NEW, RISK-BASED STANDARDS FOR FLOOD PROTECTION IN THE NETHERLANDS

H. van der Most[1], I. Tánczos[2], K.M. de Bruijn[1], D. Wagenaar[1]
1. Deltares
2. Ministry of Infrastructure and Environment, Rijkswaterstaat Agency

ABSTRACT: The standards for flood protection in The Netherlands are being revised within the framework of the Delta Programme. The revision of standards includes a re-evaluation of the existing flood protection system. This flood protection system is based on so called dike rings, a set of embankments, dunes and structures that form a closed ring. A risk approach is being adopted to strengthen the coherence in the requirements on the flood or failure probability of various parts of the flood protection system.

The new standards will better reflect the expected consequences in case of flooding due to a dike breach. This implies amongst other more differentiation in requirements on flood or failure probability of dikes and hydraulic structures (on a smaller scale than the existing rings). The height of the standards will be based on the individual risk of becoming a victim of flooding ('basic safety'), the societal disruption due to large scale flooding and the economic efficiency of investments in flood protection. To support the development of new flood protection standards both an analysis of casualty risk and a cost benefit analysis have been carried out.

The paper addresses at first the principles guiding the development of new standards. Next it is discussed how these principles have been operationalized making use of the methods and data of the casualty risk and cost benefit analyses. Different principles pose different requirements; the paper describes how these different requirements have been integrated to obtain the provisional standards being presented in this paper. Finally, the paper provides an outlook into the implementation of new flood protection standards.

Keywords: risk approach, flood protection standards, Netherlands, economic efficiency, basic safety

1. INTRODUCTION

The Netherlands is vulnerable to flooding from the sea and the large rivers which cross the country. To protect the country against flooding a flood protection system has been developed based on so called dike rings, a set of dikes/embankments, dunes and structures that form a closed ring. In addition to these embankments there are dams and barriers in rivers and estuaries which limit water levels and wave heights under extreme conditions. Thanks to these structures, the hydraulic loads on embankments located behind the dams and barriers will be reduced. The layout of the Dutch flood protection system is shown in Figure 1.

A system of legal flood protection standards was developed to design and maintain the flood protection system. The current standards were proposed by the Delta Committee following the major flood of 1953, which struck the south-western delta of The Netherlands. The standards were derived based on an economic optimization of investment costs and the benefits of damage reduction. The standards were defined as the frequency of exceedance of the design water level for the dikes surrounding the dike ring areas (Van der Most , 2011).

The growth in population and assets to be protected since the 1950/60's call for a revision of the current flood protection standards. There are also new insights in the consequences of flooding to be taken into account. The current standards in The Netherlands are being revised within the framework of the Dutch Delta Programme (Van Alphen et al, 2014). This process did start In 2006/2007 with the policy project 'Flood Protection 21st Century' (WV21-studies) and will result in a so-called Delta decision on flood risk management in 2014. The development of new standards takes into account climate change and economic development.

Figure 1 Layout of the Dutch flood protection system

2. TOWARDS A NEW FLOOD PROTECTION POLICY

2.1 Principles in flood protection policy.

The update of the flood protection policy is guided by three principles as set forth in 2013 in a letter to Parliament by the Minister of Infrastructure and Environment. The wider policy of flood risk management is described in Van Alphen et al (2014). The focus of the current paper is on flood protection standards to control the probability of flooding from the national perspective. Regional flood risk management strategies are described in Kind et at (2014) and Schielen et al (2014). The Deltamodel was used to assess the hydraulic impacts of these strategies on design flood levels (Slomp et al, 2014).

