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From coastal flood defence towards coastal flood risk management

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Abstract

Climate change induced sea level rise will lead to higher coastal flood risks. Adaptation strategies in Germany traditionally focus on technical flood defences that ensure defined safety standards. In this paper, after a short discussion of sea level rise scenarios, possible constraints of flood defence schemes are described. It is argued that a sustainable adaptation strategy implies a holistic coastal flood risk management consisting of the elements prevention, protection, preparedness, emergency response, recovery and review. These integral components are described as parts of a control loop. In an outlook, the EU Flood Directive and its implications for coastal flood risk management in Germany are described.

1 Introduction

Storm surges may cause temporal flooding of coastal lowlands. When the flooding is perceived by society as a threat to life and property, it becomes a hazard that needs consideration or, rather, risk management. Risk may be defined as a combination of the occurrence probability of a hazard and its harmfulness for society, i.e., the damage expectations. Hence, coastal flood risk management (CFRM) may be implemented by controlling the occurrence probability of flooding (by technical means) and/or by controlling the damage expectations (figure 1). The classical approach in Germany to reduce or limit the risk of coastal flooding is protection by technical measures like dikes. These defences are designed with a certain safety standard in order to prevent flooding up to a defined storm water level. Today, after more than 2,000 years of coastal flood defence, about 2.5 million people live in the coastal lowlands of Germany.

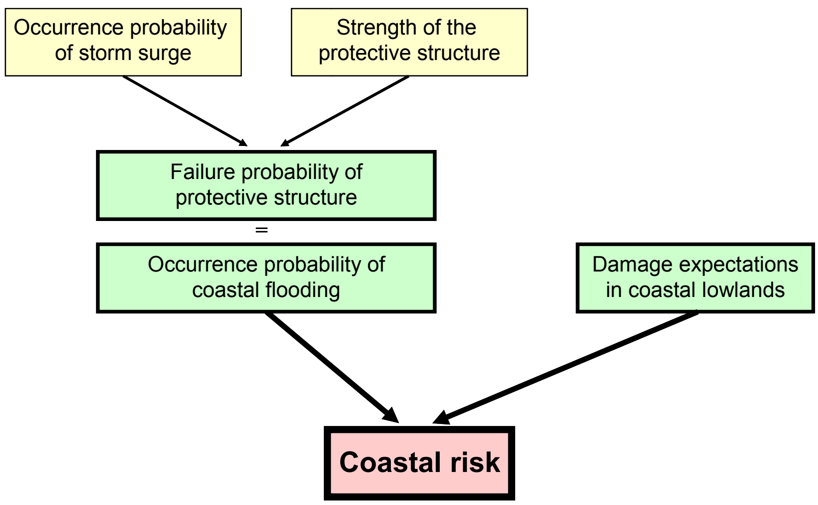

Figure 1: Schematic presentation of coastal flood risk (adapted from Probst 1994)

Implementing CFRM through controlling the damage expectations in coastal lowlands is increasingly getting attention in science and administration (CPSL 2005, Hofstede 2007a). So far, such options have only exceptionally been implemented in Germany. In contrast to technical flood defences, these solutions may cause development constraints in the coastal lowlands and result in more personal responsibilities and higher efforts for the affected population. The possible consequences of climate change for maintaining the existing safety standards and other possible constraints of flood defences justify the evaluation of alternative and complementary options for CFRM.

In this paper, after a short discussion of sea level rise scenarios, possible constraints of technical flood defences are described. Further, the CFRM cycle as a holistic and integrated approach is elaborated in detail. The paper ends with an outlook.

2 Sea level rise scenarios

Anthropogenic sea level rise (SLR) will result in higher storm surge water levels and, therewith, in higher coastal flood risks. The fourth assessment report of the Integovernmental Panel on Climate Change (IPCC 2007) delivered a range of global SLR scenarios. Depending on the models and emission scenarios, the values range from 0.19 to 0.58 m of SLR between 1980/99 and 2090/99 Accelarated melting of the Greenland icecap may contribute up to 0.2 m of extra SLR to these values.

