Journal of
Flood Risk Management

Economically efficient flood protection standards for the Netherlands

J.M. Kind

Deltares, Utrecht, The Netherlands

Correspondence
Jarl Melchior Kind, Deltares,
PO Box 85467, 3508 AL Utrecht,
The Netherlands
Tel: +31 0 88 3357712
Fax: +31 0 30 2564855
Email: jarl.kind@deltares.nl

DOI: 10.1111/jfr3.12026

Key words
Delta Committee; Delta Programme; economic efficiency; floods; optimal; protection standards; social cost-benefit analysis; the Netherlands.

Abstract

Within the context of the Dutch Delta Programme, economically efficient flood protection standards for the entire Netherlands were calculated using a recently developed methodology for cost-benefit analysis and up-to-date insights into flood risk assessment. This results in economically efficient flood protection standards for different parts of the Netherlands that significantly differ from current legal flood protection standards. The cost-benefit analysis shows that it is economically efficient to raise protection standards especially along the rivers Rhine and Meuse, while for many dike ring areas in the coastal region, existing legal flood protection standards seem relatively high. An additional Monte Carlo analysis shows that in light of many uncertainties, these are also robust conclusions. The cost-benefit analysis does not support a general increase of the legal flood protection standards for all flood-prone areas in the Netherlands by (at least) a factor 10, as was recommended by the (second) Delta Committee in 2008.

Introduction

Current flood protection standards in the Netherlands

More than half of the Netherlands is exposed to the risk of large-scale flooding. Over the ages, the Dutch have built a flood protection system consisting of some 3500 km of primary flood defences (dikes, dams and dunes). In this system, 53 larger areas (the 41 little dike ring areas along the upper branches of the Meuse are not discussed in this article) are distinguished, which are protected by a connected system of dikes, dunes or high grounds, the so-called 'dike ring areas'. For those dike ring areas, the level of flood protection is specified by law (Figure 1). These vary from 1/1250 per year for the dike ring areas along the upper reaches of the rivers Rhine and Meuse to 1/10 000 per year for the most densely populated areas in the western part of the country, where major cities like Amsterdam, Rotterdam and the Hague are located.

The foundation of the existing flood protection standards was laid by Van Dantzig and Kriens (Van Dantzig, 1956; Van Dantzig and Kriens, 1960) as part of the work of the (first) Delta Committee (Deltacommissie, 1960–1961). This Committee advised the Dutch government on the necessary flood protection measures after the major flood of February 1953 in the south-western part of the Netherlands, which killed 1800 persons and led to an economic loss of approximately 10% of gross domestic product. A cost-benefit analysis was carried out for the dike ring area with the highest economic value and population size (dike ring area 14, Central Holland). In this cost-benefit analysis, the cost of increasing protection was balanced against the reduction in flood risk. This resulted in a flood protection standard of 1/10 000 per year for dike ring area 14.

Based on the result for dike ring area 14, the Delta Committee recommended flood protection standards for the other dike ring areas along the coast as well by comparing estimates of potential flood damage in these dike ring areas with the potential damage in dike ring area 14. The investment cost of reaching those standards in the other dike ring areas was not taken into account. Hence, the protection standards of the other dike ring areas along the coast were not based on cost-benefit analyses.

The existing flood protection standards for dike ring areas along the rivers Rhine and Meuse (1/1250 per year) are based on an advise of a separate Committee in 1993 (Commissie Toetsing Uitgangspunten Rivierdijkversterking, 1993). This Committee placed a high value on the environmental damage that dike improvement projects had caused along the rivers in the preceding decennia. Therefore, they chose to analyse only protection standards of 1/500 and 1/1250 per year, not higher. So here again, existing protection standards for the dike rings along the rivers were not

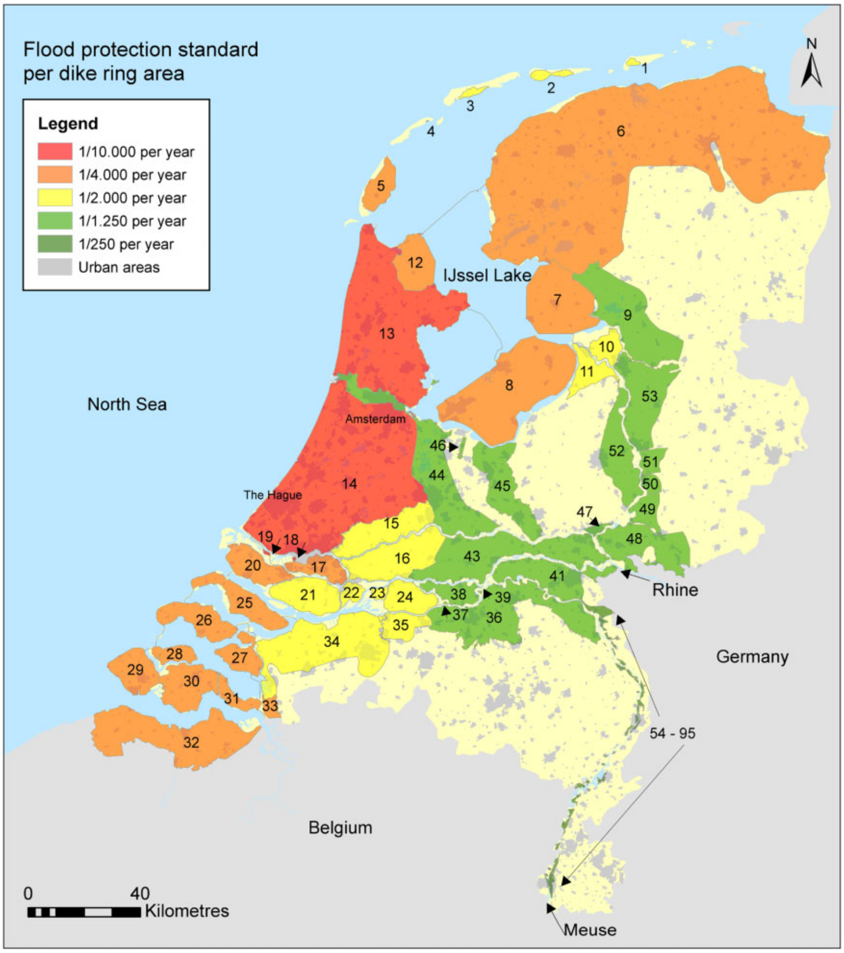

Figure 1 Existing legal flood protection standard per dike ring area.

based on (sound) cost-benefit analyses (Ten Brinke and Bannink, 2004).

In 1996, the flood protection standards of all dike ring areas were made statutory. Since then, each 6 years, all flood defences are tested to see if their standards are still met. In case of noncompliance, reinforcement projects are initiated. The majority of the cost of those projects is financed by the federal government.

Recent studies on Dutch flood protection standards

The Dutch national flood risk management policy was independently reviewed in 2004 (Ten Brinke and Bannink, 2004). In this review, two main questions were asked: is the agreed flood risk management policy implemented properly, and does this policy indeed lead to the higher development objective of realising a 'safe and habitable Netherlands'? The answer to the second question involved a critical review of the level of the existing protection standards. The review presented an analysis of economic damages and fatality risk for all dike ring areas in the Netherlands. This led among others to the conclusion that the existing legal protection standards for the different dike ring areas did not properly reflect the economic values in those dike ring areas.

In 2005, the Netherlands Bureau for Economic Policy Analysis (in Dutch: *Centraal Planbureau, CPB*) published a cost-benefit analysis for the project Room for the River (Eijgenraam, 2005). This project, with a budget of 2.2 billion Euros, consists of more than 30 smaller projects that have to be carried out along the rivers Rhine and Meuse to ensure that the current flood protection standards of 1/1250 (upper reaches) and 1/2000 per year (lower reaches) are met. Although the current flood protection standards were at that time formally not a subject of discussion, the study included a novel methodology to determine economically efficient flood protection standards for dike ring areas. To this end, a dike optimisation model was developed. This model was partly based on the original work by Van Dantzig (1956) and Van Dantzig and Kriens (1960), but included major improvements, especially in the treatment of the fixed part of the investment costs and in the treatment of economic growth (Eijgenraam, 2005, 2006). This study concluded that the current legal flood protection standards in the areas along the rivers Rhine and Meuse are on average economically efficient for the present situation. It was indicated, however, that further research was needed to confirm this conclusion.

