ASSESSING CLIMATE CHANGE IMPACTS ON FLOODING RISKS IN THE BELGIAN COASTAL ZONE

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Abstract

Within the scope of the Belgian project CLIMAR an attempt is made to develop an evaluation framework for adaptation scenario's as a response to the climate change induced impacts in the North Sea area. Primary effects are direct consequences of climate change such as sea level rise, erosion, changes in temperature and precipitation and increased storminess. Secondary impacts are direct and indirect results of the primary effects on different sectors. A first phase of the project consists of identifying and scoping the secondary impacts on ecological and social-economic activities. In this paper results will be presented regarding the secondary impacts of flooding only.

Climate change induced primary effects such as sea level rise and increased storminess lead to higher risks of flooding of low-lying coastal areas. One of the most significant social secondary effects is the number of people at risk due to flooding. An important economical effect of climate change is the amount of damage costs. Besides direct damages there will also be indirect economic results such as temporary suspension of production and loss of jobs. Other ecological effects of increased flooding risks are the loss of beach and dune area, as well as associated specific habitats such as wetlands. Indirectly this leads to loss of biodiversity.

The magnitude of the most significant secondary effects is quantified by carrying out risk calculations. For each of the sets of the changing physical parameters a related storm scenario is statistically determined. In a first approach, the flooding risks during an extreme storm under present climate conditions and sea level rise are estimated. By means of a set of numerical models the areas susceptible to flooding in the Belgian coastal plain are identified. The resulting flooding risk maps are then used to estimate the scope of the secondary impacts.

1 The Belgian coastal zone

With more then 85% of the coastal zone under a 5m elevation, Belgium is one of the most vulnerable European countries in terms of sea level rise and flooding (European Environment Agency, 2006). As illustrated in figure 1, a large part of the coastal hinterland is located at approximately 2m below the level of an average yearly storm of 5,5m TAW (reference level mean low tide), (Verwaest et al., 2005).

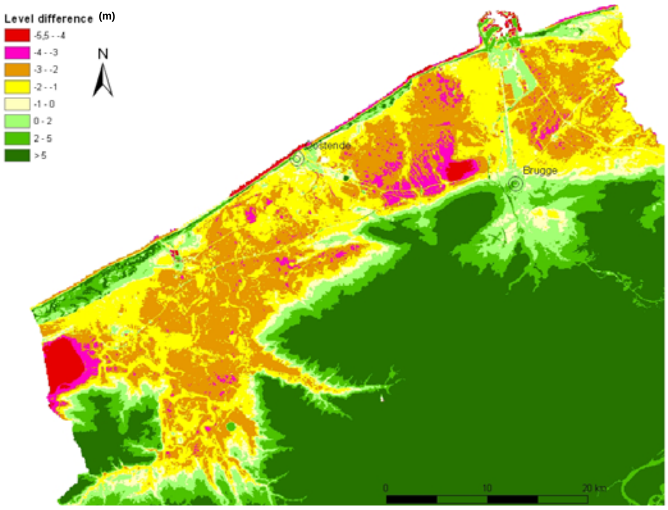

Fig. 1. Level difference between land and North Sea during an average yearly storm of 5,5m TAW (edited from Verwaest et al., 2005)

2 Identification of primary and secondary impacts

2.1 Primary impacts

The most important primary effects of climate change that have a determinant influence on flood risks along the Belgian coastline are sea level rise, changes in hydrodynamic climate (increase in storminess), changes in wave climate (increase in wave height) and changes in circulation patterns (orientation and velocity of ocean currents). The combination of these elements will result in an increase in flooding risks and a higher erosion rate of the coastline. Ponsar et al. (2007) present three different scenarios of climate change by the year 2100 (Fig. 1): a moderate scenario (M), a warm scenario (W) and a more improbable ‘worst-case’ scenario (Worst). The first two scenarios are furthermore divided in a scenario with no significant differences in air circulation (M, W) and in a scenario where the air circulation changes significantly (M+, W+) resulting in increased storminess.

	M	M+	W	W+	Worst
Air temperature	+ 2° C	+ 2° C	+ 4° C	+ 4° C	+ 4° C
Change air circulation	No	Yes	No	Yes	Yes
Winter precipitation	+ 8 %	+ 14 %	+ 16 %	+ 28 %	+ 28 %
Wind velocity	0 %	+ 4 %	- 2 %	+ 8 %	+ 8 %
Summer precipitation	+ 6 %	- 20 %	+ 12 %	- 40 %	- 40 %
Sea water temperature	+ 2.5 °C	+ 2.5 °C	+ 3.5 °C	+ 3.5 °C	+ 3.5 °C
Mean sea level	+60 cm	+ 60 cm	+93 cm	+93 cm	+200 cm

Fig. 2. Series of climate change scenarios by 2100 (Ponsar et al., 2007)

On its turn, primary effects of climate change will cause considerable secondary impacts on ecologic, economic and social structures. A wide range of possible effects of flooding and prevention of flooding in the Belgian coastal zone has been identified (Van der Biest K., 2008).

