Robust multi-functional flood defences

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1 Description work package

1.1 Problem definition, aim and central research questions

In the Netherlands, the existing flood defence system is optimized for flood protection and merely allows additional functions for living, transport, recreation or nature conservation. It is sometimes suggested that a broader flood protection zone might be a promising alternative to replace traditional embankments under uncertain future climates. Scientifically, the Netherlands' flood defences are analysed in so-called 'dike-rings', and therefore broad flood defences should be investigated within a framework that encompasses the entire ring. The challenge is to spatially delimit and design the flood defence zone in such a way that apart from reducing flood risk it also provides additional cost-effective economic, cultural or natural values. In some cases this may involve lowering the wave load on the embankment by salt marshes and sand dikes which can be sustained by enhancing natural processes (e.g. in the Wadden area).

At present, robust structures are not defined in a risk assessment environment, nor are instruments and procedures available to quantify and visualize conflicting interests and goals which facilitate the reconciliation of multiple functions with flood defence. A concise, visual, spatially-explicit, multivariate overview of the opportunities and constraints for specific cases can stimulate stakeholder-participation.

The aims of this work package are:

1. to develop effective instruments and procedures for decision making about the design of multi-functional flood defences and natural climate buffers at the local as well as regional level;
2. to define and to assess the contribution of robust multi-functional flood defences to flood risk reduction of entire dike-rings;

Central research questions are elaborated in the project descriptions below.

1.2 Interdisciplinarity and coherence between the projects

The link between the two projects within this work package (WP3) is that project 3.1 delivers information about the possibilities and impacts of local interventions, whereas project 3.2 evaluates the effectiveness of local interventions in the context of a dike-ring. Project 3.1 gives input to project 3.2, and project 3.2 provides feedback and poses boundary conditions to project 3.1.
To achieve the interaction between the two projects, a close co-operation is foreseen between the two researchers. Consequently, both projects partially focus on the same case study areas (‘Wadden Sea’, ‘Large Rivers’).

Both projects cross the borders beyond (already quite broad) disciplines like civil engineering, spatial planning, mathematics, ecology or agronomy. Especially when evaluating the contributions of alternative land-use functions and natural processes to the flood defence function it is important to combine knowledge from these disciplines (e.g. the combination of civil engineering knowledge on technical dimensioning with knowledge on agronomy or on nature conservation and natural processes in saline environments). In addition, (economic) values of recreation, transport, infrastructure, housing, cultural history and the landscape quality should be assessed.

Co-operation beyond this work package is also foreseen, viz. as follows: within theme 1, especially with WP1 (flexible flood defences), WP2 (natural climate buffers) and WP6 (climate robustness and spatial quality). With other themes in KfC 2nd tranche co-operation is especially foreseen with theme 5 (Infrastructure) and theme 7 (Governance – which also focuses on the Wadden Sea case study).

1.3 Stakeholders

Hotspot Waddensea: Province of Fryslân, Province of Groningen, Wadden Islands (e.g. Texel, Terschelling and/or Ameland), Local Water Boards (Wetterskip Fryslân and Waterschap Noorderzijlvest), LTO Noord, municipalities along the Waddencoast (e.g. Delfzijl, Harlingen, De Marne), NGO Waddenvereniging, Ministery of Agriculture, Nature and Food Quality (northern region).

Hotspot Large Rivers: Local Waterboards (e.g. Waterschap Rivierenland, Waterschap Hollandse Delta), Programme 'Ruimte voor de Rivier' (Ministry of Transport, Public Works and Water Management), municipalities.

Hotspot Rijnmond Region: municipality of Rotterdam, Havenbedrijf, Water Board Hollandse Delta, waterboard Delfland, waterboard Schieland.

Ministry of Transport, Public Works and Water Management. Ministry of Agriculture, Nature and Food Quality (e.g. Directie Landelijk Gebied). Union of Water Boards (UvW) and STOWA (as the responsible organisation for applied research of the UvW).

