SPATIAL MODELLING OF TANGIBLE AND INTANGIBLE LOSSES IN AN INTEGRATED RISK ANALYSIS

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The expected climate change and the associated possible increase of the frequency and magnitude of extreme storm surges may lead to larger storm surge hazards than have been observed in the past. Therefore, the German XtremRisK project aims to improve the understanding of the impact of extreme storm surges under current and future climate conditions by conducting an integrated flood risk analysis for two selected pilot sites in Germany which may be representative for an open coast (Sylt Island) and a megacity in an estuarine area (Hamburg). The research has also been focused on developing and improving the knowledge, methods and models for the assessment of intangible losses (social and environmental), their spatial modelling as well as their integration with direct and indirect economic losses. After a brief introduction into the integrated flood risk analysis being implemented, the paper describes the methodologies and discusses the results with a focus on the modelling of tangible and intangible losses in the pilot site Hamburg-Wilhelmsburg.

Keywords: extreme events, integrated flood risk analysis, intangible losses, spatial risk modelling

INTRODUCTION

In the past, storm surges have frequently led to major damages also along the German coastline. Responsible authorities accomplished considerable efforts in order to reduce and prevent flood damages. However, due to expected climate change (IPCC 2007) and increasing frequencies of storm surges, storm surge hazards might significantly increase in the coming decades. Moreover, extreme events might also lead to substantial harm along coastlines and estuaries. Hence, it is urgently required to develop reliable assessment and mitigation tools and to further improve mitigation measures under sustainability aspects.

In order to fill some of the remaining R&D gaps after the completion of the EU-Project FLOODsite, the 4-year joint research project XtremRisK (Extreme Storm Surges at Open Coasts and Estuarine Areas - Risk Assessment and Mitigation under Climate Change Aspects) has been initiated in 2008 (Oumeraci et al. 2012).

The XtremRisK project brings together scientists from different German universities (Braunschweig, Siegen, Hamburg) as well as from the Agency of Roads, Bridges and Waters in Hamburg. The end-users of the prospective results for Hamburg (Hamburg Port Authority, Agency of Roads, Bridges and Waters Hamburg) and Sylt Island (Schleswig-Holstein Agency for Coastal Defence, National Park and Marine Conservation) are also involved as cooperative partners. Moreover, there is a close cooperation with other ongoing national and international research projects. The project will be completed at the end of 2012.

The integrated flood risk analysis has been implemented for two selected pilot sites in Germany, representing open coasts (Island of Sylt) and estuarine areas (Hamburg). However, the methods to be developed in XtremRisK will be generic enough to be applied to other coastal and estuarine areas at risk.

Worldwide, risk is permanently increasing in coastal zones and estuarine regions due to (i) mean sea level risk on a local and global scale (IPCC 2007), (ii) accelerated urbanisation in coastal zones and world population growth (Schwartz 2005) (iii) rising economic wealth which leads to an increased vulnerability, and (iv) significant degradation of coastal zones ecosystems, which are of highest value for flood defences, food supply and recreation (Oumeraci 2004).

The paper first gives a brief introduction into the integrated risk analysis and the applied methodology. The results are presented with a focus on the spatial modelling of tangible and intangible losses and the results of the integrated risk analysis for the pilot site Hamburg-Wilhelmsburg. A short outlook is given for possible counter-measures to reduce flood risk. However, further research is required on the issue of risk acceptance – not only with respect to extreme events – in order to allow a decision making process on a robust and transparent basis.

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INTEGRATED RISK ANALYSIS

In the XtremRisK project, flood risk R is defined as the product of the probability of flooding due to an extreme storm surge $P_{f,cond}$ and the expected damages D. The probability of flooding is given by the conditional failure probability $P_{f,cond}$ as the product of the probability of the storm surge P_e and the conditional probability of failure P_f.

The integrated risk analysis is based on the Risk Source-Pathway-Receptor Concept, which was successfully applied in the European research project FLOODsite (Figure 1).

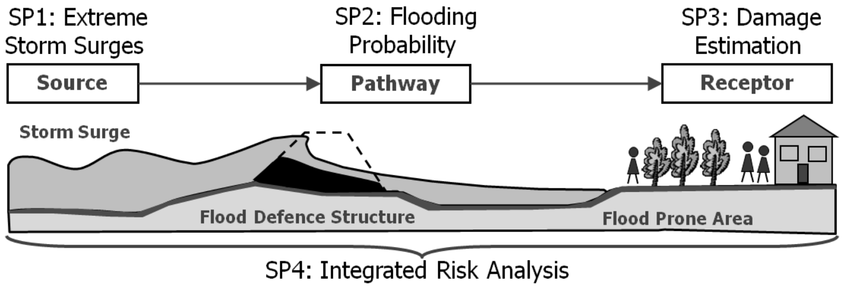

Figure 1. Risk Source-Pathway-Receptor concept and subprojects (SP) as applied in XtremRisK.

The integrated risk analysis differs from previous similar flood risk studies and approaches in the sense that (i) it focuses on the extreme storm surge events which are physically possible (Gönnert et al. 2012, Gönnert 2012) including the statistical determination of the events using multivariate statistical approaches (Wahl et al. 2012), (ii) it is based on a detailed modelling and reliability analysis of the failure of the entire flood defence system (Naulin et al. 2012a, 2012b), (iii) the assessment of tangible flood damages includes both direct and indirect losses (Ujeyl et al. 2012), (iv) the assessment of intangible losses is performed on a spatial basis including both social losses and environmental losses (this paper), (v) both tangible and intangible losses are consistently integrated to assess the overall flood losses in the risk analysis (Dassanayake et al. 2012a, 2012c), and (vi) a systematic framework for admissible flood risks is provided for decision making on risk reduction measures and risk management (cf. Burzel and Oumeraci 2011a).

For integrated risk analysis, new approaches have been developed for the assessment of tangible and intangible losses. A focus has been put on research for the investigation of intangible losses, i.e. fatalities, injuries, cultural losses and ecological losses. As a result, suggestions for the evaluation of intangible damages have been proposed by Dassanayake and Oumeraci (2010).

Next, the feasibility for the spatial modelling of these losses was investigated. In addition, new approaches for the micro scale assessment of direct and indirect economic losses, such as damages on buildings, property and infrastructure, have been developed (Ujeyl and Kowalewski 2012).

In order to enable the spatial modelling of both tangible and intangible losses, a flexible and robust approach for the spatial modelling of risk has been developed by Burzel and Oumeraci (2012).

