Mapping casualty risks in the Netherlands

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Abstract

Flood risk maps are useful tools for spatial planning, flood risk management and flood event management, because they give insight into the spatial distribution of flood risks. The report aims to develop flood casualty risk maps for the Netherlands. It provides indicative flood casualty risk maps for the Netherlands as a whole as well as quantitative risk maps for the Drechtsteden area. The project uses the work done in 2007 (the first approximation) as starting point. For the 'second approximation' of flood casualty risk maps for the whole of the Netherlands improved input data have become available, but it was also desired to more closely relate the risk maps to the well-known and frequently-used concepts of Locational and Group risks. These concepts stem from environmental policy, more specifically the domain of external risk management. They are becoming quite popular nowadays in flood risk management too.

Locational Risk (LR) and Group risk (GR) are indicators of casualty risk which are used in the discussion on safety standards. This discussion has become more prominent lately and focuses on acceptable risk levels .To facilitate this discussion it is relevant to have good insight into the current casualty risks and into the location of the riskiest places. Flood casualty risk maps can enhance this discussion.

The report first discusses recent developments to estimate flood casualties and indicators to express casualty risks. This serves as background for the development of mapping approaches. Secondly, casualty risks are indicatively mapped for the Netherlands as a whole, and thirdly in a more quantitative way for a case study area: the Drechtsteden area. The results of the detailed case study are compared with the map for the Netherlands as a whole and used as a kind of 'validation'. The resulting nationwide indicative map shows the locations with higher Locational Risks and Group Risks. The Drechtsteden case study risk maps provide casualty risk figures. These must be considered with care.

References

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Contents

1 Introduction

1.1 Background

Flood risk maps are useful tools for spatial planning, flood risk management and flood event management. Flood risk maps give insight into the spatial distribution of flood risks (De Bruijn, 2007a). Therefore, they may be used to prioritize flood defence measures to certain areas, to restrict developments in hazardous zones or to identify locations for which compartmentalization measures could be considered or for which flood emergency plans are crucial. In other words, they help flood risk management planning. For these reasons, the European Flood Risk Directive requires the generation of such maps.

The Netherlands is a low-lying country in the delta of the Rhine and Meuse rivers. Flood risks are an important subject for the Netherlands to take into account and flood risk management needs to be reconsidered and improved regularly. Most flood-prone areas are protected from flooding by embankments. Furthermore, storm-surge barriers and dunes prevent coastal flooding. Because most flood-prone areas have a low elevation and a large extent and since dangerous flooding only occurs due to failure of defences, risk assessment and flood risk management in the Netherlands differs from that in other countries.

In the Netherlands flood risk maps have and will be used in the reconsideration of flood risk management policies (Water Safety in the 21st Century project: WV21), for improving flood event management (Taskforce Flood Management: TMO) and by the Ministry responsible for spatial planning (VROM).

Flood risks comprise economic flood risks, risks to people, and ecological risks. This project, called ‘Flood casualty risk mapping’, aims to develop flood risk maps focusing on casualty risks. We distinguish between casualty risks and other risks, because they are measured by different indicators, the factors which contribute to those risk types differ, and, therefore, other knowledge and data is required to assess casualty risks. Furthermore, both risk types are considered differently in the discussion on appropriate protection standards.

Since the beginning of 2007 risk mapping for the Netherlands has rapidly progressed:

- The RPB developed risk maps as an aid to spatial planning (Pols *et al.,* 2007). The maps distinguish flood-prone areas according to the expected inundation depth (deep or shallow) and the arrival time of the flood water after a dike breach (early or late);
- Delft Hydraulics made a first approximation of casualty risk maps (De Bruijn, 2007a; De Bruijn & Klijn, 2009);
- Nijwening *et al*. (2008) produced a discussion report on the possibilities of risk zoning as an instrument for spatial planning.

However, the maps produced are still very general and may be considered as first attempts.

1.2 Aim and approach

The project aims to produce indicative flood casualty risk maps for the Netherlands as a whole as well as quantitative risk maps for the Drechtsteden area.

For the ‘second approximation’ of flood casualty risk maps for the whole of the Netherlands improved input data have become available, but it was also desired to more closely relate the risk maps to the well-known and frequently-used concepts of Locational and Group risks. These concepts stem from environmental policy, more specifically the domain of external risk management. They are becoming quite popular nowadays in flood risk management too.

Locational Risk (LR) and Group risk (GR) are indicators of casualty risk which are used in the discussion on safety standards. This discussion has become more prominent lately and focuses on acceptable risk levels .To facilitate this discussion it is relevant to have good insight into the current casualty risks and into the location of the riskiest places. Flood casualty risk maps can enhance this discussion.

Firstly, some recent developments to estimate flood casualties and indicators to express casualty risks are discussed. This serves as background for the development of mapping approaches. Secondly, casualty risks are indicatively mapped for the Netherlands as a whole, and thirdly in a more quantitative way for a case study area: the Drechtsteden area. The results of the detailed case study are compared with the map for the Netherlands as a whole and used as a kind of ‘validation’.

