FLOOD RISK ANALYSIS FOR THE FLEMISH-DUTCH COAST

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The coastal lowlands of the Belgian region Flanders and of the Dutch region Zeeuws-Vlaanderen constitute a single cross-border flood unit. If a dike breaches in the Dutch part of this flood unit, the water might well flow into Belgium and vice versa. In order to achieve common approaches, a cross-border project, including some form of transnational co-operation with the responsible local authorities like the "Zeeuws-Vlaanderen Water Board", becomes necessary. Within the INTERREG IIIB project COMRISK and under the auspices of the North Sea Coastal Management Group, an international platform to implement such a cross-border pilot study has now been set up.

1. Introduction

The coastal lowlands of the Belgian region Flanders and the Dutch region Zeeuws-Vlaanderen constitute a single cross-border flood unit (Figure 1). If a dike breaches in the Dutch part of this flood unit, the water might well flow into Belgium and vice versa. For historical reasons, both countries have rather different coastal defence approaches and safety standards. These different approaches might result in unbalanced investments for coastal defence schemes in the two sections of the flood unit.

The responsibilities of Dutch and Belgian coastal defence administrations end at the respective national borders. In order to achieve common approaches, a cross-border project, including some form of transnational co-operation with the responsible local authorities like the "Zeeuws-Vlaanderen Water Board", became necessary. Within the INTERREG IIIB project COMRISK (EU-project – www.comrisk.org) and under the auspices of the North Sea Coastal Management Group, an international platform to implement such a cross-border pilot study is founded. The Coastal Division of the Flemish Community leads the subproject about the Flood Risk in the cross boundary area Flanders-Zeeuws-Vlaanderen. The study is carried out by the consultant IMDC and subcontractors. A steering committee was established to guide and discuss the results. The committee consists of governmental organizations of Flanders

(Coastal Division and Flanders Hydraulic Research) and the Netherlands (Rijkswaterstaat, the province and the polder board)

The methodology of risk assessment consists of:

- Hydro meteorological boundary conditions
- Methodology for failure probabilities
- Modelling of flooding
- Economical damage
- Casualties
- Risk assessment method

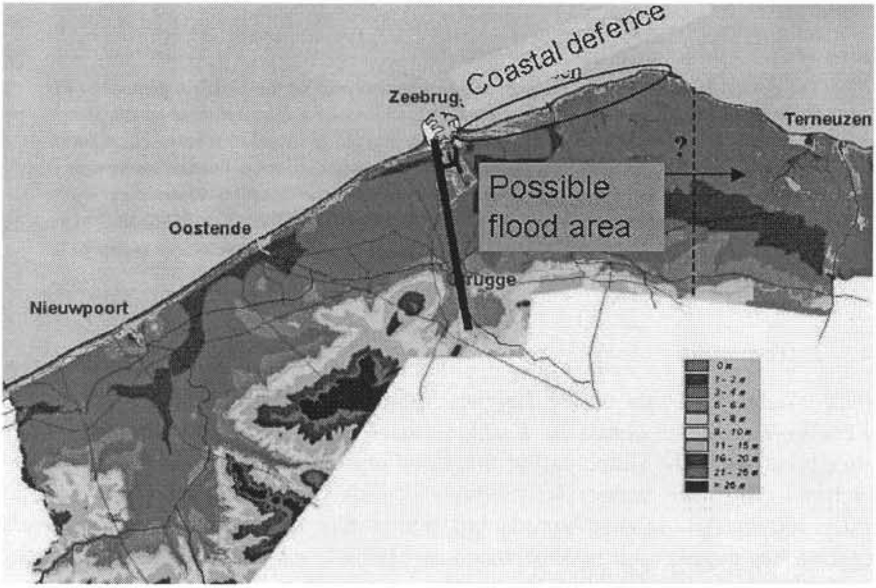

Figure 1. Flood risk area

2. Risk assessment method

Risk is defined as the product of the probability of occurrence of an event and the consequences (damage, casualties). Knowledge of the risk can be interesting for a number of reasons: to compare risks in order to set priorities, to determine the anticipated damage for insurance purposes, to carry out a cost-benefit analysis to evaluate investments in coastal works/dikes/ beach nourishments, to elaborate contingency plans for possible scenarios of breaching of defences, to compare the relative importance of defences, to inform and sensibly the public about the importance of defences.

