Towards climate-change proof flood risk management
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Towards climate-change proof flood risk management

Exploration of innovative measures for the Netherlands’ adaptation policy inspired by experiences from abroad

Interim report, executive summary

theme 1

Knowledge for Climate research programme

Editors
Frans Klijn, Matthejs Kok, Hans de Moel

Authors (contributions)
Nathalie Asselman, Robbert Biesbroek, Maaike Bos, Philip Bubeck, Karin de Bruijn, Alma de Groot, Hans de Moel, Mindert de Vries, Joep Keijsers, Frans Klijn, Matthejs Kok, Heidi Kreibich, Marjolein Mens, Jan Mulder, Anne Loes Nillesen, Edmund Penning-Rowsell, Ate Poortinga, Ties Rijcken, Michel Riksen, Jantsje van Loon-Steensma, Mathijs van Vliet

Report nr. KfC 57/2012
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On the research theme: vision and approach

Climate change and adaptation

Especially in low-lying deltaic areas, a sound adaptation policy is urgently needed, because relying on a global mitigation policy for climate change is way too risky. Both the Netherlands’ policy response and our research therefore focus on adaptation.

In the Netherlands, climate change is given due attention for about two decades already, which now culminates in our current research for ‘Knowledge for Climate’ (KfC). Parallel to the research agenda, various policy initiatives were taken. The most important is the Delta Programme, which can be considered the national authorities’ response to an advice by the 2nd Delta Committee on climate-change related problems and needs. Next, the joint water boards also initiated a combined research and management programme, called Delta Proof. This can be considered the regional authorities’ response to the potential impacts of climate change. Obviously, we constantly tuned our research agenda to the research needs of these national policy and regional management programmes.

In this context, we aim to add to the vast pool of knowledge on the subject of climate-change proof flood risk management and co-operate with the many research groups involved in the Delta Programme and Delta Proof. In our report, we try to give due reference to all our colleagues from outside KfC while still emphasizing our own contribution to the research progress.

Flood risk management: principles, measures and instruments

Comprehensive flood risk management differs from earlier approaches, such as flood defence, flood control or flood management, because it acknowledges that:

1. one should not manage the flood, but the risk (i.e. the flood hazard and the vulnerability of the flood-prone area – as constituted by people, their property and their activities – equally).
2. one should equally consider physical and ‘non-structural’ measures without prejudice (i.e. also regulatory instruments, financial instruments and communicative instruments).
3. one should bear in mind that flood risk management is a continuing cycle of assessing, implementing and maintaining flood risk management measures to achieve acceptable risk in view of sustainable development.

Against this background, we defined the objective of flood risk management as:

to reduce flood risks to a societally acceptable level, against societally acceptable costs.

This definition is supported by various Netherlands’ advisory organizations and authorities. In this definition, flood risks may comprise all kinds of negative effects of flooding, such as loss of property, indirect economic consequences of business being impossible, psychological impacts, loss of life, and impacts on natural or cultural heritage. Costs refers to all costs, i.e. not only monetary costs from an economic efficiency point of view, but also intangibles, such as social equity and ecological integrity.
Flood risk: key concepts and definitions

A clear conceptualisation of flood risk and its constituents helps to identify the points of attack for risk reducing measures. The following two definitions of flood risk are often used:

\[ \text{risk} = \text{probability (of flooding)} * \text{consequences (of flooding)} \]

respectively

\[ \text{risk} = (\text{flood}) \text{ hazard} * \text{vulnerability (of the society/ area)} \]

The first definition is preferred among engineers, who usually aim at reducing the probability of flooding by designing and constructing flood protection. The second definition is preferred by planners, who usually regard the hazard as a given and the spatial planning as the means to adapt to that given.

We tried to reconcile these two competing definitions and ‘schools’ by explicitly distinguishing exposure as a separate constituent of flood risk. This is depicted in Figure 0.1.

![Figure 0.1](image)

*Figure 0.1* Flood risk can be conceptualized as multiplication of flood probability and consequence or as geographic overlay of hazard and vulnerability, or as a combination of 3 key constituents: probability, exposure characteristics and vulnerability (after Van de Pas et al., 2012).

Even then, the terms we use remain ambiguous, and have therefore been defined more precisely, in order to allow clear distinctions between measures and instruments aimed at:

1. lowering the probability of flooding,
2. gaining control over the flooding process and the resulting exposure characteristics, as well as
3. reducing the vulnerability of the flood-prone areas.

Towards climate-change proof flood risk management
Structure of the report

In this report, we follow this distinction in the structuring of chapters in which we successively go into measures and instruments, which address these ‘risk constituents’. However, we split the first – lowering the probability of flooding – into reducing the hydraulic loads (on the defences) and improving the flood defences themselves, so that they can withstand larger loads.

This distinction is made for two reasons: first it relates to the so-called SPRC- structure (Source, Pathway, Receptor, Consequence) and secondly because in the Netherlands with its many embankments it is common use to distinguish between hydraulic loading and the defence’s strength.

We do not treat all possible measures and instruments, as we have no intention of being ‘complete’. Rather, we focus on a number of measures which have received little attention in the past or which we consider very promising for the future. The measures and instruments we have selected will in many cases be assessed from an effectiveness point-of view, in some cases by cost-benefit analysis, and in other cases primarily or also on other criteria. This relates to the fact that our investigations are not performed in isolation, but in cooperation with other research projects and programmes. In other words: it is a deliberate choice in order to prevent overlap or doubling.

Background: the expected development of flood risk in the 21st century

Our earlier analyses of the development of flood risk in the 21st century reveal that socio-economic development is by far the most important cause of increasing risks for the Netherlands as a whole. This is due to the fact that flooding probabilities are to be kept small thanks to the Netherlands’ Water Law, whereas increasing exposure has only limited
influence. This could be interpreted as a relativisation of the possible impact of climate change on flood risk, but that would be a mistake.

Firstly, we established that flood hazard probabilities do increase with a rate equal to that of the socio-economic vulnerability. Responding to this in order to comply with the legal protection standards implies huge investments, of many billions of euros. In addition, the current standards are subject to a revision as they originate from the 1960-ies and are considered outdated for various parts of the country. This too would translate into a huge investment.

Secondly, we may question whether the current policy – of flood protection – is the most attractive or desirable in view of the many uncertainties about future developments and the huge consequences of a flood disaster. The present flood risk management strategy of the Netherlands has a number of disadvantages and can be improved on many points. Moreover, climate change does not stop in 2100, but may well carry on or worsen in centuries yet to come. This requires a longer planning scope and a critical review of the current flood risk management strategy and the measures and policy instruments applied. This calls for innovations in policy making and innovative measures.

So, even when climate change does not cause flood risks to become unmanageable, nor can be considered the main reason to revise the Netherlands’ flood risk management policy, it does require the implementation of many measures and huge expenditures in the next decades. This is a good reason for a critical revision of the present policy and practice and a thorough investigation of possible innovative measures. That is what our KfC- research aims to contribute to, whereas the Delta Programme focuses on concrete strategic decision making and Delta Proof on practical application and implementation.
Results (1) on load reduction: storm surge barriers, room for rivers, wave attenuation

The idea behind load reduction is to reduce the loading on existing flood defences to such an extent that they can fulfill their flood defence function without failure, and without having to be reinforced or raised. This is especially relevant when the hydraulic loads are expected to increase as a consequence of climate change and sea level rise.

Measures which may reduce the hydraulic loads include all technical and non-structural measures that may reduce either the flood levels – whether design flood levels or all flood levels –, and measures that reduce wave height, wave volume or wave impact. This comprises flood control measures such as barriers and dams along the coast and in estuaries, room-for-river measures, morphological changes to storm-exposed shores (shoals, mudflats, salt marshes) and the use of vegetation (salt-marsh vegetation, willow copice and forest) to reduce wave height, among other things.

The Maeslant barrier has been given special attention, as this is crucial for the area of greater Rotterdam, on special request of the Delta Programme ‘Rhine and Meuse River Mouth’. Other measures were investigated extensively in earlier projects (e.g. Room for Rivers), but we reassessed these from a flood risk management point-of-view in behalf of Delta Programme Rivers. Again others we investigated in more detail in co-operation with Building with Nature (salt marshes and willow forest), in behalf of Delta Programme Wadden Sea.

Flood level control in the Rhine- Meuse estuaries

One of the most efficient ways of controlling the flood levels in the Rhine-Meuse estuary, around Rotterdam is by means of barriers. In the Rhine-Meuse estuary there are three storm surge barriers, of which the Maeslant barrier is the best known. These barriers are usually open but can be closed during extreme storm conditions. However, these barriers can also fail, and if they fail, the water levels may become too high.

The Maeslant Storm Surge Barrier protects a large and densely populated area around Rotterdam, which is one of the biggest harbours in the world, and therefore desires an open connection with the sea. The Maeslant Storm Surge Barrier is a unique and complex object. It therefore cannot be ruled out that the barrier fails when it should be closed. At the time of writing, the probability of failure of the Maeslantkering is equal to approximately 1/110 per closing demand.; this means that we expect that it will not properly close in one out of 110 closing demands, on average (it is a probability, after all).

