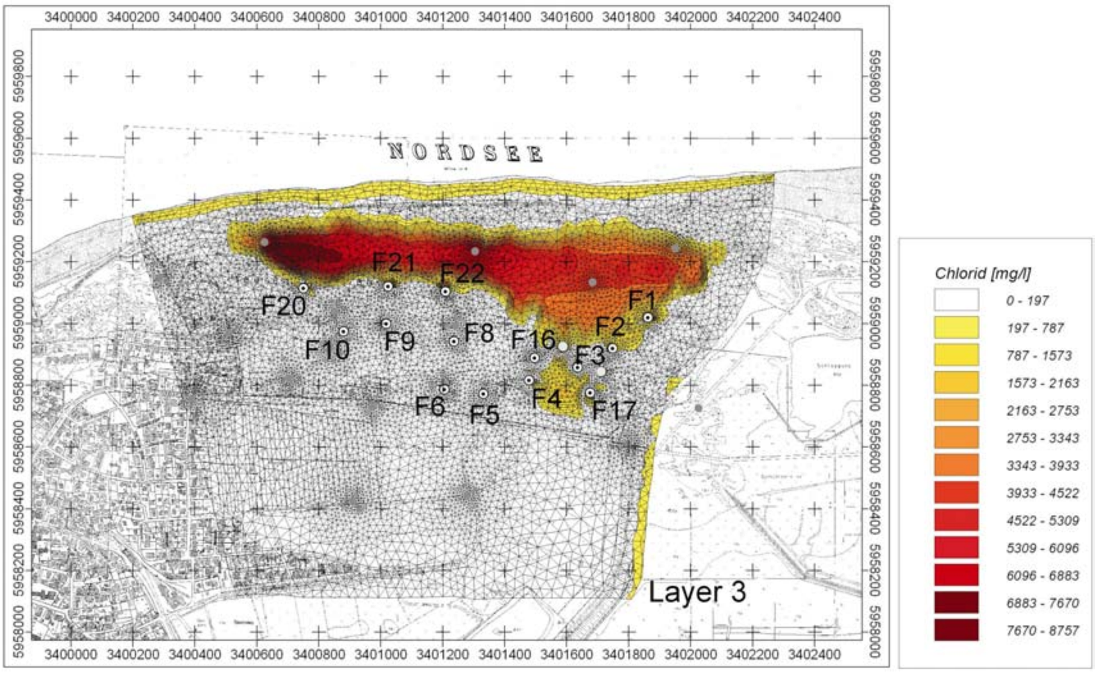
Figure 5-4: 3 D-picture: 48 hours after the break through in area 101 and 102 (Fig. 8 from IUG, 2004)

After 80 days there are only a few areas left within the saturated zone of layer 2, which show a higher value of chloride (see map 5-5).



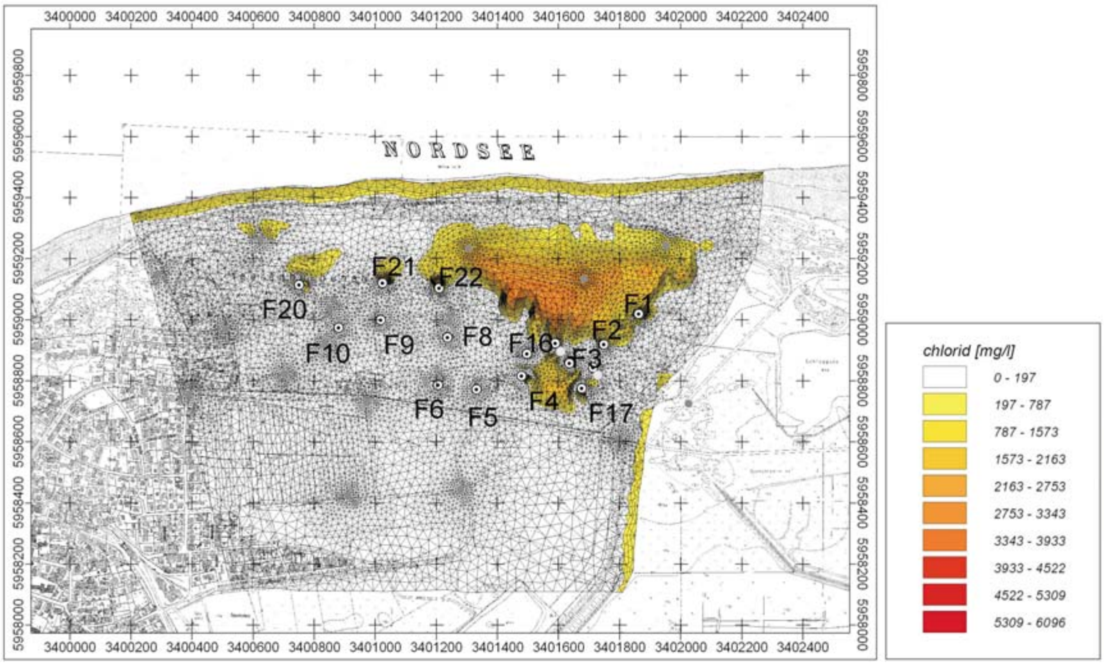
Map 5-5: Layer 2, after 80 days, Wadden sand, Depth NN : -10 m (Fig. 9 from IUG, 2004)

The wadden mud of layer 3 is a local distributed barrier for saltwater. After 80 days in some areas the hydraulic conductivity is too small for a flux of saltwater into the deeper layer.



Map 5-6: Layer 3, after 80 days, Wadden mud, Depth NN : -15 m down to -29 (Fig. 10 from IUG, 2004)

Without a barrier the saltwater reached layer 4 especially in the eastern part of the area 101 (see map 5-7). A number of wells are unaffected. Fig. 5-5 shows the development of the chloride concentration in different wells.



Map 5-7: Layer 4, after 80 days, Wadden sand, Depth NN: -17 m down to -29 m (Fig. 11 from IUG, 2004)

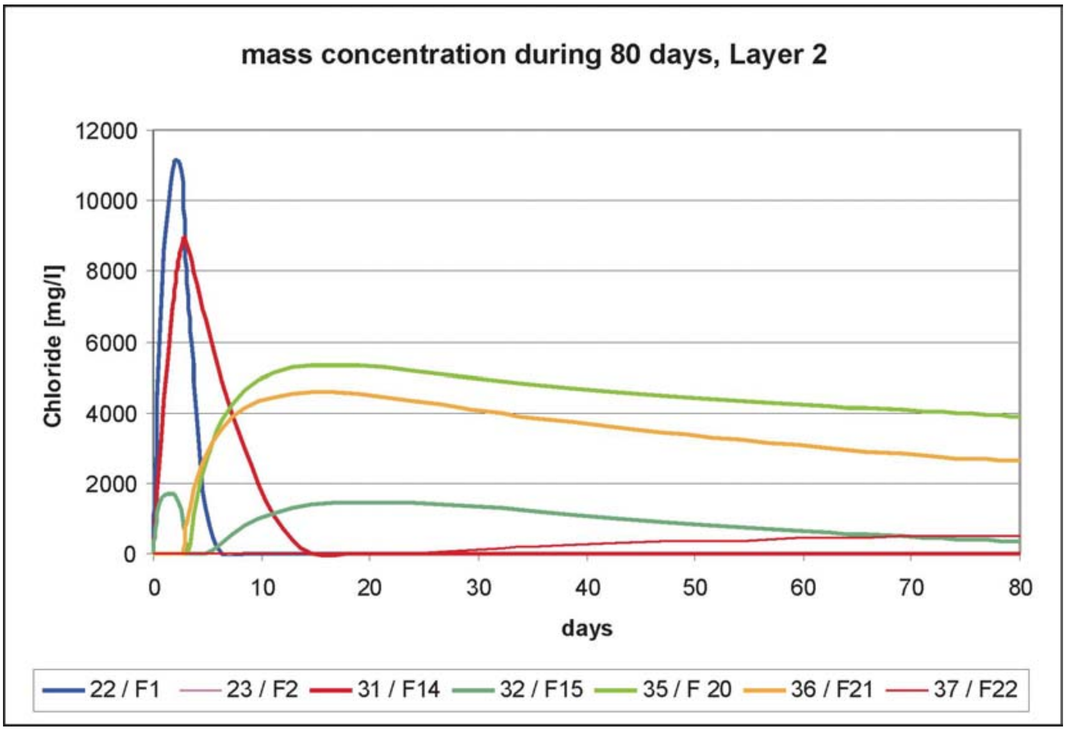


Figure 5-5: Development of chloride in selected wells (Fig. 12 from IUG, 2004)

Affected wells in scenario I:
seawater break through in the Pirola valley (area 101) and reach dune valleys in south area 102.

- ⇨ influenced wells: F1, F2, F3, F4
- ⇨ less influenced wells: F15, F16, F17, F20, F21, F22
- ⇨ uninfluenced wells: F5, F6, F8, F9, F10, F14

Affected wells in scenario II:
seawater break through in the Pirola valley (area 101) a dyke protects the dune valley in south area 102.

- ⇨ influenced wells: F1, F2
- ⇨ less influenced wells: F20, F21, F22
- ⇨ uninfluenced wells: F3, F4, F5, F6, F8, F9, F10, F14, F15, F16, F17

Comparing the results of the modelling, the number of wells, which are affected by the flooding after a break through of the dune depends on existence of a dyke. The number of influenced or less influenced wells decreases significantly in scenario II:

5.2.2 Vulnerability of the drinking water supply

Direct damages
Compared to the damage potential of the whole investigation area the total damage potential for the equipment of water supply in Pirola valley of 0.72 million € is relatively small (approximately 0.7 ‰). Since there are no experiences or data available to estimate the damage ratio due to flooding as a function of time or of flooding level, the damage to the well equipment is neglected.

