HAZARD ANALYSIS OF COASTAL REGIONS

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Abstract:
An optimized strategy in coastal protection requires the analysis of hazards to the coastal hinterland caused by failure of sea dikes during storm surges. The starting point of hazard analysis is the mapping of flood zones. Problems relating to the time-dependence of flooding at tidal coasts and to the assumptions on the characteristics of the dike breach are worked out in detail by two-dimensional numerical simulations. In a second step a meso-scale concept for the calculation of the expected loss is presented and applied to a part of the German North Sea coast.

Keywords: coastal engineering, numerical simulation, flood forecast, hazard analysis, coastal protection schemes

1. INTRODUCTION

The development of coastal protection schemes against flooding requires on the one hand side an analysis of water levels and waves in the estuary and on the other hand side an evaluation of the hazard to the hinterland due to flooding. The latter becomes more and more important because of restricted budgets for coastal protections. Therefore the coastal defence schemes cannot be designed providing the same safety standard. The graduation of safety standards of coastal defence schemes typically takes into account the land uses within the hinterland and its values.

In the following a worked out example of a hazard analysis is presented for a part of the German coastal zone near the city of Otterndorf located between the two major seaports Cuxhaven and Hamburg at the Elbe estuary (see Figure 1). The mean tidal conditions are characterised by the dominance of the M2-tide with a tidal range of 2.93 m.

The major coastal protection element near Otterndorf is a sea dike with a crest height of 8.8 m above mean sea level and slopes on the seaward side of 1 to 6 and on the landward side of 1 to 3 (see Figure 2). In order to guarantee drainage of the hinterland several sluices are integrated in the sea dike. Because no additional coastal protection elements like forelands or summer dikes [1] can be found serious consequences in case of dike failure have to be expected.

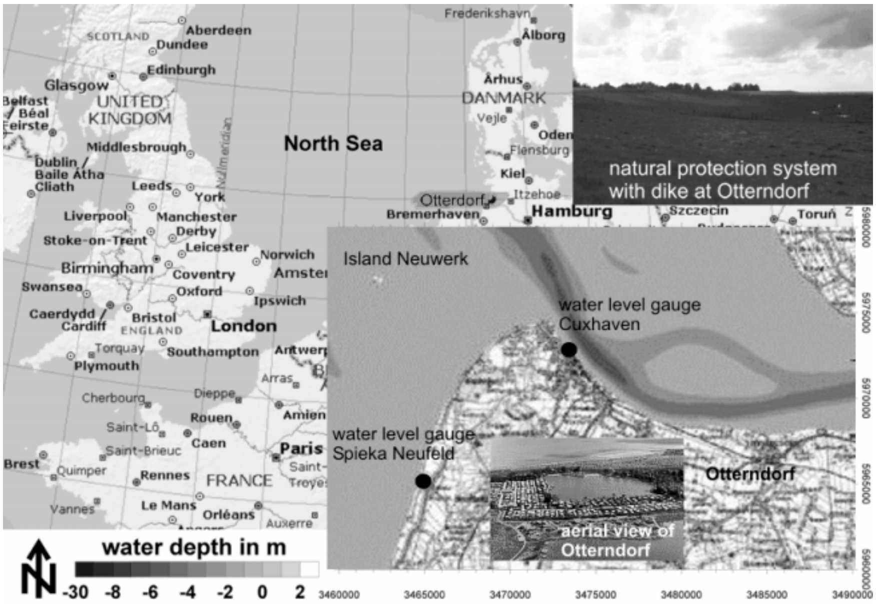


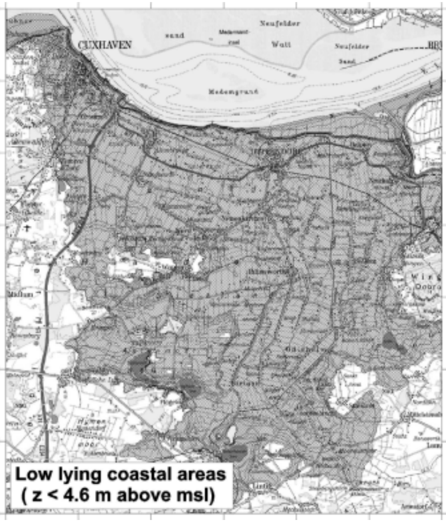
Figure 1: Location of Otterndorf at the estuary Elbe east of Cuxhaven and photography of the natural protection system with a dike

