The use of individual and societal risk criteria within the Dutch flood safety policy

- nationwide estimates of societal risk and policy applications

Abstract:

The Dutch government is in the process of revising its flood safety policy. The current safety standards for flood defences in the Netherlands are largely based on the outcomes of cost-benefit analyses. Loss of life has not been considered separately in the choice for current standards. This article presents the results of a research project that evaluated the potential roles of two risk metrics, individual and societal risk, to support decision-making about new flood safety standards. These risk metrics are already used in the Dutch major hazards policy for the evaluation of risks to the public. Individual risk concerns the annual probability of death of a person. Societal risk concerns the probability of an event with many fatalities. Technical aspects of the use of individual and societal risk metrics in flood risk assessments as well as policy implications are discussed. Preliminary estimates of nationwide levels of societal risk are presented. Societal risk levels appear relatively high in the South Western part of the country where densely populated dike rings are threatened by a combination of river and coastal floods. It was found that cumulation, the simultaneous flooding of multiple dike rings during a single flood event, has significant impact on the national level of societal risk. Options for the application of the individual and societal risk in the new flood safety policy are presented and discussed.

Key words: flood risk; loss of life; quantitative risk analysis; risk evaluation, individual risk, societal risk

1 INTRODUCTION

Flood protection is of paramount importance to the low-lying Netherlands. The Dutch government is currently in the process of updating its flood risk management policy. The Water Act of 2009 (previously the Flood Defence Act of 1996) lays down the exceedance probabilities of the hydraulic loading conditions that the primary flood defences should be able to safely withstand. Policymakers increasingly voice the need for an integrated flood safety policy, in which flood probabilities (other than exceedance probabilities of loading conditions) and flood consequences are mitigated in conjunction. EU Directive 2007/60/EC, the report of the Second Dutch Delta Committee[1] [(1)], and the recently published Dutch national water plan[(2)] all stress the need for evaluating flood probabilities and consequences in an integrated manner in a risk-based policy. In the year 2011 new flood safety standards will be defined, based on risk assessment.

Current flood safety standards are largely based on the outcomes of cost-benefit analyses. In such analyses, the sum of the discounted investments in flood defence and the discounted expected value of future losses is minimized to determine an optimal level of protection[(3)]. Various intangible losses, including loss of life, are valued in monetary terms and included in the financial balance. To inform decision-making about new flood safety standards, a new cost-benefit analysis has been commissioned by the Dutch government[(4)]. This focus on the economics of flood safety seems understandable given the costs of flood risk mitigation and the enormous economic impact of large-scale floods. On the 29th of August 2005, Hurricane Katrina struck the US Gulf Coast. The levee system protecting New Orleans proved no match for the ensuing storm surge and large parts of the low-lying city were flooded. With damages totaling 138 billion US dollar, Katrina is the costliest natural disaster to date[(5)]. Floods on the scale of

New Orleans are not unthinkable in the Netherlands, a country with broadly similar topographical characteristics as the Mississippi delta[6].

Apart from economic losses, floods can cause severe societal disruption and loss of life: over 1100 people lost their lives due to Hurricane Katrina. The Dutch government has indicated that it will explicitly and separately consider potential loss of life when deciding on the stringency of new flood safety standards. [2] In another policy domain, concerned with the safety of those living in the vicinity of major industrial hazards, loss of life *is* already explicitly taken into account in the evaluation of risks to the public. [7] Two risk metrics are used: individual and societal risk. Individual risk refers to the probability of an individual at a certain location getting killed by an accident, while societal risk concerns the probability of an accident with a large number of fatalities. To support the formulation of a new flood safety policy, the Dutch government commissioned a study about the opportunities for transferring the approach used in the Dutch major hazards policy to the domain of flood safety.[8]

The emphasis on risk in the formulation of a new flood safety policy has led to a demand for quantitative estimates of the risks to life in all flood prone areas in the Netherlands, the so-called dike rings. Ideally, such estimates would be based on detailed risk assessments. Unfortunately, detailed risk estimates are only available for a limited number of areas, see e.g. [9] for an elaboration for dike ring area South Holland. Detailed risk analyses are currently being carried out for all flood prone areas in the Netherlands in the Flood risk and safety (FLORIS) project, a study commissioned by the Dutch Ministry of Transport, Public Works and Water Management in cooperation with water boards and provinces. The complete results of the FLORIS project will not come available until after the year 2011. Hence, well-founded risk estimates for all flood prone areas in the Netherlands are unavailable at this stage. In order to give a first and preliminary indication of the level of flood (fatality) risk in the Netherlands, it was therefore decided to use an approach that combines information from a limited number of detailed risk analyses with other data sources and expert judgment.[10]. Estimates of societal risk have been presented for all dike rings in the country. As levels of individual risk are highly dependent on local flood conditions and topography, it proved troublesome to estimate individual risks throughout low-lying regions without detailed information from flood scenario calculations. As such information was unavailable, no nationwide estimates are presented for individual risk.

This remainder of this article is organized as follows. Section 2 provides background information on the individual risk and societal risk metrics used within the Dutch major hazards policy. The second part provides insight in methods for the quantification of individual and societal risks in the domain of flood safety and presents the results of nationwide estimates of societal risk (section 3). The effects of several measures on the risk levels are evaluated in section 4. The final part (section 5) then discusses institutional consequences of alternative uses of individual and societal risk criteria within a flood safety policy. Concluding remarks for the whole study are discussed in section six.

2 RISK METRICS USED WITHIN THE DUTCH MAJOR HAZARDS POLICY

The Dutch major hazards policy deals with the risks to those living in the vicinity of major industrial hazards such as chemical plants and LPG-fuelling stations. The development of the Dutch major hazards policy was strongly incident driven, as were European efforts aimed at the prevention of major industrial accidents.[11] After a number of severe industrial accidents, including the Bhopal accident in 1984 which killed an estimated 3000 people and severely injured over 200.000 [12], a European directive was drafted concerning the prevention of major accidents: the 1982 Seveso Directive. This was later replaced by the Seveso II Directive.[13] It covers a wide range of topics, ranging from plant safety requirements to inspection and land-use planning provisions. Because member states have had considerable freedom in implementing the directive, various types of major hazards policies can be found throughout the European Union. These can be grouped into two broad categories (after [14,15]): effect-based approaches (e.g. Germany, France before the Toulouse accident) and risk-based approaches (e.g. UK, France after the Toulouse accident). While effect-based approaches use reference scenarios for evaluating risk acceptability, risk-based approaches consider a wide range of accident scenarios together with their probabilities. Under the latter approach, accident probabilities are an integral and explicit part of decisions on the acceptability of risks. The Dutch major hazards policy has remained firmly risk-based ever since its foundations were laid by the annex Premises for Risk Management in 1999.[16]

The cornerstones of the Dutch major hazards policy are (i) quantitative risk analysis, (ii) individual and societal risk as risk-determining parameters and (iii) quantitative acceptability criteria for evaluating levels of individual and societal risk. [7,17,18] Individual risk is defined as the probability of death of an average, unprotected person that is constantly present at a given location.

Individual risk criteria are reference levels for evaluating individual risks. The individual risk criteria were given a legal status in 2004 by the External Safety Decree. These limits to individual risk prevent disproportional individual exposures. Permits for property developments or plant modifications are denied if vulnerable objects would then be located within the 10^{-6} contour (Fig. 1).