The so called Cellbased Risk Assessment (CRA) approach serves as an integrated framework for the spatial risk modelling on the basis of extreme storm surge scenarios. Based on the CRA approach, comprehensive geoprocessing workflows for the modelling of (i) tangible losses, (ii) fatalities and injuries, (iii) cultural losses and (iv) ecological losses have been developed and successfully applied. The CRA procedure is also used for the integration of tangible and intangible damages using an integration approach based on multi criteria analysis (MCA). The results of the CRA-based analysis are presented as grids for a given resolution. However, the CRA approach will be described in a later section.

As a result, the overall flood risk is quantified and presented in micro scale risk maps, based on the results for discrete cells. The risk maps serve as a basis for decision makers as requested in the European Flood Risk Directive by the European Union (EU 2007).

PILOT SITE HAMBURG-WILHELMSBURG

As an example for an estuarine area, the city of Hamburg has been selected (cf. Burzel et al. 2010). Hamburg is the second largest city in Germany with about 1.8 million inhabitants. The city is a centre for trade, transportation and services. In addition, the port of Hamburg is the largest seaport of Germany with a substantial importance for the hinterland.

Hamburg is located approximately 100 km upstream of Cuxhaven in the Elbe estuary. There is a strong influence of the tidal dynamics of the North Sea with a mean high tide in Hamburg of 2.1 m above sea level (a.s.l.), cf. Naulin et al. (2010).

In the past, Hamburg was affected by extreme storm surges. In 1962, a storm surge with a peak water level of 5.70 m caused 315 fatalities and considerable damages. Though a more extreme storm surge with the highest observed water level in Hamburg of 6.45 m a.s.l. occurred in 1976, the storm surge caused relatively low damages and no fatalities due to an improved flood defence system.

Within Hamburg, the quarter Hamburg-Wilhelmsburg is investigated in detail. The investigation site is located on an Elbe River Island surrounded by the Northern and Southern Elbe River branches. The overall area of the island is 50 km².

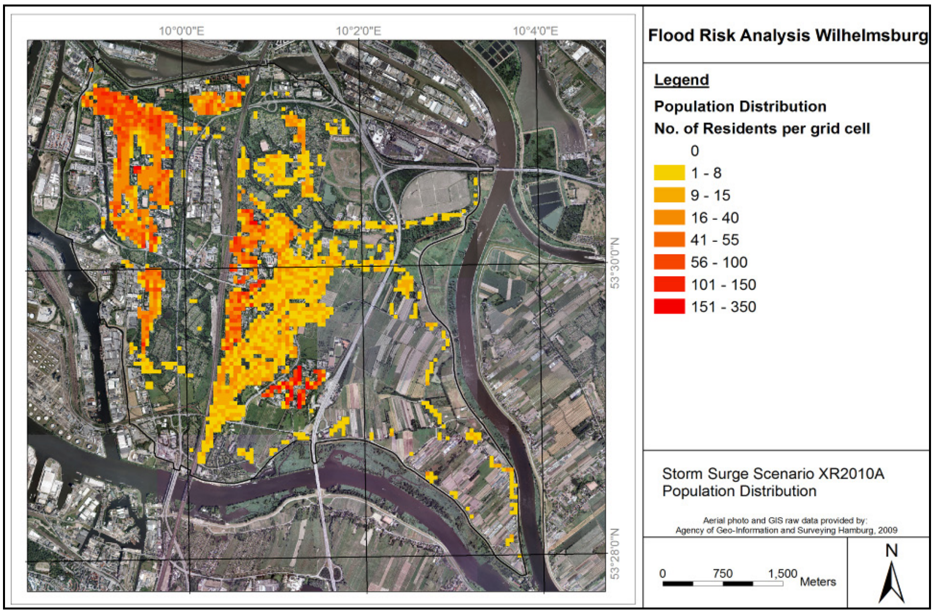

Figure 2. Pilot site Hamburg-Wilhelmsburg and CRA-based estimated population distribution in a 50 m grid (Burzel et al. 2012).

With an area of 35 km², Hamburg-Wilhelmsburg is the largest quarter of Hamburg. There are approximately 50,000 inhabitants, i.e. 1,400 inhabitants per km² on average (Figure 2). Most of the residential areas of Hamburg-Wilhelmsburg (about 15 km² in total) are located in flood prone areas. They mainly have an elevation between 0 m a.s.l. and 3 m a.s.l. Therefore, the area is protected by a flood defence ring composed of dikes and two flood walls. The dike ring has an overall length of 24 km and a height varying from 7.80 m a.s.l. to 8.35 m a.s.l. (Naulin et al. 2010).

ANALYSIS OF EXTREME STORM SURGE SCENARIOS

The integrated risk analysis is exemplarily described using the XR2010A extreme storm surge scenario. The scenario has been developed based on an increased storm surge curve than observed in 1976 at the Elbe River mouth (Cuxhaven tidal gauge) and then transferred to Hamburg St. Pauli by means of numerical simulations (Gönnert et al. 2012). At the St. Pauli gauge, the storm surge leads to water levels of approximately 8 m a.s.l. In addition, water levels and wave stages around the dike ring are calculated using a detailed numerical model which is coupling Kalypso1D2D and SWAN (Ujeyl et al. 2010).

For the XR2010A scenario, a probability of exceedance $P_{e,Cux} = 3.09 \cdot 10^{-4}$ per year has been determined at the Cuxhaven tidal gauge. Under consideration of the probability of exceedance $P_{e,d}$ for a specific Elbe river discharge of $Q_{Elbe} = 3{,}600$ m³/s, $P_{e,d} = 2.50 \cdot 10^{-2}$ per year, for the storm surge scenario XR2010A with a peak water level of approx. $h_w = 8.0$ m a.s.l., a probability of exceedance of $P_{e,HH} = 7.72 \cdot 10^{-6}$ per year is calculated for Hamburg (Wahl et al. 2012).

The storm surge event causes a non-structural failure of the flood defence system. As the failure probability has been analysed by dividing the dike line into 94 homogeneous sections, overtopping and overflow rates have been calculated for each section accordingly (Naulin et al. 2012).

The modelling of the hinterland flooding due to the extreme storm surge has been performed using MIKE21 by DHI. Overflow and overtopping have been considered as time-dependent boundary conditions. As the channels and fleets serve for transport of the flooding, the geometry has been explicitly considered when generating the triangulated computation mesh for the numerical model.

The overall inflow volume is in the order of 7.2 million m³, which results in a flooding of 75% of the area of Hamburg-Wilhelmsburg (Ujeyl and Kowalewski 2012). Figure 3 shows the flooding due to the XR2010A extreme storm surge event.

