Casualty risks in the discussion on new flood protection standards in The Netherlands

K. de Bruijn, J. Beckers & H. van der Most
Deltares, The Netherlands

Abstract

The flood risk management policy in The Netherlands focuses on flood prevention. The current safety standards for the flood defences were developed in the 1960s in response to the flood disaster of 1953. Because The Netherlands has changed drastically since the 1960s, the government decided to reconsider the safety standards. In preparation for a new set of standards for flood protection, cost benefit analyses and casualty risk assessments are carried out. The explicit consideration of casualty risks is a new aspect in the flood risk management policy in The Netherlands.

Casualty risk can be assessed from an individual point of view or from a societal perspective. Individual casualty risk is related to a person's probability to die in a flood. It may be a useful indicator to measure whether a base level of protection for everyone is provided. Societal casualty risk, or group risk, is related to the probability of many casualties caused by the same event. Both viewpoints are considered relevant for discussion on future flood protection standards.

The paper discusses the background of casualty risks, and their analysis and assessment in the context of deriving adequate flood protection standards.

Keywords: flood risk management, flood casualties, mortality, flood risks, safety standards, The Netherlands.

1 Introduction

The Netherlands is a low-lying country threatened by floods from the sea, large rivers and from the IJsselmeer, the lake in the centre of The Netherlands. The northern and western parts of the country consist of low-lying polder areas. The deepest parts are about 5 to 6m below sea level. In the low-lying western area

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millions of people are living. In this area the largest cities and industrial areas are situated.

This paper focuses on large-scale flooding from the sea and/or the large rivers. Local flooding due to intensive rainfall is not considered. Although these rainfall floods can also cause damage, they generally do not threaten lives in a flat landscape, such as The Netherlands. They are considered ‘annoying’, but not ‘disastrous’ and are managed by water boards, according to a different set of operational standards [1].

The flood protection standards for the main water bodies in The Netherlands are prescribed by the government and can be found in the national Water Law. The flood risk management safety standards are currently under examination, following the advice of the 2nd Dutch Delta Committee [5]. To feed the discussion on these standards a Cost Benefit Analysis (CBA) is carried out and flood casualty risks are being assessed [2, 3]. In this context casualties are persons that die due to flooding.

This paper discusses the current safety standards in flood risk management, casualty risks and their assessment in relation to flood safety standards.

2 Dutch safety standards

The current flood risk management policy in The Netherlands aims at flood prevention by flood defence structures such as embankments and dunes and the shortening of the coastline by dams and storm surge barriers. The current safety standards for the embankments and other defence structures were developed in the 1960s, after the 1953 flood disaster. In 1953 a storm surge on the North Sea caused the flooding of a large area in the South west of The Netherlands. About 1800 persons did not survive that disaster. After that disaster, The ‘Delta commission’ developed safety standards for the coastal areas based on a CBA [4]. Later, safety standards for the areas along the main rivers were derived from the coastal flood protection standards.

Figure 1 shows the current safety standards for The Netherlands. The flood-prone area is divided into so-called dike rings. These are areas surrounded by embankments or higher grounds. Each dike ring has a safety standard, which is defined as the probability of exceedance of the design water level and wave conditions that the embankments should be able to resist. These probabilities vary between 1/1250 per year for the riverine areas to 1/10,000 per year for the densely populated coastal areas.

Since the 1960s, The Netherlands have changed significantly. The number of inhabitants increased from about 11 million in 1960 to 16 million in 2007 and the economy grew by about a factor four [3]. However, the safety standards have not been adapted to this increase in potential flood damage.

The governmental National Water Policy [2], therefore, states that the flood protection standards need to be reconsidered and that information resulting from a CBA and an analysis of casualty risks need to be used in this reconsideration. The explicit consideration of casualty risks is a new aspect in the water safety policy in The Netherlands.

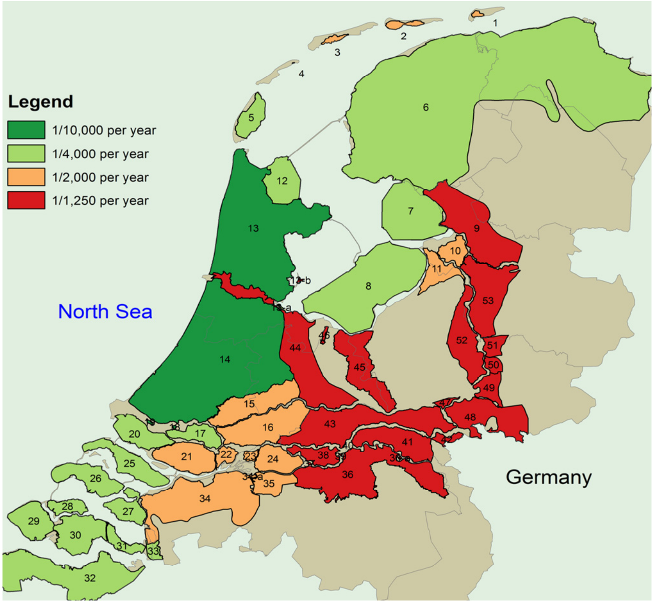

Figure 1: Safety standards for The Netherlands.