In 2008, a new (second) Delta Committee was appointed by the Dutch government with the assignment to give recommendations on how to protect the Dutch coastal zone and the low-lying hinterland against the consequences of climate change. One of the recommendations of this Committee was to increase the present flood protection standards of all dike ring areas by (at least) a factor 10 (Deltacommissie, 2008). This recommendation was, among other things, based on the fact that the values in the dike ring areas (both capital and population) had increased significantly since the 1960s. This recommendation was not based on an analysis of costs and benefits of flood protection.

Future flood protection in the Netherlands

In the National Water Plan 2009–2015 (Ministerie van Verkeer en Waterstaat, Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2009), the Dutch government announced to start a process to revise the system of legal flood protection standards. According to this plan, new legal flood protection standards would be based on the results of a (social) cost-benefit analysis and an analysis of casualty risk. The project 'Flood protection for the 21st Century' (in Dutch: *Waterveiligheid 21e eeuw*, WV21 in short) was launched to carry out the necessary research. Later, this project became part of the Dutch National Delta Programme, a programme with the objective to protect the Netherlands against floods at a socially acceptable risk level and to secure the future supply of fresh water.

Within the context of WV21, two studies were carried out to provide the scientific basis for the new standards, although the ultimate decision, expected before the year 2015, will be a political one and can include all kinds of other considerations as well. The first study, the cost-benefit analysis WV21 (Kind, 2011), was set up to determine the economically most efficient flood protection standards for all dike ring areas. The second study on individual (or location-related) casualty risk and incident-related group (or societal) risk (Beckers and De Bruijn, 2011) would provide risk indicators that could be used to determine flood protection standards from the perspective of becoming a flood victim.

This article

This article presents the general framework, methodology and results of the cost-benefit analysis for the project WV21. The resulting economically efficient flood protection standards are explained and discussed in view of the current legal flood protection standards.

Methodology of the social cost-benefit analysis

Scope

The main purpose of the cost-benefit analysis WV21 is in the first place to determine economically efficient ('optimal') flood protection standards for all dike ring areas in the Netherlands. Those optimal standards can be compared either with the actual flood probabilities, with existing flood protection standards or with the advised increase of the standards with a factor 10 as advocated by the second Delta Committee.

The cost-benefit analysis is based on the costs and benefits of dike reinforcements because this is in general the cheapest (structural) measure to reduce flood risks in the Netherlands. In the cost-benefit analysis, not only financial and economic losses are taken into account but also intangible damages such as the damage of floods to nature, landscape and cultural heritage, and the impacts of floods on humans including the loss of human live. The cost-benefit analysis, therefore, is a 'social' cost-benefit analysis.

Mitigation measures – measures aimed to reduce the potential consequences of floods – were not included in the cost-benefit analysis. Because in the Netherlands the focus has always been on collective flood prevention systems, there is little experience with such measures, and the required institutional arrangements are not in place. In the coming years, mitigation measures will be investigated in the National Delta Programme and may be included in the new flood management policy.

Optimisation model

Typically, cost-benefit analysis is used to assess the costs and benefits of a discrete number of project alternatives. This analysis then informs the decision-maker about the positive and negative consequences of a few distinguishable project alternatives. In this respect, the cost-benefit analysis WV21 is a typical one because it deals with one project alternative only – the economically optimal one. The challenge here is to find this alternative. For this, an optimisation model is used.

The optimisation principle of the cost-benefit analysis WV21 is to minimise all costs associated with floods. Those are the costs of flood protection (here: dike reinforcement) and the costs of expected (residual) flood damages. Figure 2 illustrates this principle. Investments in dike reinforcements are made until the cost of the last investment (the marginal

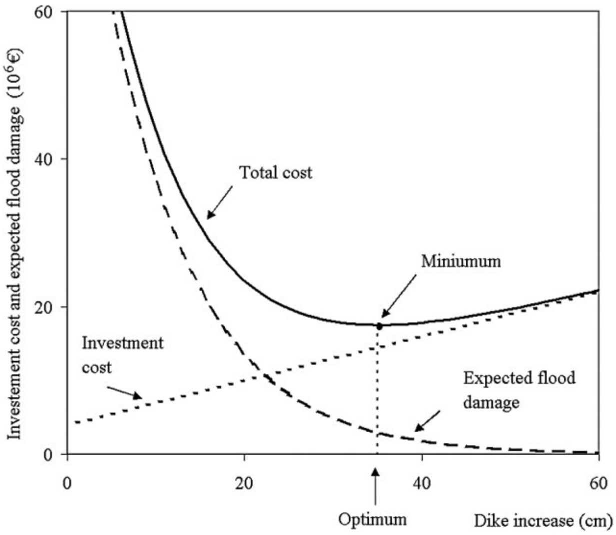

Figure 2 General principle of the cost-benefit analysis WV21.

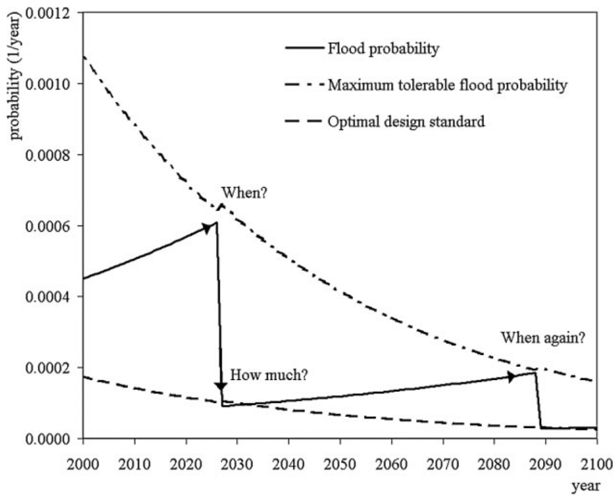

Figure 3 Economically efficient flood probabilities in time because of periodical investments.

costs) no longer outweighs the further decrease of the expected flood damage (the marginal benefits). At this point – where marginal costs equal marginal benefits – the total costs are minimal, and the height of the dikes (and hence the corresponding protection level) is economically optimal. Both higher and lower dikes than the economically optimal one lead to higher total economic costs.

Although Figure 2 adequately describes the principle of the cost-benefit analysis, it is too simple because it neglects the dynamic effects of economic growth and climate change. For the purpose of the cost-benefit analysis WV21, a more complex mathematical optimisation model named *OptimaliseRing* (Brekelmans *et al.*, 2009; Den Hertog and Roos, 2009; Duits, 2011a, b) was developed to take these system dynamics into account. This model is an extended version of the earlier dike optimisation model by Eijgenraam, 2005, 2006). The most important difference between *OptimaliseRing* and the earlier model by Eijgenraam is that in *OptimaliseRing*, a dike ring area can be built up of more than one single dike segment.

In *OptimaliseRing*, first an economically optimal, long-term investment strategy in dike reinforcement is determined, in which 'optimal' refers to the total costs of investments in dikes and the cost of expected flood damages being minimised over a long-time horizon while accounting for the effects of climate change and economic development. In a second step, the economically efficient flood protection standards are derived from the optimal investment strategy.

Because flood probabilities increase due to the effects of climate change (sea level rise and higher peak river discharges) and flood consequences mount due to economic growth, it is essential to consider both optimal design and optimal timing of dike reinforcements as part of the optimal investment strategy. With increasing probabilities and consequences in time, a decision to invest in flood defences is not a one-time decision but a recurring one. And because a considerable part of the costs of dike reinforcements are fixed costs, which are costs that do not depend on the size of the reinforcement project, it is cost-efficient to significantly reinforce the dike periodically and to take longer time intervals in between the reinforcements. So, the relevant question for the optimisation is not only 'how much' a dike should be reinforced (as in Figure 2) but also 'when' this should be done and 'when again'. This also means that the actual protection level in the course of time is not constant: just after an investment, the flood probability is relatively low, and just before the next investment, it is relatively high. The flood probability in time thus shows a saw-tooth pattern with jumps at the moments of investing. In Figure 3, this saw-tooth pattern is shown for a simple case in which a dike ring area is protected by a single stretch of a dike.

The figure illustrates that the actual flood probability (solid saw-tooth line) first increases due to climate change until a certain – from an economic perspective – maximum tolerable flood probability is reached (upper dashed line). At that moment ('when?'), an investment is made after which a high level of protection is reached (bottom dashed line). The size of this investment ('how much?') is largely determined by the ratio of fixed over variable costs; at relatively high fixed costs, it pays to make a larger investment so the next investment will be later in time. After an investment, the flood probability increases again gradually until a new tolerable maximum is reached ('when again?'). This time, the tolerable maximum is lower, as the values to be protected in the dike ring area have increased with economic growth.