There are two methods of determining risk: probabilistic and deterministic. The probabilistic method uses the distribution of probability of all the relevant parameters, including the uncertainty of these parameters. All combinations of parameters are analysed for failure (resistance less than external forces) , and the probability of occurrence is determined for each combination, and integration gives the overall probability of failure and risk.

In a deterministic method the failure points are determined for a number of return periods. By doing this for a large number of return periods, it is possible to integrate the return periods in order to determine the risk.

The deterministic method was chosen for this study for various reasons:

a) This method provides additional information about the frequency of floods: an equal risk can be caused by relatively common floods with a small amount of damage, or by very high return periods with a lot of damage.
b) In order to determine policy on residence in flood plains and insurance against damage, the authorities want to have damage maps for different return periods
c) If flood calculations and damage determination have to be linked to the probability of failure, the probabilistic method makes the work very computation intensive, as the flood assessment has to be carried out for all possible combinations. For example, failure can occur with a low water level but weak resistance (e.g. resistance characteristics of the dike material) or with a high water level but strong resistance. However, the damage will be much smaller in the first case than in the second.
d) a better understanding of the importance of the different kinds of uncertainties in the calculations of risk. The expected risk is calculated together with its distribution (e.g. standard deviation), representing the uncertainty.

In this study the damage is calculated for a number of return periods. First the external forces and characteristics of the sea dike (sea wall) are determined. The extreme value distributions of the wave height and water levels on deep water were transformed with the aid of a wave model to a site just before the coast where the waves do not yet quite influence the morphology. To determine the wave height at the toe of the dike you have to take account of a dynamic bathymetry during the storm: the beach in front of the dike will erode, so the waves will experience less resistance and the wave height at the toe of the dike will increase.

3. Inventory

3.1. *Boundary conditions*

Seventy five years of measurements of water levels and twenty five years of deep water wave measurements at the Belgian coast made it possible to get wind direction dependent statistics on water levels, wave heights and periods. These data have been transformed to nearshore wave characteristics using a calibrated numerical wave model (SWAN) (Trouw et al, 2004). The results of this study consist of water levels and wave heights at a line along the coast, with a water depth at about –5 MLLWS, a position at which the bathymetry will not change considerably during storms.

3.1.1 Variation of water level during a storm

In order to obtain information about the storm duration (necessary for e.g. beach erosion during the storm) a relation between storm surge and storm duration was examined. The results were compared with results from the Dutch administration. Figure 2 shows the water level, obtained as the sum of the astronomical tide and the storm surge. The storm surge is modeled as:

$$S = S_{\max} \cos^2(\frac{\pi t}{T_s})$$

with S the storm surge, and T_s the duration of the storm.

The storm duration (and hence the duration of the simulations) was set at 45 hours, following analysis of historical storms. A spring tide was taken as the water level, with a storm development superimposed (storm surge). The maximum storm surge is the difference between the water level at the return period concerned and the maximum water level at the selected spring tide. The storm surge varies during the duration of the storm according to a square cosine function, with a surge of 0 m at the beginning and at the end of the storm. The wave height also varies in accordance with this square cosine function with the maximum from the hydrodynamic boundary conditions and duration of 125 hours. For the peak period, is it assumed that the steepness of the wave remains constant with respect to the storm maximum.

3.1.2 Transformation of the wave data to the toe of the dike

During a storm the beach in front of the dike will erode. Due to the lowering of the bed level, waves will travel more easily towards the toe of the dike, hence to know the wave height at the toe of the dike, it is important to calculate the erosion of the beach.