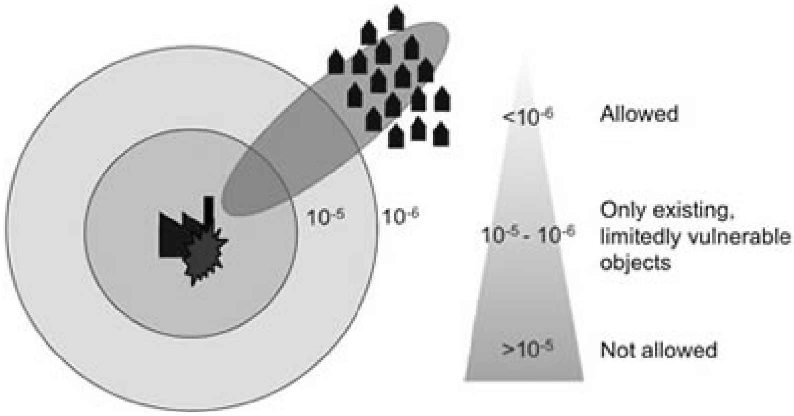


Figure 1: Individual risk contours around a hazardous establishment and the area affected by an individual accident scenario

An individual risk criterion alone cannot prevent the too frequent occurrence of multi-fatality accidents. As shown in Figure 1, the area affected by an accident can differ considerably from the area that is defined by an iso-(individual)risk contour. When individual exposures are low, there could still be a chance that a single accident kills a large number of people. While a vast number of small accidents can go by largely unnoticed, multi-fatality accidents can shock a nation. Psychometric studies have indeed shown that “dread”, or catastrophic potential, is an important factor in explaining risk perceptions.[(19)] To prevent the too frequent occurrence of large-scale accidents, societal risk criteria were implemented in the Netherlands. Societal risk refers to the probability of an accident with multiple fatalities. In general, it is graphically represented by an FN-curve that shows the exceedance probabilities of the potential numbers of fatalities ($P(N \geq n)$) on double log scale (Fig. 2).

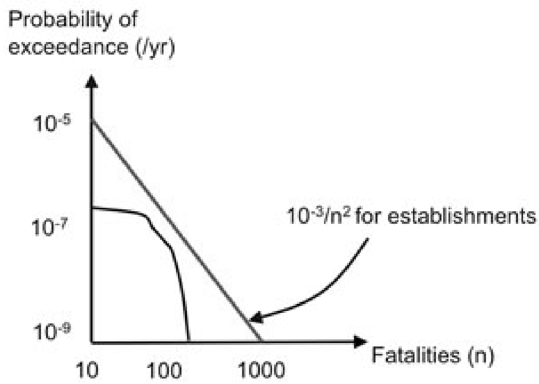


Figure 2: The Dutch societal risk criterion for hazardous establishments and a fictitious FN-curve

The Dutch societal risk criterion of $10^{-3}/n^2$ per installation per year was initially developed for LPG-fuelling stations. It was later applied to all Seveso establishments. Similar societal risk criteria thus apply to hazardous establishments of different character and size despite considerable differences between the marginal costs of risk reduction in different cases (see [20] for further discussion).

Because the outcomes of quantitative risk analyses for low-probability industrial accidents are subjected to considerable uncertainty, the position of risk contours varies of orders of magnitude, depending on engineering judgment and model used [21]. Since the outcomes of quantitative risk analysis (QRA) play an important role in the Dutch major hazards policy, such variability is troublesome for licensing purposes (land-use permits and operating permits). It was therefore decided to prescribe the use of a single risk model with little scope for interpretation on the part of risk analysts.[22] This, however, limits the opportunities for tailor-made risk analyses based on site-specific information.

3 NATIONWIDE ESTIMATES OF SOCIETAL RISK

3.1 Background: Flood risk assessment and risk metrics

Methods for the analysis of flood risk generally include three main steps: (1) determination of the probability of flooding; (2) simulation of flood characteristics; and (3) assessment of the consequences (e.g. [23]). The implementation of these steps in flood risk assessment studies in the Netherlands has been described in detail in [9,24,25]. Such methods for flood risk generally include the following steps (1) determination of the probability of flooding; (2) simulation of flood characteristics; and (3) assessment of the consequences [9]. Based on the results of the risk analysis different risk metrics can be calculated, such as the expected number of fatalities or the expected economic damage. The risks to life for flooding can also be quantified with the metrics that are also used in the major hazards policy. Following the definition that is used in the Dutch major hazards policy (see section 2), IR is determined for a person that is constantly present at a given location. The calculated IR is a property of a certain location and it can be used for risk-based land use planning. Disasters that fall within the scope of the major hazards policy, e.g. explosions, toxic releases and airplane crashes, are generally characterized by very limited possibilities for evacuation. It is therefore a reasonable assumption to ignore the effectiveness of evacuation in these risk analyses. The possibilities for evacuation could be significant when it comes to floods. It could thus be relevant to include the effects of evacuation in the quantification of IR for floods. An alternative definition of individual risk could be used that refers to the probability of death of a person at a location including the effectiveness of evacuation. In addition the societal risk level for flooding can quantified based on probability and consequence estimates for a set of flood scenarios. The results can be shown by means of an FN-curve.

3.2 Nationwide estimates of Societal Risk: Approach

The results of detailed flood risk analyses are expected after the year 2011, but policymakers wanted to gain insight in the severity of fatality risks well before that date in the context of policy development. A study was therefore commissioned to estimate nationwide levels of societal risks.[10] A simplified procedure was therefore designed to estimate societal risks from floods on the basis of available data. It rests on the following assumptions:

- In case of flooding, at least one person is killed. The probability of flood therefore equals the probability of at least one fatality
- The conditional distribution of the number of fatalities is exponential. This implies that larger numbers of fatalities are increasingly less likely in case of flood.

The first assumption seems relatively uncontroversial as failures of primary flood defences are low-probability, high-impact events. The second assumption is based on the observation that the three available FN-curves that were derived from detailed risk estimates [9,26] match this assumption relatively well. Figure 3 shows the comparison for the calculated FN-curve for one dike ring area (South Holland) with the exponential approximation. The difference between the expected value of the number of fatalities calculated on the basis of the actual FN-curve and the exponential approximation was negligible. The standard deviations differed by only 2.6%. Comparison of the approximation with the calculated FN-curves for two other areas presents a broadly similar picture. Although the second assumption is obviously coarse, an assumption regarding the shape of FN-curves is unavoidable if we are to estimate FN-curves for all dike rings on the basis of currently available data.

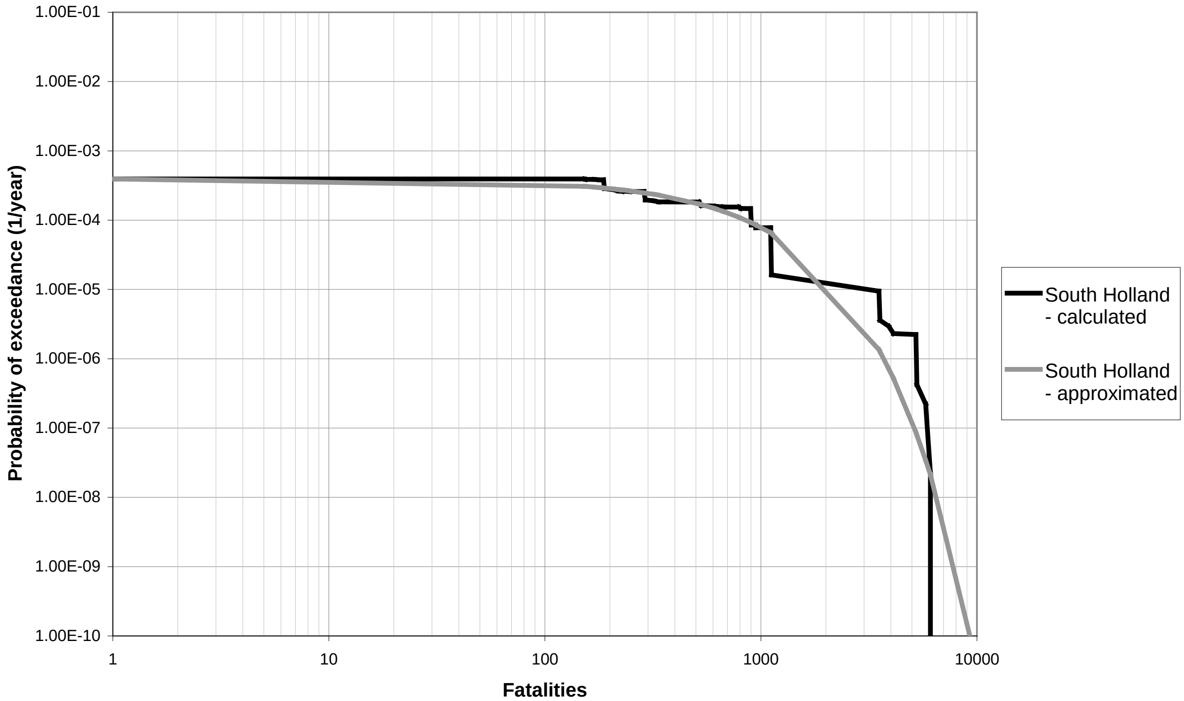


Figure 3: Comparison between the calculated FN-curve for South Holland (black line) with the approximation by means of the exponential distribution (grey line)

The FN-curve with the exponential distribution is given by:

$$P(N \geq n) = P_f \cdot e^{-\frac{(n-\xi)}{\sigma}} \quad \text{for } n \geq \xi \qquad (1)$$

where: $P(N \geq n)$ = probability of n or more fatalities [per year]; P_f = probability of flood [per year]; ξ = threshold value that determines the starting point of the exponential distribution; σ = standard deviation of the number of fatalities given flood [-].

