EXAMINATION OF CLIMATE CHANGE ADAPTATION STRATEGIES FOR COASTAL PROTECTION

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Climate change adaptation strategies for coastal protection are examined with the help of mathematical models in the Ems/Dollart Estuary in consideration of different climate scenarios. The Ems-Dollart Estuary is located at the Dutch-German border in the southern North Sea, a coastal area which has suffered from enormous land losses due to medieval storm surges. Since then the medieval retreat was partly reduced by successive land reclamation following the development of salt marshes.

Keywords: climate change, coastal protection, adaptation, storm surges

INTRODUCTION

Does the expected change of global climate require a change in the coastal protection strategy at the German North Sea coast? And if, which ones are the best with respect to safety, feasibility, economic efficiency and acceptance in the region? To answer this questions also in consideration of different climate scenarios for the next 100 years a research project was launched in the beginning of 2009 to check various alternative strategies against traditional line protection. The effectiveness of coastal protection structures depends to a large extent on a proper evaluation of design water levels and design waves in respect of as well safety as economical benefit-cost ratio. The uncertainty of the future climate impact demands a robust strategy with respect of the different climate scenarios with a wide spectrum of boundary conditions for the corresponding loads on coastal protection structures. Another important factor is the possible climate change related adaption of local morphology. This paper deals with the examination of different adaptation strategies for the lowlands at the German North Sea coast.

STUDY AREA AND DESIGN BOUNDARY CONDITIONS

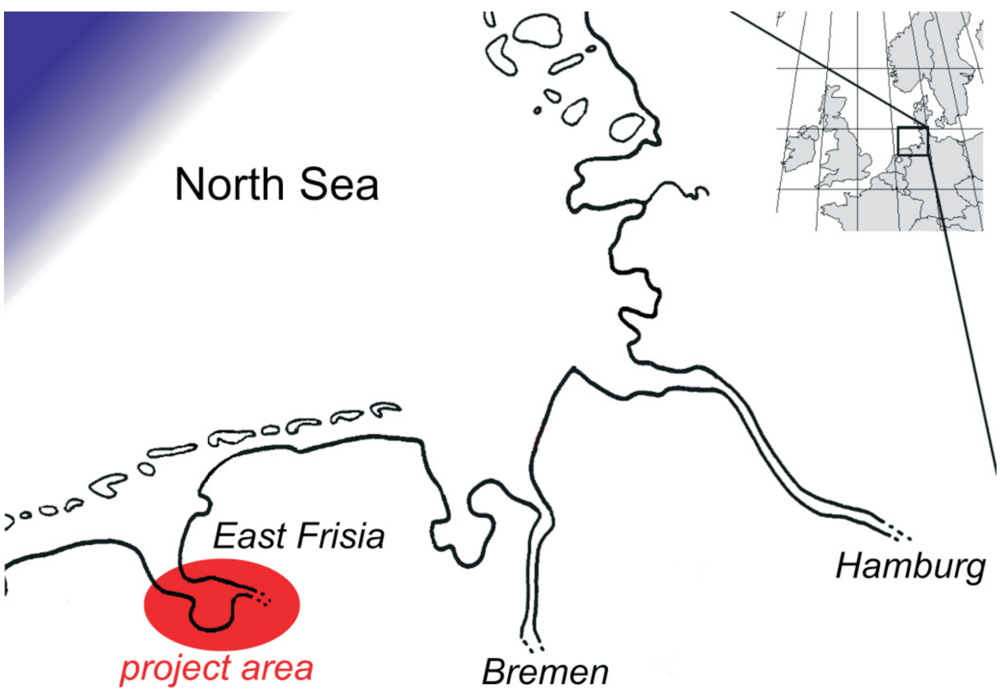

Figure 1. Project area: Dollart Bay / Ems Estuary

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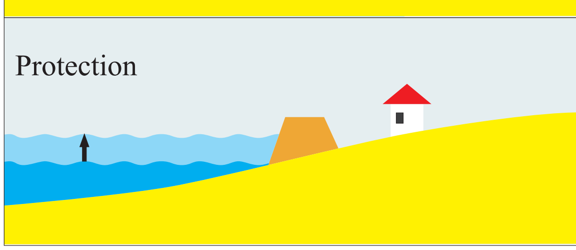
The study area is the Ems-Dollard Estuary at the Dutch-German border in the southern North-Sea (Fig. 1). The Dollard bay was created by medieval storm surges which caused enormous land losses at the Wadden Sea coasts. The then enforced enormous coastal retreat was partly reduced by silting up followed by the development of salt marshes in front of the dykes allowing successive land reclamation (Niemeyer 1994).