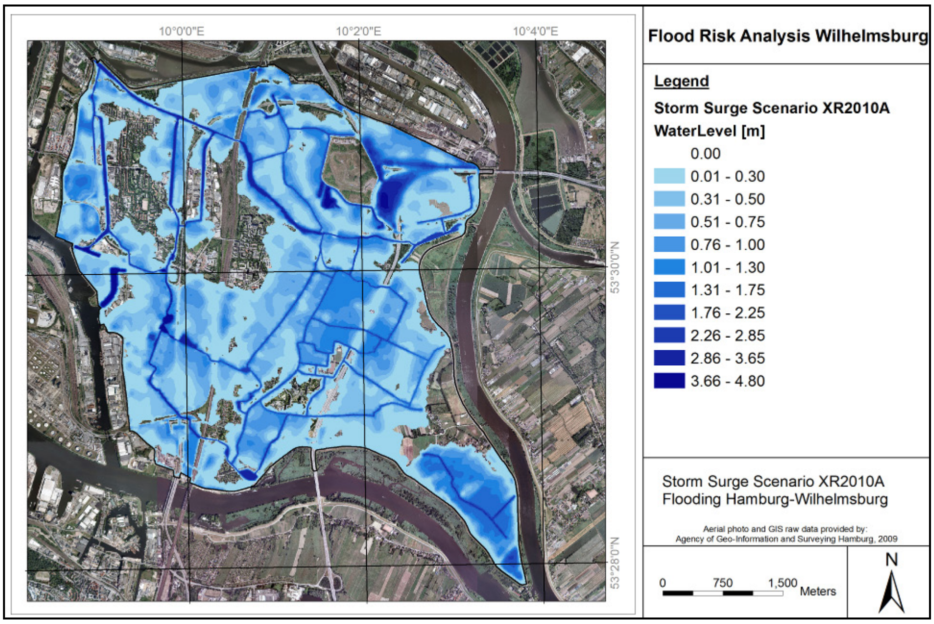

Figure 3. Flood depth for the XR2010A scenario in Hamburg-Wilhelmsburg visualized in a 10 m grid.

METHODOLOGY: ASSESSMENT OF TANGIBLE AND INTANGIBLE LOSSES

For the integrated risk analysis performed in XtremRisK, new approaches have been developed for the assessment of tangible and intangible losses. Hereby, direct and indirect tangible losses are taken into account. In addition, methods for the assessment of intangible losses, i.e. fatalities, injuries, cultural losses and ecological losses have been investigated. As both flooding and assets at risk vary within the Hamburg-Wilhelmsburg pilot site significantly, a spatial modelling approach has been developed for the assessment of tangible and intangible losses.

Tangible Losses

Tangible losses are either direct or indirect losses which can be easily valuated in monetary terms. While the former represent physical damages to residential buildings, infrastructure and further goods due to the physical contact with water, the indirect losses are rather caused by the interruption and disruption of economic activities as a consequence of the flood event. The importance and the difficulties of assessing indirect economic risk are outlined by Oumeraci et al. (2012).

According to Ujeyl and Kowalewski (2012), the assessment of direct and indirect tangible losses covers two steps. First, direct damages on residential and commercial sites are estimated using depth-damage curves for both buildings and inventory. Then, based on this result indirect damages are estimated using an economic input-output modelling approach in order to assess the indirect costs of the extreme event for the city of Hamburg.

Depth-damage curves have been developed for sample-type buildings, which represent houses with similar properties, such as the type of building, construction materials and use of the ground floor. Similar buildings are merged into a group which is represented by a sample-type building.

Based on this methodology, damage functions for 22 groups have been defined, covering 4,457 residential buildings. Moreover, 2,058 businesses have been assigned to industrial sectors according to the German sector classification system. The damages are then calculated based on relative damage curves for economic sectors under consideration of the number of employees for each business (Ujeyl and Kowalewski 2012).

Intangible Losses

In addition, intangible losses may also represent an important part of the total losses and can thus not be neglected in risk analysis. Approaches for the evaluation of intangible losses such as social losses (fatalities, injuries and cultural losses) and environmental losses have been critically reviewed by Dassanayake and Oumeraci (2010). A framework has been proposed for their evaluation and integration with tangible losses in integrated risk analysis.

Fatalities and Injuries. For the evaluation of fatalities, the loss of life model proposed by Penning-Rowsell et al. (2005) is recommended within the abovementioned framework.

The model is a comprehensive approach estimating both loss of life and injuries due to flooding. For the assessment, different input data are taken into account, such as flood event characteristics (flood depth, flow velocity, debris), characteristics of the flood prone area (flood warning measures, speed of onset, type of buildings and number of storeys) as well as characteristics of the population at risk (total number of residents, age distribution and presence of disabled people) (Figure 4).

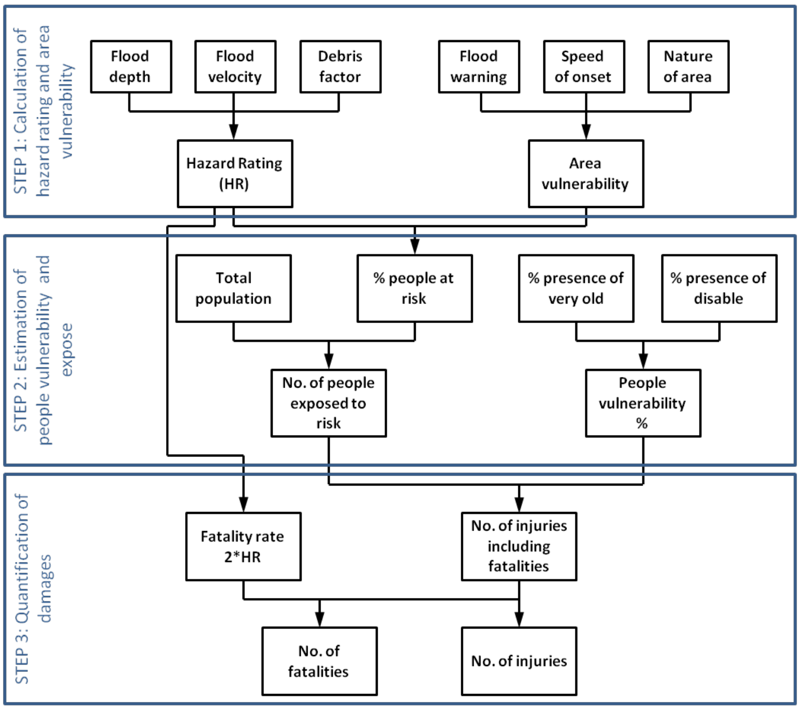

Figure 4. General loss-of-life assessment flowchart (modified from Dassanayake and Oumeraci 2010).

Though it is stated that the approach can be used for both river and coastal floods, so far the approach only has been applied for river floods. Therefore, the applicability for coastal flooding has to be verified.

For this purpose, the methodology developed by Jonkman (2007) has been selected. The approach is taking the possibilities for evacuation, shelter and rescue into account in order to estimate the total number of people exposed to a flood event. Then, mortality functions are applied depending on the flood characteristics.