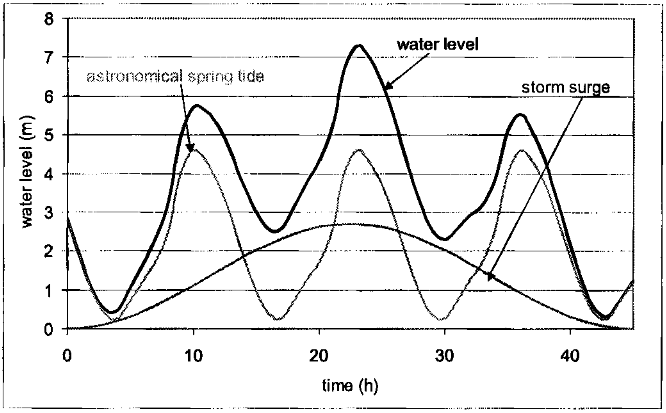

Figure 2. Variation of water level during a storm

The erosion of the beach during the storm was determined with DUROSTA (Steetzel, 1993). This is a time-dependent, one-dimensional model which determines the transformation of the wave height for a given bathymetry using an internal wave model. The most important parameters in the model are the hydrodynamic parameters and the grain diameter. The model takes the effect of hard structures such as sea dikes into account. The transformed waves cause a cross-shore transport of sand and a possible loss of sand at the sea side. After the storm, a new beach profile is obtained. For this profile, the hydrodynamic parameters are determined. This is slightly conservative, since the profile is further evolved after the peak of the storm.

In principle, the wave height must be determined at the toe of the dike. However, most wave models (Swan, Endec, etc.) produce less reliable wave heights at very shallow water depths. Therefore a certain amount of safety has been taken into account by considering the wave height at a distance of half a wave length from the toe of the dike. However, it is evident that the wave height can never exceed the water depth at the toe of the dike. This is therefore used as a limiting value.

The period to be entered in the overtopping calculations is Tm-1.0. In DUROSTA the period is assumed to have a constant value. Swan (1D) gives a better prediction of Tm-1.0. However, for Ostend an underestimate of 11% was found compared to the measured values. It is not clear to what extent this underestimation is a function of the water depth. Such an influence could be expected as in shallower water, the wave spectrum flattens out. It is proposed to use the wave period obtained from Swan, augmented by 20% (extra safety compared to the 11%), with a minimum of 1.1 times the deep water peak period, because the spectrum may be double peaked on shallow water, so it is still better to use the peak with the largest period).

Figure 3 shows an example of the evolution of the beach profile during a storm. Without erosion, the waves are not able to reach the dike, but after erosion, the water depth at the toe is 1.5m.