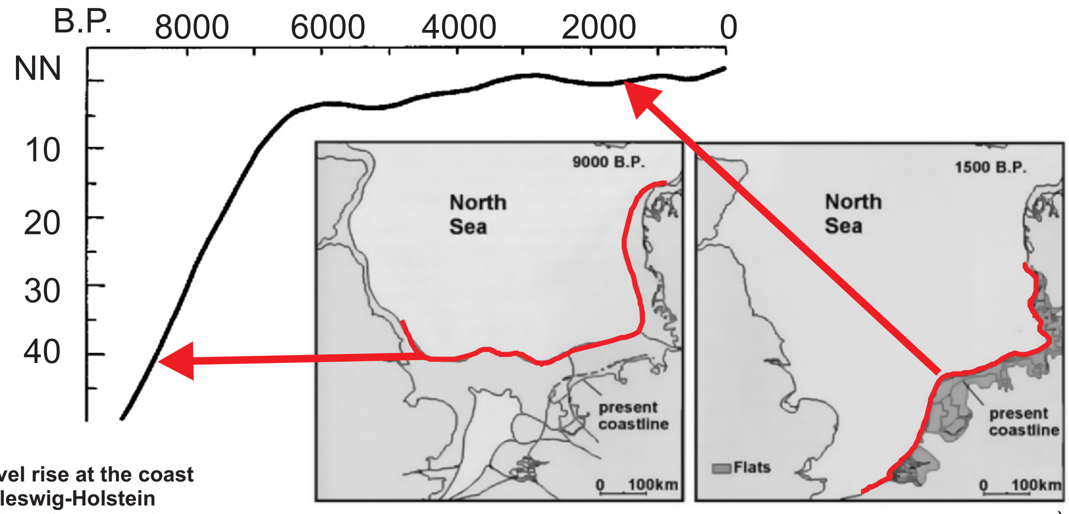
The boundary conditions for the mathematical models (30 m depth contour line at the open coast) are according to the present design water levels at the Ems-Dollard Estuary. A hierarchical cascade of three storm surge models that has been used to simulate the tide- and wind driven dynamics from the continental Shelf over the North Sea into the Ems-Dollard estuary (Herrling et al. 2010). The model set up is successfully verified against water level observations of several severe storm events. Additional boundary conditions for future scenarios are calculated by the project partner GKSS-Institute of Coastal Research by downscaling the global climate scenarios over a cascade of models to the regional model for the North Sea. The derived wind fields, water levels and wave spectra for extreme conditions and different time slices up to the year 2100 are used to run the local hydrodynamic (Delft3D) and wave models (SWAN). These local models provide the input for the design formulas for the various coastal protection structures considered in this study.

ADAPTATION STRATEGIES

The main strategies for adaptation to sea level rise were raised in a report of the Coastal Zone Management Subgroup of Intergovernmental Panel on Climate Change (IPCC 1990) (Tab. 1). Retreat is an optional strategy adapting to climate change accompanied by accelerated sea-level rise and higher set-up of storm surges. This can be achieved with different levels of adaptation. In history there were phases with much larger rates of sea level rise than today (Fig. 2). The former population - if present - had no other choice than to retreat. In the investigation area retreat under the recent scenarios of the IPCC (without any coastal protection) will be a draw

Table 1. Main strategies for adaptation to sea level rise according to the Coastal Zone Management Subgroup of the IPCC (1990)

	RESPONSES
 Today	"The responses required to protect human life and property fall broadly into three categories: retreat, accommodation and protection."
 Retreat	"Retreat involves no effort to protect the land from the sea. The coastal zone is abandoned and ecosystems shift landward. This choice can be motivated by excessive economic or environmental impacts of protection. In the extreme case, an entire area may be abandoned."
 Accommodation	"Accommodation implies that people continue to use the land at risk but do not attempt to prevent the land from being flooded. This option includes erecting emergency flood shelters, elevating buildings on piles, converting agriculture to fish farming, or growing flood or salt tolerant crops."
 Protection	"Protection involves hard structures such as sea walls and dikes, as well as soft solutions such as dunes and vegetation, to protect the land from the sea so that existing land uses can continue."