Cultural Losses. For the evaluation of cultural losses, an assessment methodology has been developed by Dassanayake et al. (2012b).

It is proposed not only to take physical damages on cultural assets into account, but also to consider the level of cultural values based on the historical and societal significance of cultural assets at risk. Both components are combined in a cultural loss assessment matrix (CLAM) as shown in Dassanayake et al. (2012b).

Environmental Losses. In addition, a methodology for the evaluation of environmental losses has been proposed by Dassanayake and Oumeraci (2010) based on the Ecosystem Services approach.

For each ecosystem, related ecosystem services are assigned. The classification is slightly modified from MEA (2005), as only Provisioning Services, Regulating Services and Cultural Services are considered (cf. Dassanayake et al. 2012c). For the identification of ecosystems at risk, CORINE land cover data are analysed.

The changes of ecosystem services are then estimated using ecosystem specific impact factors, such as flood depth, flow velocity, flood duration or salinity. The change in ecosystem services due to all impact factors is summarized under consideration of weighting factors, which are determined by the Pairwise Comparison Method (PCM) derived from multi criteria analysis (MCA).

However, the ecosystem risk assessment is not applied within Hamburg-Wilhelmsburg and will therefore not be discussed in this paper.

Spatial Modelling Approach

Following, the feasibility for the assessment of tangible and intangible losses on a spatial basis was investigated. It has been found, that the properties with respect to vulnerability and hazard, i.e. population distribution, relief height and water level, amongst others, vary significantly within an investigation site (cf. Figures 2, 3 and 5).

Therefore, Geographic Information Systems (GIS) and the GIS raster concept have been applied in risk analysis in the past. However, the main disadvantage of the raster data concept is that only a single data subject (attribute) can be stored in one raster file. Thus, a combination of the raster and vector concept is desirable (Burzel and Oumeraci 2011b).

A polygon based concept for spatial risk analysis has been developed, merging the advantages of both, raster and polygon concepts. The so called Cellbased Risk Assessment (CRA) approach serves as an integrated, flexible and robust framework for the spatial modelling in integrated risk analysis (Burzel and Oumeraci 2012).

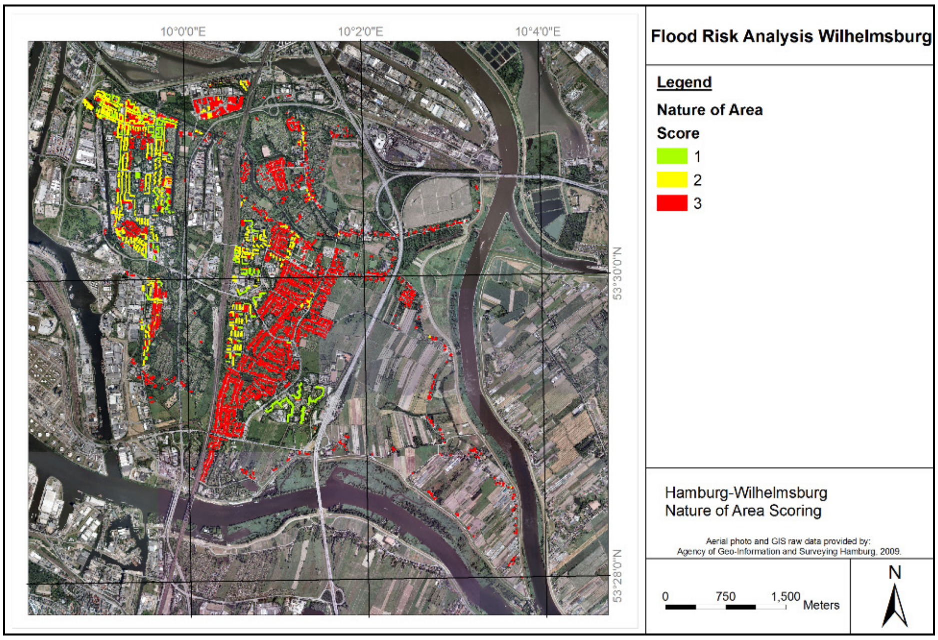

Figure 5. Variation of the input parameter 'Nature of Area' for loss-of-life modelling depending on the number of storeys (1: low risk, more than 4 storeys, 2: medium risk, 2 to 4 storeys and 3: high risk, building with less than 2 storeys as classified in Penning-Rowsell et al. 2002) (Burzel et al. 2012).

For the CRA based analysis, the pilot site is divided into uniform polygons (cells) of a given size which mainly depends of the size of the area and the scale of the assessment. These cells build a uniform grid and are therefore termed as grid cells. For Hamburg-Wilhelmsburg, three different resolutions are applied, which lead either to a 100 m, 50 m or 10 m grid.

Due to the implementation of comprehensive geoprocessing workflows, there is almost no limitation for the application to more complex risk analysis. Moreover, it is possible to apply the same model in different resolutions and on different pilot sites, as the general geoprocessing workflow remains similar. The workflows are developed in a modular structure using the Model Builder environment in ArcGIS.

The Cellbased Risk Assessment (CRA) consists of three main steps: (i) conversion of all irregular shaped input data into the assigned compartmentation, (ii) application of the selected model for all cells within the investigation site, (iii) visualisation of the results on a spatial basis.

ANALYSIS: SPATIAL MODELLING OF TANGIBLE AND INTANGIBLE LOSSES

Based on the CRA approach, modelling tools for (i) direct tangible losses, (ii) fatalities and injuries, (iii) cultural losses and (iv) ecological losses as described in the next section have been developed and successfully applied for different extreme storm surge scenarios.

Tangible Losses

The assessment of direct damages on the basis of depth-damage functions is performed in two steps. First, the defined depth-damage functions are applied on all residential buildings, which have been assigned to one of 22 different sample-type buildings. As the water level has been transferred into grid cells, the buildings' polygon or point based shapefile is intersected with the water level grid. Then, the damage for each building is calculated based on the water level. In a second step, the results for all buildings within one grid cell are summarized to be used for further analysis.

Fatalities and Injuries

The spatial loss-of-life model for scenario based analysis has been developed as a modular geoprocessing routine. According to the structure shown in Figure 4, the geoprocessing model was split up into 7 modules. For the analysis, all relevant parameters, such as distribution of residents, number of storeys, availability of evacuation measures and water depth have been converted into grid cells.

The Hazard Rating is calculated for each grid cell under consideration of the maximum flood depth, maximum flow velocity and the debris factor, depending on both maximum flow velocity and maximum water depth.