Indirect damages
The intrusion of salt water into the freshwater lens is assessed qualitatively to consider the consequences in the risk assessment. The water quality of the freshwater lens is mainly influenced by the salt concentration (chlorides). As a rough approach the legal maximum concentration of 250 mg/l chloride for drinking water will be used for the raw water won in the wells.

Damage to drinking water supply in scenario I

Assuming a flooding duration of 48 h, only a small amount of seawater (approximately 3.7 % of the entire volume of the freshwater lens) can seep into the groundwater. Despite this relatively low amount of seawater the model calculations show a significant rise of the chloride values in the freshwater lens.

According to the prognoses of the model the calculated chloride concentrations at distinct wells after flooding, rise up to 11000 mg/l (seawater approx. 20000 mg/l).

Considering that all wells are in operation with an average assistance capacity the chloride concentration in the raw water rises up to about 1500 mg/l. This result represents a worst case, because during the winter months only approx. 30 % of the wells are in use.

During the disconnection of wells, which is strongly recommended, the chloride in the raw water will still rise up to max. 1000 mg/l. Afterwards the chloride concentrations will decrease.

The decrease of salt concentration cannot be determined at present, since the results of the model contrary to expectations point out a very fast vertical penetration of the seawater through the freshwater lens. The reliability of the model is therefore expected to be relatively low since the applied model parameters and boundary conditions could not be calibrated on the basis of field measurements so far.

A durable reallocation of the wells within the area covered by the freshwater lens might be a considerable measure to lower chloride concentrations.

Despite an optimized well controlling as a counter-measure a temporary exceeding of the legal limit value of 250 mg/l may not be prevented. Exceeding the limit is only allowed with a special permission up to a certain height and duration. The freshwater lens is used intensively already at present and there are no extraction alternatives for the drinking water production. There is a risk of destabilizing the freshwater lens and thus further endangering of the water extraction by reallocating the extraction wells.

Considering the present results, using additional technical measures for the treatment of the groundwater may be needed. The associated economic consequences of these measures are not quantifiable at present.

According to the modelling a complete destruction of the freshwater lens in the given scenario is not expected.

Damage to drinking water supply in Scenario II

The results of the modelling show, that the effects of flooding could be clearly reduced by a artificial barrier situated at the point “A-B”, this is the foot path between Pirola valley and polder B in the south.

From the 16 wells 10 wells are not usable in the scenario I and up to 5 wells in the scenario II. The shortfall of wells can be replaced for the time of flooding by the remaining wells. The time of the restarting extraction as well as the long-term operation depends on the development of the chloride contents in the freshwater lens.

5.3 Damage estimation by depth-damage functions

Micro-scale evaluations use depth-damage functions 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. Since the risk element categories (chapter 3) show a different vulnerability, different functions are needed. In many cases, a higher water level would cause a higher degree of damage up to a maximum value. This maximum value will be normally smaller than 100%, i.e. total loss. A total loss due to flooding is rare because some parts of a risk element are always indestructible by flooding as e.g. massive constructions. Functions for other categories start with a certain threshold because of a tolerable small flooding level. For example vehicles like cars are not affected by 0.1 m water level whereas buildings with carpets are.

To derive the depth-damage functions for specific categories, (real) damages caused by flood events are analysed. The functions used in the following are based on the MERK-report which used the data basis HOWAS ‘Hochwasserschadensdatenbank des Bayerischen Landesamtes für Wasserwirtschaft’.

The storm surge forecasts provide a detailed warning at least 3 hours and an advance warning 12 hours before the event will occur.

Therefore a reduction of damage potential due to evacuation of assets to safe places can be taken into account when estimating the damage. The potential flood level is calculated for each storey to check whether a safe place exists within the building. This calculation is based on the individual location, the water level in the particular sub-area and the ceiling height for a building type (see table 5-2).

Beside this aspect of withdrawal storeys to evacuate inventory, fixed assts etc, assets like vehicles or life stock can be relocated to safe places. The table shows a detailed information concerning the used evacuation rates depending on damage category and suitable withdrawal place.

	Type of building	**Room height [m]**
1	Basement	2.2
2	Attic	2.4
3	private used	2.7
4	commercial used	3.3
5	Hall	4.3

Table 5-2: Room height including average ceiling and foundation heights (cited after MERK])

		Existing suitable withdrawal possibility	No withdrawal possible
1	Inventory (private)	30 %	5 %
2	Stock value	20 %	5 %
3	Fixed assets of: service operation and administration	30 %	5 %
4	Fixed assets of: production	1 %	0 %
5	Vehicles	80 %	0 %
6	Life stock	50 %	0 %

Table 5-3: Evacuation rate (= reduction of damage potential) (cited after MERK)

Damage to a building calculated for the whole building

Type of building: 2 floors without basement

$y = 5*x$ equation 5-1)

Type of building: 2 floors with basement

$y = 5*x +3$ equation 5-2

Type of building: 4 floors without basement

$y = 3*x$ equation 5-3

Type of building: 4 floors with basement

$y = 3*x + 3$ equation 5-4

Type of building: hall

$y = 12.5*x$ equation 5-5)

where:

x: flood water level [m]

y: estimated damage ratio [%]

Damage to the inventory separately calculated for each level / floor

Basement

$y = 68 * x^{0.5} -6$ equation 5-6

Upper level

$y = 60 * x^{0.5}$ equation 5-7

maximum vale per level/floor is a damage rate of y = 0.65

where:

x: flood water level [m]

y: estimated damage ratio [%]

Damage to small Vehicles (car/electro-car)

Case of x in: 0 - 0.3 m

$y = 0$ equation 5-8a

Case of x in: 0.3 - 0.7 m

$y = 25$ equation 5-8b

Case of x > 0.7 m

$y = 50 * x – 10$ equation 5-8c

The maximum value per small vehicle is a damage rate of y = 0.6

where:

x: flood water level [m]

y: estimated damage ratio [%]

Damage to commercial vehicles

Case of x in: 0 – 1.0 m

$y = 0$ equation 5-9a

Case of x in: 1.0 - 1.5 m

$y = 25$ equation 5-9b

Case of x >1.5 m

$y = 70 * x – 80$ equation 5-9c

The maximum value per commercial vehicle is a damage rate of y =0.6

where:

x: flood water level [m]

y: estimated damage ratio [%]

Fixed assets separately calculated for each level / floor (depending on economic sector)

Sector: service operation, trade and administration

Upper level

$y = 57 * x^{0.5}+5$ equation 5-10

basement

$y = 68 * x^{0.5} – 6$ equation 5-11

The maximum value per level/floor is a damage rate of y = 0.6

sector: production

basement

$y = 28 * x$ equation 5-12

upper floor/level

$y = 20 * x$ equation 5-13

hall

$y = 28 * x$ equation 5-14

The maximum value per level/floor is a damage rate of y = 0.6

where:

x: flood water level [m]

y: estimated damage ratio [%]

Damage to stock value

Stock values in trading companies

Basement

$y = 43 * x + 5$ equation 5-15

upper floor/level

$y = 38 * x + 5$ equation 5-16

hall

$y = 32 * x + 5$ equation 5-17

maximum vale per level/floor is a damage rate of y = 1:0

where:

x: flood water level [m]

y: estimated damage ratio [%]

Damage to life stock

In case of an evacuation the total damage to the stock of a farm is estimated in MERK with 55%. Due to the island-situation of Langeoog with its very limited number of suitable locations to safeguard animals, the damage is estimated to 75% of the stock value.

Cleaning / restoring of the surfaces

The coasts for cleaning and/or restoring of surfaces are for:

Unpaved surface:	3.60 €/m²
Paved surface:	6.00 €/m²
Airfiled:	2.00 €/m²

sport and recreation area

golf course:	1.00 €/m²

Damage to agricultural land and forest

Grassland	0.12 €/m²
Gardening areas	0.12 €/m²

Since there are no areas under crops within the protected area, the damage rate is not determined.

Crops	--.-- €/m²

The forest areas are not used for production of wood. Some parts are located in the national park zone.

Forest	0.00€/m²

Gross added value

To determine the damage to the gross added value the interruption duration of production time $t_{interrup}$ is calculated as follows:

$t_{interrup} = t_{flood} + t_{repair}$: [days] equation 5-18

t_{flood}: Duration of inundation [days]

t_{repair}: Duration of repair [days]

$t_{repair} = 7 \cdot * x$ equation 5-19

where:

x - flood water level in/at object [m]

The damage is calculated on basis of the yearly gross added value. The yearly gross added value is calculated on basis of relative employee per floor and the productivity of an employee depending on the economic sector.

The mean gross added value of all 880 valuated objects contributing to the gross added value of the investigation area is 130 € per object and day. Due to the relatively small contribution of this damage category to the total damage a simplification is applied. The duration of inundation is assumed to be constant for all affected elements evaluated in this analysis. The average duration is chosen to one day for the whole affected area.

Affected persons

If buildings are located within the inundated area all inhabitants (main and auxiliary abodes) are expected to be affected. Since the number of affected tourists is strongly depending on the time of flooding, tourists are taken into account by the number of “affected guest-beds”. The season and particularly the week within a certain month being considered as point in time of a flooding scenario will influence the number of guests being potentially present on the island.

The number of affected persons includes only inhabitants with main or auxiliary abodes within the affected building.

Evacuated persons

If Inhabitants are affected and no upper floor remains dry since the water level is higher than 0.0 m, evacuation is set to be necessary (See also remarks on ‘affected guest beds’).

Evacuations costs are calculated on a rate of 150 €/person according to MERK.

The calculated number of evacuated persons is theoretical derived by the of definition of “persons that should be evacuated”. The used criterion is described above. But in case of a flood event the disaster management authority will organise evacuations based on other criteria.. Usually complete streets of houses or quarters are evacuated. Since the maximum flood water level is not expected to be forecasted accurately all buildings located in those assigned areas will be evacuated. Therefore the number of evacuated persons can be considered as underestimated.