1.3 Definitions and terms

This section defines the most important terms related to flood casualty risk mapping. Many of the definitions were already used by De Bruijn (2007b), but here the original source is given.

The definitions are taken from:

- Flood Risk Directive en Guidelines (FRD);
- The ‘Language of Risk’ report which gives working definitions for the EU-KP6 integrated project ‘FLOOD*site*’ (Gouldby & Samuels, 2005) (LoR)
- The PhD thesis of Bas Jonkman (Jonkman, 2007) (BJ).

Table 1.2. Definitions of some important terms used in this report

Concept	Definition	Source
Affected persons	Number of inhabitants of the flooded area (they may be absent during the flooding)	-
Flooded persons	Number of people present during the flooding	-
Casualties	Number of persons killed due to the flooding	-
Evacuation	The movement of people from a (potentially) exposed area to a safe location outside that area *before* the start of the flooding	-
Flood	A temporary covering of land by water outside its normal confines	LoR
Flood damage	Damage to receptors (buildings, infrastructure, goods), production and intangibles (life, cultural and ecological assets) caused by a flood	LoR
Flood hazard map	Map with the predicted or documented extent of flooding, with or without an indication of the flood probability	LoR
Flood risk	The combination of the probability of a flood event and of the potential adverse consequences for human health, environment, cultural heritage and economic activity associated with a flood event	FRD
Group Risk	Risk that a flooding results in many casualties. It may be expressed by: • EANC: the expected annual number of casualties • The relationship between probability per year and number of casualties, as expressed in an F-N curve	-
Hazard	A physical event, phenomenon or human activity with the *potential* to result in harm. A hazard does not necessarily lead to harm.	LoR
Hazard mapping	The process of establishing the spatial extents of hazardous phenomena	LoR
Locational Flood Risk (LR)	The probability that a hypothetical dies due to a flooding. In this report sensible behaviour such as evacuation is included in the Location Risk.	
Mortality rate	The fraction of the exposed population who die (synonyms: mortality, fatality rate, death rate, proportion of lives lost)	BJ
Risk mapping	The process of establishing the spatial extent of risk (combining information on probability and consequences). Risk mapping requires combining maps of hazards and vulnerabilities. The results of these analyses are usually presented in the form of maps that show the magnitude and nature of the risk.	LoR
Vulnerability	Characteristic of a system that describes its potential to be harmed. This can be considered as a combination of susceptibility and value	LoR

2 Existing approaches to estimate and map casualty risks

2.1 Introduction

The numbers of flood related casualties that have actually occurred in the last 50 years have been studied intensively by Jonkman (2007). This empirical research revealed that on average about 0.5% of all persons present in an area which is flooded from a river (excluding flash flood rivers) die due to this flooding. For flash floods this is 3.6% and for large scale coastal floods this is about 1%.

After a review of approaches to loss-of-life modelling, De Bruijn (2007a) concluded that the following factors determine the number of casualties:

- *Flood severity related parameters*: Flow velocity, water depth, water level rise rate, debris, flood water temperature, water quality;
- *Characteristics of the area and of the exposure of people to the floods* (Population density, size of the flood-prone area, warning time, shelter possibilities, building type (one-storey / multi-storey / caravan/ stable or collapsing));
- *The vulnerability of people*: This vulnerability of people depends on their health and age, and their preparedness: do they know where to go and what to do?

This chapter first briefly discusses the most promising of the methods to assess the number of flood casualties which De Bruijn (2007a) reviewed (section 2.2). In section 2.3 various ways to express casualty risk by metrics or graphs are discussed. Next, the risky places method developed earlier by De Bruijn (2007a) is briefly treated; this allows the indicative mapping of casualty risk (section 2.4).

2.2 Estimation of the numbers of casualties

2.2.1 Overview

There are various methods available to determine the expected number of flood casualties. Three of those are briefly discussed in this section: models based on expert judgement, semi-quantitative indicator based methods and quantitative methods based on mortality functions. They are described in more detail in De Bruijn (2007a; see also De Bruijn & Klijn, 2009).

Methods based on expert judgement, have been used by for example Klijn et al. (2004) and improved by Klijn et al. (2007). The method of Klijn *et al.* (2007) aims to get insight into the expected annual number of casualties in dike rings in the Netherlands in the current situation and in various future situations. It involves the assessment of casualties by estimating for each dike ring the percentage of the dike ring which may become flooded and the fraction of the population living in the flood-prone area, the percentage of people who may evacuate in time and the mortality rate of the people who are expected to remain during the flooding. The evacuation efficiency was estimated based on the expected warning time, the size of the flooded area, the distance to safe areas and the population density. The mortality rate was estimated to be between 0.1 and 1 % of the people present during a flooding. (Klijn *et al.*, 2007). The method is also used by Jonkman *et al.* (2008).

