Integration of Flood Risk in Coastal Hinterland Management

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Introduction

Management of coastal hinterland is usually treated separately from coastal defence planning as coastal defence systems, such as dikes, sluices, etc, have been assumed to be absolutely reliable as protection against storm surges. This opinion has now come under scrutiny as stress on defence systems is increasing due to accelerated sea level rise or economic reasons. Coastal defence planning can be integrated into hinterland management by performing risk analysis which comprises the calculation of safety of coastal defence systems as well as the losses to be expected in case of failure (Mai, Zimmermann 2003). For this purpose GIS is a valuable tool to analyse the effects of inundation. In the following this is shown for the region "Wurster Land", north of Bremerhaven at the German North Sea coast.

Safety of Coastal Defence Systems

The calculation of the safety of coastal defence systems includes the following steps: “Identification of failure modes”, “Description of statistics of hydrological or hydraulic loads resp. due to water levels and waves", “Description of statistics of the resistance”, “Calculation of the failure probability”. At the German North Sea coast the sea dike is the most important coastal defence element as wave overtopping is the major failure mechanism. For today’s water level conditions, waves and winds, the annual failure probability varies between approx. 1/6000 and 1/600. In case of water level rise of 55 cm to be expected due to climate changes until 2050, the failure probability increases to approx. 1/1000 or 1/100 resp. Figure 1).

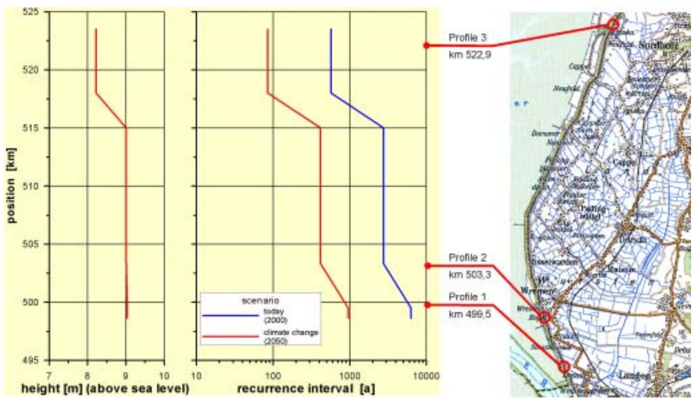

Figure 1: Recurrence interval of failure (wave overtopping) for three dike profiles at the coastline north of Bremerhaven calculated without and with water level rise of 55 cm

Analysis of Flood Scenarios

Calculation of flood damage is based on the expansion of the flood zone. The flooding process is defined by dynamic simulations using a numerical model. To analyse the affected hinterland and the resulting loss two additional tools, “Flood-Analyser” and “Loss-Calculator”, were developed under “Avenue” (Elsner 2002). The “Flood-Analyser” is used to examine the flooding process with respect to water expansion and depth. Furthermore, it is possible to determine different land uses affected by inundation. The screenshot (Figure 2) represents the analysis of a simulated dike breach near Cappel-Neufeld north of Bremerhaven during the storm surge on 3rd January, 1976. The summary table shows, e. g. that more than 100 hectares of residential area would be flooded. Figure 3 graphs the flood expansion on residential areas during the storm surge.

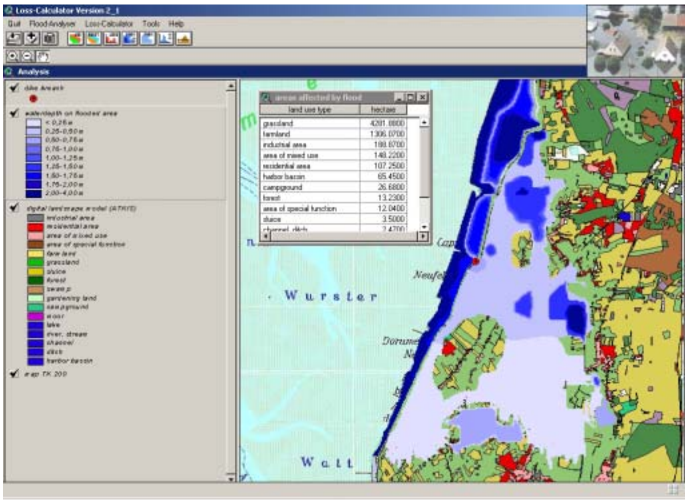

Figure 2: Analysis of the flooding process with results showing inundation areas and type of land use

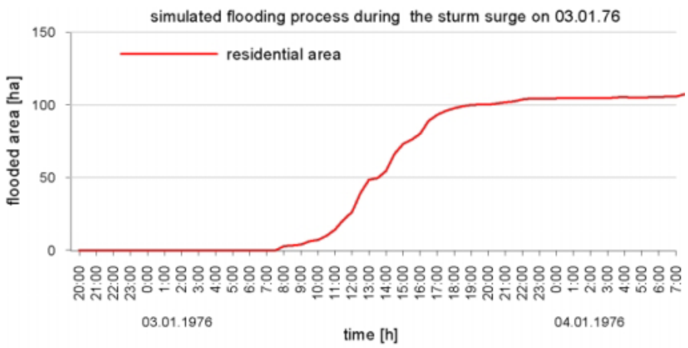

Figure 3: Flooding process in residential areas during the storm surge on 03.01.76