Figure 2: Sluice and sea dike near Otterndorf

The inundation after dike breach is calculated for the storm surges of the cyclone "Anatol" occurred on December 3rd 1999. The maximum high water level during the "Anatol" storm was 4.6 m above mean sea level, which is equivalent with a return period of 20 years. The tidal curve during the "Anatol" storm surge is given in Figure 7. During "Anatol" westerly winds with speeds up to 22 m/s were measured resulting in a wave load of 1.5 m with mean periods of 4.2 s in the Elbe estuary [2].

2. MAPPING OF FLOOD ZONES

A first estimate of the hazardous effect of a storm surge after dike breach is given by mapping areas in the hinterland lying below the highest water level of the storm surge (Figure 3). However this static approach overestimates the area of the inundated hinterland, because the time dependence of the flooding process is not taking into account. Time dependent two dimensional numerical simulations of the inundation map the flood zones much better [3].



expected inundation depths z (static approach)	area flooded $[10^4\,m^2]$
0 m	78235.0
1 m	62375.5
2 m	45644.0
3 m	35862.0
4 m	27720.5
5 m	24523.0

Figure 3: Approximativ mapping of flood zones

An example of dynamic mapping of the flood zone using the numerical model MIKE21 HD is given in Figure 4. The calculations were carried assuming a breach of the sea dike over a length of 200 m without any remaining sill which typically occurred during historic storm surges in 1962 and 1976 [4].

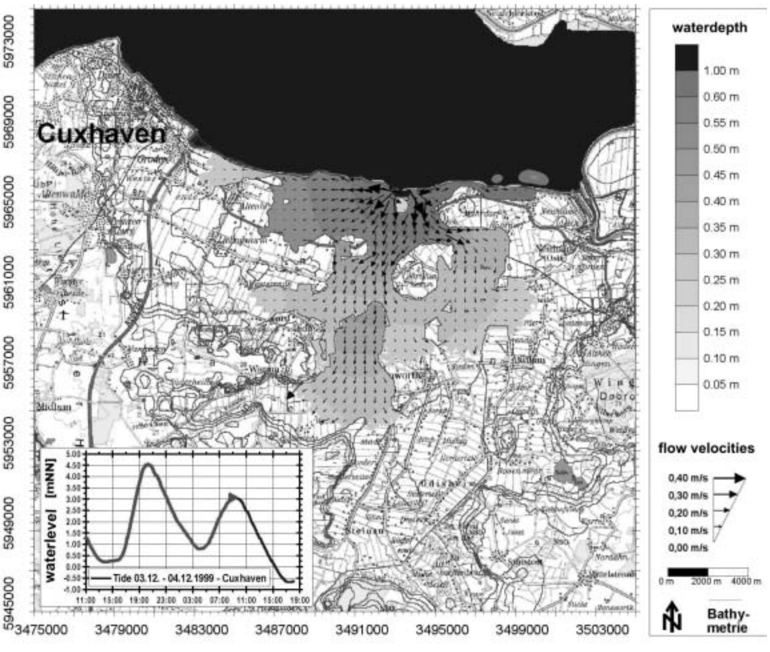


Figure 4: Dynamic mapping of flood zones

Besides that a sensitivity analysis on the influence of the characteristics of the dike breach on the results of dynamic flood zone mapping was carried out. As shown in Figure 5 the area flooded increase by a factor of 1.7 in case of an increase of the width of the dike breach by a factor of 4 while the water volume inundating increases by a factor of 2. A remaining sill in the dike breach of a height of 3 m reduces the flooded area to 16 % and the water volume inundating to 14 %.