In its report of 2007, IPCC pinpoints a number of uncertainties and unknown factors that may cause deviations from the published values. For example, IPCC states that dynamical processes related to ice flow on Greenland and the West Antarctic Peninsula that are not included in current models but suggested by recent observations could increase the vulnerability of the ice sheets to warming, thereby increasing future SLR (Shepard and Wingham 2007). Understanding of these processes is limited and there is no consensus on their magnitude. Other unknown factors that are recently discussed are the possibly reduced capacity of the oceans and tropical rain forests to store carbon dioxide as well as possible emissions of nitrous oxides (laughing gas) from the ocean floors and the permafrost regions. Laughing gas is a highly effective greenhouse gas. Both meachnisms may result in increased SLR. On the other hand, if fresh water input in the North Atlantic Ocean from the melting icecap on Greenland increases substantially, a blocking off of the Gulf Stream could occcur. Previous models (on the basis of moderate fresh water input) suggest that this hazard only has a very low probability in this century. An expert judgement from leading climate researchers (Zickfeldt et al. 2007) yielded the following result. If global temperature increases by 4o C, two third of the respondents estimated the probability of a collaps of the Gulf Stream in this century among 10 and 60 %. A collaps could result in a reduction in SLR, at least in the North Atlantic region (as well as in a recovery of the Arctic marine ice cover). Finally, SLR will not terminate at the end of this century but is expected to continue for centuries. Quantification is highly uncertain as it includes even more unknown factors.

The unknown factors give way to a number of alternative SLR scenarios (table 1).

Table 1: Sea level rise scenarios (in m) from different authors

Author	Regional (2100)	Global (2100)	Global (2200)	Global (2300)
IPCC (2007)	-	0.19 - 0.58	-	-
Rahmstorf (2007)	-	0.5 - 1,4	-	-
MPI (2006)	0.41 – 0.48 (North Sea)			-
WBGU (2006)	-	-	-	2.5 – 5.1
Horton et al. (2008)	-	0.54 - 0.89	-	-
Delta Commissie (2008)	0.65 - 1.30 (NL coast)	0.55 - 1,10	1.5 - 3.5	-
Grinsted et al. (2009)	-	0.9 - 1.3 (A1B)	-	-

Rahmstorf (2007) published a semi-empirical approach to estimate SLR among 1990 and 2100. His relationship connects observed global SLR to observed global mean surface temperature rise during the 20th century. Applying this relationship for the IPCC temperature scenarios, Rahmstorf delivered SLR projections until 2100 among 0.5 and 1.4 m. His approach is controversially discussed in the scientific community. The Max-Planck-Institute for Meteorology (MPI 2006) delivered global SLR projections among 0.21 and 0.28 m until 2100. They calculated that changes in the ocean circulation may lead to an extra SLR of about 0.2 m in the North Sea. If global temperature increase is limited to 3°C, the Scientific Advisory Board of the German Government on Global Environmental Changes (WBGU 2006) expects a long-term SLR until 2,300 among 2.5 and 5.1 m, mainly due to melting of the large icesheets on Greenland and the West Antarctic Peninsula. Horton et al. (2008) applied the semi-empirical relationship from Rahmstorf to the coupled global climate models that were used for the fourth IPCC report. With a mean of 0.71 m, the resulting global scenario values ranged among 0.54 and 0.89 m. Horton et al. (2008) states that: "Both the IPCC values and the semi-empirical SLR projections are likely to underestimate future SLR if recent trends in the Polar Regions accelerate." Grinsted et al. (2009) used a physically plausible four parameter linear response equation to relate 2,000 years of global temperatures and sea level. Future sea level was projected from IPCC temperature scenarios and past sea level from multi-proxy reconstructions (assuming that the established relationship between temperature and sea level holds from 200 to 2100). In result, SLR until 2090/99 was projected to be 0.9 to 1.3 m for the IPCC A1B scenario, with low probability of the rise being within IPCC confidence limits. In 2007, the Dutch Government installed an independent Delta Commission with the merit to evaluate and recommend possible flood risk adaptation strategies and measures (Delta Commissie 2008). The Commission decided to apply regional "worst-case scenarios" varying among 0.65 and 1.3 m of SLR until 2100 and among 2 and 4 m until 2200.

From this discussion it becomes clear that SLR will probably be higher than the lower IPCC values; a range among 0.5 and 1.4 m may be more realistic. Apart from the magnitude, the large range calls for flexible and sustainable (i.e., no-regret) adaptation measures and strategies. With respect to the starting date for most SLR projections (1990), it is interesting to note that, at least along the Dutch and German coasts, in 2008 (i.e., after 20 % of projection period) no indications of an accelerating SLR could be observed (figure 2; Hofstede 2007b).

