The use of individual and societal risk criteria within the Dutch flood safety policy (part 2): estimation of the individual and societal risk for the dike rings in the Netherlands

B. Maaskant[a,b], S.N. Jonkman[a,c] & R.B. Jongejan[a,d]

[a] *Delft University of Technology, Delft, The Netherlands*

[b] *HKV Consultants, Lelystad, The Netherlands*

[c] *Royal Haskoning, Rotterdam, The Netherlands*

[d] *Jongejan Risk Management Consulting, Delft, The Netherlands*

ABSTRACT: Loss of life is not explicitly considered in the current Dutch flood safety policy. This paper presents the results of a preliminary study in which the nationwide risks of loss of life were estimated. The risks of loss of life are expressed as individual and societal risk. The first metric is defined as the annual probability of death of an average unprotected person at a predefined location, the second as the cumulative probability of the number of fatalities. This paper covers estimation of societal risks for all flood prone areas (so-called dike rings) in the Netherlands.

1 INTRODUCTION

In the Netherlands, the government is currently investiging how potential loss of life due to flooding can be taken into account in a revised, risk-based flood defence policy, see also “The potential use of individual and societal risk criteria within the Dutch flood safety policy (part 1): basic principles” (Jongejan et al., 2009) for further background.

These policy developments have 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. It would be preferrable to provide estimates based on detailed risk analyses see e.g. (Jonkman et al., 2008) for an elaboration for the dike ring area South Holland. Such detailed analyses are currently being carried out in the Flood risk and safety (FLORIS) project that is executed by the Dutch Ministry of Transport, Public Works and Water Management in cooperation with water boards and provinces. The results of the FLORIS project will come available in 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, crude 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 expert judgment.

Societal risk refers to the probability of an accident with many fatalities and it is also used within the Dutch major hazards policy. Societal risk is generally depicted as an FN-curve, which shows the probability of exceedance of a certain number of fatalities.

The second risk metric that is being considered by policymakers is individual risk. Individual risk is defined as the probability of death of an average, unprotected person that is constantly present at a certain location (note that evacuation could be included in an alternative definition). As levels of individual risk are highly dependent on local flood conditions and topography, it is troublesome to estimate individual risks throughout low-lying regions, without detailed information from flood scenario calculations available. No nationwide estimates are therefore presented for individual risk.

This paper is structured as follows. Section 2 presents the methodology for the estimation of societal risk and its calibration based on the results of a small number of detailed existing risk analyses. Section 3 presents the input information for the nationwide study: estimates of flooding probabilities and average consequences by dike ring. Section 4 presents the societal risk estimates for all dike rings in the Netherlands. Specific topics, such as the cumulation of risks within a hydrological system, and a comparison with other risks are discussed in section 5.

2 APPROACH ON DETERMINING SOCIETAL

2.1 *Approach to determine Societal Risk*

One of the objectives of this study was to determine up to date estimates of the societal risks in The Netherlands, related to floods. For all dike rings, societal risk estimations had to be made, largely on the basis of expert judgment. Three methods were identified at the start of the project to estimate societal risks on the basis of only limited data.

These methods are described in the following paragraphs. Only one of the methods was selected and applied.

2.1.1 *Method 1: a frequentist approach*

In this method, estimates of the number of fatalities in a flood, and the flood probability are used to compute an FN-curve. Uncertainties are represented by a confidence interval: upper and lower bounds. This method results in a block shaped FN-curve. Figure 2.1 shows an example of such an FN-curve, together with its confidence interval.

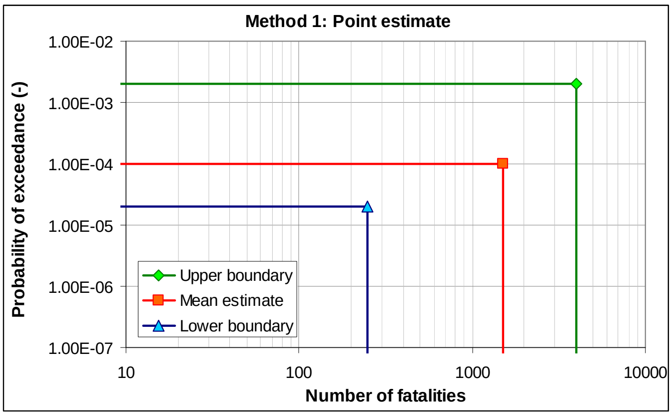

Figure 2.1. FN-Curve on basis of point estimate.