Casualty risk can be assessed from the viewpoint of an individual as well as from a societal perspective [2, 7]. The individual viewpoint can be represented by the Local Individual Risk (LIR), which is defined as the annual probability to die at a certain location due to a flooding. From a societal perspective it is also interesting to consider the societal casualty risk, or group risk. This societal risk is defined as the probability of a flood causing large numbers of casualties in one event (e.g. more than 10, 100 or 1000).

Both viewpoints are relevant for the safety standard discussion [2, 7, 12]. From the equity principle, the individual risk criterion could be used as a minimum safety level to everyone. Societal casualty risk can be a useful criterion to avoid societal disruption.

3 Local individual risk

The Local Individual Risk (LIR) is a casualty risk indicator from the perspective of individuals. In this paper, the LIR is defined as the annual probability to die in a flood, taking into account sensible behaviour such as evacuation. A different term, Locational Risk (LR), is used for the risk when evacuation is not taken into account.

The LIR varies in space. It depends on flood probabilities, the possibility to escape from the threatened area when the flood threat becomes eminent (the evacuation possibility) and the probability to die when present during a flooding (the mortality) [7]. The mortality depends on:

- Flood characteristics (flow velocity, water depth, water level rise rate);
- Possibilities to reach safe locations during the flooding;
  Vulnerability and behaviour of the inhabitants (type of houses, health, knowledge of the area, etc).

In The Netherlands, flood casualty figures are calculated using the 'Dutch Standard Damage and Casualty Model' based on the number of inhabitants of the area, an evacuation percentage, flood characteristics and mortality functions which relate mortality to flood characteristics [8, 11].

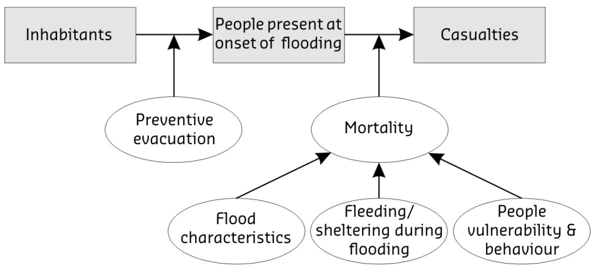

Figure 2: Schematic overview flood casualty analysis.

The Dutch model is based on mortality functions, which are mainly based on one flood disaster only: the 1953 flood disaster [11]. Di Mauro [10] validated the functions on the 1953 flood disaster on Canvey Island for which a lot of data is available [10]. The equations overestimated casualty figures a little, but reproduced the locations of those casualties very well. The resulting mortality rates must, however, always be considered with care. Since the data availability of 1953 is limited, the data fit to the mortality curves is not perfect and the 1953 disaster may not be fully representative for present day flood disasters, and actual mortality rates may be different.

The LIR can be calculated following the next steps:

1. Selection of a comprehensive set of breach locations for each dike ring;
2. Calculation for each breach location of the expected flood pattern (e.g. with a 1D2D flood simulation and a breach growth model) and the corresponding mortality with the mortality functions discussed before;
3. Aggregation of the mortality grids of each breach location to one mortality grid. This can be done by taking for each hectare the maximum mortality of all scenarios [7], or by taking the 'average' mortality grid by assigning a weight or conditional probability to each breach location.
4. Calculation of the LIR by multiplying the dike ring flood probability by the probability of being present and multiplying this by the average mortality rate. The probability of being present is

comparable to one minus the evacuation fraction which was estimated for each dike ring in The Netherlands [11, 13];

Figure 3 shows an example of a LIR map for the area around the city of Dordrecht [7]. It shows that the LIR differs in space: some areas are clearly more dangerous than others. In The Netherlands the highest LIR values are expected to be found in small enclosed areas within the riverine area, in the areas along the tidal rivers and in the reclaimed areas in the IJsselmeer (central lake) [7, 8] (see figure 4). Since peak discharges in rivers can generally be forecasted well in advance and evacuation options for the riverine area are generally good, the LIR values with evacuation and the Locational Risk values without evacuation differ much for the riverine areas. In the riverine area, the risk values which do not include the effect of evacuation are much higher.