The new standards will take into account:

- A basic level of safety for everyone living behind dikes, to be achieved by enhancing the safety in areas with relatively large individual risks. This principle assumes that arrangements for emergency management are in order, such that opportunities for evacuation to reduce casualty risk will be seized.
- Societal disruption due to large scale flooding. Large groups of casualties or extensive economic damage due to large scale floods, may disrupt the Netherlands' society for a long period. To counteract societal disruption, investments in protection will be made for areas, which may experience large groups of casualties and/or economic damages. These investments are in addition to those needed to provide basic safety.
- Protection of vital and vulnerable infrastructure. Special attention will be required for the impacts of flooding on certain utilities, hospitals etc., as this infrastructure is of vital importance for the functioning of an area during and after the flood.

Analysis of casualty risk and cost benefit analysis have been carried out to support the development of new flood protection standards. First findings from the WV21-studies were reported to parliament in 2011 (Beckers et al, 2011 and Kind, 2013). The methods and findings of these studies were further elaborated within the framework of the Delta Programme.

2.2 Revision of type of standard

The current standards are expressed in the exceedance probability of extreme conditions which embankments should be able to withstand safely. New standards will be expressed in the probability of flooding. This change in type of standard offers a number of advantages:

- The flood probability constitutes a better approximation of the 'real' probability of flooding, and as such is better suited to a direct application in a risk analysis.
- Dikes may fail in many ways. Standards expressed in flood probabilities offer a common denominator to integrate the impact of various failure mechanisms on the functioning of the flood protection system.
- A standard expressed as flood probability better matches the intuitive understanding of people of the probability of flooding. The current standards are often erroneously interpreted as flood probabilities, whereas these in fact represent extreme conditions embankments should be able to cope with.

The current standards include uniform requirements for dikes and structures within a dike ring. New standards, based on a risk approach, aim to better reflect the differences in expected consequences of flooding due to a dike breach. To this end requirements on flood probability of dikes and hydraulic structures are defined on dike sections, a bit smaller scale than the existing dike rings. The choice for dike sections as the spatial unit for the new standards was announced in the letter of the Minister of Infrastructure and Environment of 2013 to parliament.

2.3 Assessing flood risk using simulations of flood scenarios

The development of new flood protection standards is based on a quantitative assessment of flood risk. Ample use has been made of simulations of flood scenarios as developed in the VNK2-project (Jongejan et al, 2011). The number of casualties and economic damages were derived from the outcomes of these simulations making use of damage and mortality functions. Assessment of casualty risk takes into account the possibilities of preventive evacuation (Beckers et al, 2011). The evacuation fraction is regionally differentiated with relative small fraction in the western coastal part of the country and larger values in the riverine part.

The VNK2-projects also provides assessments of the flood probability of dike rings for the current situation. These assessment were the basis for definition of the reference situation, which also takes into account the impact of current flood protection programmes on the flood probability.

3. ELABORATION OF FLOOD PROTECTION PRINCIPLES

New flood protection standards will be based on the individual risk of becoming a victim of flooding ('basic safety'), the societal disruption due to large scale flooding and the economic efficiency of investments in flood protection. The next sections describe how these principles have been made operational to establish requirements on the maximum allowable probability of flooding.

3.1 Requirements from perspective of basic safety

The Local Individual Risk (LIR) has been used to derive requirements on the probability of flooding from the perspective of basic safety. The LIR has been defined as the probability per year to die at a certain location due to flooding, taking into account evacuation possibilities. It is in fact the product of flood probability, the percentage of people present at the onset of flooding and the mortality. The values of LIR have been mapped based on information on flood probabilities, available flood simulations and estimates of evacuation fractions. Relatively large values of the local individual risk are particularly found in the riverine area as well as in parts of the South western delta and the North part of the country (see also Figure 3).