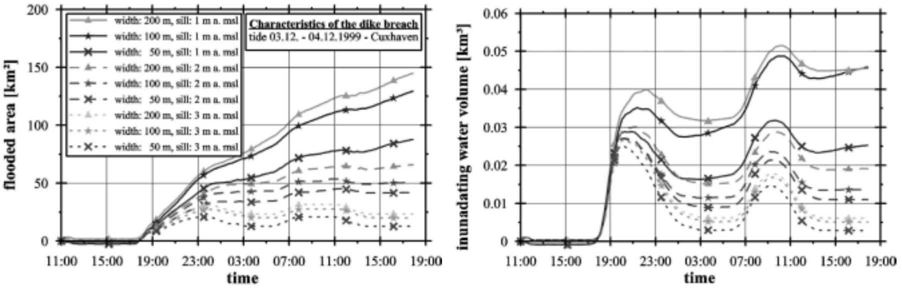


Figure 5: Characteristics of the inundation process as a function of the dike breach event

3. HINTERLAND USE AND THEIR IMPAIRMENT

The damage to be expected in case of flooding depends on the one hand side on the land use within the hinterland determining the maximum possible loss and on the other hand on the impairment of these values. The impairment is typically parameterised on the meso-scale by characteristic parameters of the inundation, like maximum water depth, maximum flow velocity or duration of flooding [5, 6]. These parameters are given in Figure 7 and were derived from the numerical simulations presented in Figure 4.

The maps of the inundation characteristics as well as the time-series of the inundation were combined with a digital landscape model as indicated in Figure 5. This combination yield to time-series of the flooded area for each type of land use (Figure 6). The area flooded is predominantly used for agricultural (meadow, farmland) and residential respectively mixed purposes.

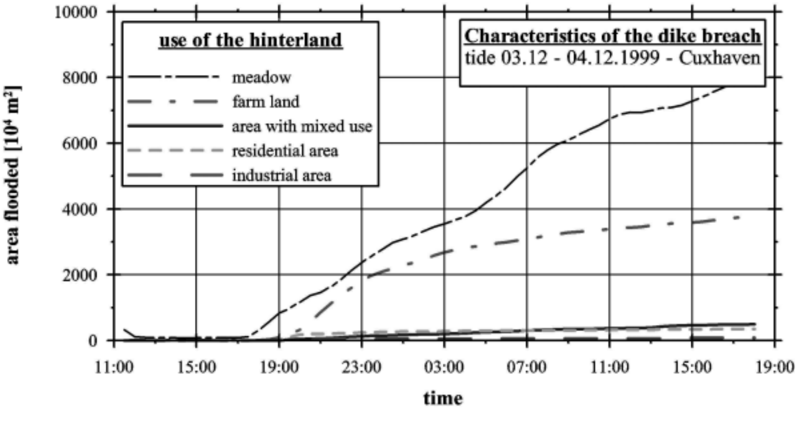
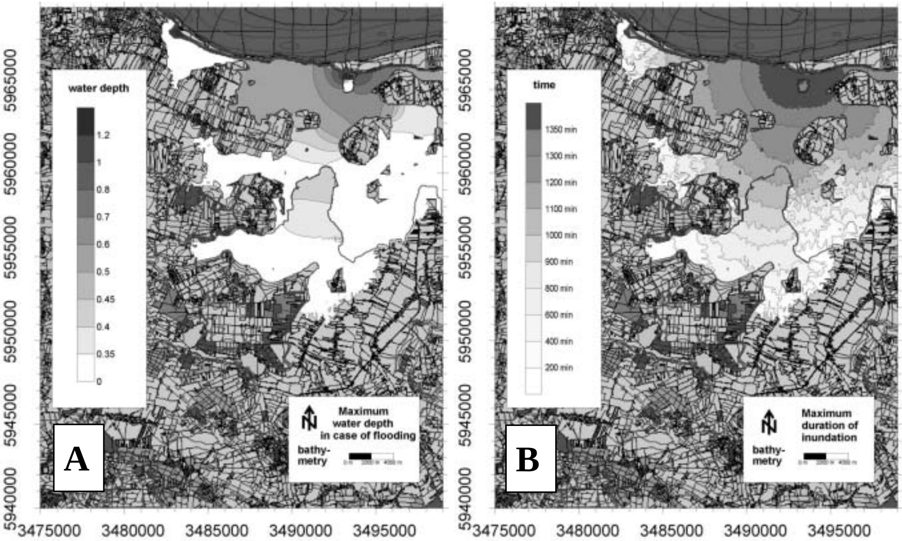
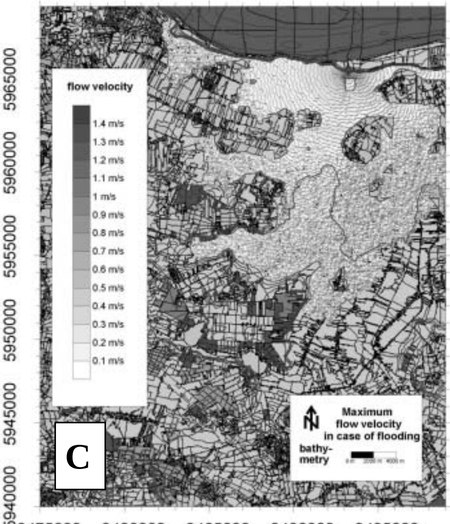