Sea level rise at the coast of Schleswig-Holstein (Streiff & Köster 1978)

Coastal retreat at the North Sea between 9000 and 1500 B.P. (Veenstra 1973)

Figure 2. Post glacial sea level rise and coastal regression at the Southern - North Sea

back to areas which are save – they have to be even higher than the levels of the highest storm surges to be expected until the end of this or of the next century. Result of this would be the abandonment of large areas with a larger order of magnitude than the flooded areas due to the catastrophic Christmas storm surge of 1717 (Fig. 3), since the sea-level was then approximately 70 cm lower than nowadays. Additionally this would require the construction of ring dykes around those major settlements and industrial areas regarded as too to valuable for being abandoned. Furthermore the protection of transport infrastructure in the areas being flooded during storm surges has to be assured. Neglected in this strategy are the numerous dispersed settlements.

Another strategy for retreat is the relocation of the dyke line landwards with the aim to reduce the wave heights and periods in front of the dykes leading to smaller design heights. A partial benefit of that strategy would be the preservation of salt marsh area which is threatened by the sea level rise in other areas of the coast.

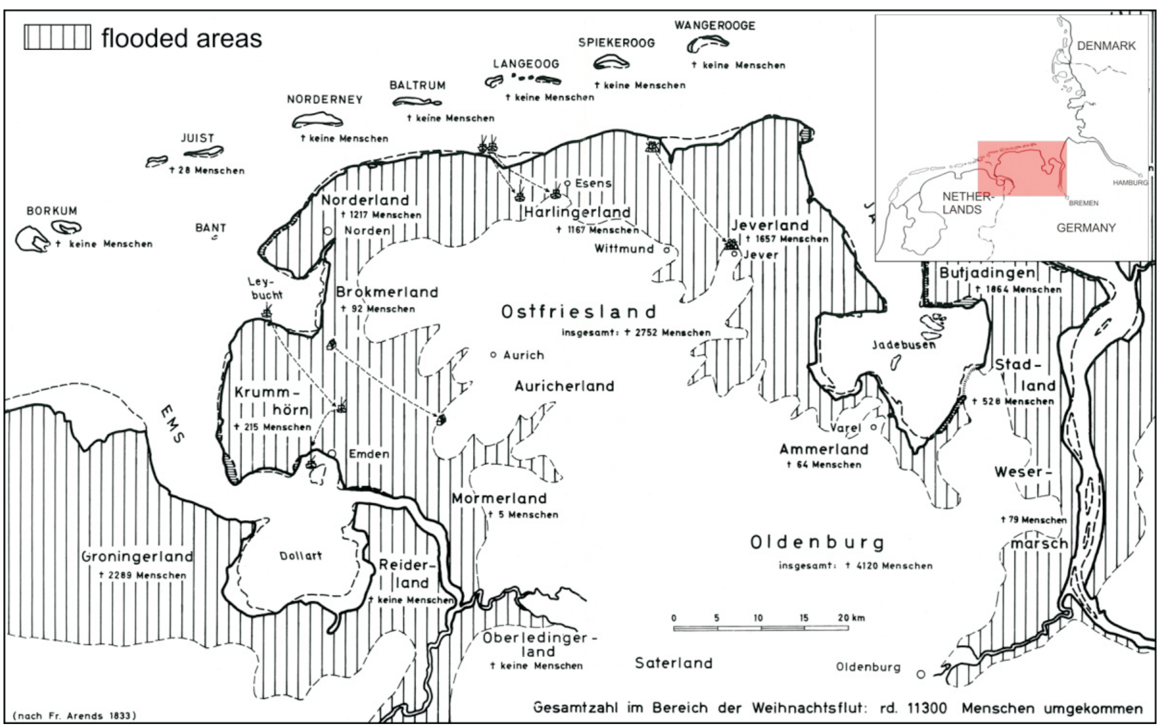


Figure 3. Flooded areas due to breaking dykes during the Christmas storm surge 1717 (Coastal Research Station, 1980)