To comply with requirements of basic safety, the local individual risk should not exceed the value of 10^{-5} per year (1 in 100.000 years). This threshold value has been defined in a motion of parliament in response to the outcome of the first analysis of casualty risk (the so-called WV21-studies). Based on this threshold value the maximum allowable flood probability can be determined, given the evacuation fraction and the mortality. Most severe requirements from the perspective of basis safety are found in the riverine area and parts of the South western delta. It often pertains to small compartments which, in case of a flood, will experience a large mortality due to a high rate of water level rise. Severe requirements are also found for dike sections within the province of South Holland

3.2 Requirements from perspective of economic efficiency of investments

The economic optimal level of protection is based on a societal cost benefit analysis, as developed in the WV21-studies. The cost benefit analysis focuses on the economic efficiency of investments in improving the water defences [Kind et al., 2013]. The method searches for an economically optimal investment strategy in which the sum of investments and expected damages is minimised. Damages include both material and immaterial damages. Loss of life has been valued in monetary terms. The approach of economic optimisation, originally developed by the Delta Committee has been further developed into a dynamic optimisation model, taking into account the impacts of economic development and climate change. Economic optimal flood probabilities are derived from the investment strategy.
The ratio of economic damage due to flooding and the costs to reduce the failure probability of embankments turns out to be a good predictor of the economic optimal protection level. So, in most analyses use is made of the so-called 'Direct method' (Gauderis et al, 2013), which offers a good approximation of the' formal' optimisation model.

Severe requirements from the perspective of economic efficiency are found again for dike sections in the riverine area and the provinces of South Holland and Flevoland. The economically optimal flood probabilities show much more regional variation as compared to the current standards. This variation is due to the large differences in costs, damages and number of casualties among the dike rings and dike sections. The general 'expectation' that current standards would be (much) too low in most dike rings is not supported by the cost benefit analysis. For a large part of the dike rings strengthening of the current standards could be considerably less than the factor 10 that was recommended by the second Delta Committee in its report of September 2008 (Delta Committee, 2008).

3.3 Requirements from perspective of group risk

From a societal point of view it is relevant to look at the probability of a large number of casualties in one flood event. One flood event with a large number of casualties has a larger societal impact than a number of smaller incidents with the same total number of casualties. This aspect is reflected in the so-called group risk (Beckers et al, 2011). The group risk depends on the flood probabilities of the different dike sections, the expected number of casualties in case of a flood event and the dependencies between flood probabilities. To quantify group risk a dedicated tool was developed for the riverine area which takes into account correlation in loads and the system behaviour of the river system (De Bruijn et al., 2014)

The calculated group risk is presented through a so-called FN-curve. The FN-curve shows in one graph the probability of having more than 10, 100, 1000 of 10,000 casualties due to one flood event. The acceptability of group risk is evaluated, based on an evaluation framework proposed by the former Technical Advisory Committee for Water Defences (Vrijling et al., 1998). This evaluation framework includes risk aversion, as adopted in the evaluation of group risk in the domain of external safety.

The group risk comprises a performance target on the national level. Such national target leaves much freedom in how the target will be met. To define requirements from the perspective of groups risk various lines of reasoning have been elaborated. These analyses show that the largest contributions to the national group risk mainly come from a couple of dike sections in the downstream (tidal) part of the riverine area (Rotterdam area).

4. FROM PRINCIPLES TO STANDARDS FOR FLOOD PROTECTION

4.1 Integrating and standardizing the requirements from different perspectives

Different perspectives pose different requirements on the maximum allowable flood probability per dike section. The derived standards are based on the requirements from the perspectives of basic safety and economic efficiency. The perspective of group risk poses additional requirements for only a few dike sections. In deriving flood protection standards for each section the perspective with the most severe requirements is guiding. For most sections the requirements from economic efficiency are more demanding than those from basic safety.

The calculated requirements have been standardized using classes. A rather robust classification has been adopted in which a difference with a factor 10 has been subdivided into two classes. So an order of magnitude difference between 1/1000 and 1/10.000 is subdivided with an intermediate boundary of 1/3000. All calculated requirements have been assigned a particular class; the resulting standards are shown in Figure 2.

The most severe requirements in terms of allowable flood probability per dike section are found in the riverine areas, the South western delta and the provinces of South-Holland and Flevoland. In the South western delta the level of the standards is mainly determined by the requirements from basic safety, whereas for the other areas the high level standards are mainly driven by economic efficiency.