The threshold value ξ equals the minimum number of fatalities in case of flood. It has been assumed that at least one person is killed in case of flood. Since the number of fatalities is an integer, both ξ =0 and ξ =1 would match this assumption. Here, a value of ξ =0 was chosen. In that case, the expected number of fatalities given a flood equals the standard deviation, i.e. $\mu=\sigma$. Estimating FN-curves now requires only two figures per dike ring: an estimate of the probability of flood, and an estimate of the average number of fatalities in a flood. The procedures for these estimates are presented in the next section.

Given the approach used the outputs are relatively uncertain, since no detailed risk estimates are available to validate the outcomes for all dike rings. It is expected however that the approach will provide useful insight in the levels of societal risk. The approach will be most accurate at estimating relative differences in societal risk levels between dike rings as the relevant factors (strength of the flood defences system, number of inhabitants, potential for evacuation and mortality) are taken into account in the estimates. Moreover, the procedures for estimating the failure probability and expected consequences given flooding have been thoroughly reviewed as part of several earlier nationwide policy studies on flood risks in the Netherlands. [27,28]

3.3 Input information: flood probabilities and fatalities

3.3.1 Flood probability

For estimates of the flood probabilities, information was used from a large ongoing government project, Water Safety in the 21st Century.[4] In that study, flood probabilities were determined for all dike rings in the Netherlands. It was assumed that the flood defences comply to the current safety standards (based on probabilities of exceedance) and that this situation corresponds to the situation in the year 2015. The resulting flooding probabilities per dike ring are shown in figure 4. The probabilities are somewhat lower than the existing safety standards as it was assumed that the actual critical overtopping discharge that the dikes are able to withstand (5 l/s/m) is somewhat higher than the current design criterion for overtopping discharge (1 l/s/m). [29]

Figure 4: Estimated flooding probabilities (the numbers in the areas refer to the numbers that are included to indicate dike rings in the Flood Defence Act)

3.3.2 Number of fatalities by dike ring

The number of fatalities can be calculated according to:

$$N = N_{PAR} F_{EXP} (1 - F_E) F_D \qquad (2)$$

where: N = number of fatalities [-]; N_{PAR} = number of people in the dike ring [-]; F_{EXP} = fraction of the total population in the flooded area [-]; F_E = fraction of people evacuated [-]; F_D = mortality i.e. the percentage of people killed by the flood [-].

In order to estimate the expected number of fatalities given flooding, average values for these parameters were estimated on the basis of available data and expert judgment. The number of people in the dike ring (N_{PAR}) approximately equals the number of inhabitants, This quantity has been obtained from national population datasets. Due to variations in elevation and limitations in inflowing water a flood event will generally not flood the whole dike ring area and thus not affect the entire population. The fraction of the population that is in the flooded parts of the dike ring (F_{EXP}) is estimated based on available information on flood scenarios, elevation and population.[(27)] The fraction of the people evacuated has been determined from a nationwide study on evacuation fractions per dike ring [(30)] in which traffic models have been applied to estimate the time required for evacuation. For the estimation on the mortality (F_D) flood events were grouped into three broad categories. These are defined by the severity of the flood, water depths and/or flow velocities, and to what extent the flood comes unexpected, with little or no warning. The three categories are:

- Dike ring with severe flooding (large water depths, high flow velocities, unexpected): mortality equals 1%, so F_D=0.01; This is the estimate used for dike rings along the coast.
- Dike rings with some warning time but still extensive flooding: mortality is assumed 0.7%; dike rings that are both influenced by sea and river.
- Dike rings with long warning time and to some extent expected flood: mortality 0.5%; dike rings along rivers.

These estimates on event mortality have been based on available detailed risk studies for individual areas.[(26)] Combining the above variables according to equation (2) yields estimates for the expected number of fatalities given flooding. The results for all dike rings are shown in figure 5.

Figure 5: Expected number of fatalities given flooding by dike ring

3.4 Results of nationwide estimates of societal risk

Based on the method and input data presented in sections 3.2 and 3.3 FN-curves were estimated for the dike rings in the Netherlands. The results are shown in figure 6. Each curve represents the FN-curve for one dike ring and the number refers to the dike ring numbers included in the Flood Defence Act (see figure 4 or 5).

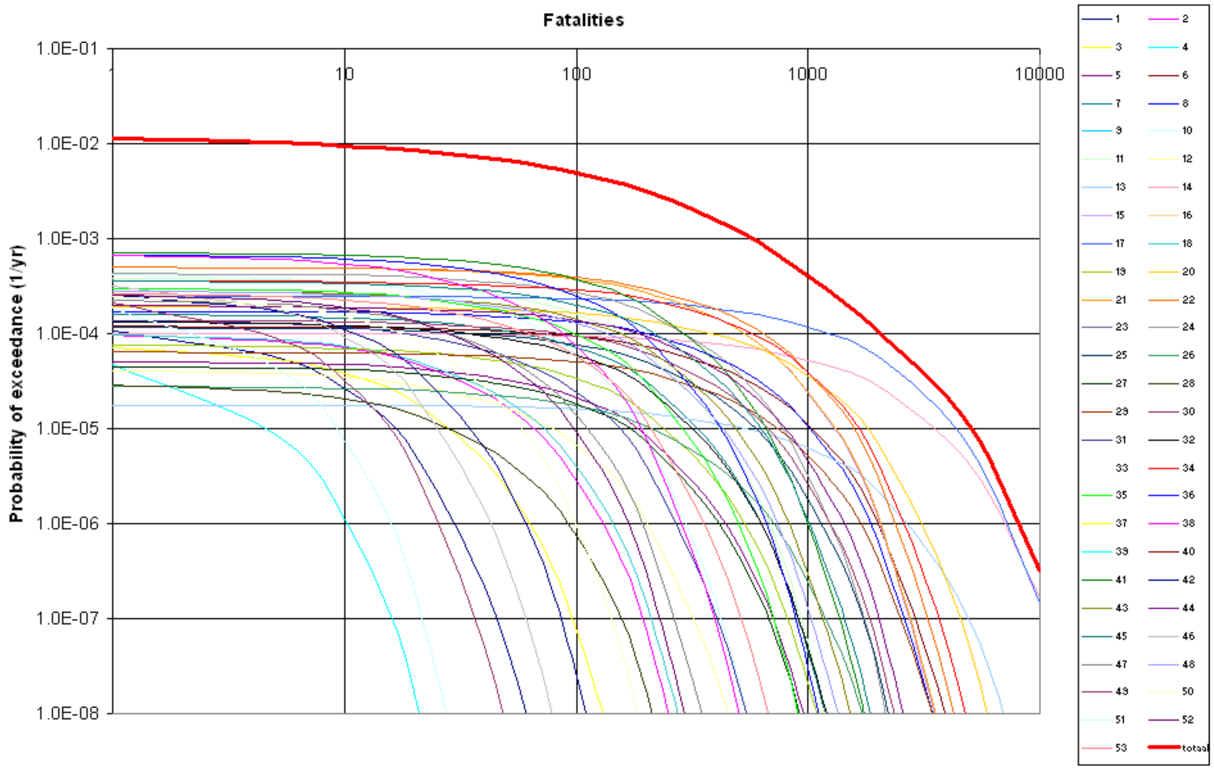


Figure 6: FN-curves for individual dike rings and the total FN-curve for flooding for the Netherlands.