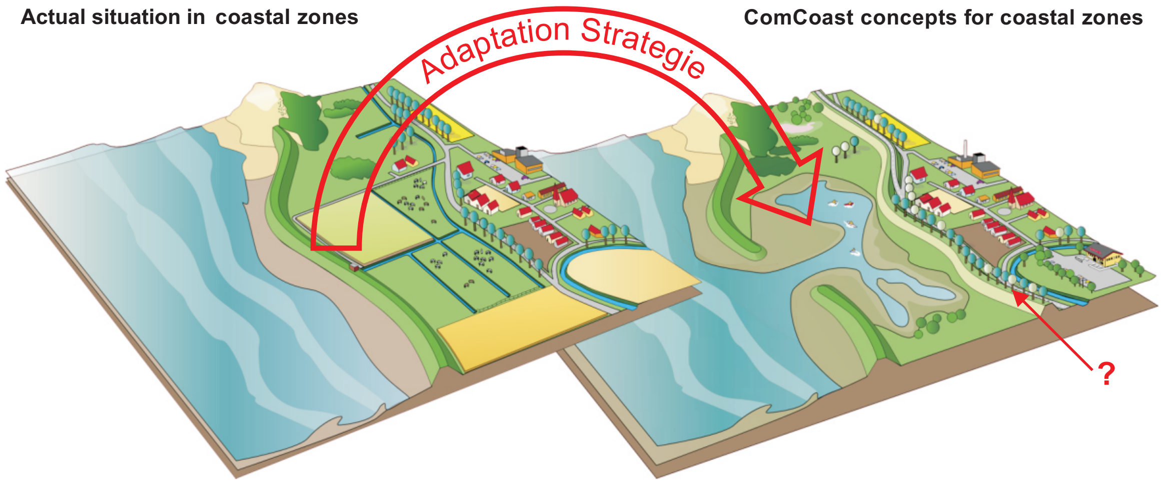


Figure 4. Adaptation strategy for coastal floodplains according to the ComCoast project (maps: ComCoast 2006)

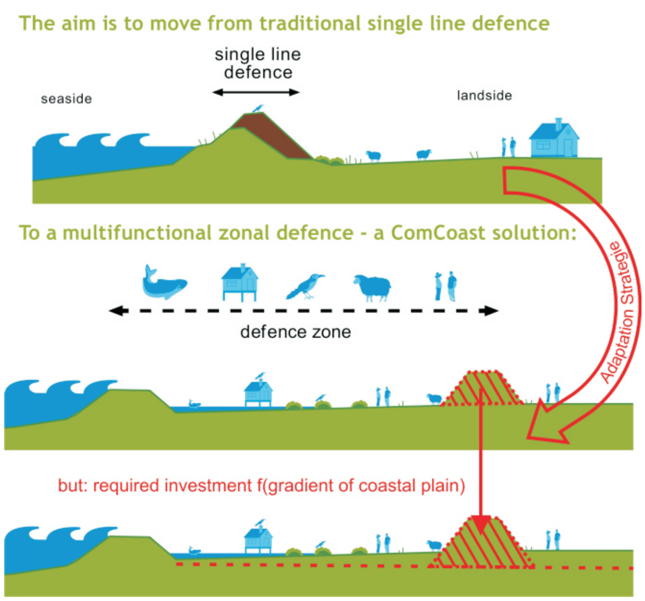


Figure 5. Economic dependance of the ComCoast strategy on account of the gradient of the coastal floodplain; sectional drawings: ComCoast Guide (2008); additional information in red

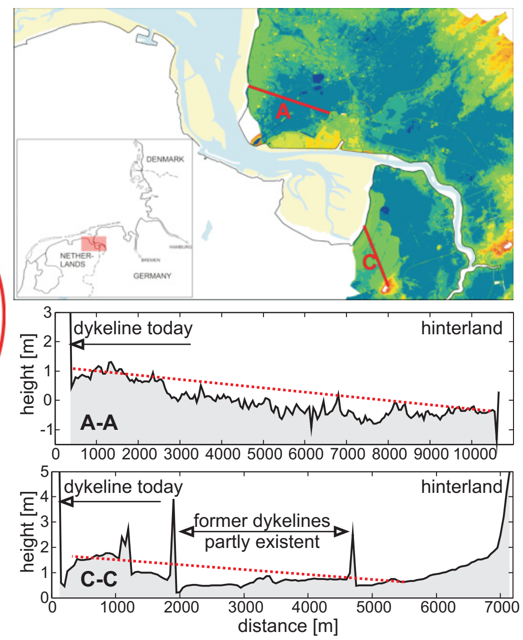


Figure 6. Coastal floodplain with negative gradient typical for the coastal lowlands at the southern North Sea coast due to successive land reclamation in the last several hundred years