The figure also illustrates that there is a theoretical difference between the optimal (legal) test standard (upper line) and the optimal design standard (i.e. the optimal flood probability that is reached just after the investment is made – bottom line).

Model equations and key parameters

The objective function in the dike optimisation model *OptimaliseRing* is to minimise the total discounted cost (K) of investment (I) and expected flood damages (S). The equations follow the basic model by Eijgenraam but have been augmented to allow for more dike segments per dike ring area:

$$K = \sum_{t=0}^{z} \frac{S(t)}{(1+\delta)^t} \Delta t + \frac{S(z)}{(1+\delta)^z} \frac{1}{\ln(1+\delta)} + \sum_j \sum_i \frac{I_{ij}}{(1+\delta)^{T_{ij}}} \quad (1)$$

Parameter δ is the discount rate. The Dutch Government rules prescribe a value of 5.5% per year for most projects. The time increments (Δt) are equal to 1 year. The first term on the right-hand side of Eqn (1) is the present value of all expected future damages unit moment z (in the calculations, $z = 300$ years). The assumption is that after z, the system remains unchanged and investments are no longer needed. After moment z, there is still a contribution to the expected damage. This is second term. The last term is the total discounted investment costs of all segments in the dike ring. The year in which the investment is realised is given by T_{ij}, where index i indicates to the successive investment and index j to the segment. The related investment costs are I_{ij}. The successive investment cost for all segments are summed; this explains the double sum in the third term of Eqn (1).

Dike heightening and investment cost

In the dike optimisation model *OptimaliseRing*, the height of the dike at different moments in time [$H_j(t)$] is the central parameter. The optimal moment for dike heightening is (T_{ij}) and the optimal size (u_{ij}).

The investment costs for the ith investment of the jth segment are given by Eqn (2) (the subscripts i and j are removed from the following equation):

$$I(u, W) = (C + bu)e^{\lambda(u+W)} \quad (2)$$

where:

I	investment cost	M€
u	dike heightening	cm
W	sum of earlier dike increases	cm
C	fixed costs	M€
b	variable cost	M€/cm
λ	scale parameter	1/cm

The cost of dike heightening is partly fixed costs C (independent of the dike increase) and partly variable costs b. The cost of the next dike increases is higher than the earlier ones, denoted by the parameter λ.

Expected flood damage

The expected flood damages is the product of the largest flood probability $P(t)$ of the dike segments and flood damage $V(t)$:

$$S(t) = \max_j \{P_j(t)\} V(t) \quad (3)$$

The flood probability of a segment at time t follows from:

$$P(t) = P(0)e^{\alpha\eta t} e^{-\alpha(H(t)-H(0))} \quad t \geq 0 \quad (4)$$

where:

$P(t)$	flood probability at time t	1/year
$P(0)$	flood probability at $t = 0$	1/year
α	scale parameter exponential distribution [equal to $1n(10)/h_{10}$]	1/cm
h_{10}	necessary dike increase to reduce the flood probability by a factor 10	cm
η	structural increase of relative water level	cm/year
$H(0)$	dike height at $t = 0$	cm+NAP
$H(t)$	dike height at time t	cm+NAP

So, the flood probability at time t is determined by the structural increase of the water level (which is a relative increase, caused by climate change and soil subsidence) and the increase of the dike height itself.

The flood damage at time t follows from:

$$V(t) = V(0)e^{\gamma t} e^{\psi\eta t} e^{\zeta(H_{j^*}(t)-H_{j^*}(0))} \quad t \geq 0 \quad (5)$$

where:

$V(t)$	flood damage at time t	M€
$V(0)$	flood damage at $t = 0$	M€
γ	increase in flood damage due to economic growth	%/year
ψ	parameter for additional damage caused by a structural increase of the relative water level	1/year
ζ	increase of damage per cm through dike heightening	1/cm
j^*	segment with the initial lowest dike height $H_{j^*}(0) = \min\{H_j(0)\}$	–

The flood damage at time t is dependent on the economic growth. Flood damage also increases with an increase in the relative water level or as a result of dike heightening. For the last parameter, before the calculations start, the segment with the initial lowest dike height is determined. It is assumed that for the determination of the increase of flood damage through dike heightening, this segment will remain the lowest during the whole time horizon.

Solving the model

The earlier model is solved using AIMMS optimisation software (http://www.aimms.com). The used algorithm is extensively described in Brekelmans *et al.*, (2009).

Proposed definition of new flood protection standards

Once the model is solved and the optimal investment strategy in dike reinforcement for a dike ring area is determined (Figure 3), an economically efficient flood protection standard needs to be derived. This is complicated by the fact that the optimal conduct of the actual flood probability follows a saw-tooth pattern as shown in Figure 3. In the cost-benefit analysis, the concept of the 'middle probability' was used, as proposed by Eijgenraam (2008, 2009). This middle probability lies in between the (maximum) tolerable flood probability (the upper dashed line) and the (minimum) flood probability (the lower dashed line). Figure 4 illustrates the concept.

Compared with its obvious alternatives (protection standards either based on the flood probabilities indicated by the upper or lower dashed lines), some of the characteristics of the middle probability are in favour of using it as indicator for an efficient legal flood protection standard (Eijgenraam, 2008, 2009). First, once the actual flood probability exceeds the middle probability, the economically efficient maximum tolerable flood probability is reached approximately 20 years later (see Figure 4). The period of 20 years is well in accordance with actual experiences in the Netherlands for the time it takes to implement large-scale flood prevention projects. Second, the upper and lower bounds for the efficient flood probabilities (dashed lines) strongly depend on the shares of fixed and variable costs in the total investment costs that determine the economies of scale and hence optimal design. Those shares are often uncertain and are much more difficult to estimate than the total costs combined. The middle probability, on the other hand, does not strongly depend on those shares but largely depends on the average costs. This implies that the upper and lower bounds are more uncertain than the middle probability.

With respect to this possible definition of new flood protection standards, one should realise that the middle probability may only be adequate as a (new) concept for legal flood protection standards if policymakers accept that this standard is not a 'hard' standard but a standard that will be exceeded for some time before (new) investments in dike reinforcements are actually implemented. The middle probability thus mainly serves as a signal that indicates the moment to start to plan a dike reinforcement project.

Figure 4 also shows that economically efficient flood protection standards increase in the course of time because economic growth leads to an increase of potential flood damages over time. The Dutch government has expressed the desire to fix the legal flood protection standards for a longer time period, at least until the year 2050. In the cost-benefit analysis efficient flood protection standards were therefore calculated for this year 2050.

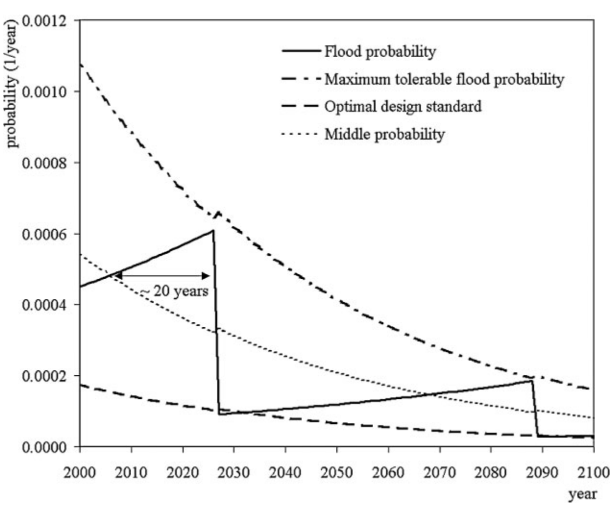

Figure 4 Middle probability as a proposed concept to define legal flood protection standards.

Selected input data and valuation issues

Essential data for the cost-benefit analysis includes the investment costs for different sizes of dike reinforcements, estimates of existing flood probabilities, estimates of flood damages and casualties, information on the effects of climate change and socio-economic development on the development of flood risk, and the relation between dike strength and flood probability. Those data were provided through several studies (De Bruijn and Van der Doef, 2011; De Grave and Baarse, 2011; Kuijper *et al.*, 2011). Appendix I provides in aggregated form, some of the most important key data per dike ring area. In this section, a few items are discussed, which are the most illustrative for the cost-benefit analysis.

Flood probabilities

The actual flood probability of a dike ring area is not necessarily equal to the flood protection standards (as shown in Figure 1). One of the reasons is that the legal standards in the Water Act are not flood probabilities at all but are exceedance probabilities of design water levels. Most of the public however perceives the legal protection standard as the maximum tolerable flood probability, and all recent Committees who advised the Government on the issue of flood protection standards did in fact the same.

