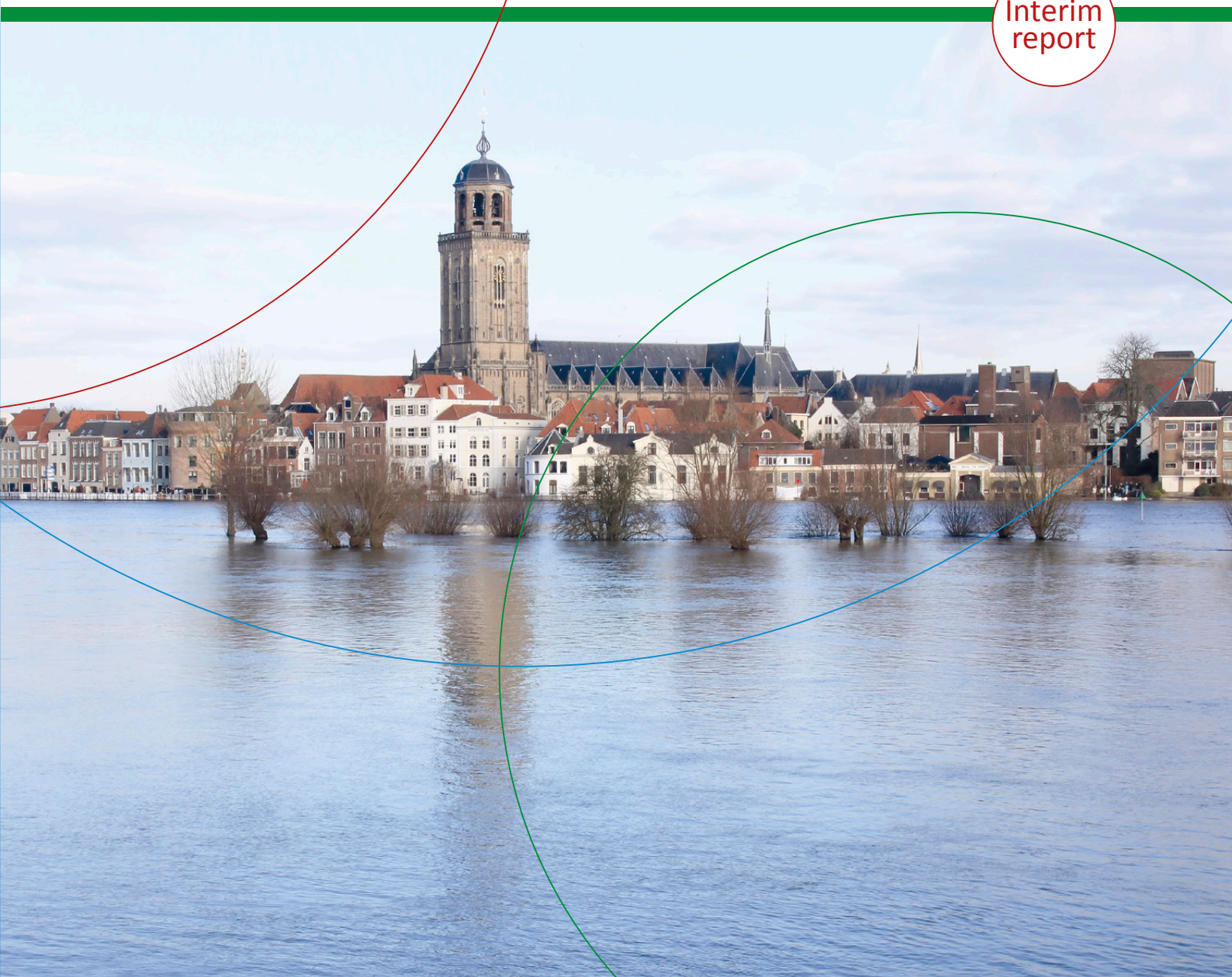




Kennis
voor
Klimaat

Towards climate-change proof flood risk management

Interim
report

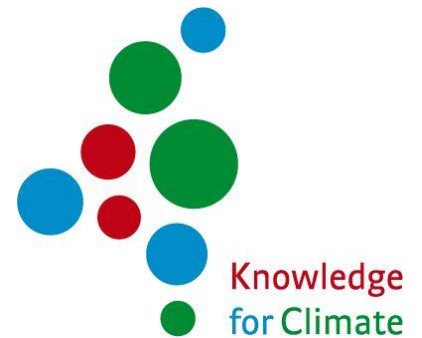


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Towards climate-change proof flood risk management

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

Interim report, full text

Theme 1

Knowledge for Climate research programme

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Executive summary

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:

risk = probability (of flooding) * consequences (of flooding)

respectively

risk = (flood) hazard * 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 1.2. 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.

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 (Figure 1.8).

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 co-operation 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 coppice 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 re-assessed 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 2.7, 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-Drechtsteden asked for more elaborate investigations on the impact of “partial functioning”.

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.

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 scientist (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 (Figure 2.21). 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 (Figure 3.1). 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).

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 m³. In the light of climate change predictions, the Delta Committee (2008) has recommended to raise the total yearly nourishment volume to 85 million m³ 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 km² to large ones of about 660, 1500, 2200 and even 4900 km². 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.
- 7 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.

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 4.9 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.

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 KfC 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.

The map of Local Damage Hazard (Figure 5.5) 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

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.

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; Figure 5.9). 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 5.7).

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.

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 (Figure 6.1). 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' (Figure 6.3), which culminates in something which might 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 (Figure 6.10), 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.

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 work group 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.

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 6.4. 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 coordinates 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-Drechtsteden (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-Drechtsteden 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 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.

1 Introduction

1.1 Climate change and adaptation

Frans Klijn

Climate change and its potential impacts attract a lot of attention of research communities and policy makers. Climate, of course, has changed in the past too, but it is the accelerated climate change caused by human activities, which causes societal concern. This accelerated climate change may affect societies in various ways, through higher temperatures, rising sea level, higher floods, longer droughts, more frequent storms, etc. These potential effects urge authorities to define climate policies.

Usually, the analysis of climate change follows the so-called DPSIR scheme (Figure 1.1), in which any policy which focuses on reducing climate change itself, or its consequences is addressed by the term response. This response may thus either aim to mitigate the climate change as such – which can only be achieved by concerted action at global level –, or focus on adapting to the inevitable.

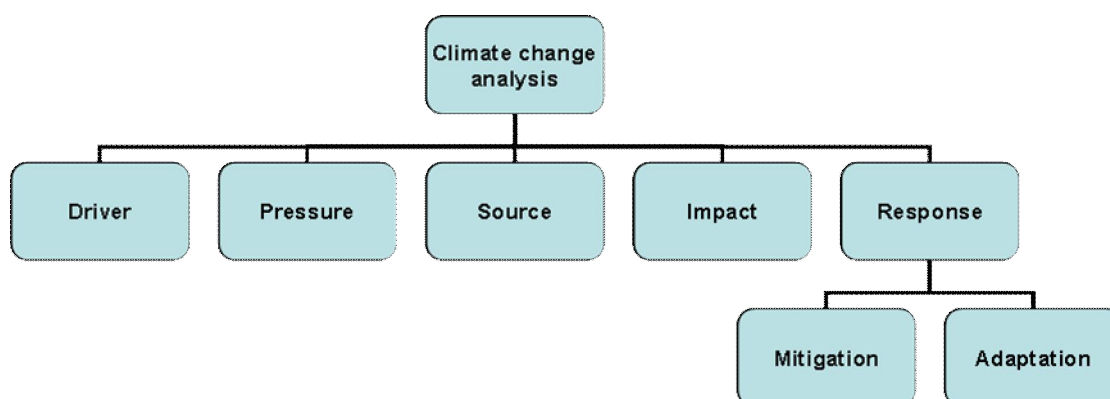


Figure 1.1 Adaptation to and mitigation of climate change, as responses according to the DPSIR scheme

Especially in low-lying deltaic areas, a sound adaptation policy is urgently needed, as relying on a global mitigation policy is way too risky. Both the current research and the Netherlands' policy response as such therefore focus on adaptation.

In the Netherlands, climate change is given due attention for about two decades already. In the national programme *Adaptatie Ruimte en Klimaat* (Adaptation Spatial Planning and Climate; ARK) the problems have been analysed and the key issues have been identified. For the Netherlands, the majority of key issues appeared related to water management: flood risk problems, drainage problems in urban and rural areas, salinisation of estuarine areas, and summer droughts (Kwadijk et al., 2006). Partly based on the outcomes of this inventory, a research programme has been defined, under the title 'Knowledge for Climate' (KfC). This programme addresses the majority of climate-change related adaptation challenges. Actually, the research on flood risk management described in this report, is primarily carried out in the context of this programme, which started in 2010. But at the same time – and before – many

other research initiatives and programmes ran, both in the Netherlands and abroad, and ranging from local to EU or global level. In many cases members of our research team were involved in these (e.g. MNP, 2007; Aerts et al., 2008; FLOODsite, 2009; PBL, 2010), and when not, we obviously connected to any of these, when relevant.

Parallel to the research agenda, various policy initiatives were taken. For the Netherlands, 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. This Delta Programme – which formally started in 2010 as well – addresses the key question of how to ensure a sustainable flood risk management and freshwater resources management for the remainder of the century. 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. It focuses on quantitative and qualitative water management problems at large. Obviously, we constantly tuned our research agenda to the research needs of this national policy and regional management programme.

From the above, it is obvious that our research takes place in a very dynamic and busy context. Moreover, the research field is so big that we cannot cover it entirely, but can only 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. In this report, we try to give due reference to all our colleagues from outside KfC while still emphasizing our own contribution to the research progress.

In the remainder of this chapter, we first introduce the key concepts of flood risk analysis and principles of its management. Next, we give a brief description of the challenge we face: the development of flood risk in the 21st century – and beyond – under the influence of climate change and other factors. We then describe the policy context in which we work, i.e. the Netherlands' delta programme, and how we relate to that. Finally, we introduce the further structure of this report.

1.2 Flood risk: key concepts and definitions

Frans Klijn, Matthijs Kok & Hans de Moel

Before we can adequately focus on innovative measures to manage flood risk in the future we need to agree on what we mean by flood risk and by flood risk management. As FLOODsite put substantial effort in defining these concepts in its 'Language of Risk' (FLOODsite, 2005), we largely follow the definitions they proposed, but we have adapted them in such a way as to better connect to the Netherlands' practice and to make them even more easily applicable for the Netherlands' Delta Programme (after Van de Pas et al., 2012).

FLOODsite (2009) stated that flood risk management pertains to dealing with flood risks based on the notion that these risks cannot be reduced to zero other than at the expense of other societal goals. This means that the **objective** of flood risk management can be defined as:

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

This definition is supported by the Netherlands' advisory organizations (e.g. ENW) and the 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. In practice, emphasis is often put on economic damage and loss of life. 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.

1.2.1 Flood risk and its constituents: ambiguous concepts

A clear conceptualisation of flood risk and its constituents helps to identify the points of attack for risk reducing measures. FLOODsite (2005; 2009) defined flood risk in two alternative ways, each of which has advantages in different applications. The first definition is:

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

This definition is preferred among natural scientists, as it allows risk calculation, and among engineers, who usually aim at reducing the probability of flooding by designing and constructing flood protection. The second definition is:

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

This definition is often preferred by social scientists, as it allows a focus on the individuals and societies affected, and among planners, who usually regard the hazard as a given and the spatial planning as the means to adapt to that given.

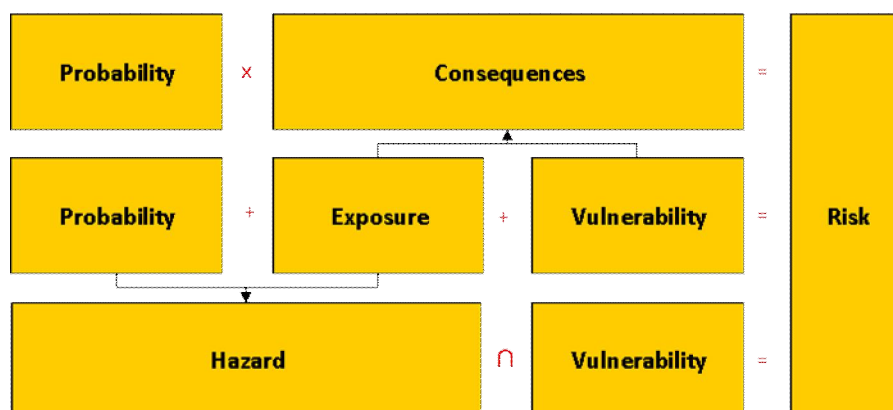


Figure 1.2 Flood risk can be conceptualized as multiplication of flood probability and consequence or as geographic overlay of hazard and vulnerability, or as a combination of 3 key constituents: probability, exposure characteristics and vulnerability (after Van de Pas et al., 2012).

The first definition (probability x consequence) has long been the only accepted definition among the engineers of Rijkswaterstaat and in the Ministry of Public Works and Water Management. It very much suits the Netherlands' situation, where about 3000 km of primary flood defences protect the majority of the flood-prone area. By multiplying the probability of a breach with its consequences, a quantitative estimate of flood risk can be obtained, where the vulnerability of the area and the flood's extent and depth are combined into one figure for 'consequence'. In the second definition, the flood's possible extent and depth (and other 'flood characteristics' including probability) are all covered by the word 'hazard'. FLOODsite defines a natural hazard as a natural phenomenon with the potential to harm. Actual harm can only occur to a vulnerable society or area.

The key difference between the two definitions lies in where the element of ‘exposure’ is being incorporated, as Van de Pas et al. (2012) argue. In the first definition, exposure characteristics, such as water depth and extent, are part of the term ‘consequence’, because they are indeed a hydraulic consequence of a breach, and also required to be able to calculate the consequences in terms of economic damage or number of fatalities (e.g. per breach location). In the second definition flood depth and extent are considered to be essential hazard characteristics, alongside with probability. By explicitly distinguishing exposure as a separate constituent of flood risk, the two competing definitions and ‘schools’ can be reconciled (Figure 1.2). In this scheme, consequences can be understood as replacing the combination of exposure and vulnerability, or hazard as replacing the combination of probability and exposure.

Even then, each term may need a more precise definition, as the terms remain ambiguous by themselves. For example, the word risk is often used for probability or likelihood. This is the case when a ‘risk approach’ is advocated to establish the breaching probability of a dike ring (a system of embankments and structures protecting an area). Instead, risk may also be considered the combination of probability and consequence, but the ambiguity then lies in consequence. Of course, a breach in an embankment is a consequence, even when the impacts are nil. In this report, we prefer to follow FLOODsite’s more encompassing definition, which requires relevant societal consequences, such as economic damage or loss-of-life, to result from a flooding before one speaks of risk. Or, as FLOODsite (2009) put it: the essence of flood risk in contrast to flood hazard lies in taking into account the probability distribution of all flood levels and the likely consequences of all possible floods.

Probability may equally refer to the probability of flooding (the hazard), or to the probability of exposure to flood water, or finally to the probability of consequences. In the latter case, probability ‘swallows’ the other concepts. We therefore prefer to delimit its use to the first definition, unless stated otherwise: thus probability of flooding (or breaching in the case of embankments).

In contrast, vulnerability may also refer to various objects. It may refer to persons or property, such as houses or cattle, which are then equally vulnerable whether on a hilltop or in a floodplain, as the characteristics of this person or property is determinant. Others use the term vulnerability for an entire area, with its characteristics such as elevation, flood defence infrastructure, etc. (e.g. Marchand, 2010), thus excluding all areas above maximum flood level. This means that the concept of exposure is then ‘swallowed’ by the definition of vulnerability. In this report, we reserve the term vulnerability for objects (e.g. persons or buildings) and do not use it for entire areas (again: unless stated otherwise).

These delimitations of the use of probability and vulnerability allow us to explicitly address the issue of exposure to flood water and its control. Exposure characteristics then comprise flow speed, water level rising rate, time span between breach and arrival at location, maximum depth, final depth and extent, and time span before drying out again. This distinction also allows defining measures which specifically reduce the exposure, such as compartmentalisation or unbreachable embankments. Moreover, the distinction between hazard and ‘objects vulnerability’ has certain advantages for spatial planning issues, as addressed in the Netherlands’ Delta Programme (cf. Van de Pas et al., 2012; Pieterse et al., 2012).

The EU Floods Directive (from FLOODsite, 2009)

Preliminary flood risk assessment (Articles 4 & 5)

It is essential that flood mitigation actions are only taken in areas where potential significant flood risks exist or are reasonably foreseeable in the future. If in a particular river basin, sub-basin or stretch of coastline no potential significant flood risk exists or is reasonably foreseeable in the future, Member States can identify them in the preliminary flood risk assessment. For these river basins and/or sub-basins no further action need be taken.

Flood hazard and flood risk maps (Article 6)

Flood hazards and risks are to be mapped for the river basins and sub-basins with significant potential risk of flooding for three scenarios:

- Floods with a low probability or extreme event scenarios
- Floods with a medium probability (likely return period > 100 years)
- Floods with high probability, where appropriate

The maps may show information on flood extent, depths and velocity of water, and the potential adverse consequences.

Flood risk management plans (Article 7)

Flood risk management plans are to be developed and implemented at river basin or sub-basin level to reduce and manage the flood risk where identified as necessary in the preliminary flood risk assessment. These plans are to focus on the reduction of potential adverse consequences of flooding for human health, the environment, cultural heritage and economic activity, and, if considered appropriate, with non-structural initiatives and/or on the reduction of the likelihood of flooding.

They are to address all phases of the flood risk management cycle but focus particularly on:

- Prevention (i.e. preventing damage caused by floods by avoiding construction of houses and industries in present and future flood-prone areas or by adapting future developments to the risk of flooding),
- Protection (i.e. taking measures to reduce the likelihood of floods and/or the impact of floods in a specific location such as restoring flood plains and wetlands); and
- Preparedness (e.g. providing instructions to the public on what to do in the event of flooding).

1.2.2 Flood risk analysis and mapping: Netherlands' research context

The scheme of Figure 1.2 can be used as an aid for flood risk analysis and mapping, as prescribed by the EU directive on flood risk assessment and management (see text box). This can be done for the present situation or any moment in the future.

By successively focusing on the probability of flooding, the exposure characteristics and the vulnerability of people and property, one can obtain a thorough understanding of flood risk, both in quantitative terms and in terms of geographical extent and distribution. This approach is followed in section 1.4 of this introductory chapter, where we address how climate change and sea level rise may affect the flood probabilities and exposure characteristics in the Netherlands, and how socio-economic developments may influence the country's vulnerability in the next decades. By combining these, we have gained a good insight into the development of flood risk proper, as well as of its causes. But the analysis which we describe was quite global in approach. For the Delta Programme, more detailed analyses have been performed.

Firstly, in the research project 'Flood Risk 21st century', which was done in behalf of the Delta Programme, the flood consequences were analysed in detail (De Bruijn & Van der Doef, 2011; Beckers & De Bruijn, 2011) and then put central to derive appropriate levels of protection (Kind et al., 2011). These levels, in terms of economically optimal flooding probabilities, were calculated by applying a cost-benefit approach, which aims at defining the protection level that yields the lowest residual risk against the lowest total costs of investment and maintenance: the protection levels (Kind et al., 2012 submitted). This approach thus relies on consequences as a given, and focuses on defining acceptable probabilities of flooding, i.e. measures for flood protection.

This 'Flood Risk 21st century' project was almost finished when our KfC project started. We consider the results as background knowledge.

A second project which largely relies on the same line of thought is FLORIS (or VNK in Dutch): FLOODRISK in the Netherlands (Projectbureau VNK, 2011). This project runs for almost a decade now, and investigates in detail the probability of failure of flood defences taking into account all relevant failure mechanisms, the consequences of a large number of possible breaches, and the combination of these in terms of risk: fatality risk and economic risk. This project too primarily aims at flood protection, for which it provides very detailed and useful information, thus allowing a better prioritization of reinforcing flood defences in such a way as to obtain the best value for money – in terms of flood risk reduction per invested euro. This VNK-project is still running and aims to have investigated all the Netherlands' dike-ring areas by 2015 (Projectbureau VNK, 2011).

We regard this project as relevant context and knowledge base for our research, which is more towards innovative approaches for flood risk management in view of global change.

The third project, we must refer to in this context, is a joint enterprise by the Delta Programme on Urban Development and Re-development and our consortium. Van de Pas et al. (2012) started from the other side, by taking hazard as a given for spatial planning purposes. They focused on how to achieve a useful and sufficiently detailed map of flood hazard in support of spatial planning: i.e. measures that reduce the vulnerability of flood-prone land. This 'mapping exercise' entailed combining information on the probability of flooding and on exposure characteristics, in order to achieve meaningful hazard maps. As this project was – at least in part – carried out by us, we come back to it in detail in one of the next chapters. It was the second attempt to systematically map flood hazard for the whole country, after a first approximation by De Bruijn (2007; cf. also De Bruijn & Klijn, 2009) and taking into account experiences elsewhere in Europe as inspiration (EXCIMAP, 2007).

We regard the results of this project as a truly innovative contribution to providing very relevant knowledge to those who are responsible for designing and planning our future flood risk management strategy.

1.3 Flood risk management: principles, measures and instruments

Frans Klijn & Edmund Penning-Rowell

Flood risk management aims to ‘handle’² the risk of flooding by striving for a balance between the reduction of flood risk and the societal costs we need to make to achieve this reduction, in terms of economic, social and environmental costs, both today and into the future. Flood risk reduction thus aims to prevent losses and damages by either preventing flooding and/or by preventing the exposure of vulnerable objects such as people and property to flooding.

1.3.1 Principles of FRM

Comprehensive flood risk management is different from earlier approaches, such as flood defence, flood control or flood management. This was acknowledged by FLOODsite (2009) and is reflected in the EU Directive on flood risk assessment and management as well. FLOODsite (2009) developed some key principles for comprehensive flood risk management, which were published by Klijn et al. (2008). We vary on these here, as they are also relevant for our current work:

- 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’³ measures without prejudice (i.e. also regulatory instruments, financial instruments and communicative instruments cf. Hooijer et al., 2002).
- 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 residual risk in view of sustainable development.

Where the first two principles speak for themselves, the latter one may require a brief explanation. We want to emphasize that risk management does not automatically imply actual reduction of the level of risk, because this depends on the assessment whether the residual risk is acceptable or not, as well as on the assessment of the costs and benefits of measures and instruments required to reduce the risk. After all, flood risk management is just a means to achieve sustainable development: the ultimate goal of all environmental policy and management.

It is generally acknowledged that flood risk in protected floodplain areas can never be reduced to zero, and that living and working in such areas yields so many economic and other benefits that a certain degree of risk is acceptable. From the standpoint of economic rationality one might argue that cost-benefit analysis would suffice, comparing the costs of risk reduction measures with the reduced expected annual damage. But in practice, more types of risk deserve attention, such as fatality risk. And there may be ethical considerations for not accepting huge disasters with many lives being lost. The rationalities of reducing economic risk, individual risk and collective (or ‘group’) risk do not always yield the same

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2. *‘To manage’ comes from the Italian maneggiare (to handle — especially a horse), which in turn derives from the Latin manus (hand).*
 3. *The commonly used term ‘non-structural’ as opposed to structural measures would – in many European languages (other than English) – suggest that the measures are less good than structural measures; this is the reason that FLOODsite abandoned the term structural measures, although the alternative (physical) has its flaws too.*

result, and may even get in conflict (Van der Most et al., 2006). And physical measures or land zoning may have consequences for natural and cultural heritage values, on socio-economic development opportunities, etc. This requires a full assessment including all the costs and benefits of risk reduction measures in view of sustainable development, as argued by De Bruijn (2005; cf. also Vis et al., 2001). A full assessment thus not only includes economic efficiency, but also social equitability (Delta Programme, 2011) and ecological integrity: not only profit, but also people and planet.

1.3.2 Measures and instruments

Measures and instruments are the actual 'tools' by which risk can be reduced. *Measures* are physical interventions in the environment. Traditionally, they include all kinds of permanent structural measures, i.e. river and coastal engineering works, such as embankments, dams, storm surge barriers, or room-for-river measures. They are usually implemented by water management authorities, which in the Netherlands means Rijkswaterstaat or the regional Water Boards.

Instruments – or policy instruments –, in contrast, are no direct physical interventions in the environment but rather means to influence the attitude and/or actions of others than the immediate responsible authorities. They aim at other parties who co-determine the flood risk. Three groups of instruments are often distinguished (FLOODsite, 2009), namely communicative, financial and regulatory instruments. A popular way of addressing these three groups of instruments is as 'chatter', 'carrot' and 'stick'. Communication may, for example, enhance risk awareness and the people's preparedness and comprises flood warning. Financial instruments may encourage people to flood-proof their property or influence their investment behaviour. Regulatory instruments allow or prohibit certain activities.

In practice, it is of course virtually impossible to implement any structural measure without appropriate regulations, without communication about the reason for its implementation and without some financial compensation for those affected by it. This means that measures and instruments can seldom be investigated in isolation. And policy instruments do, of course, influence the behaviour of others in such a way as to result in materializations in physical form, for example, by flood-proofing property or by raising the ground before development.

1.3.3 Assessing the effectiveness of measures and instruments

A first criterion to assess measures and instruments, is by their performance. Do they achieve what we expect from them in terms of risk reduction? This is often addressed as effectiveness: the degree to which aims of flood risk reduction are achieved.

Effectiveness can thus be quantified in terms of avoided flood risk, i.e. in terms of less expected annual damage, less expected number of fatalities, less expected number of people affected, or alike. In practice, more down-to-earth variables are sometimes used as indicator, such as lowering of flood water level, decrease of flood probability, reduced area at risk, or fewer flood losses. These indicators for effectiveness are easier to establish, but also less relevant from a flood risk management point-of-view.

The effectiveness of measures and instruments can be assessed before (ex-ante) or after (ex-post) their implementation. Assessment before implementation requires that the effects of a measure or instruments are quantified as accurately and reliably as possible by applying

the best scientific knowledge and technical means. This is especially difficult for a future, which is inherently uncertain because of climate change and socio-economic development.

1.3.4 Costs and side effects

Besides their performance in reducing risks, it is obviously also important to consider the costs of implementation and maintenance of measures and instruments. This comprises monetary costs, but also unintended side effects on the environment, the economy or society. Certain measures and instruments for flood risk reduction may conflict with other societal goals, such as nature conservation or economic development, so one should always balance the benefits of risk reduction against the losses in other areas of societal interest. This calls for a full consideration of all side effects, i.e. all tangible and intangible costs to society (FLOODsite, 2009).

The ratio between the intended effect in terms of risk reduction and the monetary costs of the implementation and maintenance of a measure or instrument is its efficiency, usually expressed as a Benefit-Cost Ratio (BCR). Establishing the efficiency of various measures and instruments allows ranking them for the purpose of rational decision making.

1.4 Flood risk: its development in the Netherlands in the 21st century

Frans Klijn, & Karin M. de Bruijn

The Netherlands is often regarded a vulnerable country to climate change, as 55% of its land area is protected by flood defences and hence flood-prone (PBL, 2010). On the other hand, the country has a history of about a millennium of adaptation to subsiding land and a rising sea level, in the course of which a system of flood defences evolved. These flood defences surround the flood-prone areas or connect to high grounds and constitute so-called dike-rings. In the Netherlands' Water Law 53 major dike-ring areas are defined, as well as about 40 minor dike-ring areas in the natural valley of the Meuse River. These dike-rings protect the flood-prone areas against flooding according to pre-defined protection standards, which apply to exceedance probabilities of hydraulic loads – water level and waves. The current standards range from 1: 10 000 per year along the coast to 1: 1250 per year along the rivers for the major dike-rings, and 1: 250 for the minor areas in the Meuse Valley.

That the current protection standards are being met is ensured by the Water Law and a number of dedicated regulations related to it. These prescribe that the hydraulic design conditions be re-defined every 6 years (planned to be changed to 12 years), and that subsequently the flood defences must be checked on their capacity to withstand these conditions. Thus, the reliability of the flood defences and their maintenance is more or less guaranteed, whereas adaptation to changing circumstances is built-in by the recurrent re-evaluation of the design conditions. With rising design water levels, the embankments have been raised again and again, and the coast is being kept in shape by recurrent sand nourishments to the beach and the coastal foundation from below the -20 m NAP depth contour.

The current flood risk management policy of the Netherlands thus relies entirely on flood protection, but can still be regarded as being adaptive, even though it tends to lag behind the actual developments of climate change and socio-economic development. Passchier et al.

(2009) already established that this policy can be sustained for at least this century and probably several centuries to go, as long as the sea level rise does not exceed 1.5 m per century. This applies to the Netherlands' coastal protection strategy of sand nourishment, as well as to the flood defence strategy of regularly raising the embankments along the major estuaries and lakes, and to the room-for-river strategy adopted for the major rivers. It, therefore, may seem that the Netherlands does not have to worry about sea level rise or an increasing flood risk. But that is a premature conclusion, as this strategy may not be the most desirable flood risk management strategy, as Klijn et al. (2012) argue. To begin with, it does not prevent that the vulnerability of the country to flooding increases, and it has some other disadvantages too. There are ample reasons to put further effort in analyzing the development of flood risk, its causes, and especially in the various possibilities to improve its management.

Klijn et al. (2004; 2007; 2010; 2012) analyzed the development of both economic flood risk and fatality risk in the Netherlands by establishing how the various drivers of flood risk develop; i.e. not only climate, but also other geo-ecological factors and society, and how these affect the constituents of flood risk. As flood risk is defined as probability multiplied by consequence or as a function of a flood hazard's probability and exposure characteristics and the vulnerability of the exposed socio-economic system (Klijn et al. 2004; Samuels et al. 2006; FLOODsite 2009), we need to address:

- Flood **probabilities**, as a function of flood level as affected by developments in sea level, river discharge, storm frequency and severity;
- **Exposure** characteristics of flooding, such as flooding depth, extent, inflow rate, water level rise speed, etc., as a function of elevation (subsidence), sea level, storm surge of flood water level, and infrastructure (degree of compartmentalisation);
- **Vulnerability** of the population and property, as a function of demographic and economic development, and how this affects land use.

1.4.1 On flood probabilities

Accelerated climate change and sea level rise are now widely accepted processes, but the rate of both remains uncertain. A way to deal with this inherent and inevitable uncertainty about the future is a scenario approach. This approach is commonly applied, also in the Netherlands. The Royal Netherlands' Meteorological Institute (KNMI) publishes climate scenarios every few years, Based on the IPCC-scenarios for global warming and global sea level rise. The four most recent scenarios (KNMI, 2006) show a range of sea level rise between 0.35 and 0.85 m by 2100, which values result from a translation of the IPCC-results to the Netherlands' coast, taking into account regional differences and large-scale geological movements. For a possible upper limit higher values may apply, such as the high-end scenario used by the Delta Committee in 2009 which reaches 1.3 m (cf. Vellinga et al., 2009). The KNMI scenarios thus provide us with a range for the mean sea level rise, which can be translated into the key variables for establishing coastal flood risk, viz. storm surge level and significant wave height.

The sea level also largely determines the water levels in the estuaries, the downstream ends of the large rivers and Lake IJssel, which discharges into the Wadden Sea. These water bodies experience discharge problems and backwater effects when the sea level is higher. The flood levels in these water bodies will hence also rise.

For the rivers, the discharge is the key factor which determines the flood levels. The KNMI climate change scenarios must therefore be translated into river discharges, with emphasis on the very rare extreme discharges, which may cause flooding. Various attempts have been

done in recent years to achieve future discharge regimes for the Rhine and Meuse River (e.g. Van Deursen, 2006; Te Linde et al., 2010 and CHR/ KHR, 2010) for various scenarios. These can be translated into higher flood water levels, when one assumes no changes in the river's morphology.

With the scenarios on sea level rise and river discharge regime the increase in hazard probabilities could be established (Klijn et al. 2004). This resulted in the insight that along the rivers, the coast, in the estuaries where the two meet, and on Lake IJssel the exceedance probability of the design water level might increase with a factor of about 2- 3 by 2050, assuming that no counter-measures are being taken. However, larger discharge sluices are already planned in Lake IJssel, which causes the design water levels in this lake not to rise before 2050, so here this factor does not apply. For the upstream stretches of the large rivers it was found that the 1: 1250 per year design discharge may reach 17 000 m³ s⁻¹ in 2050 in the wettest scenario, in comparison to the present 16 000 m³ s⁻¹. This translates into design flood levels about 0.1- 0.2 m higher than the present ones. These would imply an exceedance probability of the design flood level almost twice as large as at present.

This focus on hazard probabilities, however, is a very theoretical exercise, as the current policy requires that the legal protection standards are met. This means that the actual flooding probability – or rather dike failure probability – is not very likely to rise at equal rate as the hazard probability of the flood water levels (and waves, and storm surges, etc.). That would only apply if one were to presume no further raising of the embankments or other counteracting measures. Klijn et al. (2012a) assume that from about 2015 onwards, the flooding probabilities remain constant in a scenario of autonomous development and continuation of the current policy.

Until 2015, a backlog of complying with the current protection standards is being repaired by the implementation of measures which aim to reduce the flooding probability. This comprises reinforcements of flood defences along the coast ('weak spots') and inland which failed the latest check-up (Flood Defence Programme, until 2013), as well as making room for the large rivers (Room-for-River Programme, until 2015). These measures reduce the current flooding probabilities, which are larger than they should be – though smaller than ever before in the last 50 years.

Summarizing: climate change causes the hazard probabilities to increase, but the flooding probabilities are expected to stay more or less the same from 2015 onwards.

1.4.2 On exposure characteristics

When a flood defence fails, a larger difference between flood water level in river or sea and the level of the protected flood-prone land area determines how fast, far and deep the flooding will advance. De Bruijn (cf Klijn et al. 2010; 2012) was the first to investigate this issue by performing a number of flooding simulations, and by re-interpreting available existing simulations.

Various simulations were done for the coastal plains and estuaries for the present sea level and for a 1.3 m raised sea level (Figure 1.3 and Figure 1.4), and some additional simulations were done for a sea level 0.85 m higher than present. These figures correspond with the high-end scenario and the upper boundary of the KNMI scenarios for sea level rise in 2100. The simulations for the coast showed that at higher sea levels the breaches grow much larger and inflow volumes can double. And obviously the area which is flooded increases (Figure 1.3 and Figure 1.4), as well as the flooding depth.

For Lake IJssel similar calculations were done, but in a simpler way as this lake has a limited volume in contrast to the ocean. This allows treating the flooding of a deep polder as a simple example of 'communicating vessels'. For the rivers, no simulations were done either, firstly because the room-for-river policy prevents a rise of the water level in the rivers, and secondly because the fluvial dike-ring areas are inclined and already simply fill up until the level of the lowest embankment. Exposure was therefore expected not to change very much (Klijn et al., 2010; although we now think it may be affected by the shape of the discharge wave; cf Mens, 2012).

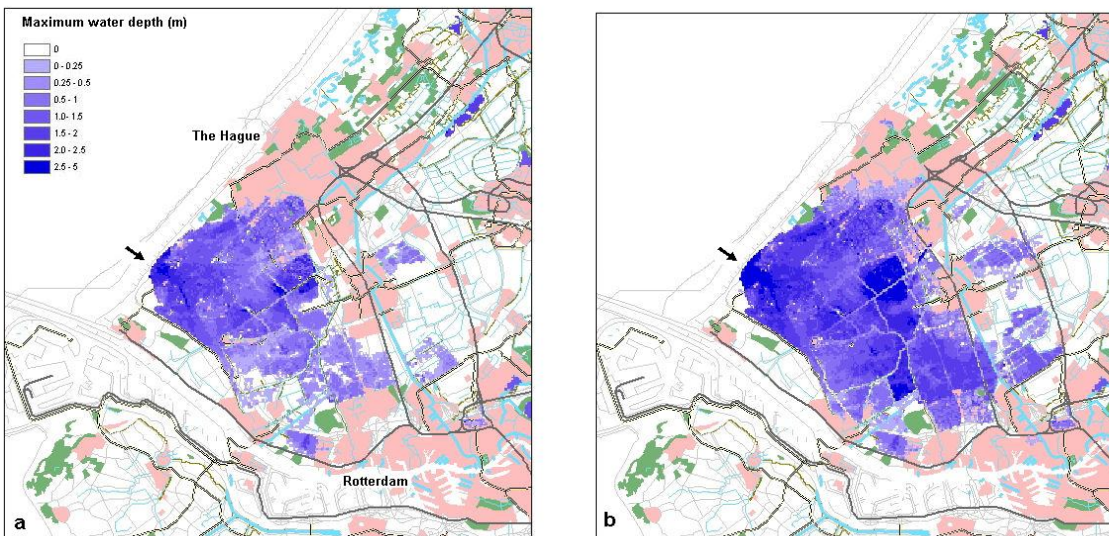


Figure 1.3 Difference in exposure in terms of flooded area and water depth (see legend) resulting from a breach at Ter Heijde (indicated with an arrow) during a 1:10,000 storm surge level with present sea level (a) and with a sea level that is 1.3 m higher (b)

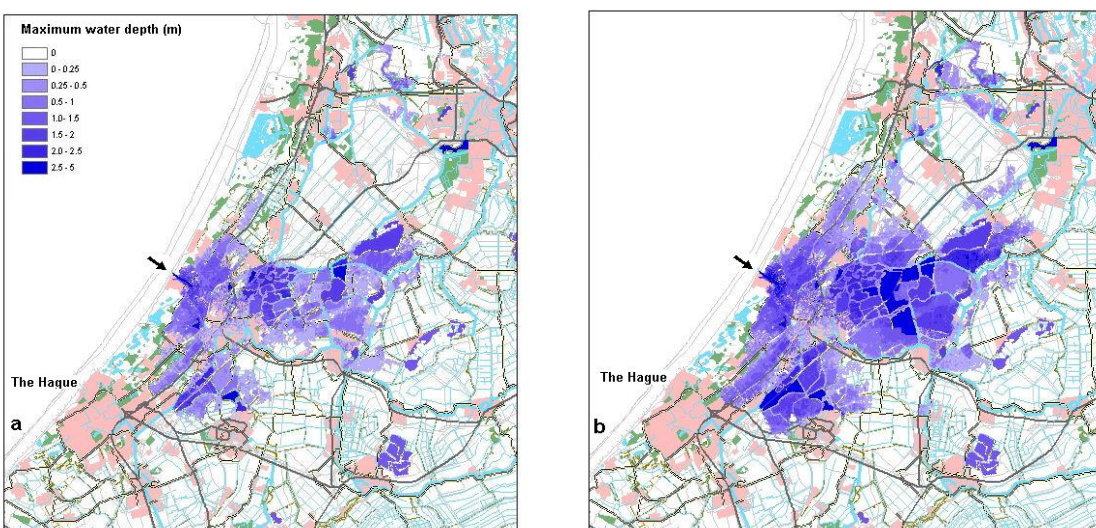


Figure 1.4 Difference in exposure in terms of flooded area and water depth (see legend) resulting from a breach at Katwijk (indicated with an arrow) during a 1:10,000 storm surge level with present sea level (a) and with a sea level that is 1.3 m higher (b)

On the basis of the flooding simulations, the resulting economic damage and number of fatalities were calculated for the present land use and population. Thus we could establish the separate contribution of greater exposure to the possible future development of risk. From these calculations, the relative increase of flood consequences was derived for dike-ring areas of different type. It was thus found that for a 1.3 m sea level rise economic damages along the coast increase with a factor of 2.2 to 3.7 for different breach locations. Fatality numbers rise with a factor from 3.1 to 4.7. We extrapolated the results to the remainder of the coastal dike-ring areas taking into account their location, size, degree of compartmentalisation, land-use characteristics and population distribution (Klijn et al., 2010), and interpolated to lesser sea level rise rates. This resulted in an estimated increase of economic flood risk for 2050 of factor 1.7 at the maximum for some coastal dike-ring areas.

Summarizing: sea level rise causes a significant increase of the exposure to flooding, which affects the coastal and estuarine areas, the downstream stretches of the large rivers, and Lake IJssel.

1.4.3 On the development of vulnerability

The vulnerability to flooding depends on the socio-economy of the flooded area. This can be expressed in terms of people – number and kind – and property – or rather economic value and economic activity. A common approximation for the latter is a land use map.

The future development of the Netherlands' population and economy can be tackled by a scenario approach too. The joint National Planning Agencies drafted four scenarios for socio-economic development. These apply for 2040 and range from a shrinkage to 15.8 million inhabitants ('Regional Communities': RC) to a growth to 19.7 million (Global Economy': GE), from the present 16.0 million. The yearly economic GBP growth in these scenarios ranges from 1.2% per head (RC) to 2.1% per head (GE). Based on these scenarios the Netherlands Environmental Assessment Agency drafted possible land use maps for 2040 (Koomen & Van der Hoeven, 2008; MNP, 2008). Figure 4 gives an example of one of these future land-use maps in comparison to present land use.

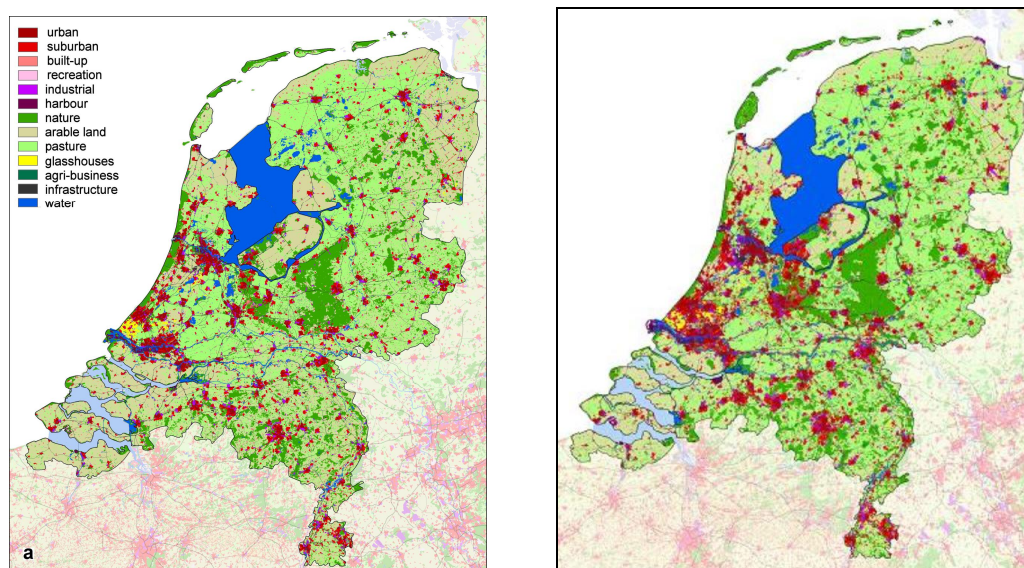


Figure 1.5 Land use in the present situation (a) and possible land use in 2050 in scenario Global Economy (after Kuiper & Bouwman, 2009).

With these land use prognoses, we established the development of flood consequences (Klijn et al., 2004; 2007; 2010; 2012). To this end, part of the economic growth was attributed to new urban development and part to increasing value of property. New urban development also means population increase, although also the household size tends to diminish. This has been accounted for. Based on these prognoses, we could estimate the additional growth of the economic damage potential and the potential number of fatalities.

This revealed that the vulnerability of the flood-prone areas increases above the country's average, because people still tend to migrate towards the coastal plains in the western part of the country and to the fluvial plains, as these areas offer the largest economic and job perspectives. Consequently, the potential loss-of-life increases above average too, and so does the potential economic damage. In the upper scenario Global Economy this increases by 45% through new urban development plus 89% through other economic growth by 2050. These figures mean that the flood risk could increase with a factor 2.3 as a consequence of demographic and economic growth alone. For 2100 this could be translated into an increase with factor 8- 10 in the high growth scenario. These factors easily overwhelm the effect of increased exposure due to rising flood water levels. Recently, these findings have been supported by a number of local and regional analyses with comparable results (Maaskant et al., 2009; Botzen et al., 2010; Bouwer et al., 2010).

Summarizing: the increase of vulnerability to flooding is by far the most important cause of increasing flood risks.

1.4.4 What does this mean in terms of flood risks?

By combining the developments in flood probability, exposure and vulnerability, it is possible to estimate the development of fatality risk and economic risk in the future. This was done for each dike-ring area separately, and for the Netherlands as a whole., the results of which have been published by Klijn et al. (2010; 2012).

Figure 1.6 and Figure 1.7 show the results of these calculations for the current situation, for the situation in about 2020 when all planned measures are implemented, and for 2050. For this year, we give the results for two distinct socio-economic scenarios, as these cause the largest differences in total flood risk. Flood probabilities are expected to remain constant, and increased exposure contributes only slightly and is limited to coastal areas only.

The figures firstly show that the measures which are now being implemented cause a substantial decrease of both fatality risk and economic risk. The decrease between 2009 and 2020 can be entirely contributed to reduced flooding probabilities. Between 2020 and 2050 flood risks increase again: fatality risk only slightly due to a relatively low population growth, but economic risk significantly due to a steady economic growth until the yearly risk level almost reaches the present risk level again.

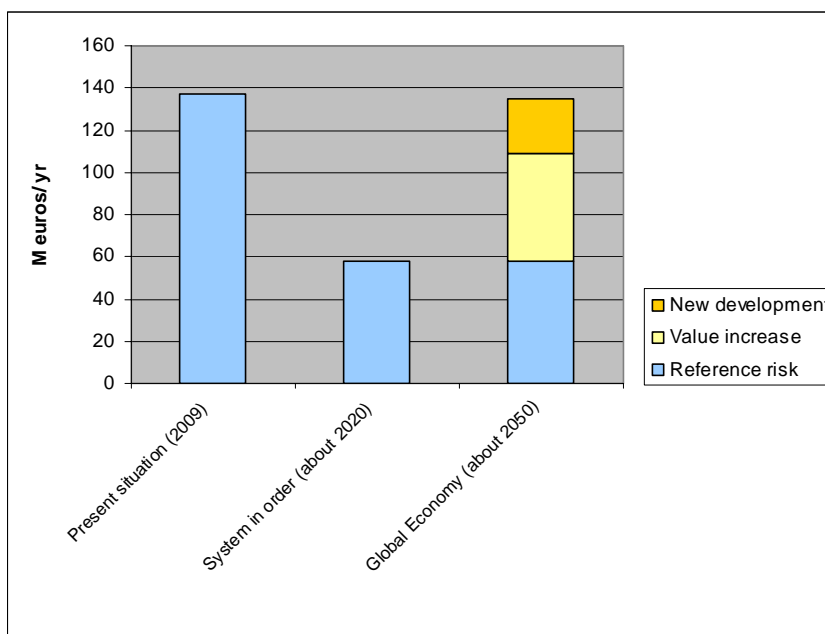


Figure 1.6 Indicative change of the economic damage risk (mean yearly damage in million Euros) and the influence the fastest economic growth scenario (Global Economy) on economic damage risk, distinguishing between value increase and new development.

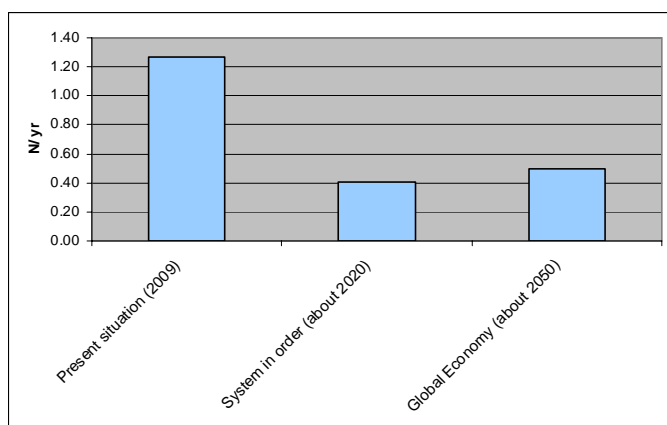


Figure 1.7 Indicative change of fatality risk (mean number of victims per year) between present and 'system in order' (about 2020) and increase of fatality risk in socio-economic (demographic) scenario Global Economy.

The absolute values for the risks depicted in the figures should be regarded as indicative, and not as absolute figures. They rely on calculations, simulations and assumptions which cannot be adequately verified on the basis of past events. Despite efforts to achieve the best figures possible, they remain surrounded with uncertainties (Klijn et al., 2012), primarily because the actual flood probability is very hard to establish. But also the consequences are uncertain, as shown by De Moel et al. (2012), who performed a sensitivity analysis and Monte Carlo analysis to three flooding simulations in the western part of the country (two of which are

shown in Figure 1.3 and Figure 1.4). They found a 95%- range of about factor 4 higher or lower than the median value.

1.4.5 Reflection

The analysis of the development of flood risk in the 21st century reveals 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 already 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 (Klijn, 2004; RIVM, 2005?). Recent research into the economically optimal protection standards (Kind, 2011) confirmed that protection levels for a number of dike-ring areas might be raised, which would translate into a huge investment too. Any improvement to the current practice of raising embankments in a conventional way is therefore welcome.

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. 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. Klijn et al. (2012a) argue that the present flood risk management strategy of the Netherlands has a number of disadvantages and can be improved on many points. 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 cause 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.

1.5 The Netherlands' policy response: Delta Programme, Delta Proof and KfC

Frans Klijn, Matthijs Kok & Hans de Moel

In the national programme Adaptation of Spatial Planning to Climate Change (ARK), it was established that flood risk management and freshwater (resources) management face the largest challenges from climate change (Kwadijk et al., 2006). This made the Netherlands' government to solicit advice from an independent committee, the so-called 2nd Delta Committee. This committee advised a Delta Programme, a Delta Fund and a Delta Commissioner to be installed, to ensure that a long-term adaptation strategy be drafted for

integrated water management and spatial planning in view of a changing climate, a rising sea level and changing river discharge regimes.

The Delta Programme started in 2010. It focuses on 3 generic nationwide issues and 6 regions where problems coincide. The generic issues are:

- Flood risk management
- Freshwater (resources) management
- Urban development and re-development

The Delta Programme is being scientifically supported by dedicated studies and by the research programme 'Knowledge for Climate (Change)'. Three of the thematic research activities of KfC relate to these 3 generic issues of the Delta Programme. This report on Theme 1 of KfC, obviously, relates first and foremost to the first, but by addressing the issue of flood hazard zoning it also strongly connects to the third sub-programme of Urban development and re-development (Chapter 5).

In the regional sub-programmes strategic decisions are being prepared, which integrate solutions for flood risk management and freshwater management with regional and local development planning. Depending on the character of the area, the objectives of the development planning may differ, between the areas but also within. Regional sub-programmes comprise:

- Integrated coastal zone management ('Coast'): primarily aiming at economic viability;
- Wadden Sea: focusing on eco-morphological functioning and enhancing natural values;
- Large Rivers: focusing on quality of both urban and rural environments;
- IJsselmeer (Lake IJssel): focusing on freshwater supply and strategic freshwater storage;
- Southwestern estuarine area: focusing on economic viability and ecological resilience;
- Rhine and Meuse River mouths: with a focus on the Rotterdam harbour area and urban floodplain development.

And not only the regional development objectives differ between these subprogrammes, but also the emphasis may vary from primarily on flood risk management versus mainly addressing freshwater management issues. Where flood risk management is a key issue, we sought cooperation and tuned our research to the needs of the regional subprogramme. This resulted in case studies along the Coast and Wadden Sea (chapters 2 and 3), along the Large Rivers (Chapters 2, 3 and 5), along the Westerschelde in the southwestern estuarine area (Chapter 3), and in the Rotterdam area (Chapter 2, 3 and 5).

Parallel to the national Delta Programme a research and management programme has been drafted by the Foundation for Applied Research for Water Management (STOWA) called Delta Proof. This programme aims to answer practical questions related to adapting the water management to a changing climate. Many questions pertain to flood protection and flood risk management at regional and local level. We tuned our KfC-research to this programme too.

1.6 On this report

In this report, we present the preliminary results of our investigations into innovative measures for flood risk management. This means that we shall 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. These may have been inspired by experiences abroad. This focus is entirely conform our research proposal.

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 some cases primarily on other criteria or even fully. This too is conform our research proposal, and relates to the fact that our investigations are not performed in isolation, but explicitly relate to other research activities, projects and programmes. In other words: it is a deliberate choice in order to prevent overlap or doubling. But, where relevant, we refer to other relevant research of course.

By referring back to Figure 1.2 , we can easily establish that flood risk management thus may involve measures and instruments which are 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 socio-economy in flood-prone areas.

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.

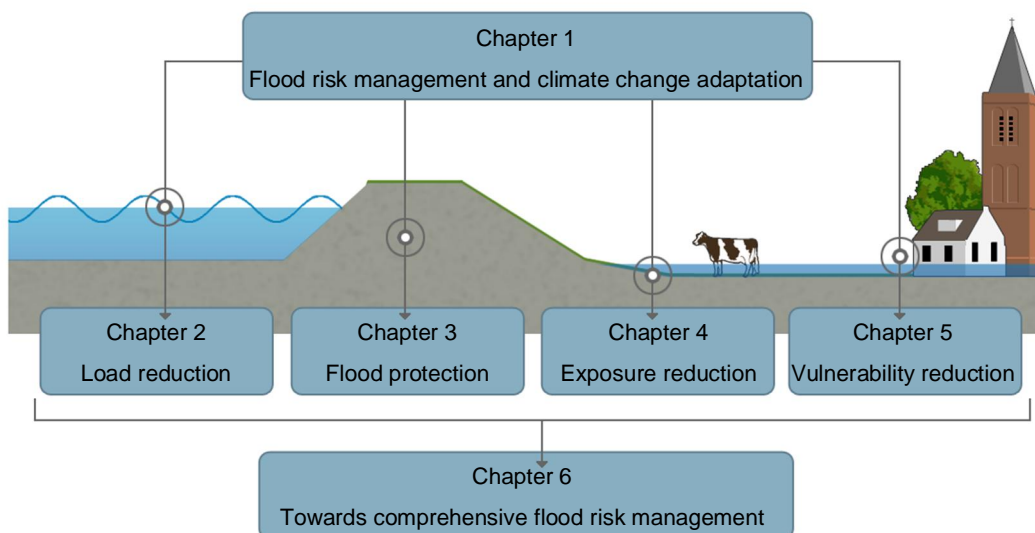


Figure 1.8 Structure of this report in relation to the key constituents of risk.

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. The SPRC model is often applied in flood risk research projects (cf.

FLOODsite), especially in the UK, but it is actually better suited for pollutants (for which the term source truly applies). One could, however, interpret SPRC as just a variant of an ‘effect chain’ – a chain of subsequent causes and effects –, which is of course a very generic ‘model’. As for the distinction between loading and strength, this is very literally applied in the Netherlands’ SBW- research programme: Sterkte- Belasting- Waterkeringen (Strength-Load Flood defences). Our research was defined in such a way as to enhance mutual benefits with this project as much as possible.

Consequently, we shall go into measures to reduce the hydraulic loads on flood defences in Chapter 2, on strengthening the defences themselves in chapter 3, on gaining some degree of control on the flooding process and pattern in case the defences would be overtopped or fail otherwise in Chapter 4, and on the vulnerability of people and property in chapter 5. The issues that will be treated in each chapter are obvious from the titles of the various and sections.

In Chapter 6 all remaining and cross-cutting issues are being presented.

We do not perform a full cross-comparison of all measures, nor of comprehensive flood risk management strategies, as this would first require that we investigate all possible measures in equal detail (which we could not) and because this is, secondly, typically the challenge for the Delta Programme (which has a much larger budget and more personnel). Consequently, each chapter and section may have another different focus, depending on the research gap we aimed to close.

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2 Load reduction: storm surge barriers, room for rivers, wave attenuation

2.1 Introduction

Matthijs Kok & Frans Klijn

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.

Hydraulic loading on flood defences is extensively being studied in the SBW- research programme (Strenght-Loading Flood Defences). For us, it is relevant that usually two different kinds of hydraulic loads are being distinguished: water levels and waves.