In method 1, the probabilities of exceedance shown in The FN-curve are given a frequentist interpretation: they should be interpreted as a relative frequencies. The intervals around the probability of exceedance and the number of fatalities are the result of the uncertainty related to the estimates of the relative frequencies and consequences of floods. An important disadvantage of this method is that its underlying philosophy differs from the one that underlies the existing curves (FLORIS-1). In the FLORIS-project, probabilities are interpreted in a Bayesian (subjective) sense, rather than as relative frequencies.

2.1.2 *Method 2: A Bayesian approach*

Method 2 differs from method 1 in that it treats probabilities as subjective figures (a Bayesian interpretation of probability), rather than as relative frequencies. In method 2, the upper, mean, and lower values from figure 2.1 are assumed to belong to a single probability density function. This probability density function corresponds to a single FN-curve (no bandwidths). This time, the FN_curve does not show uncertain cumulative frequencies and consequences. Rather, it now represents the uncertainty (related to consequences) itself.

When estimating the probability density function of the number of fatalities, it was assumed (for reasons of simplicity) that the smallest probability goes with the largest number of fatalities and the largest probability with the lowest number of fatalities. This results in the FN-curve shown in figure 2.2.

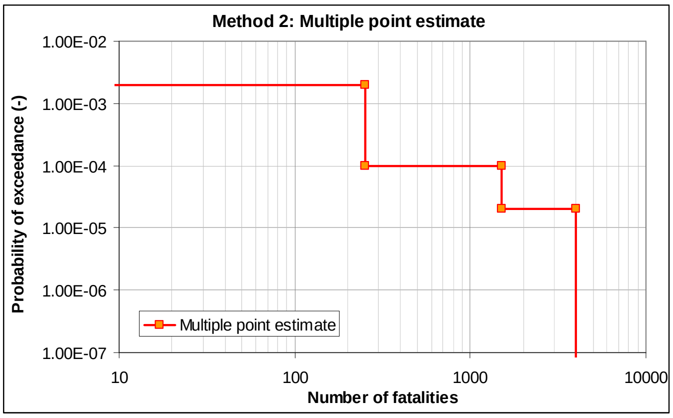

Figure 2.2. FN-Curve based on multiple point estimates.

An advantage of this method is that its underlying philosophy matches the one that underlies existing risk estimates (from the FLORIS project)..

2.1.3 *Method 3: A simplified Bayesian approach*

Constructing a probability density function for the number of fatalities from floods would require us to compute flood probabilities and consequences for a vast number of flood scenarios. This is exactly what is being done within the FLORIS-project for all dike rings in the Netherlands. The results of that project will come available by the end of 2011. But policy-makers needed insight into the severity of fatality risks well before that date. A simplified procedure was therefore designed to estimate societal risks from floods on the basis of only limited data. The simplified procedure rests on the following assumptions:

1. The probability of flood equals the probability of at least 1 fatality.
2. The number of fatalities *given flood* is (approximately) exponentially distributed.

The first assumption seems relatively uncontroversial as failures of primary flood defenses are low-probability, high-impact events. Yet the second assumption need not always be reasonable. It rests on the observation that the three available FN-curves (from the first FLORIS project) match this assumption relatively well over the relevant range (the range for which the slope of the FN-curve is between -1 and -2; this has to do with typical formulations of FN-criteria). Figure 2.4 shows the comparison for the calculated FN curve for one dike ring area (South Holland) that is compared with the approximation. Comparison of the approximation with the calculated FN curves for two other areas presents a broadly similar picture. Although assumption 2 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 very limited data.

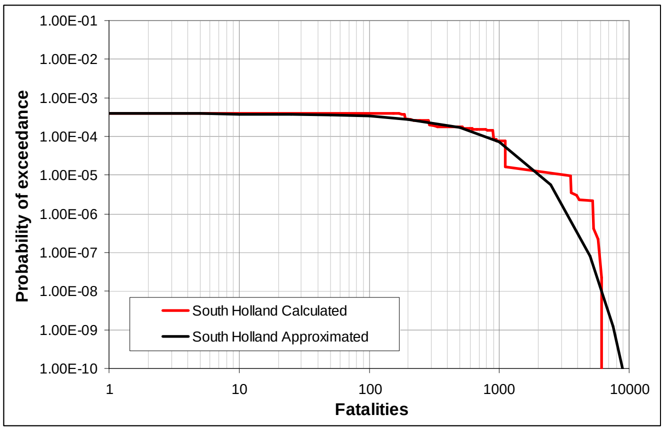

Figure 2.4. Comparison between the calculated FN curve for South Holland (red line) with the approximation with the exponential distribution (dark line).