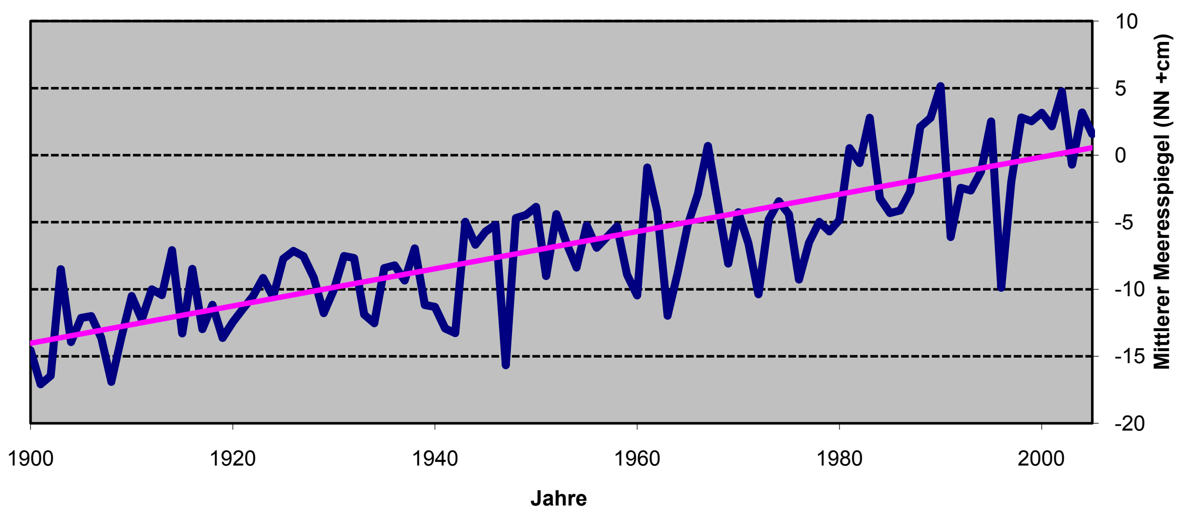

Figure 2: Development of mean sea level since 1900 AD along the Baltic and North Sea coastlines of Germany and the Netherlands, averaged from 17 long-term tidal gauge stations (Hofstede 2007b)

Apart from SLR, meteorological processes control the height of future storm surge water levels and, therewith, the necessary dimensions of flood defences. According to Woth et al. (2006), storm surges in the Inner German Bight may become up to 0.4 m higher in the period 2071-2100 compared to 1980-1999. Grosmann et al. (2006) included projections for SLR and came with a mean extreme water level projection of 0.50 m in 2085 for the city of Cuxhaven at the mouth of the Elb-estuary. Depending on the models and emission scenarios applied, the values range from 0.42 to 0.61 m. For Hamburg, the corresponding values amount to 0.48, 0.63 (mean) and 0.82 m. As with the SLR projections, these values include many uncertainties and assumptions. Further, due to the governing meteorological processes, the projections show strong local variations. For the German Baltic Sea coast, no projections are available.

3 Constraints of the present approach

CFRM in Germany focusses mainly on flood defences. Due to the fact that almost 2.5 million inhabitants of the coastal lowlands rely upon flood defences, maintaining and adapting these defences will remain a corner stone of CFRM in Germany. Dike relocation on a large scale would be financially unfeasible and ecologically unfavourable (e.g., huge costs and vast energy consumption to relocate people and activities, creation of extensive – former natural – areas for housing, infrastructure and other purposes). It is highly probable that such a massive migration would cause major economic and social disruption. Finally, at least for administration, it is clear that acceptance of the affected cannot be expected. On a local scale, dike relocations may be attractive, especially when they increase coastal resilience against climate change, when they have positive ecological effects and when the area is uninhabited. Some successful examples of dike relocation in Germany exist, for example on the barrier island Langeoog, at Geltinger Birk outer Flensburg Fjord and at the Karrendorfer Wiesen near Greifswald.

Technical flood defences underly a number of constraints.