2.2 Secondary ecological effects

a) Water quality

In order to protect the Belgian coastal zone against flooding due to sea level rise and increasing coastal erosion, there will be a need for better and more regular maintenance of existing defence structure. Beside, it will be necessary to build new and/or greater defence structures. One of the most common present-day protection measures along the Belgian coastline are sand nourishments. Sand is extracted from the bottom of the North Sea and deposited on the beach to make it higher, broader and/or larger. In some cases the sand can also be deposited on foreshore, though in Belgium this is a less common technique. The sand nourishments act as buffers for wave action and prevent further erosion from beach and dune. Though, dredging of sand causes changes of the North Sea bathymetry, which lead to alteration of water circulation patterns. Beside, foreshore nourishment itself leads to changes in circulation patterns.

The construction of offshore defence structures (e.g. breakwaters) can also cause moderation of water and sediment transport patterns.

Regular dredging on the same location may also cause increase in turbidity of the sea water. This will negatively influence the marine ecosystem and associated fauna and flora.

b) Habitat change

Due to the construction of hard defence structures to prevent the coastal zone from flooding, natural geomorphologic processes and ecosystems are interrupted and will eventually degrade. For example, dune slacks can only be formed when the sea enters the low laying dune area during spring tide.

On the other hand, an increase in sea level will lead to a permanent loss of certain specific coastal habitats like e.g. wetlands. This loss could be compensated by allowing the sea and coastal habitats to advance landward under managed retreat like e.g. the natural reserve ‘Zwin’.

The usage of sand nourishment as protection measure leads to disturbance of benthic ecosystems and loss of associated fauna and flora at the location of sand extraction in the North Sea. The deposition of sand on foreshore also disturbs the benthic habitat at the location of nourishment and buries besides benthic fauna and flora also fishes. On the other hand, the total beach area increases because of sand nourishments.

A new ecological opportunity can be found in the creation of new marine habitat on offshore defence structure. This habitat is characterised by intense wave action, high oxygen rates in the water and tidal influence. These conditions are particularly suitable for e.g. mussels, barnacles, algae, …

The construction of greater and new defence structures to protect ports against the consequences of climate change leads to erosion or accretion of beaches in the vicinity of these constructions (e.g. Bay of Heist).

c) Biodiversity

Due to sea level rise and extremer weather conditions, certain specific coastal habitats will be lost by flooding and increased erosion. This can locally lead to permanent loss of rare fauna and flora restricted to these habitats, and so loss of biodiversity. On the other hand, landward migration of coastal habitats under managed retreat can lead to an increase in biodiversity due to creation of new coastal habitats.

2.3 Secondary economical effects

a) Change in production

Due to the increase of frequency and intensity of storms, coastal erosion rates will be higher, leading to more damage to offshore infrastructure of aquaculture, wind turbines etc. On its turn, this damage can lead to temporary lower production rates.

b) Production value

Due to the necessity for greater defence structures around offshore infrastructure for economical activities (aquaculture, energy sector etc.), the exploitation costs will increase, leading to a higher price of the product (ex.: price of mussels, wind energy). This secondary effect is indirectly a consequence of sea level rise and increased storminess. Beside, ports will also need to be protected by new and greater defence structures. This will increase the price of products transported by shipping.

c) Damage costs

Flooding and coastal erosion lead to many types of damages: to coastal defence structures, service networks, transport infrastructure, private and public buildings, industry, aquaculture and agriculture. These higher damage and maintenance costs are a direct consequence of the primary effects of climate change. Indirectly, these damages also lead to economic losses: due to the permanent or temporary closure of companies, other companies (customers, suppliers) can experience economic difficulties and losses.

The construction of new and greater defence structures around ports to protect against sea level rise and increased coastal erosion lead to silting up of channels and port entrances. The regular need for dredging increases the maintenance costs of port infrastructure. This effect is an indirect secondary result of the adaptation measures to the primary effects of climate change (flooding, coastal erosion).

d) New opportunities

The adaptation measures to protect the Belgian coastline from flooding as a result of climate change can clear the way for new opportunities. The construction of new innovative offshore defence structures can be coupled with diverse economical or ecological activities. For example, hard constructions built to absorb the wave energy before they reach the beach could be used to breed mussels or oysters. Also, the developing of man-made islands in front of the coast could create new opportunities, as example for agriculture or wind energy.