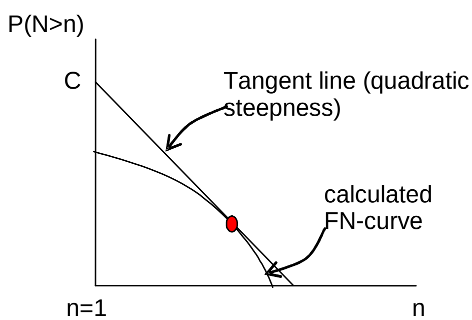
The national level of societal risk is shown as a bold line and has been estimated by vertically adding the FN-curves of the individual dike rings. This implies (as a first approximation) that floods in different dike rings are mutually exclusive events. This assumption is further discussed in section 3.5.

As part of the investigation, the societal risk levels of different dike rings were analysed and compared. For decision-making purposes it is relevant to provide insight into the areas where societal risks are highest and the areas that contribute strongly to the national level of societal risk. Two dimensions, i.e. exceedance probabilities and consequences, determine the level of societal risk of a dike ring. For reasons of presentation and communication the level of societal risk for each dike ring was characterized by means of a single value: the point where a tangent line with the calculated FN-line crosses the y-axis of the FN-curve (see figure 7). The tangent line has the following general formulation:

$$P(N \geq n) = C / n^{\alpha} \qquad (3)$$

where: $P(N \geq n)$ = probability of exceedance of n fatalities [per year]; C = constant that determines the point where the tangent line crosses the y-axis of the FN-curve [per year]; α = steepness of the tangent line;

It should be noted that this formulation is exactly the same as the typical formulation of an FN-limit line [(9)] – see also section 5. The tangent line that is found for a certain area thus equals the limit line for which the situation would just be acceptable. The value of constant *C* thus represents the vertical position of the tangent line. A quadratic steepness of the tangent line (α=2) was chosen because the same slope is used within the Dutch major hazards policy. This is a risk averse criterion and it is expected that this value will be used in further discussions



about flood safety.

Figure 7: Determination of the tangent line and constant C for a calculated FN-curve

C-values were determined for the Dutch dike rings, see figure 8 for the results. For most of the dike rings, the events with fatalities in the range between 100 en 10,000 fatalities determined the

C-values. Table I provides more detailed information for the eight dike rings with the highest *C*-values.

Figure 8: *C*-values for dike rings in the Netherlands (indicating the relative level of societal risk).

Table I: Overview of dike rings with the highest societal risk levels and C-values.

nr.	Name	flooding probability	expected number of fatalities	C-value
17	IJsselmonde	$2.5 x10^{-4}$	1341	150
14	Zuid-Holland	$1.0 x10^{-4}$	1566	103
22	Eiland van Dordrecht	$5.0 x10^{-4}$	393	39
34	West-Brabant	$3.57x10^{-4}$	452	39
20	Voorne-Putten	$1.92 x10^{-4}$	600	36
16	Alblasserwaard & Vijfheerenlanden	$5.0 x10^{-4}$	332	28
21	Hoeksche Waard	$5.0 x10^{-4}$	332	28
15	Lopiker en Krimpenerwaard	$5.0 x10^{-4}$	328	27

From figure 8, it can be seen that dike rings in the southwestern part of the Netherlands have relatively high levels of societal risk. This is due to the fact that these dike rings are densely populated, and that there is limited time for evacuation as the coastal floods that threaten these areas cannot be predicted well in advance. As part of the investigation, the relationship between the C-values and the probability and consequence estimates was analysed.

This shows that there is a weak relationship between the C-value and the flooding probability estimates. A much stronger relationship exists between the C-value and the consequence estimates. This is not surprising as a) the differences between the probability estimates for most of the dike rings are relatively small ; b) the consequences have a quadratic influence due to the choice for a quadratic tangent line. Further investigation did not reveal a strong, persistent relationship between the C-value and the underlying factors that influence the consequences of floods, such as the number of inhabitants, the size of the area at risk, or the population density. The estimates of the number of fatalities depend on dike ring specific combinations of these factors.

A sensitivity analysis was carried out using a different steepness of the tangent line ($\alpha=1$). This steepness corresponds to an FN-criterion that places equal weight on exceedance probabilities and numbers of fatalities. This type of FN-criterion is often indicated as risk-neutral. With $\alpha=1$, the group of the eight dike rings with the highest C-values remains the same, although the ranking within this group becomes somewhat different.

3.5 Societal risk and cumulation

In the determination of the national level of societal risk, the possibility that floods occur simultaneously in different dike rings should be taken into account. Experience from historical floods, both in the Netherlands and abroad, shows that multiple dike rings are likely to flood simultaneously under extreme conditions. For example, in the big flood of 1953, approximately 140 breaches occurred at approximately 10 of the (current) dike ring areas. In the insurance industry, the effect of correlations between individual loss experiences on the distribution of overall losses is called cumulation. It is relevant for the estimation and evaluation of societal risks. Due to the simultaneous flooding of multiple dike rings, the consequences of a single flood event will increase.

Figure 9 shows the difference between the FN-curves for a simple system of two dike rings for a situation without cumulation (flooding of the areas is mutually exclusive - left) and with cumulation (flooding of dike rings is fully dependent - right). Each dike ring has flooding probability P and consequences N. In case of perfect correlation, the consequences will be larger than in the base case where failures are assumed to be mutually exclusive. Note that the probability of *a* flood is lower when failures of perfectly correlated.

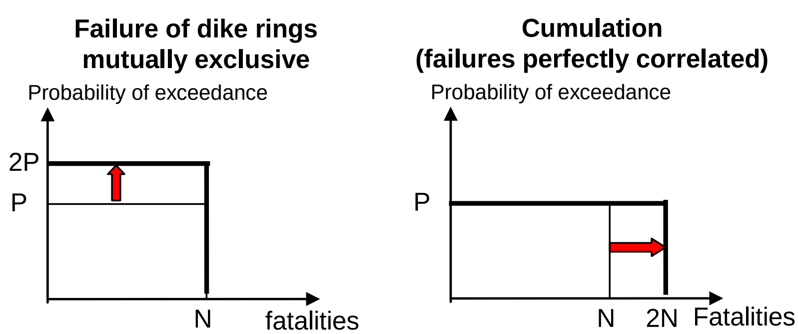


Figure 9: The effect of cumulation on the FN-curve

A full scale analysis of cumulation would require a complex probabilistic model that takes into account the development of flood waves in a system, as well as the dependencies and interactions between failures of dike rings.(31) As such a model was unavailable at the time, the following simplified approach was used to produce conservative estimates of the effect of cumulation. The dike rings in the Netherlands are located in different hydrological systems. Dike rings in the coastal zone can be flooded by storm surges, whereas the dike rings above the tidal limit are threatened only by rivers. The latter area is referred to as the “bovenrivierengebied”. The dike rings below the tidal limit are threatened by both river and coastal floods and this area is indicated as the “benedenrivierengebied”. In total, there are five hydrological subsystems in the Netherlands. Figure 10 shows these different subsystems and the dike rings located within each subsystem. The effect of cumulation was estimated by assuming that all dike rings within a subsystem will flood simultaneously. In that case, the consequences at the national level are equal to the sum of the consequences for the individual dike rings. This implies that the FN-curves for the individual dike rings should be added horizontally. This is a somewhat conservative approach, and further studies are currently being carried out to refine the estimates presented in this article.