Affected guest beds

Since, most of all guest beds need any installation located in the ground floor, a negative impact on all guests beds can be assumed if the building is affected by flooding. At least the accessibility of the most guest beds will be limited.

The criteria used: If the building is located within the inundated area all guest beds are affected.

This simplification is identical to the criteria of affected inhabitants, thus a combined evaluation of the figures is admissible. The number of affected guest beds is a intangible damage, thus the total damage is uninfluenced by this simplification.

The figure of affected guest-beds shows the wide spread of the total of affected persons on the island, if inhabitants and tourists are taken into account.

5.4 Results of the damage estimation

In chapter 3 two potentially weak spots of the costal defence system are found. One is located in the protective dune chain north the Pirolatal-Valley the other at the Hafendeich in the south of the island. Since there are several uncertainties further detailed in chapter 3 concerning e.g. location and time of failure of the coastal defence element as well as breach development, the calculation of damage estimation is done by scenarios. These scenarios are based on plausible assumptions described in the following. Additionally a variation of important input parameters for the scenarios is executed to estimate the effects of varying assumptions on the damage estimation.

5.4.1 Scenario "Dune Pirola valley"

Description of the scenario:

A storm surge with tidal high water level of NN+ 5.68 m which has a return period T=10.000 years causes a breach in the dune belt in the north of the Pirola valley. The breach of 20 m width occurs at the time of highest tidal water level and stays constant all long. The inflow into polder A (Pirola valley) shortly leads to an inner water level that is equal to the outer tidal water level. The summarised flow from polder A to polder B is shown as graph in figure 5-6. The total flow amounts to approximately 480.000 m³ which could theoretically affect some lowlaying areas in the eastern part of the village. But compared to the storage capacity of polder B, the inflow volume caused by scenario "Hafendeich" the influence of the flow B to A on the polder A can be neglected for the damage estimation in polder B. The flow from polder A to polder B is taken into account to determine the balance and water level of polder A..

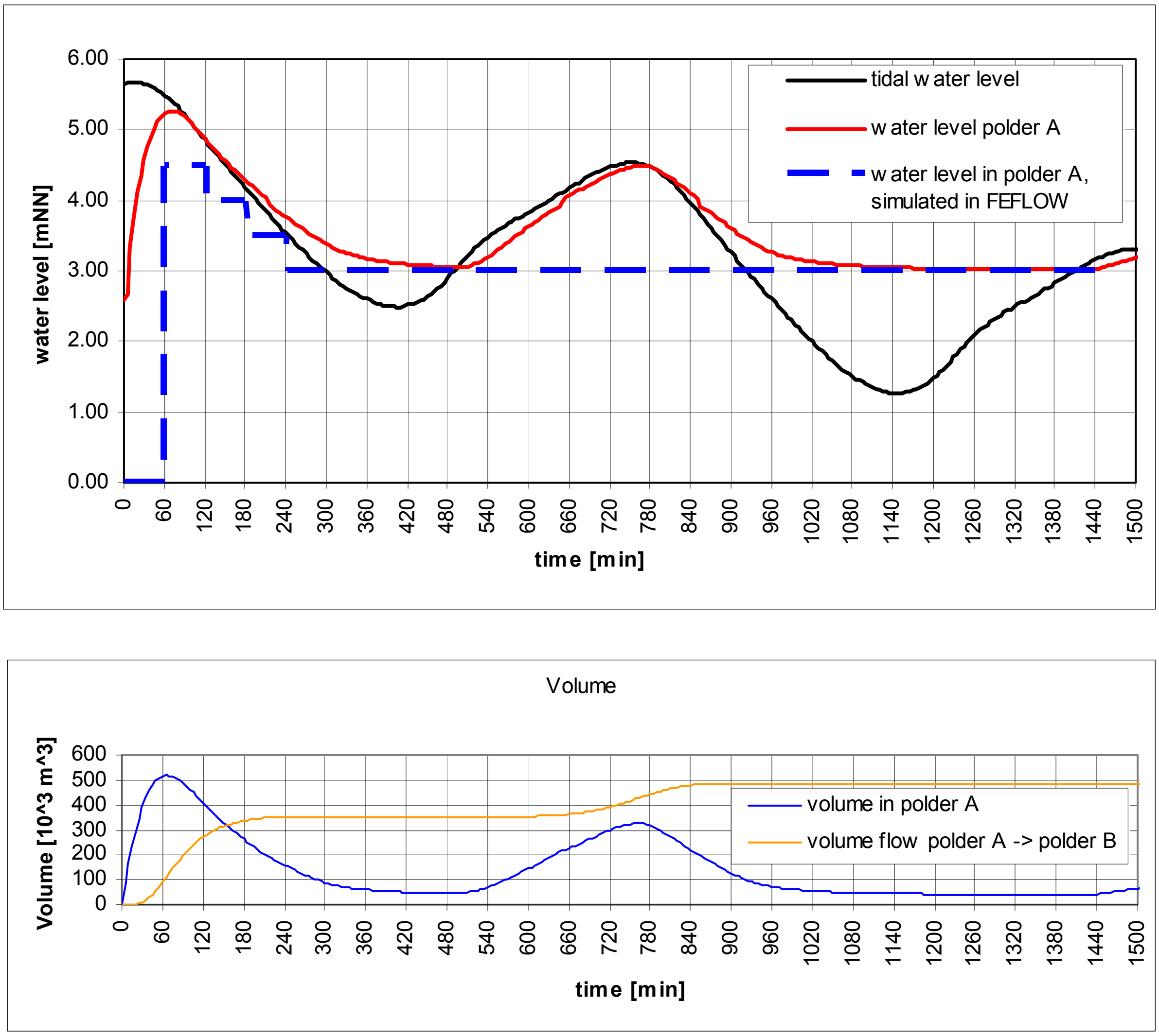


Figure 5-6: Results of flooding model for scenario “Dune Pirola valley”

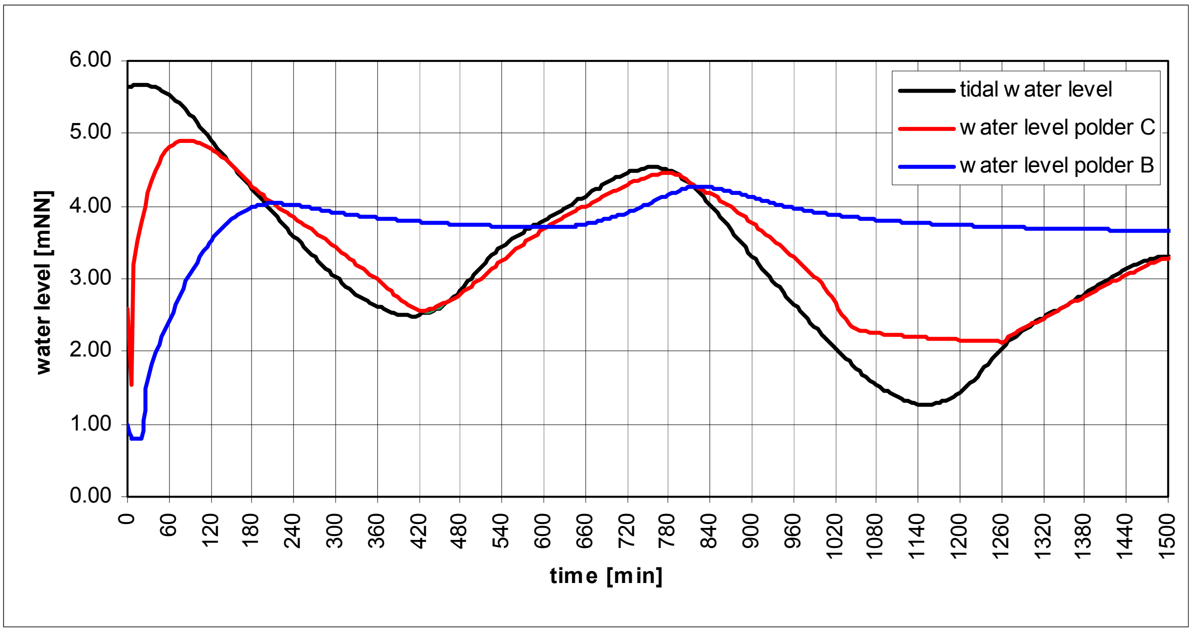
Resulting estimated damages

The damage estimation of this scenario is limited to the damage to the drinking water supply and to the fresh water lens as described in chapter 5.2. A simplified hydrograph of the inner water level used for the numerical simulation with FEFLOW is shown in figure 5-6. Since the maximum water level in the polder has a minor impact on the intrusion simulation, a simplified hydrograph is used a boundary condition for the FELOW simulation. Additional, this hydrograph can be deem to be valid for a flooding scenario of the polder A during a storm surge with a tidal high water level of NN+5.10m, i.e. design water level at present. Thus additional use of the results can be made in further investigations.

5.4.2 Scenario “Hafendeich”

Description of the scenario:

A tidal water level of NN+ 5.68 m which has a return period T=10.000 years leads to an overflow over the Hafendeich. In this scenario it I assumed, that this causes a breach of 100m with in the dyke as a scenario. The breach can not be calculated with present available approaches. It is assumed to occur at the time of highest tidal water level and stay constant during flooding of the hinterland. The inflow into polder C causes a flood water level of NN + 4.90 m and leads to an overflow into the polder B. This overflow takes place at the northern end of the road embankment, in the southern part of the village Langeoog (see chapter 5.1.3). Approximately half an hour after breaching of the Hafendeich this overflow starts and a flood water level in polder B of NN + 4.27 m is reached about 12 hours later (figure 5-7). The duration of flooding is assumed to be similar for all locations in the investigation area and is set to 24 hours, see chapter 5.3. In all, water volumes of about 5 and 3 million m³ are flooding the polders B and C, respectively.