The reason that the Water Act does not use the flood probability as legal standard is that it is only since a few years

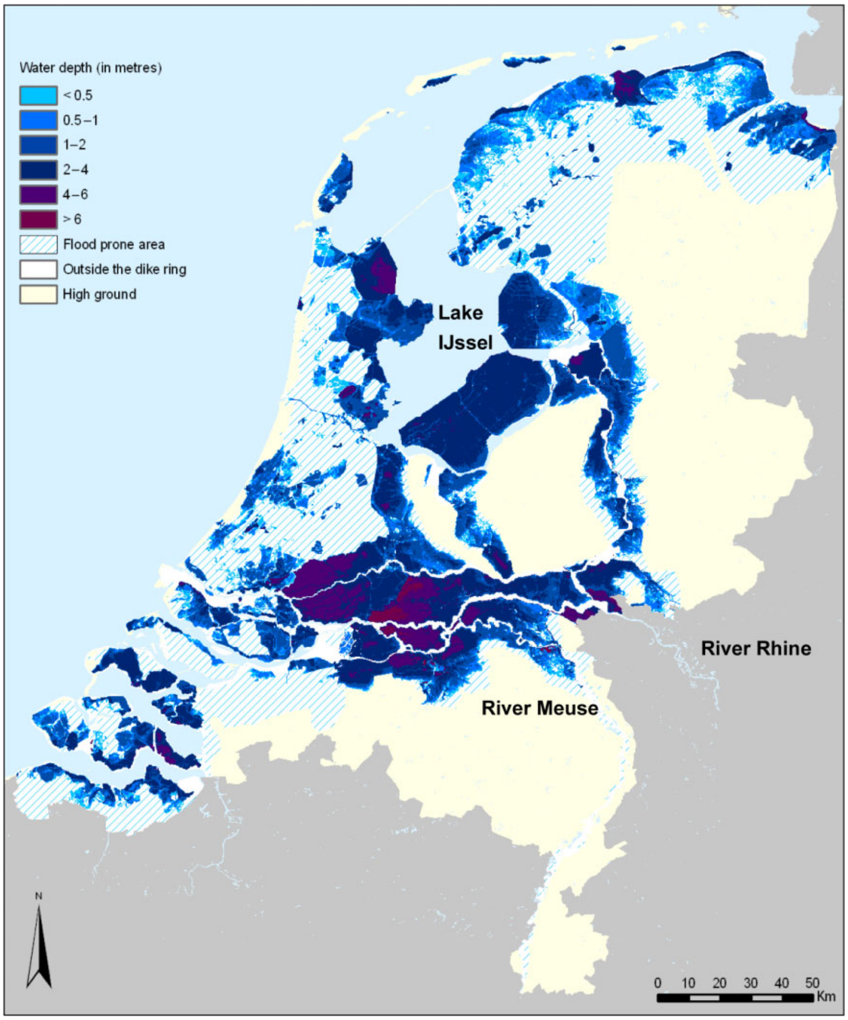

Figure 5 Maximum water depth in flood prone parts of the Netherlands according to a combination of >600 inundation scenarios (*Source:* De Bruijn and Van der Doef, 2011).

that the knowledge is available through the VNK (in English: Flood Risk and Safety in the Netherlands; FLORIS; in Dutch: *Veiligheid Nederland in Kaart, VNK*) project to calculate actual flood probabilities for dike ring areas (Jongejan, 2012). Those calculations however have not been completed yet for all dike ring areas in the Netherlands. Therefore, in WV21, the calculated flood probabilities of the VNK project for number of dike ring areas were used to estimate the actual flood probabilities for the other dike ring areas. This was considered an acceptable approach because it was already clear that the economically efficient flood protection standard calculated with *OptimaliseRing* would be relatively independent of the initial flood probability used in the model (the 'saw-tooth' line in Figure 4 will shift left or right, but the middle probability-line will stay close to its original location).

On average, the estimated flood probabilities are two to five times higher than those suggested by their legal standards. One important reason is that the VNK project showed that the failure of dikes through the process of 'piping' had so far been underestimated.

Flood inundation scenarios

The expected flood damages and casualties per dike ring area were determined on basis of a large number (>600) of flood inundation scenarios. These scenarios show which areas are flooded after a dike breach and how deep. In Figure 5, the combined maximum water depths after a flood from all WV21 inundation scenarios are shown. Clearly, especially along the rivers Rhine and Meuse, and in (relatively new) polders along the Lake IJssel, the expected inundation depths are high (4–5 m). For most coastal areas, inundation due to coastal floods is shallower and less extensive. As a result, the potential impact of floods is greatest in dike ring areas along the rivers and in polders around the Lake IJssel.

Future scenarios

For the future development of the flood risk, scenarios on climate change and socio-economic development were used. For the increase of structural water level [parameter η in Eqn (4)], the *Warm* + climate change scenario from the Royal Netherlands Meteorological Institute was used (Van den Hurk *et al*., 2007). For the increase in the potential flood damage [parameter γ in Eqn (5)], the *Transatlantic Market* scenario was used (CPB, 2004).

Intangible damages

Because this study aimed to deliver optimal flood protection standards based on social cost-benefit analysis, both tangible and intangible damages needed to be included in the calculations, otherwise optimal standards would be underestimated. Hence, the intangible damages were to be monetised. Monetisation, especially the monetisation of the impacts on humans (loss of life, injuries, traumas, etc.), may for several reasons lead to misunderstanding or ethical objection (e.g. Cameron, 2010).

For usage in the particular context of flood risk management in the Netherlands, choice experiments were held among a large number of households to derive estimates for intangible damages because of floods on humans (Bočkarjova *et al*., 2009). In this study, the concept 'value of a statistical life' (VoSL) was used, which is the aggregation of individuals' willingness to pay for fatal risk reduction and therefore the economic value to society to reduce the statistical incidence of premature death in the population by one (Wang and He, 2010). If, for example, the willingness to pay of an individual is €9 per year to reduce the probability of becoming a flood victim from 1/100 000 to 1/1 000 000 per year, the VoSL would be €1 million [€9/(1/100 000–1/1 000 000)].

The study of Bočkarjova *et al*. (2009) provided values of approximately €7 million for a statistical life, €100 000 for a (serious) injury and €2500 as a value for the inconvenience, stress etc. (all 'immaterial damages') of evacuated persons. In the cost-benefit analysis, those figures were combined with the results of De Bruijn and Van der Doef (2011) on the expected numbers of lives lost, people injured and people affected. Hence, the intangible damages per dike ring area could be assessed. On average, for all dike ring areas, intangible damages contribute to approximately 30% of the total (tangible and intangible) damages. This percentage is somewhat higher for coastal areas where the potential for preventive evacuation is probably lower (hence, higher number of casualties) and somewhat lower for areas along the river (where the potential for preventive evacuation is higher).

In the Netherlands, a standard method to properly assess the damages caused by floods to nature, landscape or cultural heritage is absent. The only available source is a study conducted by Ruijgrok and Bel (2008) on the economic valuation of imponderables in the context of flood damage mapping, a study which was commissioned by the second Delta Committee. In this study, the repair costs and temporary losses of use values were used to assess the potential environmental flood damages. Those were then expressed as a percentage of the total potential material flood damages. This resulted in a very low contribution of the environmental damages to the total flood damage of 2–6%, a percentage that was also used in the cost-benefit analysis WV21.

Risk aversion

In cost-benefit analysis of flood protection, the benefits due to a reduction of flood risk are typically valued against their expected monetary values, i.e. consequences are multiplied by (or combined with) probabilities. If households are willing to pay a larger amount of money than the value of the calculated flood risk reduction (in which case they are risk averse), this approach results in an underestimate of the true social economic benefits (see also Pearce and Smale, 2005). In the case of 'small probability – high consequences events', such as large-scale floods in the Netherlands, it is likely that household are indeed risk averse (Botzen and Van den Bergh, 2009). Most individual households simply cannot cope with the 'catastrophic' risk of losing their entire homes and will face bankruptcy without some kind of financial compensation. In this case, willingness to pay (hence benefits) for flood protection is expected to be substantially higher than the expected value of the monetary risk reduction. This results in a 'risk premium' that should also be included in the benefits of a flood protection project. This will then lead to higher economically efficient flood protection standards. Ignoring the risk premium leads to lower than optimal flood protection standard and hence to a loss of welfare.