- Flood defences are designed to withstand a defined maximum storm surge water level (figure 3). This level does not only result from technical elaborations, but also includes financial and social considerations. The result is a safety standard that is accepted by society. Higher water levels and other loading cases (e.g. terror attack, ice load) may result in failure of the structure and flooding. Hence, technical flood defences cannot guarantee absolute safety. The residual risk needs to be managed (Oumeraci 2005).

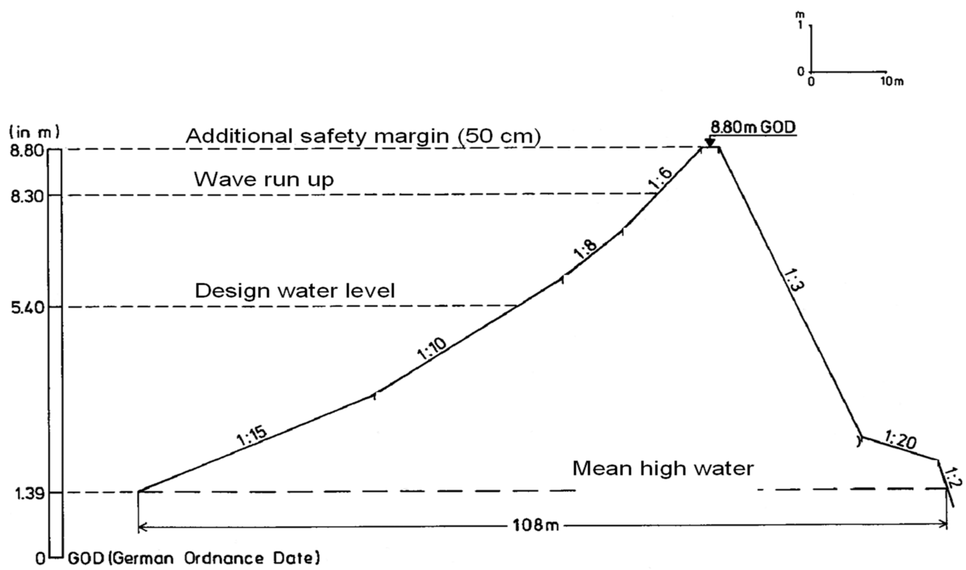

Figure 3: Dimensions of a State dike in Schleswig-Holstein

- The safety level directly depends on the willingness of society to spend money on flood defence. This willingness is governed by the awareness for coastal flood risks that rapidly sinks with time passing by since the last flooding event. Low public budgets together with low risk awareness may reduce the funds available for flood defences. Although it is questionable that a (politically) fixed safety standard will officially be reduced, a cut in financial means may lead to this. Examples are neglected maintenance or delayed strengthening of the defences (determined by SLR).
- Climate change and its consequences may reveal the financial limits of technical flood defences. Above a certain threshold the necessary financial efforts to maintain safety standards could become unacceptable for society. In this case, alternative and additional coastal risk management options become inevitable. It should be stated that technical solutions to counteract a SLR of several meters in a long-term perspective exist.
- Technical flood defences interfere with nature and may reduce the natural resilience of the coasts with respect to SLR. Examples are the fixation of the coastline in an unfavourable and artificial location or the interruption of natural sand redistribution patterns. Hence, wherever possible, natural hydromorphological processes should be allowed or furthered. In this case, however, alternative measures to reduce the risk of flooding (i.e., the damage expectations) of the hinterland may become necessary.

Apart from these constraints, focussing on (ever higher) dikes has some inherent disadvantages. The higher the dike, the stronger the inundation processes (currents, water depths) after dike breach, and the more severe the consequences will be. Further, high and strong dikes may lead to the (false) impression of absolute safety. Hence, the dependence on one single measure or dike line makes society more vulnerable.

4 The coastal flood risk management cycle

From the above considerations it becomes clear that a sectoral approach towards CFRM that only focuses on technical measures is not sufficient. The challenges arising from climate change as well as the constraints of technical structures imply that the classical flood defence schemes should be an integral part of a holistic management that combines technical measures with non-structural methods (Hofstede et al. 2005a). Sustainable CFRM may be defined as a cycle (control loop) that consists of six integral components: prevention, protection, preparedness, emergency response, recovery, and review (figure 4).