2 Project 3.1 Procedures for decision-making about multi-functional defences

Project leader: ir. Jantsje M. van Loon – Steensma

2.1 Problem definition, aim and central research questions

The current primary flood defences are designed on the basis of standards that relate to an expected flood stage for a specific return period. These standards are established via statistical models that use historical measurements and hydraulic models. Due to the inherent uncertainties in the effects of climate change, it is an important but complex task to redesign and adjust the primary flood defences in such a way that these will be sufficiently robust and also geographically flexible. Through this flexibility possibilities for future re-adjustments should be offered. An important step can be to designate a broad zone for flood defence functions, including the forelands (such as the salt marshes and dune dikes in the Wadden area). In such a broad zone belong for instance, besides the current flood defence works and extra space for future dike-reinforcements, also part of the inner- and outerdike areas where natural accretion processes can be stimulated to enhance flood safety by reducing the wave load. However, space is very scarce in the densely populated Netherlands, hence both inner- and outerdike areas are already used for functions other than flood safety, such as housing, nature, recreation, agriculture, transport, etc. Moreover, there is still hardly any scientific knowledge available to take a well-informed decision about the designation and design of a robust and multifunctional flood protection zone. Thus, insight is required in these aspects and processes of multi-functional defences.

The aim of this research project is to develop fundamental knowledge for the location-specific design of robust and multifunctional flood defense zones which fit in their environment and use the opportunities that this environment offers for flood defence. A location-specific design will be the result of a decision process with multiple stakeholders, which may use several decision support instruments. Hence this research will also pay attention to both the design and use of such decision support instruments. The focus will be on agricultural (e.g. saline agriculture and biomass production for energy) and nature functions (via ecosystem services and nature conservation) and natural processes (in particular salt

marshes and sand dikes). Information about landscape (e.q. quality, cultural-historical or recreation), urban (housing and recreation) and transport functions from other research will be used where appropriate.

In decision-making for spatial planning it is important to distinguish between: 1) specifying the spatial and temporal domains of interest as well as the financial constraints; 2) defining the set of functions that the space (or the activities therein) must fulfill; 3) recognizing boundary conditions (constraints as well as opportunities) imposed by the physical environment (a.o. natural processes) or society (a.o. property rights); 4) establishing the degree to which a specific design meets the desired functions and fits in the boundary conditions and; 5) recognizing or imposing the way by which the decision support instrument is used (e.g. how results are communicated and presented).

The research questions focus at the specification of these aspects in the decision problem in several case studies and to provide guide-lines for decision-making:

1. On the basis of which functions (physical and societal constraints and opportunities), natural processes and characteristics of the decision process should a broad flood protection zone be delimited (and what does that delimitation look like in case studies)?
2. What are possible functions (in each of the case studies) that have to be fulfilled by the foreseen multifunctional flood defences, and what weight is assigned to each of these functions?
3. What are the different physical phenomena and natural processes that constrain or strengthen a foreseen multifunctional flood defence?
4. What are the different societal boundary conditions for a foreseen multifunctional flood defense, and what weight is assigned to each of these?
5. What are the technical coefficients of (part of) a flood defence, i.e. quantitative design standards and guidelines (1) and fits within the boundary conditions / opportunities (2 and 3)?
6. How should a decision process take place and what should the information in a decision support system look like?

The formulation of sub-questions for each of the above six questions will depend on insights from the different case studies, and is therefore part of the foreseen research activities.

2.2 Approach and methodology

The most important methods that will be used in answering each of these questions will be:

1. analysis of scientific literature, application of computer models and expert elicitation (for delineating intervention zones, valuation and generation of technical coefficients for possible land use functions;
2. cost-benefit analysis (to evaluate different functions),
3. multi-criteria optimization via operation research techniques (to find preferable functions), and
4. geo-visualization (to communicate research output).

option: assessing the effectiveness of salt marshes to reduce wave load (to be negotiated and if co-financed from the Wadden hotspot area).

The case studies in this research have been selected in response to questions from the Knowledge for Climate hotspot and comprise:

- Parts of the coast of the Wadden Sea where salt mashes are relevant, and Wadden islands where dune dikes are desired (the specific areas will be decided on in collaboration with the stakeholders and WP2). This case study may also involve (saline) agriculture, recreation, nature conservation and possibly the redesign of the Afsluitdijk.
- Major rivers, involving dike-restructuring locations along the River Rhine and possibly several locations along the IJssel.

This project aims at providing fundamental scientific insights to delineate intervention zones, although also some more applied results are foreseen in the final integrative face, mainly in the form of valuation and generation of technical coefficients for possible land use functions and natural processes. Another applied result will be a guideline for making well-informed choices in developing climate-robust and multifunctional flood protection zone, along with examples where the guideline is applied. The examples are formed by the case studies and lead a.o. to technical information about costs and benefits, 2D profiles and 3D geometrics of location specific and multifunctional flood protection zones in their landscape context.