Three parameters are required for the estimation of the Area Vulnerability, i.e. flood warning *FW*, nature of area *NA* (cf. Figure 5) and speed of onset *SO*, i.e. reaction time in case of flooding. While the first two are static parameters and can therefore be converted into grid cells and scored easily, the speed of onset is strongly dependent on the analysed scenario. Therefore, an iterative analysis tool has been developed, which is flexible with respect to (a) the number of dataset to be analysed and (b) the time difference between two datasets. The speed of onset is assessed by evaluating the water level difference between two time steps for the entire flooding event. A score is set, if the rise rate exceeds a specified threshold. Finally, the Area Vulnerability *AV* is calculated by summarizing the three scores *FW*, *NA* and *SO* for each grid cell.

For the estimation of the people vulnerability, the age distribution as well as the presence of disabled people, e.g. in hospitals or residential care homes for the elderly, are analysed by using official statistics in combination with site investigations, which is then converted into grid cells (Figure 6).

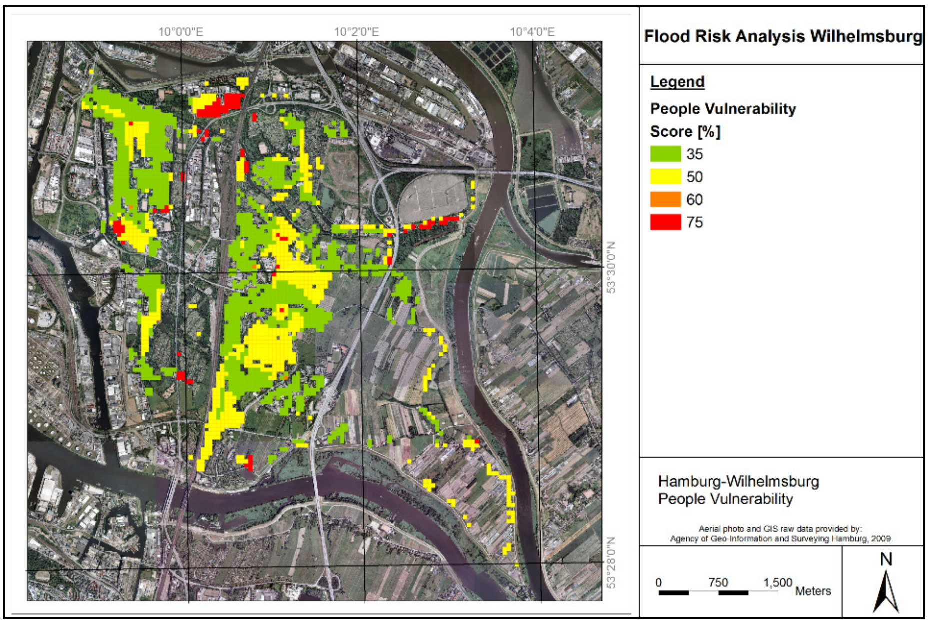

Figure 6. Spatial distribution of the result for the input parameter People Vulnerability (Burzel et al. 2012).

Based on the input parameters Population Distribution (see Figure 2), Hazard Rating and Area Vulnerability, the number of people exposed to risk per grid cell is estimated. Then, the number of injuries including fatalities is calculated under consideration of the People Vulnerability. In the last step, the number of fatalities and the number of injuries is determined taking the Hazard Rating into account.

Finally, the result can be visualised and mapped as a basis for the development of flood risk reduction measures.

Cultural Losses

For the spatial modelling of cultural losses, a comprehensive analysis of heritage and non-heritage buildings has been performed in Hamburg-Wilhelmsburg. While the former are heritage protected due to their historical importance, the latter are a substantial part of the present cultural life, e.g. libraries, galleries or expositions.

For this purpose, the official catalogue of heritage protected assets of the Free and Hanseatic City of Hamburg has been taken as a basis. The location of all listed assets has been transferred spatially into the point format using a geocoding approach. For Hamburg-Wilhelmsburg, 283 heritages and 11 non-heritage sites have been investigated (Figure 7).

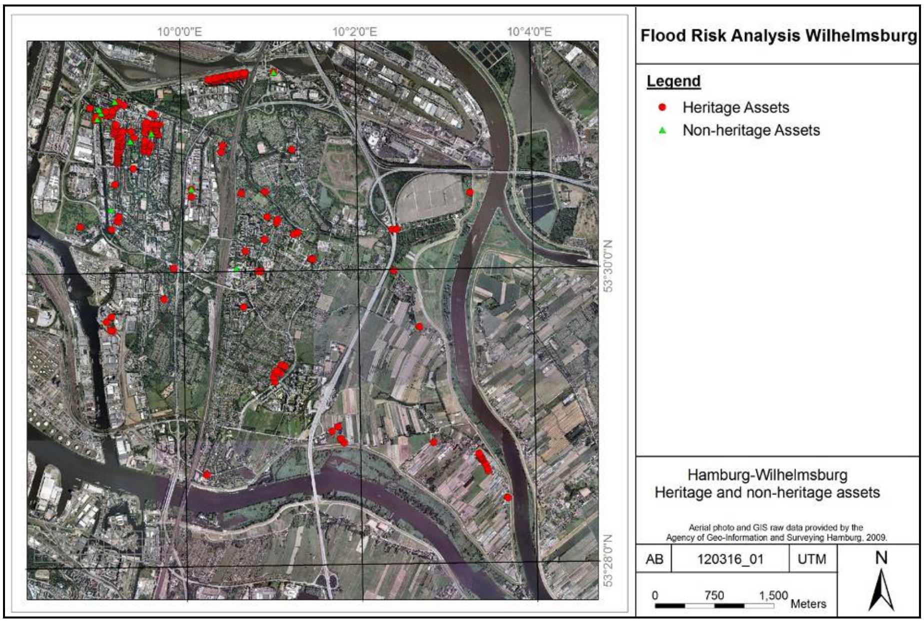

Figure 7. Locations of heritages and non-heritage assets in Hamburg-Wilhelmsburg (modified from Dassanayake et al. 2012b).

RESULTS: TANGIBLE AND INTANGIBLE LOSSES

The XR2010A extreme storm surge scenario causes the flooding of the pilot site in the order of 7.2 million m³, which covers 75% of the area of Hamburg-Wilhelmsburg (Ujeyl and Kowalewski 2012). In consequence, this leads to direct and indirect tangible as well as intangible losses.

Tangible Losses

For the XR2010A scenario, 530 million Euros damages on residential buildings are calculated (Figure 8) (Ujeyl et al. 2012). In addition, losses in the order of 70 million Euros are estimated for the interior of private households. The risk R can be calculated as the product of the probability of flooding $P_{f,cond}$ and the expected damages D. For the XR2010A storm surge scenario, a risk for residential houses R_{resid} = 4,650 Euros per year is estimated.

The results for further damage categories, such as direct damages on companies, infrastructure and agriculture as well as the results for indirect losses are described in Ujeyl et al. (2012).