Studies on such alternative strategies like that of ComCoast (2006, 2008), a recent european research project, are promising at first glance (Fig. 4,5) but do unfortunately not match reality of the coastal lowlands at the southern North Sea coast. Due to the successive land reclamation in the last centuries consistent with the natural development of the salt marshes and sea level rise the older reclaimed areas (polders) have lower levels than the salt marshes today. This has created in the project area as in most areas at the southern North Sea coast a negative gradient in ground level elevation toward the hinterland (Fig 6). Because this kind of alternative strategy for adaptation is very popular in the public discourse on consequences of climate change to coastal areas it is worthwhile to investigate it in detail.

The strategy retreat has to bear comparison with the present day strategy of holding the dyke line. One crucial part of the comparison of the different strategies are the costs involved. Beside the loss of agricultural areas that may be partly compensated by the gain of natural areas are the costs for the new coastal protection structures. This study will highlight the latter aspect with respect to the change of design water levels and design waves in dependance of the extend of the retreat. Settlements will make this issue even more complicated.

CONSEQUENCES OF THE ADAPTATION STRATEGY RETREAT UNDER DESIGN CONDITIONS

Boundary conditions

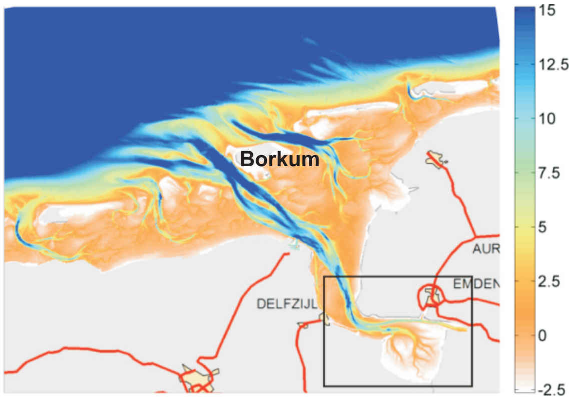


Figure 7. Bathymetry of the Ems-Dollard Estuary. Depth in [m] with respect to German datum ~ MSL. Small box shows extension of detailed maps (Fig. 11/12)

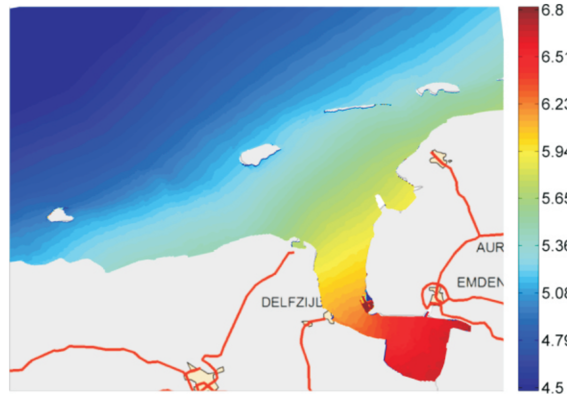


Figure 8. Max. water levels (envelope) during a design storm surge. Water levels with respect to German datum [m].

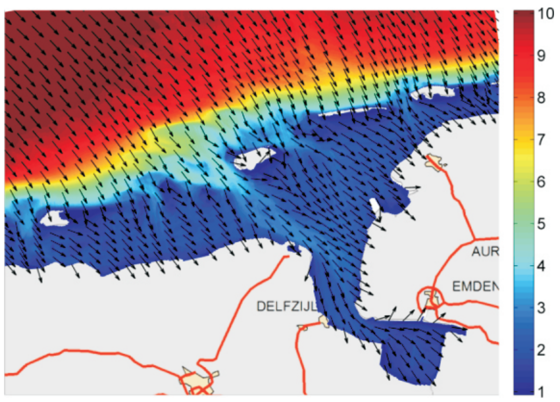


Figure 9. Significant wave heights H_{m0} [m] and mean wave directions at high water level at the island of Borkum (design conditions)