To date, virtually all technical and organizational measures have been studied to reduce the probability of failure of the Maeslantkering. Many of these ideas prove ineffective or even practically impossible. The influence of a reduced failure probability on the design water level in and near Rotterdam is, however, significant: it may be several decimeters to 0.5 m.

Now failure to close does not imply that the barrier is entirely open. It may function partially and thus still influence the design water levels. This resulted in a request to us to investigate the following:
Does the inclusion of the partial functioning of the Maeslant Barrier result in significantly different design water levels?

The influence of “partial functioning” on the design water levels in Rotterdam (where an exceedance frequency of 1/10,000 applies) is presented in Figure 0.3, which shows the difference to the current design water level. The impact of partial functioning depends on the relative contribution of partial functioning, which can be small (5%) or large (95%). A typical situation is that one of the barrier wings functions (the opening will be 50%) and the relative contribution of this scenario is 50%. In this case, the design water level is 0.12 m lower, which is significant. Whether the barrier is strong enough to function in such a case requires further study, though. The Delta Programme Rijnmond-Drechtssteden asked for more elaborate investigations on the impact of “partial functioning”.

Figure 0.3 Impact of partial functioning on the ‘design water level’ in Rotterdam (difference with current design water level, the different lines refer to different failure contributions of partial failure). The x-axes refers to the opening of the New Waterway with 0 as completely closed and 1800 m$^2$ as 50% closed, and the y-axes refers to the decrease in design water level

Room for Rivers for lowering flood levels

In the 1990-ies the Netherlands experienced two major river floods, which triggered a policy change with respect to dealing with river floods. It was decided to no longer instinctively opt for raising the embankments, but to first explore whether it was possible to lower the flood
levels by making more room for the river. The initial objective of making room for rivers was not to reduce flood risks, but merely to provide an alternative to having to raise the embankments even further. And in the debate on why opt for room for rivers, it was argued that the protected land, subsides and thus is getting lower all the time, whereas the floodplains were being silted up by sedimentation and thus getting higher all the time. This causes the difference between flood level and land level to grow bigger.

![Figure 0.4 Relative cost-effectiveness of room-for-river measures from very cost-effective (top) to relatively costly (bottom)](image)

The effect of making room for rivers on flood risk proper has never been quantified yet, but exactly this is our prime interest. We established that:

1. Lowering the flood levels means smaller probability of overtopping. Thus – without climate change –, the flood probability becomes smaller, or alternatively – with climate change –, the probability can be maintained at the present level without having to raise the embankments.
2. Lower water levels in the river may translate into less flooding depths and/or less flooding extent. Thus – without climate change –, the exposure is reduced and hence the consequences of flooding become less, or alternatively – with climate change –, the exposure does not increase and the potential consequences can be reduced (in comparison to doing nothing, but given autonomous socio-economic development). This means smaller consequences.
3 In case the river is given more floodplain surface area (by relocating embankments or making a bypass), the relationship between discharge and flood level is influenced: the Q-h relationship. This means that any extra discharge volume translates into a smaller rise of the flood level. This may affect the probability of breaching of embankments as the water level frequency distribution and the fragility curve (which represents the reliability of the embankment in relation to water level) intersect in a different fashion. It primarily affects the sensitivity to uncertainty.

4 In case a bypass is being constructed, the length of embankments increases, which translates into more locations that could possibly breach, and hence a larger flood probability. This is called the length-effect.

5 Also, bypasses result in splitting up larger dike-ring areas into smaller ones. This is a kind of compartmentalisation, which reduces the surface area affected by flooding and hence the consequences. These may, however, increase, because the flooding depth may increase, or alternatively decrease, because the flooded area is smaller.

Ad 1: The effect of lower flood levels on flooding probability can be estimated by comparing the water level lowering with so-called ‘decimation values’ for each location. Lowering the water levels by 0.3 m through room-for-the-river measures corresponds with a reduction of the flood probability with factor 2 to 3, on average. This is a gross estimate, but the only one available now. In the Delta Programme’s pilot for the Meuse, more accurate figures are being derived and used, but this is only possible when being location-specific.

Ad 2: The effect of lower water levels on exposure characteristics is obvious: the hydraulic head is smaller, so the flow velocities in the breach are smaller, the breach develops slower, a smaller volume enters the area, a smaller area is being flooded, and water depths remain smaller too. This means smaller consequences. How much smaller, depends on the characteristic of the area. For the IJssel Valley, we found that a reduction of economic damage of about 20% can be achieved.

Ad 3: A final effect has not been mentioned yet, as it is quite difficult to understand and even more difficult to quantify: making room for rivers can be done by enlarging the floodplain surface area (‘widening’) or by lowering the floodplains (‘deepening’). Both enlarge the surface area of the cross-section. But their effect on the Q-h relationship is not the same. In case of widening, the rise of the water level (h) per extra volume of discharge (Q) is usually less, because this volume of water is distributed over a larger width. At least, as long as a certain minimum water depth is exceeded; otherwise the hydraulic roughness nullifies the effect. This different effect on the Q-h relationship may affect the failure probability of the embankment, as it translates into another intersection with the fragility curve of the embankment (the curve which describes the relationship between water level (load) and failure probability (as a function of strength)). This subject has not been thoroughly investigated yet.

These effects imply that making room for rivers yields an effective reduction of flood risk. They provide valid arguments to prefer making room for rivers above raising embankments, i.e. in the non-tidal river reaches, where making room for rivers is a very good means to lower flood levels. In downstream river stretches the conveyance capacity of the river is no longer the key factor which determines the flood water level, which limits the effectiveness of making room for water.

Making room for rivers is usually more expensive than raising embankments, but in many instances the extra costs are justified by taking into account the positive side- effects on spatial quality (in the broadest sense).
Making room for rivers is especially attractive for coping with increasing discharges, i.e. in view of climate change, but it can also be applied for raising the protection levels of the existing flood defences by reducing the load. The precise contribution to flood risk reduction is now being investigated in the context of the Delta Programme for the Rivers.

**Salt marshes and floodplain forests for wave attenuation**

The interest in wetlands for flood protection is increasing among policy makers, nature interest groups, private companies and scientists (e.g. the Dutch Delta Programme, Natural Climate Buffers programme, Building with Nature programme, EU project COMCOAST). This is based on the assumed potential of shallow zones to break waves and vegetation to dampen wave height. These wetlands should therefore be developed on the gradual transition zones between land and water in front of flood defences. Along the coast such zones could comprise salt marsh, along the rivers it involves floodplain forests or willow coppice (‘grienden’).

Wave attenuation by such wetlands relies on different processes. Firstly, a wave will usually break when it encounters water depths less than wave-height and loose energy due to friction created by the surface of the shallow zone, whether vegetated or not. Secondly, a vegetation that emerges from the water may dampen the waves running through it through the friction exerted by the stems, trunks, branches or shoots. Thus, natural forelands protect structural flood defences against full incident wave attack.

Wave attenuation by forelands may reduce the hydraulic boundary conditions of waves for embankment design along coasts, large lakes and estuaries. Simulations of the effects of artificial islands, shallow wetland zones and forelands revealed that these may lead to a significant decrease in wave height, and can potentially reduce the critical hydrodynamic load.

We performed a literature review and a model study for the Delta Programme Wadden Sea in order to explore the possible application of salt marshes in a flood defence strategy that also accounts for nature and landscape values. The modeling revealed a significant possible reduction of wave height by salt marshes, but the effect decreases with larger water depths, as expected under extreme conditions. However, the effect of salt marshes on wave reduction is still significant if we reason that the height and stability of the foreshore is influenced by the marsh. Moreover, a healthy salt marsh might enhance sedimentation on the foreshore.

In the context of Building with Nature, SWAN was adapted in order to analyze the influence of emerging vegetation on wave height. This allowed to establish the effect of a willow forest on wave conditions for a new embankment which is to be build in the Noordwaard (Biesbosch, freshwater estuarine environment): it can reduce the height of the incoming waves by 50-80% within 50 m from the edge of the forest. This allows a 0.7 m lower embankment, without violation of maximum overtopping limitations.
Important issues that still need answering comprise:

- Validation of the wave attenuation effects of wetlands under extreme conditions, as all results so-far rely on either scaled down lab tests or field measurements under moderate conditions.
- Assessment whether salt marshes in the Wadden Sea are able to keep pace with an increased sea level rise, given the sediment balance at various locations, and as a function of additional sediment supply after storm surges.
Results (2) on flood protection: embankments and dunes

Robust flood defences: design and planning for multiple functions

A robust multifunctional flood defence zone is a broad, elevated area, subdivided in sub-zones which are appointed for other functions in front, behind, or on top of the embankment. The broad profile forms a deliberately over-dimensioned flood defence, which – thanks to the over-dimensioning – requires no regular adjustments because of changing boundary conditions, or a revision of protection standards. Thus, the concept is robust and future-proof. Consequently, multifunctional use of the flood protection zone can be allowed, for example with:

- Transport (transport infrastructure on, along, or even in the broad flood defence)
- Housing development and businesses (including the integration of flood protection infrastructure with buildings);
- Nature (e.g. development of a vegetated foreland in front of the flood defence that dissipates incoming wave energy, and protects the flood defence against full wave attack; over-dimensioning of the profile provides space for trees on the embankment; a robust embankment forms a refuge place for animals during high water levels);
- Agriculture (e.g. aqua-culture in coastal areas with parallel embankments which allow regular inundation);
- Landscape values (river embankments as well as sea defences are characteristic elements in the Netherlands’ landscape);
- Cultural heritage (conservation or even possible use of historical flood defences, reclamation patterns or historical land use in the coastal and river floodplain areas);
- Recreation (an over-dimensioned profile provides in urban areas space for parks);
- Energy (a robust multifunctional flood defence as suitable location for wind turbines or potential production area for the growing of biomass for energy production).