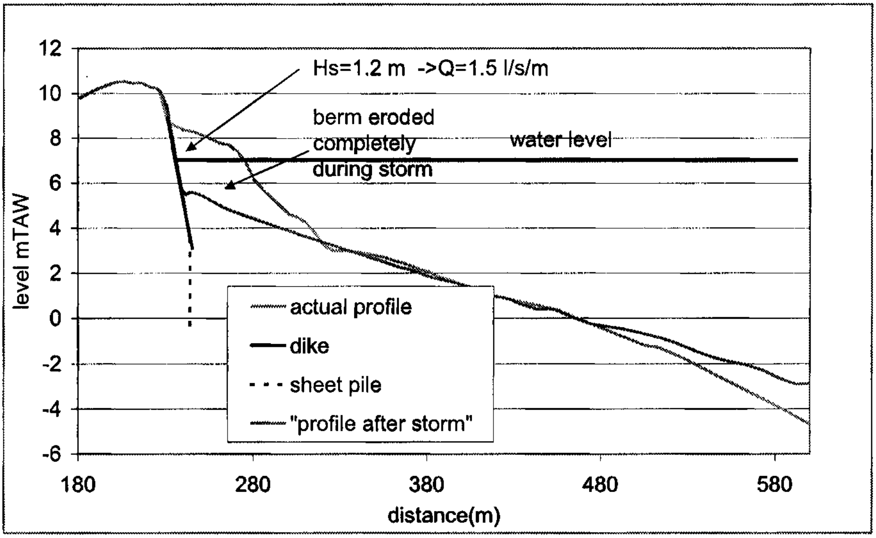

Figure 3. Evolution of beach during a storm

3.2. *Geotechnical data*

In addition to existing data, soundings and drillings were carried out along the Flemish dikes. Most of the dikes have a complex subsoil structure (e.g. figure 4). Indeed, the dikes often contain the historical sea defence, which has been breached and repaired on several occasions through time (past millennium). Also water level variations inside the dike are recorded, in order to predict the water level in the dike during an extreme storm.

Figure 4 Profile of the dike, with a sample each 0.5 m. Crest of the dike at the bottom right At the crest of the dike sand is found, going to clayed sand and at the deepest points (-15m) even organic material (wood) is found.

Various beach and dune grain size measurements are available.

3.3. *Dike structure*

Design drawings of the dikes (e.g. Figure 5) were supplemented with recent beach profiles and dike crest surveys.

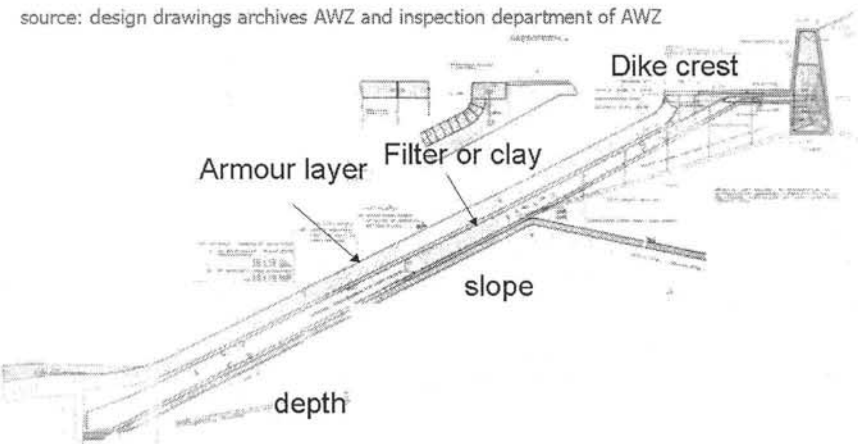

Figure 5 Dike section with typical dimensions.

4. Failure mechanisms

4.1. *Dune erosion*

To estimate the erosion risk of the dunes, the Vellinga approach was used (Vellinga, 1986). An equilibrium profile is fitted to the existing (pre-storm) profile such that the eroded volume in the dune equals the volume deposited in front of the dune (e.g. Figure 6). The Vellinga profile depends on the water level, the waves and the grain size. A breach is assumed to occur if the dune volume above the maximum water level is smaller than a critical volume.