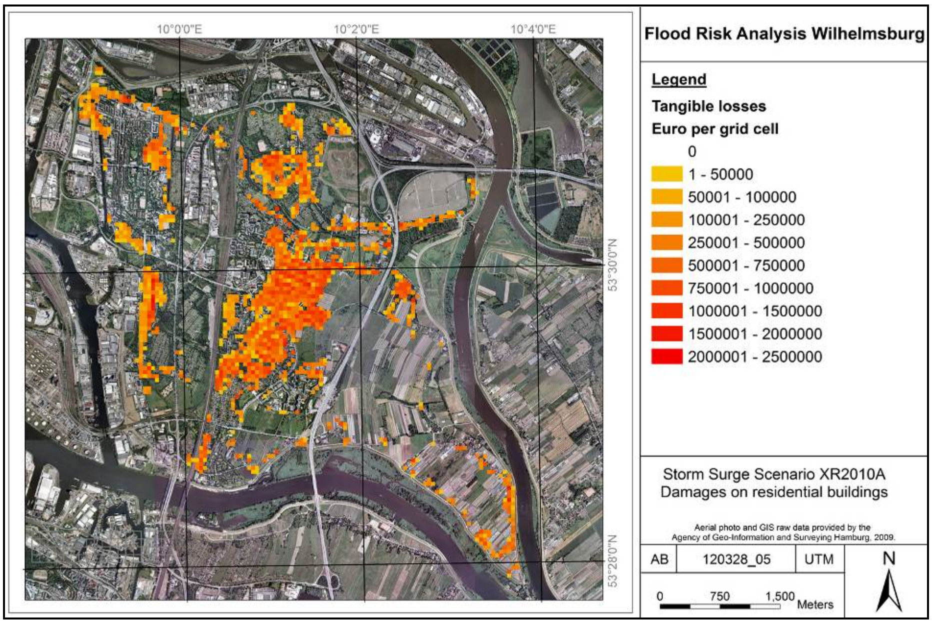

Figure 8. Tangible losses on residential buildings in Hamburg-Wilhelmsburg based on a 50 m grid.

Intangible Losses

Based on the spatial loss of life model, 916 injuries and 2 fatalities are estimated for the XR2010A scenario (Figure 9). It can be seen that the area located North-West of Hamburg-Wilhelmsburg is affected significantly. This is mainly the case due to the proximity to the dike line, the high population density and the overwhelming inflow volume. Hence, both dimensions of risk, vulnerability and hazard, are substantially high in this area. Moreover, the low-lying central part of Hamburg-Wilhelmsburg suffers social losses as single-storey buildings are located there predominantly. With respect to the XR2010A scenario, the individual risk of dying is $R_D = 2.5\cdot10^{-5}$ per year.

However, it is important to state that the speed of onset and maximum flow velocity are relatively low, as only overflow and overtopping occur. In the very unlikely case of a dike breach more severe losses have to be estimated.

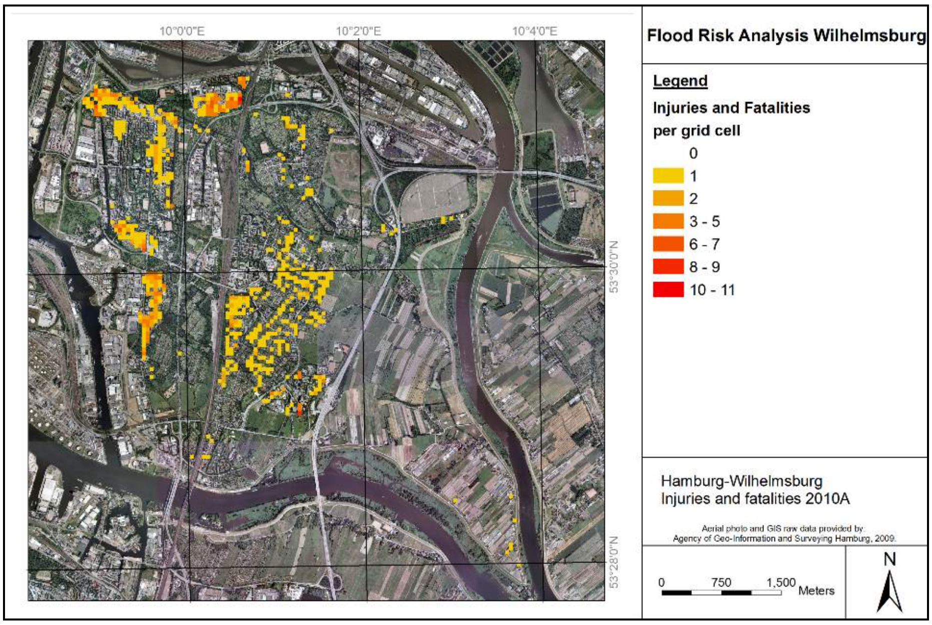

Figure 9. Estimated number of injuries (including 2 fatalities) for the XR2010A extreme storm surge scenario (Burzel et al. 2012).

The analysis of cultural losses as shown in Figure 10 also leads to the conclusion that the area located North-West of Hamburg-Wilhelmsburg is mostly affected by flooding.

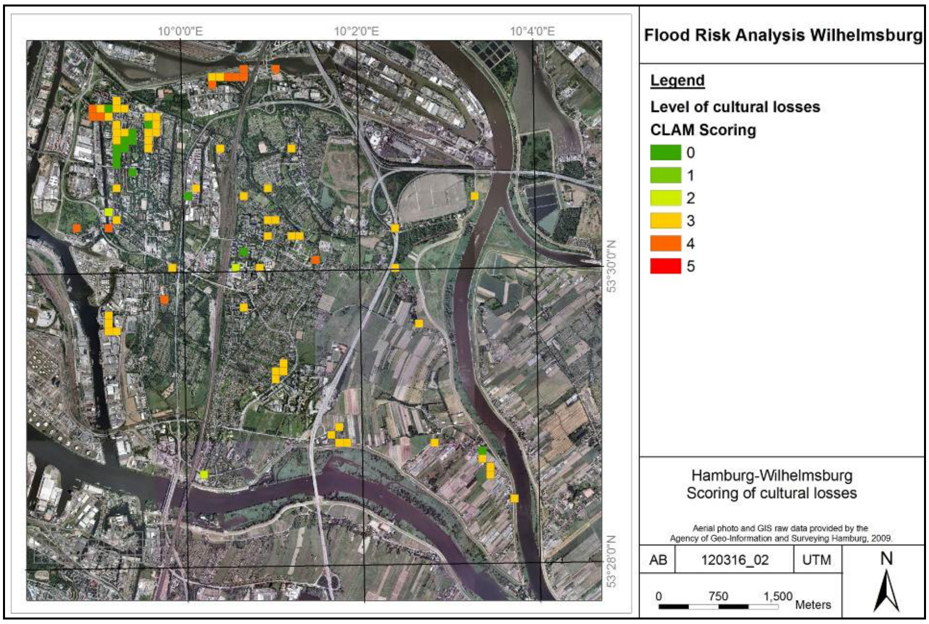

Figure 10. Cultural Losses for the XR2010A scenario in Hamburg-Wilhelmsburg (Dassanayake et al. 2012b).