Figure 0.6 Scheme of a traditional embankment, a traditional reinforcement, a delta dike, and a robust multifunctional flood defence zone (adapted after Silva & Van Velzen, 2008; and STOWA, 2011).
An over-dimensioned design may provide better protection, but it also requires more construction material and space. Consequently the initial costs of a robust multifunctional flood defence are considerably higher than the initial costs of a traditional design. On the other hand, a multifunctional flood defence also saves space, as the space is used more than once, as in Dordrecht and Arnhem where housing and recreation are combined with flood defence.

Due to different or even conflicting interests, the realization of a multi-functional flood defence is a complex and often lengthy process, which requires an enthusiastic and strong advocate. According to stakeholders, it is obvious that the parties who want to achieve their ambitions will act as initiator and driving force. Following their responsibility for the flood defences, the Water Boards usually begin to collect information about hydraulic and physical boundary conditions, set design requirements, and involve stakeholders in the process. Therefore, the Water Board can often assess in an early stage whether a robust multifunctional flood defence is applicable. In a later stage, another party may take over the lead in the detailed planning.

At the moment, over-dimensioned flood defences can only be implemented on a voluntary base, and when there is no conflict with other statutory destinations, because the current legislative framework is based on strict protection standards and design guidelines. Expropriation on behalf of the over-dimensioned profile is not feasible.

Since water boards have no task or financial resources to realize other goals than flood protection, additional funds have to be found. This requires the coordination of various governmental or local programs, or public-private financial constructions. In case of the latter, proper arrangements about ownership, management and responsibility must be made.

Coastal protection, dunes as natural climate buffers and integrated coastal zone management

In sandy coastal systems, coastal dunes represent natural defence zones against flooding of the hinterland due to their self-regenerating capacity after storm erosion. During the past centuries, the Dutch coastline has however suffered from a negative sediment balance and consequently retreated landward. This means that the quality of the Dutch coastal system as a climate buffer has deteriorated.

In 1990 the Dutch government decided to stop this negative trend, adopting a policy of Dynamic Preservation. Sand nourishments are applied to maintain the coastline at its 1990 position. Since 2001, the additional aim is to preserve the sand volume of the coastal foundation, and the annual nourishment volume has been 12 million m$^3$. In the light of climate change predictions, the Delta Committee (2008) has recommended to raise the total yearly nourishment volume to 85 million m$^3$ per year. This allows to extend the climate buffer and prepares for an increasing rate of sea-level rise from 2 to 12 mm/year until 2050. To maintain the dune system’s functions under sea-level rise, the dunes require an input of sand proportional to the rate of sea-level rise.

This defines the core problem that we aim to address:

*can dunes grow fast enough under changing climate conditions to keep pace with sea level, in order to sustainably preserve the flood protection function of the dunes in harmony with other functions of the system?*
The first results of this research show that most dunes of the Netherlands' coast have increased in volume under the current climate conditions and nourishment practice. On wide beaches, dunes tend to grow horizontally, whereas on the narrow beaches of e.g. the east side of Ameland, North-Holland and parts of Zeeland, dunes gain height rather than width. Furthermore, over periods of several years, dune growth rate is higher on wider beaches, because these provide a greater source of sediment and are able to absorb more wave and storm-surge energy.

These findings suggest that, assuming that sea-level rise is fast and beach profiles are static, sea-level rise might lead to decreasing average dune growth rates, because beaches will decrease in width. Applying both underwater and beach nourishments will maintain beach widths and provides extra sediment to maintain growing dunes.

The DUBEVEG model, which we developed, is the first to include the full interaction of wind, vegetation and sea-related processes with sufficient detail to study the effect of various factors on new dune formation and vegetation development. It gives three-dimensional results of dune development for periods up to 25 years. To further improve the model, additional research is needed so that it becomes possible to apply it on specific sites. For that, it needs...
to be tested on specific, well-known, locations along the coast. Then it will be a useful tool to investigate the effect of climate change and adaptation strategies on local dune development.

In the meantime it is difficult for local stakeholders and other non-experts to oversee the effect of different management strategies on larger temporal and spatial scales. Therefore, a more simplified Interactive Design Tool has been developed. It gives stakeholders an impression of the dune morphology in response to their management strategies. This tool has proven useful for interactive stakeholder consultations in a number of Design Workshops (Atelier Kustkwaliteit) which we facilitated for the Delta Programme Coast. At the same time, the stakeholder consultations have proven the appreciation of sandy coastal developments, whereas an analysis of dune management indicates the need to re-introduce more natural processes. This underlines the importance of improving our understanding and modeling of processes of dune formation.

Despite the gained knowledge on dune development, the effect of management strategies and the improved tools, the climate buffer potential of dunes may deteriorate over time if socio-economic developments interfere with this physical-ecological process. It is therefore essential to integrate these socio-economic aspects in the planning of management interventions in the coastal system.

Maintaining the position of the coastline by means of sand nourishments has also opened new opportunities for coastal dune management. In combination with dynamic dune management this has led to the improvement of environmental quality of the coastal dune landscape.
Results (3): measures to reduce exposure

Compartmentalisation for exposure reduction

Measures to reduce the exposure to floods aim to reduce the extent of the flooding and/or its depth. Thus, compartmentalisation, local defences around vulnerable locations and functions, and all measures that may reduce the inflow, classify as exposure reduction.

Compartmentalisation literally means: splitting up into smaller portions, a principle applied in various other risk situations, e.g. shipping or fire prevention. The idea behind compartmentalisation is that flood damage and number of people affected by a flood are for a large part related to the surface area which is being flooded, and that reducing this area may significantly reduce the flood consequences. The 53 so-called dike-ring areas in the Netherlands have very different sizes, ranging from less than 1 km$^2$ to large ones of about 660, 1500, 2200 and even 4900 km$^2$. The primary objective of compartmentalisation is to diminish the surface area which can be flooded due to one single flood event resulting from the failure of an embankment.

In a strict sense, compartmentalisation implies dividing large dike-ring areas into smaller ones by dividing embankments, which are equally high as the primary defence. But several variations are possible. For example in an attempt to influence the flooding process and pattern by merely slowing down the flood water or by guiding it to less flood-prone areas through embankments much lower than the primary defences.

We have not done new research on compartmentalisation in our KfC programme, because this measure has been studied intensively quite recently. But we still treat the subject in our report for several reasons:

- First, recent insights into actual flooding probabilities require that the conclusions on the attractiveness be revised.
- Secondly, compartmentalisation has not been considered in the context of climate change and sea level rise yet; this also affects the view on its attractiveness.
- And finally, the measure may be assessed differently when more emphasis is put on gaining control over the flooding process in view of disaster management.

The Compartmentalisation Study aimed to answer the question whether compartmentalisation would be a sensible measure to reduce the consequences of flooding, and if yes: where and under which conditions? It was concluded, among other things, that:

1. Compartmentalisation is a proven concept to reduce the consequences of disasters in many risk situations.
2. It can effectively reduce the consequences of flooding in terms of damage done and number of people affected.
3. From a narrow economic perspective it is cost-effective in only a few cases, due to the high protection standards maintained in the Netherlands.
4. Subdividing polders is especially relevant when they are ‘dangerously large’ and easy to split-up (elongated in shape).
5. The outcomes of the cost-benefit analyses in the various case studies strongly depend on the flood probability; which is only to be estimated with great uncertainty.
6. The judgement which areas should preferably be subdivided is different when annual benefit (mean annual consequence reduction) is used as criterion, than when ‘absolute’ benefit (consequence reduction in case of an event) is used as criterion.
In the Netherlands’ coastal plains the benefits of compartmentalisation are relatively low because of the many existing ancient and secondary embankments and road and railroad verges, which effectively slow down the flooding process and delimit the flood’s extent.