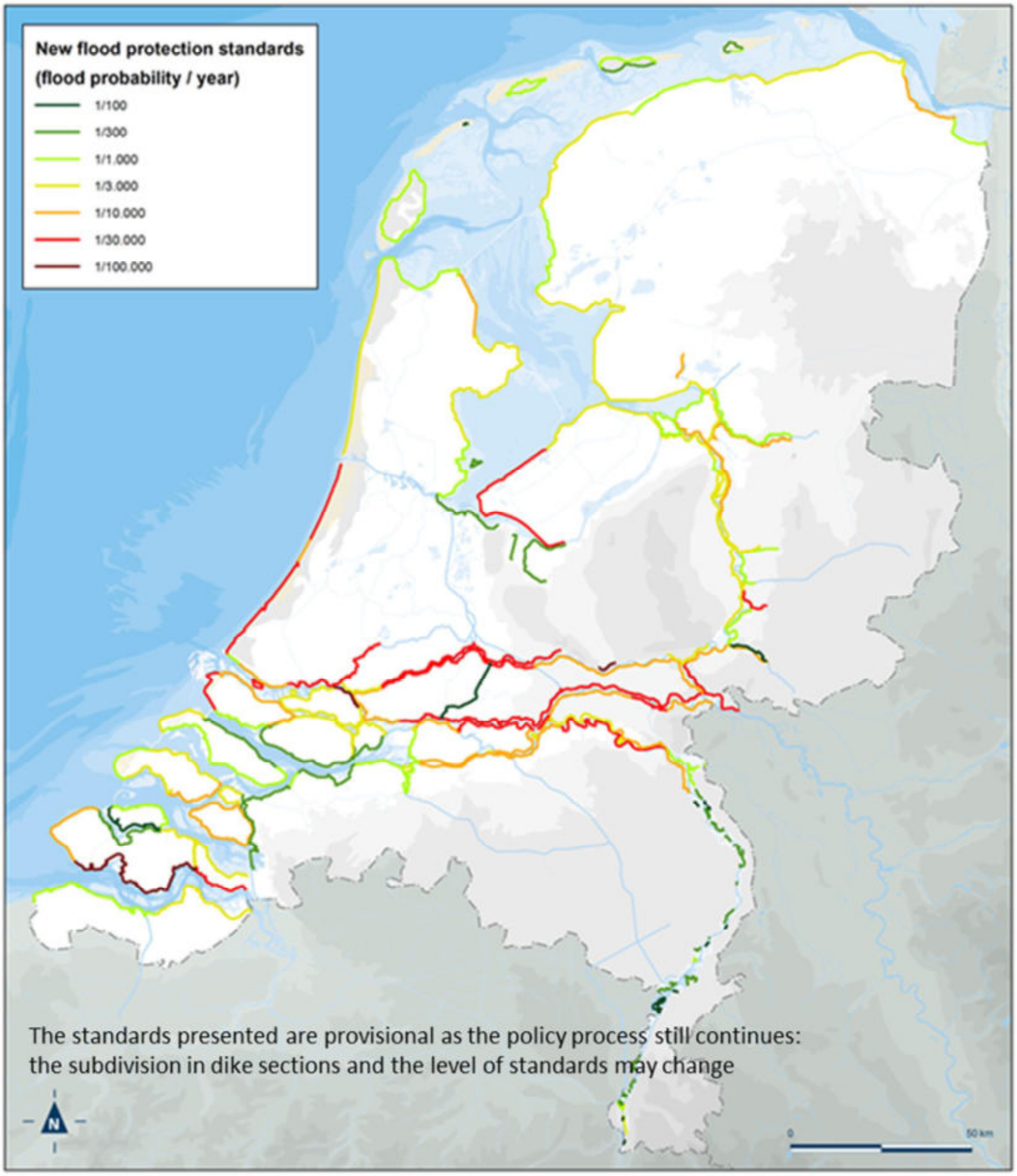

Figure 2 Protection levels based on basic safety and economic efficiency (by dike section)

4.2 Impacts of implementation of new standards

Implementation of new standards will result in a considerable reduction of both casualty risk and economic risk, as compared to the risk of the reference situation. The reference situation being defined as the expected flood probabilities per dike section after completion of the current flood protection programmes.