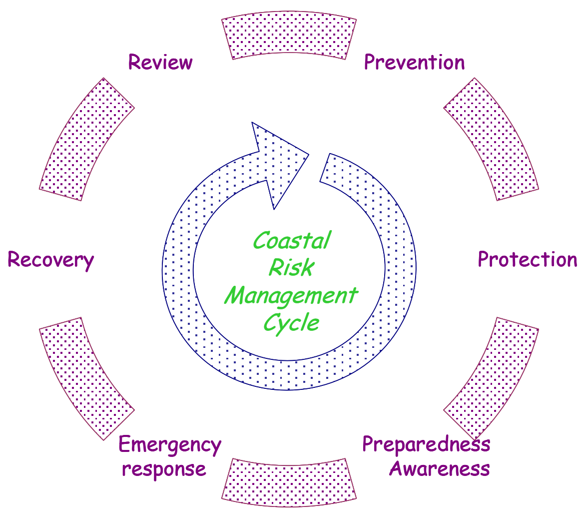

Figure 4: The coastal risk management cycle (Hofstede 2007a)

Prevention to avoid or minimize damages from flooding. As stated in the introduction, coastal flooding is a natural event. Some environments like salt marshes depend on regular inundations. Flooding becomes a hazard when society starts to utilize the flood-prone area for infrastructure, housing, etc. Controlling the development in flood-prone coastal lowlands is, thus, the first step in the CFRM cycle.

Main tool to control utilization of coastal lowlands is spatial planning. It constitutes a formalized and systematic way to influence (regulate) the distribution of people and activities geographically. The guiding principle of spatial plans and programs is a sustainable spatial utilization and development which balances the social and economic requests upon a region with its ecological functions (ROG 1998). Spatial planning in Germany is realized at regional, State and national levels. At the local level, municipalities are responsible for building or town planning. The local and regional levels have the most potential for CFRM.

On a local level, specific regulations for building areas may substantially reduce damage expectations due to coastal flooding. For example, in the 1970ies, a new building area was established near the Baltic Sea in Germany. Flood defence consisted of relatively low dikes. To keep damage expectations low, in the local building code, it was regulated that living room should be realized in the upper floors. On ground-floor level, only garages and/or storage rooms were allowed. Three decades later, these stipulations are not abided anymore. The absence of flooding events and lacking risk communication resulted in very low risk awareness and corresponding behaviour. Another actual example is the “Hafencity Hamburg”. This new building area lies outside the public flood defence line in the harbour area of Hamburg. In the building code for the area it is stipulated that the whole area has to be raised up to a level that cannot be reached by extreme floods. This regulation became well-known as the “dwelling-mound-principle”. In order to control the residual risks (see chapter 3), houses at the waterfront should have special arrangements for flooding, and evacuation routes are foreseen.

On a regional level, the identification of buffer zones and flood hazard zones constitute promising non-structural measures to control coastal flood risks (CPSL 2005). Coastal buffer zones, demarcated by setback lines in spatial plans may provide protected zones between the sea and the hinterland, where human utilization and development are strongly restricted. As the term “buffer” already implies, this measure provides a zone that allows for retreat of the coastal flood defence line or reserves space for necessary flood defence measures. In this way, the natural resilience of the coast is enhanced as well. In coastal flood hazard zones, human activities can be managed (regulated) in such a way that the vulnerability of the area is reduced. This could be realized by specific requirements or recommendations defined in the spatial plans. For example, certain roads could be constructed in elevated position (like dams) to allow for evacuation and to limit the inundated area. In specific high hazard zones, the “dwelling-mound-principle” for new building areas could be prescribed. The simple fact that flood hazard zones are depicted in the spatial plans could already increase the awareness of the risk.

Protection constitutes the second element of the CFRM cycle. It becomes necessary when flood-prone lowlands are utilized or, rather, when potential flooding is perceived by society as a threat to life and property. As stated before, with respect to the 2.5 million inhabitants of coastal lowlands, protection by technical flood defences will remain a corner stone in future CFRM in Germany. With reference to climate change and SLR, reserving space for strengthening campaigns by depicting buffer zones in regional plans is a sustainable measure.