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:

$$P(N \geq n) = P_f \cdot e^{-\frac{n}{\mu}} \qquad (1)$$

where: $P(N \geq n)$ = probability of n or more fatalities [per year]; P_f = probability of flood [per year]; μ = expected number of fatalities given flood [-].

3 INPUT PARAMETERS: FLOOD PROBABILITIES AND FATALITIES

3.1 *Approach*

To determine the individual and societal risk for all dike rings in The Netherlands information was needed on the flood probability and number of fatalities due to flooding. This information was (and still is) not available for the majority of dike rings so that estimates had to be made on the basis of previous studies and expert judgment.

3.1.1 *Flood probability*

For estimates of the flood probabilities, information was used from a large ongoing government project, Water Safety in the 21st Century (Kind, 2008). In that study, flood probabilities were determined for all dike rings in The Netherlands. These probabilities formed the basis for this study.

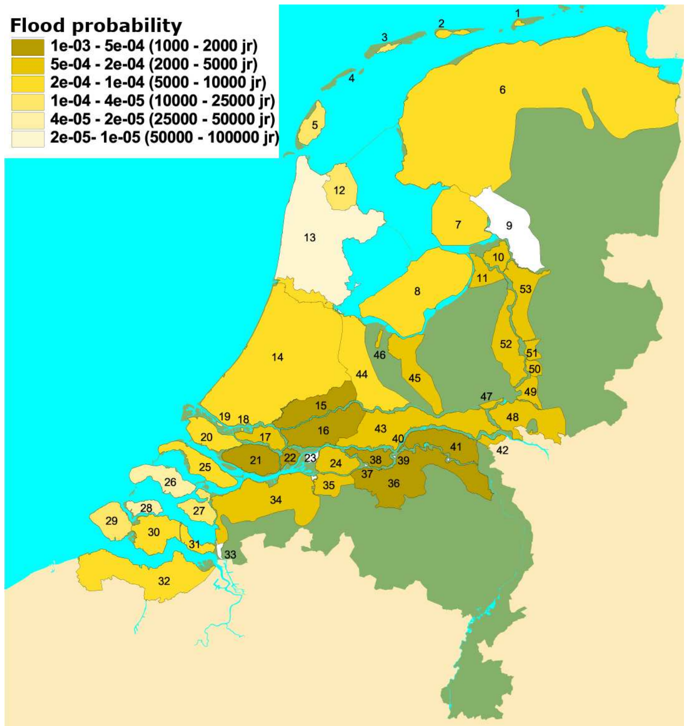

Figure 3.1. Flood probabilities.

3.1.2 *Fatalities*

The number of fatalities is determined by several variables. The key variables can be combined to estimate the number of fatalities in floods 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 people exposed to the flood [-]; F_E = fraction of people evacuated [-]; F_D = mortality i.e. the percentage of people killed by the flood.

For parameter values for N_{PAR}, F_{EXP}, F_E, information was gathered from several studies: Klijn et al. (2007), Goudappel Coffeng (2008), FLORIS-1, FLORIS-2, and Jonkman (2007).

For the estimation on the mortality (F_D) flood scenarios 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:

– Severe flood (large water depths, high flow velocities, unexpected): mortality is 1 percent; coastal dike rings.
– Dike rings with some warning time but still extensive flooding: mortality is 0.7 percent; 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 percent; dike rings along rivers.

Combining these variables according to equation (2) yields the fatality estimates shown in figure 3.2.