Figure 0.8  Water depth after a dike breach at the southeastern end (location Bemmel) resulting from a 1: 1,250 years flood, without (a) and with (b) compartmentalisation along the Amsterdam-Rhine canal

Now there may be reasons for a second opinion. We cite: *The annual benefits of compartmentalisation are directly related to the probability of a flood event. The economic benefit doubles if such an event does not have a probability of 1: 2,000 per year, but instead of 1: 1,000 per year, and it doubles again if it is 1: 500 per year, etc. This means that the flood probability is the key variable which determines the benefit/cost ratio, or – in other words – that the benefit/cost ratio is very sensitive to the assumed flood probability. Now recent research on actual flood probabilities suggests that 1) the contribution of other failure mechanisms than overtopping is much larger than 10%, and 2) that the so-called length-effect by definition causes the actual probability of flooding due to a breach somewhere in the dike ring to be much larger than the probability of a breach in one short stretch of embankment.*
The difference may amount a factor 10, i.e. a 10 times larger probability of flooding than we assumed earlier. The calculation of flooding probabilities is being heavily debated, but it certainly would influence the C/B ratios that were established in the Compartmentalisation Study, and hence the conclusions to be drawn. Compartmentalisation may economically be much more attractive than we concluded in 2008.

In the case studies performed in the Compartmentalisation Study it was confirmed that the pattern of existing embankments, road and railroad verges and other linear infrastructure is of paramount importance to the flooding process, and hence also determines whether compartmentalisation has sufficient benefits. In Central Holland with its many ancient and secondary embankments the flood spread is – at present – already effectively delimited, especially when it concerns a coastal flood caused by a storm surge; this lasts for less than 2 days, after which the external flood levels which determine the inflow through a breach already stay under the level of most secondary embankments. However, with higher sea levels and higher flood levels, the probability that this unintended compartmentalization by ‘secondary defences’ is no longer effective, increases. We established that this is the case especially along the coast. Again, compartmentalisation may therefore be much more attractive than we concluded in 2008, especially in the long run.

**Reduced exposure thanks to unbreachable embankments**

Unbreachable embankments are often regarded to classify as flood protection only, but they also have significant influence on the exposure characteristics and thus reduce a flood’s consequences. Past and recent floods worldwide reveal that the breaching of embankments may result in flood disasters with many fatalities. If embankments would not breach, uncontrollable disasters might be prevented. Unbreachable embankments therefore deserve consideration especially where fatality risks are high. They influence some of the flood’s exposure characteristics and thus enhance the possibilities for evacuation and fleeing/sheltering and reduce the number of people affected. They convert sudden and rapid inflow through a breach to gradual and slow overflow over an embankment. This reduces the inflow volume into the protected area, and thus also the resulting flood extent, water depths, flow velocities and water level rise rates. A more gradual and less severe flooding process will give the inhabitants more time to reach safe havens and take effective action.

As the Netherlands is protected by some 3000 kilometers of primary flood defences, it is considered practically impossible to convert all these embankments into unbreachable embankments within a few decades. Therefore, we performed an exploratory analysis of where the construction of these embankments should be considered first, and we did so from the perspective of fatality risk. As there are, as yet, no design rules for unbreachable embankments, we simply assumed much stricter regulations than applied for conventional embankments: 1) the contribution of the strength-related failure mechanisms should be less than 1% of the probability of exceedence of the water level, and 2) unbreachable embankments should be able to withstand overtopping and conditions beyond design. We then may ‘neglect’ the probability of breaching in comparison to that of overtopping in our analyses.

To assess where upgrading the existing embankments would be most effective from a societal risk point of view, we determined the expected number of fatalities from breaching for each dike stretch. This is, of course, firstly determined by the population density – related to the land use type: urban or countryside – right behind the breach, but also by the size of the polder behind the embankment. Figure 0.9 shows the embankment stretches where the
largest numbers of fatalities are expected, i.e. along the tidal rivers, some coastal, and one along the non-tidal Nederrijn.

Figure 0.9  Stretches of embankments which qualify for upgrading to unbreachable embankments with priority from a societal risk point of view

We established that the expected number of fatalities per year for the Netherlands as a whole may be reduced with a factor 2 by strengthening only these 200 kilometers of primary embankment. The effect on societal risk is even about 80%, if measured by a ‘C-value’ in relation to the so-called Fn-curve – a measure of the societal risk curve, which accounts for risk aversion.
Results (4) on vulnerability reduction

Hazard zoning as foundation for vulnerability reduction

The common denominator between measures that reduce vulnerability is that they concern actions that do not affect the floodwater, but rather aim to reduce the adverse effects of a given flood. Although we acknowledge that vulnerability of people is very important, we only investigated measures that reduce flood damage, except for flood insurances, which do of course indirectly influence the vulnerability of the people.

The design of measures that reduce vulnerability, such as a spatial planning regime or building codes, needs information about the geography of hazard. Spatial development planning and building regulations require sound hazard maps, which were not available at national scale. Therefore, the Delta Programme on Urban Development and Re-development asked us to investigate how to best inform spatial planners on flood hazards in the Netherlands: we joined forces. Also with the KIC theme on Urban Development.

After having established what kind of information we needed, we selected the most decisive exposure characteristics by putting central fatality risk (‘Which characteristics determine fatality risk?’), respectively economic damage risk (‘Which characteristics determine flood damage?’). This revealed that different (sets of) exposure characteristics are relevant, significant, or decisive for these two types of risk.

Next, we gathered the relevant data, for which we limited ourselves to already available data from flood simulations that were performed for a variety of projects. We focused on:

1. a nationwide map for the hazard resulting from the breaching of primary defences;
2. a nationwide hazard map of unprotected floodplain area (fluvial, lacustrine and coastal);
3. and an example for a regional hazard map for an area with secondary flood defences, as we find along canals and minor rivers.

Confronted with the difficulty of having to combine too many relevant characteristics, we turned to calculating the possible effect of all relevant factors for yearly expected damage per 1-hectare grid cell by means of the damage functions from the widely accepted HIS-SSM model, and by assuming a standard land use in each grid cell. This approach was inspired by earlier work of De Bruijn for fatalities, which was adopted for the Delta Programme ‘water Safety 21st Century’.

We thus calculated a map of Local Damage Hazard in a similar way as we did earlier for Local Fatality Hazard¹. This approach allows using all relevant factors for which stage-damage functions are available, as well as flood probability, and can thus be regarded as the ultimate means to unify all relevant factors into hazard proper.

¹ According to our concepts and terminology chapter, which builds on and reconciles risk terminology from the EU Floods Directive, FLOODsite and EXCIMAP, hazard is the better term for such a map.
The map of Local Damage Hazard (Figure 0.10) represents the likely yearly damage when one were to develop the area, independent of the current land use in relative grades between 0 (no hazard) and 1 (very hazardous). This makes it especially informative for spatial planning of new developments and re-developments. For the question where to improve or remediate risky situations, an overlay with actual land use or a map of actual risk is better suited.

The main advantage of this approach is that flood hazards in unprotected area, flood hazards in protected area and flood hazards of regional water systems can be treated equally and can be made comparable. This requires further work, especially on data acquisition.
We believe that the maps we produced are the best we can deliver at this moment, and we are sure they will be very supportive for the regional Delta Programmes, especially those of IJsselmeer, Large Rivers, Rijnmond-Drechtsteden and Southwestern Delta, as well as the regional KfC 'hotspot teams'. These – after all – have the task to design the actual spatial plans aimed at reducing flood risks – or preventing their unbridled increase through demographic and economic development in the context of what the Netherlands’ authorities call 'multiple tiered' flood risk management ('Meerlaagsveiligheid').

**Spatial planning (building elsewhere) and building requirements (building otherwise)**

Whether spatial planning can effectively reduce the vulnerability of an area, and thus the consequences of flooding, very much depends on the institutional setting: the different authorities and their responsibilities, the legal framework, regulations, and the authorities’ will to creatively use or adapt the regulatory framework to new policy objectives.

Especially in behalf of KfC hotspot Rotterdam/ Rijnmond, we have reviewed the current policies and legislation that are relevant for flood zoning and building in the Netherlands. This comprises EU legislation and guidelines, and the legislation and policies at national, regional (water boards, provinces) and community levels.

It was found that the current Netherlands’ laws and regulations do not forbid flood zoning, but do not stimulate it either. Instead, current regulations sometimes hinder the enforcement of flood zoning. So far, there has been very little attention for flood risk zoning in protected area, mainly due to the very high protection standards that apply. Only for some unprotected floodplains regulations exist, or the responsibility is put on the shoulders of the property owners.

The ‘multiple-tiered’ flood risk management policy, which has recently been defined by the national authorities in response to the EU Floods Directive, may cause some change. This recognizes a s-called ‘second layer’, which is formed by smart spatial planning (flood zoning) and building codes in order to reduce the impact of flooding, as well as a ‘third layer’ aimed at minimizing casualties. This approach is new, however, and not yet implemented in regulations.

The national policy guideline ‘Room for the River’ discourages new developments in unprotected river floodplains, but only where they have a discharge function. This does, therefore, not apply to the many already built-up areas in floodplains more downstream, e.g. in the larger Rotterdam region, where about 65,000 people live in unprotected area, a number which is expected to increase to 80,000-100,000 by 2050. This shows that not risk reduction is the intention of this guideline, but safeguarding that the discharge capacity of the rivers is not to be reduced.