However, in the Netherlands, it is the central government who is responsible for setting the legal flood protection standards and for ensuring that those legal standards are also actually met. It may be assumed, therefore, that the government will also take responsibility to provide compensation for flood damages if they occur. From the perspective of private households, a large part of the flood risk would then actually be insured by the government through the general tax system. If this compensation is high enough, the need to include the risk premium in the cost-benefit analysis largely disappears.

In the cost-benefit analysis WV21, a small risk premium of 8% of the material damages was used. This risk premium was derived using a standard isoelastic utility function, with a constant relative risk aversion of 4. It was further assumed that the flood would lead to a 50% loss of household consumption, of which 75% would ultimately be compensated for by the government.

The risk premium of 8% appears to be very sensitive to the assumed 75% government compensation. If for example 50% compensation would be assumed, the risk premium would increase to 41%.

There is no legal obligation for the Dutch government to compensate a predetermined amount of flood losses. Because the last big flood event in the Netherlands is still the 1953 event, empirical evidence is also lacking. The 75% is based on the actual damage compensation after other, smaller disasters. In the CBA report, therefore, an appeal towards the government is made to accept responsibility for damage compensation when the results of the CBA are used to base new policies on.

Economically efficient flood protection standards

Base case scenario

To facilitate the calculation of economically efficient flood protection standards, first a 'base case' was defined. In the base case scenario, 'most likely', 'expected' or 'commonly agreed' values for many of the uncertain variables in the cost-benefit analysis were chosen. These included variables related to investment costs and material and immaterial damages, and variables that reflect the uncertainty around socio-economic development and climate change scenarios. The calculations were carried out using the dike optimisation model *OptimaliseRing*, as described in an earlier section of this article.

Figure 6 shows the economically efficient flood protection standards for the year 2050 calculated for the base case. Note that for some dike ring areas, different optimal standards were calculated for different parts of the dike ring. This was the case for large dike ring areas that are exposed to different (independent) threats for flooding, for example dike ring area 13 that is exposed to the risk of flooding from the sea and from the Lake IJssel, or for dike ring areas where a relatively small part will inundate after a dike breach (e.g. dike ring areas 6, 13 or 14). This is also the reason why in Figure 6, the borders of the dike ring areas are coloured instead of the whole dike ring areas as is the case in Figure 1 denoting the existing legal standards.

Figure 6 shows that for dike ring areas in the central area of the rivers Rhine and Meuse, the economically efficient flood protection standards are predominantly between 1/2000 and 1/4000 per year, and along the river IJssel and the upstream part of the river Meuse, these tend to be slightly lower (i.e. higher optimal probabilities), around 1/1250 per year. In tidal river areas and in the central part of Holland, economically efficient flood protection standards are mostly between 1/4000 and 1/10 000 per year. For polders around the Lake IJssel, the economically efficient flood protection standard is highest (lowest flood probability) for the south-western part of dike ring area 8, Flevoland (about 1/10 000 per year). For the remaining dike ring areas around the Lake IJssel, economically efficient flood protection standards range from 1/500 to 1/4000 per year. For dike rings up north in the Wadden Sea area, the optimal flood protection standard is around 1/500 per year. For dike ring areas located in the south-western part of the country (Zeeland), economically optimal flood protection standards range between 1/500 and 1/4000 per year.

Relative high potential flood damages or low investment costs result in relatively high optimal flood protection standards and vice versa. Hence, also a small dike ring area can have a high optimal flood protection standard if the cost of protection is modest compared to the flood damage. This is for example the case for dike ring area 50, Zutphen. The optimal flood protection standard for this dike ring area is roughly the same as that for dike ring area 14-3, near Rotterdam, with much larger damages but also much higher investment costs for increased protection. The optimal flood protection standard for dike ring area 43 is much lower. In this dike ring area, the potential flood damages are high, but the cost for protection is also high because of the large length of the dikes enclosing the dike ring area.

The previous thus suggests a straightforward relationship between the optimal flood protection standard, the cost of increased protection (with dikes) and the (total) flood damage. With the help of the data in Table 1, this relationship is examined for the same dike ring areas 14-3, 43 and 50. Flood damage in 2050 is projected at €75.1 billion for dike ring 14-3, at €70.1 billion for dike ring area 43 and at € 6.6 billion for dike ring area 50. In the table, the investment costs are provided for a 10-fold decrease in flood probability. A 10-fold decrease is chosen because the calculations with *OptimaliseRing* show that when an investment is made, a decrease of the flood probability by a factor 10 is for most dike ring areas a close to optimal investment size (hence, this is also the distance between the upper and lower dashed lines

Table 1 Relation between the optimal flood protection standard, damage and investment cost

Dike ring area	Total flood damage year 2050 Billion €	Investment cost for 10-fold decrease in flood probability Million €	Ratio of damage/cost	Optimal flood protection standard 1/year
14-3	75.1	348	216	1/13 700
43	70.8	850	83	1/2 700
50	6.6	35	189	1/8 700

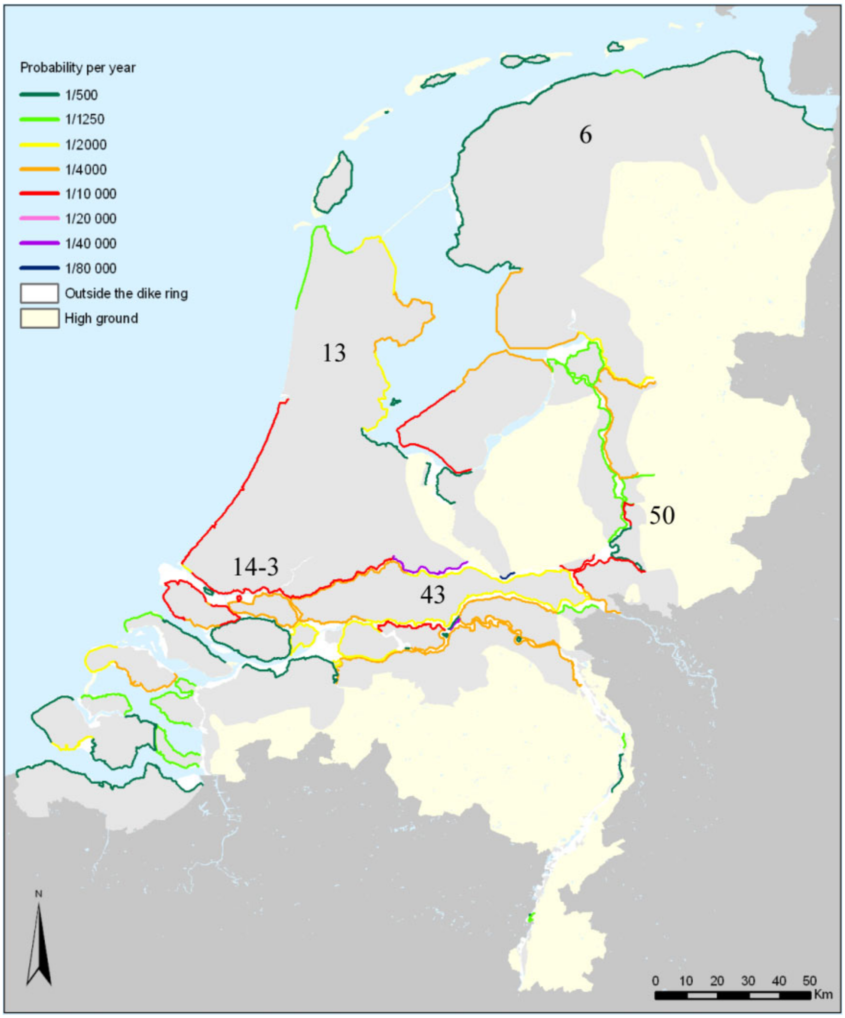

Figure 6 Economically efficient flood protection standards for the Netherlands according to the base scenario. The standards are presented in safety classes (1/2000, 1/4000 etc.), with the boundaries between the classes calculated on a logarithmic scale. For example, the boundary between 1/2000 and 1/4000 is equal to 1/2800 per year [$\approx 10^{(\log(1/2000)+\log(1/4000))/2}$].

in Figures 3 and 4). These investment costs amount to €348 million for dike ring area 14-3, to €850 million for dike ring area 43 and to €35 million for dike ring area 50. The fourth column of the table provides us with the ratio of the flood damage to the investment cost (a ratio of 216 for dike ring area 14-3, 83 for dike ring area 43 and 189 for dike ring area 50). The fifth column provides the optimal flood protection standards for the three dike ring areas (1/13700 per year for dike ring area 14-3; 1/2700 for dike ring area 43 and 1/8700 per year for dike ring area 50). The table shows the higher the ratio of damage to cost, the higher the optimal flood protection standard.