Figure 3 shows the local individual risk. In the reference situation there are large areas where a threshold value of 10^{-5} per year is exceeded (orange colour). After implementation of new standards all areas comply to the threshold value for basic safety. Compared to the reference situation, also large areas with

LIR-values in between 10^{-5} and 10^{-6} per year (yellow colour) have shifted to LIR-values smaller than 10^{-6} per year (green colour).

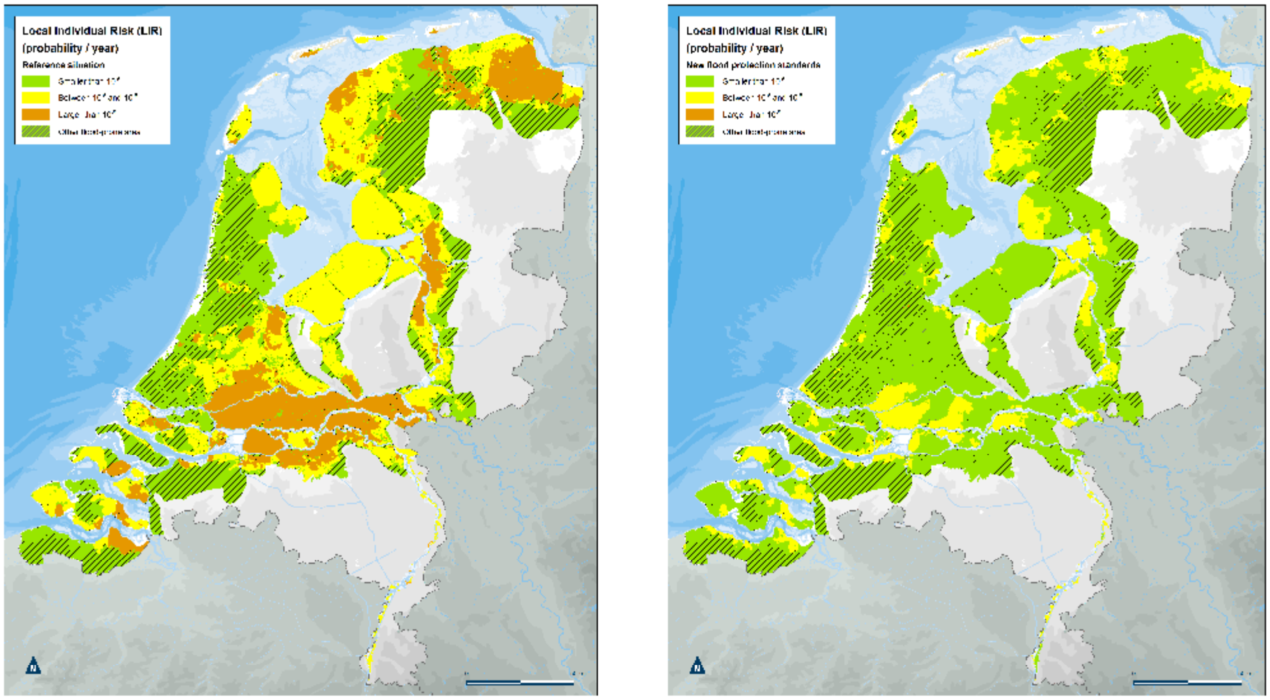

Figure 3 Local individual risk for both the reference situation (left) and the new standards (right)

Also the economic risk shows a very substantial reduction. In the reference situation there are quite a few dike sections with a large economic risk. In defining requirements from the point of view of economic efficiency, sections with large damages have been assigned (very) low flood probabilities. As a consequence the economic risk of dike sections are much more equalized.