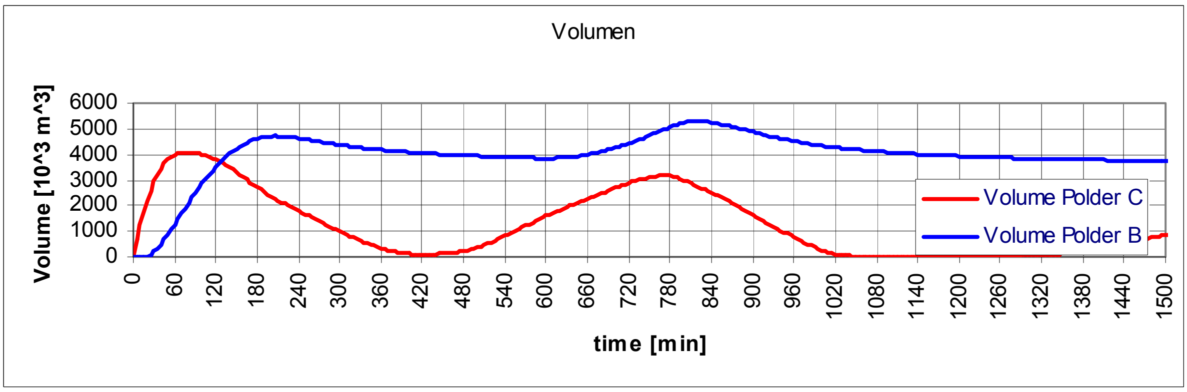
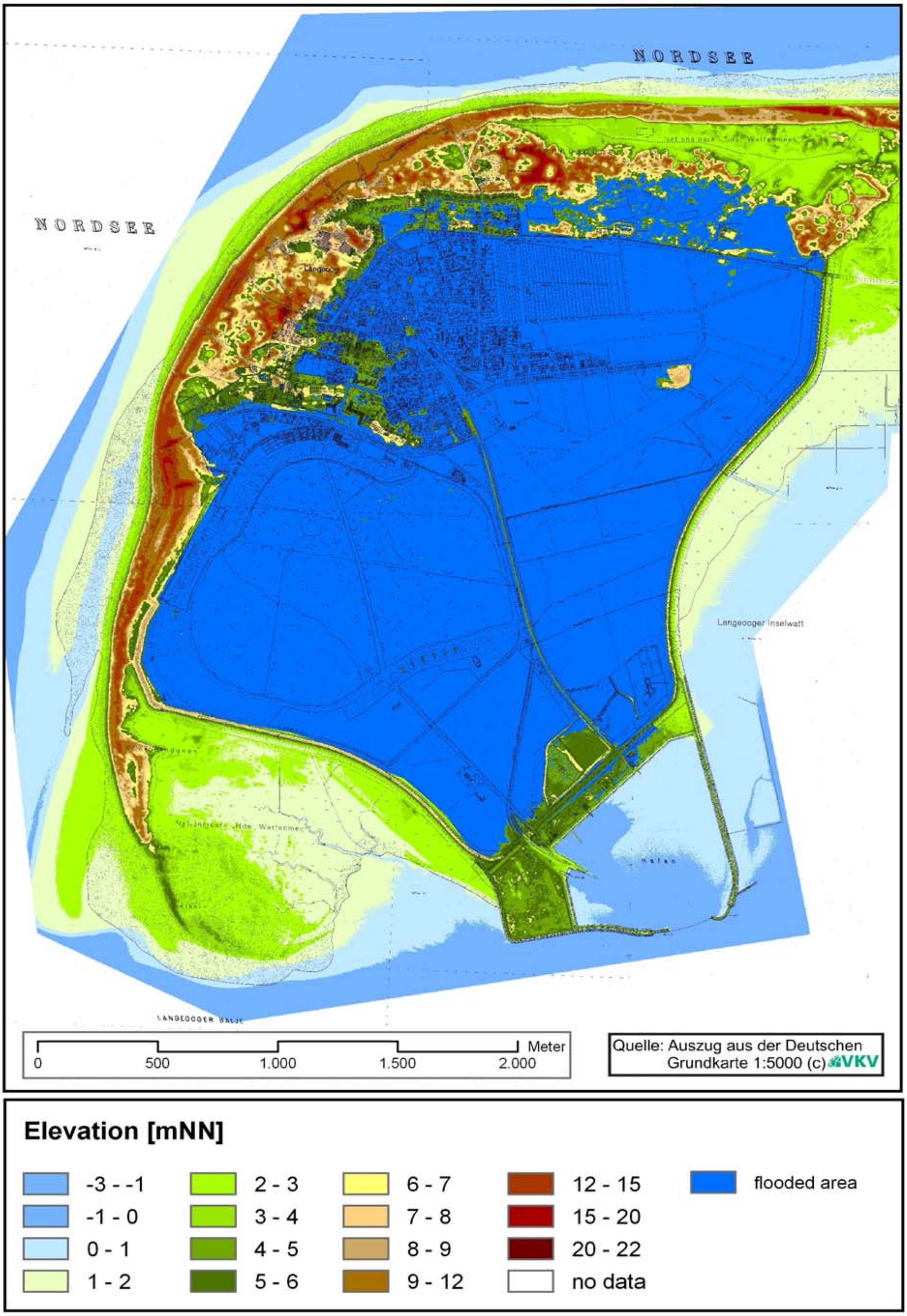


Figure 5– 7: Results of flooding model for scenario “Hafendeich”



Map 5 –8: DEM with flooded areas (blue coloured) indicating maximum flood propagation

Resulting estimated damages

Using the depth-damage functions (cp. Chapter 5.3) and the derived water depth and water propagation, the following figure are determined. The application of the functions is done by means of a GIS-Software (ESRI ArcGIS) in combination with MS Excel spread sheets.

		Szenario 'Hafendeich'
		[1000 €]
Buildings	[€]	23,901
Private Inventory	[€]	13,808
Fixed Assets	[€]	11,847
Stock Value	[€]	1,712
Vehicles	[€]	128
Lifestock Assets	[€]	178
Gross Value Added	[€]	596
Evacuation Costs	[€]	32
Number of Evac. Inhabitants	[-]	214
Traffic Areas and Recreational Land	[€]	2,956
Total	[€]	55,158

Table 5-4: Estimated damages by categories for scenario 'Hafendeich' which leads to an initial flooding of Polder C and subsequent of Polder B.

The number of affected, valuated objects within the investigation area is 1,664 (of 2235 valuated objects).

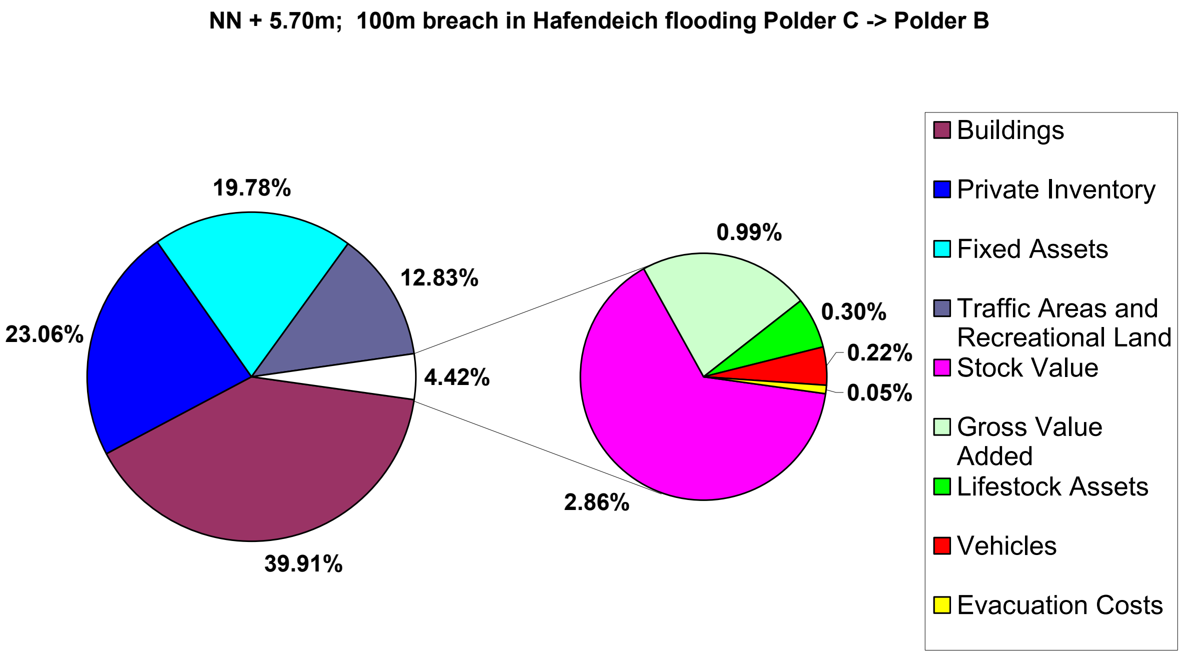


Figure 5-8: Estimated damages by categories in relation to total estimated damage for scenario "Hafendeich"

The damages of buildings are the major part of the total estimated damages followed by the damages of 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. This ratio is comparable to the distribution of damage potentials in which the buildings represent the highest values followed by the category real estate value which is not directly damaged by a flooding and the categories fixed assets and private inventory.

Comparing the distinct damage categories the category buildings show a relatively low ratio of estimated damages to damage potentials (chapter 4.4, figure 4-4 and Appendix A) whereas the categories private inventory, the fixed value and live stock mark the highest ratios (Table 5-5).