This same relationship between the damage/cost ratio and the optimal flood protection standard for all dike ring areas is depicted in Figure 7. Results for the already discussed dike ring areas 14-3, 43 and 50 are marked in red. This figure even illustrates much better the positive linear relationship between the optimal flood protection standard and the ratio of damage to cost. From the regression, it even turns out that the economically efficient flood protection standard for a dike ring can be directly predicted as 38 times the ratio of flood damage to the costs to increase the flood protection standard by a factor 10.

Monte Carlo analysis to determine uncertainty

Many of the variables used in the base case of the cost-benefit analysis are characterised by high degrees of uncertainty. This is true for example for the flood inundation patterns, damage functions, mortality fractions, evacuation possibilities, values for intangible damages, economic growth etc. The effect of these uncertainties on the economically efficient flood protection standard was assessed through a Monte Carlo analysis (see also Kind *et al.*, 2011).

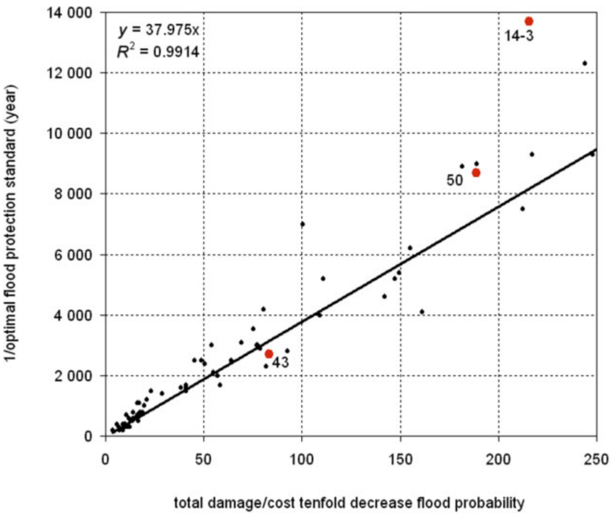

Figure 7 Correlation between economically efficient flood protection standards and the ratio of damage to the costs of reaching a 10 times lower flood probability ($n = 73$).

For the Monte Carlo analysis, the dike optimisation model *OptimaliseRing* is unsuitable because of its high calculation costs. Therefore, a direct approach was used to calculate the uncertainty around the economically efficient flood protection standards based on equations provided by Eijgenraam (2009). The idea behind the equations from Eijgenraam is exactly the correlation shown in Figure 7. It implies that if uncertainties in cost and flood damages and hence the ratio between them is sufficiently quantified, then the uncertainty of the economically efficient flood protection standard is also quantified.

Hence, within the context of the cost-benefit analysis, probability distributions of the relevant variables in the investment costs and for important factors contributing to the total flood damages were identified and quantified. Subsequently, the uncertainty around the economically efficient flood protection standards was determined on basis of 10 000 draws out of these distributions, and confidence intervals around the economically efficient flood protection standards from the base case scenario were assessed.

The Monte Carlo analysis showed that the uncertainty around the economically efficient flood protection standards is quite large. On average, on basis of an 80% confidence interval, the ratio between the upper and lower bound estimate for the economically efficient flood protection standard is a factor 5. This means that if for example, in the base case scenario, an optimal standard of 1/2000 per year is calculated, the confidence interval of 80% certainty ranges from 1/5000 to 1/1000 per year. For a 90% confidence interval, the factor would increase further from 5 to 10. Figure 8 shows the calculated 80% confidence intervals for all dike ring areas.

The uncertainty in the estimate of total flood damage in 2050 appeared to be the most important source of uncertainty. Here, uncertainties in economic growth, inundation scenarios, damage functions, evacuation fractions, mortality functions and economic valuation all accumulate. Yet, the earlier outlined relative position of the dike ring areas with respect to its economically efficient flood protection standards remains robust, even when those large uncertainties are taken into account.

Conclusions

From the results of the cost-benefit analysis and the additional Monte Carlo analysis, it is safe to conclude that the geographical pattern of the economically efficient flood protection standards (shown in Figure 6) is remarkably different from that of the current legal protection standards (shown in Figure 1). The differences can be attributed to several factors, including (i) the lack of a consistent basis behind the current framework of legal flood protection standards (see the Introduction section of this article) and (ii) improved knowledge of flood damage and flood risk showing relative high damages for dike ring areas along the rivers (see Selected input data and valuation issues section).

More specifically, the application of the dike optimisation model *OptimaliseRing* in the cost-benefit analysis indicates that especially the current flood protection standards for dike ring areas along the rivers Rhine and Meuse seem too low, while standards in the northern and south-western part of the Netherlands seem relatively high. This conclusion is robust when uncertainties (through Monte Carlo analysis) are taken into account.

This study does not support a general raise of the level of flood protection for all flood-prone areas in the Netherlands by (at least) a factor 10, as was recommended by the (second) Delta Committee in 2008.

Discussion

Although the conclusions seem robust, there are some limitations in the comparison of the economic optimal flood protection standards with the existing flood standards in the Netherlands that need to be mentioned.

First, the results of the cost-benefit analysis are (economically efficient) flood probabilities, while the current legal standards refer to exceedance probabilities of design water levels. Recent research indicates that actual flood probabilities in the Netherlands for most dike ring areas are (much) larger than the exceedance probabilities of design water levels suggest (see e.g. Jongejan, 2012). This is especially the case in dike ring areas along the rivers Rhine and Meuse, where due to the failure mechanism 'piping', flooding can

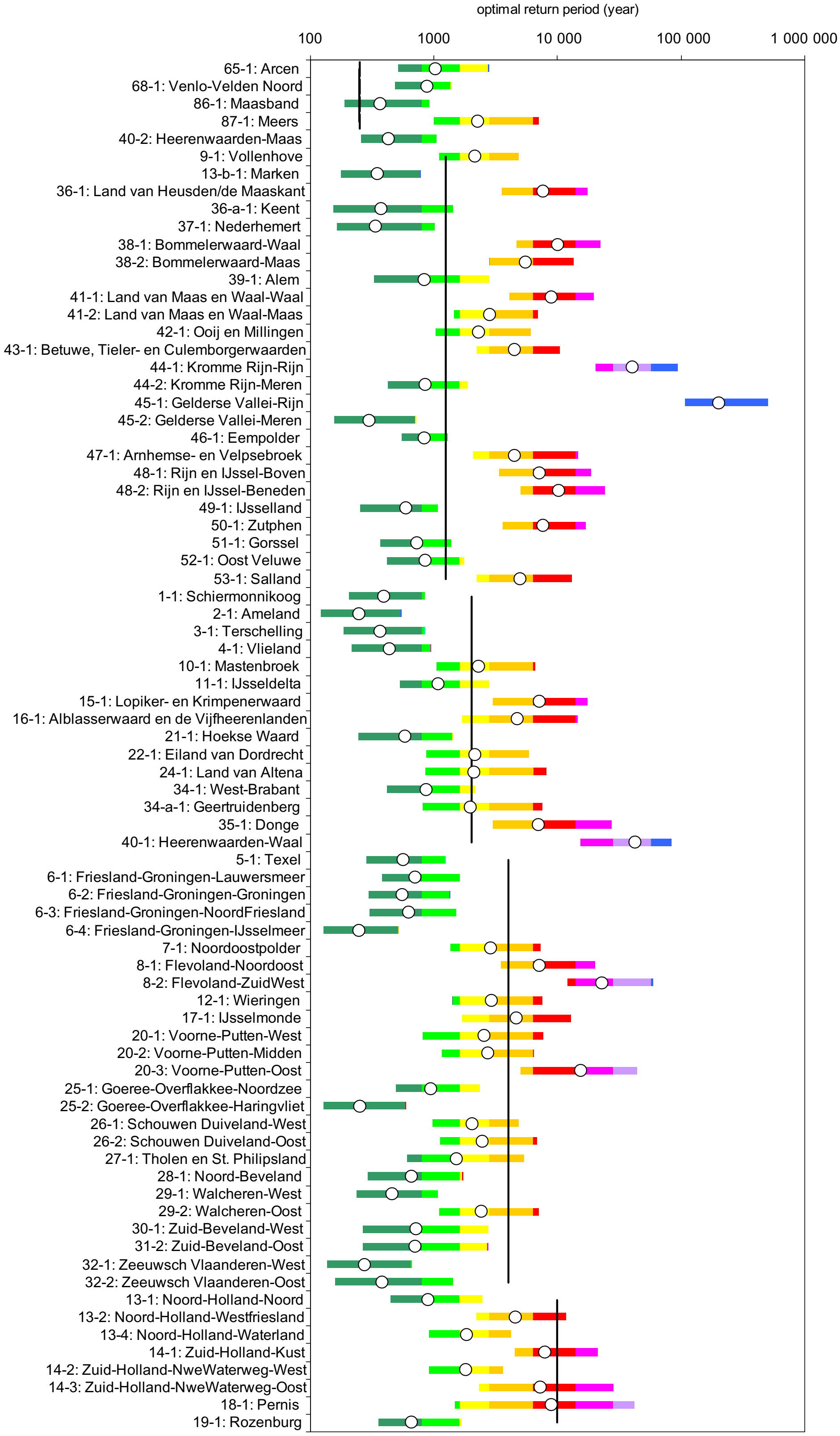

Figure 8 Results of the Monte Carlo analysis. The colour bars indicate the 80% confidence intervals around the economically efficient flood protection standards of the base case scenario (white circles). Each colour indicates a different class for the optimal standard. For colour usage and boundaries between the classes, see Figure 6. Vertical black lines indicate the current legal protection standard.