To judge whether calculated LIR levels require action, some acceptable LIR level or orientation level must be defined [7]. The choice for such an acceptable LIR level is a political one.

There are Individual Risk standards in other safety domains, such as those related to industries, nuclear power plants and storage of fuel. For those domains a safety standard of 10^{-6} per year is used for inhabited areas. This number was found by accepting an addition of one percent to the 'normal risk to die' for young adults, which is 10^{-4} per year in The Netherlands [7].

One may discuss whether this standard should be applied identically in flood risk management, since the type of risk and its general acceptability are different. For industrial risks, for example, generally no evacuation is possible, the extent of the threatened area is smaller, the origin of the hazard is of a different nature (natural hazards are generally more acceptable than man-made) and the benefits of the risky activity for the inhabitants are less.

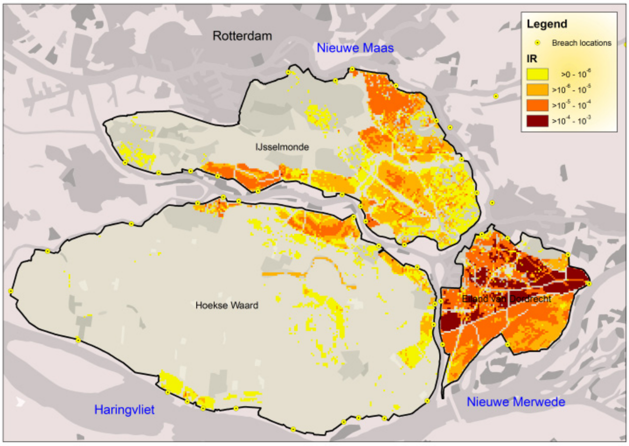

Figure 3: The LIR values in the dike rings Dordrecht, Hoekse Waard and IJsselmonde (south of Rotterdam) [7].

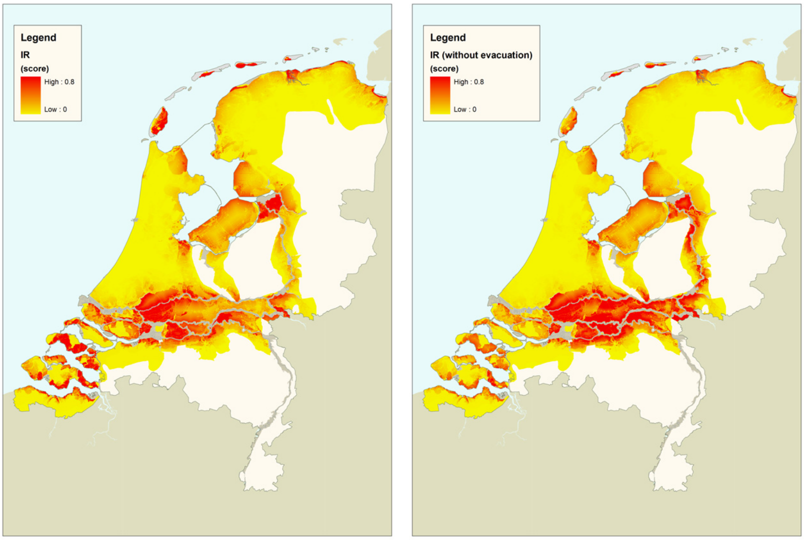

Figure 4: Relative individual risk values based on an indicative nation-wide analysis with (left) and without (right) taking into account evacuation [7].

4 Societal casualty risk

To assess societal casualty risk, the probability of major flood events and their casualty rates need to be studied. Societal risk can be represented by an FN curve, which displays the probability of an event causing more than N casualties.

Figure 5 shows an hypothetical example of such a curve of an area with two separate independent flood-prone areas with a flood probability of respectively 1/100 a year and 1/200 a year and only three possible flood scenario's (see table 1). The scenarios must be ranked according to their number of casualties and the cumulative probability of more than N casualties need to be calculated. This cumulative probability is shown on the y-axis and the number of casualties on the x-axis.

Table 1: Hypothetical example data for the Fn curve.