Category	damage potential below NN+5.5m	ratio (damage potential / total of damage potential)	estimated damage	ratio (estimated damage / total estimated damage)	ratio (estimated damage/potential damage)
	[€]	[-]	[€]	[-]	[-]
Buildings	492,789,000	52.9%	23,901,145	43.36%	4.85%
Building inventory	60,852,300	6.5%	13,808,088	25.05%	22.69%
Real estate values	230,198,600	24.7%	0	0.00%	0.00%
Motor vehicles	1,903,300	0.2%	128,789	0.23%	6.77%
Live stock	323,600	0.0%	177,910	0.32%	54.98%
Gross value added	36,377,200	3.9%	595,606	1.08%	1.64%
Fixed assets	80,663,200	8.7%	11,846,935	21.49%	14.69%
Stock value	7,895,000	0.8%	1,712,012	3.11%	21.68%
Area related #)	20,519,800	2.2%	2,956,327	5.36%	14.41%
Sum	931,522,000	100.0%	55,126,812	100.00%	

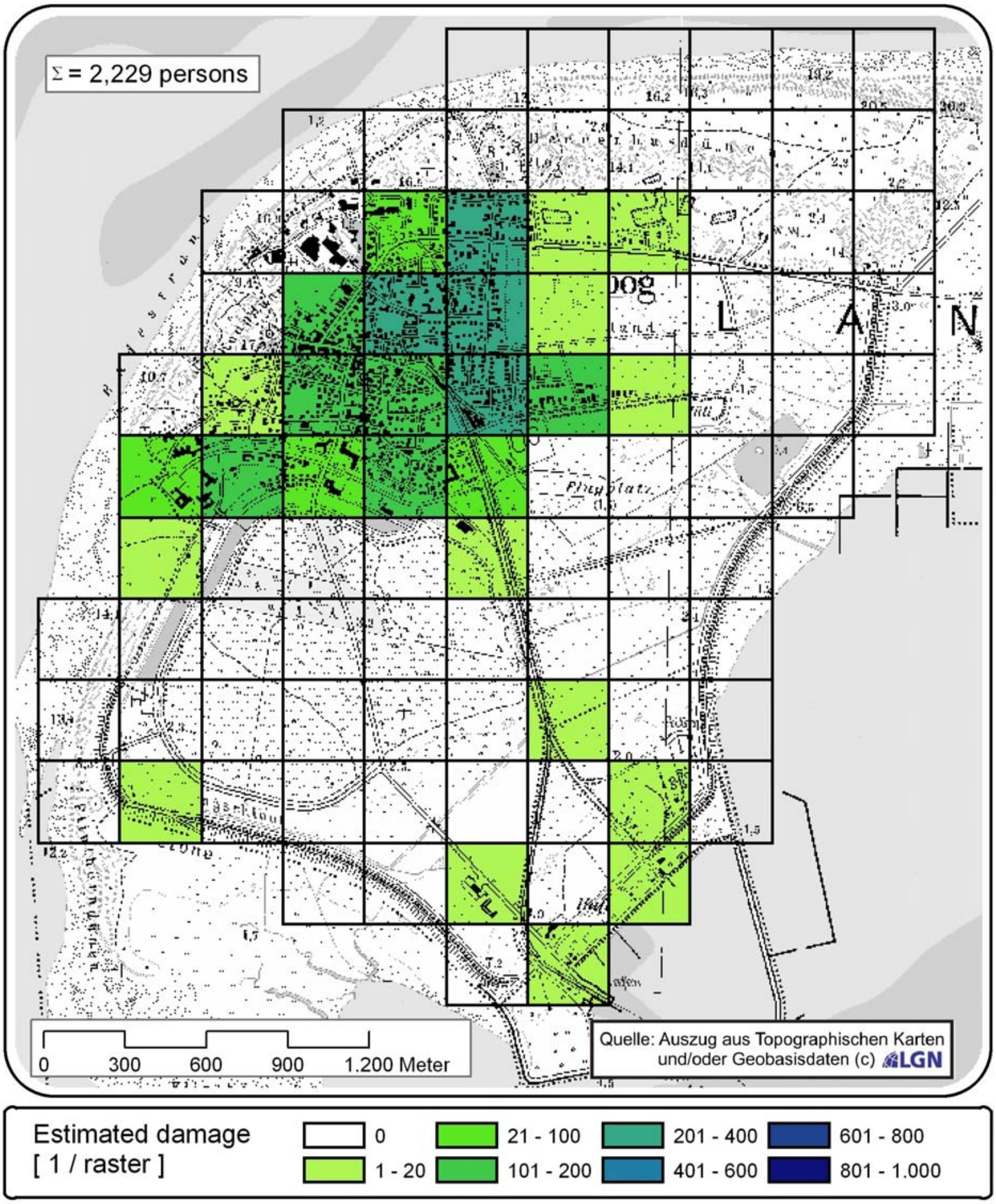
#): sum of traffic areas, agricultural areas, forest areas and recreation/vacation areas

Table 5-5: The estimated damages of the scenario “Hafendeich” in relation to the damage potential

The spatial distribution of damages for all categories is shown in detail in Appendix B.

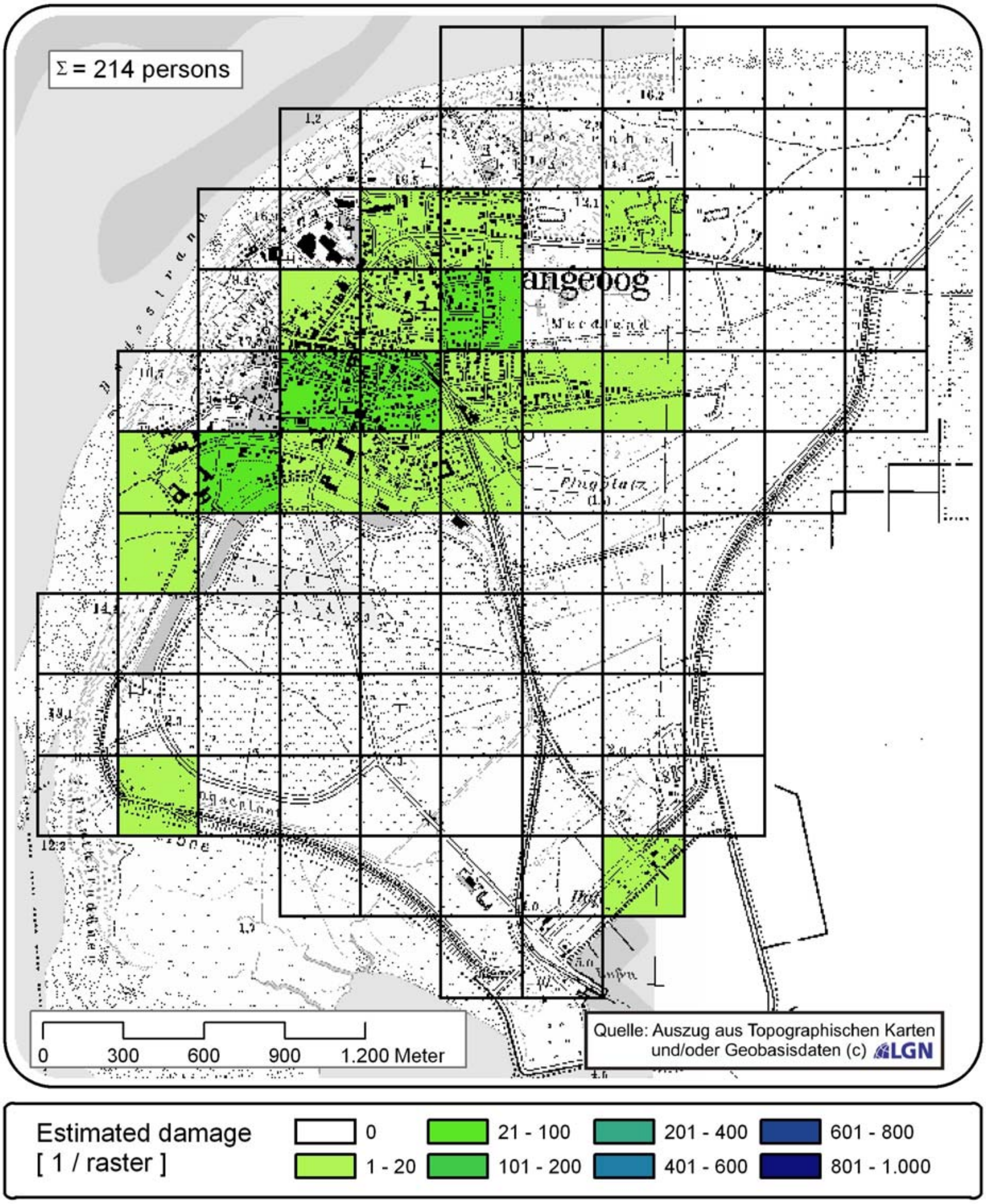
The main aspects are:

- A higher concentration of affected persons can be monitored in the eastern part of the locality Langeoog