In addition to the flood expansion the maximum water depth is an important parameter to calculate the loss because this factor determines the degree of damage for the various property assets in the flooded hinterland. By filtering the maximum water depth out of all time series grids the result grid contains the maximum water depth for each location during the storm surge. The analysis of the maximum water depth with respect to land use provides information on the maximum water level during flooding. Figure 4 shows the distribution of water depths in flooded residential areas. Thus it appears that the water depth of inundation mostly reaches values of up to 0.75 m.

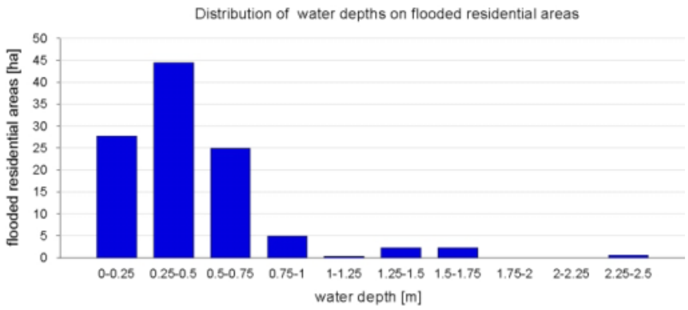

Figure 4: Distribution of water depths in flooded residential areas

Quantification and Spatial Modelling of the Damage Potential

As second input into the forecast of flood damages it is necessary to calculate the damage potential, i.e. the socio-economic values located in the coastal hinterland. The methodology developed for this (Meyer, Mai 2003) combines monetary assets from official statistics with digital land use data from the ATKIS-Basis-DLM (Authoritative Topographic Cartographic Information System), (Figure 5).

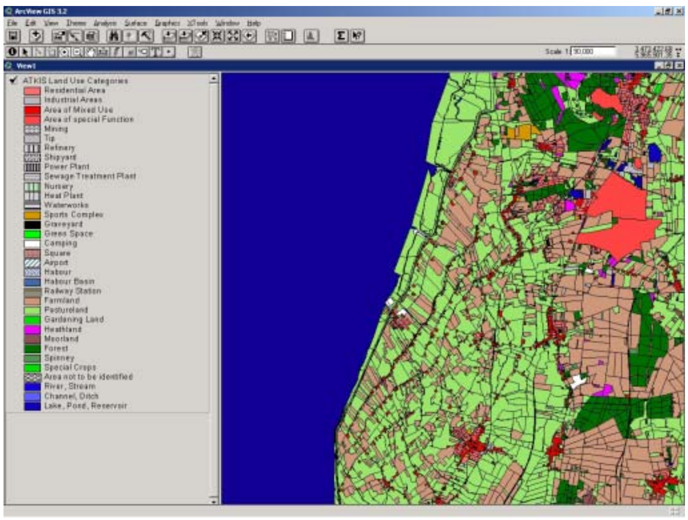

Figure 5: Land use data from digital landscape model ATKIS-Basis-DLM

In a first step, several different value categories are referred to the regional level of the municipalities. Population figures are acquired, and all assets are recorded in monetary units: Residential capital, household goods, value of automobiles, fixed assets, stock assets and gross value added of the different economic branches, road and railway networks and land value. These data are taken from official statistical publications. Some of the value categories, such as fixed assets are not available on municipality level. In this case it is necessary to disaggregate the state value: Capital per employee is referred to the state level and multiplied with the number of employees on municipality level.

To enable a more precise localisation of the values in the municipalities, the individual value categories are spatially modelled on the corresponding land use categories. This implies that the value categories “residential capital” and “household goods” are assigned to the ATKIS land use categories “residential areas” and “areas of mixed use”. In the GIS the corresponding ATKIS land use categories are selected, merged and related to the recorded values. Thus, each value category is stored in the GIS as a single layer including information on location and concentration shown in EUR/m^2 (or EUR/m for road and railway networks). Intersecting these different layers to a single layer a map showing the distribution of all monetary assets in the research area can be created by simple addition (figure 6).