High water level cause a relatively prolonged loading on defences, corresponding with the duration of a storm surge at sea or a discharge wave in a river. The defence may then fail by overflow, which may cause erosion of the inner slope, or by insufficient macro-stability. This may result in slumping, sliding or falling over of the embankment, depending on its shape and foundation in relation to underground characteristics. But the hydraulic head (difference in pressure) over the defence is also the key mechanism which may cause piping as a result of preferential flow under or through the embankment or other defence structures (Vrijling et al.,2010).

Waves cause recurrent very strong loading on the outer slope, which may cause erosion of this slope, or on the inner slope when overtopping results in a discharge pulse, which may also cause erosion.

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 coppice and (mangrove) 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 have been re-assessed from a flood risk management point-of-view in behalf of Delta Programme Rivers. Again others were investigated in more detail by our team in co-operation with Building with Nature (salt marshes and willow forest), in co-operation with Delta Programme Wadden Sea.

2.1.1 References

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2.2 Flood level control in the Rhine- Meuse estuaries

Matthijs Kok, Ton Botterhuis & Ad van der Toorn

2.2.1 Introduction

Rotterdam is the most important city in the Rhine-Meuse Estuary in the Netherlands. This city is one of the biggest harbours in the world, and therefore it is important that the city has an open connection with the sea. This open connection creates a problem, since the sea can enter the area, and with an extreme storm surge, the area can be flooded. These floods can cause much economic damage and loss of life. To prevent flooding, storm surge barriers are built to control the water levels behind the barrier. These barriers are open during daily conditions, but when extreme water levels are forecasted, these barriers will be closed. For example, the important Maeslant barrier is closed every ten years (on average). The dike rings behind the Maeslant barrier (as seen from the sea) have a safety standard of 1/10.000 or 1/4000, which means that the flood defences are designed in such a way that the defences can withstand the design water level (that is the water level which has the safety standard as the average yearly exceedance probability).

In this section we focus on measures which aim at controlling the flood levels in the Rhine-Meuse estuary. One of the most efficient ways of doing so is by means of barriers. As can be seen in Figure 2.1, in the Rhine-Meuse estuary there are three storm surge barriers. These barriers are open in daily operation, and are being closed during extreme storm conditions, and by closing them, the water levels can be controlled. However, these barriers can also fail, and if they fail, the water levels increase and flooding can happen.

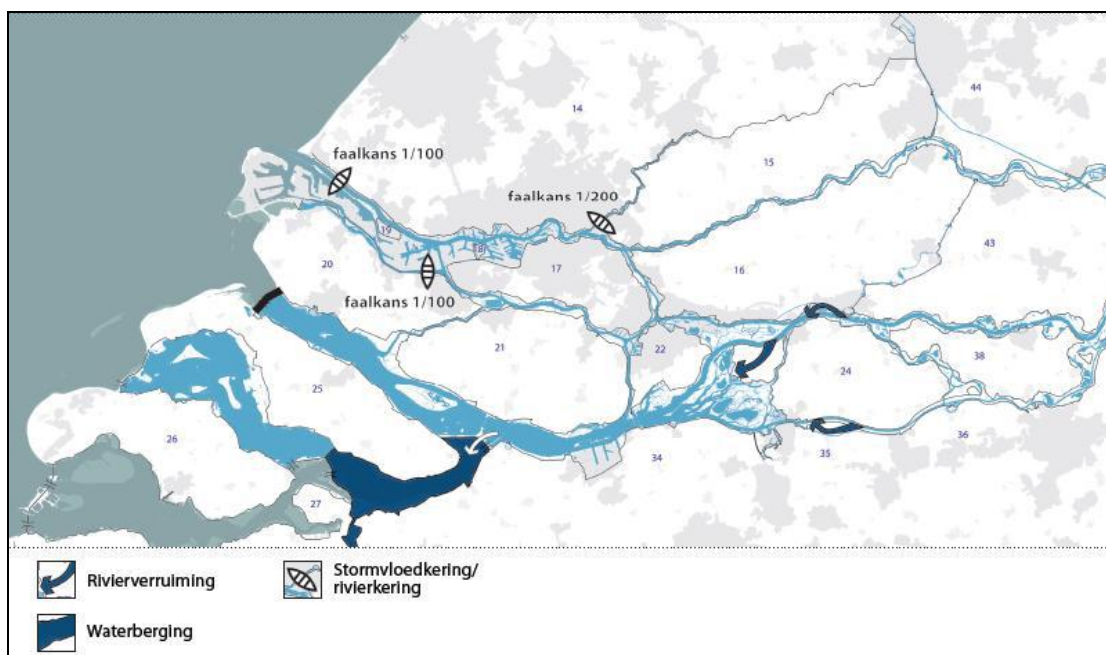


Figure 2.1 Overview of the Rhine-Meuse estuary with three storm surge barriers (Jeuken & Slootjes, 2012)

In this section we will describe two topics. First, we will discuss the results of a flood risk analysis of one of the dike ring areas in the region (dike ring area 14: Central Holland). Secondly, we shall discuss the effectiveness of reducing the failure probability of the Measlant barrier.

2.2.2 Flood Risk in dike-ring area 14 (Central Holland)

In the project FLORIS (Assessing Flood Risk in the Netherlands, in Dutch called VNK2 project) the flood risk is assessed of the dike-ring areas in the Netherlands (VNK, 2010). A dike ring is a combination of dike sections, which protect a dike ring area from flooding. The definition of flood risk in the project is: flood risk = flooding probability x consequences.

The methodology is as follows (from Jongejan et al., 2011): *“In the VNK2 project, flood probabilities are quantified in a Bayesian framework, taking into account the uncertainties related to loading conditions, resistances, and empirical models. The infinite range of potential flood scenarios is characterized by a limited set of mutually exclusive and collectively exhaustive scenarios. Probabilities are calculated for each of these scenarios on the basis of the flood probabilities per failure mechanism and dike section. The consequences per flood scenario are estimated using flood propagation models, land-use data, and profit-functions. The various possible outcomes of evacuation attempts are estimated on the basis of event trees. Economic and fatality risks are calculated by combining the probabilities of flood scenarios with the consequences associated with these scenarios. Various risk metrics are considered in the VNK2-project, ranging from expected values per dike ring to cumulative distributions and individual exposures”.*

In this section we will present the results for dike-ring area 14, one of the largest and most vulnerable dike ring area in the Netherlands. In Figure 2.2 the altitude of the dike ring area is given.

The calculated flooding probability of the main flood defences in dike ring 14 equals 1/16.000 per year (VNK, 2011). All failure mechanisms are included in this probability. Table 2.1 specifies the calculated probability of failure per failure mechanism for this dike ring.

Table 2.1 Failure probabilities of dike-ring 14 (VNK, 2010)

Type of flood defence	Failure mechanism	Yearly probability
Embankment	Overtopping	1/34.000
	Macro-stability	< 1/1.000.000.000
	Piping	1/95.000
	Failure of revetment	1/170.000
Dunes	Erosion of dunes	1/44.000
Structures	Overtopping	1/1.150.000
	Construction failure	1/6.500.000
	Piping	1/1.200.000

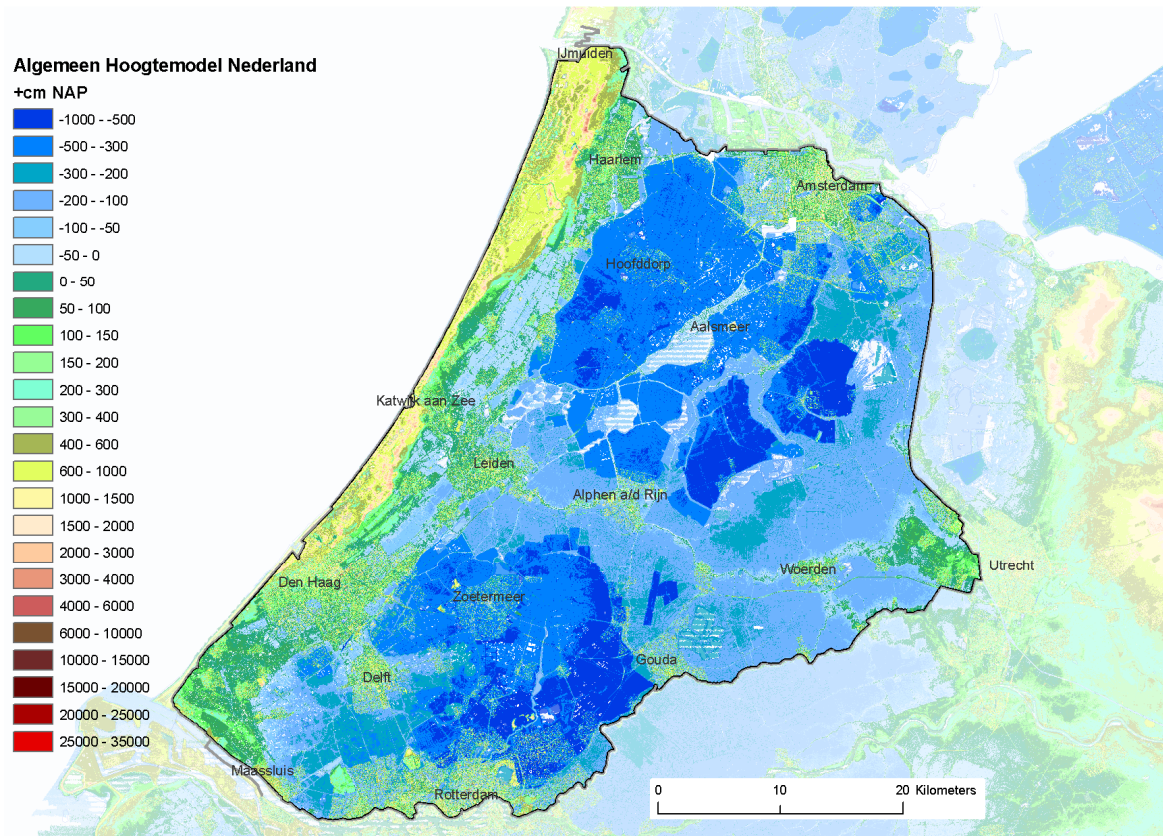


Figure 2.2 Altitude of dike-ring area 14, Central Holland. The blue area lies below average sea level (NAP). Extreme storm surge flood level can reach 5 m above average sea level (VNK, 2010).

The consequences of flooding are economic losses and loss of life. These consequences occur if there is a breach in the dike ring (also multiple breaches can happen). The flooded area is calculated with a hydraulic model, and one of the scenarios is presented in Figure 2.3 (various flood events ('scenarios') can happen, and in the VNK project many (>100) events have been calculated). The figure shows that one event is likely to cause the flooding of only a part of the dike ring area.

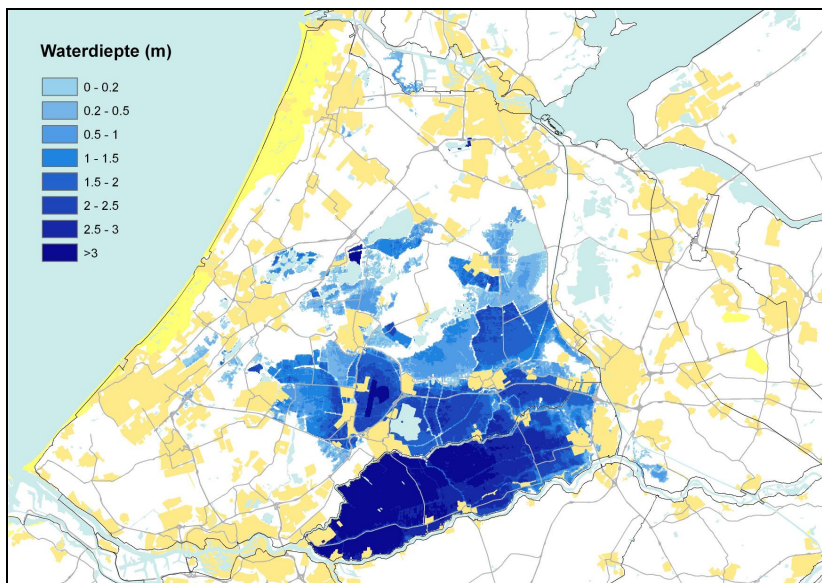


Figure 2.3 Area which may be flooded through a breach along the Lek River (VNK, 2010).

The flood risk is calculated as the flooding probability multiplied by the consequences, per scenario. The overall risk is the sum of all scenarios, for more details see Jongejan et al. (2011) and VNK (2010). In figure 4 the FN curve is plotted: it shows the number of victims (on the x-axes) and the (cumulative) probability of exceedance (on the y-axes).

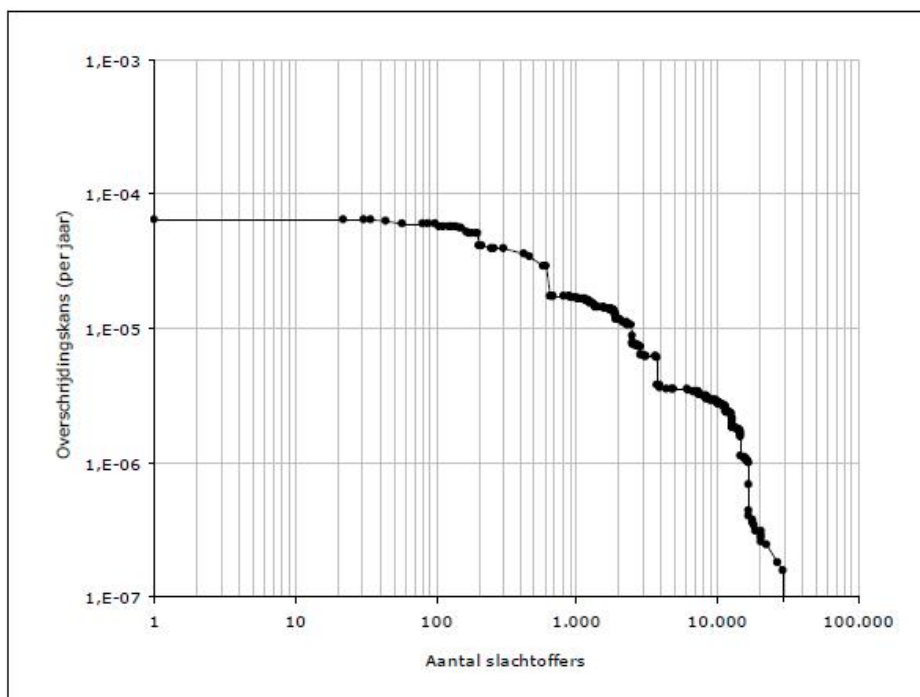


Figure 2.4 The FN curve: relationship between the number of victims and the exceedance probability. Each dot represents a flooding event/ scenario (VNK, 2010).

Based on the VNK results it is possible to assess the impact of measures to improve the flood defences, and to assess the impact of other measures, like for example room for the rivers, to improve the evacuation plans, etc.

2.2.3 Failure probabilities of storm surge barriers

Storm surge barriers can be an effective way of controlling flood levels. The main barrier in the Rhine Meuse estuary is the Maeslant Storm Surge Barrier (Figure 2.5). The reason of the building this barrier is well described in Wikipedia: *“The construction of the Maeslantkering was a part of the “Europoortkering”-project which, in turn, was the final stage of the Delta Works. The main objective of this Europoortkering-project was improving the safety against flooding of the Rotterdam harbour, of which the Europoort is an important part, and the surrounding towns and agricultural areas. This had to be carried out by the reinforcement of existing dikes as far as 50 kilometres inland. During the 1980s it became clear that this project would take at least 30 years and would cost a huge amount of money. It would also mean that historic town centres, sometimes built more than four centuries ago, had to be broken down and rebuilt behind renewed, larger dikes”.*

Hence, building a barrier was an attractive option, and a dam was not an option because it would restrict the entrance to the harbour of Rotterdam.



Figure 2.5 The Maeslant Barrier

The barrier is a unique and complex object. It therefore cannot be ruled out that the barrier fails during closure. For most problems, procedures and remedial actions are defined to do a proper closure. Nevertheless, there remains a chance that the closure fails and we say that the barrier fails. The non-availability of the barrier is expressed as a probability per closing demand. At this time, the probability of failure of the Maeslantkering should not be greater than 1/100 per closing demand. We call this the failure probability requirement. In other words, during a storm, the reliability of the barrier is at least 99%. A failure probability of 1/100

per closing demand means that we expect on average once in a hundred closures the barrier is not properly closed.

The *probability of failure performance* of the Maeslant Barrier is determined with the aid of a fault tree. In this fault tree are all the basic events defined that may lead to the failure to close the barrier ('top event'). In the case of the Maeslant Barrier the top event is equal to 'failure of closure'. This means that something is happening which causes that the barrier cannot fulfill its function. By redundancy in the system, it is not the case that a single incident can cause that the entire barrier fails. This redundancy is incorporated in the fault tree, and hence the probability of failure of the barrier is determined using the redundancy. At the time of writing, it follows from the fault tree that the probability of failure of the performance of the Maeslant Barrier is equal to approximately 1/110 per closing demand.

To date, virtually all technical and organizational measures have been studied to reduce the probability of failure of the Maeslant Barrier. Many of these ideas prove ineffective or even practically impossible. However, the impact of a lower failure probability is significant: Figure 6 shows the impact of a failure probability of 1/1000 instead of 1/100 of the Maeslant Barrier.

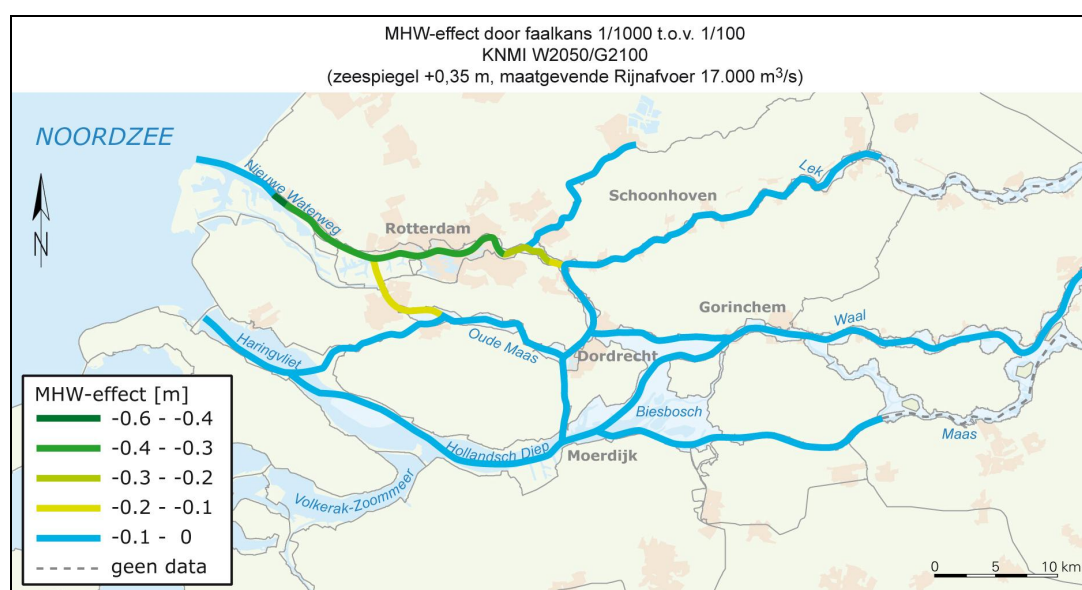


Figure 2.6 Impact of a smaller failure probability of the Maeslant barrier (1/1000 instead of 1/100) on design water levels (Slootjes et al., 2011).

Rijkswaterstaat investigated the presumption that a partial closure of the Maeslant Barrier can have a significant impact on water levels behind the barrier. The idea is as follows: if there is a problem when the barrier is not 100% functioning, it may be possible to partially close the New Waterway and in this way the water levels behind the barrier can be lowered. By "partial functioning" we mean a partial closure of the barrier. The purpose of a partial closure event is in case of failure to minimize the consequences. Hence, the question which has been addressed in the Knowledge for Climate project is the following:

Does the incorporation of the partial functioning of the Maeslant Barrier produce significantly different design water levels? The hypothesis is that the Maeslant Barrier,

even when not (yet) completely sunk, may significantly lower the water level behind the barrier.

This question is answered in a dedicated report written in the context of Knowledge for Climate (Botterhuis et al., 2012), using a fault tree analysis, hydraulic calculations and a probabilistic analysis. In this section we only summarize the hydraulic calculations.

The impact of “partial functioning” on the water levels in Rotterdam (with exceedance frequency of 1/10,000) is presented in Figure 2.7. This figure is complex, and we will explain this figure. The figure shows the difference in water levels relative to the current design water levels. The water levels are decreasing, because partial functioning of the Maeslant barrier is better than complete failure of the barrier. The impact of partial functioning also depends on the relative contribution of partial functioning. The contribution can be small (5%) or can be high (95%) or somewhere in the middle (25, 50, 75%). If the contribution is high, than the design water levels can decrease with almost 0.2 meter.

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 decreases with 0.12 meter, and that is significant. However, more research is needed whether the barrier does have enough strength to function in this condition, and whether additional operational measures are needed to control this situation.

Based on the results of the Knowledge for Climate study, the Delta Programme Rijnmond-Drechtsteden asked to study the impact of “partial functioning” in more detail. The results will be published in the annual report of the Delta Programme.

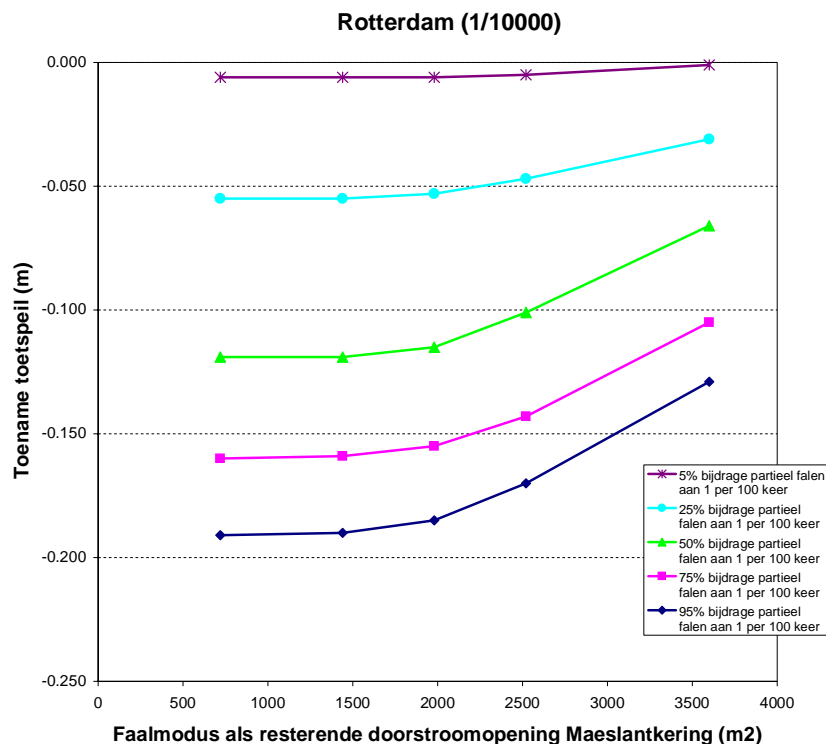


Figure 2.7 Impact of partial functioning on the ‘design water level’ in Rotterdam (difference with current design water level, the different lines refer to different failure contributions of partial failure), The x-axis refers

to the opening of the New Waterway with 0 as completely closed and 1800 m² as 50% closed, and the y-axis refers to the decrease in design water level

2.2.4 References

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2.3 Room for Rivers for lowering flood levels

Frans Klijn & Nathalie Asselman

2.3.1 Introduction

In the 1990-ies the Netherlands experienced two major floods within a few years, in winter 1993/1994 and in 1995. During the second flood, about 250.000 people were evacuated, but luckily the defences held.

The floods triggered both a rapid reinforcement of the existing embankments and a policy change with respect to dealing with river floods. The reinforcement was implemented after many years of opposition and debate about whether or not and how to reinforce the embankments, as the reinforcements had proven to demolishing highly appreciated natural and cultural landscape values. The policy change – or transition – was thus partly inspired by a re-valuation of natural and cultural heritage, but also partly because arguments related to sustainable flood risk management were introduced into the debate (cf. Van Heezik, 2007; 2008). Finally, alternatives to reinforcing the embankments were proposed and appeared feasible.

The arguments related to flood risk management involved:

- The higher the flood levels in the river, the larger the loading on the defences, the larger the probability of insufficient strength (which might cause moving, slumping, sliding or piping).
- The higher the flood levels in the river, the deeper the flooding depths, the larger the consequences.

Moreover, it was established (Klijn & Stone, 2000; Asselman & Klijn, 2001; summarized by Klijn et al., 2002) that both the Rhine River and the Meuse River were deprived of a huge surface area of available floodplain, which was reclaimed in the last 150 years and even as

recently as in the 1960-ies (Figure 2.8). This obviously results in higher flood levels, as for a certain discharge a certain cross section is needed.

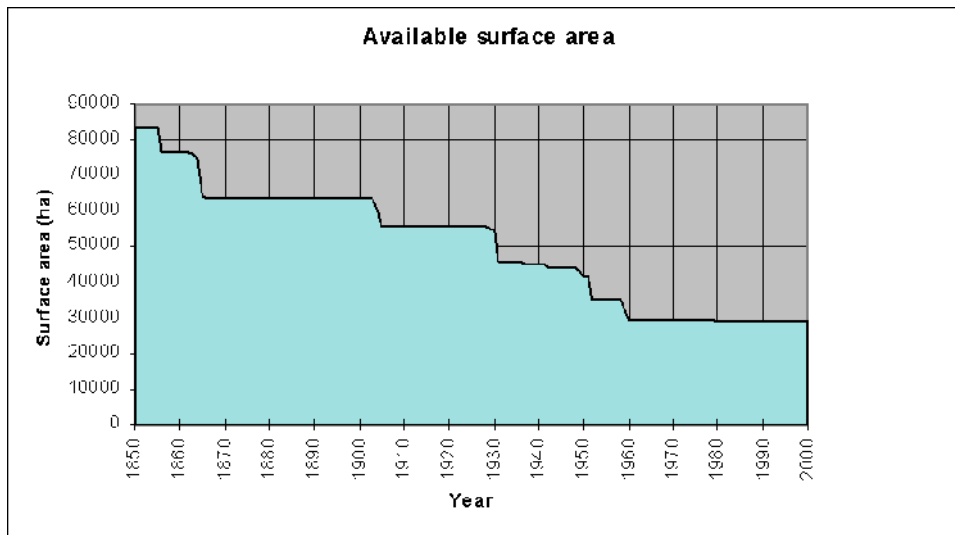


Figure 2.8 Available surface area for the non-tidal Rhine Branches in the Netherlands over time, showing large losses of available floodplain area as recent as the 1960-ies.

Additionally, it was argued that the protected land, which primarily consists of backswamps, 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. And potential flood consequences too.

Next, the steadily improved protection of the land allowed more intensive development. The population grew fast and the damage potential also increased, especially between the 1950-ies and 2000. The absence of flood disasters since 1926 meant no incentive to reserved development. This requires revising the protection levels (Ten Brinke & Bannink, 2005; Kind et al., 2011) High protection levels and subsequent development, followed by a call for even better protection, followed by further development, et cetera is often described as a vicious circle, or rather: spiral.

Altogether, these facts and arguments supported a policy transition. In 1995 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. Or returning some of the room taken from it, one might say. Raising the embankments was to be considered a last resort only, when making more room would prove impossible or totally unfeasible.

This policy change immediately came into practice, when in 2001 the design discharge was revised. The 1993 and 1995 flood had caused the 1: 1250 years discharge to increase to 16.000 m³/s instead of the previous 15.000 m³/s. This revision was according to the then prescribed schedule of re-assessing the hydraulic design parameters and the existing infrastructure every 5 years⁴. The higher discharge translated into about 0.3 m higher design

4. This was according to the Flood Protection Law (1996), which is now incorporated in the Water Law; the schedule has been changed to 6 years and is about to be changed to 12 years (mainly for budgetary reasons).

flood levels. This would require raising the embankments, or lowering the flood levels by 0.3 m on average.

Under the co-ordination of RIZA (Silva et al., 2001) various types of measures were defined and assessed on their hydraulic effect and approximate costs: to what extent could they lower the flood levels, and against which investment? The research comprised the following types of measures: storage by upstream retention or detention in order to lower the peak discharge, and increasing the discharge capacity of the river by excavating the river bed, lowering groins, lowering floodplains, removing obstacles from the floodplain (bridge abutments, mounds for housing or industries, dense vegetation), setting-back embankments and creating bypasses (floodways or 'green rivers' and bypass channels).

This yielded general knowledge on the hydraulic effects of each type of measure, as well as on the costs and relevant side-effects, e.g. on number of houses to be removed, agriculture, nature, scenery, etc. Based on this general knowledge, which was first published and thus shared with the relevant stakeholders, plans for individual measures were solicited for concrete locations along the three Rhine River branches. This yielded about 700 individual measures that were analyzed in a consistent manner. In order to facilitate the selection of an acceptable set of about 40 measures out of these 700 options in a multi-stakeholder participatory setting and within financial constraints, a 'Planning Kit' was developed (De Vriend & Dijkman, 2003; Van Schijndel, 2005; Figure 2.9).

With this Planning Kit 'Room for the Rivers' the authorities and stakeholders jointly selected 39 measures (Van der Most et al., 2006; Figure 2.10), which together lower the flood level over the whole length of the river to below the previous design water level. It was then decided that these 39 measures were to be implemented, which decision was given a legal base through a national 'Spatial Planning Key Decision' (PKB). In this decision, 1) the individual measures were mentioned, 2) their individual contribution to lowering the flood-water level specified ('hydraulic task'), 3) a second objective defined, viz. to enhance the 'spatial quality' of the area. Also, a budget of 2.3 billion euros in total was made available for their implementation, and a programme director and staff were installed (in 2006).

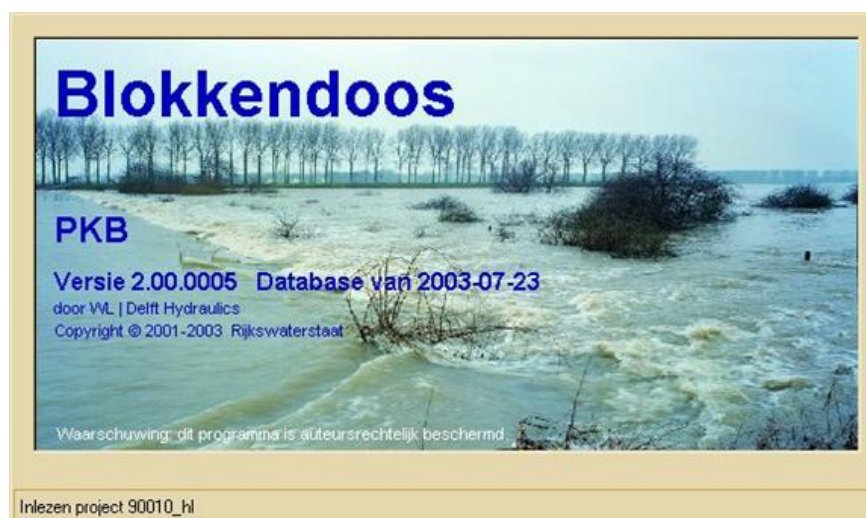


Figure 2.9 Opening screen of the Planning Kit Room for Rivers, which facilitates joint planning (www.wldelft.nl/soft/blokkendoos/)

For the next planning stage the national government considered it a good idea to preferably have the initiative for the detailed planning and design taken by local, regional or private parties. With strict constraints on hydraulic effect and budget, that is. Thus, the local stakes might be better taken into account in the designs, the commitment to the plans greater, and finally the support for implementation as large as possible. This expectation is now coming true in the majority of the cases (Q-team, 2012). Most plans are now being fixed or have already been decided on. For some implementation has already begun. All measures will be effective by 2015.

At the start in 2006, the programme director also had a quality team installed by the then minister of Traffic, Public Works and Water Management. This so-called Q-team is chaired by the then National Advisor for the Landscape (prof. Dirk Sijmons) and was given the assignment to coach the planners and designers, to peer review the designs and plans, and to report to the minister about the Spatial Quality achieved. Reason to install this Q-team was the second objective of the Room-for-the-Rivers programme, viz. *to enhance the spatial quality*. Spatial quality is a poorly defined concept, and not at all quantifiable. In contrast to flood water level, which can be assessed by hydraulic modelling. Still, the national Court of Audit (Algemene Rekenkamer) must be able to assess whether the government's spending of public money has been effective ('as intended') and efficient. This calls for proof, also about spatial quality, which is partly provided by the Q-team's annual reports (Q-team, 2008, 2009, 2012).



Figure 2.10 The 39 measures which together constitute the Room-for-the-Rivers programme are distributed along all 3 branches of the Rhine River.

2.3.2 Kind of measure

Silva et al. (2001) distinguished measures to 1) reduce the flow of water in the river, to 2) temporarily store water from the river, or to 3) increase the discharge capacity of the river. This corresponds with retention, detention, and discharging (cf. Hooijer et al., 2001) or with withhold, store, respectively discharge. The first measure cannot be considered a room-for-the-river measure, but both room for storage and room for extra discharge can be.

Both Silva et al. established that **retention** in the catchments could not effectively reduce the discharge of the downstream stretches of the large rivers in the Netherlands with their high protection levels. Retention may be effective for floods with a probability of 1:10 to 1: 100 years, approximately, but cannot reduce the discharge of even rarer floods. In extreme situations, the catchments of Rhine and Meuse are either already fully saturated or snow-covered and hydrologically respond 'as if they were paved'. As the Netherlands' flood protection along the large rivers is based on protection levels of 1: 250 years (upper Meuse valley) to 1: 1250 years, retention cannot reduce the – for us – relevant flood levels.

Storage of water may lower the downstream water levels in rivers by removing part of the discharge: the so-called peak shaving. This requires huge storage areas of sufficient capacity as far upstream as practically possible. From the Netherlands perspective this would be at or even beyond the border with Germany, respectively Belgium. Such areas are difficult to find, but a number of possible sites have been proposed and are included in the Planning Kit. Silva et al (2001) ask attention for the questionable reliability of detention areas: they must still be empty when the flood peak arrives (so not be opened too early), and they should be empty again as soon as possible after a flood wave has passed, in order to be able to accommodate a next peak of double peaked flood. This makes them quite unreliable, or their capacity should be very large, which requires over-dimensioning. In the Planning Kit, therefore, all detention basins are treated as having a capacity of half or even less their actual volume by applying a 'Silva-factor' for 'true capacity'. In the 'Spatial Planning Key Decision' (PKB) on room-for-the-rivers, it has been decided not to include any detention measures, because of their relative uncertain effectiveness, and instead to save these for later moments when climate change would progress or for beyond-design discharges (calamity measure).

Enhancing the **discharge** capacity of the rivers is the best known, and most sincere substantiation of room-for-rivers. It aims at increasing the conveyance of the floodwater. It may comprise:

- Measures in the low-flow channel
- Measures in the flood plains
- Measures in the protected areas

In the low-flow channel two measures may be taken: lowering the river bed by dredging sand or other sediments or lowering the groins.

Lowering the river bed has immediate effects on the water level upstream of and at the site of intervention. It, however, also causes a rapid morphological response of the river, which will erode in upstream direction and, in contrast, cause a rapid sedimentation in the dredged area. Such a measure is, therefore, never sustainable but will 'repair itself'. It will require constant maintenance and cause unwanted scouring of the river bed further upstream, with potentially negative consequences for the navigability of the shipping channel.

Lowering the groins causes the lowering of all water levels, which exceed the groin levels. Groins are designed to let the river maintain its own shipping channel through forcing the flow into a certain pathway (cf. Kleinhans et al., 2012). This process is especially effective when

the groins are not yet drowned, and gradually less the further they are submerged. Lower groins, however, are less an obstacle for above-average river discharges. Thus, lowering the groins causes the flood levels to drop (Silva et al., 2001).

In the floodplains, the conveyance can be enhanced by removing obstacles, such as bridge abutments, factories on mounds, etc., or by lowering the floodplains themselves. Removing obstacles often involves the removal of man-made elevations which hinder the free flow of the river and hence cause backwater effects.

Lowering the floodplains proper can be regarded as mimicking a natural erosion process, which occurs in natural rivers. In natural rivers, the channels can move freely and erode their own banks away, whereas in the Netherlands' regulated rivers the channel is kept in place causing the active floodplains to steadily silt up further and further. Asselman (1997) established that the floodplains along the Rhine River branches are now about 1.0 m higher than a century ago. This requires that 'eroding the banks away' must be done by human interference: by artificially lowering the floodplains. When this interference is performed repeatedly, this is addressed as 'cyclic rejuvenation' (Baptist et al., 2004; Baptist, 2005; Peters et al., 2006); a term long used by geomorphologists to indicate the natural development of free-flowing alluvial rivers.

Measures in the protected areas comprise relocating embankments and creating bypasses which function as floodways (also called 'green rivers'; Klijn, 2003). Both measures literally imply 'giving back' floodplain surface area to the river. With relocations, the existing embankment is removed and a new primary flood defence is constructed further inland. Bypasses are rather 'floodplains between two embankments', entirely newly constructed in situations where built-up area behind the existing embankment makes it impossible to remove it. Currently, 5 dike relocations are being implemented (Overdiepse Polder, Munnikenland, Nijmegen, Cortenoever and Voorster Klei), and along the IJssel River two bypasses are being constructed (between Veessen and Wapenveld, and near Kampen).

2.3.3 Effectiveness

Retention and storage affect the discharge of the river (i.e. Q in hydraulic formulas). Any reduction of the discharge causes lower water levels downstream of the site of intervention, as Q is the upper hydraulic boundary conditions. Enhancing the discharge capacity affects the water level on the site of intervention, as well as immediately upstream of this location, and then it gradually fades out further upstream. This is because enlarging the discharge capacity lowers the water level (i.e. h in hydraulic formulas; the lower hydraulic boundary condition), which in turn reduces the backwater effect.

The effect on the water level of all 700 room-for-river measures has been calculated by means of hydraulic modelling. An example of a result of such calculations is shown in figure xx, which shows how much the design water level upstream of 'bottleneck Nijmegen' would drop as a result of relocating the embankment on the Lent-side of the river, respectively as a result of creating a bypass (for a design discharge of $16.000 \text{ m}^3/\text{s}$ on the Rhine River; Silva et al., 2001).

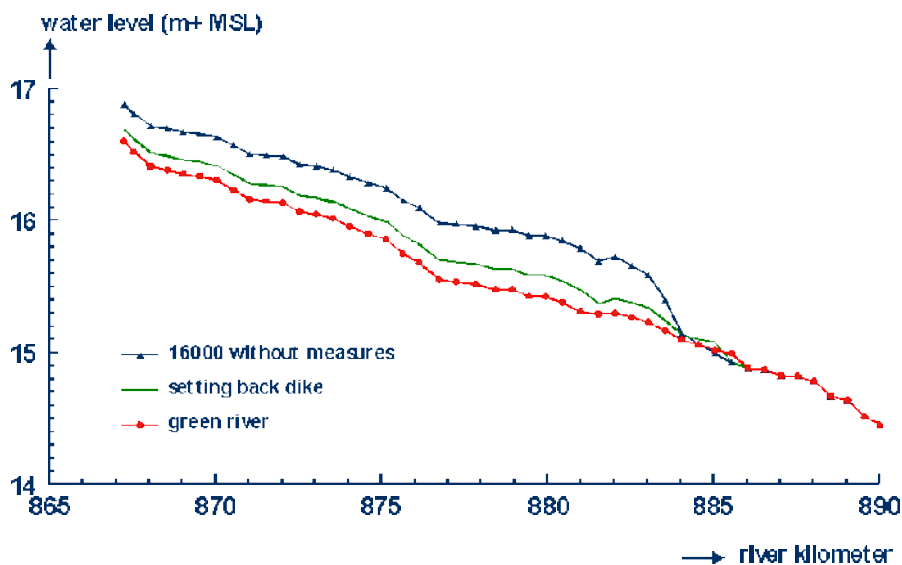


Figure 2.11 Effect on design water level of relocating the embankment at Lent (setting back dike), respectively realizing a bypass behind the village of Lent.

These hydraulic effects can be considered to be measures for effectiveness too, if we, according to a proposal by Jos Dijkman and Wim Silva, focus on:

- 1 The maximum lowering of the design water level in mm;
- 2 The total lowering of the design water level in m^2 , i.e. the integral (surface area) of the lowering of the design water level and the extent of it (upstream and/or downstream).

In Figure 2.11 this would correspond with the maximum difference between the red (or green) line and the blue line in mm, and with the surface area between the red (or green) line and the blue line over the full length of the graph (which is obviously too short in the figure!). These two measures can be used to compare the different measures on effectiveness.

In a gross simplification, Van Rooij et al. (2000) presented the following coarse guidance on hydraulic effectiveness in terms of water level lowering for the *upstream* Rhine River branches (disclaimer: not to be used outside this area, to be used as gross estimate only, dependent on local conditions and upstream and downstream context):

- Lowering of river bed by 1 m: 0.3 m
- Lowering of groins by 1 m: 0.1 m (only when sufficiently long)
- Lowering of floodplain over the whole width by 1 m on average: 0.3 m
- Widening of floodplain by relocating embankment with 500 m: 0.3 m (much more at bottlenecks)
- Widening of floodplain by adding a bypass of 500 m wide: 0.3 m ((much more at bottlenecks)

For each measure, Van Rooij et al. (2000) assumed implementation over long lengths. For the Planning Kit, the location specific effectiveness has been calculated for each of the 700 measures. And this – of course – takes into account the precise spatial and morphological context.

The effect of making room for rivers on **flood risk proper** has never been properly quantified yet. In the context of this KfC research programme, this is however, what we are primarily interested in. And also for the Delta Programme Rivers, the risk reduction that can be achieved by making room for rivers is a key question. In the case study we did on the IJssel Valley (Mens, 2012; see chapter 6), we paid some attention to this subject. And the Delta Programme Rivers did some first quantitative analyses on dike-ring areas along the Meuse River (Asselman et al., 2012).

These first investigations rely on the following reasoning about the likely risk reducing effects:

- 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 (see Chapter 6)
- 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. In the FLORIS-project this is called the length-effect (VNK, 2011).
- 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, as the flooding depth may increase, or decrease, as the flooded area may be smaller.

The first two effects are relatively easy to understand and operationalise in terms of reduced risk. The third is quite complicated and requires sound and validated knowledge about the fragility curves that apply for all embankments along the rivers. Presently, this is regarded as being too complicated to take into account yet. The fourth effect is also very difficult to operationalise, especially as the length-effect as such already mainly relies on expert-judgement. Effect number 5 can be included in risk analyses by distinguishing a larger number of (smaller) dike-ring areas.

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. These 'decimation values' refer to the difference in water levels a factor 10 apart in probability, e.g. between 1: 100 and 1: 1.000 or 1: 1000 and 1: 10.000. Asselman (unpublished) found that this value is very sensitive to the range over which it is calculated. This may cause it to vary with a factor of about 2 at least, according to 'method applied'.

Still, the 'decimation values' along the Netherlands' Rhine Branches and in the lower Meuse River are relatively typical for the very river in relation to its discharge. This relates to its

planform and the ratio between channel width and floodplain width as well as floodplain height. For the Upper-Rhine the values are about 0.8-0.9 m, for the IJssel River it ranges from 0.3 to 0.8 m, but with a centre of gravity of about 0.7; in the Nederrijn/ Lek it ranges between 0.6 and 0.8 m, and in the Waal values of 0.8- 0.9 m apply, as this very much resembles the Upper Rhine.

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 (NB: the scale used for decimation values is logarithmic). 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.

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. In Chapter 6 some results are given for the IJssel Valley, which is a natural valley with favourable relief. Here a reduction of economic damage of about 20% can be achieved by giving the river more room (Mens, 2012). Along the Rhine and Waal Rivers, with their bigger discharge, high river water levels and deep polders, the effects are expected to be much less.

The combined effect of smaller flooding probability and smaller consequences pays out in terms of reduced flood risk. But this effect can only be calculated for specific cases, and may not be generalized too easily.

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.

2.3.4 Cost-effectiveness/ efficiency

For cost-effectiveness, measures were proposed for use in the Planning Kit in relation to how effectiveness was treated. Where effectiveness was expressed in mm or m² lowering of the design water level (see above), cost-effectiveness was expressed as mm/ million € or m²/ m€. This allows to select the most cost-effective measures for each river branch or river stretch. This criterion was taken into account during the selection of the measures that are now being implemented.

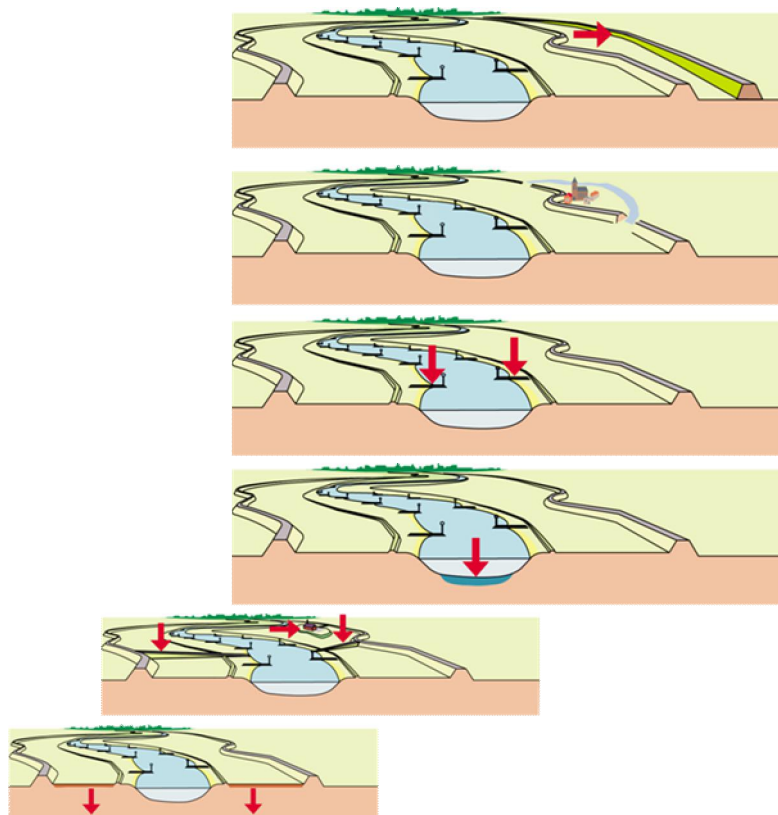


Figure 2.12 Relative cost-effectiveness of room-for-river measures from very cost-effective (top) to relatively costly (bottom)

A generalized conclusion on cost-effectiveness was drawn by Silva et al. (2001), and is depicted in a schematic way in Figure 2.12. Silva et al. found that relocating embankments, bypasses, lowering groins and lowering floodplains yielded the largest design water level effect per million euros invested. The most 'expensive' measures, from this point of view, were the removal of hydraulic obstacles and lowering floodplains. The latter especially because of the expected high costs of the safe storage of polluted floodplain sediments.

This sense of cost-effectiveness is, of course, not a useful measure in a full-fledged CBA, as we have not compared the full societal effect – comprising at least the intended reduction of flood risk – with the investment made to achieve this. The CPB National Bureau for Economic Policy Analysis reviewed the national 'Spatial Planning Key Decision' (PKB) and concluded that the plan at large was cost-effective (Ebregt et al., 2005), but that for some measures this was doubtful. The general cost-effectiveness was largely due to the positive side-effects on spatial quality: natural and cultural heritage and aesthetic landscape values.

Now this positive side-effect on spatial quality differs per measure. First per kind of measure, and then for each kind of measure per specific location and quality of re-design. Per kind of measure, Klijn et al. (2002a) gave a rough estimate of each measure's respective contribution to spatial quality with special emphasis on nature development. They were very positive ('most desirable') about relocating embankments, bypasses and removing obstacles, as these measures either add sheer surface area to the floodplain, or reduce the visible remains of human activity (artefacts). This enhances the naturalness of the area and the diversity of natural habitats. Lowering groins or riverbed was judged 'neutral', whereas lowering

floodplains was judged as 'less desirable' as this would disturb the natural relief and soil archive of the landscape's genesis.

2.3.5 Side-effects

The side-effects of making room for the river are manifold, e.g. on agriculture, nature conservation, housing, cultural heritage, recreation possibilities, costs, groundwater levels and drinking water supply, shipping, etc. These effects have been described in detail by Silva et al. (2001). And for the Planning Kit the relevant side-effects of all 700 measures, which have been taken into account for the 'Spatial Planning Key Decision' (PKB), have been quantified or otherwise specified. The same approach is now followed for the Delta Programme. Therefore, we shall not go into this issue here any further.

An exception is made for the concept of spatial quality, as this is a key concept for the room-for-rivers project. The Netherlands' government – in its Key Decision (PKB) – stated that the measures should lower the water levels to below the design water levels and that the measures should enhance the spatial quality of the area and its surroundings.

Spatial quality is a difficult to define concept. The Q-team (Quality team Room-for-the River, 2012) refers to the roman architect Vitruvius, who stated that a good design meets three key criteria: *utilitas* (or: functionality), *firmitas* (firmness or solidity) and *venustas* (beauty). This was translated into 1) hydraulic functionality as well as enabling relevant everyday other functions such as recreation, traffic, housing, agriculture, etc., 2) a design which is expected to last for many decades or even centuries through its geo-ecological robustness (self-sustained by building on natural processes, requiring little maintenance) without being (dis)qualified as 'typical early 21st century fashion', and 3) enhancing the scenic beauty of natural, countryside or urban environments (depending on location and context; Figure 2.13) by taking into account the existing landscape diversity at various spatial scale levels (river branch, stretch and site).

Each of the measures was thus designed not only from a hydraulic point of view but also in order to enhance the spatial quality, tuned to the location and the local requirements and desires, fitting in the specific regional context, and adding to the national green-blue ecological main structure (cf. Natura 2000).



Figure 2.13 Example of one of the hydraulically most effective measures, which thanks to its eminent design team also greatly enhances the spatial quality, through – among other things – a second waterfront for Nijmegen city's north bank, larger recreational potential (boulevard, event terrain, beaches, rowing course), and better ecological connectedness of floodplain ecosystems. Present situation (left) and future situation (right).

2.3.6 Applicability and attractiveness

Summarizing, 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. Still, making room for rivers helps to reduce the load on the defences, and thus reduces the probability of failure; and it may result in smaller flooding depths and flood extent, and thus reduces the consequences. The combination is an effective reduction of flood risk.

The effects on these risk constituents are valid arguments to prefer making room for rivers above raising embankments. Making room for rivers is, however, usually more expensive than raising embankments. In many instances, the extra costs are justified by taking into account the side-effects on spatial quality (in the broadest sense).

Making room for rivers remains a very good means to lower flood levels in non-tidal river reaches. In downstream river stretches the conveyance capacity of the river is no longer the key factor which determines the water level; sea level becomes determinant. This limits the effectiveness of making room for water.

Making room for rivers is thus 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 (Asselman et al., 2012).

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2.4 Wave attenuation

Jantsje M. van Loon- Steensma & Mindert B. de Vries

2.4.1 Wetlands and their vegetation: salt marshes and 'floodplain forests'

Under pristine conditions, there would be a vegetated transition zone from land to water and from fresh water to salt water on many locations in a deltaic area. This shallow zone influences incoming waves, and functions as a natural flood defence (e.g. Brampton, 1992; King & Lester, 1995; Möller et al., 2001; Costanza et al., 2008; Gedan et al., 2011). The vegetation in this transition zone is adapted to its dynamic environment. In the temperate zone, the vegetated intertidal area on elevated and sheltered areas along the coast is known as salt marsh (Adam, 1990). In the riverine area, the area with flooding-resistant shrubs and trees is called 'floodplain forests'. If these forests are regularly flooded, cultured and regularly cut, 'grienden' (willow coppice) are formed.

During the last centuries, large stretches of both wetland types were embanked and reclaimed for agricultural use or for urbanisation. Starting from the 1970s, the importance for nature and biodiversity of wetlands was recognised, leading to conservation and restoration projects and since recently the attention for the role of wetlands for water safety is increasing. Policy makers at different institutional levels as well as water boards, nature interest groups, private companies and scientist take initiatives to explore the natural flood defence values of vegetated shallow forelands (e.g. the Dutch Delta Programme, Natural Climate Buffers programme, Building with Nature programme, EU project COMCOAST).

Salt marshes

Coastal salt marshes are defined as areas vegetated by salt-tolerant plants that are subject to periodic flooding as a result of fluctuating water levels of adjacent saline water bodies (Adam, 1990) (Figure 2.14 left). Due to this dynamic environment, salt marsh vegetation is species-poor (Adam, 1990). Salt marshes generally occur high in the intertidal zone in sheltered conditions, where wave action is limited so that fine sediment can settle and accumulate (Allen & Pye, 1992).

Once the upper part of the intertidal zone is not continuously submerged, salt-marsh plants can colonize and establish and contribute to the trapping and accretion of sediment. Because of the positive feedback between salt marsh vegetation and sedimentation, salt marsh vegetation forms an important aspect in salt marsh geomorphology (Allen 2000). The vegetated area grades seaward into mud or sand flats, from which the vegetated environment often is separated by either a ramp or cliff (Allen and Pye 1992) ((Figure 2.14, right). Both saltmarshes and the fronting mudflats are an integral part of the intertidal profile (Pethick, 1992). The marsh may experience lateral accretion and/or erosion, which depends on changes in wind-wave climate. During the growth of a marsh, a creek system develops which contributes to grow conditions for vegetation by drainage and in the supply of sediment (Dijkema et al., 2001).



Figure 2.14 Flooded salt marsh (left) and eroding salt marsh (right) at south side of Wadden Sea barrier island Ameland (photographs: J.M. van Loon-Steensma).

The main physical factors that control the dynamic behaviour (vertical and lateral accretion and erosion) of salt-marshes are sediment-supply, tidal regime, wind-wave climate, sea level rise (Allen, 2000) in interaction with species specific traits of pioneering salt-marsh vegetation (Temmerman et al., 2007).

Salt marsh sediment which erodes during a storm may be re-deposited as sand and silt banks. This helps to protect the system from further storm waves, by reducing the amount of wave energy reaching the edge of the marsh cliff (Pethick, 1992; Haslett, 2009). Like most coastal sedimentary systems, salt marshes are extremely sensitive to changing environmental conditions. Changes in sediment accretion (controlled by suspended sediment concentration, inundation frequency, water depth and vegetation characteristics such as density and stiffness) and erosive processes are amongst the principal controls on salt marsh morphology and morphodynamics, and in particular in determining the position of salt marsh shorelines and the structure of channels. During periods when the influence of erosion is greater/less than the horizontal accretion of sediment, the marsh shoreline will retreat/advance. This process of retreat and advance could form part of a natural cycle of salt-marsh rejuvenation (Van der Wal et al., 2008).