Another innovative adaptation strategy to sea level rise which offers new opportunities is managed retreat. This measure allows a low-laying area to become flooded in a controlled way by removing coastal protection. In these areas susceptible to flooding, the natural intertidal ecosystem can restore itself or expand (ex.: Zwin).

At the other hand, already existing defence measure types like beach nourishments give the opportunity to the recreational sector to expand their activities on the new or broadened beaches. Another example are the artificial reefs built to protect the shoreline on which also recreational diving could be organised.

2.4 Secondary social effects

a) Attractiveness coastal and marine area

Due to sea level rise and increased coastal erosion, a certain amount of beach area and thus space for leisure activities will be lost. At the other hand, sand nourishments create new and broader beaches. Though, sand nourishments have different disturbing social effects. The sand that is used for the nourishments is generally coarser and darker then the original beach sand. It can make the beach less attractive. Also, during summer beach cabins will be at a higher level because of the nourishment, so that the sea view for people on the dike terraces is disturbed. Tourists and residents can also find the Belgian coastline less attractive due to the presence of concrete dikes which interrupt the natural ecosystem or due to the presence of offshore defence structures.

The attraction value of the coastline can increase in account of the alternative defence strategy of managed retreat. The creation or restoration of particular intertidal habitats can attract more tourists.

b) Employment

Due to the necessity of building greater and new defence structures and the maintenance of existing infrastructure to protect against sea level rise and increased storminess, there can be expected more jobs available in the construction and dredging sector.

At the other hand, damages to business properties caused by flooding will lead to a permanent or temporary loss of jobs in the affected areas.

c) Safety

Flooding of the coastal zone can directly result in casualties on the coastline and in the hinterland. Casualties can also occur on the coastline due to wave overtopping during less intense storms.

d) Accessibility

Due to the presence of hard defence structures around ports, the navigation of ships through the channels can be hampered.

When coastal transport infrastructure is damaged due to flooding, wave overtopping or coastal erosion, the accessibility to the coastal zone will be obstructed.

e) Welfare

Damages to properties and casualties resulting from flooding and/or coastal erosion will indirectly influence the life quality of people. The deceasing of economical active people leads to a decrease of the financial status of families. Damage to business properties due to flooding will also lead to temporary or permanent loss of employment in the affected areas.

3 Quantification of secondary impacts

The magnitude of the most significant secondary effects is estimated by means of numeric risk models. Each of the climate change scenarios is statistically translated into one worst credible extreme storm event. Under present circumstances of sea level and wave climate such an extreme storm is characterized by a storm surge level of ~8m TAW and is supposed to occur once every 17000 years (Willems P., 2007). In a first phase of the research risk calculations are carried out for the present situation.

In total three different models are used to assess flooding risks in the Belgian coastal zone. The first model estimates the total amount of beach and dune erosion across a specific transverse section. Along the Belgian shoreline about 380 profiles are considered. The profiles are located at the weakest points in the sea defence and with a distance of maximum 300m between each other. They are drawn from -5 m TAW in the sea to +5 m TAW behind the range of dunes, representing the natural sea defence. The structural resistance of hard defence structures (sea dikes and dune foot strengthening, as well as the buildings on top of the sea defences) are not taken into account, because in general such structures are only able to temporary withstand a super storm (Vanpoucke et al., 2008). The results of the erosion calculations are then used to calculate the remaining dune volume above the water level at any moment of the storm. This volume is compared to a critical threshold volume which is a function of wave height and wave period. When the remaining volume is less then the threshold volume, a breach is expected to occur.

Next, breach growth and hydraulic flooding of the coastal plain are simulated. The downward erosion of a breach is limited to a depth equal to the surface level landward from the sea defence. The widening of a breach is limited to the free (without buildings) width of the section. The calculations are carried out on an altimetry grid of 100m by 100m. For each pixel the model estimates depth, current velocity and rise velocity of the water flooding the coastal plain. These resulting grids are then used to calculate the total amount of damage costs [€] as well as the number of deadly victims [#] in the coastal plain. The monetary damage costs are a function of the land use, water depth and current velocity. To each type of land use a different value of maximal damage and related water depth is attributed. The number of deadly victims depends on water depth, current velocity, rise velocity, the number of inhabitants and the possibility of evacuation (however, no evacuation is taken into account considering the limited preparedness).