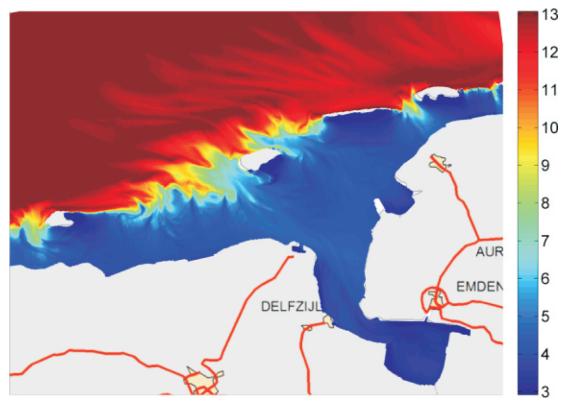


Figure 10. Energy Period $T_{m-1,0}$ [s] at high water level at the island of Borkum (design conditions)

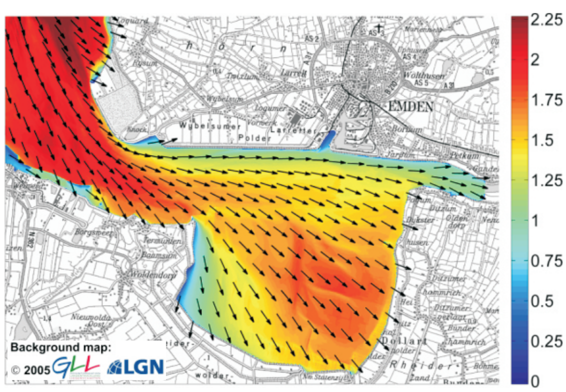


Figure 11. Significant wave heights H_{m0} [m] and mean wave directions. Local model, stationary run, wind direction 315°, other boundary conditions see (Fig. 9/10)

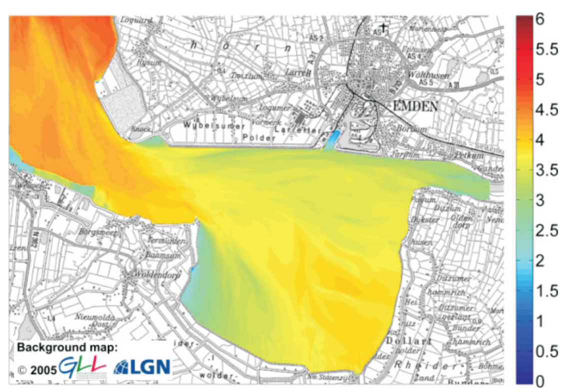


Figure 12. Energy Period $T_{m-1,0}$ [s] and mean wave directions. Local model, stationary run, wind direction 315°, other boundary conditions see (Fig. 9/10)

In order to test the strategy retreat for real world situations at the coast of the south eastern North Sea coast an area in the south east of the dollard bay was chosen. In the hinterland of the present dyke line four older dyke lines are partly existent from impoldering in the last 300 years (cross section c-c, Fig. 6). These four polders serve in this project as four steps of retreat, so that the effect of extent can easily be detected for the present design conditions. The influence of other variables (climate impact, configuration of the defense zone) have to be determined in the next steps.

The dollard bay is sheltered against wave attack during design conditions by large tidal flats and a chain of islands seawards of the tidal flats (Fig. 7). Due to the relative shallow water depth there is an increase in design water levels from 4.5 seaward of the islands to about 6.8 m in the south east of the Dollard bay with respect to mean sea water level (Fig. 8). The wave climate was calculated with an instationary SWAN-model and shows a considerable loss of energy due to wave breaking on the outer bars (Fig. 9), connected with a shift of energy to higher frequencies resulting in lower energy periods (Fig. 10). At the entrance of the inner bay the remaining wave energy is spread as a result of refraction. But the local wind provides again energy and the wave heights are increasing again until they reach a dynamical equilibrium with the local water depth (Fig. 11). The same applies for the wave periods (Fig. 12).

Local flooding scenario

The local flooding scenarios were carried out with the MIKE21 Flow Model whereas the larger coastal and offshore model areas were modeled with Delft3D. The wave climate in the detail model is also calculated with SWAN. The opening of the polders was done step by step, removing the seaward dyke line down to the level of the salt marches in front of the dyke and reconstructing the older dyke line at the interior side in the necessary dimensions as regulated by the local dyke law.