occur at water levels lower than the design water levels. On the other hand, many believe the legal standards to be guaranteed (maximum) flood probabilities, and all recent committees cited in this paper, who have given advise with respect to the level of the standards, have explicitly meant (maximum) flood probabilities. It is the recent application of new knowledge from the VNK project that we are able to actually calculate the 'real' flood probabilities.

Second, for a number of dike ring areas, the cost-benefit analysis was carried out on a lower spatial level than that of the whole dike ring area. This is for example the case in dike ring areas that are exposed to different sources of flood risk, which may justify a different level of protection for different parts of the dike ring area. An example is dike ring area 13, which can be flooded from sea and from the Lake IJssel. In other dike ring areas, on the basis of inundation scenarios, independent areas were distinguished, for which different levels of protection could be justified (i.e. for dike ring area 6). The existing legal standard, however, is a standard for the dike ring area as a whole.

References

Beckers J.V.L. & De Bruijn K.M. Analyse van slachtofferrisico's waterveiligheid 21^{e} eeuw. 2011. Projectnummer 1204144. Deltares, Delft.

Bočkarjova M., Rietveld P. & Verhoef E. *First results immaterial damage valuation: value of statistical life (VOSL), value of evacuation (VOE) and value of injury (VOI) in flood risk context, a stated preference study (III)*. VU Amsterdam: Department of Spatial Economics, 2009.

Botzen W.J.W. & Van den Bergh J.C.J. Bounded rationality, climate risks and insurance: is there a market for natural disasters? *Land Econ* 2009, **85**, (2), 265–278.

Brekelmans R.C.M., Den Hertog D. & Roos C. *Computing safe dike heights: a prototype optimization algorithm*. 2009. CentER rapport. Tilburg.

Cameron T.A. Euthanizing the value of a statistical life. In: Kolstad, C.D., ed. *Review of environmental economics and policy*. Vol. **4**, (2). Oxford: Oxford University Press, 2010, 161–178.

Commissie Toetsing Uitgangspunten Rivierdijkversterking. Toetsing Uitgangspunten Rivierdijkversterking. 1993. Advies van de Commissie.

CPB. *Four Futures of the Netherlands; production, labour and sectoral structure in four scenarios until 2040*. Den Haag: Centraal Planbureau, 2004.

De Bruijn K.M. & Van der Doef M. Gevolgen van overstromingen – Informatie ten behoeve van het project Waterveiligheid 21e eeuw. 2011. Projectnummer 1204144. Deltares, Delft.

De Grave P. & Baarse G. Kosten van maatregelen – Informatie ten behoeve van het project Waterveiligheid 21e eeuw. 2011. Projectnummer 1204144. Deltares, Delft.

Deltacommissie. Rapport Deltacommissie (6 Volumes). 's-Gravenhage: Staatsdrukkerij- en Uitgeverijbedrijf, 1960–1961.

Deltacommissie. Samen werken met water. Een land dat leeft, bouwt aan zijn toekomst. 2008. Bevindingen van de Deltacommissie 2008.

Den Hertog D. & Roos C. Computing safe dike heights at minimal costs. 2009. CentER rapport. Tilburg. Second version (March 18, 2009).

Duits M.T. OptimaliseRing – Gebruikershandleiding van een numeriek rekenmodel voor de economische optimalisatie van veiligheidsniveaus van dijkringen – Versie 2.3. 2011a. Rapport van HKV LIJN IN WATER. Lelystad.

Duits M.T. OptimaliseRing – Technische documentatie van een numeriek rekenmodel voor de economische optimalisatie van veiligheidsniveaus van dijkringen – Versie 2.3. 2011b. Rapport van HKV LIJN IN WATER. Lelystad.

Eijgenraam C. *Veiligheid tegen overstromen – Kosten-batenanalyse voor Ruimte voor de Rivier, deel 1 (CPB-document 82)*. Den Haag: Centraal Plan Bureau, 2005.

Eijgenraam C. Optimal safety standards for dike-ring areas. 2006. CPB discussion paper No. 62.

Eijgenraam C. Toetsnorm voor waterveiligheid op basis van kosten-batenanalyse. 2008. CPB Memorandum 195. 19 maart 2008.

Eijgenraam C. From optimal to practical safety standards for dike-ring areas. 2009. CPB Memorandum 213. 7 januari 2009.

Jongejan R.B. The VNK2-project: quantifying flood risks in the Netherlands. 2012. Proc. PSAM12/ESREL. 25–29 Jun. 2012, Finland, Helsinki.

Kind J. Maatschappelijke kosten-batenanalyse Waterveiligheid 21e eeuw. 2011. Projectnummer 1204144. Deltares, Delft.

Kind J., Gauderis J. & van Duinen R. Robustness of economically efficient flood protection standards. A combination of Monte Carlo and cost-benefit analysis. 2011. Poster presented at 5th International Conference on Flood Management (ICFM5), 27–29 September 2011, Tokyo, Japan. http://kennisonline.deltares.nl/product/22649.

Kuijper B., Stijnen J. & van Velzen E. Overstromingskansen – Informatie ten behoeve van het project Waterveiligheid 21e eeuw. 2011. Projectnummer 1204144. Deltares, Delft.

Ministerie van Verkeer en Waterstaat, Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, Ministerie van Landbouw, Natuur en Voedselkwaliteit. Nationaal Waterplan 2009–2015. 2009.

Pearce D.W. & Smale R. Appraising flood control investments in the UK. In: R. Brouwer & D. Pearce, eds. *Cost-benefit analysis and water resources management*. Cheltenham: Edward Elgar Publishing Limited, 2005, 71–93.

Ruijgrok E.C.M. & Bel D.J.F. Economische waardering imponderabilia: overstromingsschadekaarten. 2008. In opdracht van Delta Commissie. Witteveen + Bos, Rotterdam.

Ten Brinke W.B.M. & Bannink B.A. Risico's in bedijkte termen, een thematische evaluatie van het Nederlandse veiligheidsbeleid tegen overstromen. 2004. RIVM rapport 500799002. (English summary: Dutch dikes and risk hikes. A thematic policy evaluation of risks of flooding in the Netherlands).

Van Dantzig, D. Economic decision problems for flood prevention. *Econometrica* 1956, **24**, 276–287.

Van Dantzig, D. & Kriens, J. Het economische beslissingsprobleem inzake de beveiliging van Nederland tegen stormvloeden. 1960. In Deel 3, Bijlage JI.2 van het Rapport van de Deltacommissie.

Van den Hurk B.J.J.M., Tank A.M.G.K., Lenderink G., van Ulden A., van Oldenborgh G.J., Katsman C., van den Brink H., Keller F., Bessembinder J., Burgers G., Komen G., Hazeleger W. & Drijfhout S. New climate change scenarios for the Netherlands. *Water Sci Technol* 2007, **56**, (4), 27–33.

Wang H. & He J. The Value of Statistical Life.2010. A Contingent Investigation in China. Policy Research Working Paper 5421. The World Bank.