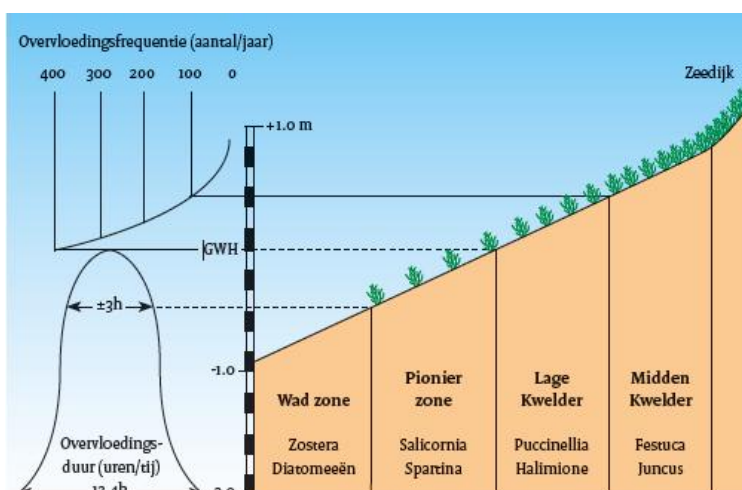


Figure 2.15 Outline of zonation and frequency of inundation (after Erchinger in: Dijkema et al., 2001)

In the marsh ecosystem, not only a zoning between the vegetated area and the fronting mud or sand flats can be distinguished, but also within the vegetated area a strong spatial zoning occurs (Figure 2.15). From the mean high water neap tide (MHWN) boundary the elevation increases land inward, while height, length and frequency of inundation by saline water decreases. This provides typical and valuable habitats, from a zone of pioneer species seaward well adapted to daily tidal flooding (e.g. *Salicornia* spp., *Spartina anglica*), grading landward to a more mature community (e.g. *Puccinellia maritima*, *Suaeda maritima*, *Aster tripolium*, *Limonium vulgare*) (Van Straaten, 1964; Dijkema & Bossinade, 1990). The boundaries of the zones are usually determined by geomorphological variables like frequency of inundation, sedimentation and erosion, which are in turn related to geological, climatological, vegetation and land use history (Doing, 1995). The floristically most diverse part of the salt marsh is the zone which submerges regularly, but not daily. In the zones that are hardly flooded, the vegetation diversity decreases with on-going succession (Dijkema et al., 2001). In a dynamic environment, the succession process is cyclic due to erosion and sedimentation. A management regime of grazing can delay or even inhibit succession and keep the salt marsh vegetation diverse and in a juvenile stadium of succession (Dijkema et al., 2007).

Forests in floodplains

Under natural conditions, forest dominated by species of willow will develop in regularly flooded parts of river floodplains upstream to the fresh water tidal zone, (www.natuurkennis.nl). However, this type of willow forests has become rare in Europe due to antropogenic influences. Especially the construction of dikes that protect large swaths of former floodplains against flooding and the use of those areas for agriculture and infrastructure have decimated this type of alluvial forests. The willow forests that grow in freshwater tidal systems are especially rare and are only found in Flanders (along the river Scheldt).

In general, the natural type of this willow forest is the result of the pioneering traits of some willow species, whose seeds are available in abundance in rivers and floodplains. In the pioneering phase, a mixed growth of willow shrubs consisting of *Salix alba*, *Salix viminalis* and *Salix triandris* often dominant, accompanied by *Salix purpurea* and on riverside sandy beaches the Black Poplar (*Populus nigra*). In later phases of succession, willow trees will become dominant (a mix of *Salix alba* and *Salix fragilis* species), with trees reaching a height of 25m (www.natuurkennis.nl).

The cultivated form of this floodplain willow forest is called 'griend'. This type of forest consists of planted and intensively cultured willow and poplar species. In the Netherlands grienden are cut in yearly to five yearly intervals, depending on the species (up to 50 willow and poplar species were used, amongst others the species occurring in natural willow forests and cultivars) and the application of the harvested branches (from binding-ropes to cask-making to dike construction with 'rijsmatten' and now bio-energy production). At the height of the griend culturing in the 19th century, 14000 hectares of floodplain were in use. To reach maximum production, the water table of grienden was often controlled by man, by construction of platforms, ditches and dikes with gates. The griend culture did already occur in the iron-age. At present most griends are not in use anymore, and are now slowly evolving into more natural willow forests. It is expected that the introduction of the beaver in the floodplains of the Netherlands will provide a tendency to resetting of the forest formation and succession by the regular felling and stripping of trees for shelter and fodder. At increasing densities the beaver could become a natural manager of willow and poplar forests (www.natuurkennis.nl).

Willow forests and grienden are located on areas of the floodplain, where the total of inundation days lies between 60 and 10 days per year. A tidal fluctuation of more than 15 cm will allow the development of the rare tidal willow forest type. Groundwater level varies respectively between 75 cm and 125 cm below the bed surface. The bed typically consists of very clayey to mixed clay-sand, depending on the sedimentation conditions during flooding events (www.natuurkennis.nl).

2.4.2 Wave attenuation by wetlands

The shallow vegetated zone influences incoming waves. When a wave encounters water depths shallower than the wave-base, the wave shape gets modified by the topography of the foreland and starts shoaling. Wave-length and wave velocity both decrease, but the energy from these reductions contributes to an increase in wave-height. A shallow-water wave will usually break when it encounters water depth that is less than wave-height and undergo refraction or reflection, and later dissipate due to friction created by the vegetation and the surface of the shallow zone (Figure 2.16) (Haslett, 2009).

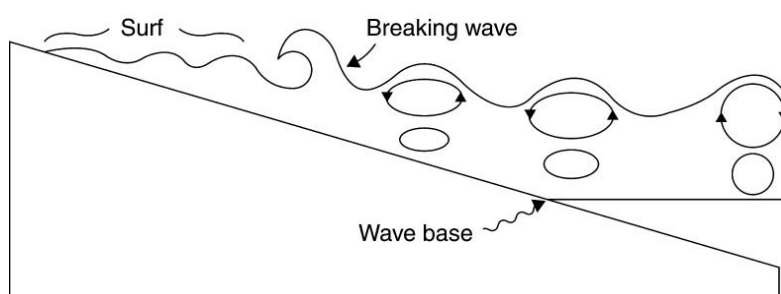


Figure 2.16 Wave shoaling as an oscillatory wave enters shallow water with a transformation from a circular to an elliptical orbit, leading to wave breaking (Haslett 2009).

Therefore, salt marshes and adjacent mud flats as well as 'grienden' form a natural foreland in front of a flood defence, dissipating incoming wave energy, and with that they protect structural flood defences against full incident wave attack. They may dampen the waves through the topography of their surface, their vegetation, substrate, and their influence on local currents. A recent literature review pointed out that until now there has not been a great deal of quantitative work on the natural flood defence capacity of salt marshes (Van Loon-Steensma et al., 2012) and floodplain forests, and most information comes from laboratory studies (e.g. Brampton, 1992; Suzuki et al., 2009) or field measurement under moderate wave conditions (e.g. Möller et al., 2001; Möller et al., 2002; Möller, 2006). Borsje et al. (2010) discuss the use of floodplain forest as wave reducing building block to provide safety against flooding.

Extent and height of natural foreland

Water depth has a strong effect on wave attenuation. If the water level is too high, no breaking or wave shoaling will appear. A broad range in the relation of wave height (H) and water depth (h) is reported for breaking of waves (H/h), from 0.45 for a horizontal surface, to 0.6 or even 1.59 (Holthuijsen, 2007). Under natural conditions, there may be strong spatial

and temporal heterogeneity in local topography of the foreland, and with that of the inundation depth. A cliff edge may lead to a local increase in wave heights (Möller et al., 2002). Wave propagation is not only determined by the elevation of the foreland, but may also be influenced by local dams, accretions works, etc.

For salt marshes applies, that, although wave attenuation by shoaling requires an substantial extent of foreland (at least some wave-lengths), most wave energy is dissipated in a zone of 10-50 m. In Norfolk (UK), Möller et al. (2002) found a wave-height reduction of 50% over the 10-20 m vegetated salt marsh. However, to apply the flood-defence value of natural forelands, it is advisable to account also for the effects of erosion during extreme storm conditions. This erosion during extreme conditions may be viewed as similar, in some respects, to the wave buffering capacity of sand dune systems. They act as an energy buffer in times of storm and are able to release sediments, stored during low-magnitude, high-frequency events, to assist in short-term morphological response of the profile to storms (Pethick, 1992).

Vegetation

Vegetation can dissipate wave energy under condition of 'low' water depths by creating friction.

Field measurements on a *salt marsh* in Norfolk (UK) pointed out that when inundation depths were low, wave energy was reduced by (on average) 87% over salt marsh and 37% over sand flats (Möller et al., 2001). Measurement and calculations of wave attenuation over a *Spartina alterniflora* vegetation in the Yangtze Estuary, China, showed that the wave attenuation rate per unit distance was 1 to 2 magnitudes higher over salt marsh than over an adjacent mudflat (incident wave height ranging from <0.1 to 1.5 m)(Yang et al., 2011). They found that, on average, waves reaching the marsh were eliminated over a distance of ~80 m, whereas this would be > 400 m without vegetation.

Field studies as well as flume experiments have shown that wave damping by salt marshes is strongly affected by vegetation characteristics. In a salt marsh in Essex (UK) the wave attenuation was affected by the height of the vegetation; a tall canopy of *Spartina* spp. dampened the waves more than a shorter canopy of the annual *Salicornia* spp. (Möller, 2006). Vegetation characteristics, however, may vary seasonally and spatially.

Möller et al. (2011) measured wave height attenuation of fringing reed beds along the Baltic coast, and found that wave attenuation through the emergent reed vegetation was significantly lower in greater water depths, suggesting (1) a reduced influence of bed friction by small shoots/roots and/or (2) drag reduction due to flexing of plants when the wave motion is impacting stems at a greater height above the bed. For a given water depth, wave dissipation increased with increasing incident wave height, suggesting that despite their ability to flex, reed stems may be rigid enough to cause increased drag under greater wave forcing (Möller et al., 2011).

Ecosystem-engineers in the coastal zone

Ecosystem-engineering species like oysters and mussels, which are common species in the intertidal zone, have the ability to form beds, and trap and stabilize sediment (Figure 2.17).

The increase in soil elevation and the oyster and mussel beds influence incoming waves. Recently, the utilization of these ecosystem engineering species for achieving civil-engineering objectives or the facilitation of multiple use of limited space in coastal protection is increasing (Borsje et al., 2010). Research focuses on the possible contribution of

ecosystem engineering species to coastal protection by their ability to modify the local physical environment by their structures or activities.

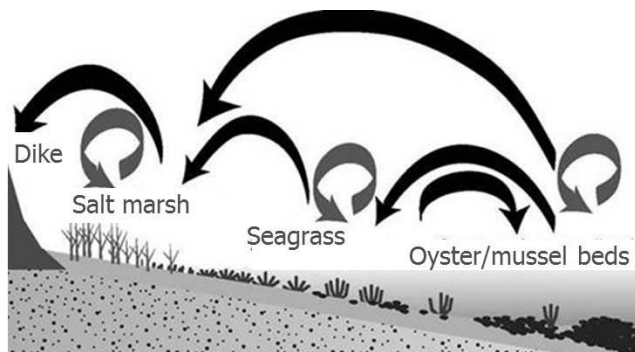


Figure 2.17 Gradient of ecosystem-engineers that may protect the coastline by trapping and stabilizing sediment (De Vries et al., 2007).

Mudflats

Liquefaction of mud flats can lead to the forming of fluid mud, known for its viscous wave energy dissipation potential. Mud fields along the coast are often quite dynamic, and seem to migrate in alongshore direction during storm conditions. Winterwerp et al. (2012) observed that wave dampening by fluid mud in the Wadden Sea occurred after the storm, and not during the storm, and hypothesized that fluid mud is formed from deposition of mud eroded during the storm, and not from liquefaction during the storm. They also found that the degree of wave dampening over a muddy bed may decrease during the storm, as the soft mud deposits may be eroded by the waves.

Effect of foreland on local currents

Creek morphology influences the wave attenuation, because a branched pattern of creeks and gullies controls the tidal-flow regime and dissipates waves of average size by decreasing the flow velocity.

Modelling

Wave attenuation by forelands is relevant for wave height boundary conditions for the design of embankments along the coast. The interplay between the various spatial (e.g. topographic) and temporal (e.g. seasonal) factors, however, introduces a significant degree of variability in the wave attenuation process that is very difficult to model (Van der Meer, 2002). To assess boundary conditions for embankment design, wave propagation and generation can be modelled with the SWAN program (Simulating Waves Near shore), a two-dimensional model which converts wind data into near shore-wave parameters (height, period and direction) for a given location.

Modelling the effects of artificial islands, shallow wetland zones and forelands in front of a dike, revealed that these constructions may lead to a significant decrease in wave height, and can potentially reduce the critical hydrodynamic load. The effect, however, decreases with increasing distance in front of the dike (Fiselier et al., 2011; Verheij, 2006). These effects are

shown in Figure 2.18, Figure 2.19 and Figure 2.20 as part of a study for the design of a completely 'soft' dike in the Markermeer.

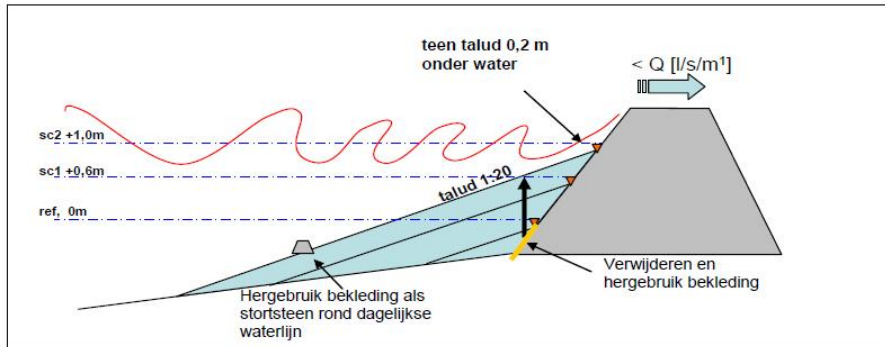


Figure 2.18 Conceptual drawing of utilisation of shallow foreshore to achieve wave reduction (Fiselier et al., 2012).

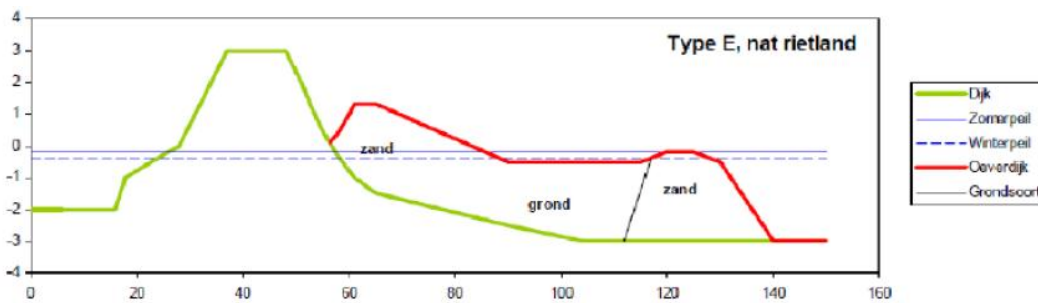


Figure 2.19 Example of safe soft dike including wetland that could replace an existing traditional dike design (Oeverdijk case, Fiselier et al., 2012).

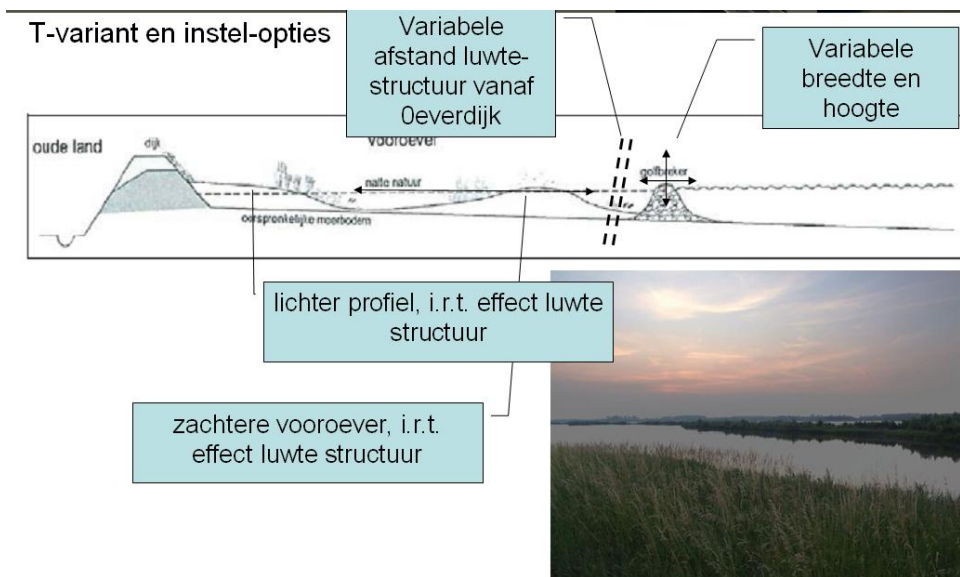


Figure 2.20 Outline of a dike, protective foreshore and wetland zone in front of the IJsselmeerdijk

A special version of SWAN has been adapted by TU-Delft and Deltares to analyze the influence of vegetation on waves. This version was used to establish the effect of a willow forest on wave conditions near a dike in the Noordwaard. Figure 2.21 shows that the willow forest (in this case a 'griend') can reduce the incoming waves by 50-80% within 50 m from the edge of the forest. Furthermore it became clear that the effectiveness of wave reduction was not sensitive to increasing water levels (as long as the water level remained below the height of the trees). In Borsje et al. (2011) an illustration is shown of a 2D application of the SWAN-veg model, illustrating the effect of the forest on a complete wave field.

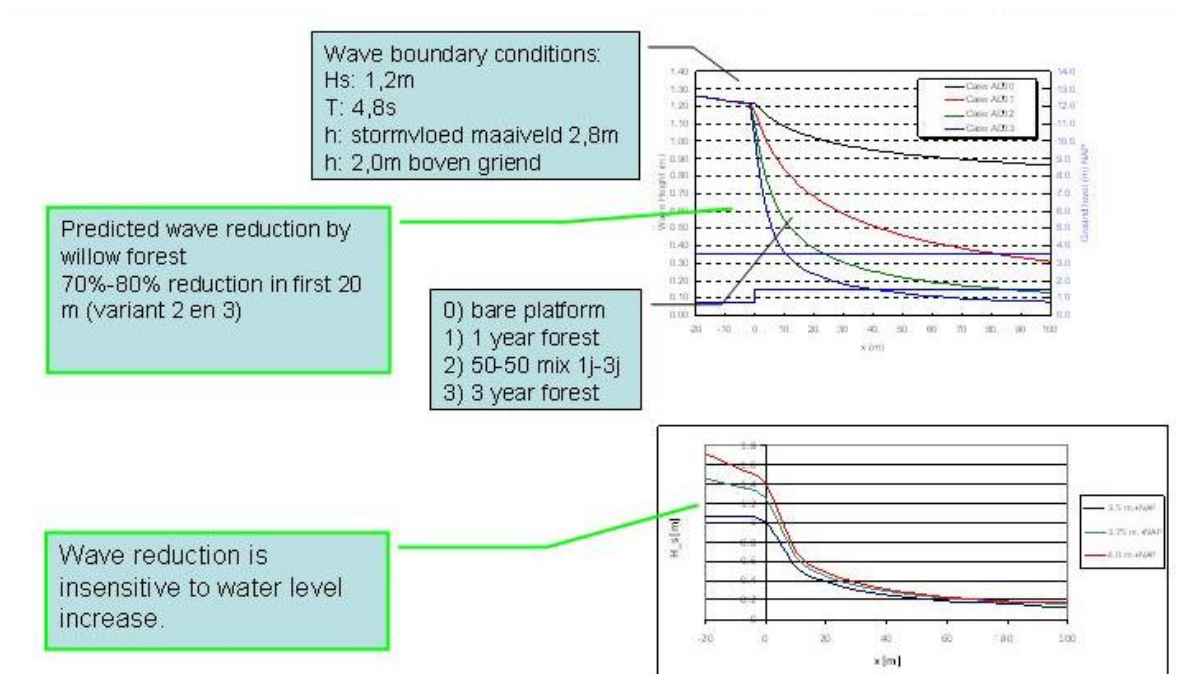


Figure 2.21 SWAN-veg predictions of wave reduction in willow forest (wave-reducing eco-dike case, Noordwaard).

2.4.3 Salt marshes in the Wadden Sea

In the Netherlands, salt marshes are found in the Wadden Sea and in the Southwest Delta area. The Wadden Sea is Europe's largest intertidal area (ca 900,000 ha) and is internationally famous for its nature values. Because of its great international importance for both flora and fauna (especially birds) and the extensive scale on which natural physical processes can occur, the Wadden Sea is protected by various national and international agreements, and was in 2009 appointed as UNESCO site. The Wadden Sea consists of a shallow intertidal sea with gullies, creeks and sandbanks behind a row of barrier island in front of the Dutch, German and Danish coast. This row of barrier islands protects the coast of the northern part of the Netherlands and the eastern part of Germany and Denmark against storm surges. Along the shores of both the mainland and the Wadden Islands salt marshes are found.

About 9,000 ha of the total area of 40,000 salt marshes in the Wadden Sea is situated in the Dutch part (Dijkema et al., 2007; Figure 2.22). The present salt marsh area is both the result of intensive accretion works carried out along the coastline of Groningen and Friesland (Figure 2.23), as well as of the construction of sand dams on the islands resulting in sheltered areas. Without human interference the total area of 'natural' salt marshes would have been much less than it actually is.

Salt marsh vegetation succession, species compositions and effects on these by management and restoration measures have been well-studied and monitored (e.g. Bakker, 1989; Olf et al., 1997; Dijkema et al., 2007).



Figure 2.22 Salt marshes in the Dutch part of the Wadden Sea (Source: Van Loon-Steensma et al., 2012).

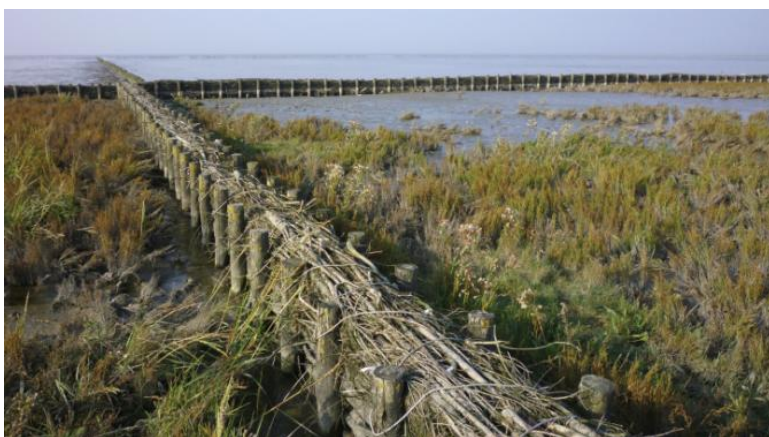


Figure 2.23 Accretion works Noorderleech (photograph: J.M. van Loon-Steensma)

The marsh forming processes on the lee side of the Wadden islands are described by Doing (1995) and schematized in an so called ‘model island’ (Löffler et al., 2008). After formation of dunes on a bare barrier, the sand flat behind the dunes is no longer inundated by tidal water from the North Sea, but only from the Wadden Sea at high spring tides. In this low-energy environment silt can accrete, so that the salt marsh can further develop. ‘Wash over’ of North Sea sand over the row of dunes during storm conditions is important for the development and revitalization of the salt marsh (Löffler et al., 2008).

Salt marshes and flood risk management policy

Although salt marshes influence incoming waves (par. 3.4.2), and are able to reduce wave run up at dikes, salt marshes are in the Netherlands only sporadically included in the flood protection policy. In neighbouring countries, such as Germany and the United Kingdom, the natural sea-defence values of salt marshes is more often incorporated into flood defence and management schemes. In the Netherlands, guidelines are formulated to account for foreland in the assessments of flood defences (Ministerie van Verkeer en Waterstaat, 2007), but due to the dynamic character and spatial heterogeneity of salt marshes, they are seldomly incorporated in the regular assessment of the actual situation of the flood defence. Design criteria, however, are based on conditions 50 m in front of the dike. Therefore, stable broad salt marshes are incorporated in the design of flood defences.

In the South-West Delta of the Netherlands along the so-called Oesterdam in the Eastern Scheldt, a large scale building with nature pilot study is implemented to protect a dike bordered by an eroding foreshore against increasing hydraulic load by wave attack. In this case a sand suppletion will be put in place in 2013 in order to provide long term safety by maintaining a shallow protective foreshore (with a possible salt-marsh formation) and to provide natural value by enhancing the intertidal area available for foraging birds (Figure 2.24).

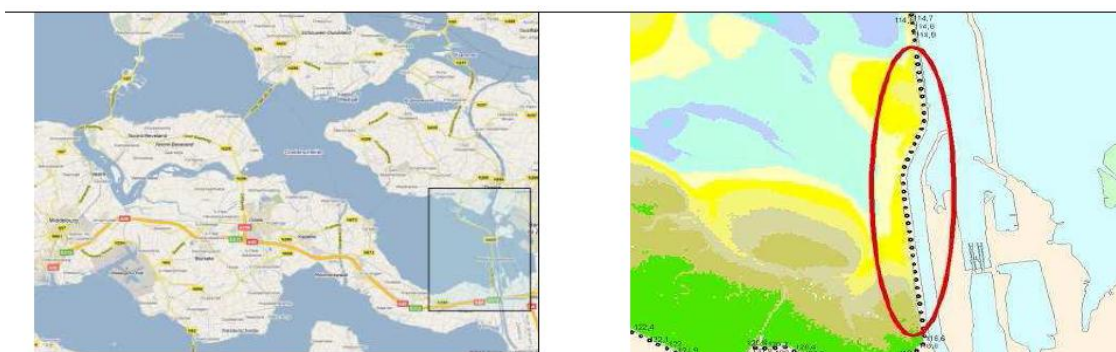


Figure 2.24 Location of the pilot

Recently, the natural sea defence value of salt marshes in the Wadden area is gaining interest. As part of the Dutch Delta Programme a literature study (Van Loon-Steensma et al., 2012) and a model study (Moerman, 2011) were conducted to explore the possible application of salt marshes in a flood defence strategy for the Wadden area that also accounts for nature and landscape values.

Modelled effect of Wadden Sea salt marshes

Based on information on local extreme water levels (at 'Lauwersoog') and wind conditions (at 'Huibertgat') Moerman (2011) modelled wave attenuation over a salt marsh zone (50, 100, 150 and 200 m in width, and 1.0, 1.5, 1.9 and 2.3 m in height) under extreme conditions (1/10, 1/100 and 1/10,000 year) with SWAN. Moerman (2011) found a significant effect of the salt marsh zone on wave attenuation, but under extreme conditions this effect decreased with higher water levels (the most extreme storm conditions) to 8% for a salt marsh of 50 m in width and 1.0 in height and 37% for a salt marsh of 200 m in width and 2.3 m in height.

The effect of the salt marsh on wave reduction is significant if we reason that the height and stability of the foreshore is influenced or more so defined by the existence of the marsh, by accretion of sediment, in equilibrium with the sea level. As an analogue to the Oesterdam example, the existence of healthy salt marsh could lead to continuous accretion of the foreshore, leading to dampening of wave energy on the dike. The dampening effect of the vegetation itself will add to this effect of shallowing.

2.4.4 Wave-reducing eco-embankment Noordwaard

The ability of willow species to attenuate waves is applied in the design of the eco-embankment Noordwaard. As part of the "Room for the River" project Noordwaard, a new primary flood defence is required in the North Eastern corner of the Noordwaard to protect the inhabitants at Fort Steurgat. Due to the removal of the current river dike near Werkendam, Polder Noordwaard will be inundated regularly. During a 1/2000 year discharge event the average water depth in the polder will be 3 meter whereby, in combination with a severe storm, waves up to 1 meter high are expected near Fort Steurgat.

A 'conventional' embankment design around Fort Steurgat would result in a dike height of 5.5 meter above NAP, with concrete blocks as armouring layer. Protests of local population initiated the search for an alternative design that provides protection, as well as additional values for nature and recreation, and is cost-effective as well as durable. This led to the design of a hybrid eco-dike with planted willow trees in the fronting zone, integrated in the riverine landscape. The willow plantation is inspired by the historic cultivation of grienden (see section 3.4.1) Wave attenuation by willows reduces wave overtopping (e.g. Coops et al., 1996; Mendez & Losada, 2004; Lövstedt et al., 2010; Koch et al., 2009), and leads to lower design requirements: a lower clay clad dike instead of higher dike with hard armour layer. The combination of clay dike and willow plantation is cheaper and generates additional natural and landscape values. In line with sustainability objectives of Dutch government, production of biomass for energy as result of regular maintenance of the willow plantation is seen as a bonus of the project. It is expected that the new design will add to recreational value of the area for local residents (www.ecoshape.nl).

In the final design a continuous willow tree plantation in front of the dike provides at 80% reduction of incoming wave height at 1:2000 storm conditions (Figure 2.25). This allows the design of a dike with a 0.70 m reduced crest height, without violation of maximum overtopping limitations.

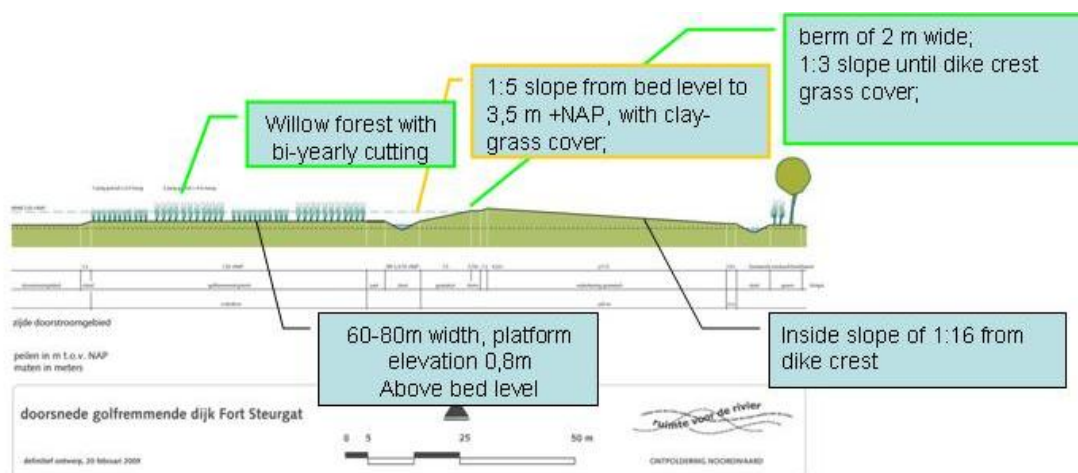


Figure 2.25 Design of a hybrid eco-dike with wave attenuating willow forest in the fronting zone

2.4.5 Applicability

Before wetlands can be widely applied in flood protection, there are still some important questions to answer.

Complexity of wave attenuation processes under field conditions

Under field conditions, spatial and temporal heterogeneity of the topography of the shallow zone, seasonal patterns in vegetation, and temporal fluctuations in water levels add to the complexity of wave attenuation processes. Therefore, it is complicated to model the effect of wetlands on wave run-up and to apply this effect in water safety policy.

Wave attenuation during extreme conditions

There is still little real data about the effects of wetlands on wave attenuation during extreme conditions. Wave model studies can be used to assess those effects but it remains important to keep in mind that these models are developed and evaluated on the basis of either scaled down lab tests or field measurements under less than extreme conditions. Hence, applying these models to predict effects under extreme conditions relies on extrapolation. The model study for the Noordwaard suggests that a safe design is possible using the available knowledge. Contingency measures have been incorporated in the plan by allowing overdesign of the wave reducing forest and the clay dike to cope with remaining uncertainties. To further evaluate and calibrate the existing models (aiming at reducing prediction uncertainties) it is advisable to monitor the wave attenuation on a number of distinctive locations, and use the obtained information.

Response on effect of changing climate

In order to apply a shallow vegetated zone as protection against wave attack, it is important to examine how these wetlands respond to the effect of a changing climate as an accelerated sea level rise, a change in river water discharge (both frequency and severity of extreme discharges), another storm climate and a higher temperature.

As for **salt marshes**, a reduction in the width and/or height of the salt marshes reduces their effectiveness in damping waves and increases the risk of overtopping or breaching of sea defence structures on their landward side (Brampton, 1992). When salt marshes cannot keep pace with sea level rise, they may deteriorate and eventually disappear.

Whether salt marshes are able to keep pace with an increased sea level rise, largely depends on the availability of sediment. Sediment supply is strongly related to the morphology of channels and tidal flats seaward of the sedimentation fields (Janssen-Stelder, 2000). However, whether the sediment is deposited (when the net supply is positive) depends on the wave conditions within the sedimentation fields. The wave heights are greatly influenced by the height and maintenance of the brushwood groynes. Further research should emphasize on ways to reduce wave action during storm surges in combination with additional supplies of sediment after storm surges (Brinkman et al., 2001). Borsje et al. (2010) discuss the implications of the dynamic accretion and erosion of salt marshes in the light of sea level rise and the risk of failure (see Figure 2.26), and mention the dynamic character of ecological engineering solutions. After an extreme event the accreting salt marshes might recover, while a traditional engineering solution is static.

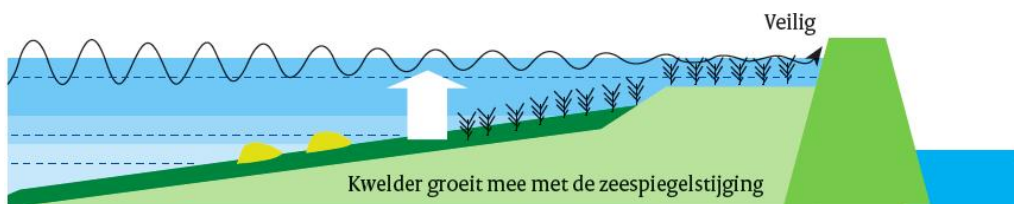


Figure 2.26 Outline of a salt marsh in front of the flood defence that can keep pace with sea level rise (source: RWS, Deltares)

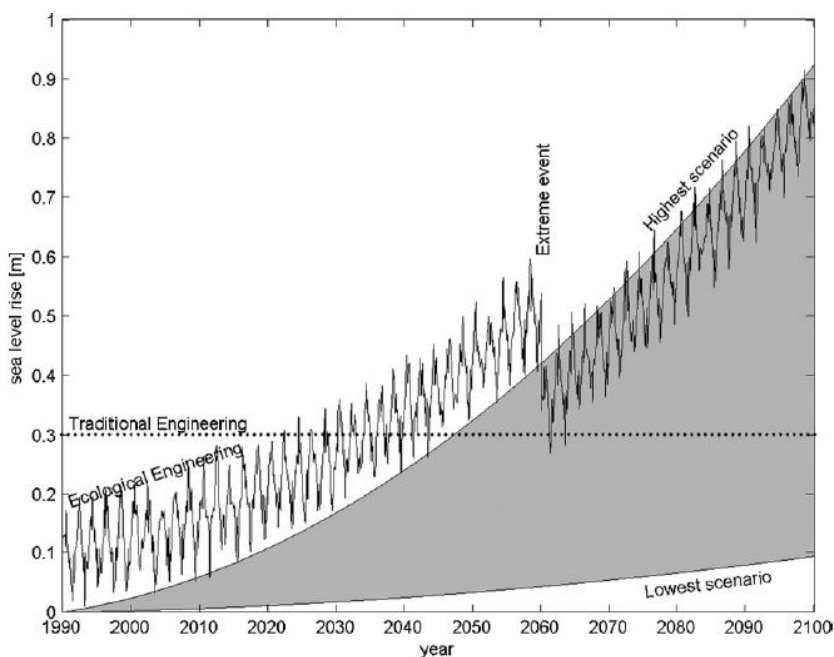


Figure 2.27 Conceptual framework to demonstrate the difference between traditional engineering (dotted line) and ecological engineering (thick line) concerning sea level rise and coastal protection (grey area enclosed by a lowest and highest scenario). Ecological engineering solutions are dynamic and after an extreme event the accreting salt marshes might recover (Borsje et al., 2010)

As for **willow forests** applies that the hybrid eco-dike in Polder Noordwaard is currently moving toward construction, which illustrates the applicability of wave attenuation by vegetation into dike design. In this case, the design adheres to the national protocol that is prescribed for the construction of safe dikes and is therefore considered as safe. Unlike salt marshes, the willow forest is providing wave attenuation through the impact of biomass that is remaining during design conditions. The salt marsh examples are effective in protection dikes through the accumulation and stabilization of sediment on the foreshore of the dike, the role of vegetation as wave dampener under design conditions is less relevant in the latter case.

Effect of other ecosystem-engineers

The effect of reef-building oysters, mussel beds and sea-grass beds on the wave climate and sediment stabilization is still under study. It is assumed that these bio-engineers could be combined with salt marshes or sand nourishments to increase the effectiveness of the design for safety and habitat diversity. The Oesterdam project in the Eastern Scheldt will assess the effect of artificial oyster reefs on waves and sediment transport. Ecoshape is funding a pilot oyster reef construction in the Eastern Scheldt that is used to provide data for the optimal design (see www.Ecoshape.nl for details).

The study of Fiselier et al. (2011) for the Delta Programme illustrates the potential of introducing ecosystem engineers in our safety policies of the 21st century. In addition, some analyses have been made on the cost-benefits and applicability for the Wadden Sea system, fresh water systems and the south west delta system.

Two approaches to apply ecology in coastal protection

The research on the application of ecosystem-engineers in coastal protections is driven by a need for innovative, sustainable and cost-effective coastal protection solutions that deal with threats related to climate change, such as accelerating sea level rise. Furthermore there is need for measures that minimize anthropogenic impacts of coastal protection structures on ecosystems and that might perhaps even offer possibilities to enhance ecosystem functioning (Day et al., 2000).

These objectives are reflected in two approaches by which ecology is integrated into coastal protection systems: (1) methods that use selected ecosystem engineering species that modify their environment to enhance safety and/or save costs on coastal protection and (2) methods in which classical coastal constructions like dams and dikes are adapted to enhance local biodiversity and ecosystem functioning.

Criteria

To apply wetlands in a water safety strategy, it is important to develop criteria (including costs and benefits), and develop an integrated approach to balance between flood protection and nature conservation objectives.

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www.wijdebiesbosch.nl/docs/ontwerpvisie%20noordwaard.pdf.

3 Flood protection: planning, design and management of flood defence zones

3.1 Flood defence zone design and planning for multiple functions

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3.1.1 Robust multifunctional flood defence zones, an introduction

The interest in the Netherlands for broad, unbreachable flood defences that also offer space for other land use functions did increase due to the advice of the Second Delta Committee. In 2008 it advised the Netherlands' cabinet on an overall strategy for spatial planning and flood risk management in view of climate change, and also recommended to consider the concept of 'Delta dikes': embankments which are virtually unbreachable due to their width, height, or inner constructions (Delta Committee, 2008).

A broad, over-dimensioned embankment is more resistant to erosion and keeps its protective function, even when significant amounts of water flow over it during extreme conditions (Vellinga, 2008). Of course, such robust embankments require more construction material and space, but on the other hand they offer new opportunities for using the space as well (Vellinga, 2008, Hartog et al., 2009). Over-dimensioned embankments can be designed as multifunctional areas, combining flood protection with urban development, infrastructure, recreation, agricultural use, or nature conservation. They may also contribute to the attractiveness of the typical Netherlands' scenery.

In fact, a robust multifunctional flood defence zone is a broad, elevated area, subdivided in various subzones appointed for other functions in front, behind, or even on top of the embankment itself (Figure 3.1). The broad profile, in which these subzones are combined, forms a deliberately over-dimensioned erosion-resistant flood defence zone. Because of the over-dimensioning, no regular adjustments are needed as a result of changing boundary conditions, or a revision of the protection standards. Consequently, the concept is robust and focuses on the long term.

Figure 3.1 shows the main differences between a traditional embankment, a traditional reinforcement, a 'lean' unbreachable delta-dike and a robust multifunctional flood defence zone as proposed.

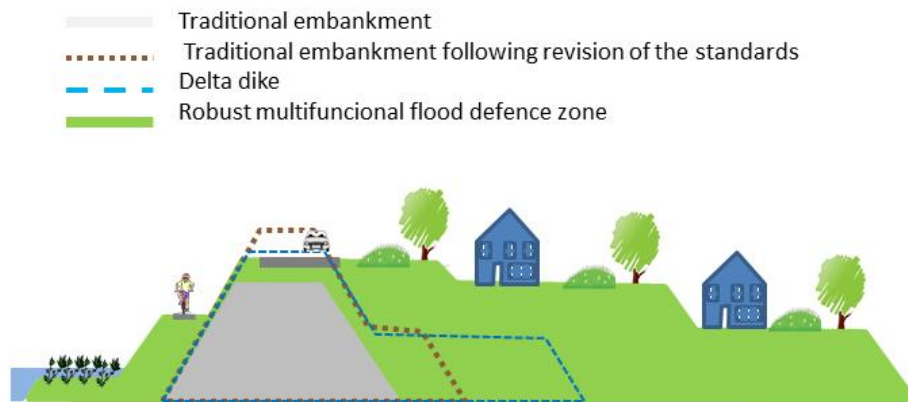


Figure 3.1 Scheme of a traditional embankment, a traditional reinforcement, a delta dike, and a robust multifunctional flood defence zone (adapted after Silva & Van Velzen, 2008; and STOWA, 2011).

Current situation

The design requirements for flood defences are currently exactly defined, and management as well as regular assessment are prescribed. The current Netherlands' flood risk management policy prescribes a 'robust design' of any reinforcement of the embankment to account for changes in hydrodynamic boundary conditions and in the protected values (Rijkswaterstaat, 2007). Such a 'robust' flood defence is thus dimensioned on *expected* changes in boundary conditions in a certain pre-fixed time frame. In addition, a certain amount of space is reserved for future adaptations. This 'reservation zone', however, is seldom appointed for permanent use.

Many traditional flood defences do already fulfil a range of other functions, as long as there is no interference with their primary protection function. Although the design of a traditional embankment takes functions such as transport into account, such additional functions have usually not been included in a long-list of additional design requirements.

Interest in robust multi-functional flood defences

Due to the intensive use of space in the urban area, improvement of a flood defence in this environment is extremely difficult. In the Netherlands' river cities often quay walls, or a combination of embankments and water retaining walls, are used for flood protection. At this moment, several cities and local water boards have started projects to explore robust multifunctional flood defences. The city of Rotterdam for example, is interested in the opportunities of a terraced quay-wall that host functions for transport and building. In such a terraced quay-wall the less vulnerable functions, like traffic roads, can be placed on the lower levels of the terrace or staircase, while functions as housing can be situated on the higher levels of the quay. In case of rising water level, the lowest level of the terraced system is flooded first, and the road may not be accessible for traffic, but the functions on the higher levels may not be influenced (Urbanisten, 2010). In other cities, like Nijmegen, opportunities are explored of a system in which buildings are part of the flood defence. In the concept Adaptable Flood Defences (AFD), structures like car parks, buildings, dwellings or roads are

transformed and redesigned with the additional capability of protection of the hinterland against flooding (Stalenberg, 2010). Also, in rural or less densely inhabited areas, there is currently interest in possibilities to integrate flood protection with other functions (see Textbox 1).

3.1.2 Effectiveness

The flood defence performance of the robust multifunctional flood defence zone is based on over-dimensioning of the profile. When exposed to design loads, overflow may occur, but in contrast to embankments with a traditional narrow profile, overflow-related erosion does not lead to the collapse of the flood defence. Therefore, the dose response relationship is far less abrupt for the broad flood defences in comparison with the narrow embankments (Figure 3.2), and hence a broad flood defence zone may be regarded as unbreachable. Silva & Van Velzen (2008) defined unbreachable as having a hundred times smaller probability of overflowing and subsequent erosion or failure due to piping or macro-instability at the land-side than according to the current standards.

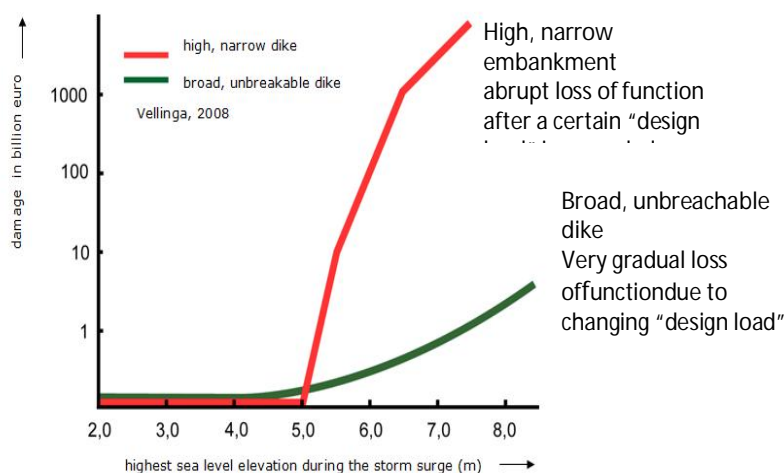


Figure 3.2 Damage functions of narrow and broad embankment (Vellinga, 2008).

Nuisance versus disaster

As a consequence of overtopping during extreme conditions, water will enter the low lying hinterland, but the damage would be limited in comparison with a complete inundation due to failure of the flood defence. Particularly relevant in this context is that the damage would increase only gradually with higher surge levels and not abruptly as with the narrow embankments. Therefore, much depends on the duration of the extreme conditions. In general storm surges at sea only last for a short period (hours), whereas in the rivers extreme rainfall can lead to a high and prolonged discharge (days to weeks). In case of long-lasting extreme conditions, overflow may cause an inundation level comparable to a breach, but creates at least time to prepare or to evacuate. Furthermore, the impact of overflowing is determined by the characteristics of the hinterland. Besides characteristics like economic

value of land uses, the connections to other areas, and the number of people living in the flood prone area, also the financial situation determines the effect of an inundation and the ability to recover.

Climate change

All climate models predict changes in mean temperature and rainfall intensities. Accurate prediction of the future climate is constrained, however, by the complex nature of climatic variables and by the existence of many feedbacks in the climate system. Therefore, the robust, broad embankments will improve the robustness of the protective system significantly over a wide range of possible futures and uncertainties, and subsequently are feasible as a climate adaptation strategy (Vellinga, 2008).

Effect of multifunctional use on erosion

Especially in urban areas, integrating housing, transport and underground infrastructure into the multifunctional flood defence is attractive in view of efficient use of the limited space. However, there is yet not much knowledge available about the behaviour of buildings or infrastructure in flood defences, about their influence on erosion and the stability of the berm, and on the impact of overtopping water on these objects.

3.1.3 Cost-effectiveness

The current Netherlands' flood protection policy is based on a risk approach, which takes both flood frequency and the damage due to a breach into account. Therefore, protection standards for densely populated and vital economic regions are higher than for sparsely inhabited and economically less important regions. This approach implies that the costs of flood protection are deliberately weighed against the stakes involved.

An over-dimensioned design provides more safety, but 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 use of flood defences would help to optimize the use of limited space, like in Dordrecht and Arnhem, where the over-dimensioned profile is used for housing and recreation. Moreover, these other functions could bear (part of the) additional costs. If indeed costs are borne by other stakeholders, then in view of flood risk management a robust multifunctional flood defence is cost-effective: better protection for less money.

Moreover, on the long term a robust design may be more efficient due to lower maintenance costs and no need for short-term adjustments (see Textbox 3.1).

According to Silva & Van Velzen (2008) an unbreachable embankment requires at least a 1:3 inner slope. Due to the current design of sea defences, Klijn & Bos (2010) estimated that only ca. 140 ha is needed to convert these ca. 1000 km sea defences into 'Delta dikes', whereas ca. 3000 ha is needed to adjust the 1400 km river embankments. In order to prevent future adjustments, a robust multifunctional flood defence zone requires much more space.

Textbox 3.1: Case Streefkerk

For Streefkerk, a small village with ribbon building all along river 'Lek' and several socio-economic challenges, possibilities for a robust multifunctional design were explored by De Moel et al. (2010).



Figure 3.3 As a result of past reinforcements, many historic and characteristic houses are situated against or even on or in the current embankment (photograph: J.M. van Loon-Steensma).

The actual flood protection challenge in Streefkerk according to the last assessment comprises a reinforcement aimed at reducing the instability of the inner shoulder. A common solution would be the raising and enlargement of the inner shoulder. Without removal of a large number of houses, such a common reinforcement is impossible (Figure 0.3).

As alternative, a robust multifunctional embankment was designed (Figure 3.4). The design was based on the 'W+' climate change scenario (Van den Hurk et al, 2006), a protection level 100 times safer than current standards prescribe, and for a time frame of 100 years (instead of 50). Over-dimensioning offers the possibility retain many of the current characteristic houses and provides an opportunity to build new ones. This results in a possibility for co-funding of this over-dimensioned (and thus more expensive) design.

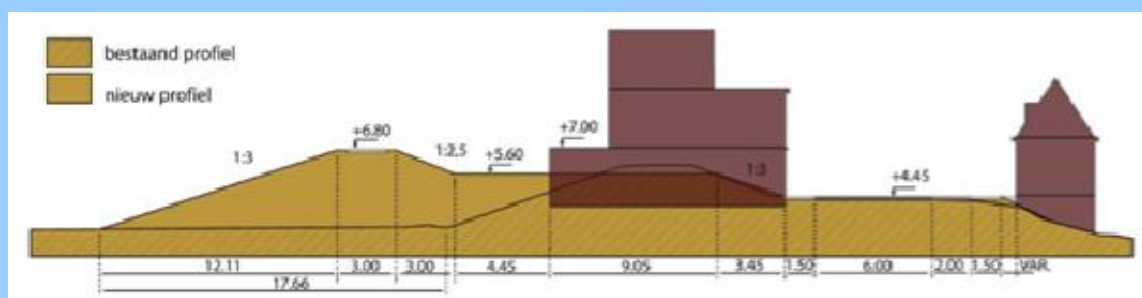


Figure 3.4 Robust multi-functional design for Streefkerk (De Moel et al. 2010).

De Moel et al. (2010) estimated the initial costs of this robust multifunctional profile of 200 m in Streefkerk at € 1.240.000, whereas a traditional design was estimated at € 960.000. However, they estimated maintenance costs of the robust profile at 75% of the costs of the traditional profile (i.e. € 9.600 per year versus € 7.200 per year) so the payback period is approximately 100 years. The calculated benefits due the reduction of potential damage was € 18.100 per year. Furthermore, De Moel et al. (2010) estimated that a second reinforcement of € 380.000 within the next 50 years could be prevented. Based on this analyses, the long term monetary benefits of the over-dimensioned profile outweigh the initial costs.

Total costs for converting all embankments along the coast, estuaries and large rivers into unbreachable 'delta dikes', was estimated at 11.5 billion euros (4.6 million euros per km) by Silva & Van Velzen (2008). Knoeff & Ellen (2011) estimated initial costs at 20 billion euros (8 million euros per km), whereby the costs for river embankments are mainly determined by widening the inner shoulder and costs for sea defences by strengthening the revetment.

No-regret measure

It is clear that a robust multifunctional design would have to be justified against other alternatives. Especially in areas with limited space, it is attractive to combine and integrate various functions and values into a multifunctional design. However, given the long life span of flood defences as well as buildings and infrastructure, it is important to consider long term effects in order to prevent regretful decisions with respect to infrastructure. Over-dimensioning may prevent costly implementation of adaptation measures on a later stage or short-term small adjustments, but on the other hand does claim the space for a long time span.

3.1.4 Side-effects

The concept of the robust multifunctional flood defence is based on the deliberate combination of flood protection with other desirable functions. These other functions may comprise:

- 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).

Competing claims

An over-dimensioned flood defence may conflict with other functions, such as nature conservation or agriculture. In the Netherlands, large parts of the river floodplains and the sea and coastal mudflats and salt marshes in front of the flood defence, are appointed as Natura 2000 sites because of their biodiversity value. Degradation of habitats is only allowed if the necessity of an intervention is shown, the effects of the intervention are studied extensively and any losses of protected habitat are compensated elsewhere.

Texbox 3.2: Streefkerk

As part of an integrated vision on the future development of Streefkerk, a flood defence zone was designed in such a way that it would allow realizing a square with shops as well as waterfront housing development (Figure 3.5 and Figure 3.6).

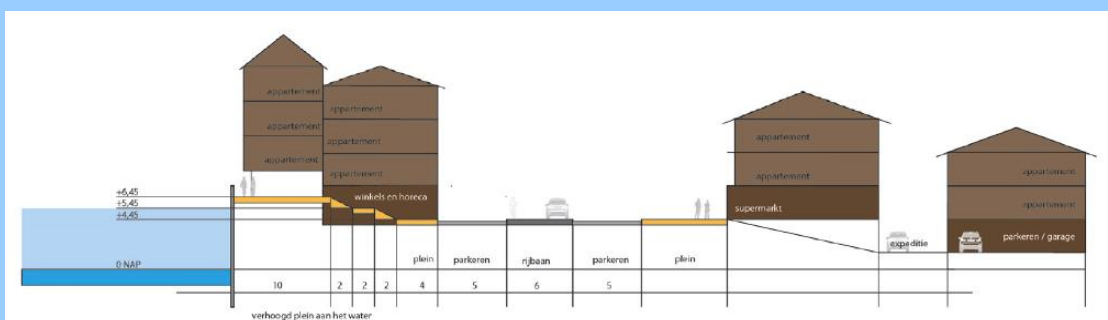


Figure 3.5 Design with a square and buildings adjacent to the waterfront (Terra Incognita, 2010).



Figure 3.6 Connecting the village to the river (Terra Incognita, 2010).

At a meeting in January 2011, municipality 'Liesveld' shared its ideas about the future development of Streefkerk with the inhabitants, and the water board presented the challenges that arose from the revision of the flood protection standards as well as some reinforcement alternatives. The meeting, which was very well attended, made clear that the residents of Streefkerk were primarily concerned about the preservation and enhancement of facilities and housing opportunities for young people. Based on this participatory process and on the results of an environmental impact assessment (EIA) the water board designed an over-dimensioned stretch of embankment.

Due to the intensive use of space in the urban area, adjustment of the flood defence is extremely difficult. It may be necessary to remove historical buildings, use private property such as gardens, or remove transport infrastructure to realize an over-dimensioned profile. In the Netherlands' river cities often quay walls or a combination of embankments and water retaining walls are used for flood protection.

3.1.5 Applicability and attractiveness

Complex process

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 (Van Loon-Steensma, 2011). 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 (in case of a dike reinforcement) 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 (see Textbox 3.2).

Financial resources

As already mentioned, over-dimensioned flood defences require more material and space, and are subsequently more costly than flood defences with a traditional profile. 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. Combining the building of robust multifunctional flood defences with regular reinforcement, could save costs (Knoeff & Ellen, 2011).

Legislative framework

The legislative framework for flood defences is based on protection standards and design guidelines. Therefore, over-dimensioned flood defences can only be implemented on a voluntary base, and when it does not conflict with other statutory destinations, such as nature or landscape conservation. Expropriation on behalf of the over-dimensioned profile is not feasible. In case of initiatives of other parties for combining functions in a flood defence zone, the Water Board has to give preconditions based on the Water Act. However, to guarantee flood protection in the long term, flood protection has to be the main function in the planning process and management scheme.

Radical versus incremental adjustment

Replacing the existing high and narrow embankments by over-dimensioned multi-functional embankments can be considered to be a radical adjustment or a true system change (Vellinga et al., 2009). This is particularly attractive on the long run and has to be fixed for a long period, whereas an incremental heightening of existing embankments can be adjusted over time to the monitored effects of climate change. It is a noteworthy, however, that retrofitting technological solutions could be very costly, and in some cases even prohibitively expensive.

Locations

While in view of the flood risk management strategy, complete dike ring should be adapted rather than a small section, it may still be wise to start with some sections. The construction of over-dimensioned flood defences on risky places, which are densely inhabited areas adjacent to flood defences with a relatively short warning time and a difficult situation concerning evacuation (De Bruijn & Klijn, 2009), could prevent severe fatalities and economic damage, and reduce flooding risks substantial. Unbreachable flood defences are therefore recommended as an appropriate measure to reduce risks by the Netherlands Environmental Assessment Agency (Ligtvoet & Van Gerwen, 2011).