Necessary measures may be implemented in a more sustainable way that minimizes the impacts on ecology and the natural resilience of the coasts. CPSL (2005) list a number of such solutions like performing sand nourishments (figure 5) to balance SLR as well as dune management techniques to stabilize and sustain the dune systems as natural flood defences. Necessary dike maintenance and strengthening may be performed in a sustainable way that minimizes the ecological interferences. Coastal defence administration already implements this minimizing principle, e.g. by performing dike relocations where appropriate (see above), by strengthening dikes to the landward side and by taking the necessary clay from the inland (wherever possible). Unavoidable interferences with nature are compensated.

Figure 5: Sand nourishment on the island of Sylt (Germany)

With respect to the large uncertainties in the scenarios, more flexible (no-regret) flood defence measures are investigated and implemented. Sand nourishments balance the observed SLR or, rather, the sediment deficit resulting from SLR (figure 5). If SLR increases, more sand may be deposited and vice versa. Nourihments, thus, present a flexible no-regret measure. Further, they increase the natural resilience of the coast and pose a relatively low impact on nature. On the other hand, strengthening a dike for an expected SLR of 1.5 m may turn out to be highly ineffective, namely if SLR takes two centuries to reach this level. In this case, it is much more cost-effective to spread the costs over the centuries by performing two or three strengthening campaigns. Considering building reserves (for extra heighthening) may be more appropriate and flexible. In its almost finished strengthening campaign, the city of Hamburg included a static building reserve of 0.8 m to allow for future heighthening of its flood defences (sheet pile walls, sluices, etc.).

Preparedness, being the third component in the CFRM cycle, is closely related to risk awareness. Aware people are prepared to personally undertake preventive and emergency actions. Further, they (are prepared to) accept the high costs for flood defences and other possible constraints of CFRM like flood-proof housing or living in the upper floor. In consequence, appropriate coastal risk awareness or, rather, a high level of preparedness may significantly reduce the damages resulting from flooding. The main tool to achieve coastal risk awareness (apart from flooding) is risk communication.

A public opinion poll consisting of 2,000 questionnaires that were distributed in five coastal towns around the North Sea showed that the awareness for coastal risks is not well developed (Hofstede et al. 2005b). Although the cities are situated in protected coastal lowlands, 30 % of the 411 respondents thought that their house could not be flooded after dike-breach (figure 6). Furthermore, 90 % of the respondents who estimated the probability of flooding in their region to be very high had not taken any precautionary measures. This indicates that the information flow about the risk towards the population is either insufficient, does not reach the recipients or is not taken seriously (ignored or disclaimed). The study concluded that there is an apparent deficit in coastal risk communication.

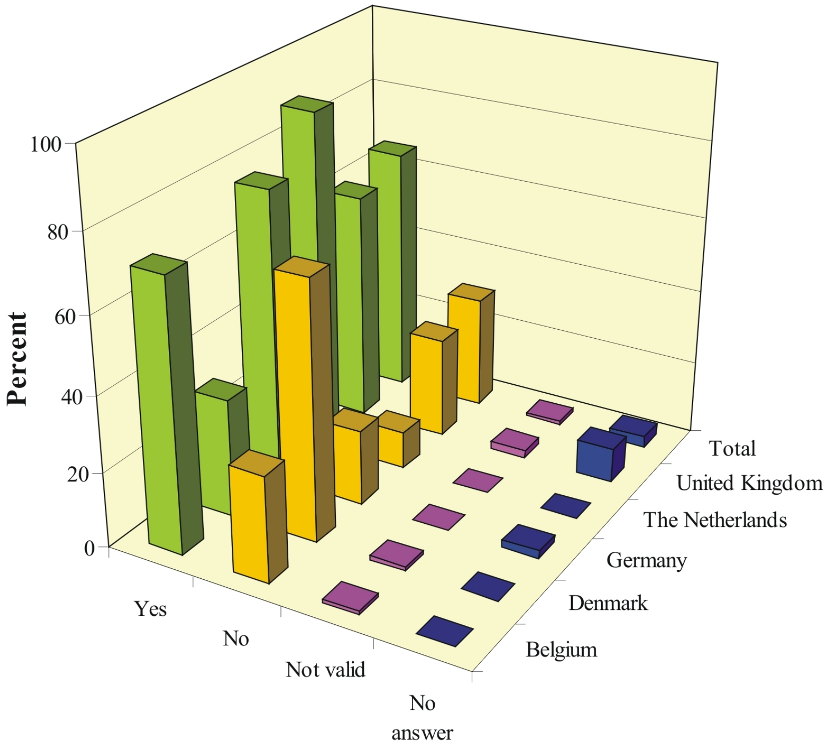

Figure 6: Response to the question: "could your house be hit by floodwater in case of a coastal flooding?" (Hofstede et al. 2005b)