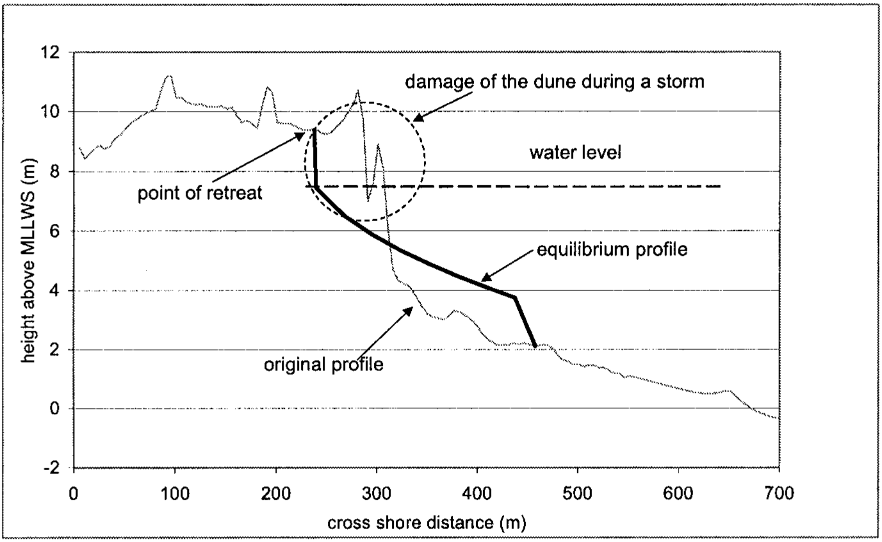

Figure 6. Dune erosion with indication of original and equilibrium profile

4.2. *Wave overtopping*

Wave overtopping is calculated using the formula of Van der Meer (TAW, 2002). Wave overtopping is critical if

a) the volume of overtopping water is too large, causing floodings in the inhabited area behind the dike, or
b) the overtopping rate causes erosion of the crest/inner slope of the dike, resulting in breaching of the dike.

The water velocities over the dike caused by the overtopping are calculated with the formulae of Schuttrumpf (2003)

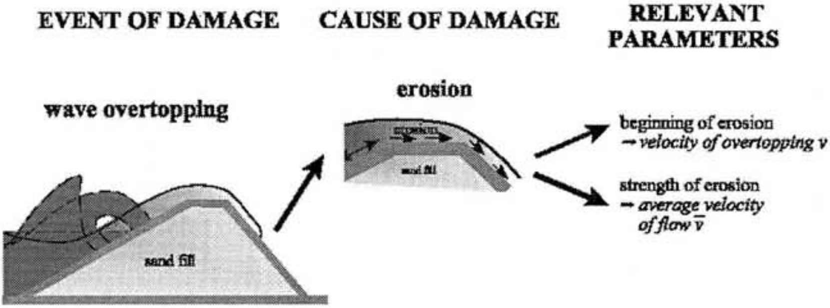

Figure 7 Overtopping of the dike (Schuttrumpf, 2003)

4.3. *Macro stability Outer Slope*

The macro stability of the front slope of the dikes has been tested by means of the SLOPE/W software (Geo-Slope, 2002). The method of Bishop has been used. In general, this method compares the moment of the resistance forces to the moment of the driving forces. The ratio of both moments is the safety coefficient. The resistance forces consist of the shear resistance of the soil, cohesion and the weight of a part of the structure and the soil. The loads consist of the other part of the structure and the soil that result in shear driving moment. To determine the weight of the structure and the soil, the level of the groundwater inside the dike (calculated with Geuze and Abott, 1961 and verified with groundwater level measurements in the dike) is of utmost importance. For a large number of predefined slip surfaces, the safety coefficient has been calculated. The smallest value of the safety coefficient, which should be larger than 1, corresponds to the most critical slip surface (e.g. figure 8). The most critical situation occurs at low water after the highest high water.