2.3 Scientific deliverables and results

Four scientific publications focusing on:

- The opportunity to combine saline agriculture with water safety in a broad flood protection zone in the Wadden Sea and comparable deltas; e.g. in Agriculture, Ecosystems & Environment.
- Nature development and conservation in a broad flood protection zone and the possible contribution by the dynamics of natural systems to the flood protection function; e.g. in Journal of Coastal Conservation.
- A guideline for decision-making to plan broad protection zones; e.g. Journal of Environmental Management
- Governmental aspects of implementing robust multifunctional flood defences (in cooperation with theme 7, Governance)

PhD thesis (based on the above foreseen peer reviewed scientific publications) and some site-specific designs of broad protection zones.

Despite the fact that all case studies are located in the Netherlands, the knowledge, procedures and instruments developed in this research are also applicable to deltas elsewhere.

2.4 Integration of general research questions with hotspot-specific questions

The questions from the hotspots closely match with the general research questions of this project.

Wadden Sea area. The question here is if and under which conditions the mudflats and salt marshes can act as buffers which enhance flood safety. In addition the question is whether a more offensive coastal defence strategy can be developed whereby there is also room for nature, recreation and saline agriculture. Wadden island Texel is interested in multifunctional flood defences near 't Horntje'. The province of Groningen is interested in the possibilities for a broad coastal flood protection zone that can act as buffer for the lower lands of Groningen where both nature and agriculture functions are combined. The questions resulting from reconnaissance study on adaptation possibilities in the Ems delta (conducted in the first tranche of Knowledge for Climate) will be used as starting point for this study.

Major Dutch Rivers. In different areas the river dikes need to be adjusted to the current flood safety standards and 'Room for the River' in which space is being created for future peak discharges. The question in this hotspot is if and how future dike enhancements can be made as rubust and multifunctional as possible.

2.5 Societal deliverables and results

One or more papers in applied journals and magazines.

Some site-specific designs of broad protection zones (focusing on the involved case studies) and the attached overview of impacts and values of these broad protection zone on the identified site-specific functions (e.g. safety, economy, nature conservation, agronomy, recreation, transport, landscape, etc.).

For the Wadden Sea area: location-specific sketches of promising flood protection and a sketch of longer coastline stretch. These designs will be provided to decision makers to serve as possible alternative for the adaptation in their region.

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3 Project 3.2 Flood risk in dike-ring areas with innovative flood defences

Project leader: dr. ir. M. Kok (TU Delft)

3.1 Problem definition, aim and central research questions

Over the last two decades, first generation models for flood risk assessment have been developed in the Netherlands. These are used in studies by the Ministry of Public Works and Water Management Rijkswaterstaat), provinces and water boards: the FLORIS-project (VNK). Although current methods provide useful insights in the factors that influence the reliability of flood defenses, they lack essential elements and sufficient detail for the integrated management of flood risks in the Dutch delta. Current methods do for instance not allow us to take into account the correlations between simultaneous floods in different parts of the country, while historical experience shows that floods can affect entire coastlines or fluvial floodplain systems. The lack of detail of current risk assessment techniques implies that knowledge about the effectiveness of interventions is inadequate for the development of an integrated flood risk management policy. In the figure below the basic idea behind assessing the risk of failure of conterminous flood defenses (dike rings) is presented.