Emergency response in the CFRM cycle includes all measures related to impending or real coastal floodings. The aim is to prevent or reduce catastrophic consequences and, therewith, the flood risks. Emergency response includes measures like flood warnings (based on flood forecasts by hydrological services), evacuation, placing sand bags, and aftercare. During an emergency, the responsible disaster management authority may access the capacities of other authorities like health services, fire departments, flood defence administration, etc.

SLR and, in reaction, higher dikes as well as increased utilization of coastal lowlands have the potential to intensify flooding catastrophies. If a dike-breach occurs, the water levels in the flooded area will rise faster and higher, thereby increasing the damage expectations. Accordingly, the importance of adequate emergency response increases.

Recovery aims at restoring the affected area to its previous state. It starts after immediate needs like closing the breaches or social and medical aftercare, are addressed. Recovery actions are primarily concerned with measures that involve repair of essential infrastructure and rebuilding of destroyed property. Hence, in a strict sense, recovery is not part of the CFRM cycle as it does not directly control or reduce the risks. However, effective recovery should take advantage of a "window of opportunity" (Alexander 2002) for the implementation of preventive and protective measures that might otherwise be unpopular. Citizens of affected areas are more likely to accept these measures when a recent disaster is in fresh memory. Implemented in this way recovery can contribute to the aims of CFRM.

Review stands for monitoring and regular (scientific) evaluation of all integrated CFRM components. In a broader sense, it also includes research on changes in SLR, storm surges and spatial development in coastal lowlands as these factors determine future coastal flood risk. Based on the outcomes of the evaluations and research, the next CFRM cycle may be optimized.

In an administrational structure, CFRM may be seen as a safety chain. It starts with spatial planning authorities that control/minimize the vulnerability of lowlands (prevention). Coastal flood defence administration is the next chain that guarantees a certain safety standard in the utilized flood-prone lowlands (protection). Disaster management – the third administrative body in the chain – starts with preparation, mainly through risk communication (but also by training and exercising). Conducting emergency response measures (from warnings till aftercare) is the second and main task of disaster management. Rebuilding society after the disaster (recovery) is not a public responsibility and, last but not least, the reviewing process is a task for all responsible authorities.

From the above elaborations it becomes clear that all CFRM elements complement one another. For example, depicting buffer zones in spatial plans facilitates the long-term implementation of coastal flood defence. Raising awareness by effective information or "intelligent" recovery inceases the acceptance of necessary planning measures like living in the second floor. Vice versa, the depiction of flood hazard zones in spatial plans increases the awareness and preparedness. Finally, an appropriate reviewing process is prerequisite for developing optimal information tools like travel exhibitions. Hence, in combination, the six integral components present a holistic approach towards CFRM.

5 Outlook

Justified by the common goal (controlled coastal flood risks), the complementary character of and the interactions among the elements, holistic implementation of the cycle is a precondition to achieve sustainable CFRM. This fact is acknowledged by the EU-Flood Directive. Purpose of this Directive is to establish a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community. Based upon a preliminary flood risk assessment, flood risk areas shall be delineated. For these areas, flood hazard and risk maps as well as flood risk management plans shall be established. Focussing on prevention, protection and preparedness, all aspects of the CFRM cycle should be addressed in these plans. In order to achieve tailor-made solutions and to raise risk awareness, Member States shall make all products available to the public. Further, active involvement of interested parties in the production, review and updating of the flood risk management plans shall be encouraged. Concordingly, the implementation requires close coordination among competent authorities (coastal flood defence, disaster management, spatial planning) and active involvement of the affected parties. In Germany, where public procedures still show sectoral aspects, the Flood Directive may be seen as a chance.

This paper focusses on public-administrational aspects of CFRM. It is evident to realize that the most important partners in CFRM are the affected; the inhabitants and private investors in the coastal lowlands. Only if they adequately perceive the risks, accept their personal responsibility, and act accordingly, coastal flood risks remain manageable and a long-term sustainable development in the coastal lowlands is possible.

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