It appears that the responsibility to regulate developments in unprotected floodplains relies with provincial authorities. The national authorities take responsibility only for the protection of the dike-ring areas, and – as yet – not even for the spatial development within these dike-ring areas in view of flood risk. Some provinces have already taken up this challenge, e.g. South-Holland and Overijssel.

In the past, flood-proof building was quite common, as evidenced by the old city centre of Dordrecht. Nowadays, flood proofing is seldom applied in the Netherlands, but it is gaining more attention, especially for unprotected floodplain. Again, we reviewed the current legislative framework of building codes in the Netherlands.
The national building codes ensure that buildings are built safely, and can be used safely. They contain, for example, rules for fire safety, rainwater discharge, and isolation, and also standards related to heavy rainfall, but not for flooding. As the national building codes just underwent a revision (2012), it is not very likely that they will be revised again soon. This is especially unlikely as the state explicitly aims for less rules, instead of more.

The national building codes have a pre-emptive effect, which means that other authorities cannot enforce standards that are stricter than the building codes’ standards. Consequently, it is difficult to enforce wet and dry-proofing.

Municipalities are entitled to develop local building rules, but via the Housing Act these are limited to aspects like the location of facades or allowance to build on contaminated soil; they are not allowed to define stricter standards on the same topics as the national building codes. On the other hand, jurisprudence shows at least one case in which a development plan was expunged because it had not adequately taken into account flood risk in an unprotected area: the municipality should have demanded a minimum elevation of the ground floor level to prevent frequent flooding of the houses. This relates to the general obligation that municipalities should strive for 'good spatial planning'.

Water boards can enforce stricter standards for the water resistance of facades only when these are an integral part of a flood defence.

Summarizing, there are no rules that forbid people to dry- or wet-proof their homes, but at the same time it seems almost impossible for municipalities to enforce such measures. Municipalities that desire buildings to be flood-proofed will have to reach an agreement with the owner or developer. They could provide a financial incentive in the form of a subsidy. Another option is to include it during the discussions on the financial planning of new developments.

Effectiveness of private flood mitigation measures

Private households can undertake various flood mitigation measures in order to prevent or reduce flood damage: build without a cellar, adapt the building structure, deploy mobile flood barriers such as sandbags or safeguard possible sources of contamination, such as an oil heating. Such measures are especially taken in unprotected floodplain area, for example along the large German rivers Elbe Danube and Rhine. We collected and analyzed data from these areas, in order to learn from practical experience on this matter.

The damage-reducing effect of private flood mitigation measures along the Rhine was examined by comparing the behaviour of households and the damage suffered in two successive flood events (1993 and 1995). The damage reported for 1995 was substantially lower than in 1993. By a household survey we examined whether this was due to an improved preparedness of the population and whether the difference could be attributed to improved mitigation measures.

We found that the lower damage to contents and structures in 1995 indeed resulted from an increased level of precaution and was related to a doubling of the number of individual precautionary measures taken.
From a micro-economic point of view, a household's decision to self-protect against flood damage is an optimisation calculation: the benefits of taking measures (damage reduction or avoidance) should outweigh the costs (investment and maintenance costs). We investigated some measures which we found had effectively reduced damage during past flood events along the major German river courses, including flood-adapted building use, the safeguarding of hazardous substances and the deployment of flood barriers. Cost benefit analyses for these measures showed that the latter are cost-efficient also in areas with lower flood probabilities (1:50 per year), whereas the others are cost-effective only when flooding is frequent.

We also established that flood experience is a strong trigger for an increased rate of implementation: the level of implementation strongly increases in the aftermath of severe flood events, such as the one in 1993. This is an important finding as climate change may result in the flooding of areas that have little prior flood experience. The voluntary adoption of private precautionary measures by households then seems unlikely, because of a lack of experience. Additional policies, such as stricter building codes or financial incentives via insurance policies, may be necessary in such cases.
Burden sharing: insurance arrangements as incentive to take individual measures

Flood insurance arrangements vary across markets in respect of consumer structure and risk transfer mechanism. All models have the basic aim of spreading the burden of flood losses, or potential flood losses, across as wide a population as possible. In no sense is this a measure designed for vulnerability reduction, except insofar as vulnerability may be reduced by more rapid recovery, which undoubtedly can be assisted by insurance arrangements.

At its most basic level, insurance arrangements involve brokers who sell policies to individuals, insurance companies which take the risk, and reinsurance companies to which some of that risk is transferred. Any good model incorporates elements of each of these three components, although reinsurance is only necessary, generally, where risks are substantial and the normal insurance companies would fail if all their policies had to be paid out on a single occasion.

The intended consequence of insurance arrangements is to compensate those who suffer losses, from the pool of premiums paid to the insurance company. This is wholly to be encouraged, except where there are unintended consequences in terms of burden on the public purse, which appears to be the situation in the UK.

Also not to be encouraged are situations where insurance leads those at risk not to take sensible risk reduction measures. They may do this either because they feel the insurance company bears the risk, rather than they themselves doing so, or because the presence of insurance leads to a denial of risk. Thus the side-effect of insurance arrangements is a reduction of the likelihood that risk reduction measures are being taken; this is common and unfortunate. It can be mitigated if the insurance policies have deductibles which discourage trivial claims and encourage policyholders to understand the risks that they face and take risk reduction measures appropriate to the circumstances.

The wide range of insurance arrangements (‘models’) applied worldwide has developed incrementally, reflecting local circumstances. It is not wise to suggest that one model is necessarily better than another, but a comparison is useful when considering the development of an insurance model when none currently exists; as is the case for the Netherlands.

Against this background, we undertook a review of international models with regard to predefined success factors. These success factors relate to coverage, insurability, incentives for mitigation, and equity within insurance markets. There is a wide variety of different insurance models existent across developed and developing economies around the world (Table 0.1).

Our research indicates that no single existent insurance market model performs well on all measures of success. While a wholly private market often leaves property owners highly exposed, most state-backed schemes provide limited levels of protection to a larger customer base. It is possible that a private public partnership which combines market insurance with some government intervention towards mitigation and equity considerations may be more generally acceptable.

What is clear already, however, is that insurance arrangements for the Netherlands will be quite problematic insofar as they focus only on protected flood-prone areas, i.e. the dike-ring areas. These areas contain properties at low risk but the consequences of flooding would be considerable as it involves half the country. Insuring these without a larger body of property with less risk and fewer consequences (the elevated other half of the country?) could render the insurance company involved at considerable risk of failure if many policies were the...
subject of claims at once. This will have to be considered further in the second half of this research project.

In the second half of the project, the focus of our research will shift to making some suggestions about the situation in the Netherlands, from the base of a comprehensive understanding of the insurance models currently in place in the UK.

Table 0.1 A summary of the international review (Lamond & Penning-Rosell, 2011)

<table>
<thead>
<tr>
<th>Country</th>
<th>Available</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>Private/optional</td>
<td>Low to Very low</td>
</tr>
<tr>
<td>Taiwan</td>
<td>Part of typhoon add-on private provision</td>
<td>Less than 1% due to high rates</td>
</tr>
<tr>
<td>Belgium [3]</td>
<td>Optional private</td>
<td>Low &lt;10%</td>
</tr>
<tr>
<td>Brazil</td>
<td>Bundled into general private buildings cover</td>
<td>Low linked to low property insurance</td>
</tr>
<tr>
<td>China</td>
<td>Included in standard fire policy private and state owned</td>
<td>Low and mainly in urban areas</td>
</tr>
<tr>
<td>Canada</td>
<td>Optional private cover for some risks</td>
<td>Low</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>Included in most fire cover</td>
<td>Low linked to low property insurance penetration</td>
</tr>
<tr>
<td>Ecuador</td>
<td>Within standard fire policy private provision</td>
<td>Low related to property insurance low coverage</td>
</tr>
<tr>
<td>Italy</td>
<td>Option as an endorsement</td>
<td>&lt;5%</td>
</tr>
<tr>
<td>Philippines</td>
<td>Part of typhoon cover add-on to fire policy private provision</td>
<td>10-20%</td>
</tr>
<tr>
<td>Germany</td>
<td>Optional private</td>
<td>5-10% in most regions</td>
</tr>
<tr>
<td>Indonesia</td>
<td>Supplement to fire policy privately or state owned</td>
<td>20%</td>
</tr>
<tr>
<td>Poland</td>
<td>Add-on to Fire cover . Private companies</td>
<td>25%</td>
</tr>
<tr>
<td>Japan</td>
<td>Available within comprehensive fire cover which is an optional extension. Private provision</td>
<td>72% and 40%</td>
</tr>
<tr>
<td>Portugal</td>
<td>Included in natural perils as part of fire cover</td>
<td>High because of bundling with earthquakes</td>
</tr>
<tr>
<td>South Africa</td>
<td>Add-on to fire cover Private provision but not available in highest risk areas</td>
<td>30-50% households but 75%+ by value</td>
</tr>
<tr>
<td>France</td>
<td>Bundled in natural hazards, Public Private Partnership</td>
<td>Close to 100%</td>
</tr>
<tr>
<td>Israel</td>
<td>Optional add-on to fire policy . Private cover</td>
<td>95%</td>
</tr>
<tr>
<td>Spain</td>
<td>Bundled into all buildings cover</td>
<td>Very high</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Standard part of buildings cover state provided</td>
<td>100%</td>
</tr>
<tr>
<td>UK</td>
<td>Bundled in general household</td>
<td>95%</td>
</tr>
<tr>
<td>Denmark</td>
<td>Compulsory sea flooding cover Bundled into fire policies</td>
<td></td>
</tr>
<tr>
<td>New Zealand</td>
<td>Part of earthquake cover compulsory</td>
<td></td>
</tr>
<tr>
<td>Norway</td>
<td>Compulsory as part of property policies</td>
<td></td>
</tr>
<tr>
<td>Turkey</td>
<td>Some might be covered under earthquake</td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>Optional state provided</td>
<td></td>
</tr>
</tbody>
</table>
Results (5): towards comprehensive flood risk management strategies

The design of a flood risk management strategy for the future involves combining measures and instruments and a plan for their implementation over time. A policy analysis can support such a decision making process, where we consider a policy analysis to be an analysis in behalf of planning and policymaking.