The situation with two opened polders displays the dependency of the design parameters water level and wave height on the configuration of the coastal flood plain (Fig. 13-15). The ground level elevation in the first polder are in the order of 50 cm lower than the salt marshes in front of the present dyke line and is reduced in the second polder again in the order of 50 cm. Due to the onshore directed wind and the larger fetch the water levels in front of the second dyke line increase in the order of 5-10 cm compared to the present dyke line. Also the significant wave heights have an increase of 5-10 cm in the center of the new (reconstructed old) dyke line.

When the set back is extended also to the third and fourth polder similar results were gained. Although the ground level does not decrease further in the third and fourth polder the local water levels are still sufficiently high to allow a further increase of significant wave height and energy period up to the reconstructed dyke line at the interior side of the fourth polder. The nearly linear run of the curves for wave height and periods indicates that the increase in the parameters will apply also for longer distances.

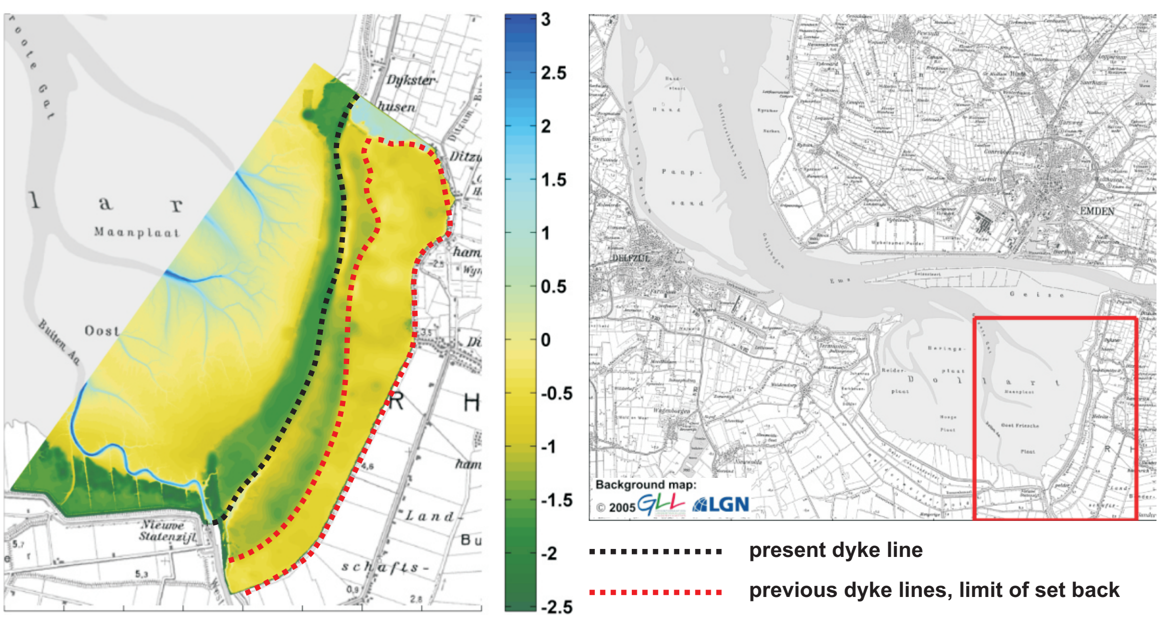


Figure 13. Bathymetry of the area with set back of the dyke line (two polders; depth with respect of German datum)

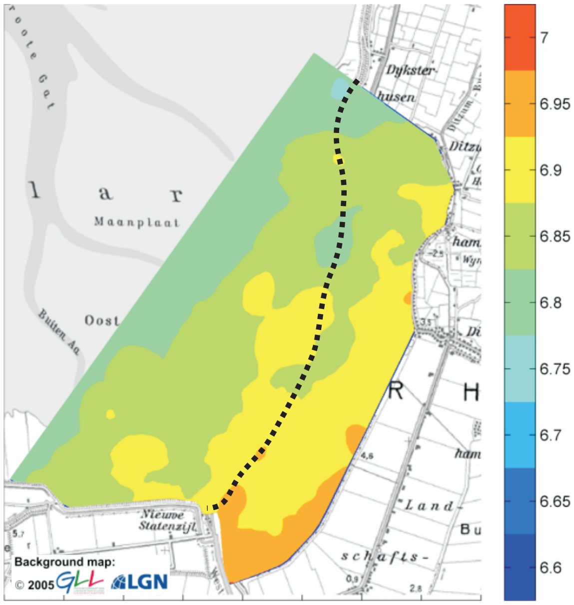


Figure 14. Design water level for present situation with opened Polders (2) with respect to German datum