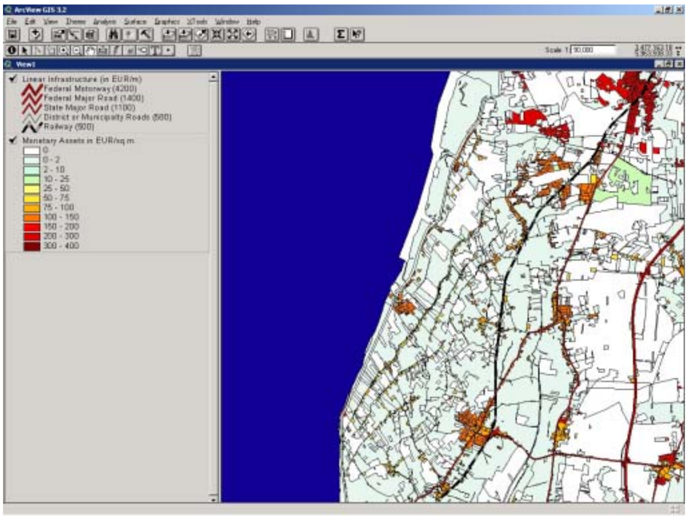

Figure 6: Distribution of monetary assets

Loss Functions

For the calculation of damages caused by a fictitious flooding event so called loss functions are used as third element. These functions are derived from empirical damage data, showing the damaged share of a value category as function of the inundation depth. Figure 7 shows the damage functions used here, which were developed for a comparable study by Klaus & Schmidtke (1990). The expected loss in a residential area caused by inundation of 1 m would amount to 20 % of the residential assets located on it.

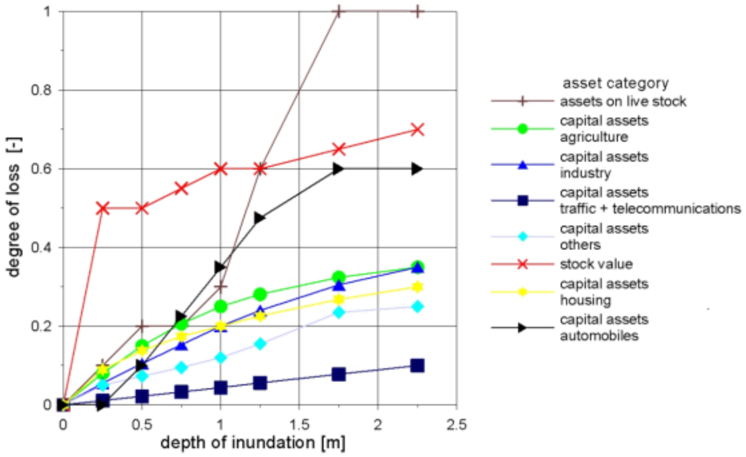

Figure 7: Loss functions for different asset categories (based on Klaus & Schmidtke 1990)

Automated Forecast of Loss

In order to automate the calculation the tool “Loss-Calculator” was developed. The first step of this calculation is to combine each type of land use (e.g. residential) affected by flood with the maximum water depth in order to estimate the degree of loss. For this purpose all relevant categories of asset (e.g. household goods, residential capital) are related to the type of land use in order to determine the loss function to be applied. The outcome of the multiplication of the property value with the degree of loss is the expected loss for the respective asset category. The summation of all relevant categories results in the total amount of loss for the type of land use. Figure 8 shows the complete loss calculation for the flood scenario.

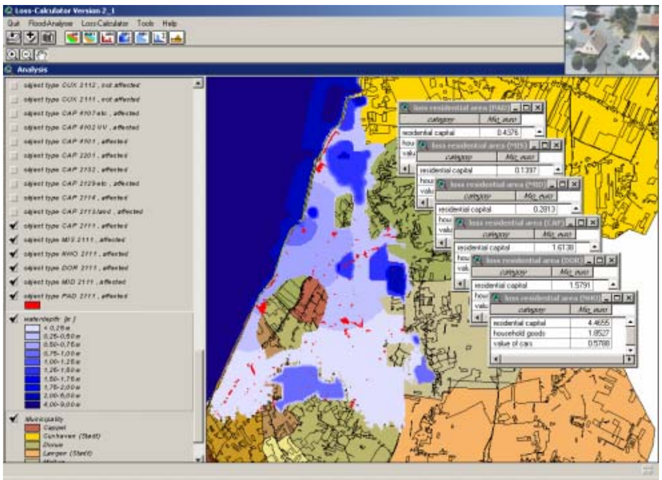

Figure 8: Loss calculation from dike breach scenario near Cappel-Neufeld for land use type „residential area“, subdivided into municipalities

The tables represent the detailed loss for the object type „residential area“ for each of the municipalities. In case of failure of the coastal defence system the expected loss in the municipality Nordholz in residential areas is 6.88 million Euro, subdivided into 4.46 million Euro for “residential capital”, 1.85

million Euro for “household goods” and 0.57 million Euro for “automobiles”. Adding all partial results of the land use types the resulting total loss amounts to 32.6 million Euro in case of a dike breach near Cappel-Neufeld.

Prospect

In future the presented mesoscale method for loss estimation in case of failure of costal defence system has to be integrated in coastal hinterland management. The combination with the failure probability results in the risk for the coastal zone by storm surge. Both, loss estimation and failure probability, are currently enhanced with respect to the resolution of the data to get even more detailed results.

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