Such a policy analysis requires following a stepwise procedure. Key elements of this procedure are (1) the definition of strategic alternatives, as coherent sets of physical measures and policy instruments, and (2) the assessment of these alternatives.

In this context, we studied four key issues:

1. Nowadays, planning involves stakeholder participation, which requires sharing knowledge and the development of tools which support joint planning. We investigated various methods and tools for such an enterprise. This is treated below under SimDelta.
2. A second issue we studied, relates to uncertainty. Long-term planning inherently involves dealing with uncertainty about future climate and socio-economic
developments. But we also have to deal with uncertainty related to natural variability and lack of knowledge. Therefore, we put some effort in defining and operationalising the ‘robustness’ of flood risk systems. We consider this a relevant additional criterion to judge policy alternative policies. Below we give some results of a case study on the IJssel River valley.

3 Another important assessment criterion, which is very important for the acceptance of physical protection measures to be taken by the general public, is spatial or design quality. This criterion cannot be quantified and is very difficult to operationalise. We did some development on an assessment framework and tried it on the case of the Delta Programme Rhine-Meuse mouth (surroundings of Rotterdam and Dordrecht).

4 Finally, we co-operated with KfC theme 6 on Governance, in an investigation of how four European coastal cities govern a transition towards enhanced flood resilience. This main aim of this research activity was to learn from foreign practice. It aims at hotspot Rijnmond/ Rotterdam.

‘SimDelta’: the use of interactive media to define and assess strategic flood risk reduction strategies

The idea behind SimDelta is twofold. First: interactive maps can explain a complex system of scenarios, problems and solutions faster and more intuitively than reports and presentations. Second, many stakeholders can be served at lower cost more frequently by using the internet than by attendance in workshops. Whenever they want and wherever they are, they can explore the Rhine-Meuse problems and solutions, leave comments, drop additional ideas or answer questions by other users.

Interactive maps provide both the suppliers (engineers, architects and other designers) and the consumers (the stakeholders) with sufficient understanding of the system to come up with feasible designs and to make well-informed choices. A project can then be chosen for two reasons. It can do well in the systems analysis (the ‘semi-objective’ part), presented with interactive maps and supported by downloadable background documents. But a project can also inspire by attractive visualizations, a good ‘story’ and good marketing (the more subjective elusive part).

Building an intuitive and attractive interactive model in which stakeholders can pick their favorite projects designed by engineers and architects and see their estimated costs and effects, for a case as large as the entire Dutch water system, stretching far into the 21st century, under various climate and economic scenarios, is an extensive task. The ultimate goal, stakeholder preference analysis to support democratic decision making on water infrastructure improvements to be implemented in the Netherlands after the year 2020, must be built on a number of ‘blocks’, which culminates in something which could be called a serious game:

an ‘experimental and/or experiential rule based, interactive environment, where players learn by taking actions and by experiencing their effects through feedback mechanisms deliberately built into and around the game’.
Connecting stakeholders through serious gaming is often done by putting a group of people in one room, and have them play and discuss at the same time, happening a couple of times a year. However, on-line communities with physically separated users can serve more users more frequently and probably against lower costs per stakeholder. This alternative is called crowdsourcing, and it is the ultimate goal of our developments, as it helps to perpetually self-correct and self-improve. Thus it not only suits the original attempt of ‘systems analysis’, namely to ‘depoliticize complex and highly political decisions’, but it also revitalizes this through the contribution of modern internet community technology.

If enough stakeholders join the pool, their aggregated contributions will result in either: (1) too much criticism or too many alternative ideas. Analyzing this will give suggestions for further research, development and design priorities; (2) too dispersed choices. This will lead to maintaining the status quo until new elements are introduced in the system, such as new ideas or new scenarios; (3) enough convergence to support the government to decide on a thorough investigation of particular short-term projects. These three possible outcomes more or less correspond to the outcomes envisioned in the MIRT- procedure which is prescribed by government for any investment plan of the Delta Programme.
Robustness of flood risk management strategies: the IJssel case

Robustness of a flood risk system means that the failure of one system component (e.g. an embankment, sluice or storm surge barrier) does not lead to a flood disaster or otherwise unmanageable flood consequences. Robust systems are particularly relevant when disturbances are uncertain and the consequences of failure are high, which is exactly the case in most flood risk systems which rely on embankments only. Both the ability to withstand disturbances (resistance) and the ability to respond and recover (resilience) add to system robustness.

The analysis of a flood risk system’s robustness requires exploration and quantification of the consequences of a variety of possible discharge waves, and the assumption that system components may fail. The analysis thus covers both the natural variability of flood waves that enter the system – with their probabilities and uncertainty about these probabilities –, and the uncertainty about the strength of flood defences.

The starting point for a quantification of robustness is drafting the response curve, which relates consequences to probabilities of occurrence, and a number of criteria, which are largely related to this curve:

- Resistance threshold, or the smallest river discharge that will cause substantial economic damage;
- Response severity, or the flood damage in absolute terms;
- Response proportionality, or the sensitivity of the response to changes in discharge;
- Recovery threshold, or the discharge that will cause unmanageable flood disasters.

For the IJssel Valley, our case study area, we investigated which alternative set of flood risk management measures performs best in terms of robustness. To this end we applied a two-dimensional hydrodynamic simulation model on a 100x100 m grid basis, and a damage model that estimates flood damage in euros based on maximum inundation water levels and depth-damage functions per land use type. And as input we used a range of river discharge waves with different peaks and duration.

![Response curves of the alternative system configurations, and the design discharges indicated with vertical dashed lines (RR = room for rivers; CE = conventional embankments; UE1 = unbreachable embankments everywhere; UE2 = as UE1 but higher near cities).](image-url)
We found that the following characteristics enhance the system robustness of the IJssel Valley:

- Limited uncertainty about where, when and how embankments will fail. If a flood is better predictable, it is better manageable which increases the system's robustness. This can be achieved by building unbreachable embankments, preferably differentiated in height.
- Good balance between a high resistance threshold and yet a relatively low flood damage. This can be achieved by ensuring a limited difference between design water levels and the elevation of the protected area. The case study showed that it is possible (e.g., by giving room to the river) to increase the design discharge without increasing the potential damage, whereas just raising dikes does increase the potential damage.

Based on this trial, robustness is considered a useful additional criterion for decision making about flood risk reduction strategies that take into account uncertainty. Enhanced robustness may provide an extra argument – besides flood risk reduction and costs – to invest in measures that make a system less sensitive to uncertainties.

**A method to assess spatial (design) quality**

The focus of the research is to develop a methodology that allows for an integrated approach to flood risk management and urban design. This 'research by design’ methodology should support debate and decision-making, by enabling a quantification of effects of risk management measures on spatial quality in complex urban contexts, such as the Rijnmond-Drechtsteden area. This requires that spatial quality can be assessed.

The concept of spatial quality has therefore been the focus of our research efforts so-far. This was simply regarded as a combination of three qualitative parameters, namely 1) utility or functionality, 2) attractiveness or beauty and 3) robustness or solidity. From this starting point we developed a method in co-operation, and we tried it on measures in KfC hotspot Rotterdam-Drechtsteden.

We developed our method on the basis of the Ruimtelijke-KwaliteitsToets (RKT), which was used in the decision making process of Room-for-the-Rivers. We evaluated this method and found it to be useful and applicable, but needing adaptation for the specific planning context of our urbanised case study area. The methodology has been adapted in such a way as to be more suitable for assessing the impact of large scale interventions on local scale spatial quality in an urban delta region. It allows application in earlier stages and does not require concrete design proposals to be available.

For its development, we were assisted by an expert panel that consisted of two urban designers, a landscape architect, an architect and an ecologist. They participated in two workgroup sessions where the criteria were tried, improved on and added to. Thus, we ended with a longlist of criteria, which apply more or less in different situations.