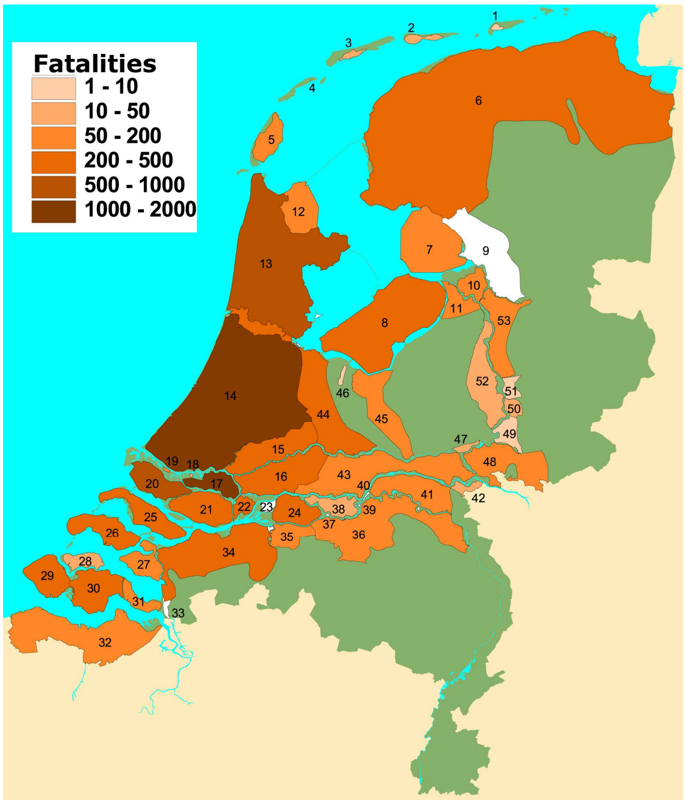

Figure 3.2. Number of fatalities by dike ring.

4 RESULTS RISK ESTIMATION

4.1 *Societal risk*

Based on the method presented in section 2.2 and the input data for probabilities and consequences presented in section 3, FN curves were estimated for all dike rings in the Netherlands. The results are shown in figure 4.1. Each curve represents the FN curve for one dike ring.

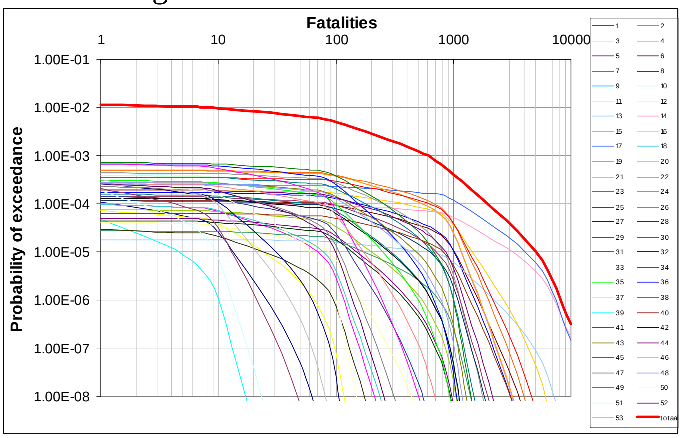

Figure 4.1. FN-Curve of the Societal Risk, including the Societal Risk for The Netherlands.

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 that (as a first approximation), floods in different dike rings are assumed to be mutually exclusive events.

4.2 *Societal risk and cumulation*

In the determination of the national level of societal risk, the possibility that floods occur simultaneously in different die rings, should be taken into account. Experience from historical floods, both in the Netherlands and abroad, shows that it is likely that multiple dike rings will flood simultaneously during one flood event, either during a storm surge at sea or a high river discharge. This effect is called cumulation and is relevant for the estimation and evaluation of societal risks. Due to the simultaneous flooding of multiple dike rings, the consequences of a flood event will increase (but note that the probability of *a* flood will be decrease).

Figure 4.2 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) and with cumulation (flooding of dike rings is fully dependent). Each dike ring has flooding probability P and consequences N.

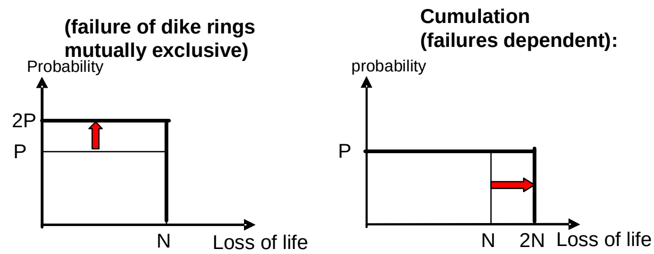

Figure 4.2. The effect of cumulation on the FN-curve.