Appendix

Nr	Name	Existing legal standard (1/year)	Economic damage (mln euro)	Fatalities (number)	Affected persons (numnber)	Total damage (mln euro)	2050 Total damage (mln euro)	Cost 10x reduction flood prob (mln euro)	Factor total damage 2050 to cost	Optimal flood protection standard 2050 (1/year)
1-1	Schiermonnikoog	1/2000	76	0	732	85	178	18	10	1/300
2-1	Ameland	1/2000	184	1	1 930	215	448	69	6	1/300
3-1	Terschelling	1/2000	193	1	1 314	216	450	49	9	1/300
4-1	Vlieland	1/2000	27	0	468	33	68	7	10	1/300
5-1	Texel	1/4000	535	3	5 077	620	1 292	118	11	1/300
6-1	Friesland-Groningen-Lauwersmeer	1/4000	627	4	3 460	699	1 456	78	19	1/800
6-2	Friesland-Groningen-Groningen	1/4000	3 279	41	42 690	4 087	8 516	580	15	1/600
6-3	Friesland-Groningen-NoordFriesland	1/4000	2 088	24	35 089	2 688	5 601	353	16	1/700
6-4	Friesland-Groningen-IJsselmeer	1/4000	318	1	4 463	381	794	143	6	1/400
7-1	Noordoostpolder	1/4000	5 239	93	39 830	6 363	13 258	172	77	1/3000
8-1	Flevoland-Noordoost	1/4000	13 427	311	102 521	16 790	34 983	238	147	1/5200
8-2	Flevoland-ZuidWest	1/4000	19 622	475	149 543	24 672	114 169	206	554	1/9200
9-1	Vollenhove	1/1250	1 989	19	23 106	2 405	5 010	86	58	1/1700
10-1	Mastenbroek	1/2000	2 484	79	21 251	3 277	6 829	167	41	1/1600
11-1	IJsseldelta	1/2000	1 879	39	26 965	2 477	5 160	181	29	1/1400
12-1	Wieringen	1/4000	3 031	41	11 008	3 443	7 173	88	82	1/2300
13-1	Noord-Holland-Noord	1/10000	1 615	78	29 079	2 499	5 207	248	21	1/1200
13-2	Noord-Holland-Westfriesland	1/10000	10 716	216	158 213	14 143	29 467	270	109	1/4000
13-4	Noord-Holland-Waterland	1/10000	4 258	58	76 227	5 598	11 663	259	45	1/2500
13b-1	Marken	1/1250	76	1	1 693	104	217	22	10	1/400
14-1	Zuid-Holland-Kust	1/10000	21 905	857	397 858	32 619	67 961	313	217	1/9300
14-2	Zuid-Holland-NweWaterweg-West	1/10000	643	6	6 146	762	1 587	39	41	1/1700
14-3	Zuid-Holland-NweWaterweg-Oost	1/10000	13 373	3 131	133 677	36 022	75 052	348	216	1/13700
15-1	Lopiker- en Krimpenerwaard	1/2000	21 356	1 105	171 377	30 899	64 378	355	181	1/8900
16-1	Alblasserwaard en de Vijfheerenlanden	1/2000	21 844	2 536	160 814	40 844	85 099	768	111	1/5200
17-1	IJsselmonde	1/4000	6 332	592	90 363	11 430	23 814	296	80	1/4200
18-1	Pernis	1/10000	764	698	4 515	5 499	11 456	47	244	1/12300
19-1	Rozenburg	1/10000	491	17	10 759	738	1 537	92	17	1/500
20-1	Voorne-Putten-West	1/4000	2 341	112	41 013	3 606	7 514	100	75	1/3530
20-2	Voorne-Putten-Midden	1/4000	930	43	16 022	1 418	2 955	55	54	1/3000
20-3	Voorne-Putten-Oost	1/4000	4 639	567	67 449	9 281	19 337	78	248	1/9300

Appendix *Continued*

Nr	Name	Existing legal standard (1/year)	Economic damage (mln euro)	Fatalities (number)	Affected persons (numnber)	Total damage (mln euro)	2050 Total damage (mln euro)	Cost 10x reduction flood prob (mln euro)	Factor total damage 2050 to cost	Optimal flood protection standard 2050 (1/year)
21-1	Hoekse Waard	1/2000	842	40	11 464	1 253	2 610	224	12	1/600
22-1	Eiland van Dordrecht	1/2000	4 218	312	39 995	6 807	14 183	293	48	1/2500
24-1	Land van Altena	1/2000	2 840	213	26 582	4 601	9 586	175	55	1/2100
25-1	Goeree-Overflakkee-Noordzee	1/4000	302	6	4 444	400	834	36	23	1/1500
25-2	Goeree-Overflakkee-Haringvliet	1/4000	92	2	1 183	121	251	77	3	1/200
26-1	Schouwen Duiveland-West	1/4000	515	9	4 092	630	1 312	26	50	1/2400
26-2	Schouwen Duiveland-Oost	1/4000	1 322	49	11 233	1 793	3 735	54	69	1/3100
27-1	Tholen en St Philipsland	1/4000	934	66	8 722	1 486	3 097	81	38	1/1600
28-1	Noord-Beveland	1/4000	244	4	2 262	301	626	36	17	1/800
29-1	Walcheren-West	1/4000	307	5	5 481	411	855	81	11	1/700
29-2	Walcheren-Oost	1/4000	3 748	184	48 972	5 591	11 648	182	64	1/2500
30-1	Zuid-Beveland-West	1/4000	1 485	179	14 103	2 857	5 953	325	18	1/700
31-1	Zuid-Beveland-Oost	1/4000	1 145	132	5 488	2 100	4 375	261	17	1/1100
32-1	Zeeuwsch Vlaanderen-West	1/4000	802	11	3 744	919	1 915	280	7	1/200
32-2	Zeeuwsch Vlaanderen-Oost	1/4000	1 362	110	17 101	2 314	4 822	513	9	1/400
34-1	West-Brabant	1/2000	1 192	16	3 615	1 342	2 797	200	14	1/600
34a-1	Geertruidenberg	1/2000	600	29	6 039	873	1 818	32	57	1/2000
35-1	Donge	1/2000	3 488	206	37 391	5 334	11 113	120	93	1/2800
36-1	Land v Heusden/de Maaskant	1/1250	17 615	221	184 127	21 394	44 575	277	161	1/4100
36a-1	Keent	1/1250	13	3	64	35	74	6	12	1/300
37-1	Nederhemert	1/1250	9	1	32	16	34	4	9	1/400
38-1	Bommelerwaard-Waal	1/1250	15 021	189	97 477	17 506	36 474	172	212	1/7500
38-2	Bommelerwaard-Maas	1/1250	4 910	63	42 620	5 865	12 220	86	142	1/4600
39-1	Alem	1/1250	76	14	479	174	362	27	13	1/500
40-1	Heerenwaarden-Waal	1/2000	4 375	66	49 036	5 431	11 315	13	870	1/29300
40-2	Heerenwaarden-Maas	1/500	87	6	1 159	144	300	24	13	1/500
41-1	Land van Maas en Waal-Waal	1/1250	15 817	201	178 164	19 387	40 394	261	155	1/6200
41-2	Land van Maas en Waal-Maas	1/1250	4 946	61	54 094	6 030	12 564	164	77	1/3000
42-1	Ooij en Millingen	1/1250	4 426	104	40 732	5 632	11 734	287	41	1/1500
43-1	Betuwe, Tieler- en C'waarden	1/1250	28 894	344	223 311	33 993	70 824	850	83	1/2700
44-1	Kromme Rijn-Rijn	1/1250	35 112	356	481 004	43 509	90 652	82	1 106	1/41800
44-2	Kromme Rijn-Meren	1/1250	529	4	5 696	628	1 308	72	18	1/700
45-1	Gelderse Vallei-Rijn	1/1250	22 680	298	261 556	27 947	58 228	14	4 159	1/159600
45-2	Gelderse Vallei-Meren	1/1250	211	2	5 560	294	613	70	9	1/200
47-1	Arnhemse- en Velpsebroek	1/1250	4 119	63	33 887	4 965	10 345	103	100	1/7000
48-1	Rijn en IJssel-Boven	1/1250	17 174	362	174 682	21 785	45 388	304	149	1/5400
48-2	Rijn en IJssel-Beneden	1/1250	8 452	125	97 792	10 511	21 900	116	189	1/9000
49-1	IJsselland	1/1250	547	3	4 097	619	1 289	92	14	1/800
50-1	Zutphen	1/1250	2 538	33	32 969	3 168	6 601	35	189	1/8700
51-1	Gorssel	1/1250	276	1	4 802	343	714	45	16	1/1100
52-1	Oost Veluwe	1/1250	1 546	13	21 550	1 899	3 957	203	19	1/1000
53-1	Salland	1/1250	8 203	200	91 201	10 680	22 251	283	79	1/2900