After positive trials with the Delta Programme Rijnmond-Drechtsteden, we consider our method to be suited for further and wider use in the Delta Programme. It is, however, recommended to evaluate a larger number of cross-sections than we did in our trials in order to improve the reliability of the assessment. This requires a map that shows the occurrence of specific types of locations throughout the region, which can help clarify what the locations and cross-sections actually represent.
Location: Stadshavens Rotterdam Mercuriusweg

Figure 0.15 Visualisation of alternative interventions for a specific location (in this case Stadshavens Rotterdam, Mercuriusweg): input for the expert panel
In the coming period we plan to further use the developed assessment tool and to incorporate it into a more encompassing ‘research by design’ methodology.

**International comparison of governance approaches to building flood resilience in four coastal city regions**

Restoring and increasing ‘resilience’ in relation to flood risk has become an increasingly popular concept, which is adopted by coastal city regions around the world in an endeavour to prepare for unavoidable climatic changes. In this context ‘flood resilience’ is understood as the capability of a system to absorb the impacts of a flood disaster, retain functions as much as possible, return to a normal or near-normal functioning shortly after the event, and ensuring that failures occur in a controlled way.

Building resilience requires concerted societal efforts. We refer to these efforts as governance: the deliberate interactions between purposeful actors to steer towards a negotiated agreement about a solution to a problem. Actors comprise governments, private actors, businesses, or any other stakeholder.

We investigated the governance approaches aimed at increasing flood resilience as formulated and applied in four different coastal city regions: Rotterdam, London, Venice and New Orleans. This investigation is a joint effort with KfC-theme 6 on governance.

For a start, we distinguish four meta-types of governance approaches:

- **Governing by authority**: the traditional way of top-down enforcement rules, regulations and standards by governments, for example through the use of sanctions.
- **Governing by provision**: refers to the access to and mobilization of resources to allow public and private initiatives across scales to increase flood resilience, primarily through network ties and financial resources.
- **Governing through enabling**: how city governments can coordinate, facilitate and stimulate local engagement between public and private initiatives across scales to increase flood resilience. Tools generally include, persuasion and coercion.
- **Self-governing**: capacity of cities to self-mobilize the increase of flood resilience, relying on re-organization, institutional innovation and strategic investments.

Although the first three are central to the discussions on flood risk management, building flood resilience by city regions relates primarily to self-governing.

The four city regions were compared by 8 key variables, which are considered to yield a good insight in the key differences in governance approach. An overview of the results of this comparison is presented in Table 0.2.
### Table 0.2 Summary of flood resilience governance in four coastal cities

<table>
<thead>
<tr>
<th>Decentralization and self-organization</th>
<th>London</th>
<th>New Orleans</th>
<th>Rotterdam</th>
<th>Venice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong role for national government; Decentralized municipal authority; stimulate self-organization</td>
<td>Strong central role for national government; increasing self-organizing capacity, but dependency is high</td>
<td>Influenced by national government, but decentralized authority; more ambitious than national government; room for local initiatives</td>
<td>Centralized decision-making; limited local power on flood management decisions</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Knowledge systems for flood management</th>
<th>London</th>
<th>New Orleans</th>
<th>Rotterdam</th>
<th>Venice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Several knowledge platforms and mechanisms; update knowledge and monitor change; knowledge and information available on websites</td>
<td>Increasing, but still building. Expertise from other countries is used; New Orleans is scientific case to understand resilience/adaptation</td>
<td>Few knowledge systems; Capitalize on knowledge production and innovation; close cooperation with research community; scientific reports</td>
<td>Climate change knowledge is still low but developing; flood risk knowledge is high; Available knowledge on flood is accessible, that on climate change is more difficult to access.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diversity and redundancy</th>
<th>London</th>
<th>New Orleans</th>
<th>Rotterdam</th>
<th>Venice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety of coping strategies, strong focus on infrastructure and soft approaches; follow flood risk management approach</td>
<td>Combination of grey and green infrastructures; efforts to increase diversity of coping strategies</td>
<td>Limited set of coping strategies; reliance on grey and green infrastructures; shift towards more adaptive water management</td>
<td>Dependency on grey and green infrastructural measures. Low diversity and redundancy</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Innovation and room for experimentation</th>
<th>London</th>
<th>New Orleans</th>
<th>Rotterdam</th>
<th>Venice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Much room for experimentation, stimulated by political leadership; resources available</td>
<td>Generally low, use knowledge and expertise from other cities/countries. Recovery stage</td>
<td>Strong focus on innovation; capitalize on knowledge production</td>
<td>Little room for experimentation; mostly use high level technical knowledge is produced locally</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Responsiveness and flexibility to deal with flood events</th>
<th>London</th>
<th>New Orleans</th>
<th>Rotterdam</th>
<th>Venice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible decision approach; emphasis on preparedness, response and recovery</td>
<td>Improvements to responsiveness are being made, but focus is on protection / structures.</td>
<td>Tipping point and flexible adaptation options approach advocated but not implemented; low flexibility to deal with events</td>
<td>Flexibility to small floods is high, but large flooding events is low as there is only one rigid solution (mobile barriers)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Public participation and inclusion</th>
<th>London</th>
<th>New Orleans</th>
<th>Rotterdam</th>
<th>Venice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public inclusion is average, but efforts are made to increase; public awareness of flood risk is low.</td>
<td>Limited public participation; top-down decision making</td>
<td>Public inclusion and participation is average; public awareness of flood risk is low</td>
<td>Public consultation rather than public involvement in decision making; through NGO’s</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Networks, institutions and organizations</th>
<th>London</th>
<th>New Orleans</th>
<th>Rotterdam</th>
<th>Venice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fragmented and complex fabric of flood related networks and institutions; high redundancy in the system</td>
<td>Increasing number of institutions and organizations involved.</td>
<td>Flood risk part of Rotterdam Climate Proof initiative; Important role in international water city networks</td>
<td>Several institutions in place, but hardly the capacity to prepare for major flood events (lack of coordination)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Capturing learning and utilizing experience</th>
<th>London</th>
<th>New Orleans</th>
<th>Rotterdam</th>
<th>Venice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Few flood events, mechanisms to capture learning from past events</td>
<td>Katrina as example of catastrophe; several projects designed to capture learning events; experience is not used to change to alternative states</td>
<td>History on flood protection/water management; learning mechanisms not present</td>
<td>Frequent flood events increase public awareness</td>
<td></td>
</tr>
</tbody>
</table>
Some key findings are:

- The cities show very different modes of governing flood resilience. London combines all four modes of governance; flood risk is primarily conducted through provisions and authority but leaves sufficient room for self-organizing initiatives. The role of government in Rotterdam is much stronger – primarily through enabling and provision. Venice and New Orleans govern by provision and authority. Especially in Venice, there is sufficient room for self-organizing. Shocks in Venice and New Orleans have not changed their modes of governance.

- Although Rotterdam and London have both taken considerable steps in changing their flood risk management approach, transitions have not been identified. Even after the system collapse in New Orleans, which created an window of opportunity for deliberative transformational change, the system is being rebuild with only minor efforts to increase resilience. Formalized (national) flood protection levels are much lower in New Orleans and Venice than in London and Rotterdam, who both prepare for more extreme sea level rise and climate change scenarios than the other two. The reliance on traditional flood risk management approaches in New Orleans and Venice is only slowly changing.

- Although all cities express their willingness to increase resilience, only London was found to have invested heavily in resilience (‘from flood protection to recovery’), in particular by soft en low-regret measures. The city of Rotterdam invests primarily in knowledge production and innovation by co-operating with the scientific community. Here, soft approaches are limited and public participation is generally low compared to London. Venice and New Orleans show only few signs of actual change. Resilience approaches are in early stages of development here.

- Bottom-up initiatives, decentralization, and self-organizing are central concepts in resilience theory, but all national governments are shown to play a very dominant role in urban flood resilience, primarily through rules and regulations, guidance and reporting obligations. Within this institutionalized framework, cities such as London and Rotterdam have followed a more ambitious approach than national governments have foreseen and have been given the political space to invest and innovate. This requires leadership, creativity and persistence to continue building flood resilience. These are currently weakly developed in New Orleans and Venice.

**Societal impact**

Our consortium is strongly engaged in the societal debate on flood risk management in the Netherlands, both at national level and regional levels.

Many of our researchers also participate in dedicated investigations commissioned by the national authorities, the Delta Programme, individual water boards and the STOWA (who co-ordinates research on behalf of the water boards), and provincial authorities. This is due to their acquaintance with the field and the institutions working in this field, and partly also to their position outside the consortium, e.g. in their daily function (at Deltares, HKV or TU Delft), or as member of relevant advisory committees (e.g. ENW, Q-team room-for-the-river).
Role in Delta Programme

We consequently have very close working relations with the Delta Programme. Our participation – with some invited lectures – in subsequent ‘knowledge conferences’ of the Delta Programme (both 2011 and 2012) already reflects this good working relationship.

We are especially involved in the generic Delta Programmes ‘Water Safety’ and Urban Development and Re-development, and do case study research in co-operation or in behalf of the regional programmes Rhine-Meuse mouths, Rivers, Southwestern Delta and Wadden Sea. We thus have close working relations with the KfC hotspots too, as these geographically largely correspond with the regional Delta Programmes, as is the case with Wadden Sea, Rijnmond-Drechsteden (Rotterdam) and Rivers.