Figure 10: Dike rings in the five hydrological subsystems in the Netherlands

Figure 11 shows the FN-curves for each subsystem, and the total FN-curve that would be found by (vertically) summing the risks for the subsystems (bold line – thus assuming that flooding of subsystems are mutually exclusice). The analysis shows that the national total for larger numbers of fatalities (more than 500) is largely determined by the areas below the tidal limit (the "benedenrivierengebied") that are threatened by both coastal and river floods. The resulting national societal risk line (bold) is compared with the national societal risk line that would result if cumulation would not be taken into account (the dashed grey line). It is clear that the curve with cumulation shows higher consequences. Especially if a risk averse evaluation criterion is used, such as an FN-limit line with a quadratic steepness, cumulation could significantly influence risk appraisal.

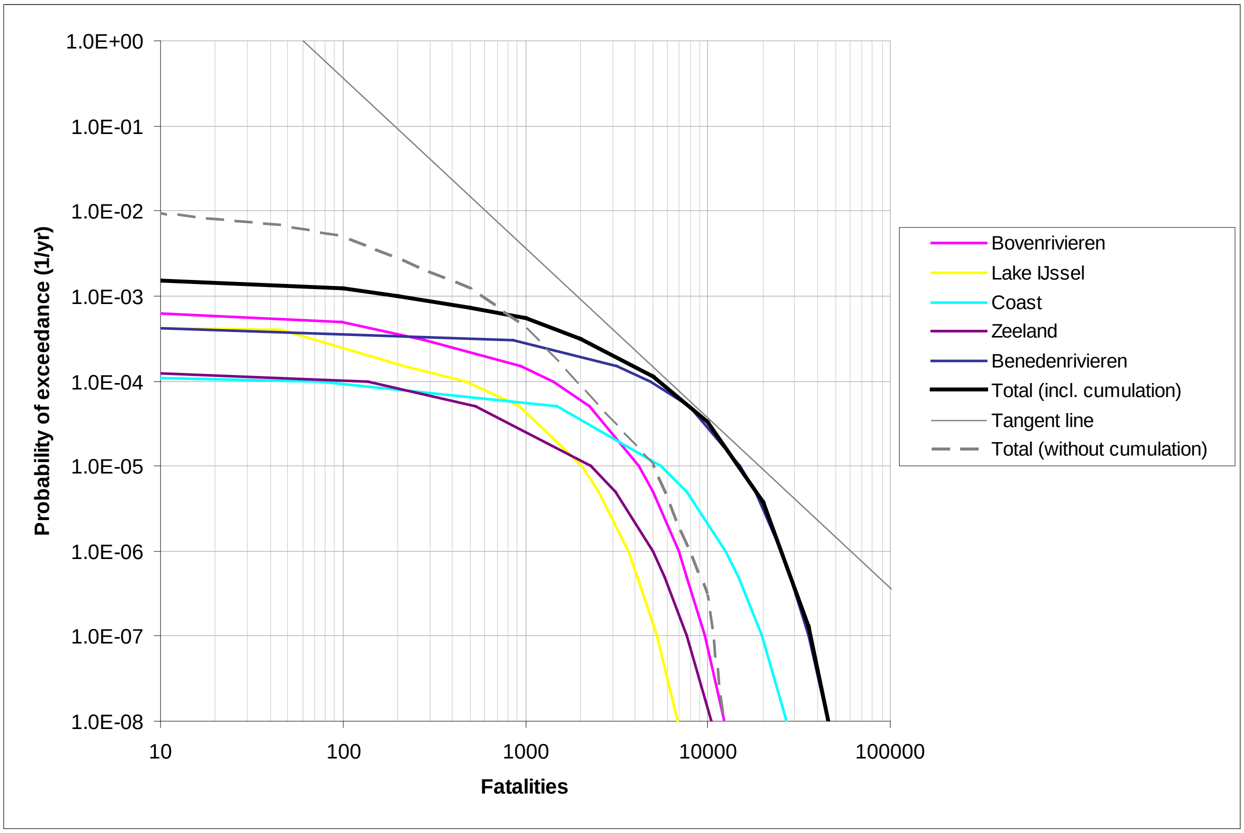


Figure 11: FN-curve for the five subsystems from figure 10 (including cumulation within subsystems) and at a national scale (assuming floods in different subsystems are mutually exclusive events)

4 THE EFFECTIVENESS OF STRATEGIES FOR MITIGATING FLOOD RISKS

As part of the discussion on the role of individual and societal risk in the new flood safety policy it was also desired to have insight in the effects of several interventions on the level of risk. Broadly speaking, there are three types of strategies to reduce flood risks:

- *Reducing flood probabilities*. Measures include dike strengthening, beach nourishment, and widening of rivers to increase their runoff capacity.
- *Reducing the consequences of floods*. Measures include flood proofing of buildings and infrastructure, improving the opportunities for evacuation (early warning, constructing shelters, etc.), safety zoning, and splitting dike rings into smaller compartments.
- *A combination of the above*.

FN-curves and individual risk maps are useful tools for demonstrating the effects of a wide variety of risk reduction measures on fatality risks. They can thereby be used to facilitate the evaluation of alternative flood risk management strategies.

The effects of several interventions have been analysed for one flood prone area for which detailed risk estimates are available. The estimates of the individual and societal risk for this area, South Holland, are presented in [(9)]. These estimates were used to illustrate the effects of several measures on fatality risks. The effects of interventions were quantified on the basis of available studies and expert judgment. These are rough assumptions and further quantitative (risk) studies are recommended to provide more detailed insight in the effectiveness of risk reduction measures.

Figure 12 shows the FN-curve in the reference situation for the dike ring South Holland in the Netherlands [9] and the effects of two risk reduction strategies. Strategy one concerns the reduction of the flooding probability by a factor of 10 due to dike strengthening. For example, for riverine areas this could be achieved by heightening dikes by about 1 meter and by widening of the dikes. Because the failure probability of every dike section is assumed to be lowered by the same factor, the FN-curve shifts downwards without changing shape. The second strategy concerns the construction of compartment dikes within a dike ring. In that case the consequences can be significantly reduced, as the exposed area and population are limited. However, there are cases in which compartmentalizing dike rings can also raise fatality risks, as rise rates and water depths in smaller compartments exceed those in larger compartments. In this case it has been assumed that the compartmentalization is highly effective and reduces the loss of life by 50%. Reducing the consequences of floods will cause the FN-curve to shift to the left.

The third strategy concerns the improvement of the opportunities for evacuation. The effectiveness of such a strategy is shown in figure 12. FN-curves are depicted for two situations: the reference situation and a situation in which the probability of successful evacuation and the evacuation rate are relatively high. Every evacuation rate has been assigned a probability by means of an event tree (see reference 9 for details). As shown by figure 12, the tail of the FN-curve cannot be avoided by efforts to improve early warning or disaster preparedness. This is because the probability of a failed evacuation stays non-zero.