Conclusion

In general, initial costs for a robust multifunctional flood defences are higher, but on the long term an over-dimensioned robust design may be more cost efficient due to lower maintenance costs and no need for short-term adjustments. An over-dimensioned profile is better suited when considering uncertainties in climate change projections or changes in land use or socio-economic values than a tailored profile. Especially when functions with a long life span like buildings and infrastructure are integrated with flood protection in a multifunctional flood defence, it is advisable to over-dimension the profile.

3.1.6 References

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

Joep Keijsers, Jan Mulder, Alma de Groot, Ate Poortinga & Michel Riksen

3.2.1 Introduction

In sandy coastal systems, coastal dunes represent natural defence zones against flooding of the hinterland due to their self-regenerating capacity after storm erosion. On the condition that the total dune volume exceeds a certain minimum value related to the safety standard, coastal dune systems represent natural buffers to climate change. The quality of this buffer function is related to the sediment balance in the system. During the past centuries, the Dutch coastline has experienced negative sediment balance and consequently retreated landward, resulting in a loss of total dune area. 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. Implicitly this should lead to preserving the quality of the coastal zone as a climate buffer. From 2001 on, the annual nourishment volume has been 12 million m³. In the light of climate change predictions, the Delta Committee (2008) has recommended to raise the total yearly nourishment volume to 85 million m³ 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 (Mulder et al., 2011).

An underlying assumption of the nourishment policy is that natural processes will redistribute the nourished sand – on the shore face and beach – in such a way, that the coastal system will “grow with sea level”. To maintain the functions of the dune system 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?

This problem will be tackled along two complementary lines. One is a physical ecological approach deriving models of dune development (sections 3.2.2 and 3.2.3). Another is a participatory planning approach involving both stakeholders and experts, aimed at integration of requirements for dunes as a dynamic climate buffer, with needs for socio-economic development (section 3.2.4).

3.2.2 Dune development at micro and meso scale, and effect of sea-level rise and climate change

Micro scale

Coastal dunes result from the interaction between wind, sand, vegetation and sea. Sediments on the beach surface are blown into the dunes if the wind speed exceeds a certain threshold value. The threshold value depends on the moisture content of the beach surface, but also sediment size and composition. Coastal dune growth only occurs if the sediment gets transported by the wind in the direction towards the dune (field), and this sediment is trapped by the vegetation present on the existing dunes. This process of aeolian sediment transport is the main driver behind coastal dune development. Periodically storm surges attack and erode the dunes, taking back sediment to the sea. The balance between the forming and destructive forces determines dune behaviour: dunes can only grow if more sediment is blown into the dunes than is removed by the sea.

To investigate the relation between sand transport and dune development, a three-month field campaign was conducted on the beach of Ameland, in the North of The Netherlands. During the autumn of 2010, we took detailed measurements of meteorology and sand transport across the beach. At 40 points on the beach, the amount of sand transport per day was measured. The gridded field set-up allowed us to study both temporal and spatial patterns of transport and to gain better understanding of the factors controlling transport (Figure 3.7).

For windy autumn days, we found that on average between 5 and 25 kg of sand moves over a virtual line of 1 m width, every hour. If all of this transport is effectively directed towards the dune zone, it takes a week of windy weather for a dune to gain 1 m³ of sand. This measurement result is reasonable compared to the average dune growth rate per year, which is in the order of 10 m³ per year for Dutch coastal dunes, and the Dutch wind climate (Arens & Wiersma, 1994; Van der Wal, 2004).

We found that, unfortunately, the process of sand transport by the wind is difficult to predict on the basis of a few easy to determine factors. Intuitively, stronger winds would lead to higher transport rates. But this is not always the case, as dune morphology, micro-topography, sediment characteristics, surface moisture, vegetation and meteorological conditions all play an important role. These factors are difficult to measure and are known to change rapidly, both in time and space (e.g. Baas and Sherman, 2006). This results in a high variability in sand transport rates in time and space, which we found in our measurements. An important question is whether this variability persists when measurements are done over time periods longer than days. We expect that, as the time period under consideration gets longer, variability averages out and better estimates can be made of average transport rates.



Figure 3.7 Field-work location at Ameland, The Netherlands. The dry and moving sand (light) contrasts with the more moist beach surface (dark). The grey boards were used as a spatial and colour reference. The 'Beach cam' took a picture every 5 minutes to monitor the continuously changing beach surface and visualise dune development.

Meso scale

In addition to exact measurements of the transport process, we can also study dune growth by measuring the result of the battle between sand accumulation and erosion by the sea. Since 1966, the Ministry of Public Works and Transportation yearly measures beach and dune elevations along the Dutch coast. This large database allows us to study changes in dune dimensions and relate these to beach dimensions.

In the last decades, the majority of the dunes have been stabilised to improve coastal safety (Arens & Wiersma, 1994). Still, the dunes change in shape. In most cases, the dunes have grown in volume because the amount of sand accumulation exceeds erosion (for example the location of Figure 3.8). This is partially due to the sand nourishments. However, several years of steady sand accumulation can be undone by a single storm, which reminds us of the major influence large storm events may have.

For the Dutch coast, we found that on wide beaches dunes tend to grow horizontally towards the sea (as illustrated in Figure 3.8), 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 they provide a greater source of sediment and are able to absorb some of the wave impact that causes dune erosion.

These findings suggest that, assuming sea-level rise is fast and beach profiles are static, sea-level rise leads to a decrease in beach width, lowering average dune growth rate. Applying sand nourishments to both under-water and above-water parts allows us to keep beach widths larger and to thus feed growing dunes.

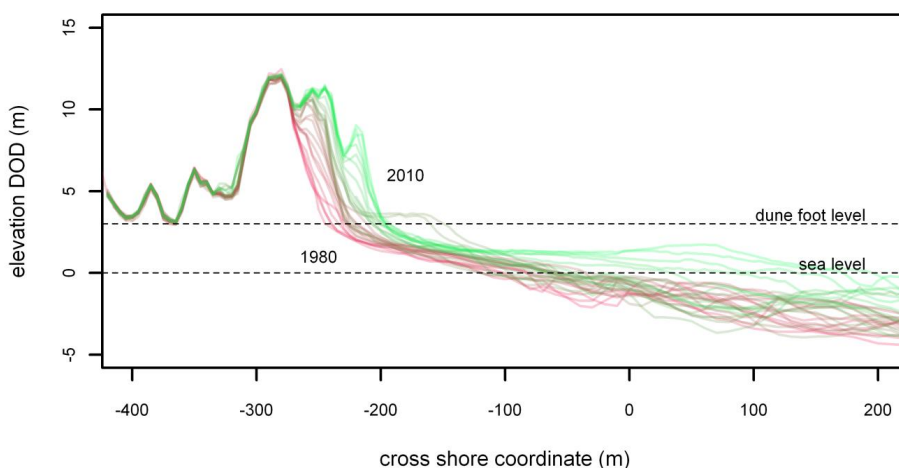


Figure 3.8 Cross-section of a growing dune, situated on the west side of Ameland. Land is on the left, sea on the right. From 1980 (red) to 2010 (green), new dune ridges were formed and the beach has become wider. This is a typical dune development for beaches wider than 150 m.

From a large meteorological dataset we calculated the number of days per year that have suitable conditions for sand transport by wind, based on our micro-scale measurements. This includes wind speed above a certain value, winds directed from the sea towards the dunes and absence of precipitation. Some years have significantly more of these days than others, but this is not reflected in the dune growth rates for the corresponding years. The calculations thus show that windy years may be profitable for aeolian sediment transport, but also coincide with more storm surges. Therefore, in windy years there might be both stronger growth and stronger erosion, both leading to morphological changes of the dune. Whether the net changes over a year are positive or negative, however, cannot be predicted from meteorological data alone.

Although we cannot predict rates of dune growth per day, month or year, we found useful relationships in the medium term (about 30 years). Aided by sand nourishments, dunes are currently growing along nearly the entire Dutch coast. The morphological development of these growing dunes and the growth rate itself depend for a part on beach width. In the next phase of the study, we will use this knowledge to make estimates of the effect of a rising sea level on coastal dunes.

3.2.3 Dune modelling for research, developing management strategies, and informing stakeholders

Field measurements are essential for understanding the natural processes that build dunes, and dune behaviour. However, such measurements only give information on the period in which the measurements are done and for the specific situation at that time. To get an impression of how coastal dunes will respond to climate change and management measures, models are an indispensable tool. Models allow researchers to run various scenarios over long timescales. Moreover, models are useful to identify the most important dune-building processes, so that managers can take these into account when designing protection measures. We developed two models for coastal dune development, one to get detailed

insight and a second one for long-term predictions. They fit into the larger framework of coastal dune research in the Netherlands (De Groot et al., 2012) and are described here in more detail.

Short-term dune behaviour under influence of climate change and beach nourishments

The first model is called DUBEVEG (DUne, BEach and VEGetation model). It considers areas up to 1 km and time spans up to 25 years. It has been developed for understanding the processes that drive coastal dune formation, so that the effect of beach nourishments and climate change can be simulated. Coastal dunes develop through the interplay of sand supply, sea action, sand transport by the wind, and vegetation growth. In contrast to earlier models, our model takes all these processes explicitly into account (Figure 3.9).

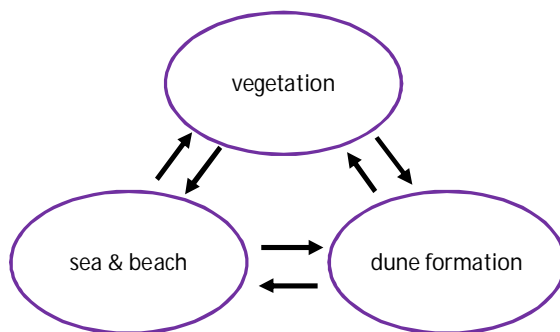


Figure 3.9 Schematic representation of the model

The basis is an aeolian (i.e. wind-driven) sand transport model that builds dunes based on a number of rules (Baas, 2002; Nield & Baas, 2008). Sand packages are transported by the wind and pile up to form dunes. If the slope of a dune becomes too steep, sand will avalanche down until the slope is stable again. On the downwind side of a dune, there is a local wind shadow from which no sand can be picked up, and sand that is transported to that zone will always be deposited. If vegetation is present, the chance of erosion by the wind is smaller, and deposition increases. Plants grow by taking up nutrients and when they die, their nutrients are cycled through the soil organic matter and come available for the plants again. Two vegetation types are simulated: one consisting of Marram grass, which is the most important dune building plant along the Dutch coast, and a second one consisting of a mix of species that grows in dune slacks and on green beaches. The vegetation types have contrasting requirements regarding the amount of salt, burial and deflation of sand, and moisture. Finally, the erosion and deposition of sand by the sea is simulated. When the weather is good, the sea brings in sediment. But when storms elevate the water level the sea erodes the dunes, the degree of erosion depending on water level and whether vegetation is present. The model can be used to simulate the effect of changes in environmental factors and management activities on coastal dunes. We give here two examples of such simulations.

The first example considers an increase in average wind strength. Starting out with an average beach and dune topography for the Dutch coast, the model runs for 15 years in which wind, sea and vegetation modify the landscape. The left panel of Figure 3.10 gives the beach and dune after 15 years under the current wind climate, the right panel the situation

where the wind is 1.5 times stronger. In both cases, small new dunes have developed in front of the original dune, with a dune slack in between. In the case with more wind, the dune grass does not grow well on the newly-formed dune at the seaward side: it is overwhelmed by the sand. These new dunes are also bigger than in the normal situation, because the wind is capable of transporting more sand out of the intertidal area. The large, original, dune is higher, more mobile, and is moving faster landward (i.e. out of the model space) than in the current wind climate. This means that the dunes will become more dynamic with an increase in wind strength, but that the vegetation still manages to hold them in place to a certain degree.

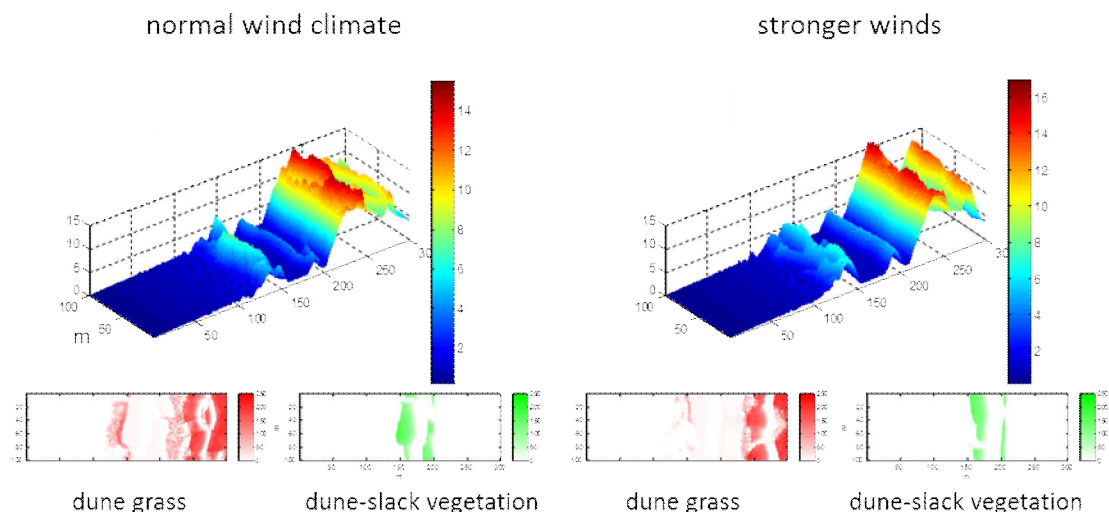


Figure 3.10 Dune development and vegetation distribution under normal (left panels) and increased wind strength (right panels), after 15 years. Topography is in meters (upper panels), biomass of the dune grass and dune-slack vegetation (lower panels) in $g\ m^{-2}$. The sea is to the left of the pictures, and the wind is blowing from the left to the right.

The second example shows how a beach nourishment gives rise to temporary dunes. During a beach nourishment, a large amount of sand is put onto an eroding beach so that it is widened and elevated. In the following years, the beach is eroded back to its original state by the sea. In the meantime, the sand can be transported by the wind. Figure 3.11 shows how after a few years, new dunes develop on the wide beach. It takes a while before vegetation establishes: first the new dunes need to be high enough for the dune grass to be out of the reach of the sea, and for the dunes to shelter a low-lying area in the back from the sea. Such new dunes and vegetation are considered to be valuable nature areas. Because the sand is stored into the dunes and is not directly eroded by the sea, the dunes form a buffer for wave attack. Eventually, with ongoing erosion the new dunes disappear into the sea. Although nourishments are primarily carried out for coastal safety, and initially form a disturbance for nature, this model shows that large nourishments, carried out at large intervals, may give rise to the temporary creation of valuable and endangered habitats.

The DUBEVEG model is the first model to include all most relevant processes for coastal dune formation, so that a full picture of the development of beach and dunes can be obtained. The effect of various climate change parameters can be simulated, such as wind strength,

increased vegetation growth, and rising sea level. Further, the effect of management strategies such as nourishments and foredune management can be simulated. The model thus gives insight into the natural buffering capacity of the coast against changes. The limitations of the model lie in long computing times for larger areas, and in the fact that the processes are necessarily schematised, so that the outcomes gives general behaviour of beach and dune rather than the development on a specific site.

In general, there is still much unknown about the interaction between plant growth and sand dynamics, leading to uncertainty in the model. We will work on the latter in the second term of the Knowledge for Climate program. Another uncertainty lies in the establishment speed of vegetation, which will be tackled in a separate study.

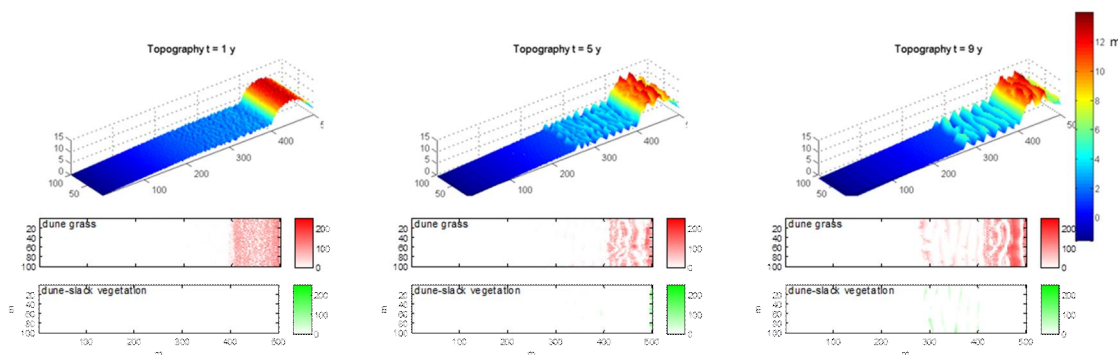


Figure 3.11 Dune and vegetation development on a nourished beach at 1, 5 and 9 years after the nourishment. The nourishment is designed to last 10 years before it needs to be applied again.

The influence of long-term changes on the dunes of Holland's coast

As a consequence of climate change, coastal protection along the Dutch coast needs to be intensified. It is difficult for local stakeholders and other non-experts to oversee the effect of different management strategies on larger temporal and spatial scales. At Deltares, within the Building with Nature program, an Interactive Design Tool is being developed. This tool is used as awareness tool in stakeholder consultations (see section 4.3.4) where stakeholders can define management strategies. These strategies are simulated on the spot and then visualised in Google Earth. There is special interest for so-called mega-nourishments, where the coast is nourished with a large surplus of sand, that is allowed to erode and serve as a source of sand for large area (Mulder and Tonnon, 2010). The basis of the tool is the UNIBEST model (Deltares Systems, 2012) that calculates coastline change as the result of longshore sediment transport and human changes. It considers the entire Holland coast, for timescales up to 100 years. The coastline changes are then translated into dune morphology. The latter part of the model has been developed at Wageningen University.

The requirement for a fast calculation puts constraints on how much detail the dune model can include. As a start, literature search and analysis of coastal profiles was done to reveal relations between coastal volume change and dune volume change, and dune shape. This yielded a surprising lack of generally applicable relations. On top of that, mega-nourishments form an unprecedented method of coastal management, for which it is difficult to find comparable, natural situations. Therefore, the model consists of a simplified approach, based on data and expert judgment. Given a certain coastline change with respect to the initial coastline, dunes are classified as being erosive, stable ('normal'), having new dune formation,

or strongly seaward extension ('mobile dune' and 'green beach', Figure 3.12). This gives stakeholders an impression of the dune morphology in response to their management strategies. The long time horizon and strong schematisation of the processes leads to relatively large uncertainties, especially on longer timescales. However, the approach has already proved useful in stakeholder sessions by serving as a start for discussion in a better informed way than before. Climate change is not implemented yet, but is envisaged to be so in future. This tool will then form an excellent opportunity to visualise the combined effects of climate change and adaptive management on coastal dunes for a wider public than coastal engineers alone.

To explicitly include climate change, a stand-alone model for coastal dune formation on this relatively long temporal and spatial scale is under development in parallel at Wageningen University. Based on findings when developing the above model, a probabilistic approach looks most promising.

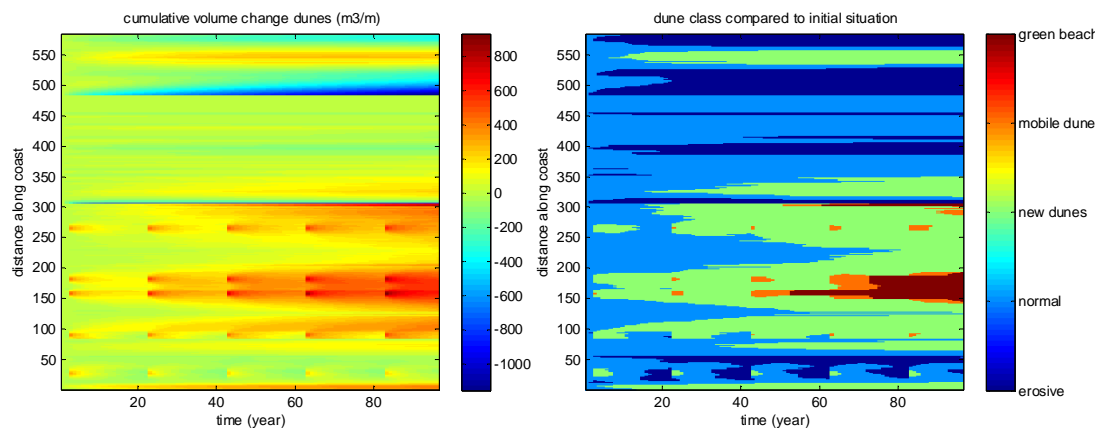


Figure 3.12 Example of long-term model results: output coastline volume changes through time (horizontal axis) are first translated into cumulative dune volume changes (left panel) and subsequently into dune types (right panel). Distance along the coast is given in profile numbers (vertical axis), extending along the Holland coast from South to North. In this specific scenario, a large nourishment is done every twenty years at five locations in the lower half of the figure. The upper part of the area shows autonomous behaviour.

3.2.4 Dunes as dynamic climate buffers in a socio-economic environment

The potential of the dune system as a dynamic climate buffer is not only depending on physical and ecological factors. An awareness of the dynamic character of the coastal zone and of the need to accommodate and integrate natural processes in socio-economic development of the coast, is equally important. Technically, a negative sand balance of the system may be effectively countered by sand nourishments. Our knowledge of sediment transport processes may be such that we are able to design nourishments leading to optimal growth of the dunes. If, however, socio-economic developments interfere with this physical-ecological process, however, the climate buffer potential of the dunes may deteriorate over time.

In order to optimize the potential of dunes as dynamic climate buffers and integral part of socio-economic developments, we study the issue at three different levels: (1) the perception

of citizens on the contribution of sandy coastal reinforcements on safety against flooding and environmental quality, (2) participatory design of development scenarios of the coast and (3) an analysis of changes in dune management and their effects on dune development.

Perceptions on coastal flood risk and spatial quality

In 2010, the coast of Zeeuws Vlaanderen between Nieuwvliet and Groede was reinforced. An artificial dune and extended sandy beach were created seaward of the existing clay embankment (Figure 3.13).

To investigate the effect of these measures on the perception of local citizens with regard to safety and spatial quality, MSc student Geertje van Wijk organized a survey end 2011.

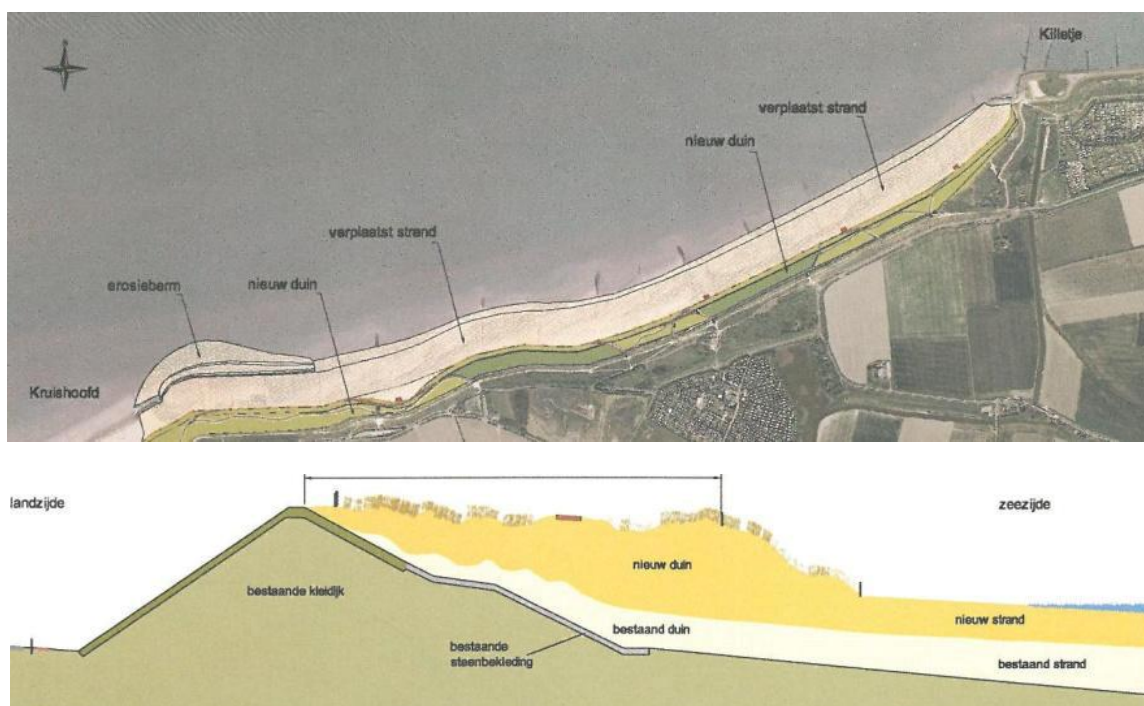


Figure 3.13 Sandy reinforcement of the coast between Nieuwvliet and Groede (Zeeuws Vlaanderen; NL).

The main results of 52 respondents show the following regarding risk perception:

- 77% believes that the coastal reinforcement has increased the level of protection;
- 90% indicates that they regard the level of protection to be very safe or sufficiently safe.

.. and regarding spatial quality:

- over 50% indicates that accessibility and space for recreation has improved;
- 25% indicates that they will visit the coast more frequently than before;
- 70% regards the coast to be more beautiful, more attractive and more pleasant than before.

From this research also followed that people who perceived a high risk were more involved with the design process than people who perceived a low risk.

Design of future development strategies

In the framework of the Delta Programme, a national vision on coastal development of the Netherlands is being designed. The Delta Programme aims at protecting the Netherlands and its future generations from flooding and ensuring a sufficient supply of freshwater (www.deltacommissaris.nl). A number of Design Workshops (AKK; Atelier KustKwaliteit) are held at various locations along the coast. Participants from all levels of government, NGO's, businesses, experts and local residents contribute to the vision development, by designing different future development scenarios.

Each workshop starts with an exchange of basic information by each participant. As experts on coastal morphology we illustrate the basic development principles of a sedimentary coast: the importance of the sediment balance and sediment distribution in general, the role of dunes and potential of sand nourishments more in detail (Figure 3.14) and the importance of dynamics.

An important communication tool to illustrate the dynamic character of the system, is the Interactive Design Tool as mentioned in section 4.3.3. It enables a quick evaluation of different design alternatives, showing dynamic effects on larger time and space scales. Stakeholders learn to appreciate the dynamics, resulting in more realistic designs (see Figure 3.15).

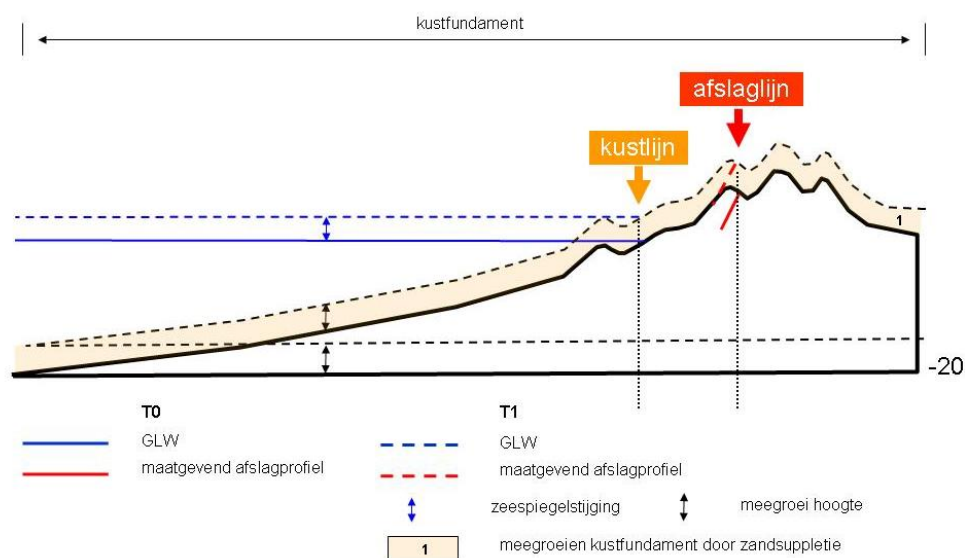


Figure 3.14 Simplified illustration of the principle of Growing with Sea Level by sand nourishments (Van Parridon & De Groot, 2012).

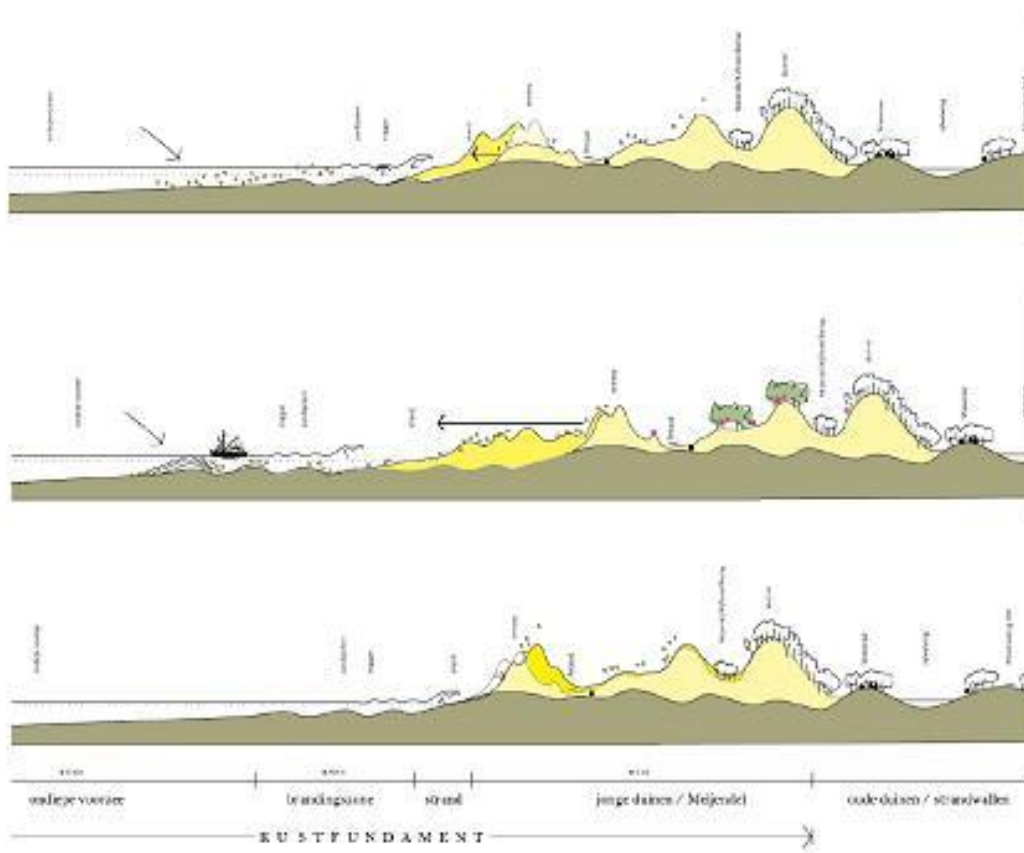


Figure 3.15 Preliminary prognoses for future development of the natural dune coast of Holland (Van Parridon & De Groot, 2012).

Changes in dune management⁵

In 1990, in order to guarantee a sustainable preservation of safety against flooding and of values and functions in the dune area, the government decided to maintain the position of the coastline by means of sand nourishments. An intensive management of the foredunes was no longer required. This implied a fundamental change from a reactive type of management (in response to storm damage), to a more pro-active approach (adapting to large-scale changes due to coastal erosion; Mulder et al., 2011). Consequently, natural processes in the foredunes revived, and the sediment budget of the beach-dune system changed (Figure 3.16; also see e.g. Santinelli et al., 2012).

⁵ Based on: Arens et al. (2012), submitted

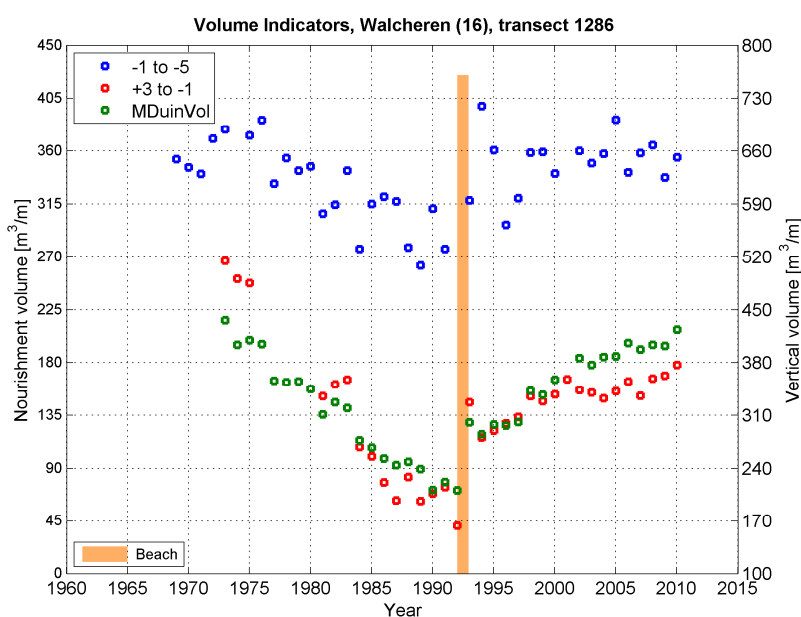


Figure 3.16 Typical example of volume changes in different depth zones at Walcheren. (MDuinVol = volume of foredunes; Beach = beach nourishment)

Roughly, two types of responses are visible. In some areas the increased input of sand resulted in the development of embryonic dunes in front of the former foredunes, leading to an increased stabilization of the former foredunes. In other locations, the declined management efforts resulted in increased importance of wind erosion features in the foredunes, development of carves and blowouts, and even new development of parabolic dunes. The reasons for the differences are not yet clear, especially since the interaction between shoreface, beach and dunes is still poorly understood.

In the same period, nature conservation managers became aware that, in order to maintain the threatened, very rare pioneer species in the inner dunes, more blowing sand was necessary. From the mid 90ies on, several attempts have been made to restore aeolian dynamics in the dunes behind the foredunes. Results indicate that destabilization activities yielded an important increase of blowing sand and effects on ecology, but with limited desired overall dune remobilization. One of the main problems is formed by the roots that remain in the sand after removal of vegetation and topsoil. It seems to be essential to follow up the initial management by removing roots for a number of years, but also then it remains unsure whether the remobilized dunes will remain mobile in the long run without other management measures.

The remobilization attempts of the inner dunes have always been designed independently from the changed developments in the foredunes. We argue that an integrated and a dynamic approach to coastal and dune management, taking account of all relevant functions (both protection against flooding, natural values and others) and of the dune-beach system as a whole, may provide new and durable solutions. Such integrated approach would imply:

- 1 providing fresh sand to the system by nourishments;
- 2 giving room for natural redistribution of sand within the system with a minimum of management interference;

- 3 stimulating and restoring inland transport of sand by removing vegetation behind the foredunes.

Enhanced inland sand transport will contribute to a gradual raising of the surface levels in the dune belt, allowing the dunes to grow with sea level, thus creating boundary conditions for a sustainable (long term) preservation of safety against flooding. Crucial requirements are 1) reservation of space for freely moving sand, not impeded by infrastructure or legal restrictions; 2) minimal management interference, except active destabilization of over-stabilized surfaces in foredunes and inner dunes; 3) allowing a long time scale of development.

Experimental nourishment schemes, not only designed to maintain the reference coastline position, but also to stimulate optimal landward transport of sand and retardation of vegetation succession of the (inner-)dunes, seems essential to explore the potential of this idea.

3.2.5 Conclusions

The first results of this research on coastal dune formation under climate change and various adaptation strategies, show that on the Dutch coast, most dunes 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 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 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 time 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 to be useful as awareness tool in interactive stakeholder consultations. At the same time stakeholder consultations have proven the appreciation of sandy coastal developments and 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 a coastal dune management. In combination with dynamic dune management this has led to the improvement of environmental quality of the coastal dune landscape.

Acknowledgements

Model development by Alma de Groot was additionally funded by Building with Nature (HK 3.6 and 4.1) and the Wageningen UR IPOP program. Deltares developed UNIBEST and visualisation of the Interactive Design Tool, and Wiebe de Boer, Bas Huisman and Arjen Luijendijk are thanked for their collaboration.

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4 Exposure reduction: compartmentalisation and unbreachable embankments

4.1 Introduction

Frans Klijn

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. Exposure reduction thus implies technical flood defence measures, such as embankments or overflow sills, which makes the distinction with flood protection an arbitrary one. On the other hand, in the Netherlands all measures that are taken *within* dike-ring areas instead of on their outer limit constituted by the primary defences, are usually considered as ‘consequence reduction’ (Table 4.1). Therefore, we here treat these measures separately and under the heading of exposure reduction.

Table 4.1 Examples of measures aimed at reducing the flood probability and/or at reducing the consequences of flooding (Klijn et al., 2010).

	Preventive Flood Risk Management	Flood Event Management
Reduction of flood probability	<ul style="list-style-type: none"> • Embankments, new and strengthening • Strengthening dunes • Storm surge barriers • Room-for-Rivers measures • Beach nourishment 	<ul style="list-style-type: none"> • Sand bags • Temporary strengthening of weak spots
Reduction of consequences (exposure or vulnerability)	<ul style="list-style-type: none"> • Compartmentalisation • Spillways and unbreachable embankments • Dedicated protection of vital infrastructure • Development planning • Flood proofing 	<ul style="list-style-type: none"> • Warning • Evacuation • Rescue of people and property

We have not done new research on compartmentalisation in our KfC programme, because this measure has been studied intensively quite recently (Asselman et al., 2008). But we still treat the subject here, 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. We therefore summarize a paper by Klijn et al. (2010),

based on the findings of Asselman et al. (2008), but add a new interpretation from a climate-change proof flood risk management point-of view.

A second measure which we treat here are the unbreachable embankments. These are often regarded to classify as flood protection only, but they have significant influence on the exposure characteristics and thus reduce a flood's consequences. We copy parts of a conference paper by De Bruijn et al. (2012) on this issue.

4.1.1 References

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4.2 Compartmentalisation

Frans Klijn & Nathalie Asselman

This chapter is a shortened version of a paper by Klijn et al. (2010), to which we add some new insights related to recent research findings on flood probabilities and in view of climate change and sea level rise. We first explain the ideas behind compartmentalisation, and then we summarise the main findings of the study by Asselman et al. (2008), which comprised three different research activities: 1) review of existing knowledge, 2) nation-wide assessment of attractiveness and 3) exploratory analysis in case-study areas. Next, we discuss how new research findings may influence the conclusions on the attractiveness of compartmentalisation into the future.

4.2.1 Principle and objective of compartmentalisation

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. The flood-prone part of the Netherlands is divided into 53 so-called dike-ring areas, which have protection levels ranging from 1: 1,250 per year to 1: 10,000 per year. These dike-ring areas have very different sizes, however, ranging from less than 1 km² to large ones of about 660, 1500, 2200 and even 4900 km². 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.

Compartmentalisation literally means: splitting up into smaller portions. The principle is applied in various other situations, where risk is an important issue, e.g. shipping or fire prevention. In shipping, water tight compartments are often applied to prevent ships from sinking when a leak occurs – i.e. for their own sake –, whereas in oil tankers the tanks are

divided to prevent that all the oil is being spilled due to one leak only – i.e. to protect the external environment. Buildings are applied with fire-proof walls and automatically closing fire doors to prevent that fires spread. And in forestry, parcels are divided by roads to – again – firstly prevent a fire from rapid and easy spreading, and, secondly, to allow easy access for the fire brigade.

In 1953, the Netherlands experienced a major flood disaster, caused by a storm surge, and resulting in 1836 fatalities and over 72,000 people made homeless (Gerritsen 2005). Many polders were then flooded, but in many cases not entirely, because the protected areas consisted of many small compartments, which were the by-product of a history of recurrent land reclamation. This experience made the Delta Committee (1961) advise to the government to not only focus on better protection – although that was their main advice –, but to also divide large polder areas into smaller ones. This element of the advice has been neglected in the following decades and almost forgotten since. Recent flood simulations (Asselman, 2006), however, show that even remnants of old embankments are still very effective in slowing down the flooding process and in limiting the flood extent (Figure 4.1).

Compartmentalisation thus aims to reduce flood risks by reducing the consequences of any flood event. 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 (Asselman, 2006). But also by making compartments of very different size, sometimes resulting in ‘lines of secondary defence’, which keep the larger part dry, or instead allowing large rural areas to be flooded whilst keeping small urban areas dry by ‘city rings’.

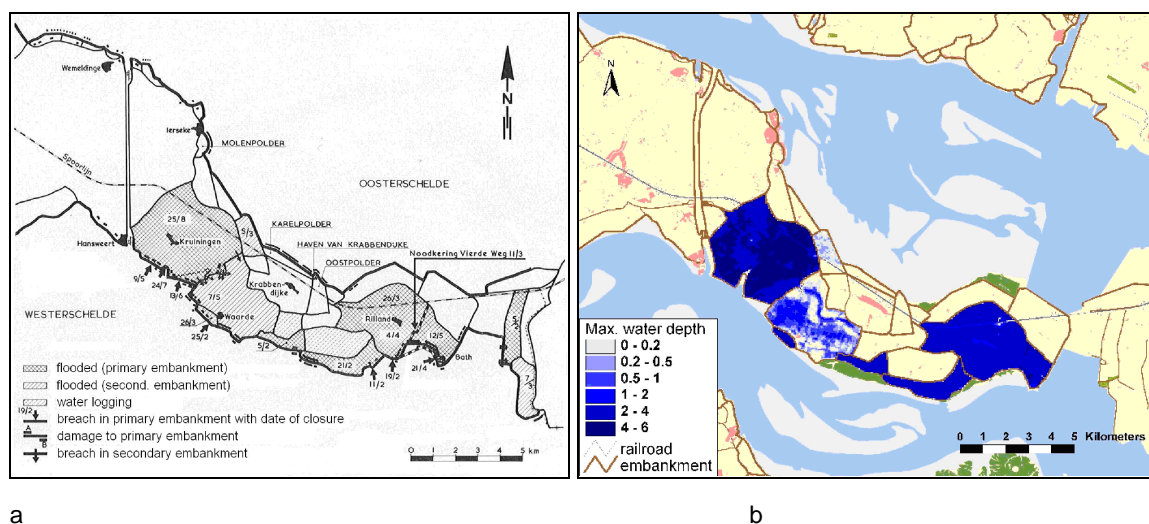


Figure 4.1 Areas flooded in a dike-ring area in the southwest Netherlands during the 1953 disaster (a) and flood pattern and depth resulting from breaches in the same locations as simulated with SOBEK 1D-2D (b), both showing the influence of former flood defences on flooded surface area (sources: Rijkswaterstaat & KNMI, 1961 and Asselman, 2003).

4.2.2 Ascertained and supposed advantages and disadvantages

The advantages and disadvantages of compartmentalisation were investigated by (1) a historic review of almost 1000 years of flood defence and connected societal and scientific disputes (Van Heezik, 2008b), (2) a literature review of recent research into controlling flooding processes and patterns (a.o. Asselman, 2006; De Bruijn, 2005; De Bruijn et al., 2008; De Bruine, 2006; Kok et al., 2006; Theunissen, 2006; Verwijmeren, 2002; Vis et al., 2003), and (3) a brief inventory of considerations in other risk domains (shipping, fire).

This yielded the following list of advantages, or at least presumed or conditional advantages:

- Reduction of flooded surface area and hence economic damage and number of people affected;
- Slower growth of breaches, because of backwater effects and smaller discharges through the breach;
- Respite, allowing counter-measures to be taken;
- Easier evacuation of smaller numbers of people over shorter distance;
- Refuge for people and cattle on the additional embankments, as well as safe evacuation routes.
- Reduction of flood duration, especially in tidal areas because breaches can be closed more easily.

Possible disadvantages of compartmentalisation which were identified, comprised the following:

- Increased risk of loss of life in smaller compartments, because of faster water-level rise and greater maximum water depth;
- Lack of space to situate a secondary defence or dividing embankment, especially in densely populated areas;
- Destruction of natural and cultural landscape values;
- High costs of implementation and maintenance, which were better spent on the primary defences.

Some of these advantages and disadvantages were recognised both in past centuries and nowadays alike. But there are also some remarkable differences. For example, the trust in the primary defences was much less in the past, which was reason to argue for compartmentalisation for the eventuality that the primary defences would fail well before the maximum water level would be reached. Nowadays, the trust in the primary defences is such that dividing embankments are regarded useful especially to reduce the residual risk, which is connected with design flood levels being exceeded. Here we shall not dwell on all recognised advantages and disadvantages, as many speak for themselves. Some may do with some clarification and distinction, however.

Firstly, the reduction of flooded surface area and hence economic damage and number of people affected was already mentioned as being the main goal of compartmentalisation. However, when the amount of water, which can enter an area, is limited, like with smaller rivers or lakes, a smaller surface area may imply greater water depths. As the largest percentage of maximum potential damage in most land-use functions is already incurred at small water depths (cf. depth-damage curves, e.g. Jonkman et al. 2008), the gains of smaller flooded surface area usually outweigh the losses caused by greater water depths.

In contrast, the probability of fatalities depends much more on water level rise rate and water depth (Lumbroso et al. 2008; Jonkman et al. 2008), than it does on surface area. Loss of life is especially expected close to breaches (little warning time and response time; high flow rates) and in small deep polders where the water is obstructed (rapid water level rise; disturbed eye-ball navigation) (De Bruijn and Klijn 2009). Both water level rise rate and water depth are usually high in small compartments. Making compartments too small therefore seems not advisable.

However, small compartments usually also contain less people, and evacuation routes to safe ground are generally shorter. The four largest dike-ring areas in the Netherlands contain about 300,000, 950,000, 3,200,000 and 1,000,000 inhabitants, respectively. Effectively evacuating such numbers of people is not regarded feasible. Dividing such dike-ring areas may have the advantage of easier and faster evacuation of less people over smaller distances.

Finally, the costs of additional embankments are often mentioned as disadvantage, especially in relation to a supposed competition for funding of better protection by reinforcing the primary defences. It is obvious that decisions on compartmentalisation require a thorough and fair comparison with other flood risk reducing measures, but this can be addressed by subjecting all possible measures to a (societal) cost-benefit analysis.

4.2.3 Where and why compartmentalisation? A nationwide assessment

In order to establish where compartmentalisation might be sensible, a nationwide assessment has been carried out. This was done for the major 53 existing dike-ring areas in the Netherlands, applying a land evaluation approach, which was aimed at assessing the 'suitability' for compartmentalisation. First, the relevance of compartmentalisation of each dike-ring area was evaluated. Secondly, the potential for cost-effectively splitting-up the dike-ring areas was assessed. And thirdly, these two elements were combined into a final judgement of suitability – or rather 'potential' or 'attractiveness' – of each area for further compartmentalisation.

The **relevance** of compartmentalisation involved establishing where the reduction of economic damage and of potential number of fatalities would be desirable. This is especially the case in 'dangerously large dike-rings', where the expected societal benefit of compartmentalisation – in terms of avoided economic damage, avoided number of people affected, and lives saved – is probably largest. Relevance was thus evaluated by the following criteria:

- Sheer size of flood-prone area (large dike-rings are likely to suffer more damage);
- The expected number of fatalities, the number of people affected and the expected economic damage;
- Physiographic characteristics which determine the flooding process and pattern, such as the internal relief and the internal network of linear infrastructure (remains of flood defences, embankments along canals and other small water bodies, and other linear obstacles).

The evaluation thus encompassed a quest of figures on expected economic damage and potential number of fatalities per dike-ring, which were available from earlier studies (Klijn et al. 2004, 2007). For the evaluation the following thresholds were used: for size of the area

100 km² and 1,000 km²; for number of people affected \geq 100,000; for expected number of fatalities \geq 100; and for expected damage 5 and 10 billion euros.

A physiographic characteristic which is especially important is the inclination of the terrain in the protected area. Polders on river floodplains, due to their geomorphological genesis, are often inclined towards the sea. This causes the water from an upstream dike breach to rapidly flow through; in the case of the Rhine and Meuse River floodplains this is towards the west. The upstream parts of such polders often become inundated only shallowly, whereas embankments perpendicular to the main river may function as obstacles and cause rapid water level rise (De Bruijn, 2005, pp 59-64). In such a case, there is a possible trade-off between a smaller flooded surface area versus greater flooding depths.

On level terrain, such as the majority of the coastal plains and land reclamations, the flooding process is entirely different. Some deep polders are filled like bathtubs because of large differences between water level and ground level, whereas coastal plains which lie at or slightly above mean sea level are inundated relatively slowly.

Finally, the degree of existing subdivision by remaining or secondary embankments influences the flooding process and pattern to a large degree. Only in dedicated case studies can this be assessed in sufficient detail by simulating various flood events. In the nationwide assessment only a global judgement could be made.

Evaluating the potential for cost-effectively splitting-up the dike-ring areas involved establishing where at acceptable costs and without insuperable societal or ecological consequences a new dividing embankment might be considered. Since investing in compartmentalisation may imply some competition with investing in reinforcing the flood defences all-around, this meant a search for relatively elongated dike-ring areas: short dividing embankments are likely to be cheaper than long surrounding defences. But also dike-ring areas which are bound by higher grounds on one or several sides may qualify. The following criteria were taken into account:

- Shape of the dike-ring area (elongated versus 'contained');
- Orientation in relation to hazard source (splitting up is easier when the threat comes from one short side only);
- Spatial distribution of vulnerable functions within the protected area (concentrated urban areas are easier to delimit than patchy developments);
- Existing major linear infrastructure (turning highway or railroad banks into dividing embankments may be cheaper than erecting entirely new embankments).

The results of the evaluations of relevance and potential (Figure 4.2) were combined into a final judgement on suitability ('attractiveness'; Figure 4.3). These Figures seem to suggest that the majority of the country should be compartmentalised, but this is a bias caused by the fact that in a map the large dike-ring areas are the eye-catchers. In numbers, only 8 of the 53 dike-rings are judged to require serious consideration for further subdivision, whereas for another 18 it may be considered. Half the dike-ring areas do not qualify at all.

Of the 8 areas classified as most seriously requiring further study, 4 have been selected as case studies for further investigation. They were selected by relative relevance, but also in such a way that a variety of physiographic situations was covered, in order to allow extrapolation of the findings to the rest of the country.

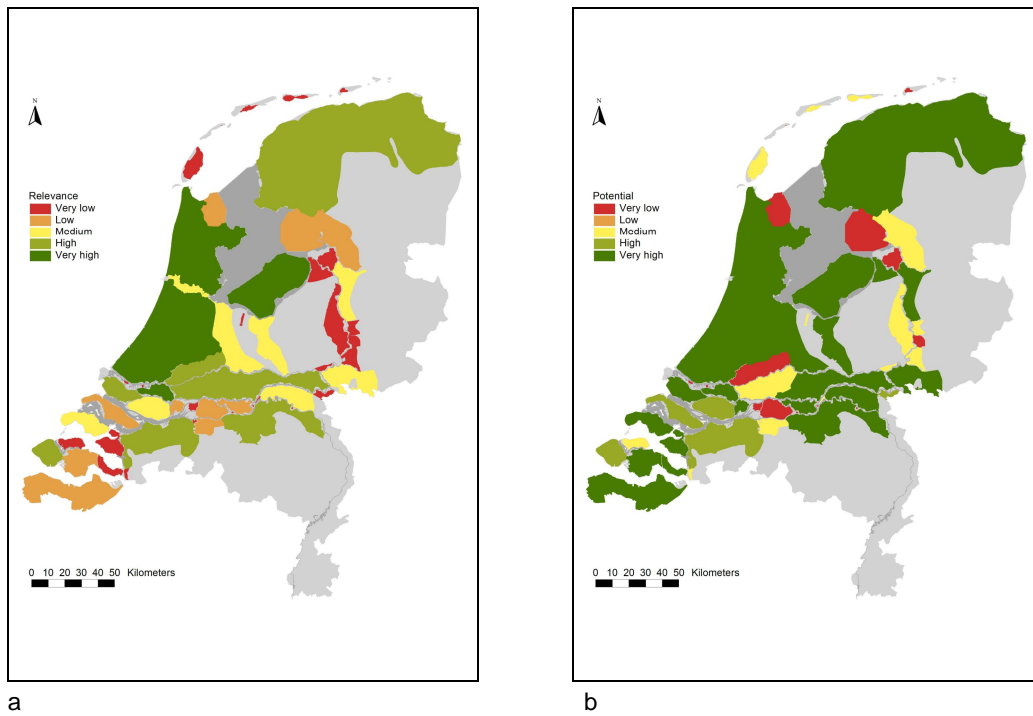


Figure 4.2 Assessment of (a) relevance and (b) potential of compartmentalisation per dike-ring area

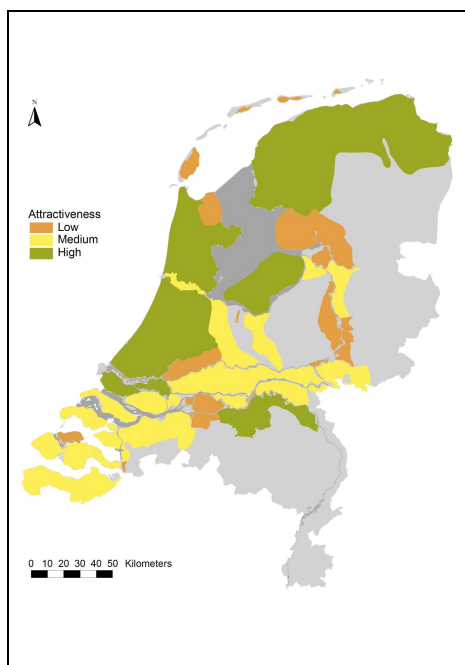


Figure 4.3 Final judgement of suitability ('attractiveness') of further subdividing dike-ring areas

4.2.4 Case studies

Asselman et al. (2008) studied the following four case studies: Flevoland (8); Central Holland (14); Land van Heusden (36); and Betuwe (43). It concerns dike-ring areas of different character.

Flevoland (8) is a deep polder area, part of the reclaimed Lake IJssel (former Southern Sea), where urban development is very rapid. The main city of Almere, mirroring Amsterdam, is intended to grow from about 170,000 inhabitant in the present situation to 350,000 by 2030. The primary aim of splitting up this polder is to prevent a large number of victims, as preventive evacuation of this area is practically impossible because of too little road capacity and too few bridges out of this insular polder area (Windhouwer 2005).

Central Holland (14) is the most densely populated and economically important part of the country, which is threatened from various sources: the North Sea, the Rotterdam harbour area behind a storm surge barrier (Maeslandt barrier) and a Rhine River branch. Because of the significance of this area as economic heart of the country, flooding could have enormous consequences for an area much bigger than the inundated area itself.