5. MAXIMUM ALLOWABLE FAILURE PROBABILITIES OF DAMS AND BARRIERS

Apart from the embankments and dunes directly protecting the adjacent land, the flood protection system consists of dams and barriers in rivers and estuaries. These structures have been build to attenuate the dynamics of both water levels and waves behind the dams and barriers to reduce the hydraulic loads on the embankments. In most situations the length of embankments behind a dam or barrier is much larger than the length of the dam or barrier itself. So, it is normally most efficient to build (or reinforce) dams and barriers in such a way that the failure probability of dams or barriers does not have a significant effect on the hydraulic loads for the embankments behind the dam/barrier.

The current rule that the dam should have a standard equal to the embankment behind the dam with the most severe standard, provides a reasonable first approximation. However, the rule requires adaptation, as the standards for the embankments are no longer expressed in probability of exceedance of extreme water levels, but in the probability of flooding. For most dams or barriers a similar approach was adopted as for the economic optimal flood probability of embankments; it means deriving a flood or failure probability based on the ratio of economic damages and the costs for improvement. For movable barriers and dams which close off large water bodies another approach is required.

For movable barriers it is generally not feasible to limit the failure probability to such an extent that its impact on the hinterland is negligible. Especially the probability of non-closure may be hard to reduce. It means that the failure probability of the barrier should be incorporated in determining the hydraulic boundary conditions for the embankments behind the barrier. This is in fact current practice for a number of the major barriers.

There are a few dams which close off large water bodies, i.e, the Afsluitdijk (Closure dam) which separates Lake IJssel from the Wadden Sea and the Houtribdijk which separates Lake Marken from Lake IJssel. These dams require a different approach. For these dams the buffering capacity of the large water body will dampen the impact of failure probability on the hydraulic loads on the embankments. The requirements on failure probabilities for these dams have been derived from an assessment of the hydraulic functioning of the system.

The available data on the failure probability of dams and barriers is rather limited. The existing failure probability is not known for most dams and barriers; the same is true for the consequences of failure. So, a semi-quantitative approach was adopted to assess requirements on failure probabilities. The result of the approach is a range for required flood probabilities. This range can be used in the evaluation of the structural integrity of dams and barriers. If evaluation shows that the dam/barrier does not comply with the standards, the next step should be a full-fledged cost benefit and risk analysis.

6. IMPLEMENTATION OF NEW FLOOD PROTECTION STANDARDS: AN OUTLOOK

The new flood protection standards will be future oriented: all areas should meet the required protection levels around 2050. The transition to the new standards for flood protection will require the development of new tools for assessment and design of water defences. The periodic safety assessment as prescribed by law has to be adapted to the new standards. Where the present system gives a more or less binary outcome (the dike passes the test or not), the new system will allow for a more gradual evaluation also providing insight into the accuracy or significance of the outcome of the evaluation. This outcome can subsequently be used to assess the urgency of flood protection measures. A special programme (WTI2017) is being executed to develop the methods and tools for the new safety assessment.

Design of water defences in the Netherlands is as yet strongly based on so-called design water levels including wave action. When designing to achieve a certain flood probability more aspects have to be taken into account. This gives more freedom to shape flood protection measures; it will also require more choices to be made. The design process should be supported by appropriate tools. The design process should include a proper risk analysis which will provide insight into the contribution of different parts and failure mechanisms to the total flood probability of the dike section

Although current regulations allow for implementation of innovative dike concepts, actual implementation may be hampered by the perception that the existing regulations are not apt for the evaluation of the feasibility and robustness of such innovations. The new system will provide better opportunities to implement innovative concepts as it gives more freedom to the designer. The performance of the innovative water defences can be evaluated through a risk analysis. The findings of such risk analysis – the contribution to the flood probability of the dike section - can be more easily integrated with the evaluation of other dikes and structures within the section.