However, most of the cultural assets are only moderately affected, as the scoring mainly varies from 0 to 3, with an average of 2 (Figure 11). For the cultural losses the risk can be expressed as an average score per year. For the XR2010A scenario, a cultural risk R_{cult} = $1.54 \cdot 10^{-5}$ per year is determined.

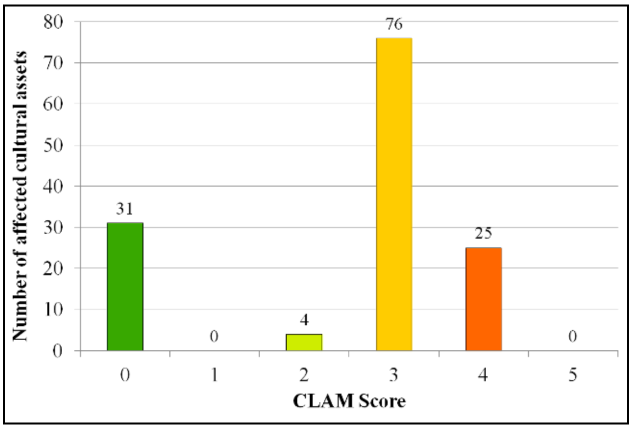

Figure 11. Severity of cultural losses based on the Cultural Loss Assessment Matrix (CLAM) assessment for the scenario XR2010A.

Integration of Tangible and Intangible Losses

For the risk analysis, the integration of tangible and intangible losses is performed on the basis of multi criteria analysis as proposed in Dassanayake et al. (2011) using the CRA approach.

In order to allow the integration of both monetary and non-monetary results with a significantly different order of magnitude, a standardisation is performed based on utility functions first. Next, weighting factors are determined as shown in Dassanayake et al. (2011) which describe the relative importance of each category of losses.

Here, economic losses are weighted by 0.2, fatalities by 0.5, injuries as 0.2 and cultural losses by 0.1 as shown in Figure 12. The integrated risk is then expressed as a non-monetary dimension (integrated risk units per year).

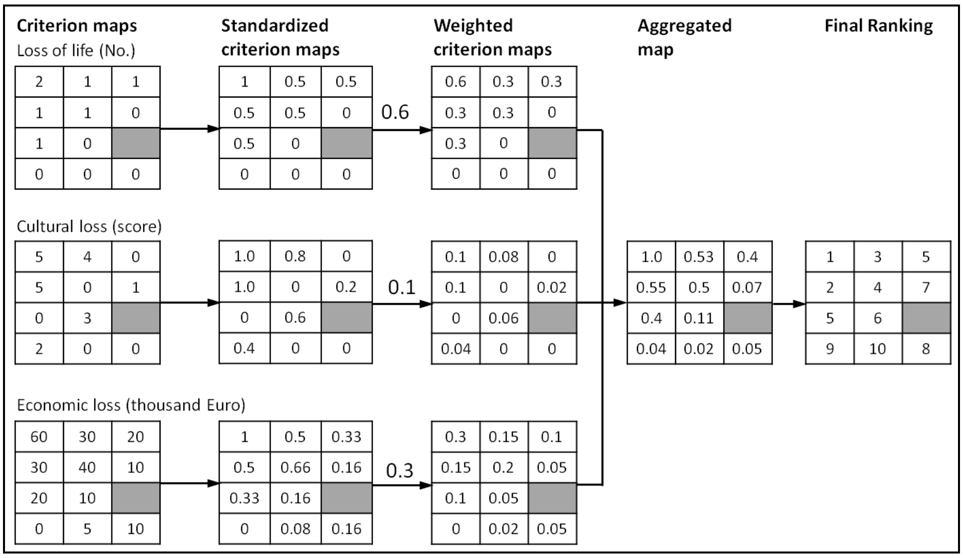

Figure 12. General integration procedure for different damage categories using the Simple Additive Weighting Method (SAW), (modified from Dassanayake et al. 2011).

The risk for the XR2010A scenario after the integration of all categories of losses is shown in Figure 13 classified in 5 risk levels. It is important to note that only two cells exceed a risk of $R = 0.01$ integrated units per year (medium risk). These are the cells where fatalities are estimated. However, further scenarios have to be analysed in order to derive a risk curve, which then allows one to assess this 'virtual' dimension of risk.

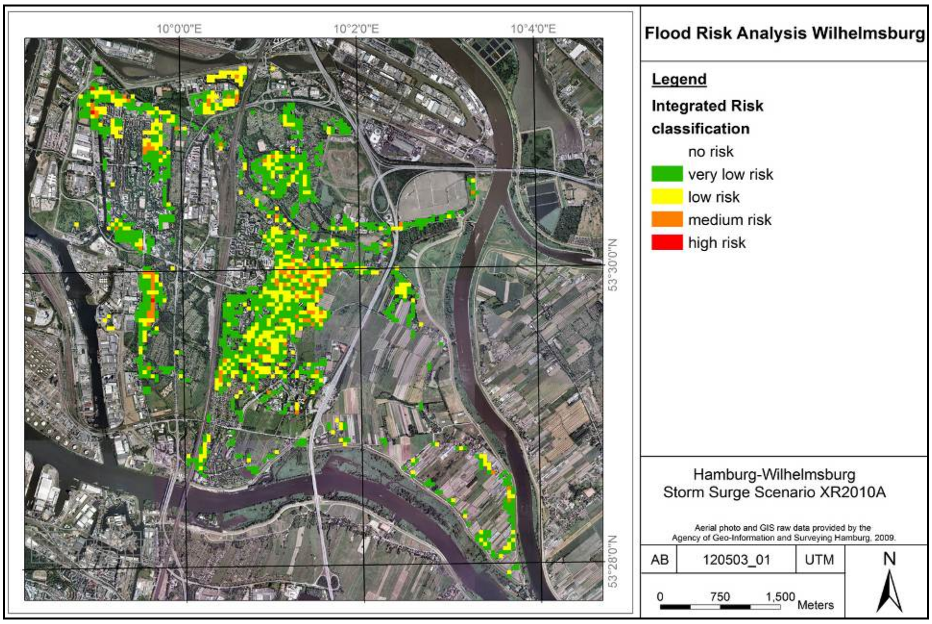

Figure 13. Integrated risk based on the XR2010A scenario for Hamburg-Wilhelmsburg.