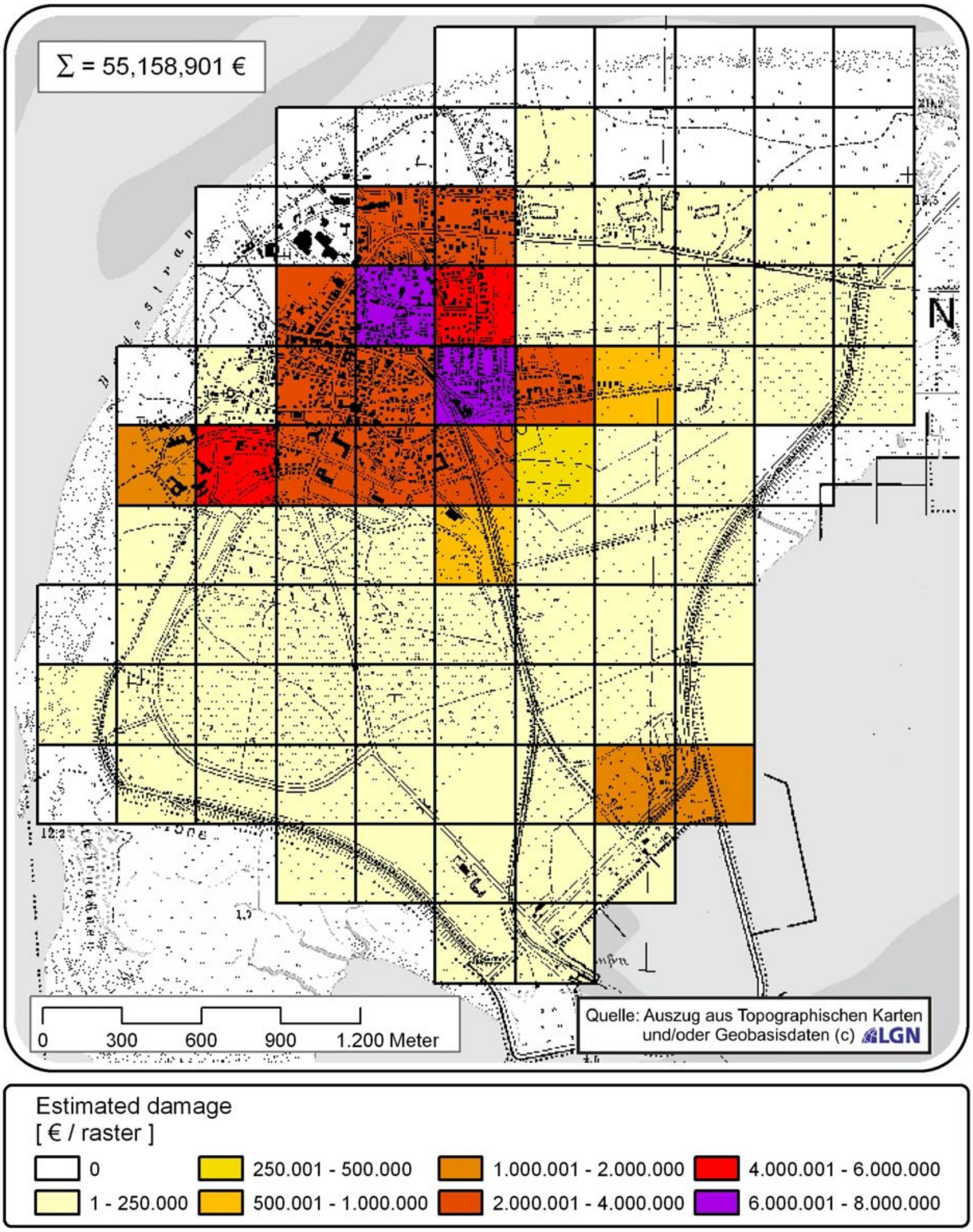
Map 5-9: Estimated affected persons due to scenario “Hafendeich”

- Locations of inhabitants to be evacuated are nearly evenly distributed over the village area except the north western parts. Some buildings that do not offer suitable withdrawal possibilities are in an isolated location in case of a flooding event such as closed to the Flinthörndeich and the harbour area.



Map 5-10: Estimated evacuated persons to due to the scenario "Hafendeich"

- Significantly high estimated damages with 6 to 8 million €/evaluation raster are located:
  - in the village area east of the railway station and
  - north of the "Hauptstrasse" to the east of "Barkhausenstrasse"



Map 5-11: Total estimated damage to valuated risk elements due to the scenario "Hafendeich"

Damage estimations in comparison with damage estimations of MERK report

Since this report in hands and the MERK report are based on identical valuation methods and similar, comparable damage estimation approaches the results of MERK report and the above described figures are compared. This comparison is limited to MERK locations Timmendorfer Strand and Sankt Peter-Ording, classified as tourism resorts. Since the damage ratio is depending on the flood water level only MERK-scenarios with significant estimated damages are taken into account.

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Considered are the total sum of estimated damages, the number of affected inhabitants and the ratio of the damage categories in relation to total. Additionally, the ranking of the first four categories by their contribution to the total damage is shown in brackets.

	COMRISK	**MERK – report**			
	LangeoogHafendeich	**Timmen-dorfer Strand TS-1**	**Timmen-dorfer 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]	2,229	476	1,987	1,271	1,954
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

Table 5-6: Comparison of estimated damages between Langeoog "Hafendeich" and MERK scenarios for Timmendorfer Strand and St. Peter-Ording

The figures in table 5-6 show that damages for major categories, i.e. buildings, private inventory, fixed assets and damages to traffic and recreational used areas, are comparable. An exception is SP-1 due to the very low total estimated damage of 0.88 Mio €. The ratios and ranking calculated for Langeoog do meet the figures of the scenarios for tourism resorts investigated in the MERK report.

Qualitative assessment of damage to drinking water supply

In chapter 5.2.1 the numerical simulation of saltwater intrusion in the fresh water lens is described. It should be taken into account that this simulation is based on preliminary boundary conditions and model verifications that need to be improved for a detailed modelling. Hence the simulation results described in the following provide a more qualitative insight in potential impacts on the fresh water lens (IUG, 2004):

- a complete destabilisation of the freshwater lens is not expected
- in the worst case scenario (scenario I) 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 fresh water might be continued with the remaining unaffected wells in both scenarios, but additional technical measures are expected to be necessary.

5.4.3 Variation of parameters

A variation of parameters has been conducted to point out the influence of hydraulic calculation (e.g. statistics, inflow and inundation modelling) on estimated damage.

Variation of the breach width

A variation of breach width from 80 m to 120 m influences the water level in Polder C (harbour and forest) and Polder B (village). The levels show a range of 0.32 m in case of polder C and 0.08 m in polder B. An 80 m breach will cause a flood water level in Polder C 0.17 m lower than the level of a 100 m breach. A 120 m breach will lead to an increase of 0.13 m (see Table 5-7).

	Polder C water level	Polder B water level	Polder C difference to b=100m	Polder B difference to b=100m
breach width				
[m]	[mNN]	[mNN]	[m]	[m]
80	4.73	4.22	-0.17	-0.05
90	4.82	4.25	-0.08	-0.02
100	4.90	4.27	0.00	0.00
110	4.97	4.29	0.07	0.02
120	5.04	4.30	0.13	0.03

Table 5- 7: Water level and water level differences in polder B and C due to the variation of the breach width

Variation of the flood water level

Since the water level is an important variable for the estimation of damages a variation is conducted. The accuracy of water level calculation depends on the used numeric model,,the accuracy of the model topography which could influence e.g. flood propagation. Furthermore proper chosen scenario parameters like breach width, number and location of the failures might influence the water level significantly..

A variation of water level within the protected area (output of inundation model valid for scenario “Hafendeich”) with constant values within the interval [-0.5..0.5] by steps of 0.1 m results in changes in total amount of estimated damage (elements at risk) of -28 % and 32 %, respectively (see table 5-8). In this variation the damages to traffic areas, recreational and green land are calculated for the extremes of the interval, i.e -0.5 m and 0.5 m. The value for variation steps between the scenario water level, i.e. 0.0 m of variation, and these interval boundaries are interpolated linear.

	Water level variation [m]										
	-0.5	**-0.4**	**-0.3**	**-0.2**	**-0.1**	**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
Damage of [1000 €]											
Buildings	15,358	16,960	18,561	20,163	21,765	23,901	25,869	27,836	29,804	31,771	34,508
Private inventory	11,356	12,073	12,502	12,771	13,008	13,808	14,407	14,794	15,089	15,351	16,330
Fixed assets	8,833	9,489	9,948	10,339	10,613	11,847	12,647	13,191	13,645	14,047	15,030
Stock value	1,062	1,174	1,286	1,399	1,511	1,712	1,864	2,015	2,167	2,318	2,501
Vehicles	99	103	107	122	126	129	132	137	149	155	159
Life stock assets	162	162	162	162	162	178	178	178	178	178	178
Gross value added	358	399	458	476	518	596	633	711	753	797	882
Evacuation costs	25	25	25	25	25	32	32	32	32	32	40
Traffic areas, recreational and green land	2,684	2,738	2,793	2,847	2,902	2,956	2,986	3,015	3,044	3,073	3,103
Total	**39,937**	**43,124**	**45,843**	**48,303**	**50,630**	**55,159**	**58,748**	**61,909**	**64,861**	**67,722**	**72,731**
Ratio of total / total(0.0m)	72%	78%	83%	88%	92%	100%	107%	112%	118%	123%	132%
Number of evac. Inhabitants	169	169	169	169	169	214	214	214	214	214	264

Table 5-8: Estimated damages by categories for variations of the scenario “Hafendeich”

The figures of table 5-8 are shown as graphs in the figure 5-9. The abrupt rises of evacuated inhabitant results from equidistance height zones generated to attribute the heights of buildings (see chapter 4.3).

For all categories an increasing water level leads to rising estimated damages. The strong increase in damages to buildings is remarkable. This increase is absolute and relative higher than the increases of the other categories. This is shown in figure 5-10 where the ratios of the categories in relation to the total estimated damage are compared.