The effects of cumulation have been analysed as follows. The dike rings in the Netherlands are located in different hydrological systems that are subjected to different flood threats. Dike rings in the coastal areas can be flooded by storm surges (different groups of dike rings were distinguished in the river systems). And dike rings in riverine areas can be flooded by rivers. Storm surges and high river discharges have different causes and can be treated as independent events. .Figure 4.3 shows the different subsystems in the Netherlands and the groups of dike rings within each subsystem. The effect of cumulation has been estimated by assuming that all dike rings within one subsystem will flood simultaneously. Thereby, the consequences will be equal to the sum of the consequences for the individual dike rings, whereas the flooding probability of this simultaneous event will be equal for all 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 needed to determine the exact level of cumulation within each subsystem.

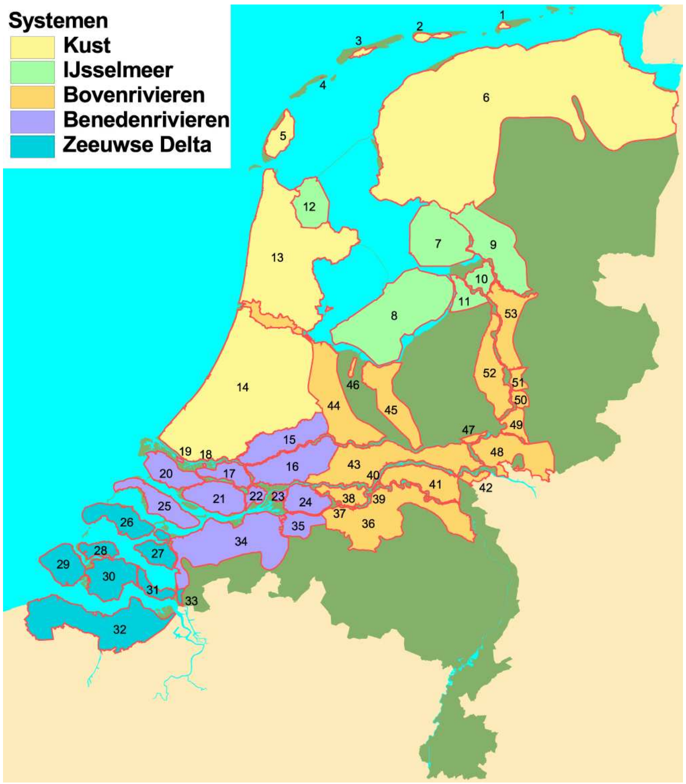

Figure 4.3. Dike rings in hydrological subsystems in the Netherlands.

Figure 4.4 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). 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 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, this could become very relevant in decision making.

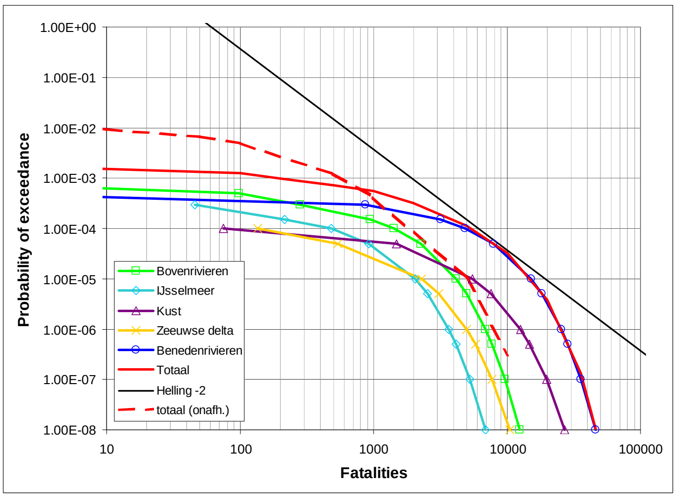

Figure 4.4. FN curve for subsystems (including cumulation within subsystems) and at a national scale (assuming floods in different subsystems are mutually exclusive events).

5 COMPARISON OF SOCIETAL RISK BETWEEN DIKE RINGS

As part of the investigation, the societal risk levels of different dike rings were analyses and compared. For purposes of decision-making it is relevant to have an insight into the areas were societal risks are higherss. Two dimensions, i.e. exceedance probabilities and consequences, determine the level of societal risk of a dike ring. In this study, the level of societal risk for a dike ring was characterized by means of one measure: the point where a tangent line with quadratic steepness crosses the y-axis of the FN-curve. A quadratic steepness was chosen because it is expected that this level of risk aversion will be used in the discussion on potential safety standards for flood defences. A similar criterion is used within the Dutch major hazards policy that deals with the risks to those living in the vicinity of hazardous installations and transport routes (also see Jongejan et al., 2009 for further discussion). The tangent line therefore has the following general formulation:

$$P(N \ge n) = C / n^2 \quad (3)$$

where: $P(N \ge n)$ = 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]. The value of constant C thus determines the height of the tangent line. The higher the value of C, the higher the societal risk level. Figure 5.1 shows how the value of the constant C is determined.