Risk Mapping

The CRA approach is finally used for the compilation of risk maps as demanded by the EU Flood Risk Directive in order to support the next phase of the Directive, i.e. the flood risk management.

It is aimed to present maps for both dimensions of risk, i.e. hazard and vulnerability. The vulnerability maps can be further divided into tangible and intangible losses (Figure 14). Hence, different topics can be presented for the decision making of stakeholders and responsible authorities in order to develop risk reduction measures, which strongly depend on the category of loss and can therefore not solely be derived from the integrated risk map.

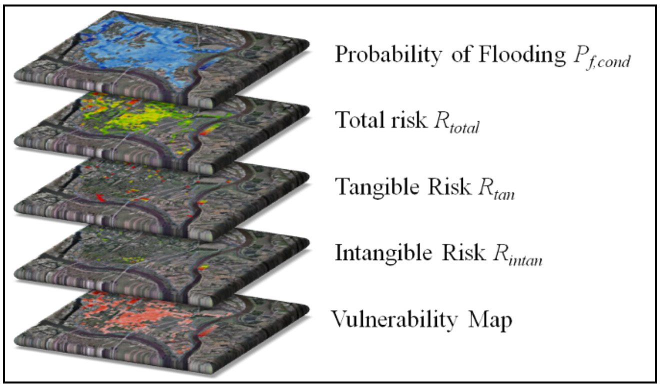

Figure 14. Risk related layers for the decision making process (modified from Burzel and Oumeraci 2011).

POSSIBLE RISK REDUCTION MEASURES

Due to sea level rise, population growth and rising economic wealth, flood risk is expected to increase significantly in the future. In order to reduce the possible consequences of coastal flooding due to extreme storm surges, new defence strategies are required.

For the pilot site of Hamburg-Wilhelmsburg, the system of cascading flood compartments (CFC-approach) has been proposed by Pasche et al. (2009). The CFC-approach is a mitigation measure as a response strategy to flooding of the hinterland as well as to the vulnerability of the flood plains (Ujeyl et al. 2012). In case of flooding, inner dikes built compartments in order to retain the floodwater in less vulnerable areas (Figure 15). The polders are also termed as flood compartments. Within Hamburg-Wilhelmsburg, the water is retained in agricultural areas and zones with a low vulnerability.

According to Ujeyl et al. (2012), an overall risk reduction of 59% for residential and commercial losses based on the XR2010A scenario can be achieved. Final recommendations for counter-measures will be derived from the final results of the integrated risk analysis and in close collaboration with the stakeholders in the two pilot sites.

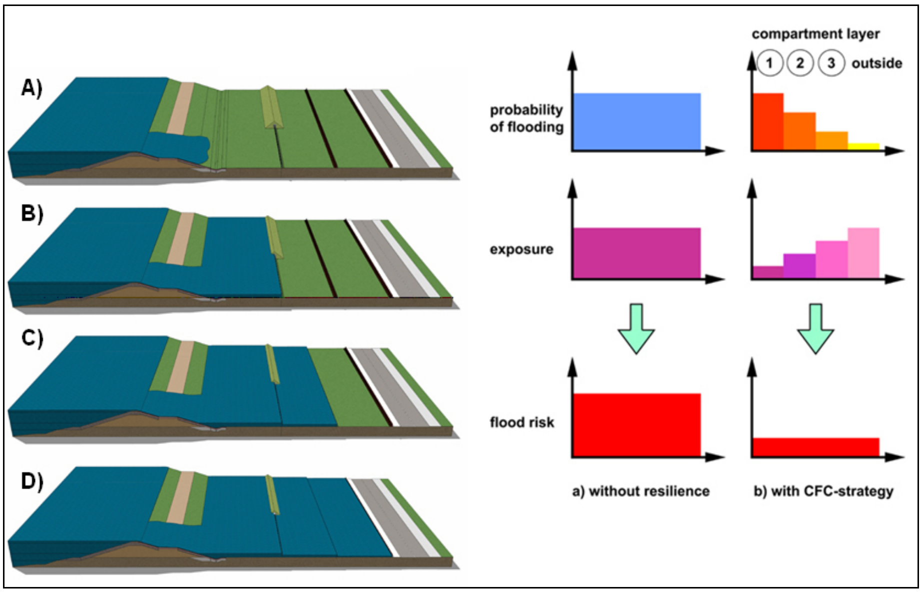

Figure 15. Principle of a system with flood compartment (left: flooding of the first, second and third compartment, right: risk reduction due the CFC-approach) (modified from Ujeyl et al. 2012).

CONCLUDING REMARKS AND OUTLOOK

The German joint research project XtremRisK aims at performing an integrated risk analysis of extreme storm surges on the basis of the Risk Source-Pathway-Receptor concept for selected pilot sites in an urban estuary and an open coast.

The overall project consists of four subprojects, which analyse the physics and statistics of extreme storm surges (risk source), the loading and stability of the flood defence system under extreme storm surges and the related failure probabilities (risk pathway), the vulnerability and expected tangible and intangible losses within the selected pilot sites (risk receptors) as well as the scenario based risk analysis and integration of different categories of losses (risk analysis).

The application of the Risk Source-Pathway-Receptor approach enabled a detailed integrated flood risk analysis. Moreover, risk reduction measures can be developed taking risk source, risk pathway and risk receptors into account.

Prior to the estimation of intangible losses, a GIS based spatial modelling approach has been developed. The so called Cellbased Risk Assessment (CRA) approach is also applied for the assessment of tangible losses, the integration of damage categories and risk mapping. With respect to the development of flood risk reduction measures, the CRA approach can be used for the provision of evidence of the selected methods, as these measures can also be modelled spatially.

The integrated risk analysis has been exemplarily presented for the XR2010A storm surge scenario with a maximum water level of 8.00 m a.s.l. and a probability of exceedance $P_{e,HH} = 7.72 \cdot 10^{-6}$ per year. However, in order to develop a risk curve for extreme storm surges, further storm surge scenarios under current and future climate change conditions have been analysed within XtremRisK. Furthermore, the relative contributions of the different types of losses (direct/indirect economic losses, environmental and social) and the effect of the uncertainties on the integrated risk analysis were analysed.

The results of the XtremRisK project are expected to substantially improve the ability of responsible agencies and end-users to better mitigate potential damages by extreme storm surges. However, for the development of risk reduction measures, knowledge about the level of accepted risk is strongly required. Therefore, a framework for the evaluation of risk acceptance will be proposed based on the XtremRisK results. The key achievements, the work in progress, the encountered difficulties and the lessons learned are summarized by Oumeraci et al (2012) – though the XtremRisK project is not fully completed.

Further information about the XtremRisK project is also provided at the project website under www.xtremrisk.de.

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