Scenario	Areas flooded	N	Scenario Probability	Cumulative probability of more than N casualties
1	1	10	0.00995	0.01
2	2	20	0.00495	0.005
3	both	30	0.00005	0.00005

FN curves can be made for each dike ring in The Netherlands. Next to the analysis per dike ring, a nationwide analysis is sensible, because of the possibility of events that inundate many dike rings. To calculate the FN curve for The Netherlands as a whole, four steps need to be taken:

First, the flood probability for each dike ring and the expected number of casualties per dike ring in case of flooding must be determined. The number of casualties can be based on several flood simulations per dike ring and the flood mortality functions discussed in section 3. The contribution of different breach locations and their conditional probabilities should also be considered.

Secondly, the correlation between different dike rings need to be studied to be able to take into account scenarios which affect multiple dike rings. Two areas with highly correlated reliability functions have a high flood probability during the same event. Dike rings with zero correlation will probably not be flooded during the same event. Scenarios in which multiple dike rings become flooded will be generated by first defining a number of sub-systems that have negligible correlation (see figure 5). The assumption of zero correlation was verified in sensitivity analyses. Dike rings within the same subsystem are highly correlated.

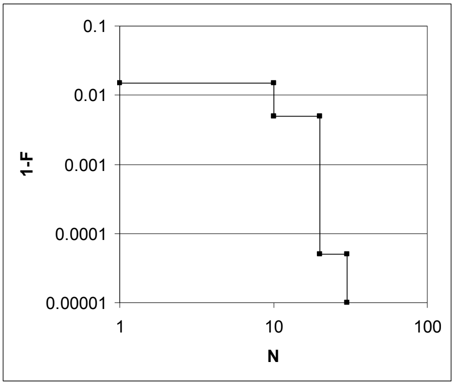

Figure 5: Example of an FN curve.

Thirdly, the system behaviour of the river need to be studied based on data available from flood simulations. If a flooding occurs, it is likely that the load on more downstream areas is reduced by the outflow of water from the system. The extent of load reduction differs from case to case and depends on the moment of breaching, the breach growth and final width, the discharge in the river, the storage capacity of the flooded area and so on. By taking this system behaviour into account, the scenarios with many breaches along the river become less likely. The effect of system behaviour on the FN curve for the river area is significant. The effect on the FN curve for The Netherlands as a whole is small.

Finally, the average casualty figures per flooding scenario must be replaced by exponential distributions, in order to represent the collection of possible outcomes instead of the just the expectation value. This has a large effect on the tail of the FN curve, i.e. the probability of a very large number of casualties.

Societal group risks are expected to be dominated by the tidal river area and upper river area [11] (see figure 7). These areas have the highest flood probabilities, high potential inundation depths and especially the tidal river area is densely populated.

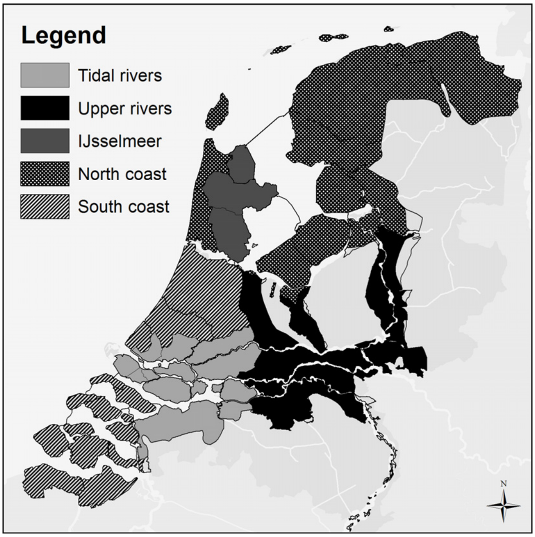

Figure 6: The subsystems used.

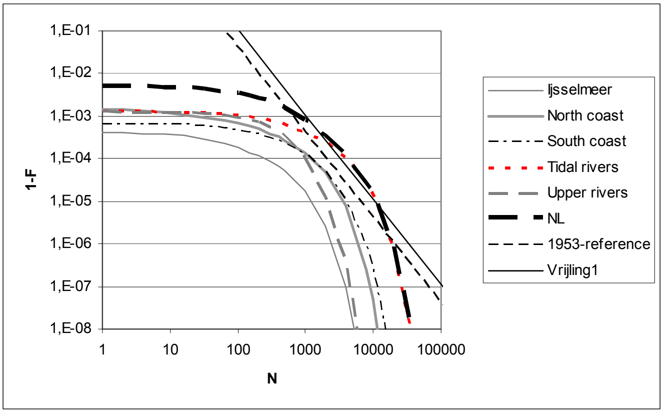

Figure 7: FN curves for each subsystem and for The Netherlands and possible orientation lines (based on data from [11]).