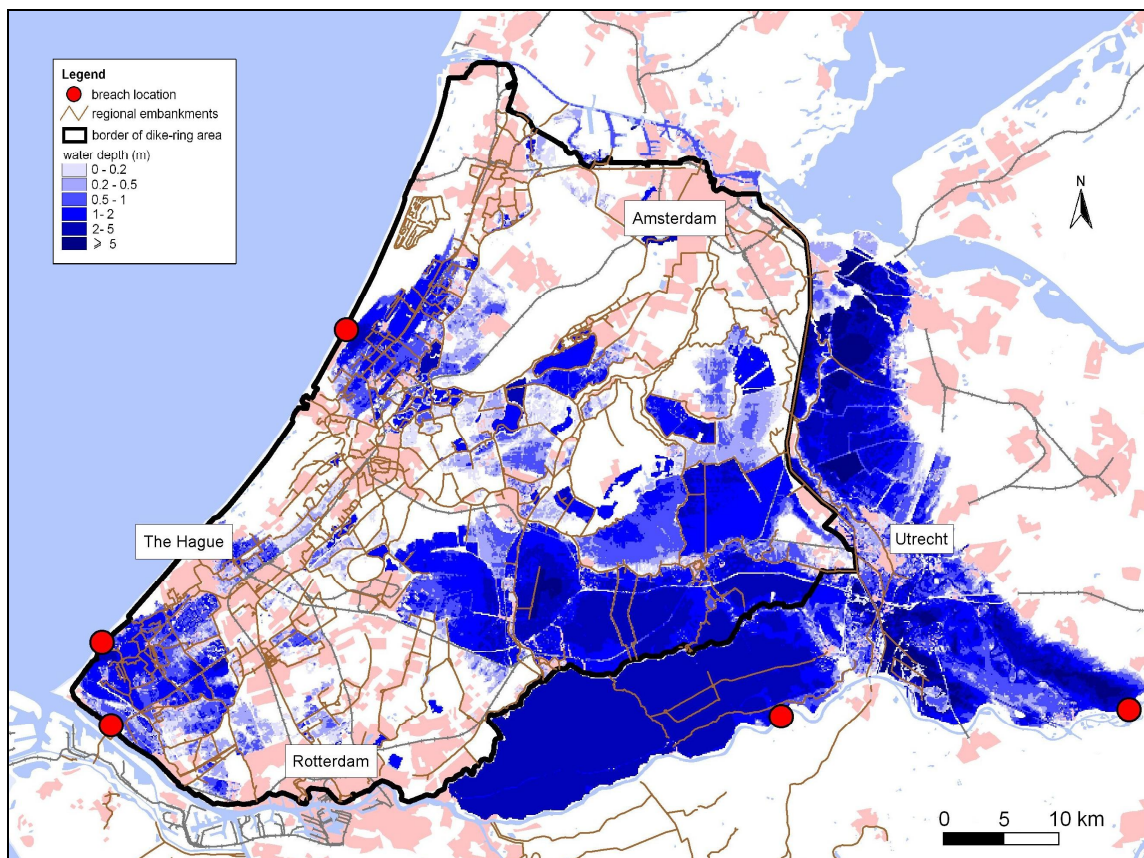
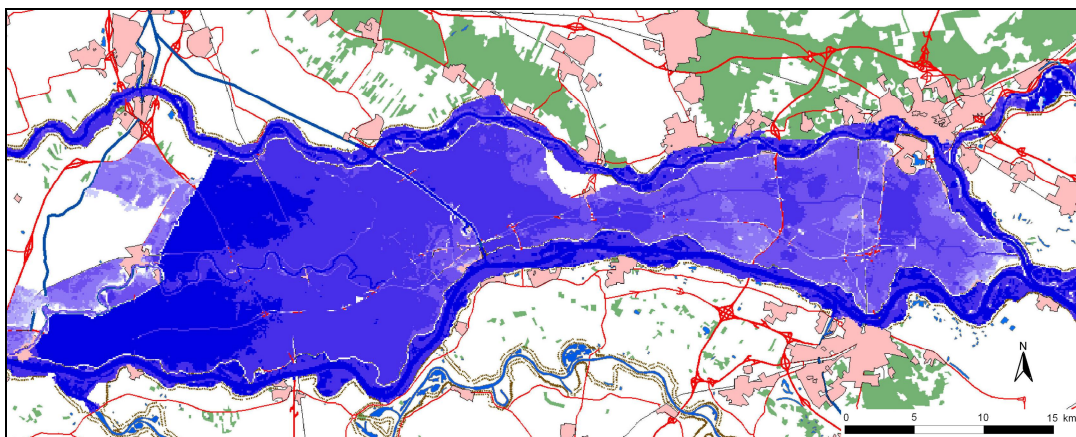


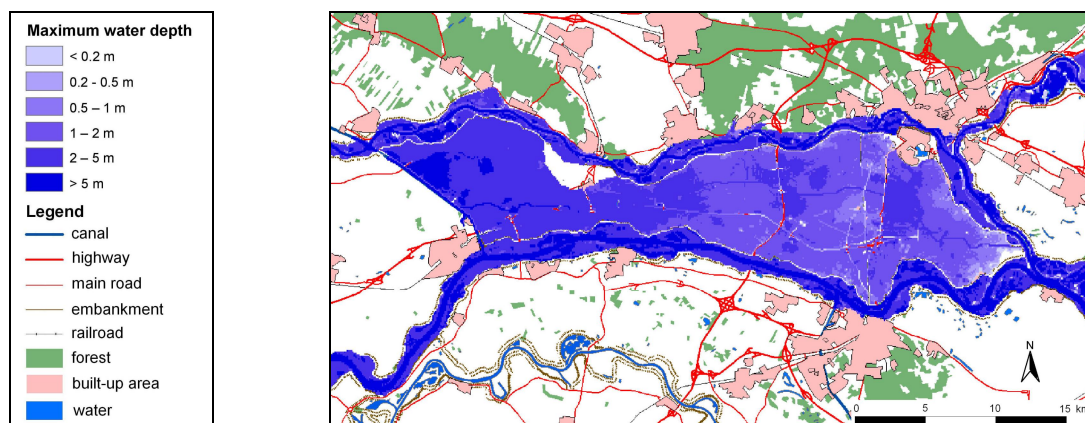
Figure 4.4 The maximum flood extent in Central Holland (dike-ring area 14) is effectively – though unintendedly – limited by existing secondary embankments and linear infrastructure in this case without additional compartmentalisation (all simulated breaches indicated with red dots and plotted in this one figure).

Land van Heusden (36) lies along the Meuse River, and is bounded by elevated Pleistocene sandy terrain on its southern side. This allows easy evacuation. Compartmentalisation would primarily be aimed at safeguarding the large but low-lying city of 's Hertogenbosch and the A2, which is one of the country's key highways.

The Betuwe (43) is located between two Rhine River branches. It has a very elongated shape and is surrounded by more than 170 km of embankment. Being reclaimed from the Rhine River floodplain it is definitely inclined towards the west, causing a flood from an upstream breach to keep flowing in for many days and the inundation to proceed to the furthest western end. This dike-ring area scores among the highest on the criterion of potential economic damage.



a



b

Figure 4.5 Water depth after a dike breach at the southeastern end (location Bommel) resulting from a 1: 1,250 years flood, without (a) and with (b) compartmentalisation along the Amsterdam-Rhine canal

The aim of the case studies was again to determine whether, by which siting or plan, and under which conditions compartmentalisation of these specific case-study areas would be

sensible. At this spatial scale of analysis, the identification and assessment of alternative plans or sitings of compartmentalisation embankments was the main challenge. For each case, this involved a comparison of the situation in subdivided dike-ring areas with the situation in the present undivided dike-ring areas. For this comparison it was assumed that all the embankments are well-maintained, as national law demands, and also updated for the effects of climate change, either through reinforcing the embankments or through room-for-river measures to lower the design water levels. This assumption is important, because it determines the probability of flooding and hence the average annual risk reduction, and consequently the cost/benefit ratio.

4.2.5 Some results from the case studies

For each case study a number of alternative plans/ sitings for embankments were investigated. Table 4.2 gives an overview of the costs and economic benefits of all the investigated plans/ sitings for all case studies, which are specified in the 2nd column in Table 4.2. For some case studies it also proved relevant to distinguish between different flood events, primarily determined by the breach location – some breaches causing much more inflow than others –, or additional engineering works such as outlets (3rd column in Table 4.2).

The table shows the expected economic benefit in terms of avoided damage in case of flooding, as well as the annually avoided damage taking into account the probability of flooding. To estimate the annual economic benefit (columns 5 and 6), different assumptions on flood probability were applied: a flood probability equal to the protection standard – which was then regarded an overestimate –, and a flood probability which might be expected when the dikes are well-kept and taking into account that design guidelines require that they are designed to withstand the design probabilities with at least 90% certainty. The latter would yield an actual flood probability of less than 10% of the probability of the design flood – which in turn would mean an underestimation of the importance of failure mechanisms other than overflow/ overtopping.

Recent research on flood probabilities (VNK, 2011) suggests that 1) the contribution of other failure mechanisms is much larger than 10%, and 2) that the so-called length-effect causes the actual probability of flooding due to a breach somewhere in the dike ring to be much larger than that of a breach at a certain location. The difference may amount a factor 10, i.e. a 10 times larger probability of flooding than we assumed. This issue is being heavily debated, but it does influence the C/B ratio and thus the conclusions to be drawn! Compartmentalisation may be much more attractive than we concluded from our 2008 study (Asselman et al., 2008).

Table 4.2 Overview of the benefits (for a representative event and annually) and benefit/cost ratio of all the investigated sites/routes (design probability refers to protection standard, true probability refers to the expected flood probability according to Klijn et al. 2007, which is often significantly lower).

Case study area	site/ plan	breach location/ case	benefit in case of flooding (10 ⁹ euro)	annual benefits (10 ⁶ euro)		costs (10 ⁶ euro)	1 st year benefit/cost ratio in 2015	
				design prob.	'true' flood prob.		design prob.	'true' flood prob.
Betuwe	Betuwelinie	Bemmel	7,8	7,2	4,5	81	2,6	1,6
		Elden	-0,1	-0,2	-0,1	81	0,0	0,0
	Kesteren-Echteld	Bemmel	4,6	4,3	2,7	145	0,8	0,5
		Elden	-0,7	-0,6	-0,4	145	-0,2	-0,1
	ARK-W Waal sluice	Bemmel	14,2	13,3	8,3	87	4,3	2,7
		Elden	0,7	0,6	0,4	87	0,2	0,1
	ARK-W NR/Lek sluice	Bemmel	16,0	15,0	9,4	87	5,0	3,1
		Elden	1,7	1,6	1,0	87	0,5	0,3
Land van Heusden	HW east		6,5	6,1	3,2	141	1,3	0,8
	HW west		3,9	3,6	2,3	96	1,1	0,7
	Parallel_east		6,5	6,1	3,8	178	1,0	0,6
	Parallel_west		3,9	3,7	2,3	112	1,0	0,6
	RBSO		4,1	3,3	2,0	113	1,0	0,6
Flevoland	A27		8,5	2,9	1,2	350	0,2	0,1
	ZZ-Flevoland		8,7	3,0	1,2	346	0,3	0,1
	east of A6		7,3	2,4	1,0	258	0,3	0,1
	High Ring	with A27	8,5	2,9	1,1	389	0,2	0,1
	railway	with A27	10,4	3,4	1,4	195	0,4	0,2
Central	Oude Maasdijk	Vluchtenburg	1,5	0,2	0,1	10	0,5	0,3

Case study area	site/ plan	breach location/ case	benefit in case of flooding (10 ⁹ euro)	annual benefits (10 ⁶ euro)		costs (10 ⁶ euro)	1 st year benefit/cost ratio in 2015	
				design prob.	'true' flood prob.		design prob.	'true' flood prob.
Holland		Zijdijk-Zanddijk	1,5	0,2	0,1	11	0,5	0,3
	Hook of Holland – The Hague	N211	5,9	0,7	0,3	72	0,3	0,1
		west N211	5,9	0,7	0,3	63	0,3	0,2
	Katwijk	N206	4,4	0,5	0,3	162	0,1	0,1
		east N206	4,4	0,5	0,3	185	0,1	0,0
	Hollandsche IJssel	without outlet	1,8	1,1	0,4	210	0,1	0,1
		with outlet	8,0	4,7	1,9	220	0,6	0,2
	Prinsendijk and Oude Rijndijk		0,1	0,1	0,0	383	0,0	0,0
	Amsterdam-Rijnkanaal	entirely	-0,3	-0,3	0,0	89	-0,1	0,0
		S. of Utrecht	-0,5	-0,5	0,0	28	-0,5	0,0

For all case-study areas it was found that, in case of flooding, a well-placed compartmentalisation embankment could substantially reduce the economic damage and the number of affected people, and might also significantly lower the number of fatalities. A reduction of the economic damage and the number of affected people of some 50 – 80 % could be achieved in most case study areas. The reduction of the number of fatalities is of the same order of magnitude, but we have not reported absolute numbers as they could not be quantified with sufficient certainty, as any loss-of-life estimate is very sensitive for assumptions on warning time and evacuation effectiveness – two very uncertain and heavily debated factors in our case (cf. also Jonkman, 2007; Lumbroso et al., 2008; Lumbroso & Di Mauro, 2008).

For the assumed flood probabilities, the annual benefit of a dividing embankment in the Betuwe case, along the western side of a large shipping canal (from Amsterdam to the Rhine River), is highest (8 to 13 million euros per year). In the cases Flevoland and Land van Heusden an annual benefit of about 3 to 5 million euros can be expected, whereas the lowest annual benefit of compartmentalisation is achieved in the case-study area of Central Holland. This relates to the very low flood probability in this area (< 1: 10,000 year).

The overall investment costs, including maintenance, vary from some 10 million euro for the reinforcement of an existing inland embankment (Oude Maasdijk) to almost 400 million euro

for the heightening and reinforcement of the Prinsendijk and embankment along the Oude Rijn (Old Rhine); both in Central Holland, which is a difficult to divide dike-ring area. Most compartmentalisation plans are, however, estimated to require an investment of between 100 and 200 million euro.

From a purely financial cost-benefit point-of-view – based on the first year benefit/cost ratio (using a discount rate of 2.5% and assuming the maintenance costs to amount 1% of the investment costs, and assuming 2% economic growth) –, compartmentalisation would be an attractive flood risk reduction measure only in one of the cases, namely the Betuwe area. This is caused partly by the relatively low investment costs, but mainly by the large annual benefits. For the case Land van Heusden the benefit/cost ratio is only > 1.0 when it is assumed that the actual flood probability equals the protection level. When it is even larger, as recent findings (VNK, 2011) suggest, it would certainly be attractive.

4.2.6 What the case studies taught us

The case studies showed that each case-study area has its own specific complications, which requires a dedicated investigation; general principles seldom apply.

Firstly, 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 (Alkema & Middelkoop, 2007), and hence also determines whether compartmentalisation has sufficient benefits. In Central Holland with its many ancient and secondary embankments the flood spread is 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 (Figure 4.4). A key uncertainty we identified, however, is whether the secondary embankments will stand the flooding.

Secondly, our analyses revealed that in inclined areas along rivers, such as the Betuwe and Land van Heusden, an outlet on the lower side of the dike-ring may substantially reduce the damage. The lower part of such dike-ring areas may become very deeply inundated, as any upstream breach will continue to flow in, whilst the flood water will flow through the area to the lower end. Especially when such dike-ring areas are split up, such an outlet is quintessential to lower the flood levels, as the flood levels may exceed the level of the embankments causing a knock-on effect on neighbouring polders. Also the negative impact of greater depths on damage may then exceed the positive impact of the smaller flooded area (see the negative benefits for Betuwelinie and Kesteren-Echteld in Table 4.2).

Thirdly, fitting new or reinforced defence structures into an existing landscape without devastating the historically grown spatial quality, proved not so easy. In many cases, existing embankments are built-up on one or both sides, inhibiting their reinforcement without pulling-down the majority of the houses. In such cases, entirely new embankments appeared easier to fit in, but these require either the design of an entirely new landscape, or planning a new embankment into the existing landscape with the least possible impacts. By involving landscape architects in the study, several good examples could be made, which enhanced the discussion with the local stakeholders.

Finally, and most importantly, we experienced that policy makers, stakeholders, and also the researchers were inclined to allocate the most weight to the assessment criterion of economic cost/benefit ratio: the financial cost-effectiveness. This strongly influenced the preference for the most promising plan/siting of an embankment within a case, but also strongly affected the

opinion of many policy makers on whether or not to consider compartmentalisation at all. There are two important issues related to this experience, however. Firstly, the annual benefit depends on the expected flood probability, which is very uncertain. And secondly, we obviously need to seriously and constantly take into account the trade-off between better flood protection and the reduction of consequences.

As to the first issue, we found it very difficult to quantify the annual benefits of compartmentalisation, because these are directly related to the probability of a flood event: a series of happenings from high water level (rare), dike failure, breach development, inflow and spread of water. 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. These may seem large differences, but they fall within the range of flood probabilities as estimated by known experts for the same place. And for such rare events as extreme floods, we cannot fall back on measured probabilities; we have to rely on the few measurements available, statistics, extrapolations, simulations and assumptions. In contrast, the estimates of investment and maintenance costs are much less uncertain. 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.

As to the second, related, issue, the tight correlation between flood probability and benefit/cost ratio means that in well-protected dike-ring areas compartmentalisation would be much less desirable than in dike-ring areas with lower protection levels. In other words: ‘the better protected, the less profitable compartmentalisation’ (or whatever measure to reduce flood consequences). This would affect the answer to the question put in an earlier section on where compartmentalisation would be attractive. And it implies that compartmentalisation must be evaluated not only by itself, but also in comparison to increasing flood protection standards as already done by the Ministry of Transport, Public Works and Water Management, (2006; Kind, 2006), and even in comparison to further differentiating those which is still being debated (Van der Most et al., 2006). However, in the practice of the Netherlands’ flood risk management, the best protected areas are also the most vulnerable areas with the largest potential consequences in terms of damage and number of inhabitants. If a flooding would occur in any of those areas, the consequences would be tremendous and very likely unacceptable, both socially and politically.

4.2.7 Conclusions on attractiveness

The objective of the study was 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? As the reduction of flood risks in a densely populated and intensively used country like the Netherlands, is quite complicated. no simple answers can be given without compromising on nuances. Nevertheless, we shall share our main findings, without wandering into detail.

On *whether* compartmentalisation is sensible:

- 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.

On **where** compartmentalisation is attractive:

- 1 Subdividing polders is especially relevant when they are 'dangerously large' and easy to split-up (elongated in shape).
- 1 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.
- 2 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.
- 3 For the case Flevoland it was found that no additional compartmentalisation embankments would qualify as being both cost-effective and robust. This is regarded as a conclusion which is representative for deep polders, such as those bordering Lake IJssel.
- 4 The further splitting up of Central Holland is not cost-effective, but its contribution to a reduction of consequences is very substantial and it may prevent societal disruption. This conclusion is regarded representative for all large flood-protected coastal-plain areas in the Netherlands and abroad (Germany, UK, USA).
- 5 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. The ability of those linear elements to withstand a prolonged period of flooding is, however, very uncertain and requires thorough investigation.
- 6 Subdividing the Land van Heusden can reduce the flood consequences with some 50 - 80%. It is, however, very costly and not quite cost-effective.
- 7 In the Betuwe a well-placed compartmentalisation embankment is both cost-effective and can be fitted in in the existing landscape quite acceptably.

On the question **under which circumstances** compartmentalisation is sensible:

- 1 Compartmentalisation is the most effective in reducing flood consequences when combined with additional measures, such as a downstream outlet along rivers, differentiation of protection levels (better protection for urban area than for countryside), and evacuation planning.
- 2 A compartmentalisation embankment should be designed in such a way that it can also withstand conditions which might occur after a breach resulting from above-design flood conditions, as otherwise a knock-down effect may occur with additional damage in compartments further downstream.

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4.3 Unbreachable embankments

Karin de Bruijn, Han Knoeff & Frans Klijn

4.3.1 Rationale

Past and recent floods worldwide reveal that the breaching of embankments may result in flood disasters with many fatalities. Breaching embankments make floods come by surprise, since it is difficult to fore-cast when and where embankments may breach. Besides, people behind embankments generally feel safer than those in unprotected areas and are therefore sooner taken by surprise when the area does unexpectedly become flooded.

If embankments would not breach, but would only be overtopped under extreme circumstances, uncontrollable disasters might be prevented. Overtopping is a more gradual process, which results in smaller inflow volumes, slower water level rise rates in the flooded area and less area being inundated less deep. This gives inhabitants more time for evacuation or to seek safety, even when the inflow has already started. Besides, people may observe the water levels and waves by themselves and assess whether the embankments are going to be overtopped, instead of having to rely on sophisticated computer models. They will certainly be less surprised by a flooding than in case of a sudden breach.

In the Netherlands, there is an increasing attention for flood protection and flood fatality risks, especially after a call from a governmental committee (Delta Committee, 2008) to pay more attention to fatality risk and the potential large numbers of flood fatalities in particular (Beckers & De Bruijn, 2011; Klijn et al., 2010). Since especially fatality numbers may be lowered by strengthening the embankments into virtually 'unbreachable' embankments, these embankments deserve consideration where fatality risks are high.

As the Netherlands is protected by some 3000 kilometers of primary flood defences, it is, of course, practically impossible to convert all these embankments into 'unbreachable' embankments in a few decades. It would, first, simply require too much time to re-construct all these embankments, the investment would be too large to bear, and they may not be needed everywhere either, in the sense that they would not be cost-effective. 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. We thereby built on an earlier 'quick scan' by Silva & Van Velzen (2008), used data from the national studies for revising the Flood Risk Management Strategy (Water Safety 21st century; Beckers & De Bruijn, 2011; De Bruijn, & Van der Doef, 2011).

In this chapter – which is a shortened version of the paper (De Bruijn et al., 2012) we submitted for the FLOODrisk2012 conference in Rotterdam (November 2012), we first discuss what we mean by 'unbreachable' embankments, how they differ from conventional embankments and how they affect fatality risk. Then we give a short overview of flood hazard and risky places in the Netherlands. Next, we go into the method which we used to identify priority locations for the construction of unbreachable embankments from the perspective of fatality risk. Finally, we discuss the results and repeat the main findings.

4.3.2 What is the difference between conventional and unbreachable embankments?

In the Netherlands, strict guidelines apply for the design and construction of embankments (e.g. TAW, (1985, 1989) and ENW (2007). All embankments are designed according to legal protection standards, which refer to exceedance probabilities of design hydraulic conditions – for water levels and waves. The exceedance probabilities of these design conditions vary between 1:10,000 per year along the coast to 1:1,250 per year along the rivers. The embankments are designed to be *sufficiently* high and strong to withstand these conditions.

The level of the crest of the embankment is based on these design water level and wave height. The critical overtopping discharge by waves is 0.1 to 1.0 l/m/s. Higher discharges may damage the embankments and eventually cause breaches. The crest should thus be high enough to make sure that the probability of higher overtopping discharges is equal to or below the design probability.

The design guidelines prescribe that the probability of failure of the embankment due to conditions lower or equal to the design conditions should be less than 10% of the design probability (TAW, 1998). This requirement applies to all possible failure mechanisms that could lead to a breach, such as failure of the outer revetments, erosion by overtopping waves, piping, or instability of the slope (sliding, slumping). This requirement should, supposedly, turn the probability of failure of the embankment into somewhere near the exceedance probability at maximum, or with a good range of uncertainty around this value. However, recent insights show that even if embankments comply with the design regulations, the contribution of the strength-related failure mechanisms is sooner more than 50% than less than 10%, and may even be more than 90% in some cases (VNK, 2012). Consequently, recent assessments (VNK, 2012) reveal that the flood probabilities of many protected areas in the Netherlands are much larger than the legal protection standards would suggest. This may result in embankments breaching well before they are loaded to the limit. This is difficult to explain to the public, and may hence be undesirable. To make the embankments comply with the 10% rule many (river) embankments need to be strengthened.

For unbreachable embankments there are, as yet, no design rules, as such embankments have never been built yet. For this exploratory analysis, we simply assumed much stricter

regulations than applied for conventional embankments. The contribution of the strength related failure mechanisms should be less than 1% of the probability of exceedence of the water level. Unbreachable embankments should be able to withstand overtopping and conditions beyond design.

By assuming such strict design regulations for unbreachable embankments, we may neglect the probability of breaching in comparison to that of overtopping. Of course, we are aware of the fact that the probability of breaching can never be eliminated entirely, for example in case of heavy earthquakes, heavy ice pressure or terrorist attacks, but we are confident it can be reduced significantly.

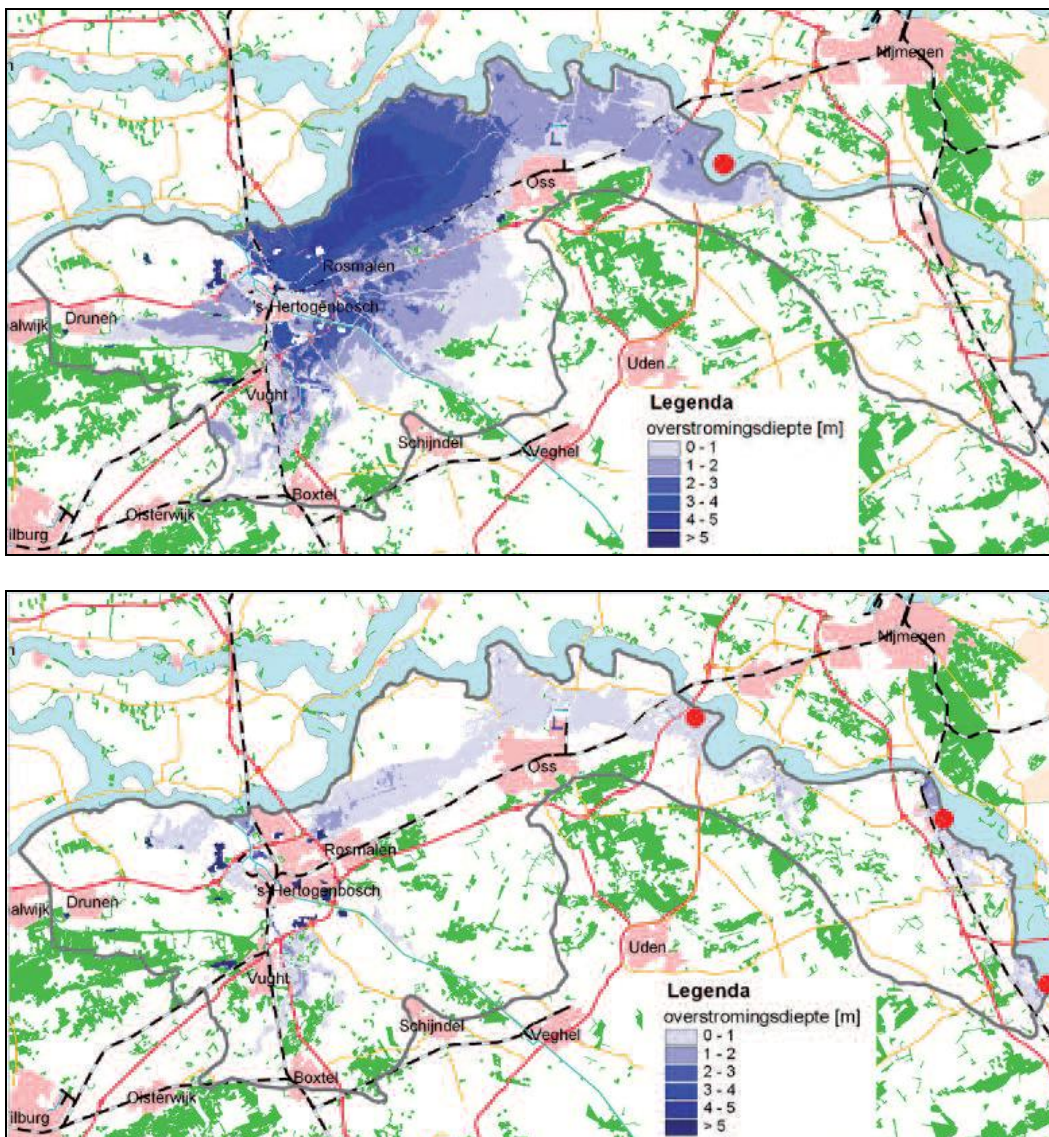


Figure 4.6 Flood extent and depth due to an extreme flood in the Meuse River after a breach (above) and resulting from overtopping (below)

The effect of unbreachable embankments on exposure characteristics

Unbreachable embankments may reduce fatality risks because 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. Such a more gradual and less severe flooding process will give the inhabitants more time to reach safe havens and take effective action instead of panicking. Figure 4.6 gives an example of the maximum water depths attained after a breach respectively due to overtopping.

4.3.3 Flood hazard characteristics and fatality risk

Flood fatality risks depend on flood hazard characteristics (flood probability, flood patterns) and the vulnerability of the area and the people (De Bruijn & Klijn, 2009).

Flood probabilities differ from place to place and in time. They are related to the protection standards, but not equal to those. Also exposure characteristics differ per area: the most severe events in terms of flood extent and depth are expected along the large rivers and in the polders around Lake IJssel. The river floods are more severe than along the coast, because 1) Rhine River floods last longer (many days to weeks, whereas storm surges at sea drop back within two days), because 2) the height difference between land and flood level is larger than in the coastal plains, and because 3) the protected river floodplains are less compartmentalized than the protected coastal plains

The vulnerability of an area and its inhabitants – in relation to fatality risk – is defined by demographic characteristics, such as number of people, their age distribution, and by the evacuation possibilities from that area. Consequently, the most vulnerable areas are cities and especially those in areas from where evacuation is difficult.

For the Netherlands applies that the possibilities for evacuation are best in the dike-ring areas along the upstream stretches of the rivers: river floods can be forecasted days before they arrive here, i.e. much earlier than coastal storms, and safe areas are within reach. Along the tidal river stretches in the west, the evacuation possibilities are the worst: this area consists of dike-ring areas surrounded by water, access roads are limited in number and capacity, the area is densely populated and floods are often difficult to predict. Floods here may originate from either a high river discharge, or a storm surge at sea, but more likely from an unfortunate and difficult to predict combination of the two.

De Bruijn & Klijn (2009) already combined all hazard and vulnerability factors in order to geographically identify 'risky places': locations where large numbers of fatalities may occur (Figure 4.7). Since they drafted their map (first approximation), many flooding simulations have become available which allow for improvements. Besides, research by for the national programme on Water Safety 21st Century has recently increased our knowledge about fatality risk in more quantitative terms (Beckers & De Bruijn, 2011).

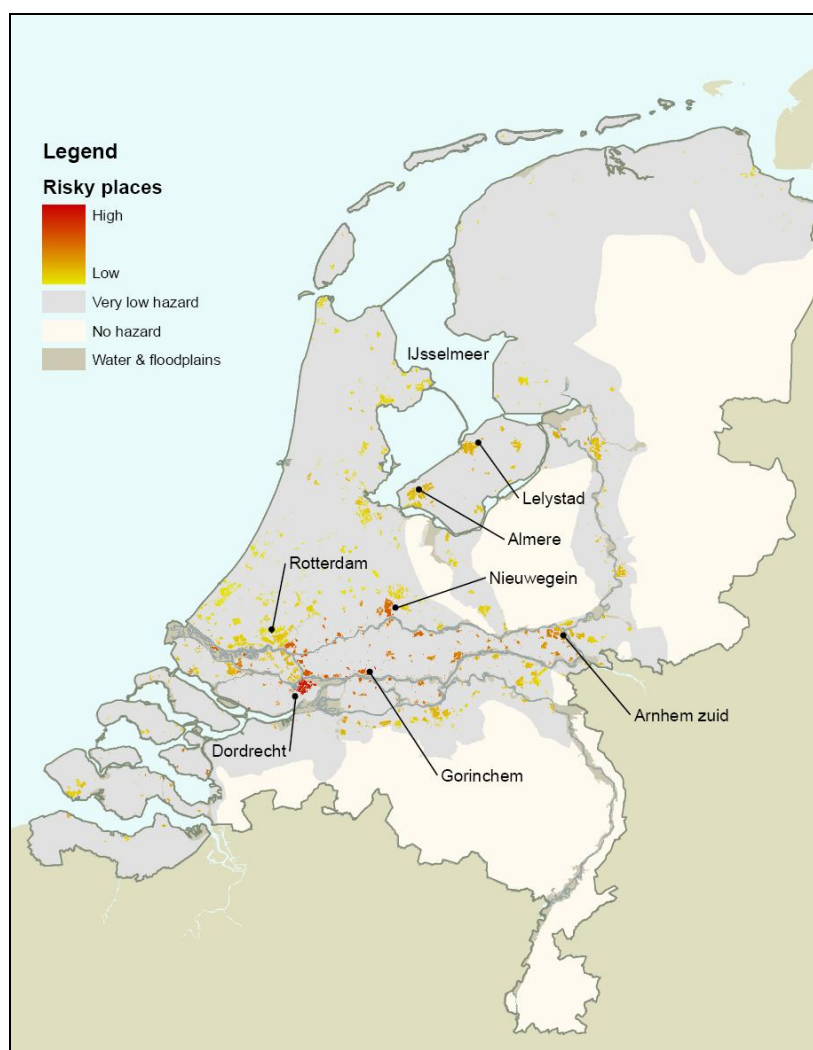


Figure 4.7 At 'risky places' unbreachable embankments may be very effective in reducing the risk of loss-of-life (De Bruijn & Klijn, 2009).

Flood fatality numbers, which may result from a breach, vary strongly from dike stretch to dike stretch, as we illustrate for the tidal river area in Figure 4.8. 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. Where secondary embankments divide the polder area in small 'compartments', some of these may fill up quickly and to great depth. In for example, the Island of Dordrecht (Figure 4.8), a breach at the easternmost end may result in more than 1000 fatalities, while breaches in the southern embankment would result in few fatalities only. The easternmost stretch protects a built-up deep polder, whereas behind the southern embankment an agricultural compartment must be flooded first, whilst the historic next-in-line embankment may then still hold or at least retard the flow towards the town of Dordrecht. Currently, all the embankments around the Island of Dordrecht must comply to the same legal protection standards. But obviously, the island as a whole could be made much safer by preventing a breach at particularly the easternmost end of the island.

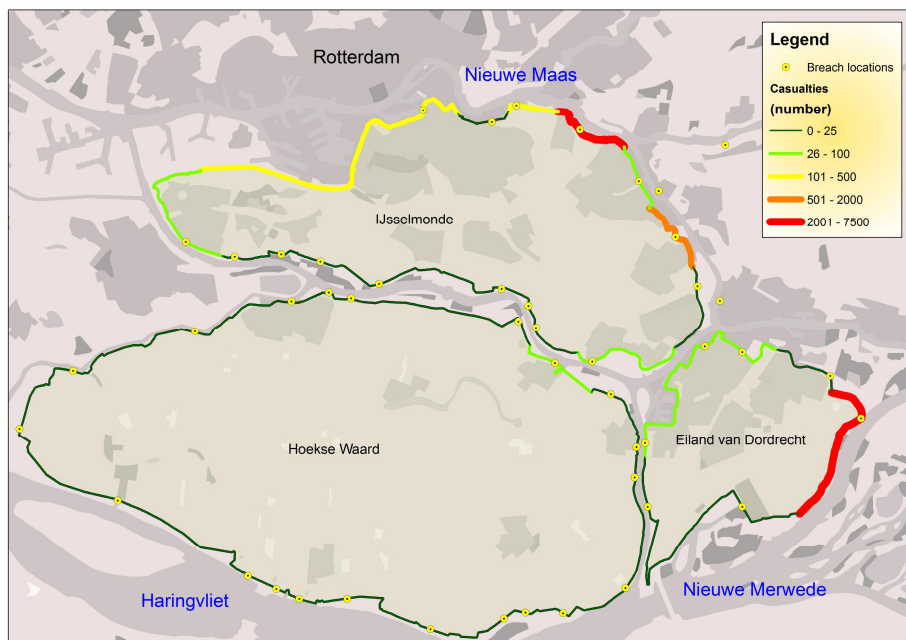


Figure 4.8 Fatalities (casualties) per dike stretch (De Bruijn, 2008).

4.3.4 Effectiveness: where would unbreachable embankments be most attractive ?

Approach

To assess where upgrading the existing embankments would be most effective from a societal risk point of view, we first determined the expected number of fatalities from breaching for each dike stretch (De Bruijn & Klijn, 2011). To this end, we used over 1000 flood simulations of sufficient reliability from all available sources. With the Netherlands' mortality functions (Di Mauro & De Bruijn, 2011; Beckers et al., 2011) fatality numbers were calculated for all flood simulations.

Next, we reconsidered the division of the embankments in stretches: some stretches protect largely the same area and could be merged into one larger stretch. This was mainly the case for the dike-ring areas along the rivers, which are large and not compartmentalized into smaller sections.

We assumed that the fatality numbers resulting from overtopping or overflow are negligible in comparison to those caused by a breach in the same stretch. Based on this assumption, we could assess the effectiveness of upgrading each dike stretch. As a measure for effectiveness we took the number of prevented fatalities divided by the 'costs' required to upgrade the entire stretch. Because we had no access to detailed cost information at the time, we assumed that the length of the stretch could apply as indicator. Thus we assessed the number of prevented fatalities per kilometer. We also determined the reduction of the average number of fatalities per dike-ring area given a flooding, in case of upgrading a stretch (a dike ring area is an area surrounded by dikes and higher grounds for which one protection standard has been defined). This average number of fatalities is a relevant measure in the

current societal debate on revising the flood protection standards, which currently still focuses on entire dike-ring areas.

Because the aim of our exercise was to select a limited number of stretches where making the embankments unbreachable should get priority, we defined thresholds for both our measure of effectiveness and for reduction of the average number of fatalities. For this first exercise, this was done in a pragmatic way, such that a limited number of dike stretches was found. We selected stretches with an effectiveness larger than 25 prevented fatalities per kilometer of embankment and which also reduced the average number of fatalities of the dike-ring area with more than 50%.

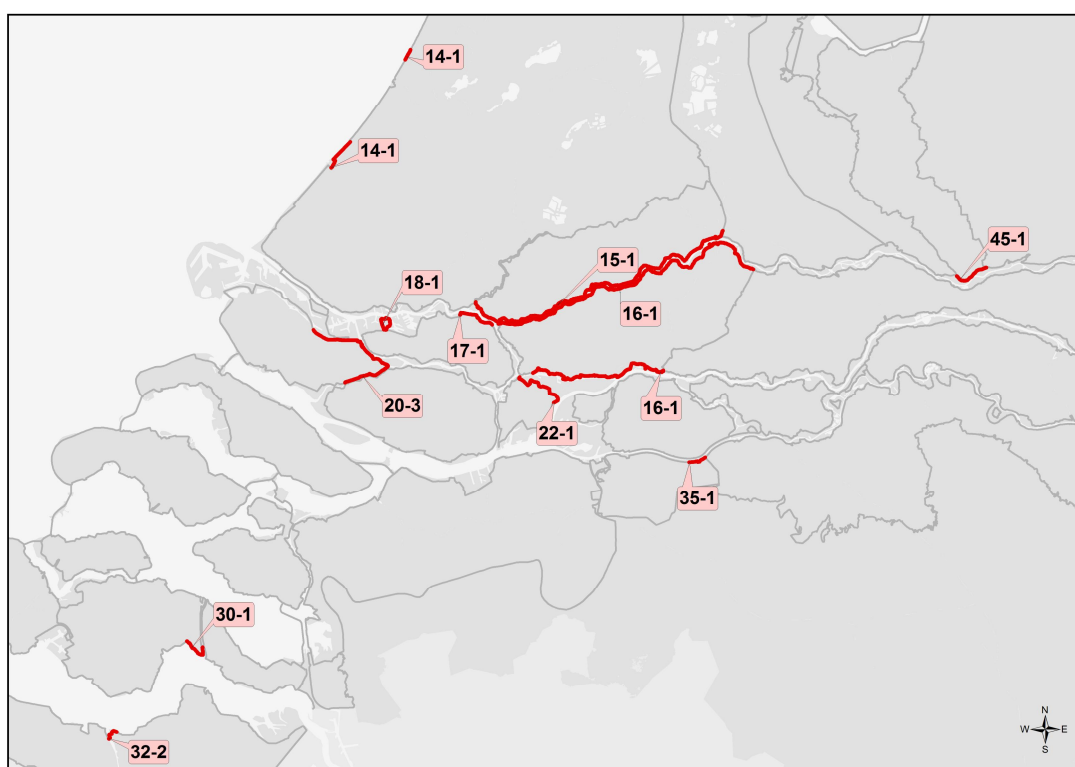


Figure 4.9 Stretches of embankments which qualify for upgrading to unbreachable embankments with priority from a societal risk point of view

Results

Figure 4.9 shows the embankment stretches, which qualify to these threshold criteria. The majority of them are located along the tidal rivers, four are coastal, and one lies along the non-tidal rivers. Dike-ring stretch 45-1 (see Figure 4.9), for example, is a stretch of only 5 kilometers, which protects a densely populated valley between two ice-pushed ridges (Veluwe and Utrechtse Heuvelrug) from Rhine River floods. A breach in this embankment would cause about 260 fatalities. Upgrading this short stretch may thus be worth considering; actually, it is already being studied more elaborately. The large polder areas Lopiker- and Krimpenerwaard (15-1) and Alblasserwaard (16-1) may be flooded completely and to great depth. Strengthening only a short stretch does not result in significant reductions of the

number of fatalities in these bathtub-like polders. Therefore, long lengths need to be strengthened (50 respectively 70 kilometers). We selected about 200 kilometers in total to be transformed into unbreachable embankments with preference (De Bruijn & Klijn, 2011). This would result in a reduction of the fatality risk in the individual dike-ring areas considered of 60% to more than 90%.

We also investigated the effect of upgrading these embankments to unbreachable embankments on the total societal risk of the Netherlands. We found 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 out of a total of about 3000 kilometers of primary embankments in the Netherlands. The effect on societal risk is even a factor 5, if measured by a 'C-value' in relation to the so-called Fn-curve (cf. Vrijling et al., 1998) – a commonly used measure for societal risk in the Netherlands (De Bruijn et al., 2010).

4.3.5 Attractiveness

If embankments do not breach when they are being overtopped, flooding will not result in a disaster, but only in (severe) inconvenience. Damage may be much less and large numbers of fatalities are very unlikely. The construction of unbreachable embankments is thus worth considering. It appears, however, not feasible to upgrade the 3000 kilometers of the Netherlands' primary flood defences within a few decades only. Therefore, we aimed to identify priority locations for unbreachable embankments, and took the perspective of societal fatality risks as point of departure for this.

We established that upgrading about 200 kilometer may already have a strong impact on the overall societal fatality risks in the Netherlands. The expected number of fatalities per year is reduced by 50%, and the C-value – a measure of the societal risk curve which accounts for risk aversion – by about 80%.

Unbreachable embankments sound like a utopia, but it appears technically possible to make embankments so strong that the probability of breaching before and even during overtopping can be considered negligible. This can be achieved in ground material or by constructions.

Opinions about the costs and benefits of unbreachable embankments differ widely, but can often be explained by differences in assumptions, expected effectiveness, and uncertainties about the actual economic and fatality risk. Silva & Van Velzen (2008), in their quick-scan, estimate the costs for making embankments unbreachable to be between 2 and 7 M€/km, but they may have used less strict requirements for strength than we have proposed. By taking into account the fact that some embankments along the coast may already qualify as unbreachable, they estimate a total investment of 6.4 billion Euros for the whole country. Were we to anticipate climate change and sea level rise, the investment would amount 11 billion Euros. Recent estimates by Knoeff & Ellen (2011) add up to 16 billion €.

The expected economic risk reduction does not justify such a huge investment (Klijn et al., 2012). However, many stretches in the Netherlands must be reinforced in the next decades anyhow, either because the embankments do not meet the current standards or for reasons of maintenance and improvement in view of climate change and land subsidence. This is an opportunity to transform these stretches. If the embankment should be strengthened anyway, the additional costs of making the embankments unbreachable may be much lower, ranging from an extra 30% of the costs for traditional strengthening along the coast to an additional 80% of the usual costs along the rivers (Knoeff & Ellen, 2011).

Finally, in urban areas embankments not only function as flood defence, but also fulfill other functions: as recreational area, to build on, as road, parking lot, or otherwise. Multipurpose embankments (see Chapter 3) are often made much larger and stronger to account for such utilization. Consequently, many embankments in urban areas are already unbreachable, and may be made so while adding to the quality of the urban living environment.

All in all, we feel confident that unbreachable embankments may score as relatively attractive, and – because they primarily affect the flood characteristics – may also prove to allow for yet undiscovered synergies with hazard zoning and vulnerability reduction (cf. Knoop et al., in press).

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5 Vulnerability reduction

5.1 Introduction

Hans de Moel

This chapter explores some ways in which flood risk can be reduced by reducing the vulnerability, the third component which – together with probability and exposure – determines flood risk. All the measures discussed in this chapter relate to reducing the vulnerability with respect to damage. Although we acknowledge that vulnerability of people is very important, we shall not discuss this, as we have not put much effort in this issue in our KfC-research. An exception is formed by flood insurances, which we do discuss, and which do of course influence the vulnerability of the people

There are many different measures that may reduce the vulnerability to flooding. They may be implemented at various spatial scales, and by a variety of actors. Whilst measures to reduce the probability of a flood event are mostly, though not exclusively, the domain of engineers, reducing vulnerability, in contrast, requires spatial planning and/or action by local land or property owners. Consequently, communication and cooperation between authorities and local stakeholders is vital for effective flood risk management.

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. This is largely determined by the geographical distribution of buildings (which constitute the largest potential damage) and how they are build. For instance, urban developments could be directed towards the safest places or existing vulnerable objects could be moved outside possible inundation zones. In order to be able to take such measures, it is essential to know which areas are possibly hazardous (flood extent), and to what degree (possible flooding depths). For this purpose, hazard maps should be created, which can convey this information and be used to base various policies on. The drafting of such maps for the Netherlands, stimulated by the EU flood directive, is discussed in section 5.2.

Next, section **Error! Reference source not found.** discusses the current policy framework in the Netherlands related to spatial planning in order to explore the potential to use hazard information to reduce vulnerability. This will relate to spatial zoning as regulatory measure for development planning, but also to measures that can be taken at the scale of individual buildings, such as elevating buildings or flood-proofing them. Implementing and maintaining such building-scale measures relates directly to existing buildings codes, which could hamper, or stimulate the realisation of such measures.

In the Netherlands, spatial planning and flood-proof building are largely the domain of governmental institutions. But also individuals can take measures to reduce the vulnerability of their property and thus the flood damage they will experience.. Homeowners can take a variety of measures, like adapting the use of their homes (e.g. elevating expensive items, water proof floors), using mobile flood barriers (or emergency sandbags), and securing possible sources of contamination (like oil tanks). Such measures will be explored in section 5.4 based on empirical data from Germany.

Finally, the vulnerability of the people affected by a flood can be reduced by easing the financial impact of a flood event to them. The financial damage of a flood can be huge. Individuals suffering damage can instantly lose a large part of their capital, which may have consequences throughout their lives, and businesses may not be able to continue for a long time. To facilitate financial recuperation after a flood, insurance schemes can help. By insurance schemes for flood damage, the financial burden is shared over time and between people, reducing the individual impact. Moreover, insurance can stimulate the implementation of damage reducing measures, as has been the case with fire insurance and related safety regulation. Section 5.5 reviews international flood insurance schemes in order to establish success factors. Based on this, it is intended to formulate recommendations for insurance possibilities for the Netherlands, where flood insurance is not available now.



5.2 Hazard zoning

Frans Klijn, Bas van de Pas, Karin de Bruijn & Kymo Slager

5.2.1 Introduction

For designing flood protection, the expected consequences of flooding are the key data needed to derive protection levels that are required or desired from an economic or societal point of view (Kind et al., 2011). This is reflected by the top blocks in Figure 1.2, which we repeat here. In contrast, 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. This is represented by the lower blocks in Figure 1.2.

In the Netherlands, hazard mapping did not attract much interest in the past, as the flood risk management policy has been focused primarily on flood protection ever since the 1953 flood disaster. Only recently, some first mapping exercises were done by De Bruijn (2006; De Bruijn et al. 2008; cf also De Bruijn & Klijn, 2009), which attracted a lot of attention from policy makers (e.g. the Delta Committee, 2008).

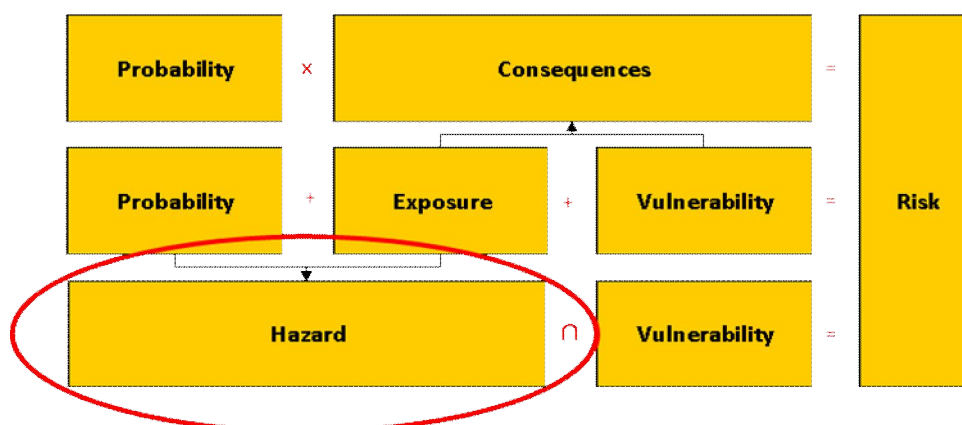


Figure 5.1 For spatial planning and building regulations hazard maps are provide essential information (after Van de Pas et al., 2012).

The preparation and launching of the EU-Directive on flood risk assessment and management raised further awareness in the Netherlands about of the potential of other flood risk management measures than protection, and the many contacts with other countries in Europe and beyond attracted interest in mapping. This lead to the making available of the summarized outcomes of many hundreds of flood simulations in the Netherlands on a composite map (www.risicokaart.nl), which showed the maximum water depth as a result of the breaching of primary defences at any location in the country. Also, the responsible ministry became interested in hazard mapping and risk zoning in behalf of spatial planning (Haskoning, 2008) and at the same time the Netherlands' Environmental Assessment Agency started research into this issue (Pols et al., 2007, PBL, 2009).

In the EXCIMAP-project (EXCIMAP, 2007) a number of European countries looked in each other's kitchen of hazard and risk mapping, and learned a lot from each other's experiences. In this project, the conceptualization and terminology, which we have explained in Chapter 1 of this report, was generally adopted⁶.

The EU-Directive prescribes that maps of hazard and vulnerability are produced by all member states by 2015. This requirement is, in the Netherlands, responded to by a huge inventory and mapping project under the acronym ROR (Richtlijn OverstromingsRisico's; Alberts, 2010). In this project, maps of many relevant phenomena are being produced, related to flood probability, exposure characteristics and vulnerability. However, first the deadline for this project is 2015, which is too late for the Delta Programme to make adequate use of it. And, secondly, there is no obligation to combine all the relevant data into one – or a few – unifying hazard maps for spatial planning purposes. The project is rather a huge inventory than aimed at any innovation.

Against this background, the Delta Programme on Urban Development and Re-development asked Deltares and PBL to investigate how to best inform spatial planners on flood hazards in the Netherlands. This request related to the announcement in the National Water Plan (Ministry of Public Works and Water Management, 2009) that *“the Netherlands” government will, in a joint effort with other authorities, develop a method for risk zoning’ aimed at ‘a clear, unambiguous and robust representation of a number of distinct risk zones, for which specific objectives and frameworks can be defined’.*

We (i.e. our KfC consortium) joined forces in this investigation, which has recently been published (Van de Pas et al., 2012). We explained the results to all 6 regional Delta Programmes and made the maps available to them for application in their search for Comprehensive Flood Risk Management.

5.2.2 General approach

Based on Figure 2.1 we first established that we needed a hazard map, which combines information on flood probability with information on exposure characteristics. We then reviewed the methods applied in other European countries, which could be based on the EXCIMAP-project (EXCIMAP, 2009), as this did both a thorough inventory of current practices and described what they consider good practice.

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. This was no surprise, and it is already taken into account in the commonly used models for flood consequence assessment (HIS-SSM; Kok et al., 2005).

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

⁶ It implies that the map published as www.risicokaart.nl is actually a map of (an) exposure (characteristic), viz. flood water depth.

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.

We used simulation results from FLORIS (VNK, 2011) as well as many other regional projects, which are also being used for www.risicokaart.nl and ROR (Alberts, 2010), but we were more selective on the issue of comparability of the simulations. In many cases, the simulations were done for a variety of different hydraulic conditions (flood levels) or with deviating assumptions on moment of breaching or breach growth, which yielded the results incomparable. This reduced the number of simulations we could use, but it still amounts to many hundreds.

With the geographical data we then constructed a number of maps for single parameters, such as flood depth, speed of onset, water level rising rate, etc. In this step, various legend classes were tried and visually assessed (by the research team) in order to achieve meaningful and communicative maps.

Next, we experimented with various combinations of maps in search of comprehensive but understandable maps. These experimentations were inspired by examples from abroad (drawn from EXCIMAP, 2007) They soon showed – not unexpected – that combining more than 2 parameters in one legend and map by systematic permutation (i.e. making a matrix) was practically impossible. Thus, by such a method one is practically obliged to delimit oneself to the 2 key parameters only. This means either selecting the most decisive exposure characteristic, as probability is an obligatory factor already. Or to make exposure maps for 1 class of flood probability only, as done by Pieterse et al. (PBL, 2009) who combined speed of onset and maximum depth attained. In the latter case, however, one actually has not achieved a hazard map, but rather an exposure map for one class of flood probability only; this hampers the general applicability and is also unsatisfactory.

Inspired by earlier trials by De Bruijn (2006; De Bruijn et al., 2008), we then also attempted other means to combine flood probabilities and relevant exposure characteristics into hazard grades. Where De Bruijn (2006) combined relevant factors through a mathematic formula which allowed weighing the various parameters, we now used damage modelling to achieve at hazard grades which could subsequently be classified. This approach allows the drafting of nationwide maps of Local Flood Damage Hazard and Local Flood Fatality Hazard. We consider this approach a real methodological innovation and the resulting maps the most adequate tools for spatial planning currently available.

5.2.3 Flood probability

Flood probability is the first key constituent of hazard. This seems a relatively unambiguous parameter. For unprotected floodplain areas this is indeed true, but this is not the case for protected areas: the majority of the Netherlands' land surface, subdivided into so-called dike-ring areas.

The probability that the flood defences, which constitute a dike-ring, fail is not the same as the probability that a certain location within a dike-ring area is being flooded. The latter, after all, depends on the elevation characteristics of the area including the many linear elements which

affect the flooding process. This means that locational probability is not the same as the probability of dike failure, wherever in the dike ring. Moreover, the actual failure probability of a dike ring is difficult to establish, as is illustrated by the FLORIS-project (VNK, 2011). This probability depends on a number of possible failure mechanisms, related to both loading and strength of the embankment (see Chapter 4), and may differ substantially from the legal protection level defined for that very dike ring area. A first reason for this is that the protection level refers to flood level height only, whereas the strength of the embankments and other structures is covered by design guidelines of lesser legal bindingness. A second reason lies in the so-called length effect, which reads that longer defences may fail in more places than shorter ones, and hence – by definition – result in larger failure probabilities. And thirdly, most embankments are designed in such a way as to not fail, so slightly higher than actually needed; this, in contrast, reduces the probability of overtopping and subsequent failure.

In order to get around all these complications, we assumed that the flooding probability at a certain location would be more or less equal to the protection standard for the very dike-ring area, but also classified the probabilities in broad classes to allow for substantial variations, and indicate these classes by words rather than figures (Table 5.1).

Table 5.1 Flood probability classes as distinguished for the hazard mapping of both actual floodplain and protected areas.

Probability/ frequency of flooding	Actual active floodplain	Protected area
Frequent (about every 10 year: < 30 year)	main water system	regional water system (defined by various water boards)
Regular (about every 100 year: 30 – 300 year)	main water system	regional water system and minor protected areas along the Meuse River
Rare (about every 1.000 year: 300 – 3.000 year)	main water system	regional water system and fluvial dike-ring areas (Rhine and Meuse Rivers)
Very rare (about every 10.000 year: 3.000 – 30.000 year)	Not applicable	Coastal and lacustrine dike-ring areas
Extremely rare Potentially flooded/ former floodplain	Not applicable	Former floodplain area/ potentially flooded by Worst Credible Flood Events
Elevated/ hillside	Not applicable	Elevated parts of the country which cannot be flooded as a consequence of a dike breach

5.2.4 Exposure characteristics

The second key constituent of hazard is exposure. This is unfortunately a multiple concept, which can only be adequately defined by a large number of characteristics at the same time. We, therefore, first investigated which characteristics were significant for fatality risk and which for damage risk, and to what degree. This overview is given in Table 5.2, with an indication of the relative relevance, and with a preliminary classification for each characteristic.