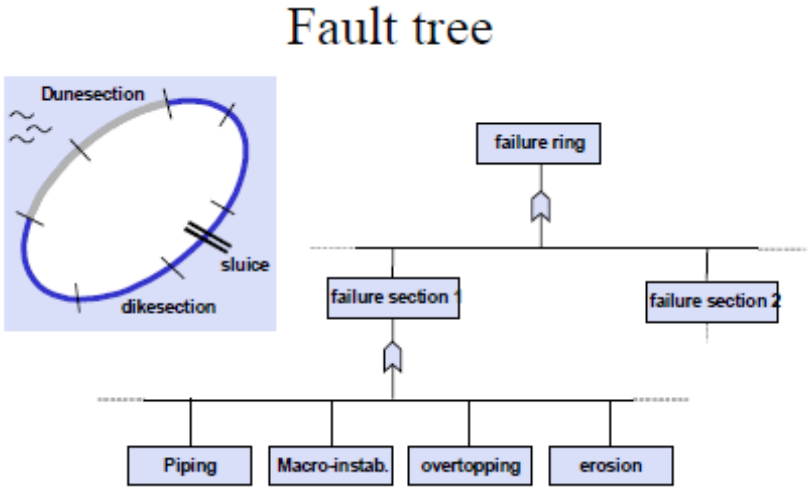

Figure 1 The dike-ring approach

In order to reduce flood risks, many strategies are possible. Nowadays, especially in urban areas, it may be attractive to integrate the flood defense with other functions, such as housing and recreation. These multifunctional solutions need a robust approach, since it is quite complicated to improve these structures later on. It is an open question how to define 'robust' in a engineering approach, and how to design these structures using a dike-ring approach. Obviously, in a dike-ring approach the weakest link determines the safety of the total ring.

The consequences of a flood in Delta regions can be very high. The flooding of New Orleans has shown that flooding in modern societies has a catastrophic impact. More than 1000 persons lost their life. Direct material damages have been estimated at well over the initial estimate of 30 billion dollar (Munich Re estimated damages worth 138 billion dollar; the legal claim against the federal government is more than several hundreds billions of dollar). It can be noticed that catastrophic floods have traditionally been seen as natural hazards, but that the perception has changed. These catastrophes often have a strong man-made component, e.g. when flood defences protect land from extreme storms or river discharges, or when climate change increases storm frequencies. There has been a change in the perception of flood hazards in recent years, as concluded in a study about the Dutch flood policy (RIVM: "Risico's in bedijkte termen"). Flood defences in the Netherlands are nowadays regarded as engineering structures like factories and planes, and failure of these structures is perceived as a failure of government policy.

This project *aims* at the development of quantitative risk assessment techniques, the definition of 'robust' flood protection measures and the assessment of the effectiveness of these solutions in a dike-ring context. To this end it will develop risk assessment models that can be applied to highly reliable flood defenses, it will try to reduce the knowledge uncertainties in the assessment of failure probability and it will assess the impact of new protection measures such as the so called "fail safe" flood defenses.

The main *research question* of the project is: how can we extend the present risk assessment methods to apply for high-reliability flood defence systems and uncertain climate change?

3.2 Approach and methodology

In this project we will use and develop quantitative risk assessment methods for high-reliability flood defence systems. On the basis of knowledge and methods from mathematics and civil engineering, new methods will be developed to address the following issues:

- The integrated treatment of uncertainty induced by climate change in flood risk assessments and the risk-based design of flood defenses.
- The impact of structures which for their closing rely on human action on the probability of flooding of a dike ring area.
- The cumulation of risks for larger systems such as a river catchment or a coastline: floods could occur simultaneously, causing significantly higher losses per event.
- The effects of emergency measures on the reliability of flood defences, taking into account the effects of extreme conditions on logistics.

Next to the approach to reduce the probability of flooding (which is the 'business as usual' approach in the Netherlands), measures have been proposed to mitigate the consequences of floods, for example through spatial planning and flood proofing buildings. Although spatial planning and flood proofing reduce consequences, more insight is needed about their relative effectiveness by considering their impact on flood risks.

3.3 Scientific deliverables and results

A first deliverable are new quantitative risk assessment models for evaluating the safety of high-reliability flood defence systems. A second deliverable are the results of a quantitative estimate of the effectiveness of flood defense measures on the probabilities and consequences of floods.

These deliverables will be communicated through:

- 3 scientific papers
- 2 popular papers about the outcome of the research
- PhD thesis

3.4 Integration of general research questions with hotspot-specific questions

This research will adopt case studies from the region Rijnmond and the Drecht Cities. In this area much attention is given to the 'climate proofing' of the region, and also on measures which do not only decrease the flood risks, but also strengthen other functions of the area. More spefically, the following questions will be addressed:

1. Is it possible to have an open closed Rijnmond area with structures which have to be opened and closed, and are therefore vulnerable to human failure?
2. What is the most effective way (mix of possible measures) of protecting the region against flooding taking uncertainties about climate change into account?

3.5 Societal deliverables and results

The project will result in new methods in the field of flood risk assessment, which are relevant for the societal debates about flood risk management. In this debate, it is sometimes suggested that the probability of a flood is not important, since flood events cannot be entirely excluded, even if a flood has a very low probability. In the debate we shall argue that the probability of a flood is also important.

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