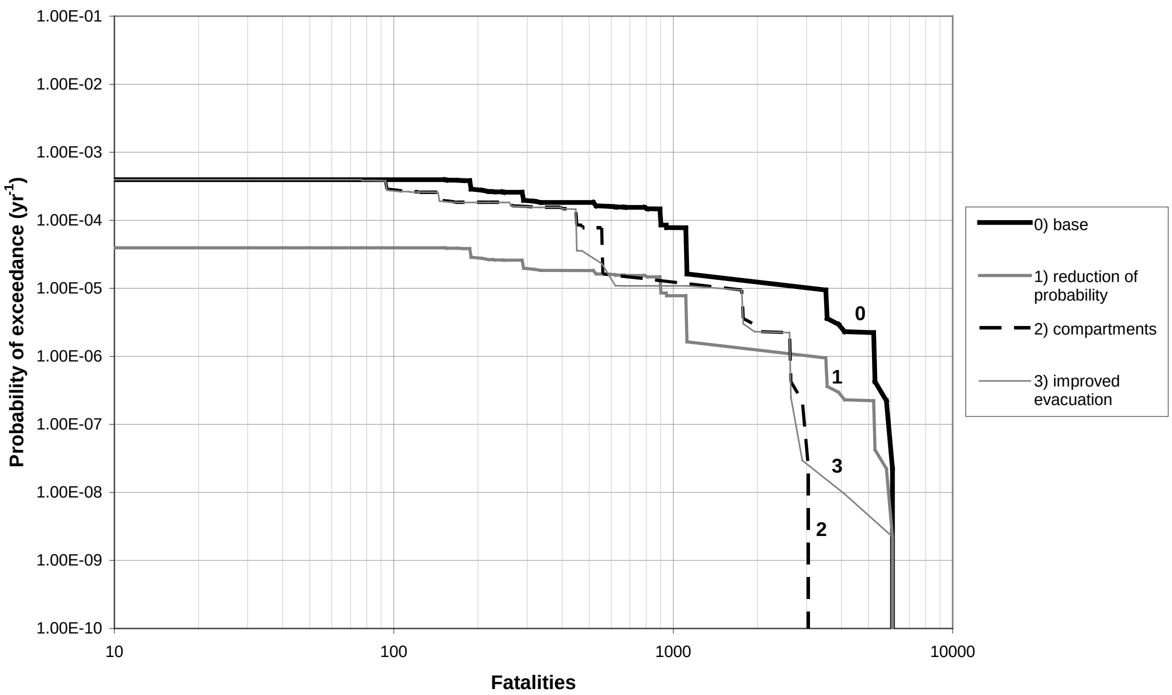


Figure 12: The impact of the strategies 1) dike strengthening; 2) compartimentalization and 3) improved evacuation on the FN-curve for South Holland (the numbers in the FN-curve indicate the strategies).

As shown by figures 12, FN-curves provide a useful basis for comparing the effectiveness of alternative flood risk management strategies. Cost-effectiveness can be evaluated by relating the costs of measures to the reduction of the risk to life. The reduction of the flooding probability will push the FN-curve downwards. Such an intervention will be especially attractive when a limited number of weak links in the flood defence system can be strengthened at relatively low cost. Through compartmentalization, the number of flood victims in the Netherlands could realistically be reduced by up to 50% (the effectiveness of compartmentalization could be lower depending on local circumstances; note that compartmentalization can also increase fatality risks). This strategy would generally require considerable investments in new compartment dikes within flood prone areas. Compartmentalization becomes less cost-effective when the probability of failure of the outer ring (the primary flood defence) becomes smaller. This is because the compartmentalizing flood defence only pays off when the outer ring fails. Improving the opportunities for evacuation and emergency management can reduce loss of life but the probability of events with many fatalities cannot be reduced to zero as evacuation and emergency response might fail.

Similar exercises can illustrate the effect of alternative risk management strategies on individual risks. Figure 13 (left) shows the level of individual risk in the base case. In total about 1.9% of the flooded area (0.7% of the total dike ring area) is characterized by risk levels higher than 10^{-6} per year. However, the levels of individual risk for most of the other parts of the area are lower because (i) the probability of flooding is relatively low, (ii) flood mortality is typically substantially less than one, and (iii) not all flood scenarios affect similar parts of South Holland. Reduction of the probability by a factor of 10 leads to a reduction of individual risk, see figure 13 (right). Almost all the areas that had risk levels higher than 10^{-6} per year are now eliminated. The IR-level remains higher than 10^{-6} per year in 0.1% of the flooded area.

In these IR-plots, the effectiveness of evacuation is not taken into account. It is possible to create an individual risk map for South Holland that takes into account the effectiveness of evacuation. However, the maximum evacuation rates that can be achieved for this area are generally limited to 20% to 30% of the population. This is due to the large amount of time required for evacuation and the limited time available.[32] In addition, the individual risk map uses a logarithmic scale so that the differences between individual risk maps without and with evacuation are very limited.

Figure 13: Individual risk for South Holland (base case – left, from reference 9) and the effects of reduction of the flooding probability by a factor of 10 (right)

Although the effects of measures will depend on local characteristics of the dike ring and the flood hazard it is expected that risk reduction by means of dike strengthening and compartimentilization will be of a similar order of magnitude for other areas. The effectiveness of evacuation will differ more between regions. For areas threatened by river floods it is expected that evacuation will be more effective than for a coastal area. The reason is that river floods can be generally predicted longer in advance than coastal floods.

5 POTENTIAL USES OF INDIVIDUAL AND SOCIETAL RISK CRITERIA IN THE DUTCH FLOOD SAFETY POLICY

5.1 Evaluating individual and societal risks

As also discussed in previous sections, loss of life will play a role in the design of new safety standards for flood defences in the Netherlands. Loss of life can be evaluated from two distinct perspectives [(33-35)]:

1. The individual perspective: the safety of a particular individual.
2. The societal perspective: the probabilities of large numbers of fatalities.

A limit to individual risk can be used to guarantee a minimal safety level to every individual living behind a primary flood defence. The introduction of such a basic safety level has also been proposed by the Second Delta Committee.[(1)] The proposed individual risk limit equaled 10^{-6} per year (including the effectiveness of evacuation) for the provision of flood safety to those living behind primary flood defences. The proposed value is similar to the individual risk limit used in the Dutch major hazards policy (with the exception that evacuation is not considered in this field). Further research is needed to see whether such a stringent safety standard would also be feasible for the Dutch flood safety policy, given the measures that would have to be taken.

FN-curves show the probability distribution of the number of fatalities and can be used for the evaluation of fatality risks from a societal perspective. To facilitate the evaluation of FN-curves, criterion lines could be defined: an FN-curve should, in principle, not exceed the criterion line. An FN-criterion is defined by three variables: (i) its base point (the exceedance probability of 1 fatality), (ii) its slope, and (iii) its probability and/or consequence cut-off. Figure 14 shows the different constraints that could make up an FN-criterion.

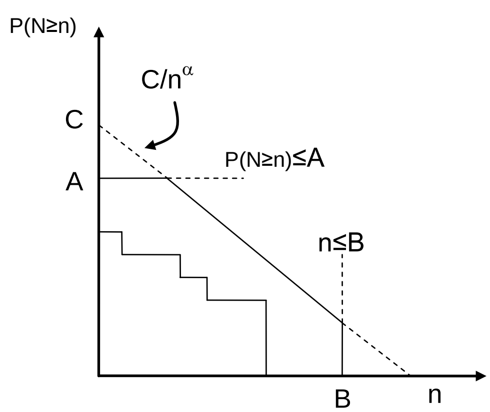


Figure 14: A fictitious FN-curve and different FN-criteria

A theoretical link between expected utility theory and FN-criteria might be hard, if not impossible, to establish [20, 36] and the use of FN limit-lines has been criticized on that ground [37]. Yet FN-criteria have proven themselves in the Dutch major hazards policy as practical tools for the evaluation of the probabilities of large-scale accidents. The FN-criteria used in the Dutch major hazards policy have a quadratic steepness, meaning that the exceedance probability of 10 times as many fatalities should be 100 times lower. This has been motivated by public aversion to large numbers of fatalities. A recent study on flood events found that individuals are more concerned about “low probability / high damage” flood events than reflected by the annual expected value of flood damages.[38] It should however be noted that FN-curves with different slopes are used in different counties.[39]

The stringency of societal risk criteria could, amongst other, be based on cost-benefit considerations on risk-risk comparison across domains.[34] Relative levels of societal risk within one domain could also be evaluated by comparing levels of societal risk in different objects (e.g. dike ring areas) as a basis for prioritization (see section 3 for examples).

Societal risk can be quantified and evaluated for areas of different sizes, for example for a city, a province, a dike ring, a hydrological subsystem, or an entire country. The boundaries of such areas could be aligned with institutional boundaries. Various government actors are responsible for influencing (mitigating or creating) flood risks, most notably the national government, provinces, municipalities, and water boards. Each of these entities has its own territorial boundaries. An alternative would be to align the boundaries of the areas for which societal risk is evaluated with those of the natural system, such as the boundaries of hydrological systems (e.g. Rhine, Meuse, coast) or dike rings (note that the boundary of a dike ring does not necessarily coincide with the territorial boundary of a water board). It is currently being proposed to evaluate societal risk at the dike ring level because: (i) current safety standards are also defined per dike ring and the future safety standards will likely have the same format [(2)]; (ii) measures taken at a dike ring will mostly affect the risk within that ring, and (iii) current risk studies are mainly focusing on separate dike rings. An alternative could be to consider the risks within a hydrological subsystem (see figure 10). It seems reasonable to assume that multiple dike rings within one subsystem could flood during the same extreme event, but that it is unlikely that dike rings from different subsystems will be flooded simultaneously (see also section 3.5). An assessment of the risks at subsystem level will allow for a proper evaluation of the effects of cumulation. An assessment of the risks at the national scale would provide insight in the threat at a national level. By combining information for the different spatial scales, those areas and subsystems could be identified that give the highest contribution to the overall national level of risk.