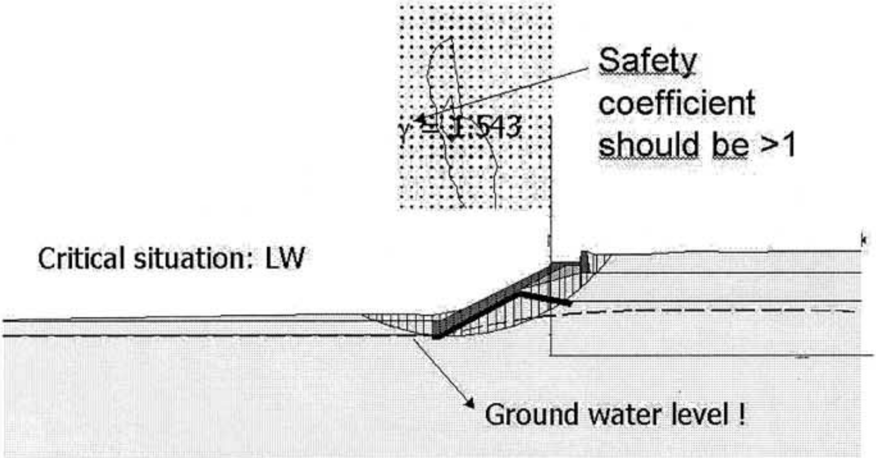

Figure 8. Output of a Geo-Slope-calculation

4.4. *Revetment*

The revetment consists mostly of armed concrete (Flanders) and asphalt or stones (Zeeuws-Vlaanderen). The stability of the revetment is evaluated with the Duth safety assessment methods. (TAW, 2004). The armed concrete does not contribute to failure, the asphalt or stones fail, but mostly they are covered with a layer of sand, which does not erode completely during a storm.

4.5. *Others*

Other failure mechanisms (macro stability inner slope, micro stability, piping and heave) were tested using the Dutch safety assessment method but proved to be not critical.

4.6. *Cascade of failure*

It often happened that a failure mechanism occurred but did not result in a complete breaching of the dike. If e.g. in Figure 8 the front slope of the dike becomes unstable, no complete dike breaching is expected. In that case the residual strength is calculated, by testing all failure mechanisms again for the situation after sliding occurred.

5. Flood modelling

A two-dimensional hydrodynamic model (Mike21) was used for the flood modelling. The Digital Terrain Models of both Zeeuws-Vlaanderen and Flanders were used for the altimetry. The Zeeuws-Vlaanderen model was available as a 5 m grid, the Flanders model consisted of points with an average density of 3 per 10 m2. These DTMs were further improved with land survey data of canal dikes inside the flood plain: these narrow elements are important for controlling the water levels and extend of the inundated area. The final modelling grid is rectangular with a grid size of 25m.

The water level at sea was used as a boundary condition. (e.g. Figure 2)

Breaching dimensions along which the water can flow were determined using expert opinions.

The roughness is taken uniformly over the entire terrain. Indeed, sensitivity tests indicated that the roughness values don't significantly influence the extension of the flood area.

An example of breaching in a dike in Knokke (for an extreme return period!) is shown in Figure 9.

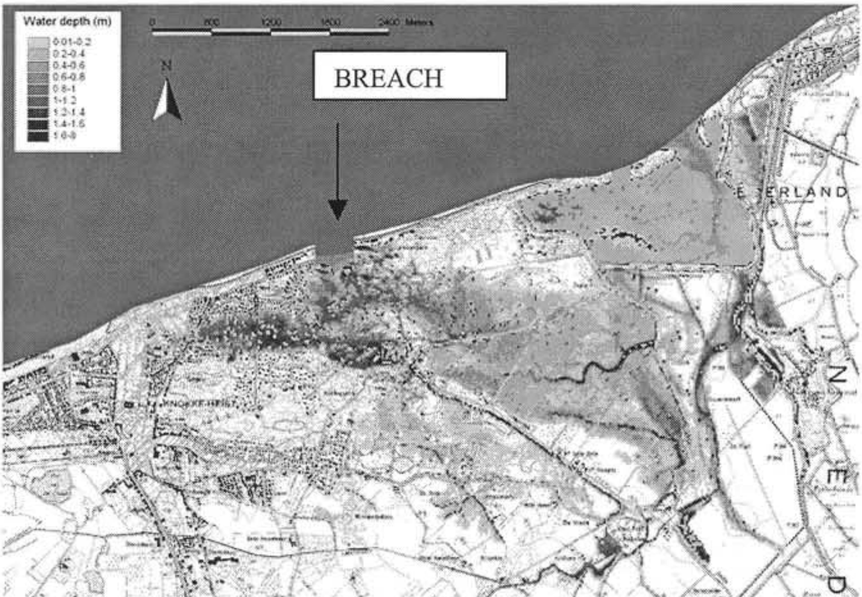

Figure 9. Maximum water depth for a simulated breaching in Knokke (background: topographic map 1:10000 c NGI Belgium)

6. Damage

To calculate the damage and casualties, the method developed by Flanders Hydraulics Research is used for Flanders, and the Rijkswaterstaat (Directorate General of public works and Water management, the Netherlands) method is used for the Netherlands. The two methods are similar.