Table 5.2 Relevant exposure characteristics with an indication of their relevance for flood fatalities and flood damage, and a preliminary classification/ legend

Exposure characteristics	... related to fatalities	... related to damage	Legend/ classes
Maximum water depth	very relevant	very relevant	very shallow (0-0,2 m; cars can still drive, limited damage) shallow (0,2-0,5 m; people can still walk, substantial damage) moderately deep (0,5-0,8 m military vehicles can still proceed, large damage) deep (0,8-2,0 m (second floor still safe, very large damage) very deep (2,0-5,0 m; attics and rooftops still safe) extremely deep (> 5,0 m; survival only possible in high-rise buildings, maximum damage)
Time of arrival (first water) after breaching	very relevant	limitedly relevant	immediate (< 6 hours; only vertical fleeing within building) soon (6 – 24 hours; short time span for fleeing the area) late (> 24 hours; sufficient time to leave the area)
Water level rise rate (reaching > 1.5 m after arrival)	relevant	limitedly relevant	very fast (< 6 hours, vertical fleeing only) fast (6 – 24 hours, fleeing to nearby areas only) slow (> 24 hours, allowing to leave the area)
Duration of flooding	relevant	relevant (?)	short (< 2 weeks) long (> 2 weeks)
Current velocity	limitedly relevant in the Netherlands	limitedly relevant in the Netherlands	slow (< 0,5 m/s; people can still walk) fast (> 0,5 m/s; walking impossible)

As the table shows, the most relevant characteristics are maximum water depth, time of arrival of the first water and water-level rising rate. We also found a close correlation between the last two characteristics. This is relevant, as it is practically impossible to combine all relevant characteristics in one classification/ legend through systematic permutation when too many characteristics are taken into account.

We decided to combine only the most relevant characteristics into an exposure map, which implies maximum water depth for actual floodplain area. For protected areas, water depth would suffice too from a point-of-view of flood damage, but for fatality risk also time of arrival was considered important (cf. PBL, 2009). With these characteristics, we drafted a composite exposure map for protected areas, according to the legend of Table 5.3. This map (Figure 5.2) gives a good impression of exposure in 9 different classes.

Table 5.3 Legend for composite exposure maps as matrix of the two selected key characteristics: maximum water depth and time of arrival of the first water.

Time of arrival	late (> 24 uur)	soon (6 – 24 uur)	immediate (< 6 uur)
Water depth			
shallow (< 0,5 m)	shallow and late (1)	shallow and soon (2)	shallow and immediate (3)
deep (0,5 – 2 m)	deep and late (4)	deep and soon (5)	deep and immediate (6)
very deep (> 2 m)	very deep and late (7)	very deep and soon (8)	very deep and immediate (9)

The map is composed by making an overlay in GIS of the maps of maximum water depth and time of arrival. Both are based on flooding simulations, but the maximum water depth may relate to another breach location than the time of arrival. This could result in an overestimate of exposure. An analysis of the map by sampling revealed that in more than 90% of the cases both characteristics pertained to the same flooding event. We considered this satisfactory.

Another possible bias in the map relates to the location of the simulated breaches. As already mentioned. Despite the fact that the map is based on several hundreds of flooding simulations, it still clearly reflects the location of the simulated breaches. This becomes especially visible when we take a closer look at the underlying map of the time of arrival with the locations of the breaches indicated by black dots (Figure 5.3). This characteristic is especially sensitive to the breach location, much more than the maximum water depth. The effect is very pronounced in Flevoland, a bathtub-like dike-ring area where only three breaches have been simulated (see frame). This bias needs further attention, e.g. by GIS-buffering along dikes, calibrated by the simulation results; this has already been tried by Van de Pas et al. (2012) for a sample area, inspired by earlier work of De Bruijn (2007).

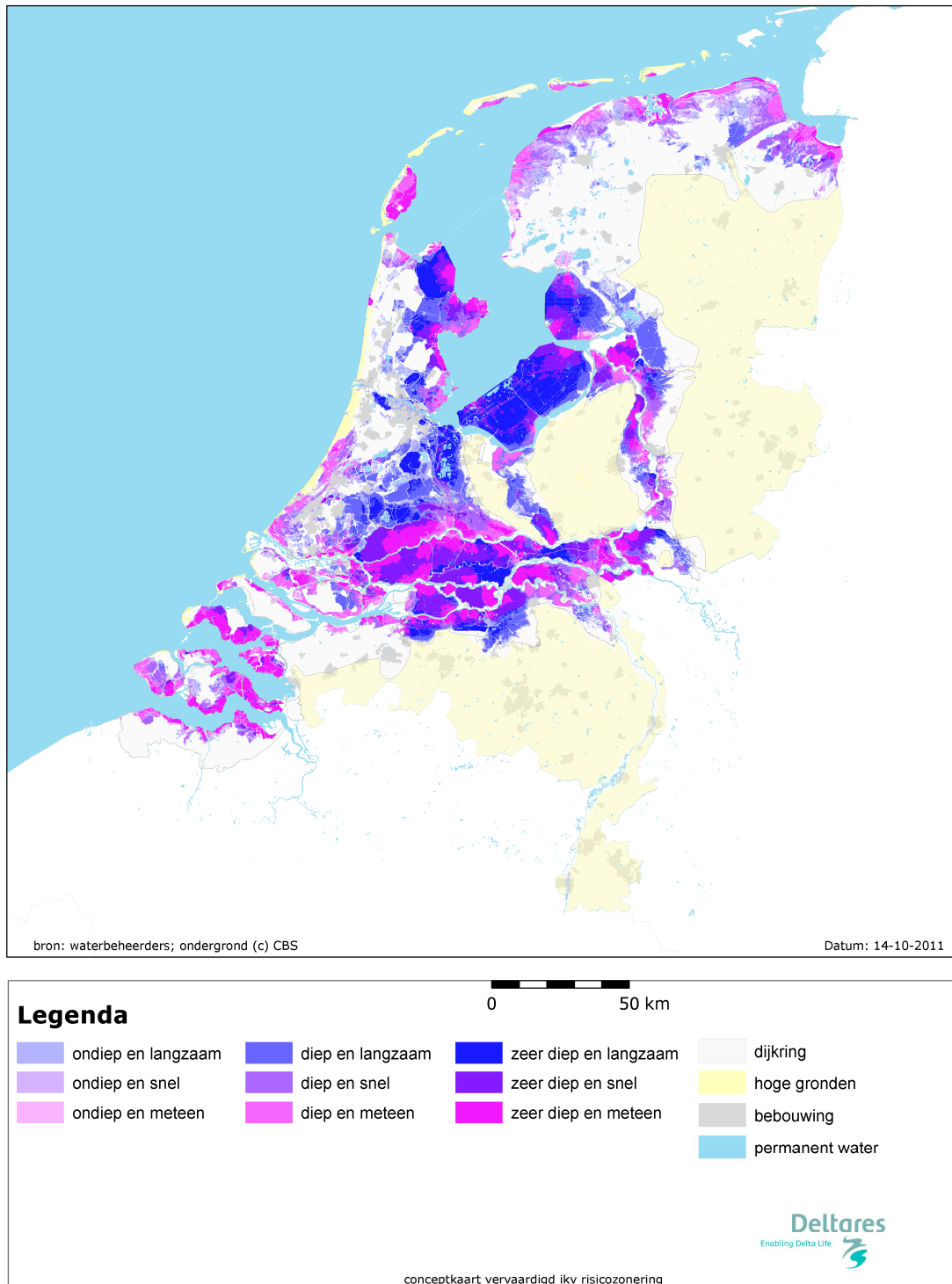


Figure 5.2 Composite exposure map for protected areas, showing maximum water depth en minimum time of arrival as a result of embankments breaching at design conditions

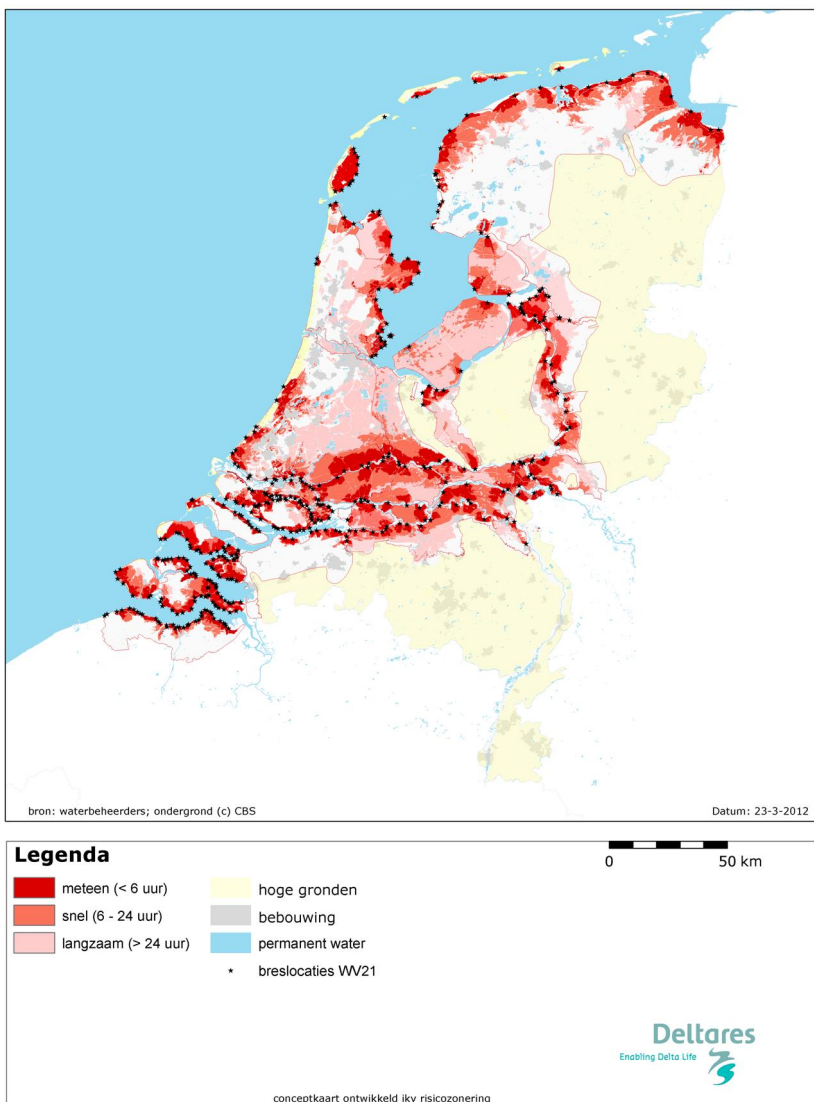


Figure 5.3 Time of arrival as derived from the available flooding simulations, showing the sensitivity to number and location of simulated breaches

5.2.5 Hazard maps: combined flood probability and exposure

A hazard map should combine the relevant risk constituents flood probability and the relevant exposure characteristics. In unprotected floodplain, the time of arrival of a flood is no relevant criterion, as this is always immediate, i.e. together with the flood wave arriving. Moreover, there usually is a close correlation between frequency and depth. Therefore, it is relatively easy to combine the two into one map which is both easy to interpret and meaningful. Such a hazard map gives information about the likelihood of flooding and the depth related to more frequent or more rare floods. Usually, the places, which are flooded frequently, also become deeply flooded during more rare events, whereas places that are flooded only incidentally, will often experience shallow flooding only, even during extreme events.

We produced such a composite hazard map for the unprotected fluvial and lacustrine floodplains (Figure 5.4), with three classes for flood probability/ frequency and three classes for depth. It shows that the frequency class 'rare' is virtually absent, and so are 'frequent and shallow' and its neighbouring classes.

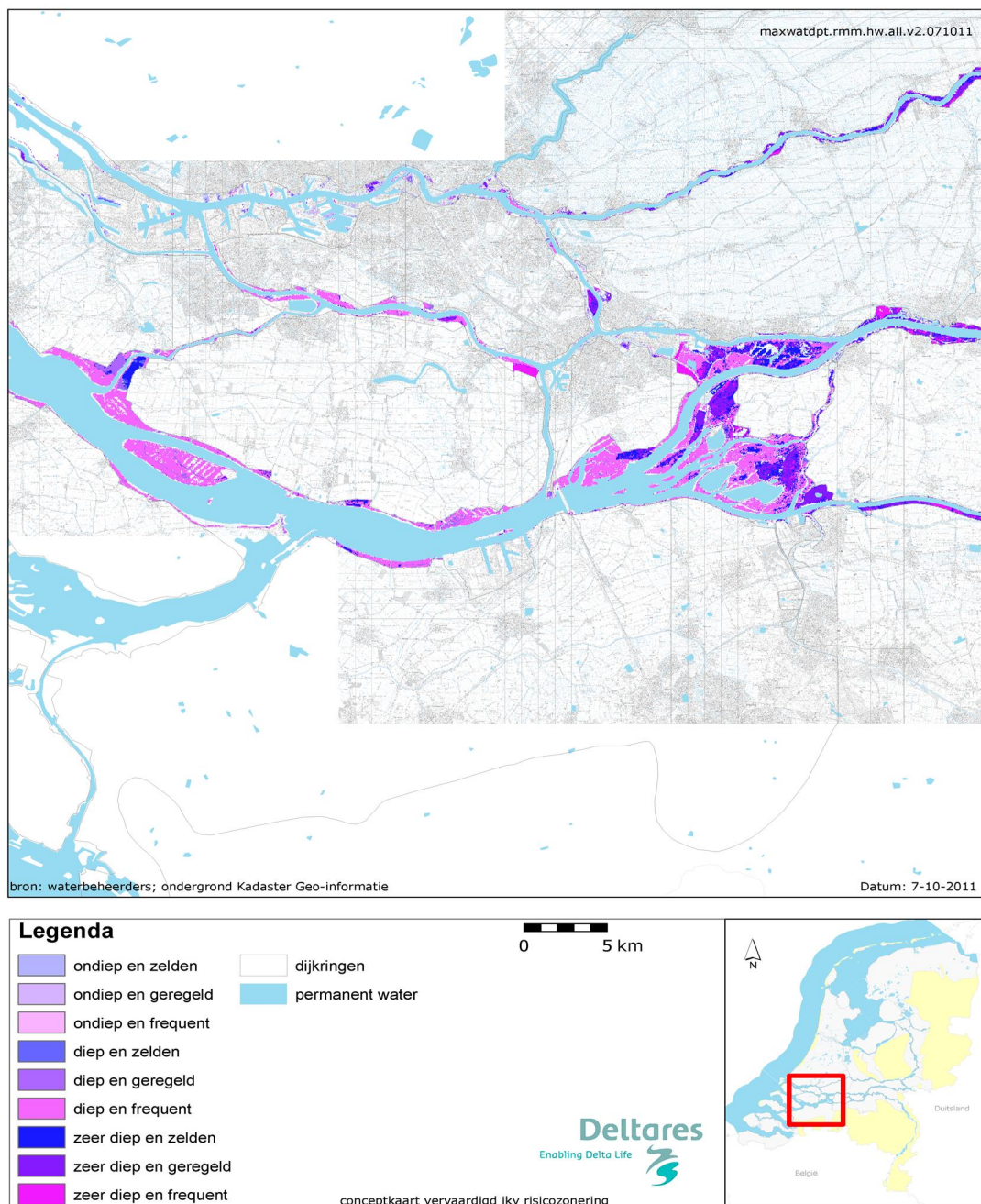


Figure 5.4 Hazard map for the actual floodplain area in the Rhine and Meuse River mouths, as a combination of flood probability and flood depth.

A similar map would be nice to have for protected areas too, but here we were confronted with the difficulty of having to combine too many relevant characteristics. Therefore, we turned to first 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 (De Bruijn et al., 2008) for fatalities, which was also adopted and adapted for the national WV21 project, for which the Local Fatality Hazard⁷ was calculated and mapped (De Bruijn et al., 2011).

Thus, we calculated the Local Damage Hazard in a similar way as Local Fatality Hazard, which allows using all relevant factors for which stage-damage functions are available, as well as flood probability. This approach can thus be regarded as the ultimate means to unify all relevant factors into hazard proper. Key to this approach is the assumption of a hypothetical standard land-use type – in our case an urban development; this is similar to assuming that a hypothetical person is present on a certain location in the case of calculating Local Individual Risk (or in our terminology: Local Fatality Hazard).

The map of Local Damage Hazard is shown in Figure 5.5. It 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 might be 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 does, however, require that the scaling is equal, which is not yet the case in this example map. Further work is thus needed.

5.2.6 Are the maps sufficiently stable in view of climate change?

Hazard is by definition independent of socio-economic developments, but it is affected by climate change. Both flood probabilities may change and exposure characteristics such as flooding extent and depth, as described in Chapter 1.

As the Netherlands' flood risk management policy does not allow flood probabilities to increase in the protected dike-ring areas, we only investigated how the higher water levels at sea, and in the rivers and lakes may affect the flooding process and resulting exposure characteristics of those areas. On the other hand, we do acknowledge that the protection standards are being debated and may be changed, with obvious effect on flood probabilities, and thus hazard. For unprotected areas the situation is quite different, of course: here both the flood frequencies and depths will increase with rising water levels. This is especially important in the area around Rotterdam (Rhine-Meuse River mouths).

Higher flood levels may cause faster and more prolonged inflow through breaches. Higher flood levels and higher mean water levels are at least expected along the coast, as these

⁷ Unfortunately, we introduced the term Local Individual Risk for this, which has been rapidly adopted and is now widely used.

cannot be counteracted. Along the rivers, however, design flood levels can be maintained at the present level by making more room for the River. In the large lakes (e.g. IJsselmeer), it depends on whether we decide to let the water levels rise with the sea level, or to pump out the excess water in order to keep it at the present levels. This means the design conditions main change to various degrees.

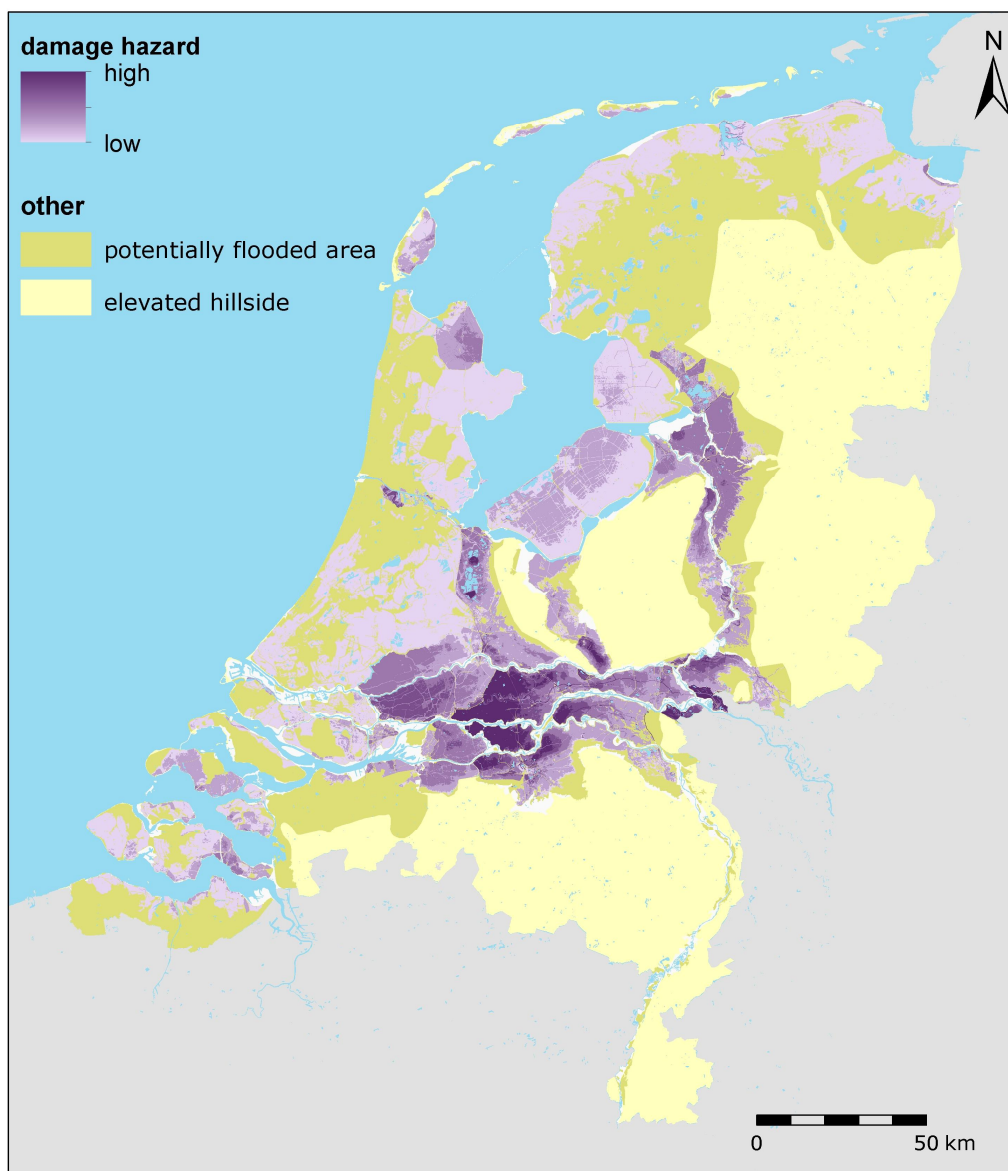


Figure 5.5 Local Damage Hazard (LSG) for present flood protection system and present hydraulic design conditions

To get to grips with this issue, we simulated a coastal breach near Katwijk in a similar way as discussed in Chapter 1, but now with a sea level which was raised by 85 cm and with the present sea level for comparison purposes. This 85 cm higher sea level is according to the

upper limit of the KNMI (2006) scenario W and W+ for 2100. Figure 5.6 shows the results of the simulations. With the present sea level, the floodwater does not reach far, as it is slowed down and often entirely stopped by regional embankments – e.g. around the Haarlemmermeer –, roads and railroads.

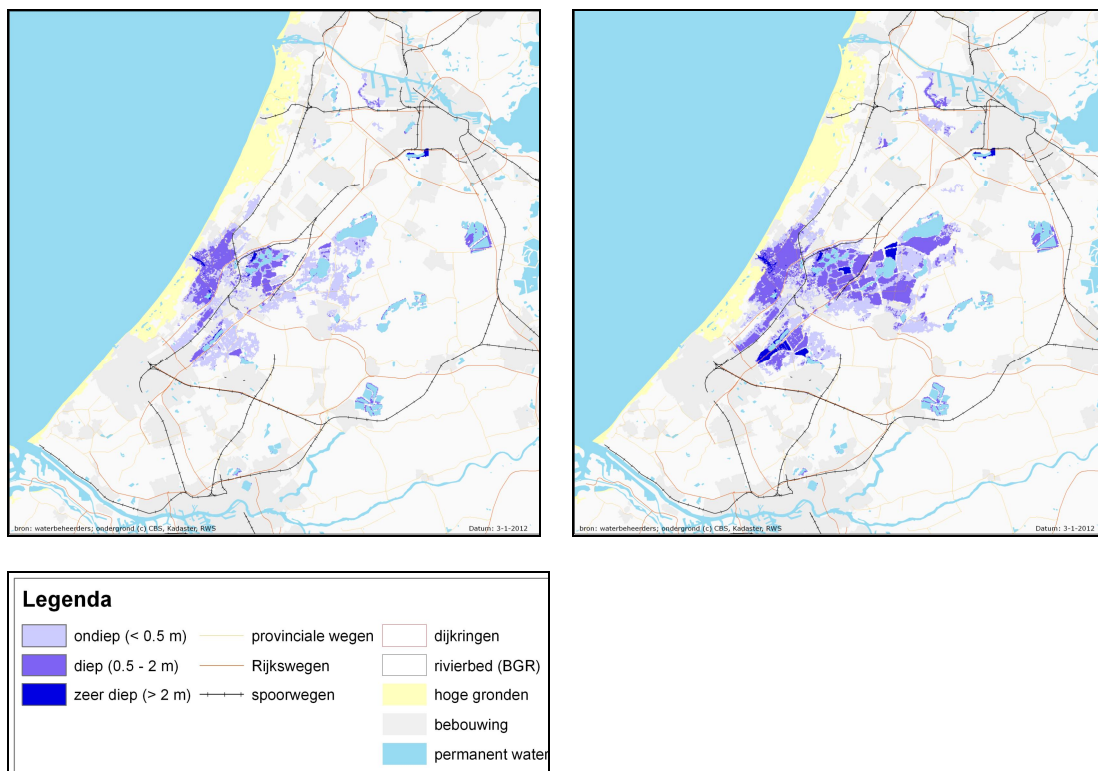


Figure 5.6 Maximum water depth after a breach at Katwijk at design storm surge level and waves (left) in the present situation and with a 85 cm higher mean sea level (right)

This unintended compartmentalization is very effective in reducing the exposure to flooding in this low-lying area (cf. Asselman et al., 2008; Klijn et al., 2009). With a higher sea level, both the flooding depth and the extent of the flooding increase substantially. This means that especially the dike-ring areas with an elevation around sea level, which are also compartmentalized by accident (or historic genesis, for that matter), are very sensitive to rising water levels. The now effective compartmentalisation will fail when climate changes. This concerns e.g. Zuid-Holland, Noord-Holland, Groningen-Friesland, IJsselmonde, Hoekse Waard, the islands and peninsulas in the southwest, Voorne- Putten, and Western-Brabant. Small dike-ring areas, which are already flooded entirely to great depth (so-called bathtubs), are much less sensitive. And dike-ring areas along the large rivers are already being filled into the lowest dike level at the downstream end, and are not very sensitive either.

This evaluation shows that the hazard maps for protected area are subject to some change as a result of climate change. And to change as a result of policy changes. This is inevitable. We therefore still believe that these maps are the best we can deliver at this moment, and we

sincerely hope they will satisfy the needs of those who have to design the actual spatial plans aimed at reducing flood risks – or preventing their unbridled increase through demographic and economic development. This is especially needed in the regional Delta Programmes, especially those of IJsselmeer, Large Rivers, Rijnmond-Drechtsteden and Southwestern Delta.

How flood consequences can actually be reduced is the subject of the next two sections.

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

Mathijs van Vliet & Hans de Moel

5.3.1 Spatial planning and flood zoning policies in the Netherlands

Spatial planning can effectively reduce the vulnerability of an area, and thus the consequences of flooding (Schelfaut et al., 2011; van Herk et al., 2011). Not only water management has a long tradition in the Netherlands, but so has spatial planning. Below, we will review the policies and legislation that affect flood zoning in the Netherlands Table 2 gives an overview of these policies and legislation, a short description of their content and their implications for flood risk reduction.

European legislation

As part of the European Union (EU), EU regulations affect the Dutch regulations. After a number of severe floods, the EU developed the European Flood Directive (2007). It offers a framework for assessing flood risks and guidelines for decreasing negative consequences of floods. Member states need to develop flood damage and flood risk maps, which serve as basis for flood risk management plans. (website Flood directive, 2011) The new Water Act (or Water Law) of 2009 incorporates the EU Flood Directive in the Dutch legislation.

The Netherlands national policy framework

General policy

The Netherlands has incorporated the European Flood Directive in its legislation, but there is still little attention to flood zoning. Land use planning as well as water management, however, have a long tradition in the Netherlands. Because of the high protection standards of the embankments spatial planning gives little to no attention to floods. For the unprotected areas the state has developed the Major Rivers policy, which states that the primary function of the major rivers and their floodplains is to discharge water to the sea. New activities in the floodplains are only allowed under a number of rules which aim to maintain the rivers' discharge capacity (Ministry of Transport Public Works and Water Management, 2006):

- The policy guideline Major Rivers uses a five step approach. In the first four it discerns between the type of activity and the place where it is executed. A division is made between areas with a storage regime (areas that mainly store water during high flows) and a discharge regime (areas through which the river discharges). Some un-embanked areas contribute little to the overall discharge capacity and are therefore excluded from the guideline. The fifth step lists a number of conditions that should be met, such as:
 - Activities need to be situated in such a way that the safe functioning of the river and its flood defence systems is maintained;
 - They form no barrier for increasing the rivers discharge capacity in the future;
 - The increase in water level or decrease of storage capacity should be minimized, and
 - The increase in water level and decrease in storage capacity should be compensated, except for small and temporary activities and activities needed for river management.

Legislation

The policy framework Major Rivers is enforced via the Dutch spatial planning regulations (Ministerie van Infrastructuur en Milieu, 2011) and the Water Act (Ministry of Transport Public Works and Water Management, 2009). The spatial planning regulations contain extra rules and regulations. It aims to protect national interests, like maintaining the discharge capacity of the major rivers.

The spatial planning act states that municipalities should develop land use zoning plans ('Bestemmingsplan') every 10 years. They have to incorporate legal rules from higher government layers. By law, the land use zoning plans should always be financially possible. For areas that will be re-developed or newly developed land use zoning plans could very well be used for flood zoning. Land use zoning plans, however, cannot enforce land use changes but only allow for a certain use. A new function can only be assigned when it is clear that the old function will be stopped within the planning horizon (10 years). This makes it difficult to force functions that are very sensitive to flooding to move to safer areas. Governments can try to move sensitive functions, but it can only force people to leave their property in the case of a clear and urgent need and it should serve the public good. Before they can force owners to sell their property, they first have to try to buy it via an 'amicable settlement'.

The water Act protects water courses and their embankments. In the Netherlands, the state is, by law, responsible for the water safety in the embanked areas. It is her responsibility to compensate for flood damages in the embanked areas. The law also contains the exceedance probabilities for the different embanked areas. The state is not responsible for compensation in the unprotected areas, where building is for own risk. This can be seen as a first form of flood zoning, although many inhabitants of the unprotected areas are not aware that they live in such an area (De Boer et al., 2012).

Provinces

Policy

The twelve provinces have different approaches on flood management in the unprotected areas. The province of Flevoland, for instance, has designated embankments in unprotected areas, of which the water board has to maintain the current safety level. The province of Overijssel focuses on flood safety in the embanked areas and enforces flood risks to be taken into account in land use zoning plans (Neuvel et al., 2011). In Utrecht new developments have to meet a safety level of 1:4,000 years. The province of South-Holland takes a risk based approach for flooding of unprotected areas (Huizinga et al., 2011). With a GIS-based model municipalities can check the effect of spatial plans on the expected number of casualties and social disruption. The target levels can be met via various methods, including adaptive building techniques and flood zoning (replacing flood-sensitive functions). Although municipalities are urged to use it, it is a voluntarily tool. It seems likely that it will increase the awareness of flood risks among municipalities.

Legislation

The provinces can also protect provincial interests via binding spatial planning rules. The province of South-Holland has no specific rules for unprotected areas and does not enforce the use of the risk method. The province of Overijssel does force municipalities to include a 'flood paragraph' in the land use zoning plans.

Table 2; Overview of policies and legislation on different government levels in the Netherlands, with a short description and implications for adaptive building (based on (Van Vliet and Aerts, in prep.).

	Policies and Guidelines	description	Implications for adaptive building	Legislation	description	Implications for adaptive building
European Union	Flood Directive ¹	Risk approach, Assess protection and damage reduction measures Develop flood damage and flood risk maps	No direct impacts, Flood risk maps can create awareness. Incorporated in Dutch Water Act.			
National	Guidelines Major Rivers ²	Development in floodplain ³ restricted; only if discharge is not changed Damages for own risk	Little new development in floodplain, No refund of damages gives some incentive for adaptive building. Rotterdam's unembanked areas are excluded.	Rules for Spatial planning ⁴	Enforcement of guideline Major Rivers, implemented by municipalities via land use zoning plans	Little new development in protected floodplains, no refund of damages gives some incentive for adaptive building
				Spatial planning Act ⁶	Municipalities must develop land use zoning plan each 10 years and must have a spatial policy	Structures new developments, Possibility to ask for minimal ground floor level for new developments on low lying floodplains.
				Water Act ⁷	maintaining national flood safety levels	Does not allow for building on or near embankments
Province of South-Holland⁸	Risk Guideline ⁹	Guidelines for casualties and social disruption for new developments	Municipalities should test land use plans for minimal casualties and social disruption. Can integrate adaptive measures.	Land use planning rules (<i>Verordening Ruimte</i> ¹⁰)	Secures provincial interests No special rules for unembanked areas	none

Municipality	Spatial policy	Document showing the desired future land uses.	Spatial policies can show the need for adaptive measures and create awareness	Land use zoning plan	Shows which land uses are allowed on which location Can include regulations that need to be fulfilled before land used can be implemented. (linked to spatial planning Act	Zoning possibilities (mainly effective in new to develop areas) Gives possibility to demand minimal ground floor elevation in low lying areas, but little used.
	City vision Rotterdam ¹¹	Long term vision for Rotterdam. Includes redevelopment of harbours near city centre into housing and commercial area.	States the need for taking future sea level rise into account, without detailing how.			
	Rotterdam Water plan ¹²	Plans for water infrastructure, developed together with water boards	Includes plans for floating buildings and small neighbourhoods, but not detailed.			
Waterboard	Several policy documents	Focused on embanked areas	No implications for building in unembanked areas	'Keur' ¹³	Regulations on embankments and water courses	No building on or near embankments

^{1.} (website Flood directive, 2011)

^{2.} (Ministry of Infrastructure and the Environment, 2006)

^{3.} Here: the unembanked areas of the floodplain.

^{4.} (Ministerie van Infrastructuur en Milieu, 2011)

^{5.} (Ministry of Internal affairs, 2011)

^{6.} (Ministry of Infrastructure and the Environment, 2008)

^{7.} (Ministry of Transport Public Works and Water Management, 2009)

^{8.} Policies differ per province; Rotterdam is part of the province of South-Holland.

^{9.} (Huizinga et al., 2011)

^{10.} (provincie Zuid-Holland, 2011)

^{11.} (Gemeente Rotterdam, 2007)

^{12.} (Gemeente Rotterdam et al., 2007)

^{13.} e.g. (Morreau, 2009)

Municipalities

Policies

Municipalities develop spatial policies and spatial planning vision. These visions show the desired land use and land use changes. They form the basis for the land use zoning plans.

Legislation

Municipalities need to develop land use zoning plans, which show where which functions are allowed. Land use zoning plans are legally binding, also for civilians. They show which land use is allowed on which place, but it cannot be used to enforce changes. They can only contain spatially relevant measures and, by law, should demonstrate a 'good spatial planning'. This is how flood zoning could fit in, as sensitive functions should not be allowed in areas that are regularly flooded.

Requests for new developments or large re-development of current buildings, will always be evaluated against the current land use zoning plan. If the land use zoning plan allows for the new development the municipality, in principle, has no right to refuse the building permit.

The problem is that land use zoning plans allow for desired changes. If a municipality wants to make commercial activities possible, they can re-zone the area and designate a commercial function. When the current function is different, e.g. residential, the owner can still maintain that function and nothing will change. It is however, not possible to start an industry or any other function than commercial if the current owner of the residential building leaves. Also an enlargement of the current function becomes difficult. However, assigning a new function can only be done when it is clear that the current function will leave within the planning horizon (10 years). In new developments, possibilities for flood zoning are much larger.

Municipalities could also try to buy the property, which gives them much more control on new developments. They are allowed to declare that they will have the first right to buy the land when it is to be sold by the owner, but only if they already have specific plans for the area. They will have to offer market prices. As a last resort they can expropriate the land, but this can only be done if there is a clear and urgent need and when it is in the common interest.

Water boards

Policies

The water boards are a separate government layer in charge of water management: they maintain most embankments and the watercourses within the primary embankments. The management of the major rivers and part of the primary embankments are managed by the state water services (Rijkswaterstaat). To increase the attention on water management in the spatial planning process, water boards must be consulted during the development of land use zoning plans. However, flood zoning in the protected dike-ring areas is hardly applied. The province of Overijssel has developed an guideline for municipalities to deal with flood risks in those (parts of) embanked areas that can suffer a deep and fast flood (Neuvel et al., 2011). As water boards are responsible for the embanked areas they are often less concerned about water safety issues in the unprotected areas. Rijkswaterstaat is mainly focused on maintaining discharge capacities. As the state does not feel responsible for flood damages in the unprotected areas, Rijkswaterstaat pays little attention to flood damages in these floodplain areas.

Legislation

Water boards develop rules and regulations which can be found in the 'keur'. The 'keur' describes which activities are allowed near and in watercourses and near or on embankments. In principle, no buildings are allowed on or near embankments.

5.3.2 Implications of the policy and legal framework on flood zoning

From the literature study it became clear that the policies, laws and regulations do not forbid flood zoning. At the same time, the regulations sometimes hinder governmental enforcement of flood zoning.

The national policy 'Major Rivers' discourages new developments in most unprotected areas, which can be seen as a form of flood zoning. There are, however, already many built-up areas in the floodplains. In the larger Rotterdam region about 65,000 people live in unprotected area, and this expected to increase to 80,000-100,000 in 2050 (Wardekker et al., 2010). Most of these unprotected areas are excluded from the Major Rivers policy, because they have no discharge function. The province of South-Holland has issued the risk method, which should lead to a stronger attention to flooding in the unprotected areas and possible flood zoning measures. The province of Overijssel has developed a guideline for incorporating flooding in certain embanked areas where flooding will be deep and/or fast. It is possible that more provinces will develop these guidelines in the light of the European Flood Directive.

An important problem for the implementation of flood zoning is that land use plans are mainly effective for flood zoning in new to develop areas. Up to recently, there has been relatively little attention to flooding in land use zoning plans, probably due to the very high safety norms of the Dutch dykes, which provides a large sense of security to the people living behind the dykes. Recently, however, there is an increasing attention to other flood measures than embankments in the Netherlands. A three 'layer' approach is studied in which the first layer is formed by prevention (structural methods). The second layer is formed by smart spatial planning (flood zoning) and building codes in the embanked areas, reducing the impact when a flood occurs. The third layer is formed by evacuation and preparedness strategies, mainly focused on minimizing casualties. As the three layer approach is new, it is not yet implemented in regulations.

Since 2001, the water assessment process has to be followed for all spatial plans. In principle, this is a good way to make sure that water aspects are taken into account in spatial planning. Although much progress has been made, the communication between water managers and spatial planners could be improved (Ten Brinke & Bannink, 2004). Furthermore, most of the time no attention is given to flood hazards. Possibly the EU flood framework can change this. The maps that need to be developed can be used during the water assessment process.

5.3.3 Flood proof building and building codes in the Netherlands

Flood proof building is seldom applied in the Netherlands. In the past, more attention was given to flood proofing, as can be observed in the old centre of the city of Dordrecht. Recently flood proofing is gaining more attention (e.g. Zevenbergen et al., 2008; Aerts et al., 2008;

Gersonius et al., in prep.). Below, we will discuss the current legislative framework of building codes in the Netherlands.

The **state** has developed building codes to ensure that buildings are built safely, and can be used safely. It contains, for example, rules for the building process, the fire safety, electricity, heating, rainwater discharge, and isolation of the building. It also includes standards for the water resistance of facades and foundations. (Ministry of Internal affairs, 2011) These national building codes have a pre-emptive effect; other government layers cannot enforce standards that are stricter than the building codes' standards. The standards in the building codes are designed for heavy rainfall, not for flooding. Because of pre-emptive effect of the national building codes it is difficult to enforce wet and dry-proofing techniques for flooding. 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 cannot define stricter standards on the same aspects as the national building codes.

Only when facades are an integral part of a flood defence can the **water boards** enforce stricter standards for the water resistance of such facades. For the enforcement of dry-proofing it could therefore be an option to assign a new embankment.

Each of the twelve **provinces** is allowed to develop its own spatial and water policies within the framework of national policies. Due to the pre-emptive effect of the national building codes few include dry- and wet proofing. The province of Flevoland has designated embankments in unprotected areas. Some of them include the facades of buildings. The province of Overijssel focuses on flood safety in the embanked areas and requires that flood risks are taken into account in land use zoning plans (Neuvel et al., 2011). This authority also suggests changes to buildings, but at the same time it states that it is difficult to enforce them. The province of South-Holland has recently developed the 'risk method' (Huizinga et al., 2011). It applies flood risk analysis to quantify the impact of new developments in the unprotected areas on the expected number of casualties and social disruption. It includes adaptive methods such as elevating and flood-proofing. It does, however, not provide a means to also enforce these measures.

A case: the municipality of Rotterdam

For all new developments municipalities are obliged to make new land use zoning plans. These should demonstrate 'good spatial planning'. In this context, it can be necessary to demand extra measures to be taken. Jurisprudence shows at least one case in which a 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 makes it possible to demand measures such a elevating ground level in more unprotected areas, i.e. if this is not forbidden as is the case in most of the floodplains along the large rivers to guarantee sufficient discharge capacity (Ministry of Transport, Public Works and Water Management, 2006). Some lawyers argue that wet and dry-proofing could be enforced in a similar way, but opinions differ on this matter, especially because of the pre-emptive effect of the national building codes. And there is no jurisprudence on this.

5.3.4 Discussion and conclusions

In principle, there are no rules that forbid people to dry- or wet-proof their homes. It is, however, not possible for municipalities to enforce such measures. Municipalities that want

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 and give other incentives like better public spaces in return. A good communication of the risks and the advantages of flood-proofing, might also provide sufficient incentives for voluntarily flood proofing.

In order to be able to enforce such measures the state will need to change the national building codes. They just underwent a revision (2012), which makes it is not very likely that they will be revised again soon. Furthermore, the state aims for less rules, instead of more. However, the new national building codes do include an exception for buildings next to a railroad used for the transport of hazardous goods. Municipalities can demand stronger facades to protect the building against explosions. A similar exception might be used to protect buildings against collapse due to flooding in unprotected areas.

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5.4 Private flood mitigation measures

Philip Bubeck & Heidi Kreibich

5.4.1 Introduction

Flood damage in Europe and worldwide has increased considerably in recent decades due to an on-going accumulation of people and economic assets in risk prone areas (Barredo, 2009). Large-scale flood events such as the 1993 and 1995 floods in the Rhine catchment caused total losses of €810 million to €1 billion (Kron, 2004, Engel, 1997). Damage caused by the extreme flood event of August 2002 in the Elbe and Danube catchment amounted to €11.6 billion in Germany, only (Thieken et al., 2007). In coming decades, it is projected that also the effects of climate change will further add to increases in flood risk, which is defined as probability times damage in this chapter. For instance, winter discharges and consequently flood probabilities along the Rhine, one of Europe's largest and economically most important rivers, are expected to increase in coming decades (Te Linde, 2011). In order to mitigate this increasing loss trend and to deal with the considerable uncertainties associated with these future developments, significantly improved flood risk management is required, which, alongside the efforts of public authorities to prevent flooding, also comprises improvements in the mitigation measures adopted by private households (Kreibich et al., 2011a).

Against the background of the projected increases in flood risk due to the effects of climate change and growing exposure, as well as the considerable uncertainties associated with these developments, flood risk management has increasingly shifted towards more integrated flood risk management concepts in many European countries and world-wide in recent decades (Bubeck et al., 2012b). In addition to flood prevention by means of flood defence measures such as embankments, the latter also aim at preventing or reducing damage in case of a flood event through measures taken at the building level. Previous studies indicated that flood mitigation measures adopted by private households, such as flood-adapted building use, the deployment of mobile flood barriers or the securing of contamination sources, can effectively reduce damage (Kreibich et al., 2005). Accordingly, the contribution of private households to damage and thus risk reduction has become an important component of contemporary flood risk management portfolios in many countries (Bubeck et al., 2012b). In Germany, for instance, the responsibility of flood-prone residents and business to contribute to damage prevention gained prominence following major flood disasters along the river Rhine in 1993 and 1995 (Federal Environment Agency, 2010). The disastrous floods along the River Elbe and the River Danube in 2002, again revealed significant regulation and implementation deficits in terms of damage prevention (Federal Environment Agency, 2010, Petrow et al., 2006). As a result, regulative power was shifted from the federal states (Bundesländer) to the national government to provide more stringent and uniform regulations in terms of spatial planning and damage prevention by households and businesses (Wasserhaushaltsgesetz, 2009). Even The Netherlands, which long-time focused solely on

structural flood defences recently started to consider flood mitigation measures as a complementary option for areas that are not protected by the dike ring system (Bubeck et al., 2012b).

However, even though the contribution of private households to damage and thus risk reduction has become an important component of many contemporary flood risk management portfolios, knowledge on the latter remains scarce and is often confined to specific regions (e.g. Thielen et al., 2007). Aim of the project Climate Proof Flood Risk Management, which is part of the Dutch national research Programme Knowledge for Climate (www.climateresearchnetherlands.nl), therefore, is to gain better insights into the effectiveness and cost efficiency of private precautionary measures. Moreover, in terms of risk communication strategies, it is of interest to understand the factors that influence the decision of individuals to undertake protection measures against flooding. The remainder of this chapter proceeds as follows: Section 6.3.2 reports the results of the analyses regarding the damage-reducing effect of flood mitigation measures. Section 6.3.3 discusses under which circumstance such measures are cost efficient. The influence of flood experience and other factors on the precautionary behaviour of flood-prone residents are discussed in Section 6.3.4. Section 6.3.5 concludes and discusses the implications of our findings for contemporary integrated flood risk management.

5.4.2 Risk reducing effect of flood mitigation measures

Private households can undertake various flood mitigation measures in order to prevent or reduce flood damage. These measures are, for instance, to build a house without a cellar, to adapt the building structure, to deploy mobile flood barriers such as sandbags or to safeguard possible sources of contamination, such as an oil heating (ICPR, 2002, Kreibich et al., 2005). To gain further insights into the damage-reducing effect of flood mitigation measures, empirical data from private households along the large German river courses, namely the rivers Elbe and Danube, as well as the river Rhine in Germany were analysed within the framework of the Climate Proof Flood Risk Management project.

Damage reducing effect of flood mitigation measures along the Rivers Elbe and Danube

In order to discover the damage-reducing effect of private flood mitigation measures along the River Elbe and River Danube, computer-aided telephone interviews were conducted with private households in Germany after the flood in 2002 and again after the floods in 2005 and 2006 (Thielen et al., 2007; Kreibich & Thielen, 2008; Kreibich et al., 2009, 2010). Lists of flood-affected streets were identified with the help of information from local authorities (e.g., personal communication with the administrative districts affected), flood reports or press releases, as well as with the help of flood masks derived from radar satellite data (DLR, Centre for Satellite Based Crisis information (www.zki.caf.dlr.de)). This provided the basis for generating building specific random samples of households. The first phase of the survey after the 2002 flood resulted in 1697 completed interviews. The second phase in 2006 resulted in 461 interviews, and a survey in the city of Dresden resulted in 454 completed interviews with private households affected by flooding. All the questionnaires addressed, among other things, the following topics: precautionary measures, flood parameters (e.g., contamination, water level), building characteristics and flood damage to buildings and contents. Building damage included all costs associated with repairing the damage to the building structure, such as plastering, replacing broken windows and repairing the heating

system. Contents damage included all costs incurred through repairing or replacing damaged contents, such as domestic appliances, telephone and computer systems and furniture. The questionnaire contained detailed questions addressing not only total damage but also the area affected per storey, the damage ratio, the type and amount of the most expensive item damaged, and the type and costs of all building repairs and all expensive domestic appliances affected (Kreibich et al., 2011a).

The analysis of these household data supports previous findings that building without a cellar and safeguarding of hazardous substances to avoid contamination of flood waters can effectively reduce flood damage (Figure 5.7 and Figure 5.8). The damage reducing effect of two other precautionary measures, namely to adapt the building structure and to deploy mobile flood barriers is provided in Kreibich et al., 2011.

Constructing a single-family house without a cellar may be an efficient precautionary measure in flood-prone areas, as buildings without cellars are generally damaged less by flooding. Such homes suffer no damage when homes with cellars are affected by low flood water. Thus, the average building damage of €14.382 and the average contents damage of €9.091 of single-family houses with cellars could be avoided completely in these cases (Figure 5.7). In cases with higher levels of floodwater, where the ground floors were additionally affected, the building and contents damage was also significantly reduced on average by €23.904 and by €4.419, respectively, where the single-family houses were constructed without a cellar compared with the ones with a cellar. In the cases where no oil contamination occurred, building damage was significantly lower on average: by €10.482 if only cellars were affected and by €26.447 if ground floors were affected as well (Figure 5.8). Surprisingly, contents damage was significantly reduced, by an average of €4984, if only cellars were affected (Figure 5.9).

Generally speaking, oil contamination can cause damage to buildings that is three times as great on average as without contamination and in particular cases it can even lead to total loss (Egli, 2002). For example, during the Whitsun flood of May 1999 in the region of Kelheim, Bavaria in the south of Germany, the mean damage to buildings amounted to € 15.622. In cases where there was additional oil contamination, the mean damage increased to € 52.886 (Deutsche Rückversicherung, 1999).

Damage reducing effect of flood mitigation measures along the River Rhine

The damage-reducing effect of private flood mitigation measures along the Rhine was examined by comparing the precautionary behaviour and damage suffered of households that were affected by two flood events in 1993 and 1995. Such a comparison is of interest, because the hazard characteristics of both flood events were of a comparable magnitude (Engel, 1997). For example, the water level in the city of Cologne, which was heavily affected by both events, the water level differed by 6cm only in 1993 and 1995, with slightly higher water levels in 1995. Nevertheless, aggregated damage reported for the 1995 event along the Rhine were substantially lower than in 1993 and it has been repeatedly suggested that this was due to an improved preparedness of the population affected by the 1995 flood (e.g. Engel, 1997, Kron & Thumerer, 2002). However, it has not been shown on a household level, yet, whether damage indeed differed between the two flood events and whether this difference can be attributed to improved mitigation behaviour.

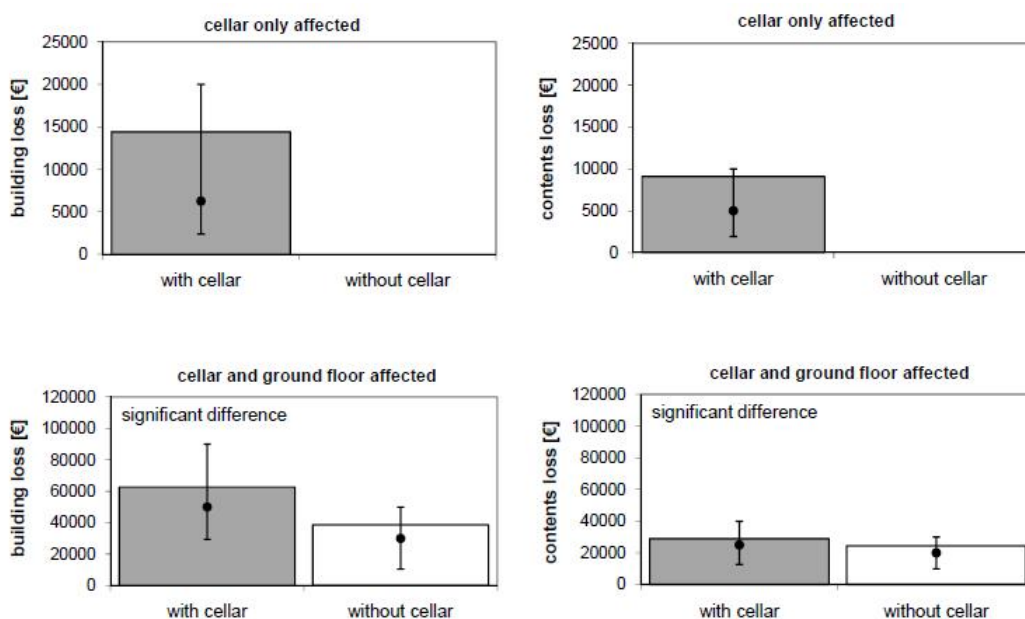


Figure 5.7 Differences in building and contents damages between buildings with or without cellars, separated into cases where only cellars were affected and cases where ground floors also were affected (bars = means, points = medians and 25–75% percentiles, significant differences between the cases with/without cellar are indicated) (Kreibich et al., 2011).

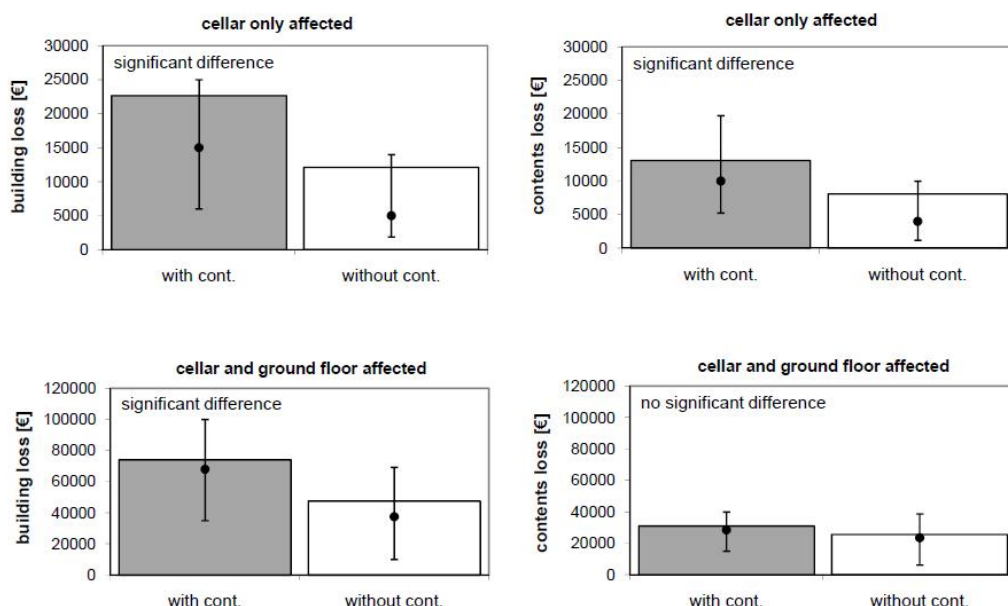


Figure 5.8 The influence of oil contamination on building and contents damages, separated into cases where only cellars were affected and cases where ground floors were affected as well (bars = means, points = medians and 25–75% percentiles, significant differences between the cases with/without contamination are indicated) (Kreibich et al., 2011).

To examine this aspect, 752 telephone-aided interviews with flood-prone households were carried out in May and June 2011. Flood-prone households along the Rhine were identified by means of aerial photographs of past flood events (BFG, 1995), stakeholder information such as the ICPR, and flood hazard maps (ICPR, 2001). The thus derived sample of households lives in highly flood-prone areas, what is exemplified by the fact that 64 per cent of the households had experienced at least one flood, and, 87 per cent of the respondents live in areas that have been actually flooded in recent decades. In addition to questions about flood experience, risk perceptions and socio-economic characteristics, respondents were asked for the damage that they suffered to contents and building structure during the two most severe flood events they had experienced. Moreover, it was elicited whether respondents had implemented different types of flood mitigation measures and when they did so (Bubeck et al. 2012).

The analysis reveals that an increased level of precaution of the flood-affected population indeed resulted in lower damage to contents and structures in 1995. Table 1 shows the number of flood mitigation measures implemented by private households (n=160) before the 1993 and before the 1995 event. It shows, that, in total, the number of measures more than doubled from 212 before the 1993 flood to 437 before the 1995 flood (Table 1).

Table 5.4 Number of measures implemented by households (n=160) before the flood in 1993 and before the 1995 flood (Bubeck et al., 2012).