In many instances it is difficult to distinguish which part of the work is KfC and which is Delta Programme, so close is the co-operation and the sharing of knowledge, experience and results. This is also reflected in this report. In many cases the results are already being applied, before we even had the opportunity to report, let alone publish in scholarly papers. This is, for example, the case with the maps we produced to sustain spatial planning to reduce vulnerability. These are used by the various regional Delta Programmes. And the same goes for methods to assess spatial quality or robustness; these too are already being applied, respectively in Rijnmond-Drechsteden and Rivers.

In practice, it means that we have quite some influence on the public debate, and the concrete design of alternative flood risk management strategies, as they are being developed for closer investigation in the regional Delta Programmes.
Relation to practice in regional water management

We also have a very close working relationship with STOWA’s research programme Delta Proof, which aims to support the regional water managers and flood risk managers. We developed a joint communication strategy and sustain STOWA’s initiative on Delta Facts.

Jointly with STOWA we organized a one day workshop on ‘Embankments of the Future’ in November 2011, which was attended by about 80 practitioners from all over the country. The programme was very much appreciated, and has influenced the opinions of many an engineer. This is bound to play a role in the design of flood defences for the future.

Interdisciplinarity and co-operation within KfC

Internally, our consortium is already interdisciplinary in character, but with a bias towards the natural (environmental) sciences and engineering. The majority of our researchers could be qualified as transdisciplinary, as they come from disciplines such as civil engineering, agricultural engineering, geography and ecology.

Only the social sciences are underrepresented in our consortium. Therefore, we co-operated with social scientists from Theme 6 (Governance), especially in our search for comprehensive flood risk management strategies and the related implementation problems. And we involve economists from our respective ‘home institutes’, e.g. the Free University of Amsterdam (IVM-VUA) and Deltares.

We also co-operate with Themes 2 (drought), 4 (urban) and 8 (methodological). With theme 2 we aim to develop the risk approach for floods and droughts in a similar way, and to also operationalise the criterion of robustness for both problems. Theme 4 we assisted in their writing of a basic report on the future challenges that urban areas face in the context of climate change in behalf of the Delta Programme. And theme 8 is involved in some of our case studies, which they support with the Touch Table and other appropriate methods and tools for participatory planning and knowledge sharing.

Reflection on the interim reporting and outlook

Part of our work has already produced applicable and interesting results, as evidenced by our full interim report. The chapters and sections, which treat these results, will, therefore, not change very much in set-up, but mainly be improved or extended with new findings. This concerns the research tasks, which made a quick start, such as those on dune formation or robustness.

A very small number of research tasks have already finished (e.g. on learning from governance arrangements abroad). The sections in our report on these tasks will not change very much any more, or are at least unlikely to produce large amounts of new results. Some updating and polishing may, however, be expected.

A larger number of research tasks, however, have actually just begun. The results of some of these have therefore not been incorporated in this interim report yet, but can be expected to result in additional sections in the final report. This is the case, for example, for improving
Towards climate-change proof flood risk management

13 August 2012, executive summary of interim report

embankments and their assessment from a flood risk reduction point of view (work package 3) and from a spatial quality point of view (work package 6), and for reducing the vulnerability of built-up areas in unprotected floodplain area (work package 4).

Finally, in the course of our work, some new ideas have come up. Where these constitute truly innovative ideas, we shall attempt to tweak our research work so that we can give them the attention they deserve, and we will of course share our findings in our final report. Otherwise we would not act according to our and KfC’s mission to support our policy makers and flood risk management practitioners with the best and most novel knowledge we are able produce.

Consortium publications: state of affairs mid 2012

Articles in scientific journals


Ruijgh-Van der Ploeg, T., Ebskamp, M., Mens, M., Kwakkel, J., (in prep.). Exploratory modeling in support of robust policies for flood risk management

Articles in professional journals and magazines

Mens M., 2011. Tekst over promotieonderzoek voor Nederlandse Vereniging voor Risicobehersing en Bedrijfssicherheit

Books and book chapters


Contributions to conference proceedings


Rijken T., Kok et al. (submitted). INVESTIGATING MOVEABLE FLOOD BARRIERS IN THE RHINE-MEUSE ESTUARY – METHODOLOGICAL LESSONS FROM A MULTIDISCIPLINARY EXPLORATION, 5th International Conference on Flood Management (ICFMS) flood risk conference Tokyo.

Reports


Loon-Steenma van , J.J., (2011). Kweldervorming langs de Terschellinger Waddendijk; een verkenning naar kansen, beperkingen en vragen rond kweldervorming langs de Waddendijk e.o. van Terschelling. Alterra-rapport 2172; ISSN 1566-7197


Tsimopoulou, V. (in prep.). The Great Eastern Japan earthquake and tsunami: Field observations on the coast of Tohoku six months later.

Poster presentations


Keijers, J., M. Riksen, 28 September 2011, Modelling coastal dune development in The Netherlands, Sense research school course, Delft


Tsimopoulou, V., 2011. "A decision-support model for time-dependent investments in flood-defences" Poster presentation at the 5th International Conference of Flood Management (Tokyo, Japan), September 2011.

Lectures and oral presentations


Klijn F., Kennisontwikkeling voor een onzekere toekomst. Wat doen de onderzoeksinstellingen (zoals Deltares) en de onderzoeksprogramma’s (zoals Kennis voor Klimaat) zoal? Inleiding op Kennisconferentie Delta programma. 16 juni 2011, Amsterdam.

Klijn F., Dijken voor de toekomst: waar hebben we het over, en wat verwachten we ervan? Studiedag dijken voor de toekomst, KvK en STOWA. 24 november 2011.
Klijn, F. *Veiligheidsfilosofie? Framing is blaming!* Inleiding op Kennisconferentie Deltaprogramma. 13 augustus 2012.


Loon-Steensma van J.L, Kennis voor Klimaat Projectendag 2011 (7 april 2011 in Amersfoort): inleiding voor sessie ‘Bouwstenen voor een klimaatbestendige Wadden’

Loon-Steensma van J.L, Tentatieve rapport Kweldervorming langs de Terschellinger Waddendijk; belangstellenden Terschelling (bewoners en gemeenteraadsleden) (woensdag 15 juni 2011, te Midsland)

Loon-Steensma van J.L, Presentatie rapport Kweldervorming langs de Terschellinger Waddendijk; bij DLG (voor experts en betrokkenen) (28 april 2011 Leeuwarden)

Loon-Steensma van J.L, Tentatieve rapport Kweldervorming langs de Terschellinger Waddendijk; Bijeenkomst begeleidingsgroep Gebiedsontwikkeling Terschelling (27 april 2011 Terschelling)


Loon-Steensma van J.L, op 9 december 2010: ‘Streefkerk: de brede dijk als kans’ op Symposium de Brede Dijk; Veilig leven in de toekomst (KvK + Movares), Utrecht

Mens, M.J.P., Presentatie gegeven op Hydropredict congres in Praag (zie proceedings)


Mulder, J.P.M. 4 oktober 2011. Sedimentperspectief op de kust, samen werken met sediment, Atelier Kustkwaliteit ‘Lange termijnperspectief van het kusttype ‘smal duin’; Hoek van Holland


Penning-Rowsell E.: presentation to the Department of Environment, Food and Rural Affairs (Defra) on the flood insurance regime in the UK. 2010

Rijcken T., Lezing: Water Infrastructure Development in the Netherlands – Center for Watershed Sciences, Univ. California, Davis, USA, 9 maart 2011

Rijcken T., Lezing: Interactive models/Serious Gaming in water infrastructure development in the Netherlands - RESIN group UC, Berkeley, USA, 20 juli 2011


Rijcken, T.: A Dutch perspective on integrated waterfront development - New York University

Rijcken, T.: Afsluitbaar Open Rijnmond - KvK en VROM

Rijcken, T.: AOR-SG, Deltaprogramma Rijnmond Drechtsteden

Rijcken, T.: Water Infrastructure Challenges. Dutch Pavilion World Expo Shanghai

Rijcken, T.: Afsluitbaar Open Rijnmond - Waterbouwsymposium mei 2010

Rijcken, T.: Deltadijk - Dag van de Dijk
Rijcken, T.: Living on a Water Machine. Columbia University, Committee on Global Thought
Rijcken, T.: Middagsessie DeltaDeelProgramma Rijnmond-Drechtsteden
Rijcken, T.: Rhine Delta Climate Proof - iTunes U 2010
Tsimopoulou, V., September 2011. "Rationalization of safety factors for breakwater design in hurricane-prone areas". Coastal Structures Conference (Yokohama, Japan).
Vellinga P. and Marinova N., 23/11/2010, Practical Sea level rise scenarios for Venice, UNESCO workshop on global sea level rise, Venice, Italy

Public media

Vrijdag 19 augustus 2011 om 9.40 uur op KRO radio 1, Goedemorgen Nederland; interview Zandmotor
Zondag 16 januari 2011, 09-10 uur, Vroege Vogels VARA Radio 1; interview Zandmotor