To evaluate resulting societal risk values, acceptable levels or orientation levels of societal risk are required. To come to such acceptable levels different approaches can be followed: 1) by comparison with other group risk standards, such as industrial safety standards (e.g. fuel storage, chemical factories, nuclear power plants), 2) by using a reference flood, such as the 1953 disaster, and 3) by investigating the maximum achievable level of protection, given available budgets.

Vrijling (1998) has explored the first option, defining a variable 'β' to express the tolerance of society to different types of risk [6]. Based on this analysis the acceptable societal risk level should lie below the line indicated in figure 7.

The second option uses the reference flood of 1953. The acceptable probability of such a disaster happening again was set at 10^{-4} per year by the Delta-committee for the design of the Delta protection program in the sixties. Next, the risk averseness should be defined as the slope of the acceptable probability in the FN curve on double-log paper. For industrial risks, the risk averseness is represented by a quadratic relationship, i.e. disasters with ten times more casualties (e.g. 100 instead of 10) should have a probability that is at least one hundred times smaller (e.g. 1/1000 instead of 1/10). The acceptable societal risk then has a slope of -2 in a double-log plot. Figure 7 shows the resulting norm line based on the starting point of an event with 2000 casualties and a probability of 10^{-4} per year.

Figure 7 shows that the FN curve for the tidal river region and the total curve are above the discussed orientation lines. This result leads to the conclusion that the tidal river area should receive most attention.

If an acceptable risk is defined at the national level, this needs to be translated to the dike ring level, in order to decide where and which measures to take. There are several ways to implement such a translation, one of them being the equal distribution of the national acceptable risk level to the individual dike rings. Another possibility is to set a maximum flood probability for each dike ring based on their expected number of casualties in case of flooding. A third option is to perform a CBA that will determine the most cost-efficient way to reduce the societal risk to the acceptable level. Combinations of these options are also possible.

5 Discussion and conclusions

The discussion on the flood protection standards in The Netherlands will amongst others be based on the most efficient flood risk levels resulting from a CBA and on the maximum acceptable flood probability considered from individual and societal casualty risks [2]. These different viewpoints each have their own value and provide different perspectives of flood risk. Adding the casualty risk analysis to the CBA approach in the discussion on flood protection levels is therefore a step forward.

The final results of the CBA are not yet available, but preliminary results indicate that, from an economic point of view, the level of protection is relatively low in the river threatened area, some reclaimed areas in the IJsselmeer and the densely populated coastal and tidal river dike rings [3]. In the less densely populated coastal areas in the north and south and in small dike rings current flood protection levels are in coherence with acceptable cost-benefit ratios. From the perspective of casualty risks the flood protection levels of the (tidal) river areas are relatively low.

In most cases, the results from CBA and societal risk analysis are aligned. This can be explained by the fact that most damage and casualties are expected in the areas where people live and work. However, the economically most efficient flood probability may differ from the maximum acceptable flood probability from the viewpoint of taking casualty risk into account.

In general, the areas that contribute most to the societal risk also have a high LIR value. There are, however, also areas with a high LIR value, but with little casualties because there are not many inhabitants.

Combining the results for the three criteria (CBA, LIR and FN curves) in deriving safety standards is a political process, since it requires weighing the outcomes. For those areas where all three criteria point into the same direction, the decision to derive an appropriate flood protection standard is relatively easy. For other areas, where the CBA and casualty risk results indicate different acceptable flood protection levels, further discussion is needed. The most complex cases are the areas where the LIR suggests the need of a high safety level, while the population density is very low and the protected value is small (e.g. in small river islands).

The casualty risk analyses and assessments are uncertain, because mortality, evacuation rates and conditional probabilities of flood scenarios are uncertain. However, the general picture, the order of magnitude and regional differentiation are meaningful. It is, therefore, not recommended to look in detail into the precise results at each location or to define a strict standard for flood casualty risks itself. Instead, it is recommended to use the outcomes of the casualty risk assessments as 'orientation levels' in the process of deriving adequate flood protection levels.

The ongoing discussion in The Netherlands generally focuses on flood protection standards and associated flood prevention measures. However, also a wider discussion on how to reduce casualty risks is considered beneficial. Casualty risks can also be reduced by other types of measures such as adequate emergency management, land use change, or compartmentalization. Furthermore, it is possible to maintain the overall dike ring flood protection level, but to strengthen one dike section at a location where a dike breach would be disastrous. This could be an option near low-lying, small and densely populated parts. It is recommended exploring such measures in order to conclude the discussion on flood protection standards and to discuss on how to reach acceptable casualty risks. The LIR and societal risk results may support these considerations by indicating dangerous locations and the probability of events with many flood casualties.

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