Flood mitigation measure	1993	1995
Relocate heating system to avoid contamination	20	47
Replace oil heating system to avoid contamination	13	33
Improve building stability	12	25
Use of flood-resistant materials	13	31
Secure oil tank to prevent contamination	12	20
Install a back flow protection system	39	58
Avoid expensive fixed interior in flood-prone storeys	25	56
Avoid expensive items in flood-prone storeys	41	81
Deploy fixed or mobile flood barriers	9	32
Total number of measures	212	437

Accordingly, also flood damage to contents and building structure was significantly lower in 1993 and 1995. The distribution of reported damage to contents and building structure for both events is depicted in Figure 2a and Figure 2b. Both box-whisker plots show that the median damage to contents and structure was higher in 1993 (median^{content} = €1000 / median^{structure} = €1500) than in 1995 (median^{content} = €0 / median^{structure} = €1000). Also the inter- quartile ranges show higher upper limits for both damage to contents and structure in 1993 and a larger variation. The same holds true for the upper quartile, which shows again that a higher upper limit of damage exists in 1993, which has a larger variation. Moreover, damage cases considered as outliers are higher in 1993 than in 1995. In conclusion, Figure 2a and 2b indicate that households suffered higher flood damage to contents and structure during the 1993 flood event (mean^{content} = €4588 / mean^{structure} = €6072), compared with 1995 (mean^{content} = €2233 / mean^{structure} = €4351). The Wilcoxon signed-rank test confirms that damage to content (z = -5.832, p < 0.001, r = -0.37) and structure (z = -4.219, p < 0.001; r = -0.27) was lower in 1995 at statistically significant levels. The damage reducing effect to

content was stronger for damage to contents as to building structures. Further analysis confirmed that these differences in damage between 1993 and 1995 were no function of differences in water levels individually experienced by the respondents. Also for respondents that reported identical water levels in 1993 and 1995, the same damage-reducing trend was observed (Bubeck et al., 2012).

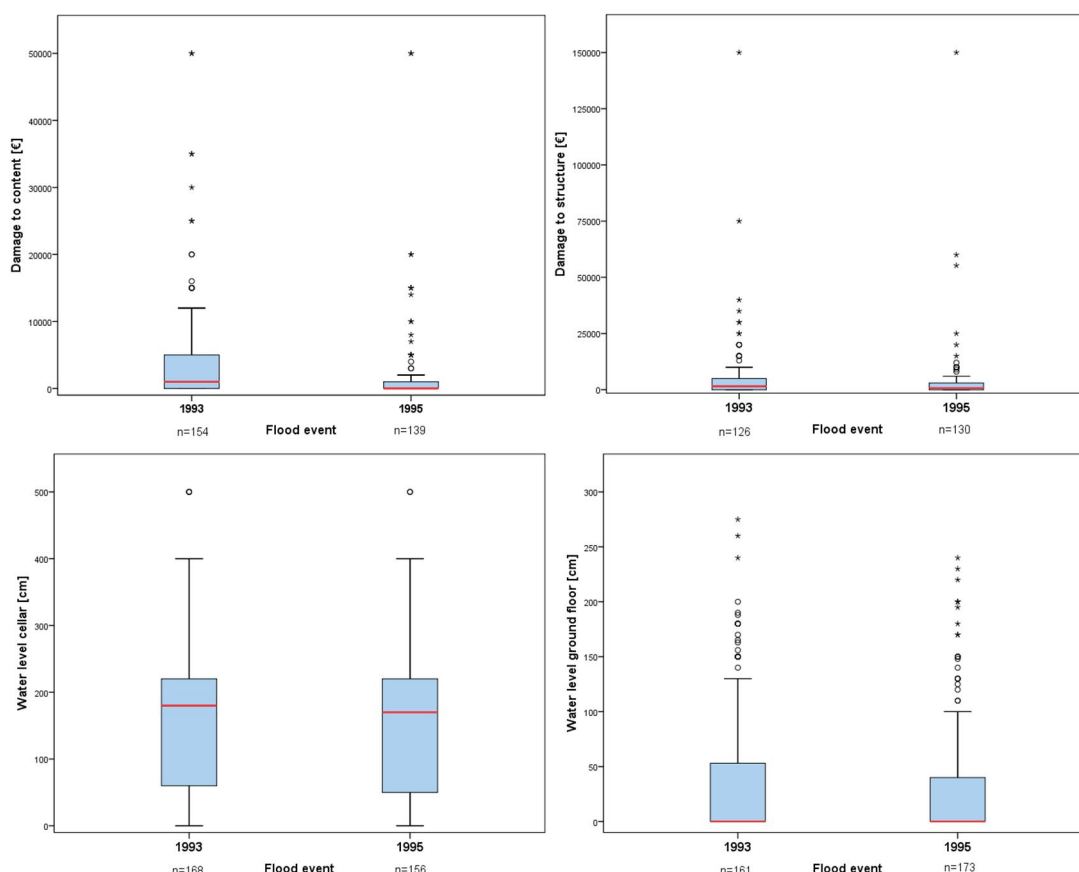


Figure 5.9 Box-whisker plots of damage to contents (a), damage to structure (b), the water level in the cellar (c), and the water level in the ground floor (d).

Note: Damage to contents, damage to structure, water levels in cellar and ground floor are significantly different (Wilcoxon signed-rank test) at the 1 per cent level.

5.4.3 Cost-effectiveness of flood mitigation measures⁸

From a microeconomic point of view, households' decision to self-protect against flood damage is an optimisation calculation. To undertake a flood mitigation measure is economically beneficial, if the benefits (damage reduction or avoidance) outweigh the costs (investment and maintenance costs). Therefore, it is important to gain a better understanding about the cost efficiency of private flood mitigation measures. This was examined for the

8. This section is based on Kreibich et al., 2011 and Kreibich et al., 2012.

household sample along the River Elbe and River Danube (6.3.2.1) and for two types of measures, namely building without a cellar and to secure possible contamination sources. The cost efficiency of two other precautionary measures, namely to adapt the building structure and to deploy mobile flood barriers is provided by Kreibich et al. (2011; 2012).

To construct buildings without a cellar seems reasonable in flood-prone areas, particularly since buildings without cellars are also less expensive to construct. The costs of living without a cellar depend mainly on the availability of alternative storage area. If there is enough storage area in higher storeys, e.g., the attic, no costs are incurred by this measure. In this case, building houses without a cellar is always economically efficient, since only benefits result (mitigated flood damages (Fig. 2), perhaps lower construction costs). If alternative storage area needs to be rented elsewhere due to a lack of space, opportunity costs are incurred. Average rental prices for floor space provide an estimate of these opportunity costs. Rental prices for floor space are between € 3 and 4 per m² (IHK Dresden, 2009) depending on the location in the federal state of Saxony in Germany. Since having “a cellar in one’s own house” can be equated with being in a particularly attractive location, the upper limit of € 4 m⁻² is taken here. Thus, for a storage area of 65 m² the alternative costs amount to € 3.120 a year. Since these costs are expenses incurred annually, interest charges do not need to be considered. Benefit-cost ratios are shown in Table 5.5. The construction of residential buildings without a cellar and renting alternative storage space is an efficient precautionary measure in high risk areas which are flooded once a year.

Table 5.5 Benefit-cost ratios for the construction of residential buildings without a cellar (Kreibich et al., 2011).

Cellar only affected	Opportunity costs: annual rental prices	Benefit per year (see Fig. 2)	Benefit-cost ratio
Affected once a year	3120 €	23 473 €	7.52
Affected once in 10 years	3120 €	2347 €	0.75
Affected once in 50 years	3120 €	469 €	0.15
Cellar and ground floor affected			
Affected once a year	3120 €	28 323 €	9.08
Affected once in 10 years	3120 €	2832 €	0.91
Affected once in 50 years	3120 €	566 €	0.18

Oil tanks should be secured in all flood risk areas, not only because of the potential economic damages to buildings and other assets but also due to the risk of ecological damage. The costs of doing so are €1.009 for a flood proofed oil tank with a volume of 1500 litres which is secured against buoyancy (Fachgemeinschaft Ölwirtschaft & Wärme & Service, 2008). Given an average lifetime of an oil tank of 30 years (Fachgemeinschaft Ölwirtschaft & Wärme & Service, 2008), annual costs amount almost € 34. Securing oil tanks is a measure that consistently shows a positive benefit-cost ratio above one (Table 5.6).

Table 5.6 Benefit-cost ratios for securing oil tanks (Kreibich et al., 2011; Kreibich et al. 2012).

	Costs per year	Benefit per year		Benefit-cost ratio	
		i.r.* 4%	i.r. 3%	i.r. 4%	i.r. 3%
Only cellar affected					
Affected once per year	33.63	9430.15	10620.21	280.38	315.76
Affected once in 10 years	33.63	943.02	1062.02	28.04	31.58
Affected once in 50 years	33.63	188.60	212.40	5.61	6.32
Cellar and ground floor affected					
Affected once per year	33.63	16125.65	18160.66	479.45	539.96
Affected once in 10 years	33.63	1612.57	1816.07	47.95	54.00
Affected once in 50 years	33.63	322.51	363.21	9.59	10.80

5.4.4 Flood experience as an important driver for taking individual measures

The analysis of the household data along the Rhine further revealed that flood experience is a strong trigger for flood precautionary behaviour. Figure 5.10 provides an overview on the flood events reported as most severe by the respondents as well as the long-term development of four different types of flood mitigation measures among flood-prone households between 1980 and 2011: namely, structural measures implemented by homeowners, structural measures implemented by owners and tenants, avoidance measures and flood barriers.

In terms of implemented flood mitigation measures, Figure 1 shows that all four types were deployed gradually over time, with major flood events being important triggers for an accelerated implementation. Especially in the aftermath of the severe floods in 1993, a remarkable increase in the number of undertaken measures can be observed for all four types. Despite the severity of the 1995 flood, the level of implementation remained comparably low afterwards. Since the 1995 flood inundated similar areas as in 1993, it can be assumed that the level of preparedness was already high in the aftermath of the 1993 event, and, therefore, did not increase that much anymore afterwards.

That flood experience strongly influences the adoption of precautionary measures is also confirmed by correlation analyses. The reported number of flood events per year shows a strong correlation (Cohen, 1994) with the number of implemented measures. The correlation coefficients range from $r = 0.52$ for structural measures to $r = 0.67$ for avoidance measures. These findings are in line with previous studies, which also observed that (flood) hazard experience is an important factor of influence on precautionary behaviour (Weinstein, 1989, Bubeck et al., 2012a, Kreibich & Thieken, 2009, Kreibich et al., 2011b).

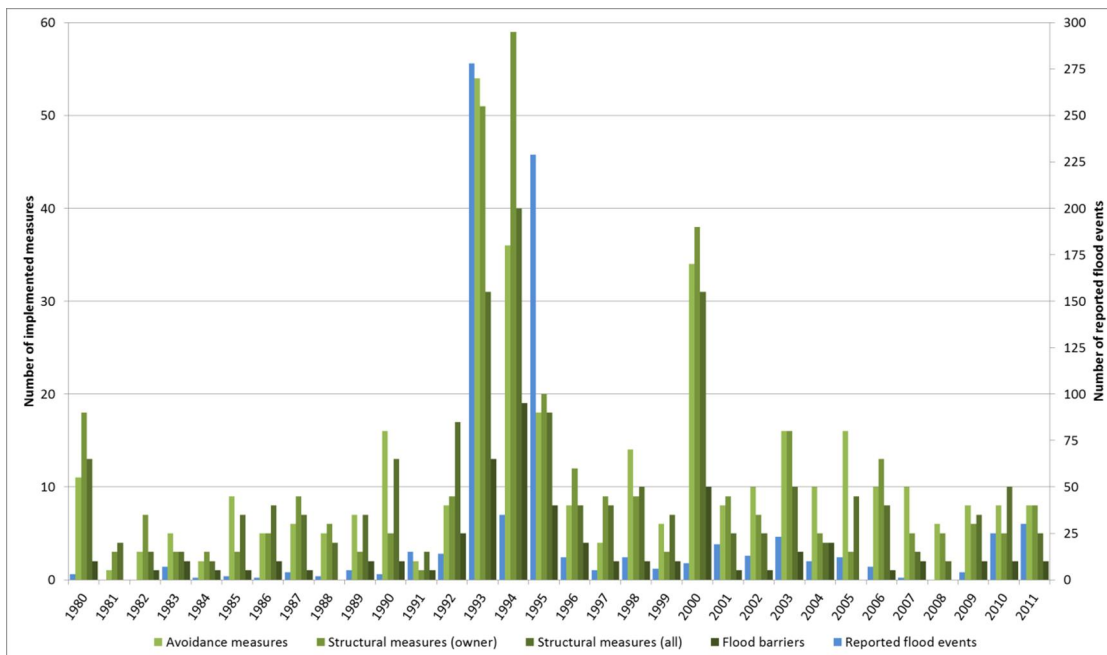


Figure 5.10 Long-term development of the implementation of four types of flood mitigation measures by flood-prone households (n=752) along the German part of the Rhine

5.4.5 Conclusions

The contribution of private households to damage and risk reduction has become an important component of contemporary integrated flood risk management concepts in many countries. The latter have been increasingly adopted in Europe in response to major flood events, the projected increases in flood risk and the large uncertainties associated with these developments. Our analyses of empirical household data within the framework of the project 'Climate proof flood risk management' show, that private precautionary measures can be a promising option to complement traditional flood protection. We find that measures such as flood-adapted building use, the safeguarding of hazardous substances or the deployment of flood barriers effectively reduced damage during past flood events along the major German river courses. Moreover, cost benefit analyses for measures undertaken by flood-prone households along the rivers Elbe and Danube demonstrate, that the latter are cost-efficient also in areas with lower flood probabilities (1:50 per year).

Analysis of the long-term development of flood mitigation measures among private households along the Rhine, which indicates changes in vulnerability over time, further revealed that flood experience is a strong trigger for an increased rate of implementation. In line with previous studies, the level of implementation strongly increased especially in the aftermath of severe flood events, such as the one in 1993.

These findings have important implications for flood risk management. Against the background of climate change, it can be expected that areas will be increasingly affected that have little prior flood experience. Our results suggest that these areas will, at the same time, also be highly vulnerable to flood impacts, as the level of precaution is supposedly low, given the lack of direct disaster experience. If private flood mitigation measures are supposed to play an important role in contemporary and future integrated flood risk management, the

voluntary adoption of these measures by private households seems not to result in adequate protection. Additional policies, such as stricter building codes and spatial planning policies or incentives via insurance policies (Aerts & Botzen 2011) seem necessary to increase the level of implementation also in areas without direct flood experience.

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5.5 Burden sharing: insurance arrangements as incentive to take individual measures

Edmund Penning-Rowsell

5.5.1 Character of flood insurance

Flood insurance models 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 is assisted by insurance arrangements

The wide range of insurance models has developed incrementally, reflecting local circumstances. It is not wise to suggest that one model is necessarily better than another, but the comparison is useful when considering the development of an insurance model when none currently exists. Criticisms must be accompanied by substantial caveats, so for example we judge that the UK market model exhibits strengths in terms of high level of coverage but also weaknesses in terms of moral hazard.

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.

5.5.2 Effectiveness: an international review of 'success factors'

Any judge of effectiveness must take into consideration that it is location-specific rather than absolute. Therefore we would rather talk of 'success factors' than effectiveness *per se*.

In this respect a review of international models with regard to predefined success factors has been undertaken. 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 5.7 summarizes information for a large number of markets and demonstrates the wide variety of cover.

This review reveals eight basic categories of insurance market within the developed world and alternative market structures for developing markets. Solvency of insurance markets seems strong, partly because insurers and reinsurers can choose to exclude markets, which would give rise to insolvency, or they can diversify their portfolios to include offsetting perils.

The features which boost insurance cover are 'bundled' policies and mandatory insurance with mortgage finance. Insurability is also enhanced by risk diversification across risks and markets and decreased by stand-alone risk based flood insurance. Conversely encouragement of mitigation is in theory boosted by risk based pricing although the evidence for this happening in practice is not strong. Low coverage or absence of cover in risk based private markets detracts from the potential of risk based incentives for mitigation. It is noted that to achieve equitable insurance cover some government intervention is necessary. A consensus of recent insurance reviews is that no single model performs well on all measures of success but that some sort of public/private partnership will lead to the most balanced insurance solution.

The report prepared for this project (Lamond & Penning-Rowsell, 2011) gives details of the range of these insurance models. For this interim report we just highlight two, owing to their relevance for the Knowledge for Climate research programme. These are the circumstances in the Netherlands and in the UK, discussed below.

Netherlands

In a country with about 55% of the country being flood-prone and 60% of its population living in this flood-prone area, floods and sea-level rise clearly pose a major natural hazard.

Optional private insurance cover does not include the major causes of flooding such as dike breaches of primary and secondary flood defences as this is covered by the state guarantee within the dyke system. However, studies reveal that in the light of changing hazard, legal safety standards are perhaps not sufficient and the total risk might overcome the level of protection available (MNP, 2004).

Raising the level of protection is seen as cost effective in some eight dike-ring areas but other areas will be increasingly exposed to flood hazard. In the year 2000, the Association of Dutch Insurers advised that private coverage of damage caused to properties by flood as a consequence of extreme rainfall could be made available (Jha, 2011). The coverage that is available in the market is therefore against extreme rainfall but does not include flooding from the rivers or the sea.

The UK scheme

The UK scheme involves private insurance companies offering cover for a wide range of properties at risk from flooding. Policies are bundled in the domestic sector so that cover embraces fire, flood, theft and subsidence. Whilst there are considerable strengths in the system, there are also weaknesses. To us, the major weaknesses of the UK scheme for insurance against flooding appear to be twofold, as outlined below.

First, the voluntary nature of the agreement between insurers and the state leaves open the potential for the market to harden if insurance claims worsen, thus exposing the most at-risk policies to the danger of unaffordable or unavailable cover. At some point, it may become difficult to obtain reinsurance, but this seems an unlikely occurrence in the short to medium term.

There does not appear to be a market in which a wholly private insurance market can be assured in the long term. State backing is probably necessary if a long-term guarantee of flood cover is desired. The French and Spanish examples demonstrate that the policy of state reinsurance of a partly private market can work, if solidarity of risk is accepted (ref?). Alternatively, a national catastrophe bond approach, such as the Mexican example (ref?), might be considered. However, such a bond would be most cost effective for a government which would struggle to cover the probable maximum loss (PML) with either tax revenue or regular borrowing after the event. As the PML for the UK situation is relatively small in relation to GDP, this is unlikely to be the most cost-effective option.

The second major weakness is the situation of moral hazard, which research implies still exists in the UK market. Approaches to reduce moral hazard could be to price policies more closely to risk. This approach is the situation in most private markets in the world, such as Germany, Australia etc. It is highly likely, however, that market pricing will reduce the extent of cover/penetration. In fact, it may lead to reduction of cover for other perils in the situation of bundled policies, as homeowners will not be able to afford the bundle of risk. Alternatively, the standard policy could exclude flood risk and an add-on flood cover option be provided. This option would be likely to reduce flood cover even further.

5.5.3 Cost-effectiveness: the picture in the UK

Any analysis of the cost-effectiveness of insurance arrangements is not unproblematic. This is because costs and benefits are distributed across different sectors of the population, and a benefit for one (in terms of compensation for flood losses) is a cost to another (being the insurance company taking that risk).

Therefore, we need to be careful what we call benefits and what we call costs. In this respect, householders and businesses are not necessarily the final beneficiary of flood risk management (FRM) investment if their losses from the floods thereby averted would have been recovered through insurance arrangements. Such insurance is uniquely common in the UK, where private companies sell cover to property owners and competitive market pressures appear largely to determine premiums (Arnell, 2000; Lamond et al. 2009).

Based on the government's Household Expenditure Survey and evidence from its own members, the ABI estimate (ABI, 2009) that the take-up of insurance in the UK is such that 93% of all homeowners have home buildings insurance cover (a standard condition of a UK mortgage), although this falls to 85% of the poorest 10% of homeowners. Some 75% of all households have home contents insurance, although half of the poorest 10% of households do not have this protection.

Notwithstanding these differences, by far the majority of house owners are insured against flood losses, within the bundled policies combining flood, theft, fire and storm cover. This does not mean that all flood losses are covered, because many of those insured are under-insured and, of course, none of the so-called 'intangible' losses from floods (Tapsell et al. 2002) are covered at all. But under a series of agreements between the insurance industry and government stretching back to the 1960s (Arnell, 2000), insurers have obligations to provide continuity of cover for most households and small businesses in exchange for government continuing to invest in risk reduction measures (ABI, 2008).

To examine this question of flood damage avoided very broadly, in this context, we can assume that if there is investment on flood risk management in a community (and nationally) then flood losses there should decline. If there is no such decline in flood losses, then the investment will not have been worthwhile. If there is this decline in flood losses, then insured claims should be fewer (and/or lower). This, in turn, should be reflected in lower premiums – or changes to other arrangements such as reduced excesses (i.e. 'deductibles') – paid by those whose risk of flooding has been reduced. If there is no such change in premium arrangements, then the relevant insurance company will retain its full premium income, but have lower costs (i.e. lower claims payouts). This should result in the insurance company making larger profits for its shareholders.

The consequence of this kind of conclusion is that any measure of cost-effectiveness must take into consideration the people affected both as payers and as receivers of resources. This will be a clear focus of our work in the second part of this research project.

5.5.4 Side effects

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.

Table 5.7 A summary of the international review (Lamond & Penning-Rowsell, 2011)

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

Thus the side-effect of insurance arrangements is a reduction in the likelihood of risk reduction measures 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.

There is also a chance, unfortunately, that the presence of private insurance undermines the willingness of the state to invest in risk reduction measures. This is difficult to detect, but the evidence is that the insurance industry presses hard for governments to take risk reducing measures, as part of a public expenditure package, so that their efforts at risk compensation are not prejudiced by government inaction. This is currently unlikely to be the situation in the Netherlands or the UK, but must be guarded against in the future.

5.5.5 Conclusions: applicability and attractiveness for the Netherlands

This chapter reports on approximately half of the research under the Knowledge for Climate project. Within this sub-project we have looked at insurance arrangements around the world, and undertaken a more detailed evaluation of the situation in the UK. This will continue in the second half of the project, but the focus then 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.

Our research has indicated 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.

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6 Towards comprehensive flood risk management strategies

6.1 Policy analysis for flood risk management

Marjolein Mens & Frans Klijn

6.1.1 Policy analysis: the procedure

In the process of considering a gradual change or a transition of a flood risk management policy, a policy analysis can help in the exact framing of the problem and in the exploration of possible alternative policies (Klijn et al., 2012). The term 'policy analysis' can be interpreted in two distinct ways: as an analysis of actual policy or as an analysis in behalf of planning and policymaking (Thissen, 1997; Walker, 2000). We follow the second interpretation (Walker, 1986).

Such a policy analysis requires following a stepwise procedure, which we adapted from a general 'framework' for the purpose of long-term flood risk management planning (De Bruijn et al., 2008). Figure 6.1 depicts this procedure, which consists of a number of stages.

Key elements of this procedure that will be discussed in this chapter are (1) the definition of strategic alternatives, as coherent sets of physical measures and policy instruments (FLOODsite, 2009), and (2) the assessment of these alternatives. That is because our research activities focused on these elements.

6.1.2 Assessing and comparing strategic alternatives

To compare strategic alternatives, a comprehensive assessment framework is needed. The most common way to assess alternative ways to reduce flood risk is to compare the costs for implementation and management with the expected risk reduction in economic terms. However, risk reduction is not a goal in itself. Instead, a flood risk management strategy should aim to support and strengthen sustainable development (De Bruijn, 2005). Therefore, strategic alternatives should be assessed on socio-economic impacts as well as natural and cultural effects. The basis of many assessments of planned public investments is the triple-P concept (People – Planet - Profit). This originates from Young (1992), who described sustainable development in terms of social equity (People), ecological integrity (Planet) and economic efficiency (Profit). A criterion such as benefit/cost ratio (e.g., expected risk reduction divided by the investment costs) falls in the category of Profit, equity and casualty risk are examples of criteria in the People category, and landscape quality is a Planet criterion (De Bruijn et al., 2008).

The Delta Programme assessment framework (Marchand et al., 2012) also uses the triple-P concept, but distinguishes between intended effects and unintended side-effects. For flood risk management, the primary intention is to reduce economic risk and casualty risk in a cost-effective way, while secondary effects are, for example, those on spatial quality, nature and recreation. Both primary aims and secondary effects can be sorted against the three P's.

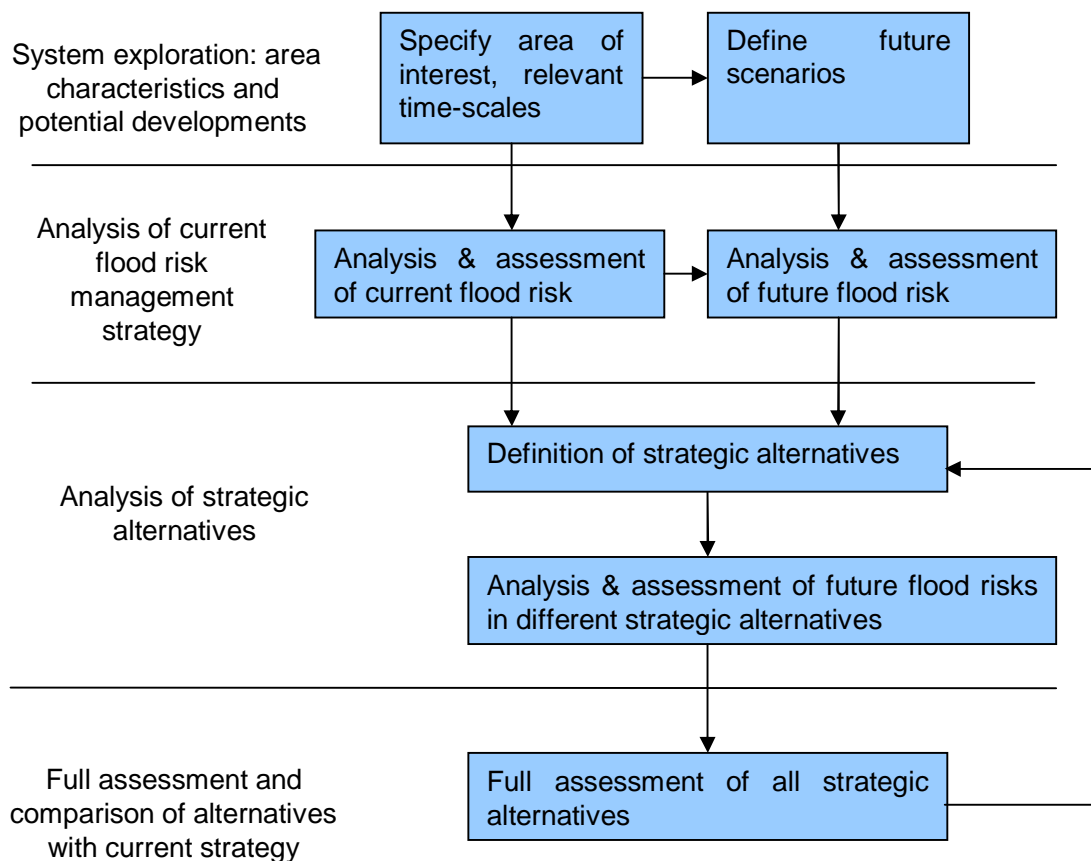


Figure 6.1 Policy analysis for flood risk management requires a systematic step-wise approach (Klijn et al., 2012), which can be generalized into a 'framework of analysis' (Deltares, 2012).

Long-term planning inherently involves dealing with uncertainty about future climate and socio-economic developments. Over the last 10 years, 'dealing with uncertainties' has gained a lot of attention in policymaking and research, partly triggered by the attention to climate change. For example, the Netherlands' National Water Plan (2008) states that because of uncertainty in climate change measures should be designed such that they can be adapted in the future. In addition, the Delta Programme now aims to design strategies that can be adapted to socio-economic developments as well, since these are as uncertain as climate change. One way to deal with uncertainty about future developments and changes is to analyze the effects of a measure or strategy under a range of plausible scenarios. However, it is still unclear how to value a measure that 'performs well' across most of the scenario's. Moreover, it does not concern uncertainty due to natural variability and lack of knowledge. For example, what would happen if the peak water levels are higher than defences are designed for, or when people behave differently than expected?

Although it is clear that 'sensitivity to uncertainties' deserves a place in assessment frameworks, more research is needed to find the right way and the right place in assessment frameworks.

To include the effect of uncertainty, robustness and flexibility have been proposed in addition to the triple-P framework (e.g. De Bruijn et al., 2008; Merz et al., 2010). If the flood risk system is insensitive to unexpected events it receives a high score on robustness, and a flexible strategy can easily be adapted if future conditions are different than expected. Here, both robustness and flexibility were seen as overarching principle, next to the triple-P criteria, thus a characteristic of the strategy itself and not changing for different scenario's. However, recent KfC-research has shown that robustness is a property of the system and should therefore be added as part of People and/or Profit. The next section discusses the research on (system) robustness as decision criterion in more detail.

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

Ties Rijcken

6.2.1 Introduction to the challenge

The preceding chapters treated individual flood risk management measures and instruments. A combination of selected measures creates a flood risk management strategy (Walker, 2000). Two questions that have not been addressed, or only partially, are:

- 1 how do flood risk management strategies relate to other water system related objectives, such as fresh water supply, ecosystem health and navigability, and
- 2 how are strategies presented to stakeholders in such a way that they can make well-informed decisions on their preferred strategies.

This section outlines an approach for using interactive modelling to address these issues in the Rhine-Meuse delta policy-making. So far, the strategies in the model are limited to projects and operations within the main water system (in Dutch: 'hoofdwatersysteem'). For example, zoning and building limitations within the protected areas (dike-ring areas) are not incorporated in the model as projects, but can be translated to the safety standards (effective zoning should lead to lowering or not-increasing the protection standards). This approach could be called 'services-based': it focuses on the services provided by the flood risk management system (such as flood probability reduction), and leaves different ways to address the related need (such as flood impact reduction) to others. In a later stage, the model could be extended to a fully 'risk-based' approach.

6.2.2 Benefits of 'SimDelta'

The added value of SimDelta to strategic water infrastructure planning would be 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 using the internet than with 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.

Let's recall this paper's objective for the Delta Program. The planning question could be taken as how to match the supply of possible projects to the demand for them. The successful websites Google, Facebook and E-Bay do just that. These sites mediate supply and demand with a standardized language, easy access, filtered information, and processes that do not get lost after use, but keep improving.

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. A project can also

inspire by attractive visualizations, a good 'story' and good marketing (the more subjective elusive part), similar to how products, companies and projects are nowadays promoted, increasingly effective over the internet.

Non-interactive communication such as reports, can only transfer and standardize a limited 'cognitive load'. The Delta Program so far works with two years (2050 and 2100), two climate scenarios (35 and 85 cm sea-level rise), two economic scenarios and a limited number of alternative solutions. For stakeholders, ranging from members of Parliament to citizens near project locations, it will be hard enough to deal with this number of variables, however limited it is. For the Delta Instruments and for SimDelta it should be no problem to process many alternative-scenario combinations once the frameworks have been set up. When the model is working properly, the model itself does not set the limits of the generated data, but by the maximum load that can be effectively communicated to the stakeholders.

Future pathways are often represented by decision trees (Haasnoot et al., 2009), such as made for the Thames estuary. A decision tree for the Delta Program that would fit on an A3-sized paper however would probably not provide enough detail for good decisions. The Thames project leader Tim Reeder writes: '*the approach to the Netherlands is more complex [compared to the Thames] (...), regional strategies in different areas, addressing different issues, need to fit on a national scale.*' (Jeuken & Reeder, 2011, p.35). Under SimDelta lies not a single decision tree, but an entire forest. The way the Netherlands Bureau for Economic Policy Analysis (CPB) handles uncertainty is by presenting a deterministic analysis, and communicating the uncertainty orally, or else the message would become too complicated (De Vries, 2010). In an interactive internet-based model, more scenarios strengthen the analysis, when enough users browse through the solution space to aggregate different reactions to different scenarios. For SimDelta, having many stakeholders is a prerequisite rather than a nuisance.

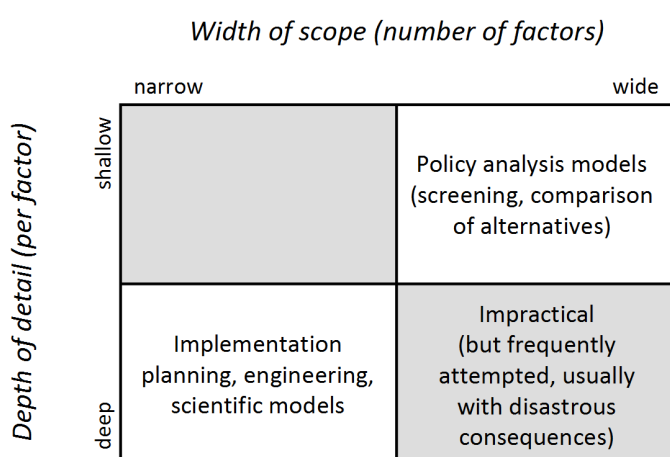


Figure 6.2 Policy support models have to be wary of incorporating too much detail ((Walker & Haasnoot, 2011, p.18).

Of course, there are disadvantages and pitfalls. Lee warns of Large Scale Model Sins (Lee, 1973) and so does Walker (see Figure 6.2). The effectiveness of internet platforms and social networks are a whole field of study (Oinas-Kukkonen et al., 2010; Ridings & Wasko, 2010). A single gaming session is often not enough to make stakeholders understand a complex case (Zhou et al., 2012). Collins and Evans address the problem of '*how to use science and*

technology before there is consensus in the technical community (Collins & Evans, 2007, p.8); lack of scientific consensus can be a problem for SimDelta. Of course, face-to-face contact will always be important. Internet-based gaming-like interactive modeling will never replace decision-making, but can help to streamline and aggregate input.

Encouragement comes from *The Wisdom of Crowds*, by James Surowiecky: 'large groups of people are smarter than an elite few, no matter how brilliant—better at solving problems, fostering innovation, coming to wise decisions, even predicting the future' (Surowiecki, 2005). Design theorists promote 'crowdsourcing': 'an online, distributed problem solving and production model. Crowdsourcing blends open innovation concepts with top-down, traditional management structures, so that crowdsourcing organizations can effectively tap the collective intelligence of online communities' (Brabham, 2008). 'The medium of the Web enables us to harness collective intellect among a population in ways face-to-face planning meetings cannot.' (Brabham, 2009). This collective intellect provides contributions in all three pyramids of Figure 5b: choices (interests and values), criticism (knowledge), and new ideas (creativity).

6.2.3 Features of SimDelta

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 decisions on water infrastructure improvements to be implemented in the Netherlands after the year 2020, has to be built on a number of 'blocks'.

The base block contains the system model. Various general methods are available for complex systems modeling (Walker, 2000; Keeney, 1996). They relate objectives, functions, measures (alternatives, solutions, projects, strategies, tactics, and so forth), scenarios, effects, etc., to each other. As part of the Delta Instruments project Deltares is currently building the Delta Model (Delta Programme, 2011). The Delta Model is streamlining existing models, connecting different regional models, nesting models of various scales, developing new parts and setting up a data validation procedure. An ideal system model has an open structure, to be able to adopt data sets generated elsewhere. It could indicate various degrees of data validity (for example 'class 1—Delta Model-approved', 'class 2—expert guess'). The system model as well as the approved data sets can be continuously expanded by more regions, measures, scenarios, functions, more detail and resolution, and smaller timesteps. Particularly exciting would be to translate the historical development of the system into the systems analysis framework for the future. The Delta Model stops at determining the effects of measures under specific scenarios and passes the effects on to the Delta Programme's regional sub-programs, more closely involved with the stakeholders (Marchand 2010, p.27). It is up to them to (supported by a comparative framework (Lamberigts & Marchand, 2011)) value the effects and to determine to which extent their objectives are met by particular alternatives. This fits the sequence of blocks, because in SimDelta all users together make their choices and give their criticisms, based on their values and understanding.

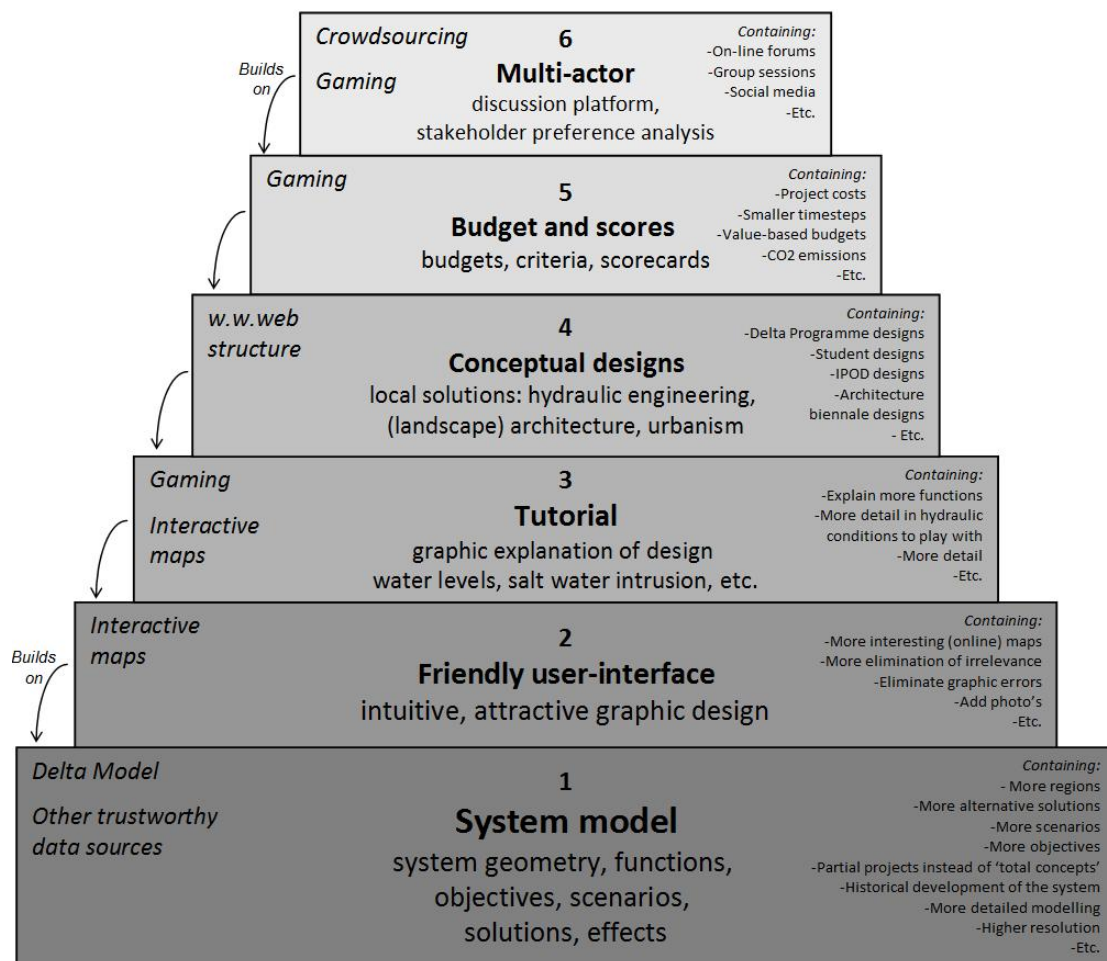


Figure 6.3 To retrieve statistical information on stakeholder preferences with SimDelta, five 'blocks' of activities (interactive software development) have to be constructed on top of the Base Block, the system model.

Block 2 is an intuitive and attractive user-interface. Between 2005 and 2007, the Dutch project Room for the River developed a software tool, called the Planning Kit (in Dutch 'Blokken': here 'blocks' are spatial projects), to support the joint selection of a set of measures from a total of 700 possible Room for the River measures. The software has excellent features, from sand extraction profit calculations to aerial photos. For many stakeholders, however, the user interface looks old-fashioned and presents too much information in a too technical way. Figure 6.4 shows an attempt to simplify the Rhine-Meuse system and to make it more attractive to use. It is made with visual design principles such as use of colour codes, icons and other semantics, schematization, simplification, layered information, 'use cues', etc. (Mijksenaar, 1997; Tufte, 2001; Luyer, 2004).

Some people might consider Block 2 just a layer of paint over a serious system model for which one would simply hire a graphic designer at the end of hard modeling work. However, a good user interface requires the difficult tasks of simplification and forcing oneself to identify with an inexperienced user. It takes many iterations to reach a really intuitive user-interface. The best interface designs are made by people who understand both sides the interface connects.

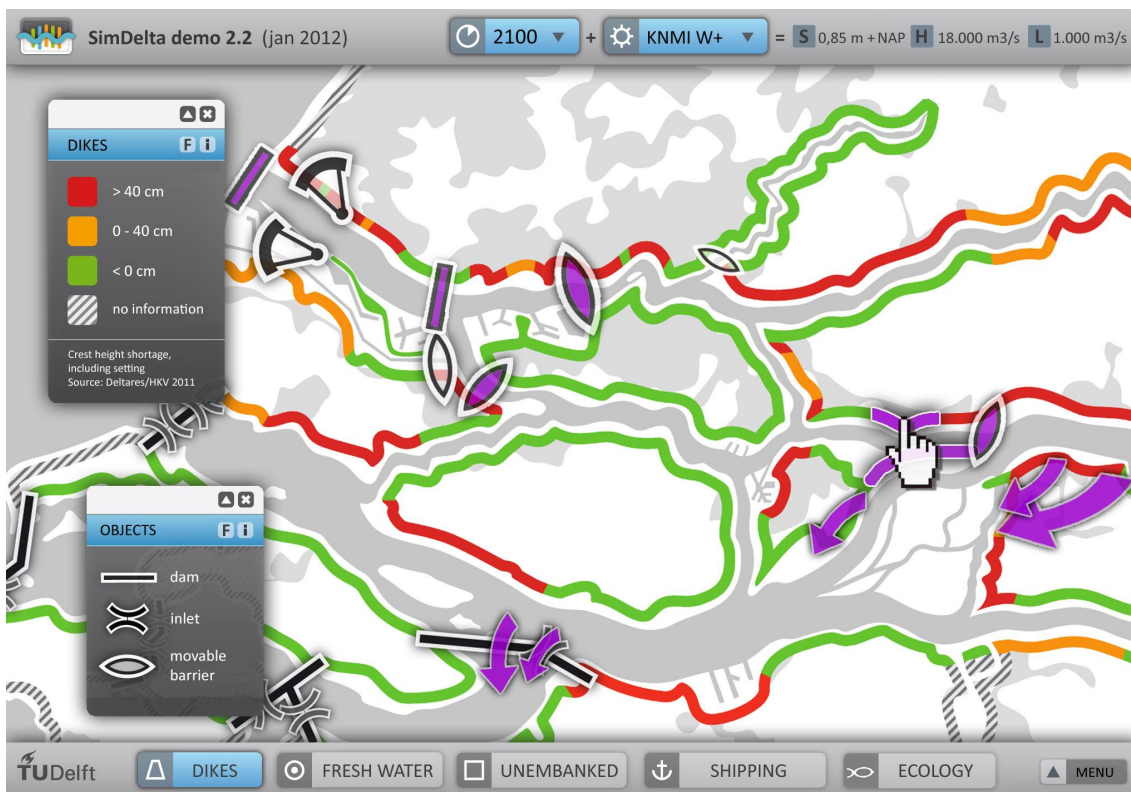


Figure 6.4 Block 2—intuitive and attractive user-interface. Users can click on objectives and scenarios, build projects or change a policy and immediately see the state of 'their delta'.

Stakeholders, such as politicians, do not need to understand detailed physical system complexity to be able to choose among alternative solutions. For example, the absolute or relative design water levels are a step in between problems and solutions; only the flood risk and the pros and cons of safety-improving solutions really matter. However, using the model becomes easier and more fun when some of the underlying system is understood. When a good user interface is in place, this can be used to design a tutorial or 'educational plug-in'. The tutorial contains extra images and animations that explain, for example, the origins of the design water levels in the lower river system (which appears to be difficult to many stakeholders). Furthermore, the more users of the model understand some of the backgrounds, the more will discover errors or give suggestions for improvements.

Block 3 will be particularly useful for architects and engineers who contribute to Block 4: conceptual spatial designs, such as multifunctional levees, surge barriers and river expansions. In workshops and meetings where designers meet water experts, time often must be spent explaining how the water system works. Designers' energy can get lost on large scale solutions that are either obvious to water experts, or impossible. The contribution of the designers lies mostly in local solutions (visualized as in Figure 6.5) or in out-of-the-box large-scale solutions with some sense of reality. Both contributions will be served with a tutorial that explains the system essentials.



(a)



(b)



(c)



(d)

Figure 6.5 Block 4—drawings by engineers and architects: (a) the Nieuwe Merwede river widening combined with nature development (by Enno Zuidema and DHV consultants); (b) a flood barrier integrated with a hotel (by Anna Dijk); (c) an open Haringvliet (by Alphons van Winden for World Wildlife Fund) and (d) a 'Parachute Barrier' in the Beneden- Merwede (by Floris van der Ziel).

The first four blocks serve to make the system understandable and show the many projects that could be built in the coming century. It is more fun to navigate through this space when there is a budget to build projects with, and when indicators measure ones performance on the model objectives (as illustrated in Figure 6.6). The budget will also further sharpen user insight on benefits and costs, and it will be more interesting to monitor his choices, his 'willingness to pay'.

With budget and outcome indicators, SimDelta so far has seven of the nine characteristics of serious games described by Mayer and Zhou. It is '*flexible and reusable, immersive, authoritative, transparent, fast and easy, integrative and communicative*' (Mayer 2009; Zhou et al. 2012, p.4). The model starts to look like 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'.



Figure 6.6 Block 5 introduces the gaming elements 'budget' and 'outcome indicators' (here for example on safety, ecology and other scores).

The two remaining characteristics are 'dynamic' and 'interactive'. 'Dynamic' here is defined as 'able to show the performance of various alternatives in relation to preferences and behavior of other stakeholders'. 'Interactive' means that the model is 'able to support the negotiation process among stakeholders' (Zhou et al., 2012, p.4). In other words: the model so far cannot connect various users to each other. The final Block 6 contains the ultimate goal, stakeholder preference analysis, to support decision-making.

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. On-line communities with physically separated users can serve more users more frequently and probably against lower costs per stakeholder. However, user input over the internet can get polluted by unserious users. This could be covered by a user admission procedure, or filtered in various ways (a possible filter could be the current 'Deltaweb', as used in the Delta Programme). It then becomes possible to involve citizens and schools of landscape architecture, urbanism, civil and environmental engineering, nationally and internationally. Live group sessions and on-line communities support each other in various ways.

A mayor represents more than one vote from a particular location and an action group chairman represents a number of voices with a particular background. An advanced model could use user profiles to weight contributions of different users. Even so, SimDelta will never replace a representative democracy. It can only relate user backgrounds to user contributions and thus serve as an opinion poll. Furthermore, the crowdsourcing mechanism will contribute to allocating additional design efforts and to determine research agendas.

Crowdsourcing in Block 6 contributes to the inevitable flaws and inaccuracies of Block 1. The accuracy and resolution of the underlying systems model is important, but not necessarily crucial. What ultimately matters are the choices, criticisms and proposed alternative ideas by all participants: each one with a particular level of knowledge, creativity and democratic contribution (see Figure 5b). These people are informed by the system model (block 1), through the layer that makes the system understandable for them (blocks 2 and 3), and

possibly 'seduced' by architects and designers into non-quantifiable benefits (block 4). They then choose based on their personal knowledge, 'gut feeling', and choices of others (blocks 5 and 6).

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 (see Figure 2 and Figure 12).

These three possible outcomes more or less correspond to the official government MIRT-research procedure outcomes (Marchand, 2010, p.B-1). The idea of SimDelta is that the outcomes are statistically supported (instead of based on arbitrary conversations among politicians and stakeholders) and graphically understandable (instead of having to rely on a small number of supposedly objective knowledge people). The case will become clearer for more people.

Crowdsourcing is not only used to poll democratic preferences, but also to perpetually self-correct and self-improve. The original systems analysis attempt, to 'depoliticize complex and highly political decisions' (Mayer, 2009, p.828), is revitalized through the contribution of modern internet community technology.

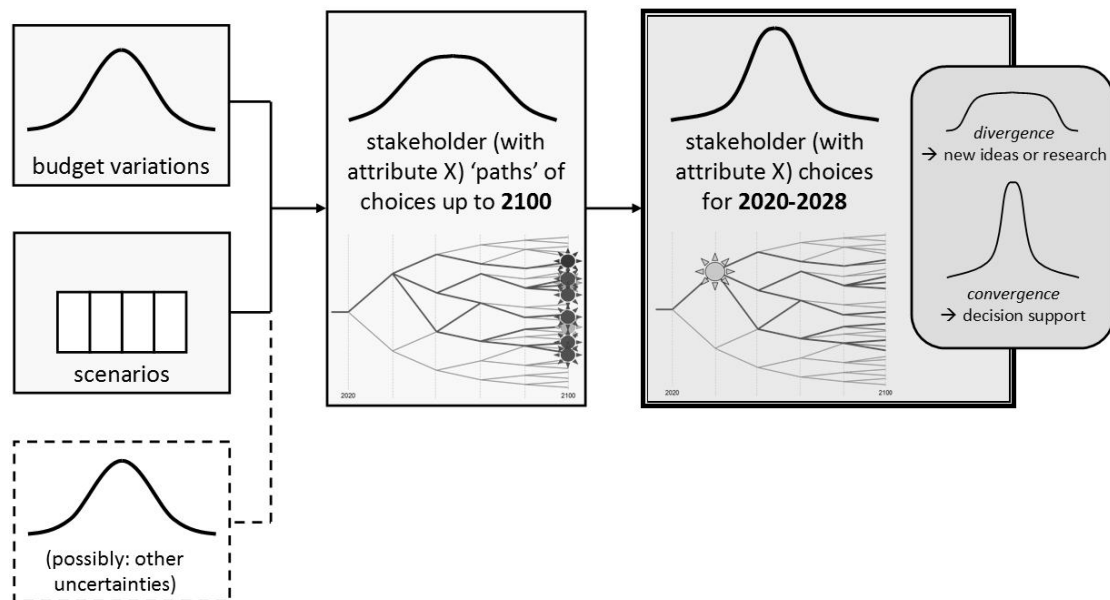


Figure 6.7 In a SimDelta session budgets and scenarios can vary. Many user sessions together result in a distribution of chosen paths (series of choices) up to 2100. This long-term distribution will probably diverge. If short-term choices converge, they can support a political decision.

6.2.4 References

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6.3 Robustness of flood risk management strategies: the IJssel case

Marjolein Mens

6.3.1 System robustness as decision criterion

As stated in the first section of this chapter, a lot of attention in policy-making goes to uncertainty about future developments and changes. It is, however, not only difficult to predict the future. An extreme flood event has a low frequency, but it may happen tomorrow; we intend to build strong dikes, but they may fail unexpectedly. Because we have become more aware of these uncertainties, arising from both our limited knowledge of the system processes and the natural variability in river discharges and other climate variables, the concept of robustness has been introduced in flood risk management (Evans et al., 2006; De Bruijn et al., 2008; Merz et al., 2010; Mens et al., 2011).

The concept of (system) robustness has been developed in the fields of systems ecology and engineering (see **Error! Reference source not found.**) and is closely related to what is called *socio-ecological resilience* in the ecosystems literature. What they all have in common is the focus on 'system performance' and the notion that disturbances cannot always be kept out of the system. If one system component happens to fail, this should not lead to failure of the entire system. 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.

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. Robustness can be seen as an elaboration of resilience, which is defined as a system's ability to recover from the response to a disturbance (De Bruijn, 2005). Both the ability to withstand disturbances and the ability to respond and recover add to system robustness. To understand a river system's robustness to (uncertain) discharges, the flood consequences must be explored for a variety of discharge waves.

Table 6.1 Examples of the use of robustness in literature

Definition or description of robustness	Type of system	Source
Consequences of structural failure should not be disproportional to the cause of the failure	Structural systems (such as buildings)	Baker et al. (2008)
A robust system's performance will not drop off as rapidly as its non-robust counterpart when confronted with external stress	Socio-ecological systems (such as fisheries)	Anderies et al. (2004)
The ability to maintain performance in the face of perturbations and uncertainty	Biological systems	Stelling et al. (2004)
A robust operating system of a computer performs well not only under ordinary conditions but also under unusual conditions that stress its designers' assumptions.	Computer systems	Burgin (2009)
Robustness is the extent to which a network is able to maintain the function for which it was originally designed.	Road networks	Snelder (2010)

6.3.2 How to quantify system robustness?

Key to a robustness analysis is to give insight into the consequences of a variety of flood waves, under the assumption that system components may fail. The analysis thus considers the natural variability of flood waves that enter the system, and the uncertainty about the strength of flood defences. A so-called response curve shows the relationship between peak water levels and potential flood consequences. Flood consequences should represent the impact of flooding on flood risk system functioning, for example economic damage, number of affected persons or the number of casualties. The response curve forms the starting point for the quantification of robustness criteria (Mens et al., 2011):

- 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.

From an application on the IJssel river valley in the Netherlands (Mens et al., 2012), it was learned that the response curve itself is uncertain due to uncertainty about the strength of the flood defences, the duration of the flood wave. Reducing these sources of uncertainty or the effect of these uncertainties on the flood consequences also enhances system robustness for flood waves, because it implies that the location and timing of a flood can be better predicted making the flood better manageable.

6.3.3 Example - robustness of the IJssel river valley

The IJssel River is a branch of the Rhine River in the Netherlands with an average discharge of about 300 m³/s. The embankments are designed to withstand water levels with a frequency of one in 1250 years. There are several reasons why it is relevant to study the consequences of flooding for a range of discharges. First, the IJssel discharge that corresponds to the design frequency is uncertain. Not only because the design discharge of the Rhine has to be estimated with statistical techniques due to lack of data (only 110 years of discharge data is available), but also because it is uncertain how much of this discharge will be diverted to the IJssel branch. Second, the (design) discharge may increase in the future, because of climate change, and because policy makers may decide to divert relatively more water to the IJssel at extremely high discharges. Finally, the strength of the embankments is uncertain. Although they are high enough to withstand design water levels, other failure mechanisms such as piping and macro-instability may cause the embankments to fail at lower water levels. Figure 6.9 shows the uncertainty about the diversion fraction in three plausible frequency curves for the IJssel discharge. If a diversion fraction of 0.16 is assumed in the design of the embankments, they will be able to withstand a discharge of about 2560 m³/s. However, due to the uncertainty the design discharge may well be 2400 or 2800 m³/s. This does not yet take into account the effect of statistical uncertainty in the extrapolation of the Rhine discharge frequency curve, which is estimated at 15% higher or lower (Langemheen and Berger, 2001), and the effect of climate change, which will also increase the 1/1250 year discharge. Thus, because of the uncertainties about the design river discharge, it is relevant to know how the system will respond to a range of discharges.

To understand the sensitivity of the IJssel system to these uncertainties, we estimated economic flood damage in six dike-ring areas for a range of river discharge waves with different peaks and duration. The question is which of the proposed strategic alternatives (see table) performs best in terms of robustness. We used 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. For details on this model approach, we refer to Mens et al. (2012).

Figure 6.10 shows the response curves of the reference system and the alternative system configurations. The design discharges are indicated with the vertical dashed lines in the response curves. The robustness criteria are given in Table 6.3. Each robustness criterion is discussed next.