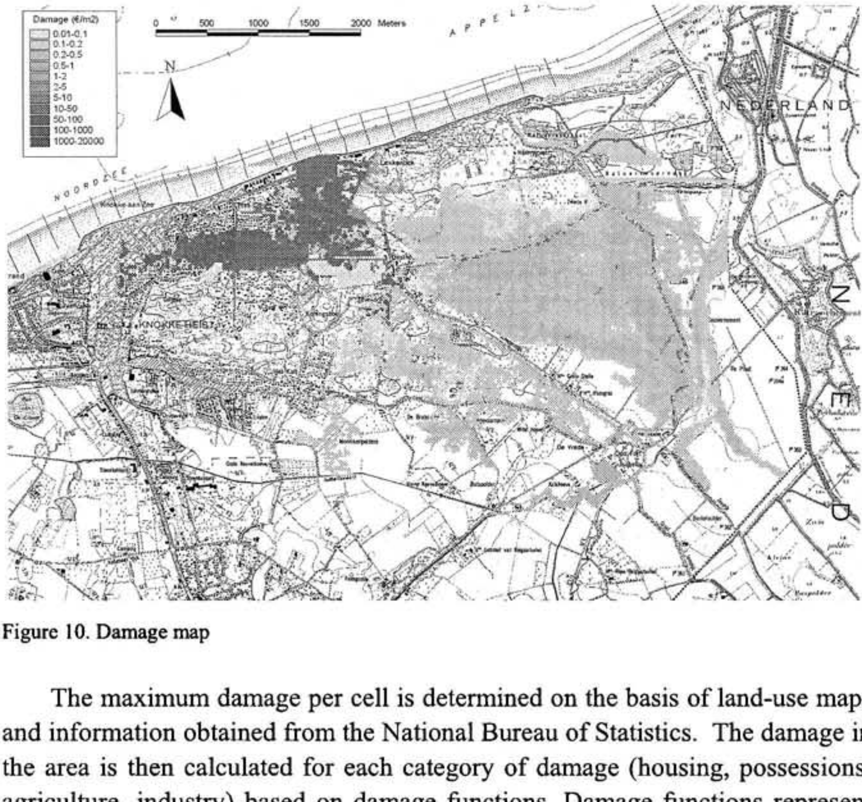

Figure 10. Damage map

The maximum damage per cell is determined on the basis of land-use maps and information obtained from the National Bureau of Statistics. The damage in the area is then calculated for each category of damage (housing, possessions, agriculture, industry) based on damage functions. Damage functions represent the development of the damage as a function of the depth of inundation, and replacement values or maximum damage values for these categories. This can be done for all potential damage categories. Combining the two sets of data produces the damage per cell. Integration allows calculation of the average expected damage

A similar method is used for casualties, with the difference that the maximum rise velocity (Flanders) or the maximum horizontal velocity (the Netherlands) is also used as an input parameter.

Using the maximum water depths of Figure 9 resulted in the damage map shown in Figure 10. 70% of the damage is due to damage to furniture and houses, as the simulation affected the built-up area of Knokke.

7. Conclusions

Risk assessment calculations such as presented above will gradually become available to:

- inform the public
- elaborate contingency plans for possible scenarios of breaching of defences
- compare the relative importance of defences

The method is not yet completed. More work needs to be done to further improve the risk assessment method before it can be used in cost-benefit analyses. These will to find a balance between investment cost in defences and reduction of damage due to the better defences.

Acknowledgments

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