With every transition there will have to be a transition period that allows for the adaptation to the new system. The results of the last 'old' safety assessment may not be valid according to the new standards and will require updating. Also adaptations will be needed in the process of issuing permits for developments in the riverbed or on the embankments. Up and till now the decision to grant a permit or not, depends on the effect of the developments on the design water level. In a system with new flood protection standards the criteria for issuing permits will need to be adapted.

In developing new flood protection standards, the Netherlands do no react to a flood disaster. Instead the flood protection standards give direction and focus to adaptation of the flood protection system to future developments. Such future oriented standards offer flexibility to tune dike reinforcement to the life cycle of flood defences. Starting with the riskiest places, the new standards may be met in an economic efficient way and will result in a more evenly distributed risk level. The new flood protection standards will be part of the so-called 'Delta decision' on flood risk management which will be submitted to Parliament in 2014.

REFERENCES

Alphen, J. van, *The Delta Programme and updated flood risk management policies in the Netherlands*. 6th International Conference on Flood Management (ICFM6), September 2014, Sao Paulo, Brazil (in prep.)

Beckers, J.V.L., D. Riedstra & K.M. de Bruijn. *Use of loss-of-life risk criteria for flood protection standards.* 5th International Conference on Flood Management (ICFM5), 27-29 September 2011, Tokyo-Japan

De Bruijn, K. M., F. Diermanse and H. van der Most. *Societal flood risk assessments: an advanced probabilistic method and its application to the Rhine-Meuse delta*. . 6th International Conference on Flood Management (ICFM6), September 2014, Sao Paulo, Brazil (in prep.)

Deltacommissie (2008), Working together with water, A living land builds for its future, Findings of the Deltacommissie 2008, September 2008, The Hague, The Netherlands.

Gauderis, J., J. Kind & R. van Duinen. *Robustness of economically efficient flood protection standards, Monte Carlo analysis on top of cost-benefit analysis*. In: Comprehensive Flood Risk Management – Klijn & Schweckendiek (eds) © 2013 Taylor & Francis Group, London, ISBN 978-0-415-62144-1

Jongejan, R.B., H. Stefess, N. Roode, W. ter Horst & B. Maaskant. *The VNK2-project: a large scale quantitative flood risk analysis for The Netherlands*. 5th International Conference on Flood Management (ICFM5), 27-29 September 2011, Tokyo-Japan

Kind, J.M. *Economically efficient flood protection standards for the Netherlands*, Journal of Flood Risk Management, 2013

Kind, J., R.Vos, A. Tijssen, A. Jeuken and N. Slootjes. *Towards the Evaluation of Adaptive Flood Risk Management Strategies for the Rhine estuary – Drechtsteden.* 6th International Conference on Flood Management (ICFM6), September 2014, Sao Paulo, Brazil (in prep.)

Ministry of Infrastructure and Environment, *Giving directions to water policy*, Letter to parliament, The Hague, April 26, 2013 (in Dutch)

Van der Most, H., *Quick scan of options for raising the levels of protection against floods of dike rings in The Netherlands*. In: Comprehensive Flood Risk Management – Klijn & Schweckendiek (eds)
© 2013 Taylor & Francis Group, London, ISBN 978-0-415-62144-1

Van der Most, H., *Economic and social criteria in setting standards for flood protection in The Netherlands*, ICID 2011, Groningen, May 17, 2011

Schielen, R.M.J. and L.F.M. van den Aarsen. A river strategy to handle climate change and new safety standards in the Netherlands. 6th International Conference on Flood Management (ICFM6), September 2014, Sao Paulo, Brazil (in prep.)

Slomp, R., H. de Waal, E. Ruijgh, T. Kroon and J. van Alphen. The Dutch Delta model for policy analysis on flood risk management in the Netherlands. 6th International Conference on Flood Management (ICFM6), September 2014, Sao Paulo, Brazil (in prep.)

Vrijling, J.K., Van Hengel, W., Houben, R.J. (1998) *Acceptable risk as a basis for design*. Reliability engineering and system safety, 59: 141-150.