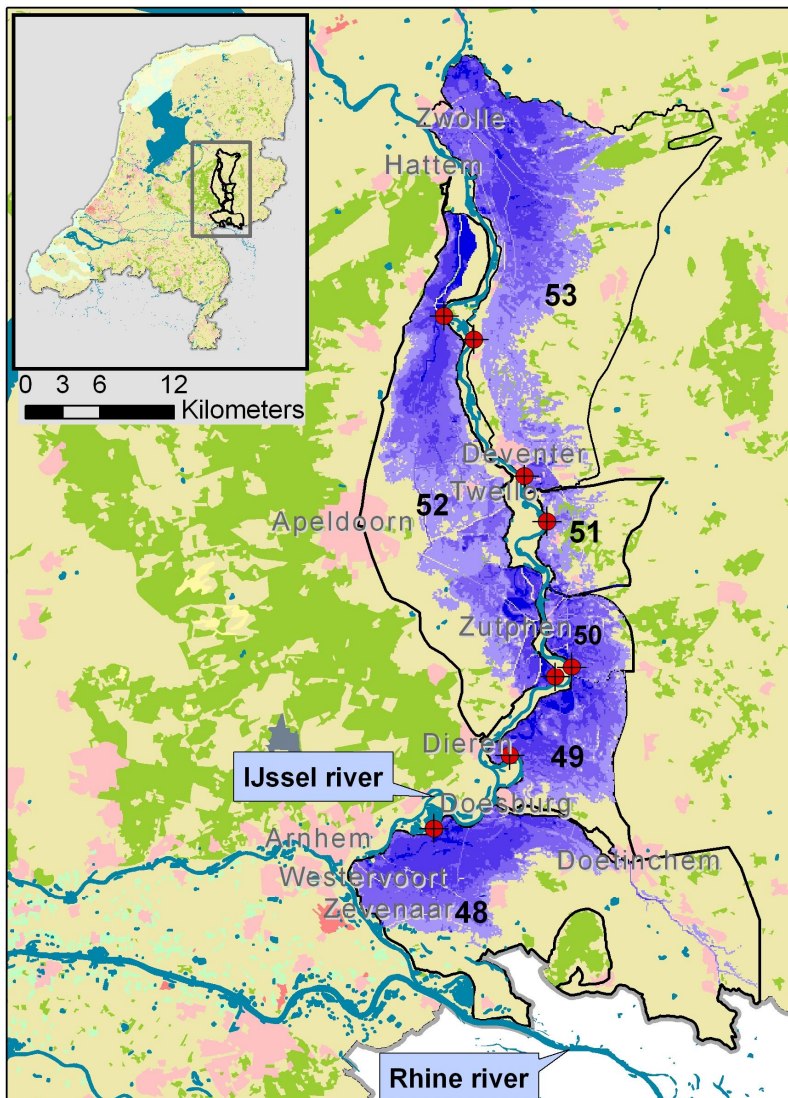


Figure 6.8 IJssel case study area with dike-ring areas and potential flood extent (Note that this shows a combination of various flood events that in reality cannot happen simultaneously)

Table 6.2 Explanation of measures assumed in the analysis and their coding

CE	Conventional Embankments: embankments are raised with a Δh (location-dependent) that corresponds to a change in discharge from $T=1250$ to $T=5000$ year;
RR	Room for the River: the floodplains are lowered such that the water level at the current design discharge is reached at a higher discharge. The ΔQ is about $300 \text{ m}^3/\text{s}$, which corresponds to the change in discharge in CE;
UE1	Unbreachable Embankments, version 1: all embankments are strengthened (not raised) such that they become unbreachable. Water that flows over the flood defence may still cause flood damage;
UE2	Unbreachable Embankments, version 2: like UE1, but embankments near cities are raised with an additional 0.5 m.

Resistance threshold

The reference system has a design discharge of $2560 \text{ m}^3/\text{s}$, which can be considered the resistance threshold. UE1 and UE2 have the same resistance threshold, since embankments have not been raised. The configurations CE and RR have a higher design discharge of $2560 + 300 \text{ m}^3/\text{s}$ ($T=5000$ years), since embankments are either raised (CE) or the stage-discharge relation has been modified (RR). For all alternatives besides UE1 and UE2 the actual resistance threshold is uncertain, since the embankment strength is uncertain. The embankments may also fail at lower discharges than what the embankments are designed for. For UE1 and UE2 a zero failure probability was assumed, which implies that only embankment height determines the resistance threshold. The level of uncertainty about the resistance threshold is the second criterion in Table 6.3.

Response severity

The response severity is indicated by the economic damage as a result of an extreme discharge wave of $3360 \text{ m}^3/\text{s}$. The level of uncertainty arises from the duration of the discharge wave and the number of breach locations, and is given in percentage. CE scores the same as the reference, whereas RR has a better score, because the same discharge leads to lower water levels and as such less water will flow into the area when the embankments fail. UE1 and UE2 have the best score, because embankments can only be overflown, which results in a limited amount of inundation water compared to embankment failure.

Proportionality

This robustness criterion indicates the sensitivity of the damage for changes in discharge. It was scored by visually comparing the response curves of Figure 6.10. The alternative with the largest change in damage at the resistance threshold and the steepest curve receives a score of 1 (low proportionality); the alternative with the smallest change in damage and the flattest curve receives a score of 4 (high proportionality).

When embankments fail at the resistance threshold, large changes in damage occur in CE and RR. In UE1 and UE2 the damage change at the resistance threshold is very small. Thus, CE and RR score 1 or 2, and UE1 and UE2 score 3 or 4. Next, the steepness of the curves are compared. The response curves of CE and RR are equally steep, but the sudden increase in damage of CE is larger. Therefore, CE scores 1 and RR scores 2. The response curve of UE2 is clearly less steep than that of UE1, therefore UE2 receives the highest score: 4.

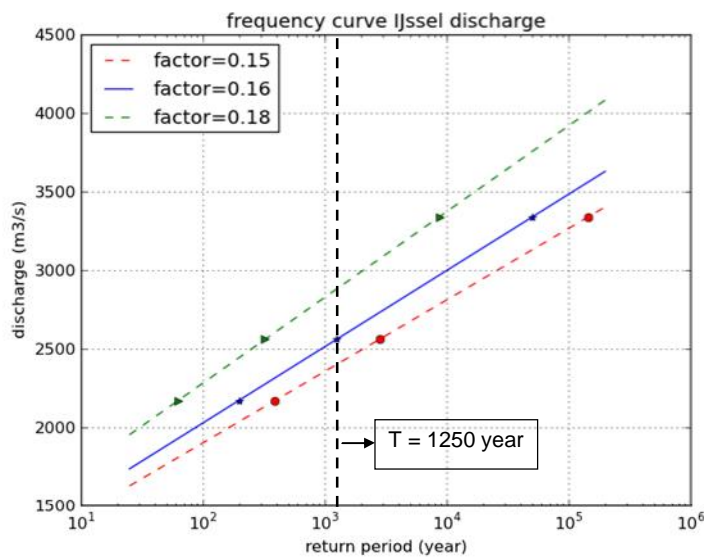


Figure 6.9 Uncertainty in the frequency curve of IJssel discharge; 'factor' indicates the fraction of Rhine discharge that diverts to the IJssel

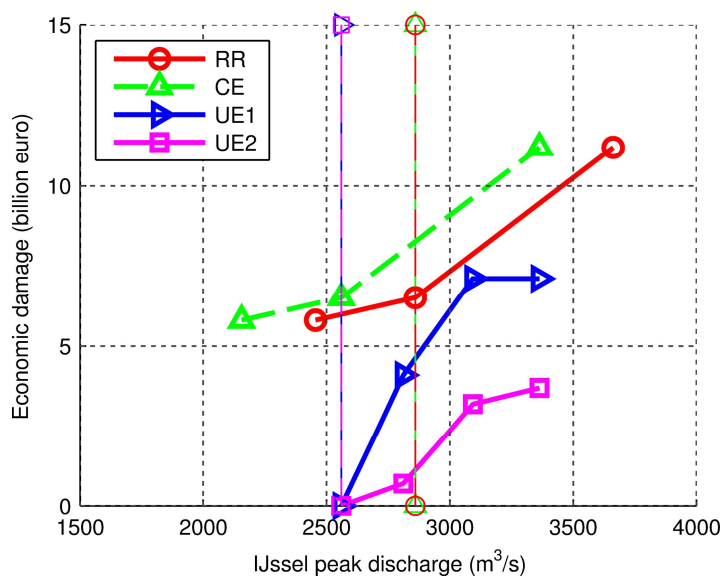


Figure 6.10 Response curves of the alternative system configurations, and the design discharges indicated with vertical dashed lines

Table 6.3 Overview of robustness scores of all analysed system configurations. Colours indicate for each criterion the lowest score (orange) and the highest score (green) in terms of robustness (Mens et al., 2012).

Robustness criterion	Dimension	Conventional embankments	Room for the river	Unbreachable Embankments	
		CE	RR	UE1	UE2
Resistance threshold	m ³ /s	2860	2860	2560	2560
<i>level of uncertainty</i>	-	<i>high</i>	<i>high</i>	<i>low</i>	<i>low</i>
Response severity	G €	11.2	9.3	7,1	3,7
<i>level of uncertainty</i>	%	-95 - 180	-95 - 190	-50 - 95	-70 - 130
Proportionality	rank nr.	1	2	3	4

6.3.4 Conclusion

Robust flood risk systems are able to limit the flood damage in many plausible flood situations, preventing floods from turning into unmanageable disasters. The response curve is an effective way to gain insight into system robustness. However, also other uncertainties, such as wave shape, breach location and embankment strength should be considered in an evaluation of robustness.

It was concluded 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 and as such it increases the system 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 example, robustness analysis method is considered a useful addition when developing flood risk reduction strategies in view of uncertainties. Robustness can be used as an additional criterion in decision making: it may be an additional reason (besides flood risk reduction) to invest in measures that make a system less sensitive to uncertainties.

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6.4 Integrated urban and spatial planning for Flood Risk Management: the Rijnmond case

Anne Loes Nillesen

6.4.1 Introduction

Future flood risk management will require improvements to existing flood protection infrastructures (Delta Committee, 2008). Such interventions – for example the reinforcement of existing defences – can have an impact on spatial quality. The concept of spatial quality is at the centre of this chapter and can be regarded as a combination of the three qualitative parameters utility, attractiveness and robustness (www.ruimtexitmilieu.nl).

In 2007, the Netherlands' government approved the Room for the River Programme. Through this programme, a new approach towards flood protection was adopted. Recognizing the limitations of traditional defences, alternative measures were defined to replace the reinforcement of embankments (see Chapter 2); extra space is created for rivers by deepening rivers, relocating embankments and creating bypasses (Ruimte voor de Rivier, 2012). Attention is given to spatial embedding of the measures, among other things by testing the impact of several different alternative interventions.

Both embankments and Room-for-River measures are relatively easy to implement in rural areas with sufficient open spaces. However, most urbanized areas in the delta lack space and flexibility; cities have grown closer to their waterfronts and embankments and higher grounds have become fully integrated in the urban fabric. Some dike reinforcements come at

extraordinary cost in order to combine improved flood protection with the preservation of characteristic waterfronts and adjacent buildings (Jeuken et al., 2011).

Not only are rivers restrained by the presence of cities with their urban fabric – in their attempts to expand or transform cities are also restrained by the presence of waterways. The location of rivers in cities can be explained by history: rivers formed attractive locations for settlement by serving as a means of transportation and as a water resource. Nowadays, many former industrial and trading areas along inner-city riverbanks are being re-developed, driving a need for an integrated approach to both risk management measures and spatial development.

The goal of the research presented here 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 processes, by enabling a quantification of effects of risk management measures on spatial quality in complex urban contexts, such as the Rijnmond-Drechtsteden area.

6.4.2 Spatial quality assessment

In the development of a methodology of 'research by design', the ability to quantify design results is important, as it allows the measurement of effects and impact of a design proposal (KNAW, 2010). For the Room for the River Programme, a method has been developed for the assessment of local scale spatial quality in rural areas, the Ruimtelijke-KwaliteitsToets (Bos et al., 2004).

Our current research, described in this chapter, concentrates on the development of a tool to assess spatial quality, which is applicable in a complex urban context. The research is a collaborative effort with Maaïke Bos and Oswald Lagendijk from Deltares. The first results of this research have been reported by Nillesen et al. (2011) and are incorporated in a synthesis report for the Delta Programme Rijnmond-Drechtsteden (Jeuken et al., 2011).

The Rijnmond-Drechtsteden area functions as a case study area. For the protection of this part of the Dutch delta, four strategic alternatives for flood protection, so-called 'cornerstones', have been defined, each using different combinations of permanent or closable flood barriers between the delta and North Sea and embankments (Delta Programme Rijnmond-Drechtsteden, 2010). The impact on water levels throughout the region is different for each of these alternatives (Huizinga, 2011); some therefore require additional interventions at a local scale that may affect spatial quality. The alternatives have been evaluated for their effects on flood risk, freshwater-availability, shipping, nature and costs (Jeuken et al, 2011).

We first evaluated the Ruimtelijke-KwaliteitsToets (RKT) and found it to be useful and applicable (Ruimte voor de Rivier, 2006). However, the criteria it employs can be difficult to interpret and may be irrelevant in a particular context; the criteria concentrate on a rural rather than an urban setting and are defined with regional scales and short term design proposals in mind. Therefore, we decided to attempt to improve the existing methodology of the RKT. Whereas the RKT provides a tool to evaluate *design proposals* at a *regional scale*, in a *rural context*, the objective of our research is the design of a methodology that allows the estimation of the impact on spatial quality of large-scale regional *flood risk management strategies* at a *local scale*, in a more complex *urban context*.

Next, we analysed the Rijnmond-Drechtsteden area for archetypical locations that occur frequently and are representative for the region. The resulting set of location types gives a fair impression of the spatial composition of this complex and diverse area. The location types are:

- An embankment in a rural setting adjacent to the Haringvliet, with buildings located behind it
- An embankment with buildings on top of it
- An embankment with historical buildings behind it
- An embankment as part of an urban river front
- An unprotected ('floodplain') urban transformation zone
- An unprotected area ('floodplain') with historical buildings
- And an unprotected area ('floodplain') with buildings of approximately 20-30 years old

For each of the regional strategic alternatives, the effects on spatial quality at a local scale have been assessed in two work group sessions with an expert panel that consisted of two urban designers, a landscape architect, an architect and an ecologist. The involvement of two urban designers allows the evaluation of judgements and arguments for consistency, and gives an indication of the level of subjectivity involved. The involvement of experts from varying disciplines increases the likelihood of identifying aspects that are relevant to the evaluation of spatial quality (Janssen-Jansen, 2009). The experts were familiar, at least to some extent, with the locations. The selected locations were depicted as cross-sections in a consistent and neutral fashion. The cross-sections contained water level estimates, corresponding with probabilities of 1:100 per year and 1:1000 per year, with the possibility of variations between the cornerstones (Huizinga, 2011).

During the first work group session, the expert panel – assisted by a civil engineer – identified suitable local interventions for each location and water level. The selection was restricted to common, widely-accepted interventions such as the construction of new, or the reinforcement of existing embankments, quays, dams or locks (Waterschap Hollandsche Delta), raising land and flood-proof buildings (Figure 6.11). Aspects related to flood protection, technology and spatial quality were taken into account while assuming the ongoing validity of existing flood protection standards. Complementing this analysis, one of the interventions was evaluated using the RKT in order to identify the applicability and shortcomings of the tool – and to allow the design of an improved version for the second work group session.

According to the expert panel, the criteria of the RKT were unsuitable for the evaluation of spatial quality in an urban environment; the criteria were considered unclear and difficult to interpret; the structure of the questionnaire was considered too rigid, and some criteria were suggestive with respect to interpretation of the qualitative aspect.

Consequently, the working principle of the questionnaire and the formulation of the criteria were changed in order to improve the applicability of the methodology. The original Ruimtelijke KwaliteitsToets questionnaire required that all criteria be evaluated and rated for any given location; the adjusted methodology allows the expert panel more freedom to explain their judgements, to limit themselves to the most relevant criteria only and to include additional criteria of case-specific relevance. Criteria that are irrelevant for a location do not need to be evaluated. For example, some criteria may be relevant in an urban setting whilst others are relevant in a rural context.

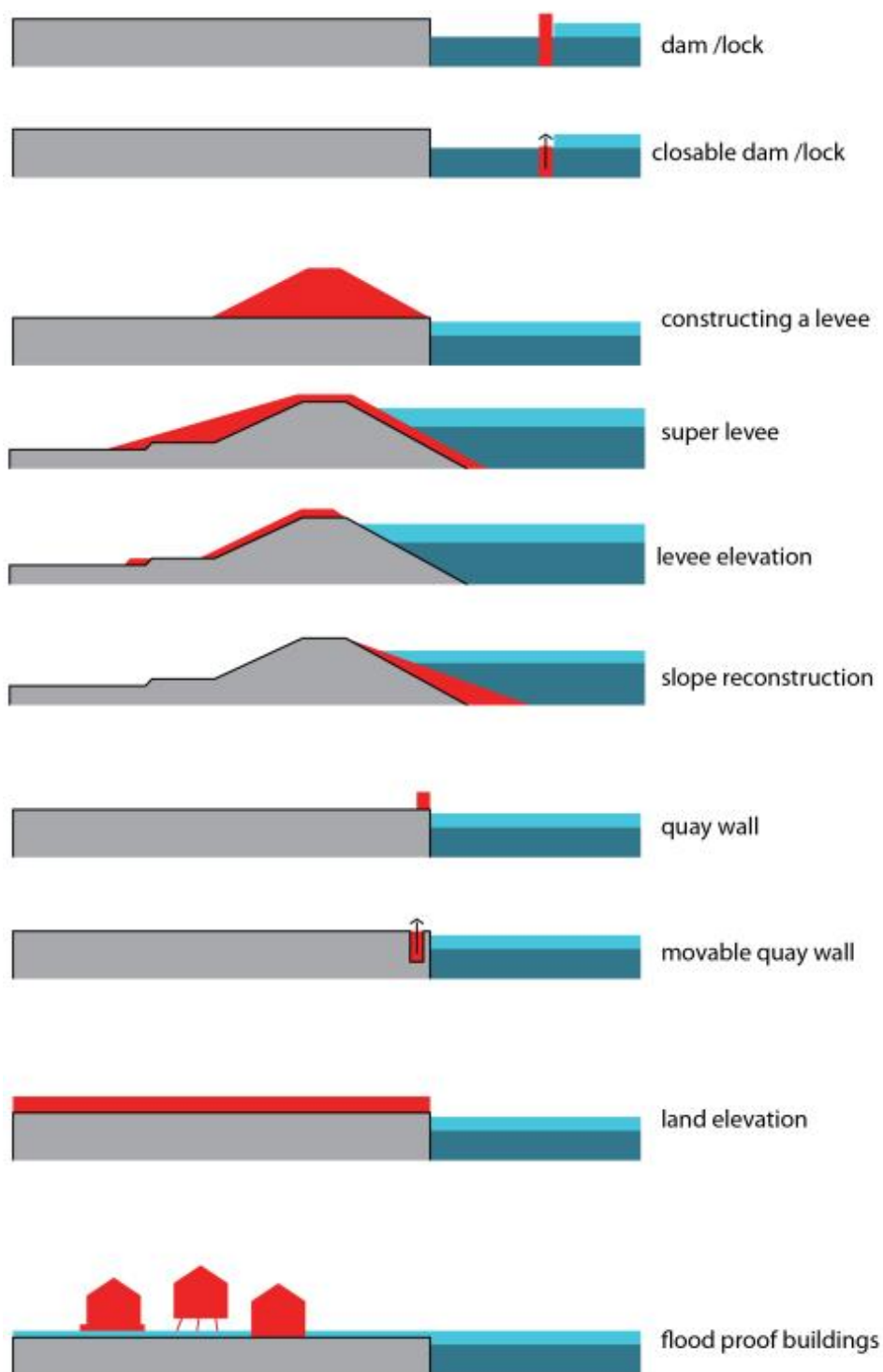


Figure 6.11 Local flood risk management interventions as identified for the Rijnmond-Drechtsteden area

Literature (Gehl et al., 2006, Hooijmeijer et al., 2001) and consultations with the expert panel served as a basis for modifications and extensions to the set of criteria. Some original RKT criteria, such as economic vitality and urban aspects, were removed or combined. Others were re-used.

Thus, the following criteria were adopted:

- Functioning as residential, commercial, recreational or public space
- Accessibility and routing
- Ecological functioning
- Maintainability
- Identity of the location / surroundings
- Recognition of structures
- Cultural recognition
- Spatial recognition
- Diversity / alteration
- Uniqueness
- Logic of spatial arrangement
- Image
- Water-safety experience
- Attractiveness
- Intervention versus location scale
- Relation to the water, reversibility
- Development opportunities
- Multifunctional space utilisation
- Robustness
- Flexibility and durability

... and 10 new criteria were added:

- Future value
- Feasibility of gradual development
- Experience value
- Colour palette
- Uniqueness
- The logic of the spatial arrangement
- Lines of sight
- Identity
- Scale of the local intervention and seasonal attractiveness

The second expert panel meeting concentrated on the application of the improved method on the local scale interventions. To this end, a map of the area, a neutral 3-dimensional sketch (Figure 6.12) and impressions from Google Street View were provided as input. Differences between the current situation and the expected future situation as a result of the strategic alternative at regional scale (cornerstone) and the associated local intervention were described. The local interventions were visualised in cross-sections for each location.

Members of the expert panel shared and explained their selection of relevant criteria and their subsequent evaluations before giving final judgements. Thus, the methodology provided ample opportunity for learning and – where relevant – for revising judgements. The expert panel was asked to reach consensus on the effects of each local water-safety intervention at the end of the evaluation of each location.

In a follow-up to the two expert panel work group sessions, a group of graduate students from Delft University of Technology, Faculty of Architecture, investigated which criteria had negative scores during a workshop. Design concepts for local scale interventions were optimised, as an attempt to neutralise their negative effects.

Location: Stadshavens Rotterdam Mercuriusweg

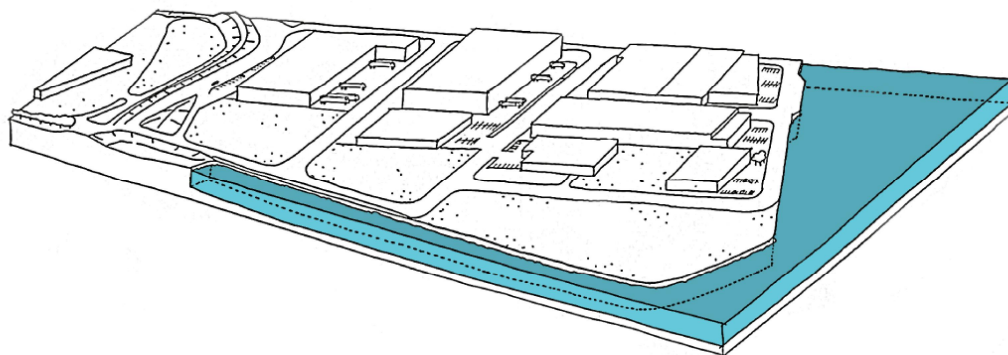
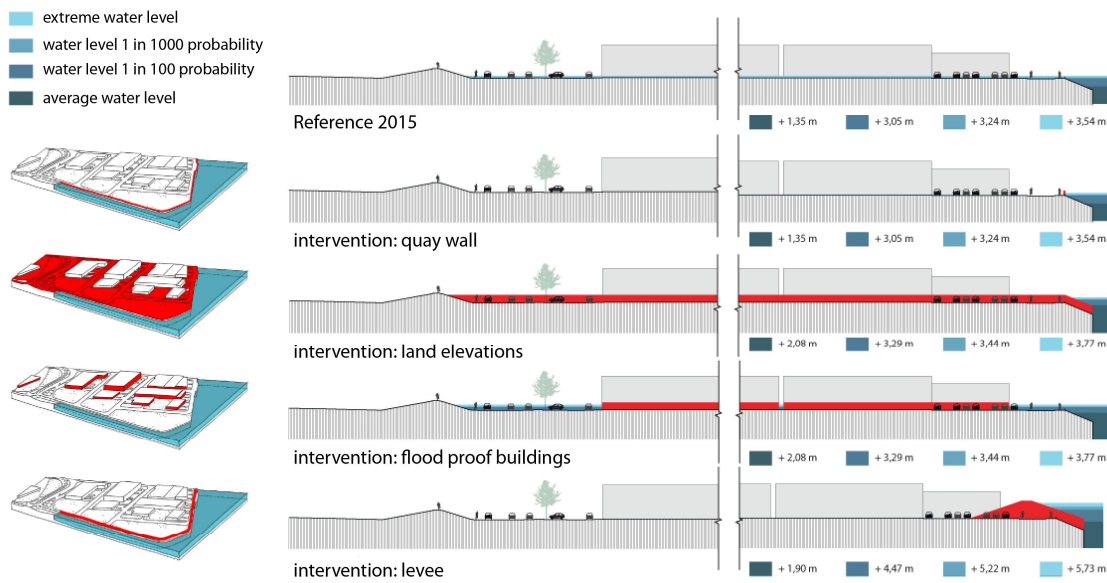
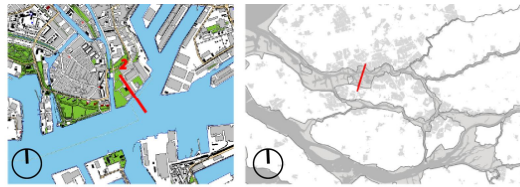


Figure 6.12 Visualisation of alternative interventions for a specific location (in this case Stadshavens Rotterdam, Mercuriusweg): input for the expert panel

6.4.3 Results and discussion

The proposed methodology for the assessment of spatial quality in complex settings has been developed throughout the research period, with a focus on applicability in urban settings. The list with criteria from RKT was amended to enable application in an urban context. During the work group sessions, four criteria were frequently mentioned, indicating their relevance for the Rijnmond-Drechtsteden:

- Direct 'view' on water;
- Opportunities for new water-related living environments;
- Logic of an intervention;
- The scale of an intervention versus the scale of the surroundings.

New visualisations – part of the revised methodology and used in the second work group session – were received as valuable additions.

In general, new or additional local flood protection interventions may enhance the spatial quality of areas that require restructuring, as they offer opportunities for the creation of distinguishable and unique water-related environments. The identity of open water and 'a view on it' are considered important qualities – these criteria frequently received a positive rating for strategic alternatives that require local interventions of up to approximately 0,7 – 1,0 m high in existing built-up areas.

Strategic alternatives that result in higher flood levels and hence would require more extreme local interventions ('*Closable but open*' and '*Closed*'), cannot do without radical reinforcements of the existing embankments, which have a strong relationship with the built environment. This type of intervention received a negative assessment, as its scale does not fit in well with the 'human' scale of the built environment. However, radical reinforcement at a local scale does not always have to be judged negatively; in case of the 'rugged' embankments along the Haringvliet, reinforcements may be of the same scale and character as the surrounding landscape and received a positive assessment. Drastic interventions in built-up area, in contrast, received negative judgements from the expert panel.

Interestingly, the two urban designers judged differently during the work group sessions. This shows how challenging it is to obtain reliable, consistent and objective results that are independent of individual, subjective opinions. As the criteria for measuring spatial quality became the starting points for the design assignment to the architecture students, they easily succeeded in making designs that scored better with respect to spatial quality. Such a design optimisation approach may be worth adding to the assessment methodology in a next phase; this 'research by design' may help with the identification of negative impacts of an intervention that can be neutralised by improving the design by reiteration, in contrast to negative impacts that cannot be mitigated and may be considered unacceptable.

6.4.4 Conclusions

A methodology for spatial quality assessment was presented based on the Ruimtelijke KwaliteitsToets (RKT). The revised methodology has been adapted in such a way as to be more suitable for assessing the impact of large scale flood risk management interventions on local scale spatial quality in an urban delta region. The new methodology allows the

evaluation of large scale interventions in an earlier stage of development, where existing methods require concrete design proposals before being applicable.

After positive trials, we consider this method to be suited for use in the Delta Programme. It is recommended to evaluate a larger number of cross-sections in order to improve its accuracy and applicability. A map should be made that shows the occurrence of specific types of locations throughout the region; this helps to clarify what the locations and cross-sections actually represent. Locations should be compared during the evaluation of strategic alternatives; a decrease in spatial quality may be a bigger problem in one location than in another.

The developed assessment tool will be further used to in the next stage of this research to develop a 'research by design' methodology that allows for an integrated approach to flood risk management and urban design.

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

Robbert Biesbroek

6.5.1 Introduction

Coastal city regions around the world are considered to be vulnerable to the impacts of climate change, more specifically sea level rise and increasing storm surges. Over time, environmental change and human action has battered the resilience of the coastal socio-ecological system and therewith increased vulnerability to flood risks (Adger et al., 2005). Restoring and increasing resilience to flood risk has now become an increasingly popular concept to prepare for and manage the unavoidable climatic changes. Traditional flood measures have focused on resisting the onset and impact of climate change and to continue to function as close to normal. However, if the system collapses, the socio-economic consequences are often (too) high. In addition, the costs of maintaining resistance strategies and preparing for climate change is considered to be unfeasible in the long run. Recent literature suggests that in addition to resistance approach, increasing resilience of systems to deal with uncertain climate change is needed, through incremental or abrupt changes of the system (Pelling, 2010). In this paper we use the concept of flood resilience to describe 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 function shortly after the event, and make certain that failures occur in a controlled way (adapted from Gunderson & Holling (2002)). The flood resilience approach aims to reduce reliability on one system and increase variety and redundancy of interlocking systems. Building resilience requires accepting the inevitability of change and adapting to live with uncertainty and surprise. We refer to 'the system' as the biogeophysical unit of the city region and its associated social actors and institutions that are vulnerable to flood risk.

Key to the concept of resilience is the capability and capacity of these systems to actively and adequately deal with the climate change impacts in the context of urban flood risk. Building resilience of systems therefore 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. In the context of governance, actors can be governments, private actors, businesses, or any other stakeholder.

Building resilience directly links to the duality of structure and flexibility; on the one hand the existing structure of institutions, norms and values that allow for persistence and functioning of the system. On the other hand the need for self-organization, flexibility and variety to allow to deal with uncertain changes in the system. Building resilience requires a variety of governance approaches to increase flexibility within the context of structure and persistence to postpone collapses, and minimize the impacts when failure occurs (Bulkeley & Kern, 2006). Alber & Kern (2009) identify four meta- types of governance approaches:

- *Governing by authority*: the traditional way of top down enforcement of flood management 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 reorganization, institutional innovation and strategic investments within the system of concern.

Although the first three are central to the discussions on flood risk management, flood resilience pays special attention to self-governing. These modes of governance are multi-scale and can refer to horizontal, vertical or diagonal forms of governing flood resilience. In practice, there often is a combination of the four types of modes of governance.

In this section we explore the governance approaches city regions take to increase their flood resilience. To conduct the analysis, we combine resilience thinking with public administration literature and compare how four cities, Rotterdam, London, Venice and New Orleans, have increased flood resilience. First, we present the indicators for the qualitative assessment followed by the method of data gathering, and case selection criteria. The next sub-section presents the results of the comparative analysis. The paper ends with concluding remarks and discussion.

6.5.2 Governance of flood resilience in coastal cities: indicators for assessment

Stressing the differences between the concepts of integrated flood risk management, adaptive water management and flood resilience seem to be primarily semantic; all concepts acknowledge the need for increased flexibility, the shift from protection to prepare, respond and recover, and stress the added value of soft and no regret measures. Different ontological origins have, however, resulted in a slightly different approach to operationalize the concept and indicators for assessment. Where the indicators for flood risk management are often made explicit, resilience theory proves difficult to operationalize.

Berkes & Seixas (2005), who study five extensive studies on socio-ecological systems, identify four categories of variables that are important to consider when studying the building of local resilience: learning to live with change and uncertainty; (2) nurturing diversity for reorganization and renewal; (3) combining different kinds of knowledge; and (4) creating opportunity for self-organization. Wardekker et al., (2010) operationalized the concept of urban flood resilience through the concepts of homeostasis, omnivory, high flux, flatness, buffering, redundancy, foresight and preparedness/planning, compartmentalization, and flexible planning/design. Drawing from resilience and governance literature, Tanner and colleagues (2009) provide a climate resilient urban governance assessment framework and illustrate it by comparing ten Asian cities. They identify (1) decentralization and autonomy, (2) accountability and transparency, (3) responsiveness and flexibility, (4) participation and inclusion and (5) experience and support as key components. We consider the following variables key in qualitatively assessing flood resilience:

- 1 *Decentralisation and self-organisation*: the capacity of the municipality to make decisions and implement them across a range of public and private sectors. This allows cities to respond quickly to environmental change and follow more flexible approaches.

- In addition, this also includes the enabling political environment for self-organisation and self-mobilisation of public and private initiative to increase flood resilience
- 2 *Knowledge systems for flood management:* The availability of, the access to, and legitimacy of data, information, and knowledge on past and future flood events that is regularly updated. This includes projecting future flood risks, for example through scenarios.
 - 3 *Diversity and redundancy:* To increase resilience, dependency on only a few flood measures should be prevented. This category refers to the diversity and redundancy in terms of knowledge production, consideration of alternative problem frames and variety of coping strategies to deal with the flood risk. For example a mixture of grey and green infrastructure combined with soft approaches.
 - 4 *Innovation and experimentation:* Resilience theory argues that innovation is key to building resilience as it enriches the portfolio of ideas, strategies and approaches. Hence, political space for experimentation and innovation is central in increasing flood resilience. This requires political ambitions and leadership for flood resilience.
 - 5 *Responsiveness and flexibility to deal with shocks:* When uncertainties cannot be removed, the system of concern should be flexible to respond to shocks and stresses under different scenarios. Increase flexibility and responsiveness reduces the chance of investment lock-ins and mal-adaptive practices.
 - 6 *Public participation and inclusion:* refers to the inclusion of especially vulnerable citizens in decision making to increase public support, educate, consider tacit knowledge in decision making, and co-create alternative strategies.
 - 7 *Networks, institutions and organizations:* refers to the dedicated formal and informal networks, institutions and organizations to stimulate building flood resilience, remove political and institutional barriers and facilitate multi-level governance (both horizontal and vertical). This includes formal plans, regulations, policies and programs on flood resilience, as well as dedicated organizations that, even when political attention to flood risk is lowering, ensures continuity in building flood resilience.
 - 8 *Capturing learning and utilizing experience:* learning from past events is key in building future resilience. Capturing experiences by building institutional memory and utilizing social memory, creativity, and experiences is central to learn and prepare for future events.

6.5.3 Research methods

Comparative policy methods were used to conduct the analysis. Four coastal cities were selected based on their progress on flood risk, efforts to deal with sea level rise, their difference in governance approaches and, more practically, accessibility to information. The selected case studies are Rotterdam, Venice, London, New Orleans. Based on an adopted set of indicators for building resilience presented above, a research protocol of the key variables was designed to make an inventory of the efforts of building resilience in each of the four cities. Data gathering methods were primarily desk studies (formal policies and plans, websites) supplemented by interviews with key actors. The results were synthesized in the data extraction table for each city. The major similarities and differences in flood resilience are summarized and highlighted in the last sub-section.

6.5.4 Results

Climate Change and Flood risk

All cities acknowledge the growing risk from climate change, sea level rise and land subsidence. Earlier projections of the IPCC estimated a global SLR increase of 18-59 cm by 2055 although other studies have shown more alarming figures. All cities stress the increased probability of storm surges and, in the case of New Orleans, hurricanes.

Selected emission scenario, rate of melting ice sheets and land subsidence show a formidable range of uncertainties in SLR scenarios across cases. Surprisingly, it was often unclear which SLR scenarios would be used to govern flood resilience. For example, the mobile barriers to protect Venice were designed in the 1980ies and copied the safety standards from the Dutch Maeslant Storm Surge Barrier and added 10 cm to adopt higher protection standards (Munaretto, 2011). In all four cases, the current safety standards are being (re)considered under SLR and climate change impacts. London is the only city with a dedicated climate change risk assessment as part of the UK climate change risk assessment in which flood risk is one of the themes (LCCP, 2012).

Building flood resilience

Decentralization and self-organization

Flood risk is national concern in all four countries. Tasks and responsibilities to increase flood resilience are fragmented and distributed across administrative scales. Investing and maintaining the dyke systems in the Netherlands for example is a matter of national concern. All national governments have devoted plans, regulations and guidance to ensure some level of flood protection. However, all four cities have the authority to increase their flood resilience and reduce dependency on national flood defence systems. Local NGOs and citizens groups in all cities have been initiating ideas to increase flood resilience. Several boroughs in London for example have used resources of international programs for example the WWF, and national programs such as the DEFRA funded LIFE project (Long-term Initiatives for Flood-risk Environments) to enable local initiatives. Rotterdam is currently developing their Regional Adaptation Strategy to adapt to the impacts of climate change, which will include a strong focus on local and regional measures to increase flood resilience.

Knowledge systems for flood management

All cities showed some form of collecting information on flood risk and making the information available to a wide range of stakeholders. Several knowledge platforms have been developed in London and Rotterdam to enhance learning across disciplines and exchange ideas and information. London has installed the Dain London forum as mechanism for facilitating knowledge exchange between boroughs. Both cities have strong ties to the research communities allowing for access to state of the art knowledge and information on climate change and flood risk. In addition, this allows them to pioneer with innovative and novel concepts and update their knowledge and information regularly. However, as one interview respondent in Rotterdam mentioned, it proved for policy makers to convince politicians that, due to changes in climate projection, more/other efforts are needed than had been approved earlier. Such mechanisms are being installed in New Orleans, but require substantial transformation in thinking and acting, not only the case for the city region, but for the US in general.

Rotterdam and London have used substantive resources to inform public of the long-term flood risks, through leaflets, brochures, campaigns and internet pages. London, for example, has used social media to collect (new) ideas of citizens to deal with climate change and flood risk. Using a postal code checker, citizens in London can access the flood risk maps and learn about the flood risks. In addition, it provides an overview of the measures taken to reduce this risk.

None of the cities were clear in their long term monitoring approach. Most of these monitoring efforts (for example SLR, increase in storms) are the responsibility of the national governments. For example the KNMI is responsible for long term climate data and monitoring in the Netherlands. City wide initiatives in Rotterdam, such as measuring temperature and precipitation, have only recently started. Forecasts and early warnings of extreme events is more prominent. For example, Venice has the Tidal Forecasting and Early Warning Center, which elaborates a daily tidal forecast bulletin which is available on the internet and locations in the city.

Diversity and redundancy

Resilience concepts suggest that increasing the diversity of coping strategies increases the resilience. All cases show grey infrastructural options such as barriers, levees, floodwalls, gates, floating houses. Rotterdam for example is investigating the option of building dykes that allow for multifunctional use. More recently, efforts include design of green infrastructures, such as sand nourishment, rebuilding of marshes, or additional water retention buffers. For example, the Coastal Protection and Restoration Authority of the State Louisiana is investing on rebuilding the coastal ecosystem as natural buffer to reduce the impacts of future storm surges, see for example the New Orleans Master Plan 2012. Similar things are happening in Venice where the Venice Water Authority is investing in beach and dune reconstruction. The relative newness of ecological design means that projects are just being started. Rotterdam show low variety of coping strategies with large dependency grey and green infrastructure. In contrast, London has an extensive set of soft approaches. Examples include to prepare (appoint lead local flood authorities, local flood management strategies and plans, emphasize individual responsibility, increasing public awareness of flood risk), respond (London strategic flood framework, national guidance reports, mutual aid agreements), recovery (London recovery management protocol to set roles and responsibilities, local recovery plans for boroughs) (GLA, 2009). The city of Venice makes use of soft measures. For example by displaying tidal forecasts and safe exits throughout the city and uses cell phone messages and sirens to inform citizens of extreme events. These soft measures increase redundancy and variety of options, but against relatively low costs.

Innovation and room for experimentation

In 2007, an international commission proposed the city of Rotterdam to invest in becoming a leading innovative city on water knowledge and climate change. This has become one of the prime political ambitions of the city and created room for experimentation with new and innovative projects, such as water squares. The project 'Rotterdam Water City 2035' in which the long-term water vision for Rotterdam was presented, was of key importance (City of Rotterdam, 2005). This political space allowed for failure of the innovation without large consequences as political ambition created persistence to innovate, even after failure. Resources to innovate were provided by the city to ensure the implementation of projects. In return, Rotterdam hopes to capitalize their investments in knowledge and innovation by

exporting expertise to other vulnerable delta cities (City of Rotterdam, 2007). Innovation fits within the Dutch political culture (De Graaf et al., 2011). Political leadership is central in innovation and experimentation to ensure that ambitions are being realized. The previous and current majors of London (Livingston, Johnson), for example, are renowned for their role in setting the climate agenda and allowing for investments in innovative adaptation strategies. The cities of Venice and New Orleans have been much less active in providing room for experimentation and innovation.

Responsiveness and flexibility to deal with flood events

All cities acknowledge that climate change will have severe impacts, but that timing and magnitude of the impacts are, and remain, uncertain. The focus is therefore on accepting the substantive uncertainty and stress the value of acquiring more knowledge to make better decisions (evidence based decision-making). Both Rotterdam and London emphasize the need to start increasing flood resilience, even under substantive uncertainty. Probabilistic modeling is one of the examples London (and the UK) uses in their most recent projection to deal with the substantive uncertainty. Acceptable, tolerable and unacceptable thresholds for risk have been identified and linked to specific flood risk options. Flexible adaptation decision pathways have been identified, both within the city as well as in the Thames Estuary (see the EA initiated TE2100 project)). Responsiveness and flexibility also includes preparedness of citizens to respond through a number of emergency and evacuation plans. The citizens of Venice are already well aware of the flood risk and have become flexible and self-organizing to deal with minor flood events: they place barriers on the front door to prevent water from entering their houses and shops and use pumps; they position valuable belongings to less flood prone areas.

Public participation and inclusion

Various forms of participatory management are discerned in the literature, ranging from informing the public about current activities to co-creation of knowledge between the city and citizens. For example, the flood resilience plans in Venice, London and New Orleans have all been made available for public comments. All cities inform their citizens about climate change and stress the role of participatory management in finding solutions. The more technocratic approach on water management in Venice and New Orleans has limited to inclusion of public actors in decision making. Inclusion requires to increase public awareness. Prior to the Thames barrier, London frequently organized flood drills. With the flood defences and the reduced probability of flooding, Londoners have become oblivious to the risk of flooding. Similarly, citizens in Rotterdam are much less aware of the probability and consequences of floods due to well-functioning flood defence systems, have high trust in government to address flood risk, and few flood events have occurred in the past (Ministry of I&M, 2011). In this respect, Efforts to raise public awareness of flood risk are therefore key in enabling public participation. Recent events in New Orleans and Venice created strong social memory but the cities hardly capitalize when it comes to public inclusion in discussions about future flood prevention.

Table 6.4 Summary of flood resilience governance in four coastal cities

	London	New Orleans	Rotterdam	Venice
Decentralization and self-organization	Strong role for national government; Decentralized municipal authority; stimulate self-organization	Strong central role for national government; increasing self-organizing capacity, but dependency is high	Influenced by national government, but decentralized authority; more ambitious than national government; room for local initiatives	Centralized decision-making; limited local power on flood management decisions
Knowledge systems for flood management	Several knowledge platforms and mechanisms; update knowledge and monitor change; knowledge and information available on websites	Increasing, but still building. Expertise from other countries is used; New Orleans is scientific case to understand resilience/ adaptation	Few knowledge systems; Capitalize on knowledge production and innovation; close cooperation with research community; scientific reports	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.
Diversity and redundancy	Variety of coping strategies, strong focus on infrastructure and soft approaches; follow flood risk management approach	Combination of grey and green infrastructures; efforts to increase diversity of coping strategies	Limited set of coping strategies; reliance on grey and green infrastructures; shift towards more adaptive water management	Dependency on grey and green infrastructural measures. Low diversity and redundancy
Innovation and room for experimentation	Much room for experimentation, stimulated by political leadership; resources available	Generally low, use knowledge and expertise from other cities/countries. Recovery stage	Strong focus on innovation; capitalize on knowledge production	Little room for experimentation; mostly use high level technical knowledge is produced locally
Responsiveness and flexibility to deal with flood events	Flexible decision approach; emphasis on preparedness, response and recovery	Improvements to responsiveness are being made, but focus is on protection / structures.	Tipping point and flexible adaptation options approach advocated but not implemented; low flexibility to deal with events	Flexibility to small floods is high, but large flooding events is low as there is only one rigid solution (mobile barriers)
Public participation and inclusion	Public inclusion is average, but efforts are made to increase; public awareness of flood risk is low.	Limited public participation; top-down decision making	Public inclusion and participation is average; public awareness of flood risk is low	Public consultation rather than public involvement in decision making; through NGO's
Networks, institutions and organizations	Fragmented and complex fabric of flood related networks and institutions; high redundancy in the system	Increasing number of institutions and organizations involved.	Flood risk part of Rotterdam Climate Proof initiative; Important role in international water city networks	Several institutions in place, but hardly the capacity to prepare for major flood events (lack of coordination)
Capturing learning and utilizing experience	Few flood events, mechanisms to capture learning from past events	Katrina as example of catastrophe; several projects designed to capture learning events; experience is not used to change to alternative states	History on flood protection/water management; learning mechanisms not present	Frequent flood events increase public awareness

Networks, institutions and organizations

All cities show a tightly knit network of organizations and institutions dedicated to flood risk management operating at a range of scales. All cities embrace the notion of multi-level governance, but flood risk responsibilities are fragmented across administrative scales. In all cases, national government plays a pivotal role in building and monitoring progress on flood resilience. The network of organizations, institutions, plans and policies in London increases redundancy of the system but at the same time it fragments and blurs the responsibility of actors in responding to flood risk. For example, boroughs in London are designated as 'lead local flood authorities' under the national Flood and Water Management Act and have to produce flood risk management plans. In addition, there are many city level reports and guidance, such as the London Strategic flood framework, and the London Climate Change Adaptation strategy that add to the complex fabric of institutions already present at regional and national scale. It requires substantial knowledge and resources to update and coordinate these efforts. All four cities are (well) connected to larger networks of cities, such as the Delta Alliance (Rotterdam), to exchange knowledge and expertise.

Capturing learning and utilizing experience

All case studies show some form of learning from past crisis and, resultantly, are informed about possible future events. Although pluvial flooding in London occurs several times a year, other types of flooding have had limited impact on London. Flood events throughout the UK have propelled public awareness and several governmental monitoring and evaluation mechanisms have been installed to capture learning from flood events. Dealing with flood risk is nothing new – much knowledge and experience has already been developed to deal with extreme weather events and natural disasters. Traditional water management in the Netherlands has protected the country for centuries and is one of the key export products. Near flood events in the Netherlands (1995) changed the water management approach in the Netherlands from 'fighting against water' to 'making space for water' (Van Stokkom et al., 2005). Transition in water management has become visible in the flood resilience approach in Rotterdam by taking an integrated rather than a sector approach to flood risk management. Rotterdam build their strategy based on the collective idea of Rotterdam being a port and the historic link between water and prosperity. However, like in London, crises have been limited – the Dutch Delta Committee explicitly refers to the 1953 flood disaster as possible image of the future. Impacts of hurricane Katrina in New Orleans has propelled discussions on flood resilience throughout the USA; several projects have been installed to capture the learning experiences from these disastrous events. Although changes towards more flood resilient cities have been promoted, this has not yet resulted in major regime changes.

6.5.5 Concluding discussion

Flood resilience is gaining increased attention, both scholarly and political. In this short paper we compared the efforts of four cities to increase their flood resilience. Although our aim is not to value judge whether one city is more flood resilient than others, some remarks can be made about the results.

First, the cities show different modes of governing flood resilience. The city of 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 city aims to remove any barriers to create an enabling environment. The role of government in Rotterdam is much

stronger – primarily through enabling and provision. Cities of Venice and New Orleans are governing 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. One could hypothesize that multiple modes of governance is needed to build flood resilience.

Literature suggests that resilience alone might not be sufficient as this implies conservation of existing systems. Fundamental governance changes could be needed to ensure long-term flood risk management under changing social and environmental conditions. Pelling (2010) identifies two forms of change: transformative change (occurs mostly after an event has taken place) and incremental change (smooth and predictable shifts). In contrast to the concept of resilience, this refers to shifts in perceptions and meanings, organizational and institutional arrangements, changing patterns of interactions and network configurations towards alternative states. Although Rotterdam and London have both taken considerable steps in changing their flood risk management approach, transitions or transformations have not been identified in this study. 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, which both prepare for more extreme SLR/climate change scenarios. The reliance on more traditional flood risk management approaches in New Orleans and Venice is only slowly changing.

Although all cities show their willingness to increase resilience, major differences in the comparison can be observed. Only London was found to have invested heavily on resilience (from flood protection to recovery), particularly through soft en low regret measures. The city of Rotterdam invests primarily on knowledge production and innovation by working closely to the scientific community, but primarily in the area of grey and green infrastructures. Here, soft approaches are limited and redundancy and public participation is generally low compared to London. Although willingness of Venice and New Orleans to change towards alternative modes of governance of flood resilience might be considerable, there are only few signs of such incremental change. Resilience approaches in New Orleans and Venice are in early stages of development.

Bottom-up initiatives, decentralization, and self-organizing are central concepts in resilience theory, but all national governments are found 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. This is currently weakly developed in New Orleans and Venice. Public awareness of flood risk is low in the cities that experience few floods but emphasize flood resilience, and high in cities where floods (have) occurred more frequently but where resilience is generally lower.

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7 Project publications

7.1 Consortium publications: state of affairs mid 2012

7.1.1 Articles in scientific journals

- Bubeck, P., H. de Moel, L.M. Bouwer, J.C.J.H. Aerts, 2011. How reliable are projections of future flood damage? *Natural Hazards and Earth System Sciences* 11, 3293-3306.
- Jongman, B., H. Kreibich, P.D. Bates, A.P.J. de Roo, J.I. Barredo, A. Gericke, H. Apel, J. Neal, J.C.J.H. Aerts, and P.J. Ward. (in prep.). *Comparative flood damage model assessment: Towards a European approach*
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- Ruijgh-Van der Ploeg, T., Ebskamp, M., Mens, M., Kwakkel, J., (in prep.). Exploratory modeling in support of robust policies for flood risk management
- Sebastiaan M. Arens, Jan P.M. Mulder, Quirinus L. Slings, Luc H.W.T. Geelen & Petra Damsma, (submitted), Dynamic dune management, integrating objectives of nature development and coastal safety; examples from the Netherlands. *Geomorphology*

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7.1.2 Articles in professional journals and magazines

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7.1.5 Reports

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- 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.

7.1.7 Lectures and oral presentations

- Aerts, J.C.J.H., 2011. Debat Waterveiligheid (KIVI-NIRIA op 27 januari 2011 te Utrecht.
- Groot de, A., 18 Oktober 2011, Modelling coastal dune formation. The biogeomorphological interplay between sand, sea and vegetation. Invited talk, NIOO-CEME, Yerseke, Netherlands.
- Groot de, A., 21 – 25 November 2011, Two ecosystem engineers in young dunes. Coastal Ecology Workshop, Hingene, Belgium.
- Gualdi S. and Natasha Marinova, 30/09/2010, Recent Sea level rise scenarios for Venice, "Deltas in time of change" conference, Rotterdam
- Jongman, B., P.J. Ward and J.C.J.H. Aerts. 2011. Global exposure to river and coastal flooding – long term trends and changes. *Presentation at ICFM5, Tokyo, Japan.*
- Keijsers, J., Riksen, M., (2011), Predicting coastal dune accretion rates for Ameland, The Netherlands (Research proposal). Presentatie op EGU (European Geosciences Union) Assembly in Wenen, 5 april 2011
- Keijsers, J., Riksen, M., 11-10-2010. Coastal defense under climate change. Bijeenkomst Centrum Bodem, Wageningen University.
- 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 Deltaprogramma. 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, 24 november 2011. Medegebruik van dijk(zones): vanwege ruimtegebrek en voor draagvlak. Presentatie tijdens Studiedag Dijken voor de Toekomst.
- 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, Presentatie 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, Presentatie rapport Kweldervorming langs de Terschellinger Waddendijk; Bijeenkomst begeleidingsgroep Gebiedsontwikkeling Terschelling (27 april 2011 Terschelling)
- Loon-Steensma van J.L., 29 juni 2010: 'Multifunctionele, klimaatrobuuste waterkeringszones' tijdens de 'Schetsschuit Groninger Waddendijken' (Waddenvereniging te Westernieland).
- 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)
- Moel de H., R. Lasage, 2011. Adaptation Planning and Practices: The Netherlands, climate change and adaptation. *Lecture for the NRDC3 delegation*. Venice International University, Italy. (Invited)
- Moel de H., 2011. Flood risk and climate change adaptation in the Netherlands. *Public lecture at RMIT University, Melbourne, Australia*.
- Moel de H., L.M. Bouwer, J.C.J.H. Aerts, 2011. Uncertainty and sensitivity of flood damage modelling. *Presentation at ICFM5, Tokyo, Japan*.
- Mulder J.P.M. & J. Stronkhorst, 20 oktober 2011. "Large scale nourishment strategy in the Netherlands- a systems approach". ASBPA conferentie New Orleans
- Mulder, J.P.M. & J. van Dalzen, 22 augustus 2011. "Current challenges in coastal management of the Netherlands; examples of pilot projects", , COPRI conferentie, San Diego
- Mulder, J.P.M. 1 september 2011 . Sedimentperspectief op de kust, samen werken met sediment, Atelier Kustkwaliteit 'De toekomst van het stille kustlandschap', Den Haag
- 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
- Mulder, J.P.M. oktober 2011, Nut en Noodzaak Meegroeiën Kustfundament, Deltares report 1204595-000, 37 pp.
- Nillesen, A. L. (August 2011). *The integration of flood risk strategies in urban design*. Colloquium for Flood Risk Management and Hydraulic Structures, Delft, The Netherlands.
- Nillesen, A.L., 14 april 2011. Presentatie effecten en kansen hoekpunt gesloten voor stedenbouwkundige aspecten. Atelier Rijnmond-Drechtsteden, Rotterdam.
- Nillesen, A.L., Mei 2011, Multifunctionele waterkeringen in de stedelijke omgeving, PAO-cursus Moderne Aspecten Waterveiligheid, Delft.
- Penning-Rowse 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., 1 september 2011. Lezing 'SimDelta' voor RWS- Waterdienst en Deltares – Utrecht,
- Rijcken T., 20 juli 2011. Lezing: Interactive models/Serious Gaming in water infrastructure development in the Netherlands - RESIN group UC, Berkeley, USA,
- 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 Pavillion 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., december 2011. "The Great Eastern Japan earthquake and tsunami: facts and implications for flood risk management". Oral presentation at the Flood Risk colloquium of TU Delft.

- Tsimopoulou, V., November 2011. "Probabilistic design of breakwaters in shallow hurricane prone areas". Oral presentation at the Coastal Management conference (Belfast, UK).
- 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
- Ward, P., Aerts J.C.J.H., Hurk B.J.J.M. van den, Keizer O. de, S.C. van Pelt, 2011. Flood risk estimation using probabilistic climate change scenarios. *Presentation at ICFM5, Tokyo, Japan.*
- Ward, P.J., Marfai, M.A., Pauw, W.P., Bonte, R., Elings, C., Poerbandono, R., Hizbaron, D.R., Yulianto, F., Julian, M.M. (2010). Flood risk management in Jakarta. Deltas in Times of Climate Change International Conference, 30 Sept 2010. Rotterdam, The Netherlands. IVM
- Ward, P.J., Pauw, W.P, Van Buuren, A.W., Marfai, M.A., 2010. A tale of two cities: Governance lessons for flood risk management in a time of climate change - the cases of Jakarta and Rotterdam. PAD symposium on climate change adaptation in delta cities. Oral presentation. City University of Hong Kong, Hong Kong, 8-9 July 2010

7.1.8 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
- Dinsdag 1 februari 2012, 20.55 – 21.25, Labyrint, VPRO Ned3 + online live 'Labyrint napraatsessie' 21.25 – 22.00 uur op www.labyrint.nl.
- Ward, P.J., 2010. Banjir terkait perubahan iklim, Kedaulatan Rakyat (Indonesian newspaper), 27 October 2011, <http://www.kr.co.id/web///detail.php?sid=227808&actmenu=37>



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