Figure 6: Time dependent flooding of the hinterland distinguishing different land uses.





use of hinterland	area flooded [10^4 m²]
meadow	8069.5
farm land	3784.0
area with mixed use	498.8
residential area	353.5
industrial area	82.8

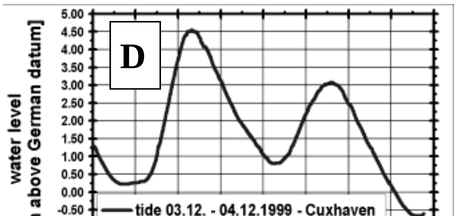


Figure 7: Characteristics of the inundation process (A: water depth, B: duration of flooding, C: max. flow velocity, D: storm surge in 1999).

A classification of the water depth within the flooded areas is given for the different land uses in Figure 8. The analysis revealed that average depth of flooding amounts to 0.3 m for meadow and arable land, 0.4 m for residential use and industrial use and 0.3 m for mixed (residential/industrial) use. The distribution of the flooding depth is used to calculated the average damage factor, i.e. the ratio of the expected loss and the total value. To do so the different damage functions given in Figure 9 were used.

Introducing the average value per unit area (see Table 1) of a specific use then results in the expected loss:

expected loss = average damage factor x average value per unit area x flooded area

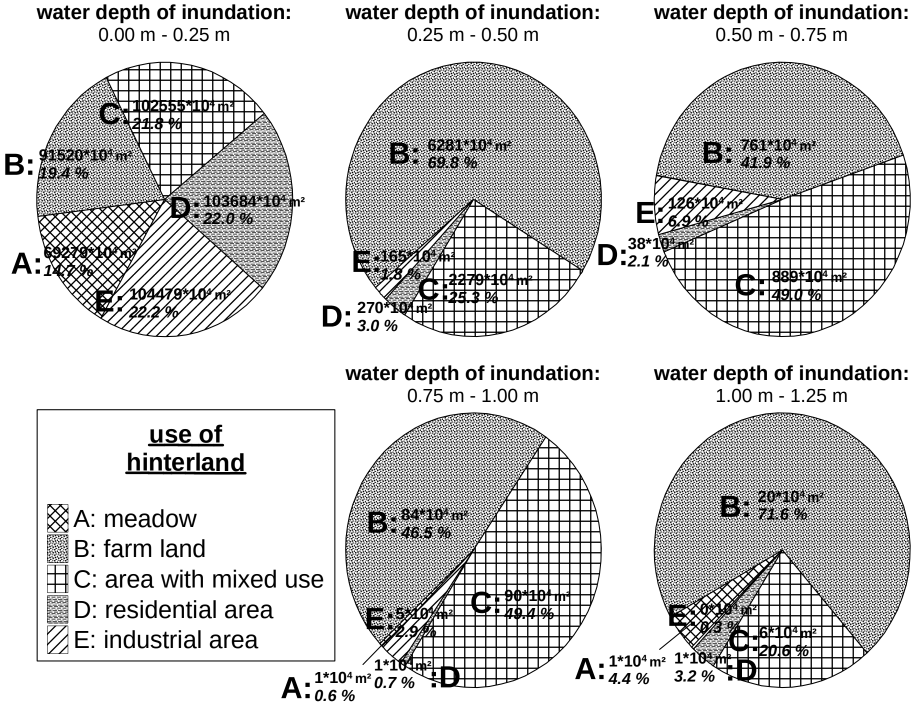
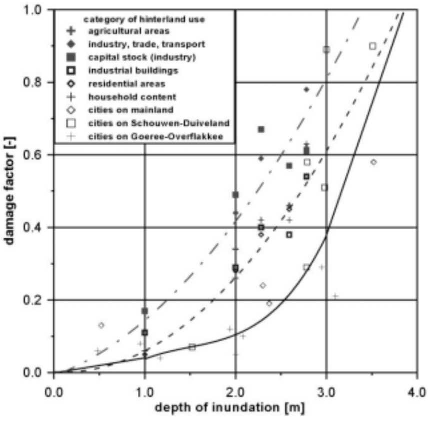


Figure 8: Classification of the utilization with respect to water depth



use of hinterland	average damage factor [-]
meadow	0.3
farm land	0.3
area with mixed use	0.1
residential area	0.1
industrial area	0.1

Figure 9: Parameterization of the degree of damage as a function of the inundation depth [7] (left) and classification of the average damage factor with respect to the utilization (right)

use of hinterland	value per unit area [€ / m²]	expected loss [Mio. €]
meadow	0.15	3.6
farm land	0.15	1.7
area with mixed use	85.00	42.4
residential area	120.00	42.4