5.2 The status given to individual and societal risk criteria

Individual and societal risk could play a number of different roles in a flood safety policy, depending partly on the status that is given to the yardsticks for judging the acceptability (or tolerability) of individual and societal risks.

Under the least binding alternative, individual and societal risk are merely used for agenda-setting and/or policy evaluation purposes. Policymakers consider (past or potential changes in) levels of individual and societal risk when making policy choices. There is no formal rule stipulating a need for action when some predefined level of individual or societal risk is exceeded.

A second option would be to define criteria or reference values for evaluating individual and/or societal risks, but to allow exceedances when there are strong reasons for doing so. Decision rules that seem reasonable in some cases, might lead to grossly disproportionate outcomes in other. Allowing for flexibility can reduce the unintended social cost of rules and regulations, but it can dramatically increase transaction cost (the cost of decision making). In the Dutch major hazards policy, there is no legal limit to societal risk, only a reference value. Exceedances of this reference value (as well as increases in societal risk below the reference value) have to be properly motivated by competent authorities. The External Safety Decree lays down the basic elements that have to be considered by competent authorities, and jurisprudence has led to further refinement of the definition of a “properly motivated” decision.

Under the third and most stringent regime, the government lays down legal limits to individual and societal risks. These limits would then have a similar status as the exceedance probabilities that are currently laid down in the Flood Defence Act. When prevention would be the basis for the flood risk management policy the government could also define maximum flood probabilities, based on considerations related to individual and societal risks. For example, for each dike ring, the probability of flood would have to be reduced until the level of societal risk would be lower than the limit line (see also figure 14). Limits to individual and/or societal risk would effectively find their way into the legal limits to flood probabilities.

It should be noted that the Dutch central government is responsible for living up to the Water Act (previously: Flood Defence Act). In this respect, the functioning of the Water Act is rather different from e.g. the External Safety Decree (see section 2) that lays down the rules of the game that individuals, firms and local governments have to play by. If local governments fail to observe the rules laid down in the External Safety Decree, their decisions can be challenged in court. But in the domain of flood safety, the government plays the role of the provider of a public good. Flood safety standards effectively define the government’s (public’s) level of ambition when it comes to the provision of flood protection. If central government fails to meet the standards laid down in the Flood Defence Act out of budgetary considerations, the government cannot be successfully challenged in court. This is because budgetary decisions are legitimized through the workings of the political system, the same system that legitimized the Water Act. Experience has however shown that legally defined flood safety standards can be highly effective in setting government priorities, as they provide a clear basis for the evaluation of the safety of flood defences and make it virtually impossible for failures to meet predefined safety standards to go by unnoticed.

5.3 Options for using individual and societal risk in the Dutch flood safety policy

As outlined in the previous sections, individual and societal risk can play different roles in shaping and implementing a new flood safety policy in the Netherlands. Key policy choices concern:

1. *The status of individual and/or societal risk:* agenda-setting/policy design, reference values, legal limits (see section 5.2).
2. *The stringency of individual and/or societal risk criteria*: when risk criteria are implemented (as either reference values or legal limits), how stringent should they be (section 5.1)?
3. *The strategy for reducing flood risks*: reducing flood probabilities, reducing the consequences of floods, a combination of both (section 4).

Based on the three strategies for reducing flood risks, three policy alternatives were defined (table II). According to current policy documents [1,2], the focus will rest on limiting the risks to life and the economy through prevention (the first strategy: the reduction of flood probabilities). In addition, the possibilities for reducing the consequences of floods will be investigated through land-use planning for existing vulnerable facilities and to guide the development of future land use.

The three strategies for reducing flood risks have different institutional implications. If, for instance, the decision were made to mitigate risks through a combination of flood prevention and safety zoning, rules would have to be laid down to ensure that local governments do not allow or develop spatial plans that lead to increases in potential damages (note that the interests of an individual local government and the central government need not be perfectly aligned).

Designing rules and regulations that steer the behaviour of local governments and property developers into a direction deemed desirable by central government would not just require answers to questions of a purely technical nature (e.g. how to ensure that the joint behaviour of individual entities does not lead to excessive societal risks?), but also to questions of a political and institutional nature (e.g. how to deal with conflicts of interest between local governments that wish to minimize restrictions on spatial plans and a central government that wishes to minimize investments in flood prevention?).

Table II: Overview of options for a risk-based flood defence policy.

Strategy for reducing flood risks, by reducing:	Characteristics and implications	Standard / policy instruments	Measures	Parties involved
1) flood probabilities	Consequences are given, increase of consequences compensated by smaller flooding probability	Prevention, flood probability reduced (determined from cost-benefit analysis and evaluation of fataility risks)	Dike strenghtening Room for Rivers	Flood defence management authorities
2) consequences	Flood probability is given (e.g. based on CBA), policy focuses on reducing the consequences. Thereby possible limitations for spatial planning and economic growth.	Steering development of consequences, e.g. by zoning Growth of consequences could limited by requiring a so-called stand-still of risks (i.e. no increase of risks allowed)	Spatial planning, zoning, flood-proof construction, shelters and mounds, evacuation	Land use planning & Emergency management authorities
3) probabilities and consequences	Case-by-case evaluation of measures to reduce the probability or consequences, e.g. based on effectiveness and side effects. Can lead to complex and therefore time consuming and costly decision-making procedures..	Cost Benefit Analysis, Evaluation of fatality risks	Dike strenghtening Room for Rivers zoning, flood-proof construction, shelters and mounds, evacuation	Flood defence management, Land use planning & Emergency management authorities

6 CONCLUDING REMARKS

The Dutch government is currently in the process of updating its flood risk management policy. One of the novelties being considered concerns a role for fatality risks in evaluating flood risks. Fatality risks already play an important role in the Dutch major hazards policy. Individual risk limits are used there to provide a minimal safety level to those living in the vicinity of major industrial hazards; societal risk criteria are used to prevent the too frequent occurrence of large-scale accidents. This article reviewed the potential for using individual and societal risk for flood risk management. Techniques are available for quantifying these metrics when it comes to floods [(9)] and it has been shown that individual and societal risk can be used for comparing the effectiveness of alternative risk mitigation strategies and for appraising flood risks.

Preliminary nationwide estimates of societal risks from floods in the Netherlands indicate that the levels of societal risk are expected to be relatively high in the southwestern part of the country where densely populated dike rings are threatened by both river and coastal floods. These areas therefore deserve specific attention when it comes to flood risk mitigation.

It was found that the so-called cumulation of risks could have important consequences for the national level of societal risk. Cumulation means that different dike rings flood simultaneously during the same storm surge or high river discharge. Conservative assumptions have been used in this study to model potential cumulation within a hydrological subsystem. Further research is needed to determine the actual level of dependence between floods in different areas.

From a purely technical standpoint, little stands in the way of using individual and societal risk for the evaluation of flood risks. But evaluating risks and designing a flood safety policy are not purely technical exercises. Key policy choices concern the status of individual and/or societal risk criteria (or the decision not to formulate criteria), the stringency of such criteria, and the chosen strategy for mitigating flood risks.

Obviously, loss of life is only one of the vast number of consequences that together make up the personal and social impact of a large-scale flood. As loss of life is often considered to be one of the most important consequence types, a separate evaluation of fatality risks constitutes a significant improvement over an approach that focuses on the economics of flood safety alone. The presented approach could therefore also be relevant for other (European) countries, as most flood risk assessments focus on potential economic damage rather than loss of life.