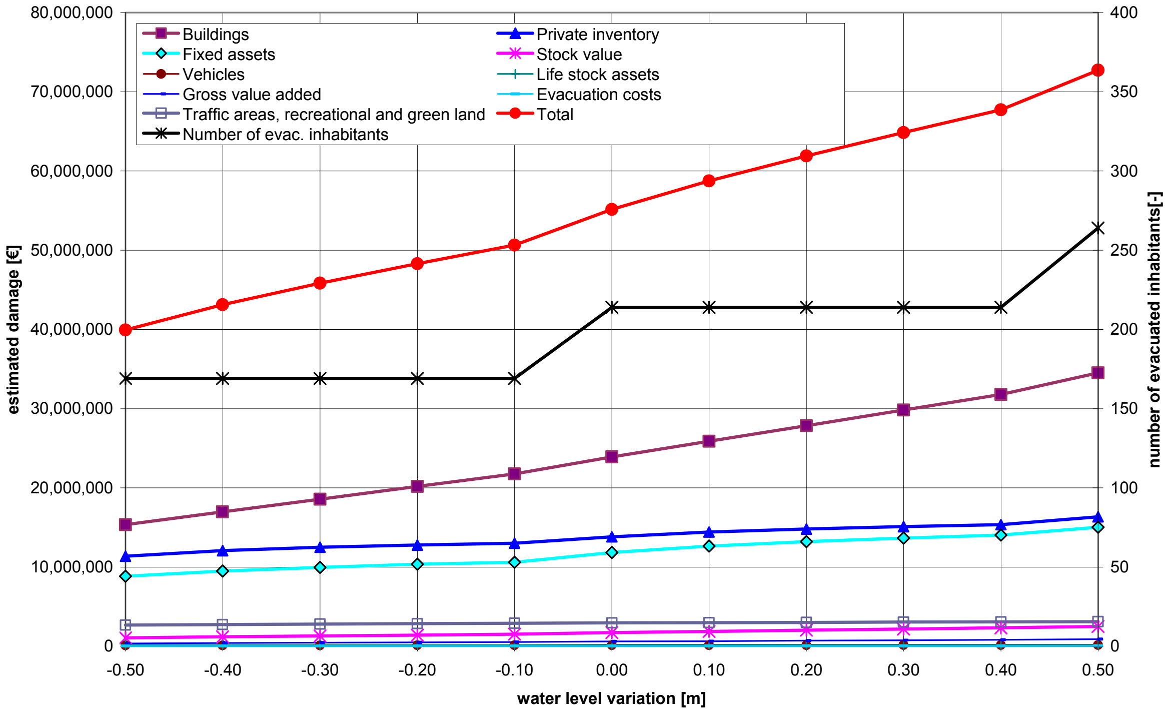


Figure 5-9: Estimated damages by categories for variations of the scenario “Hafendeich”

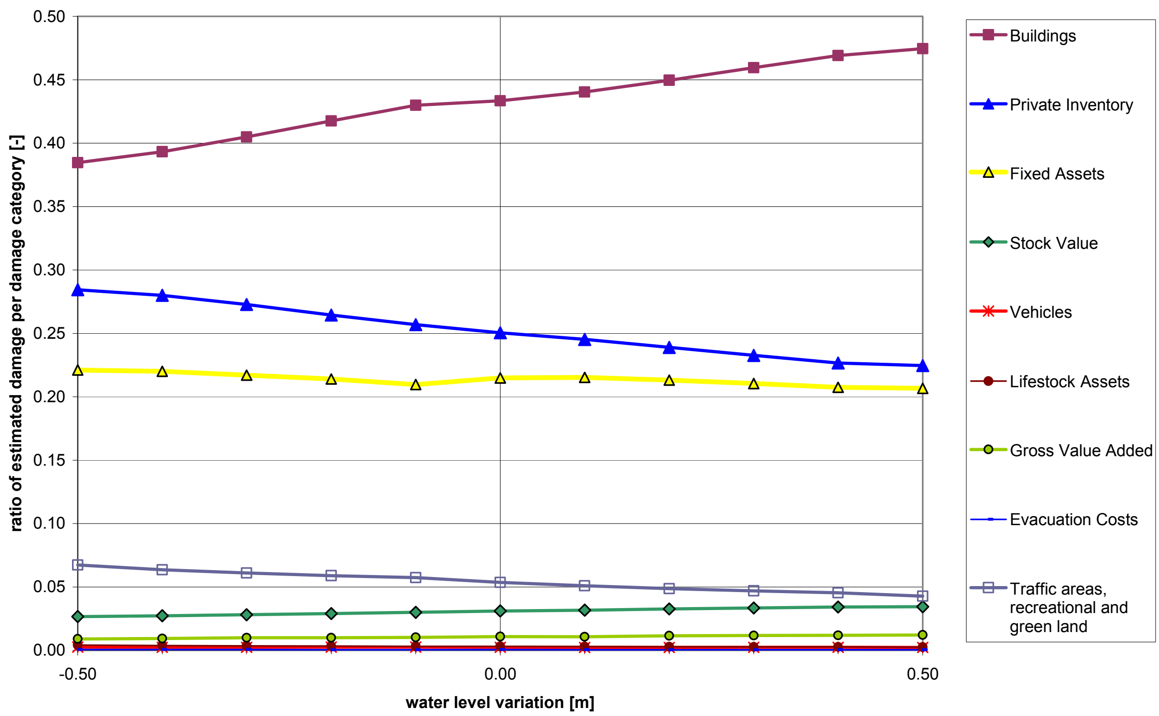


Figure 5-10: Ratios of estimated damages by categories for variations of the scenario “Hafendeich”

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.

5.5 Remarks on results

Evaluation method

A limited number of risk element categories are valuated applying the MERK method. Most of the intangible risk element categories are not considered in the valuation method nor in the risk vulnerability analysis. These are for example the damages to cultural heritage, migration, damages to biotopes or affected persons.

Inundation

As shown in chapter 4.4.3 the calculated flood water level is heavily influenced by the assumed scenarios such as time and location of failure or width of breach. A better understanding of the failure processes based on further scientific investigations will result in more detailed flooding scenario. That means more precise information about starting and development of the breach width and scour over time are needed also for dunes, clay covered dykes and dykes with revetments. Additional, the accuracy of flooding simulation has to be considered to evaluate the resulting damage figures. Figure 5- 9 shows the significant effects of changes in water level on the mayor damage category estimated damages on buildings (cp. Chapter 5.4.3). One objective in further investigations should be the minimisation of uncertainty of calculated flood water levels by means of advanced software tools.

Estimation of damage

One major factor estimating the damage to private inventory and fixed assets is the evacuation factor (cp. Chapter 5.3). This factor describes the degree of assets to be rescued from being flooded before an event occurs. There will be a dependence on forecast, warning, remaining time and available capacity and potential safe place that determines this degree. On an island with a high number of auxiliary abodes, a limited accessibility due to bad weather influence on ferry traffic and air transportation, limited safe storage capacity and limited transportation capacity the rate of evacuation success may be smaller than the proposed one in MERK located on the mainland coast in Schleswig Holstein.

The storm season from September to April is not a main season for tourism except the days around Christmas and New Year holidays. It should be remarked that the number of threatened persons may be significant higher than it is marked in the tables (cp. 5.4) and maps (cp. map 5-9 and 5-10) of this study. The number of evacuated persons shown in the tables only considers inhabitants. Since the number of guest beds is approximately three times the number of inhabitants of Langeoog, this ratio may give a upper limit of threaten persons.

The uncertainty of the inner water level due to the applied inundation model is mentioned above. The deviation of the outer tidal water level from the statistical distribution function for a defined return period, e.g. T=10.000, is shown in the confidence interval (cp. table 3-1).
Thus, the calculated damage estimations of the aforementioned scenarios comprehend a relative high uncertainty.

6 Calculation of risk

Within this context the risk R is defined as a product of vulnerability D(fs) multiplied by the probability of failure P(fs) of the coastal defence system according to KORTINHAUS et al. (2002) as follows:

R = P(fs) * D(fs) equation 6-1

Where:

R: Risk

P(fs): Probability of failure of the coastal defence system

D(fs): Estimated damage due to the failure of the coastal defence system

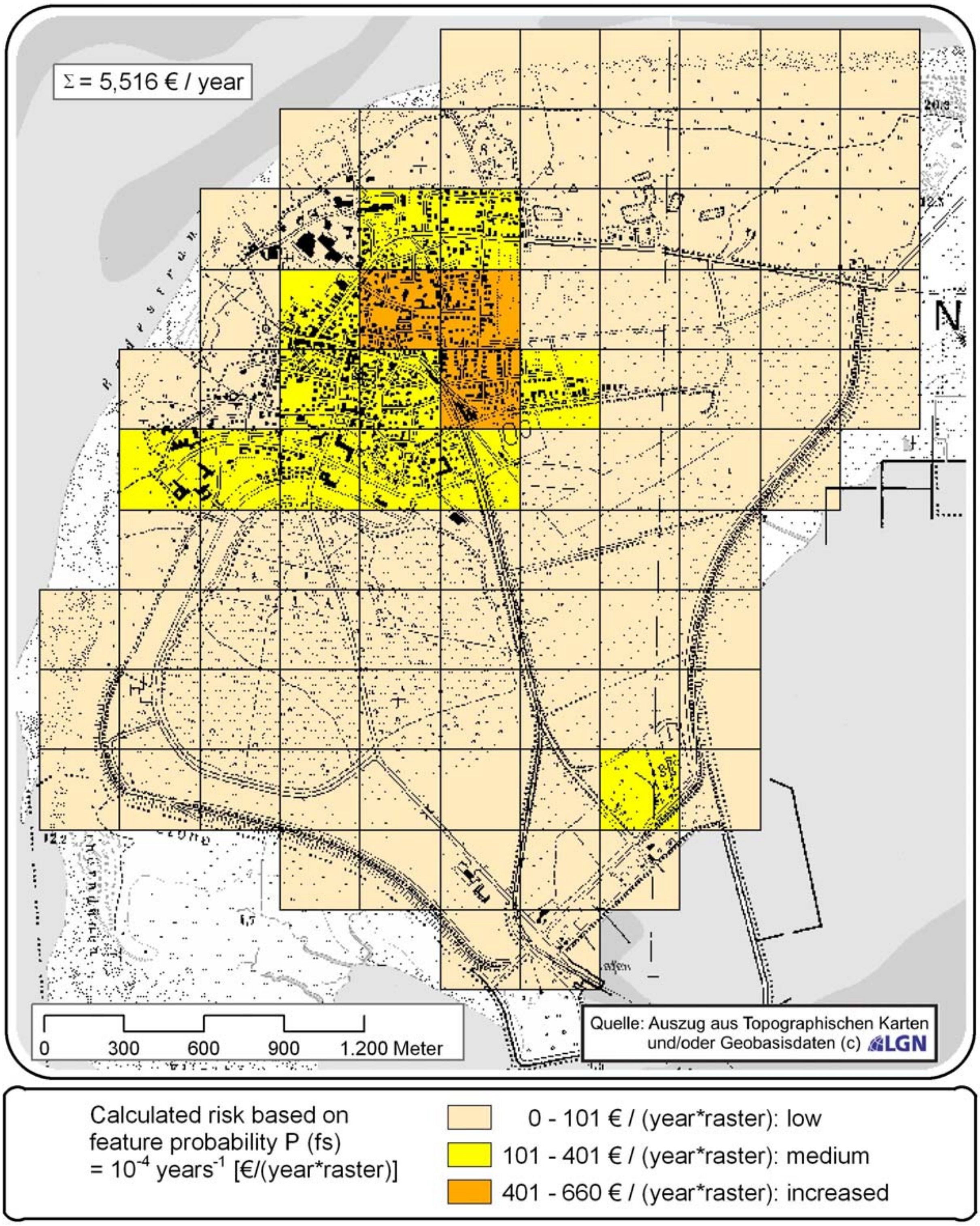
fs: failure of system

The vulnerability of Langeoog is calculated in chapter 5. Depending on the variation of parameters the figure of estimated damage to the risk elements varies in a wide range; see table 5-8.

Based on the estimated damage of scenario "Hafendeich" with approximately damage costs of 55.1 million € for the flooded areas the accumulated risk will be:

$R = 10^{-4}\ year^{-1} * 5.51\ 10^{7}$ € = 5500 €/year

Considering the margin of estimated damage due to the variation of flood water level by -/+ 0.5 m from 39.9 million € to 72.7 million € within the polders the risk figure varies from approximately 4000 €/year up to 7300 €/year.



Map 6-1: Distribution of risk of flooding due to a failure of the coastal defence system based on scenario "Hafendeich"

Since there are no established thresholds to distinguish between different risk classes, a classification based on the specific risk figures of the grid covering the investigation area is applied. The used classification was introduced by JENKS (1967). This classification method

is applied to the data in order to assign natural breaks in these data by minimizing the sum of the variance within each class. The classification is done by means of the used GIS.
Hence, the classification classes must be looked at as relative assessments valid only for this particular investigation area.

Map 6-1 shows a "medium risk" applying the JENKS-classification method for all grid cells that cover the affected parts of the village except three grid cells that are calculated as "increased". These grids with "increased risk" are located at the eastern parts of the village close to the railway station.
One grid cell in the south-eastern part of the investigation area is calculated as "medium risk". This grid cell covers some facilities in the north of the harbour, including the sewage plant and the work yard of the coastal defence agency.

7 Summery

The island of Langeoog is located in the southern North Sea off the coast of Lower Saxony, Germany. The western part of Langeog is inhabited by approximately 2000 persons having their abode on Langeoog. The main economic factor is tourism. The site of Langeoog is protected by a coastal defence system against flooding due to storm surges. At the northern and north-western side dunes are the main coastal defence element. The marshlands on the southern side are protected by dykes of different types.

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

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 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 return period of T = 10.000 years is calculated.

This extrapolation interval is significant higher than the recommended extrapolation interval of three times the time series duration (WANG / LE MEHAUTE 1983, EAK 2002) which yields 324 years in this case. The confidence intervals are determined for all investigated distribution functions to show the rising uncertainty for increased return periods and compare the confidence intervals. The chi-squared test is conducted to assess the fitting quality of the distribution functions. The results of the chi-squared test and the width of the 95%-confidance interval are the basis to choose the distribution function applied for calculating the water levels used in the further investigation.

The chosen LOG-Normal distribution yields to 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 of this event shows a margin of 1.14 m. The return period of the present legal design water level is determined to approximately 1,000 years.

In spite of a lack of hydraulic boundary data, especially wave height and period, the results of the deterministic failure calculation are usable as a basis for further calculations within the vulnerability analysis. Wave attack is not considered to be that a significant parameter in any failure mode while applying of the ProDeich model. Caused by the specific topographic situation on Langeoog all investigated dykes sections show relatively sheltered orientations. Some dykes sections are orientated opposite to wave propagation direction during severe storm surges. Others are sheltered against direct wave attack by an obstruction like a beak water or a dune area,

Due to high dynamics of the beach and the foreshore it is difficult to generalize the beach conditions or put them in a statistical framework as a basis for calculating the failure probability of the dunes.. The investigated dune sections are therefore evaluated based on the survey data from of year 2003. Since the morphological situation especially in the foreshore and the beach has a strong influence on the results of numerical dune erosion models, single storm surge events and short term morphological changes may lead to significant different results of the failure calculation.

The calculation of failure for the coastal defence system was made by applying numerical models: ProDeich and Unibest-DE are used to determine the damages to the dyke and dune, respectively. The failure is calculated by deterministic approach by determining the surge height leading to a failure of the dyke section, e.g. overtopping, or an under-run of a minimum dune width.. The probability of surge water level causing failure of the system, is assumed to be the failure probability of the coastal defence element as input for the risk analysis.

The hazard analysis concerning the dune sections and dykes under investigation taken the assumptions above into account yields the following:
Failure of the dune belt occurs in the north of the Pirola valley for storm surge water levels of NN + 5.68 m with a return period of 10,000 years.
The Hafendeich, a mild sloped dyke with a crest height of NN + 5.60 m, fails as well at the storm surge water levels with a return period of 10,000 years due to overtopping.

Vulnerability analysis

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

Valuation analysis

The valuation analyses 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.
The MERK-method, a micro scale approach that allows identifying and mapping of elements at risk on the level of separate buildings is used. The extensive field work, mapping and analysing of the damage potentials within the investigation area of Langeoog are part of the report 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 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.
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+5.5m 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.

Simulation of flooding

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 dykes. 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 dyke.

The hydrograph of the surge water level 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 is simplifying calculated using the POLENI equation 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" is approximately 8 million m³ 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.

The flooding simulation of the scenario "dune" is limited to of the dune valley south of the dune belt because of its relevance for estimation of damage to fresh water lens and drinking water supply.

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.

The scenario "Hafendeich" yields estimated damages of 55.16 million €, 2,229 affected inhabitants and 214 inhabitants who should be evacuated.

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.

A variation of breach width and of 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 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 0.5m by steps of 0.1 m. Changes in total amount of estimated damage (elements at risk) of -28 % and 32 %, respectively show the strong dependency of damage from flooding water level.

In comparison with the tourism resorts investigated in the MERK report the estimated damages 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.

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 simulated in a numerical groundwater model under certain boundary conditions. The main results of the FEFLOW simulations (IUG 2004) are that a complete destabilisation of the freshwater lens is not expected, in the scenario I 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 continued with the remaining unaffected wells in both scenarios, but additional technical measures are expected to be necessary. More detailed simulations are regarded to be necessary to improve the outcomes concerning risk calculation due to a complex groundwater situation.

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 probability of failure for the coastal defence elements is assumed to be equal to the exceedance 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 300m 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. 3.2.1, figure 3-6) into account, it becomes clear that risk figures calculated with the methods described above could differ significantly.

8 Conclusions and recommendations

This 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.

Several assumptions were necessary to conduct this study due to a lack of input data such as:

- For statistical analysis of hydraulic boundary conditions data on wave climate was 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.
- 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 / 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 my means of a simple inflow calculation and leading to

a relative rough scale of the model compared with the valuation scale. Thus it results in uncertainties of calculated water depths at the threaten objects.

- Uncertainties and limitations in the applied 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.

For improvement of 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 improvement of statistics for extreme values
- Enhancement and determination of boundary conditions for dune erosion calculation
- Further investigation of failure mechanisms on different types of dykes (e.g. revetments and geotextile enforcements) 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 dykes 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 the 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:

8.1 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.

8.2 Weak points of dyke 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 dyke 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’.

8.3 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:

- Closure of a gap in the Herrenhus dunes south of the Pirola valley which is the above mentioned “location A-B” builds 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.
- Heightening of street levels might significantly reduce the overflow volume from one polder to another for example at the above mentioned “location B-C”.

8.4 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 worthy information.

As stated in chapter 6.4.2 some buildings that do not offer suitable withdrawal possibilities are in an isolated location in case of a flooding event such as closed to the Flinthörndeich and the harbour area. This situation may lead to problems in case of a delayed evacuation.

8.5 Impacts on drinking water supply

Based on the results of the investigations about the impact of salt water flooding of the Pirola valley on the fresh water lens (IUG 2004) the drinking water board OOWV formulated the following recommendations (OOWV 2004):

- Improvement of the prognosis ability of the used model and standardization by historical data (e.g. of Baltrum) or field tests
- Determination of re-development strategies to minimize the effects on the drinking water supply in the case of a flooding
- Development of recommendations for the use of the wells after flooding
- Investigation and cost estimation of a potential measure at location A-B, i.e. the connection of the Pirola valley to the Herrenhus dunes, to block the hydraulic flow path.

9 Outlook

Within this subproject a risk analysis for the Lower Saxony Island of Langeoog characterized by tourism as the most important economic factor is performed with state of the art methods. 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 decision making tool 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 research and 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 assumption of scenarios and execution of parameter variations in case of lacks for data and methods provided important additional knowledge concerning the uncertainty margin of calculated risk figures.

The conducted analysis provides a detailed insight in the flood prone area and clear hints that prevention measures to reduce the effect of failure of the coastal defences like analyzing and blocking flood paths 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 a improved approaches of risk analysis for flood prone coastal lowlands in the North Sea region. Taking future developments in the 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).

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