industrial area	65.00	5.4
Total	-	95.5

Table 1: Value per unit area [8] and expected loss classified by the type of land use

The average values per unit area of the different land uses were calculated from the official statistics for the county of Cuxhaven [8, 9] by homogenous distribution of the total value of the specified land use over its total area. The loss to be expected in case of the inundation given in Figure 7 amounts to 95.5 million Euro. It is mostly caused from the impairment of residential and non residential buildings and its infrastructure.

4. CONCLUSION - MITIGATION OF COASTAL RISK

The hazard analysis of the coastal region revealed that the major economic threat of storm surges effects housing. However this is not the focus of today's mitigation strategy. Instead of that German coastal authorities strive for the same level of safety along the whole coast, no matter which land use can be found in the hinterland. This approach does not seem to be feasible in the future because of the increasing pressure on coastal protection systems due to an accelerated sea level rise [1,10].

Therefore future mitigation strategies should come to a more graduated and detailed coastal protection strategy. The poldering of villages and cities in the hinterland might be a reasonable alternative to reduce the vulnerability of the hinterland against storm surges. Besides that the regional planning should also take flood risk into consideration, e.g. by differentiating risk zones within the hinterland, which is already done in the Netherlands [11]. For this reason a decision support system for the risk management of the German coastal zone is under development in the moment [http://www.krim.uni-bremen.de].

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