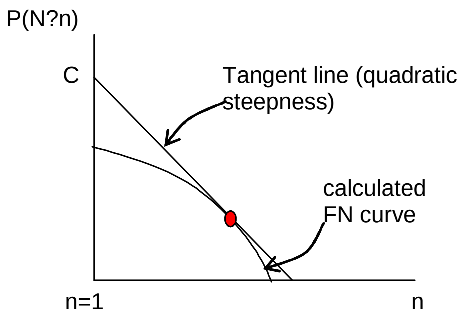

Figure 5.1 Determination of the tangent line and constant C for a calculated FN curve.

The calculated levels of societal risk for all dike rings were analysed using this approach. Based on the estimated FN curves (see figure 4.1), the C-values for the tangent line were determined. The categories of C-values are depicted in figure 5.2. For most of the dike rings, the events with fatalities in the range between 100 en 10,000 fatalities determined the C-values.

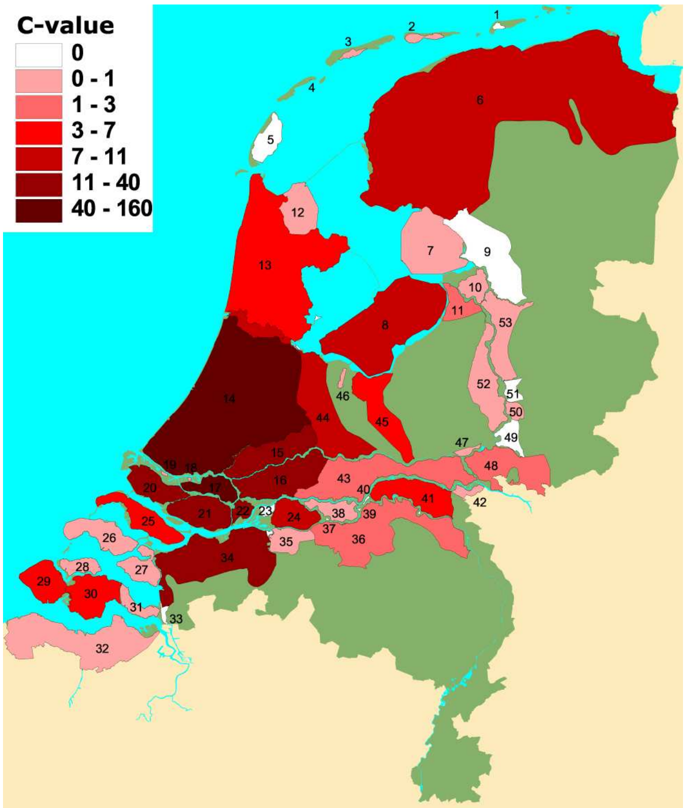

Figure 5.2: *C*-values for dike rings in the Netherlands (indicating the level of societal risk).

From figure 5.2 it can be seen that dike rings in the southwestern part of the Netherlands have relatively high levels of societal risk. This is because these dike rings are densely populated, and there is limited time for evacuation as the coastal floods that threaten these areas cannot be predicted well in advance.

6 CONCLUDING REMARKS

This paper presented preliminary, nationwide estimates of societal risks from floods in the Netherlands. These indicate that the levels of societal risk levels are expected to be 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. These areas deserve specific attention and priority when decisions are prepared about flood risk mitigation.

It was found that the so-called cumulation of risks could have important consequences for the national level of societal risk. Conservative assumptions have been used in this study the model potential cumulation within a hydrological subsystem. Further research is needed to determine the actual level of dependence between floods in different areas.

It is emphasized that the results presented in this paper 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 by 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 the one proposed by Vrijling et al. (1998). Further studies are needed to see how different measures influence fatality risks. Fatality risks can be reduced through either prevention (stronger dikes) or a reduction of the potential consequences of floods (spatial planning, evacuation, etc.).

The presented approach could be relevant for other (European) countries. In general, risk assessments related to floods focus on potential economic damage rather than loss of life. As shown, it is possible to get insight into the severity of fatality risks as well, with relatively little additional effort.

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