It is emphasized that the results presented in this article are preliminary and based on a combination of available information from risk assessments and expert judgment. Further detailed risk studies are necessary to come to a more detailed and accurate understanding of the level of fatality risks from floods throughout the Netherlands. The outcomes of the FLORIS project are expected after the year 2011. These outcomes will include estimates of the spatial distribution of individual risks.

The outcomes of individual and societal risk estimates provide an important input for the discussion on acceptable safety levels. As part of this discussion, it could be further investigated if and how standards for individual and societal risk levels could be used. Calculated risk levels can be compared with existing frameworks for deciding on risk acceptability, such as reference 33. As a basis for decision-making, further studies are needed that provide insight in the effectiveness and costs of different risk reduction strategies.

Footnote

1 - The second Delta Committee advised Parliament and the Executive about the long-term prospects for protecting the Netherlands against floods.

Acknowledgements

The authors want to thank prof. J.K. Vrijling (Delft University) and dr. Matthijs Kok (Delft University and HKV consultants) for their contributions to this research.

References

1. Second Delta Committee. Working together with water – Findings of the Deltacommissie 2008. Den Haag, Netherlands: Hollandia Printing, 2008.
2. Ministry of Transport Public Works and Water Management. Ontwerp nationaal waterplan (in Dutch). Zaandam, Netherlands: Kwak & van Daalen & Ronday, 2008.
3. Van Dantzig D. Economic decision problems for flood prevention. Econometrica, 1956; 24: 276-287.
4. Kind J. Cost benefit analysis to determine efficient flood protection standards for the Netherlands. In: Simonovic SP, Bourget PG *et al.* (Ed.) (2008) Proceedings of the 4th international symposium on flood defence: managing flood risk, reliability and vulnerability, Toronto, Ontario, Canada, May 6-8, 2008. 105/1 – 105/8. 2008.
5. Munich Re. Natural Catastrophes 2007: Analyses, assessments, positions. Munich, Germany, Topics Geo report, 2008.
6. Jonkman SN, Stive MJF, Vrijling JK. New Orleans is a Lesson to the Dutch. Journal of Coastal Research, 2005; 21(6): 1085-1085.
7. Bottelberghs PH. Risk analysis and safety policy developments in the Netherlands. Journal of Hazardous Materials, 2000; 71: 117-123.
8. Jonkman B, Jongejan R, Maaskant B, Kok M, Vrijling H, Verkenning slachtofferrisico's in het hoogwaterbeschermingsbeleid (in Dutch). Royal Haskoning, HKV Consultants, Jongejan Risk Management Consulting, Delft University of Technology. Report no. 9T2050.A0. 2008.
9. Jonkman SN, Vrijling JK, Kok M. Flood risk assessment in the Netherlands: A case study for dike ring South Holland, Risk Analysis, 2008; 28 (5): 1357-1373.
10. Jonkman SN, Maaskant B, Jongejan R, Kok M, Vrijling JK. Landsdekkende schattingen slachtofferrisico's voor overstromingen (in Dutch). Royal Haskoning Report 9T2050.B0. 2008
11. Ale BJM. Tolerable or Acceptable: A Comparison of Risk Regulation in the United Kingdom and in the Netherlands. Risk Analysis, 2005. 25(2): 231-241.
12. Shrivastava P. Bhopal Anatomy of a crisis. London: Paul Chapman Publishing Ltd. 1992
13. Anonymous. Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances. European Commission council directive 96/82/EC. 9 December 1996.
14. Papazoglou IA, Nivolianitou ZS, Bonanos GS. Land use planning policies stemming from the implementation of the SEVESO-II Directive in the EU. Journal of Hazardous Materials, 1998; 61: 345-353.
15. Christou MD, Mattarelli M. Land-use planning in the vicinity of chemical sites: Risk-informed decision making at a local community level. Journal of Hazardous Materials, 2000; 78: 191-222.

16. Anonymous. Omgaan met risico's, De risicobenadering in het milieubeleid (in Dutch). The Hague, Netherlands. Ministerie van VROM,. 1989.
17. Ale BJM. Dealing with risks of fixed installations in The Netherlands. Cryogenics, 1993; 33(8): 762-766.
18. Ale BJM. Risk assessment practices in The Netherlands. Safety Science, 2002; 40(1) 105-126.
19. Slovic P. Perception of Risk. Science, 1987; 236: 280-285.
20. Jongejan RB. How safe is safe enough? The government's response to industrial and flood risks. Doctoral thesis. Delft University of Technology. Delft, The Netherlands. 2008.
21. Ale BJM, Golbach GAM, Goos D, Ham K, Janssen LAM, Shield SR. Benchmark risk analysis models. Bilthoven, the Netherlands, RIVM report 610066015. 2001.
22. Uijt de Haag PAM, Gooijer L, Frijns PJMG, Quantitative risk calculation for land use decisions: the validity and the need for unification, In: Kao T.M. Zio M. Ho V. (Eds.). Int. Conf. on Probabilistic Safety Assessment and Management. PSAM9 Hong Kong. (digital proceedings) 2008.
23. Apel H, Thieken AH, Merz B, Bloschl GA. Probabilistic modelling system for assessing flood risk. Natural Hazards, 2006; 38(1–2): 79–100.
24. Van Manen SE, Brinkhuis M. Quantitative flood risk assessment for Polders. Reliability Engineering and System Safety, 2005; 90: 229-237.
25. Ministry of Transport Public Works and Water Management. Floris-study: full report. The Hague. DWW report 2005-081. 2005.
26. Jonkman SN, Cappendijk P. Veiligheid Nederland in kaart – inschatting van het aantal slachtoffers ten gevolge van overstroming, The Hague, DWW report DWW-2006-012. 2006.
27. Klijn F, Baan P, de Bruijn K, Kwadijk J, van Buuren R. Overstromingsrisico’s in Nederland in een veranderend klimaat. Delft, WL rapport Q4290.00. 2007.
28. RIVM (Rijks Instituut voor Milieu Vraagstukken), MNP(Milieu Natuur Planbureau). Risico’s in bedijkte termen – een evaluatie van het beleid inzake de veiligheid tegen overstroming. RIVM rapport 500799002. 2004.
29. Rijkswaterstaat. Waterveiligheid 21e eeuw - Kentallen Kosten Baten Analyse (in Dutch). Report WD 2008.044. 2008.
30. Goudappel Coffeng, Universiteit Twente. Veiligheid Nederland in Kaart – modellering en analyse van evacuatie. Delft, DWW007/Fok/0093. 28 April 2008.
31. Van Mierlo MCLM, Vrouwenvelder ACWM. Calle EOF. Vrijling JK. Jonkman SN. de Bruijn KM. Weerts AH. Assessment of flood risk accounting for river system behaviour. Int. J. River Basin Management, 2007; 5 (2): 93-104.
32. Van Der Doef M, Cappendijk P. Veiligheid Nederland in Kaart – modellering en analyse van evacuatie. Delft, Rijkswaterstaat, Report DWW-2006-007. 2006.
33. Vrijling JK, van Hengel W, Houben RJ. Acceptable risk as a basis for design. Reliability Engineering and System Safety, 1998; 59: 141-150.
34. Vrijling JK, van Hengel W, Houben RJ. A framework for risk evaluation, Journal of hazardous materials, 1995; 43 (3): 245-261.
35. Stallen PJM, Geerts R, Vrijling JK. Three conceptions of quantified societal risk. Risk Analysis, 1996;16(5): 635-644.
36. Bedford T. Keynote lecture: Multi-attribute utility theory and FN-criteria, In: K. Kolowrocki (ed.) Proc. ESREL 2005: Advances in Safety and Reliability: Gdansk, 27030 june 2005. Rotterdam AA Balkema Publishers. 2005; p. 157-166.
37. Evans AW, Verlander NQ. What is wrong with criterion FN-lines for judging the tolerability of risk. Risk Analysis 1997; 17 (2): 157–168.
38. Merz B, Elmer F, Thieken AH. Significance of “high probability / low damage” versus “low probability / high damage” flood events. Natural Hazards and Earth System Sciences, 2009; 9: 1033-1046.
39. Ball DJ, Floyd PJ. Societal risks. Report submitted to HSE. 1998.