4 Results

Under present climate conditions and sea level, 13 breaches are supposed to occur during an extreme storm along the Belgian coastline. They are located near cities where the natural sea defence (dunes) is lowered in favour of urban development. Consequently, a considerable part of the coastal plain is expected to be flooded. The landscape and relief determine the scope of the flooding in terms of current velocity, water depth and rise velocity (Fig. 3, 4 and 5). The total damage costs estimated for the current situation of wave conditions and water level are shown in figure 6 and summarized in figure 7. The area with highest flood damages is found at Oostende. The risks are higher due to the concentration of buildings and population in the city.

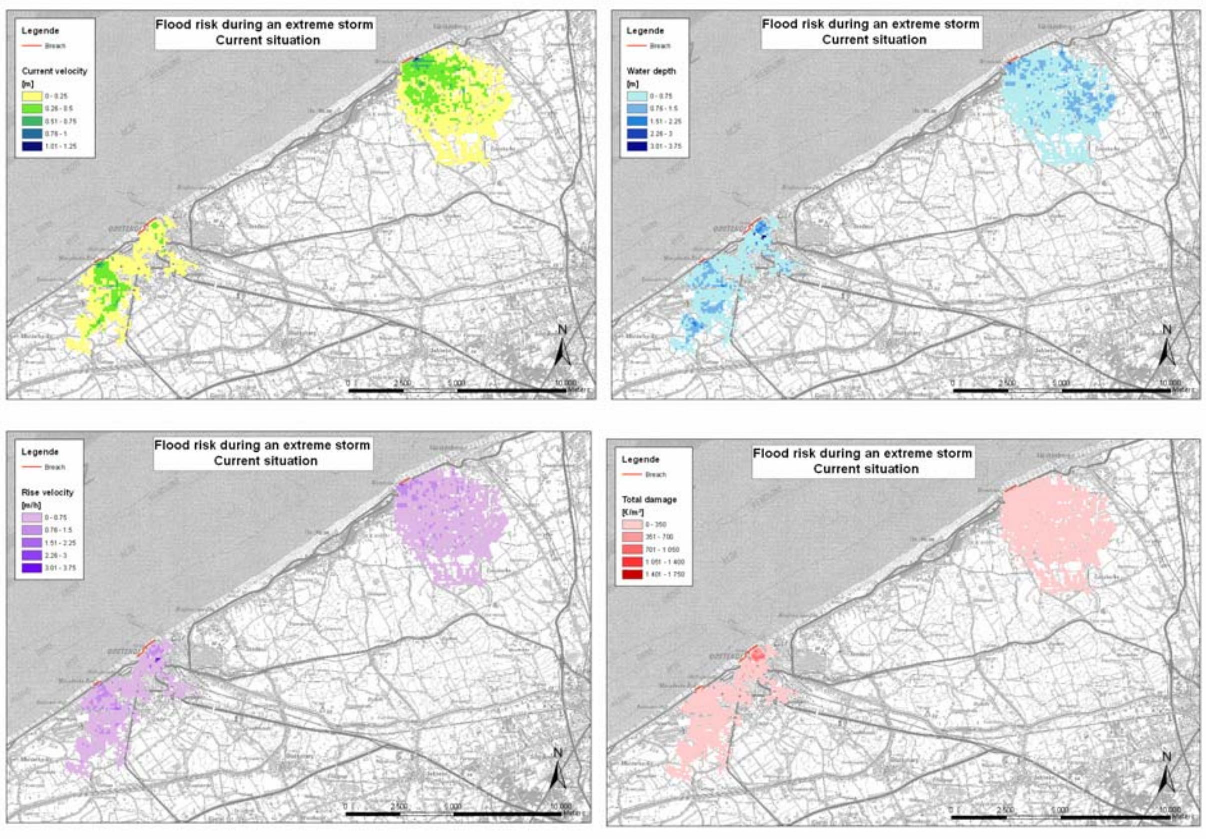

Fig. 3, 4, 5, 6. Flood risk calculations for an extreme storm under present climate conditions: current velocity [m/s], water depth [m], rise velocity [m] and total damage [€/m²].

	Coastal plain
Damage costs [€]	$500 * 10^6$
Number of victims	10-15

Fig. 7. Total damage costs and number of victims (excluding victims by wave overtopping on the sea dike) for an extreme storm under present circumstances of climate conditions.

Conclusions

The most important primary effects of climate change that increase flood risks are sea level rise and increased storminess. These primary changes can lead to a wide range of direct and indirect secondary effects on ecological, economical and social systems. Flood risk calculations are an excellent tool to assess the impact of the most important secondary effects. By applying flood risk calculations along the Belgian coastline it is found that the weakest points in the natural sea defence are located at urban developments. Besides the lowering of the natural defence for the construction of buildings and roads the risk is also higher due to the concentration of properties and population.

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