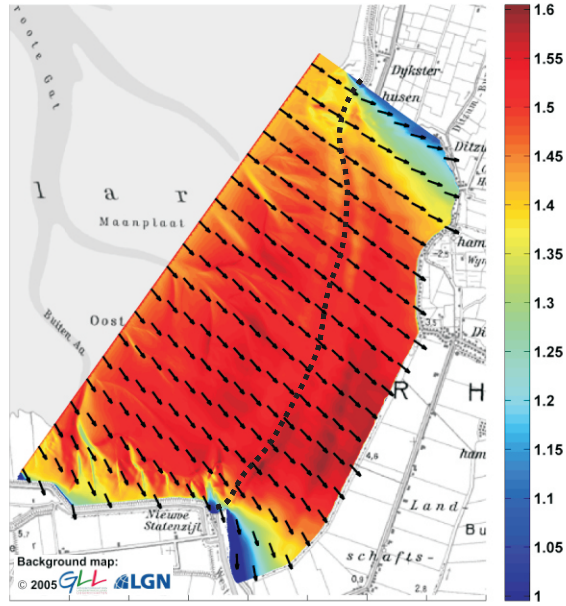


Figure 15. Significant wave heights H_{m0} [m] and mean wave directions at design water level

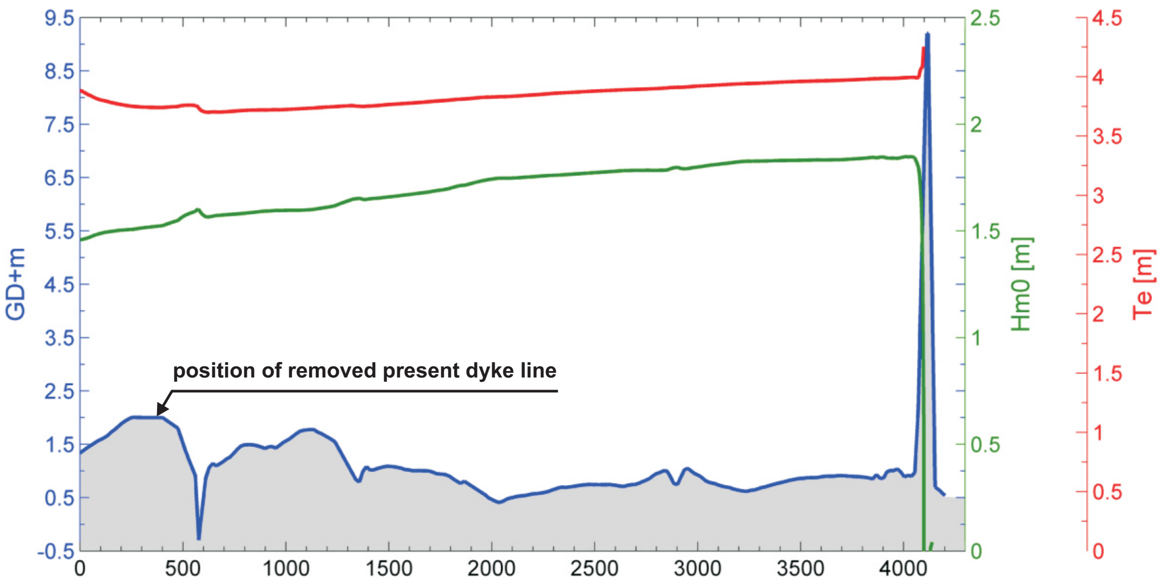


Figure 16. Design wave height and energy periods for present situation with four opened polders; depth with respect of German datum

CONCLUSION

The first results of this ongoing research project clearly indicate that the adaptation strategy retreat as a set back of the dyke line will not be effective in this particular area of the coast. This specific strategy will as well lead to higher water levels and significant waves as to longer energy periods in front of the new dyke under present design conditions as numerical model runs prove. No extra safety or better cost effectiveness can be gained by adapting that strategy. This investigations have to be extended for future climate scenarios and for modified coastal protection schemes as for example the one proposed by the ComCoast project. But the results so far point out that holding the present dyke line in all likelihood will be the best solution to tackle the requirements of climate change.

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