Semi-quantitative Indicator-based methods such as the 'Flood risks to people' method (HR Wallingford *et al.*, 2006) are slightly different. The 'Flood risks to people method' claims that flood casualty risks depend on three main groups of factors:

- Factors that determine the flood hazard: flood depth, flow velocity, the presence of debris and;
- The chance of people in the floodplain being exposed to the hazard (Area vulnerability);
- And the ability of those exposed to respond effectively to flooding (People vulnerability).

The number of casualties is thus a function of these three groups and the number of people present in the flood-prone area.

Casualties = f (population present, Hazard rating, Area vulnerability, People Vulnerability).

In this equation the population present is the number of people present in the hazard zone (at ground/basement level). The hazard rating (HR) is a function of the flood depth and flow velocity within the hazard zone considered and of the debris factor. The area vulnerability (AV) is a function of the effectiveness of flood warning, speed of onset of flooding and the nature of the area (including types of buildings). The People Vulnerability (PV) depends on the presence of people who are very old and/or infirm, disabled or long-term sick.

The third kind of method is *based on mortality functions* (e.g. Jonkman; 2007). This requires maps of expected water depth, flow velocity and water level rise rate as input and then calculates the expected number of casualties with mortality functions. The method is described in more detail in chapter 3. This approach only considers the effect of flood parameters on the number of casualties, whereas knowledge on people's vulnerability is implicitly incorporated in the mortality functions. Knowledge on warning and evacuation effectiveness may be added by the user to obtain more realistic numbers of people who reside in the area at the onset of flooding.

All methods include the following steps:

- Assessment of the number of people present at the onset of flooding (which depends on the number of people evacuated before the onset of the flooding);
- The mortality rate amongst the people remaining in the flood-prone area during the flooding.

These two steps are discussed in the following two sections.

2.2.2 Estimating evacuation possibilities

Evacuation is an important factor in the estimation of casualties because it determines how many persons are left in danger when the flooding occurs. In this report evacuation means leaving the area *before* the flooding *starts*. People who escape from the area after the initiation of the flooding or who flee to high buildings, mounds, or other higher locations inside the flood-prone area are not considered to be evacuated, but instead belong to the group of people left behind. Escaping and flying are covered for implicitly in the mortality functions (see next section).

The number of people who can evacuate depend on the time available for evacuation and the time required for evacuation. The available time is determined by the lead-time of forecast of extreme conditions, the forecast ability of the dike breach location, and the time it takes for an embankment to fail. Table 2.1 gives an indication of forecast lead-times as given by Barendrecht & Van Noortwijk (2004).

Table 2.1 The lead-time of forecasts per water system (based on Barendrecht & Noortwijk, 2004)

Water system	**Threat**	**Current lead time**
Rhine	High discharge	Lobith: about 2 days for a good forecast and 4 days for a reasonable forecast
Meuse	High discharge	6-12h for Borgharen, 2-3 days for Lith
Tidal rivers	Discharge & storm surge on North Sea	5-72 h (depending on the location)
IJssel- & Vecht delta	Discharge, high lake levels and/or storm	3-36 h depending on location
Lakes	high lake levels and/or storm	3-24h
Sea and estuaries	Storm surge at sea	4-18h

The time needed for evacuation is the sum of the time needed for: decision making, warning, response and the evacuation itself (Jonkman & Cappendijk, 2006). The time needed for the evacuation itself can be estimated with traffic or evacuation models such as the ‘evacuatiecalculator’, INDY, or the Life Safety Model (Lumbroso *et al.*; 2008)). The evacuation time depends on the number of people present, the distance to safe areas, the capacity of the roads, the traffic management, the weather and the behaviour of the people.

In general it can be concluded that riverine areas are easier to evacuate then coastal areas because the forecast lead-times are much longer. Small areas are easier to evacuate than large areas and islands are more difficult to evacuate than areas where people can easily reach higher areas.

Klijn *et al.* (2007) and Jonkman (2008) both give comparable estimates of the percentage of people who can be evacuated per dike ring based on area and flood characteristics. The expected values per dike ring are presented in figure 2.1.

2.2.3 Mortality rate

As referred to in section 2.1 about 99% of the people present in the area which is going to be flooded, is expected to survive. How many people die differs from location to location. It depends on:

- The flood severity or flooding process (see below).
- The presence of shelters such as high buildings and higher areas: After the breach of an embankment there is still time to escape the flood water. In some areas it may take days before the full flood extent is reached. People may still leave the flood-prone area, or they may go to higher buildings or high locations within the flood-prone area.
- Collapse of buildings: people who stay in higher buildings may be safe unless these buildings collapse. In the 1953 flood disaster many people died due to the collapse of buildings. Recently build houses are much stronger, but it is still possible that conditions occur in which they collapse.

- Behaviour of people: It is not unlikely that people from relatively safe locations try to leave the area and end up in traffic jams on low-lying roads. This behaviour increases the mortality rate.

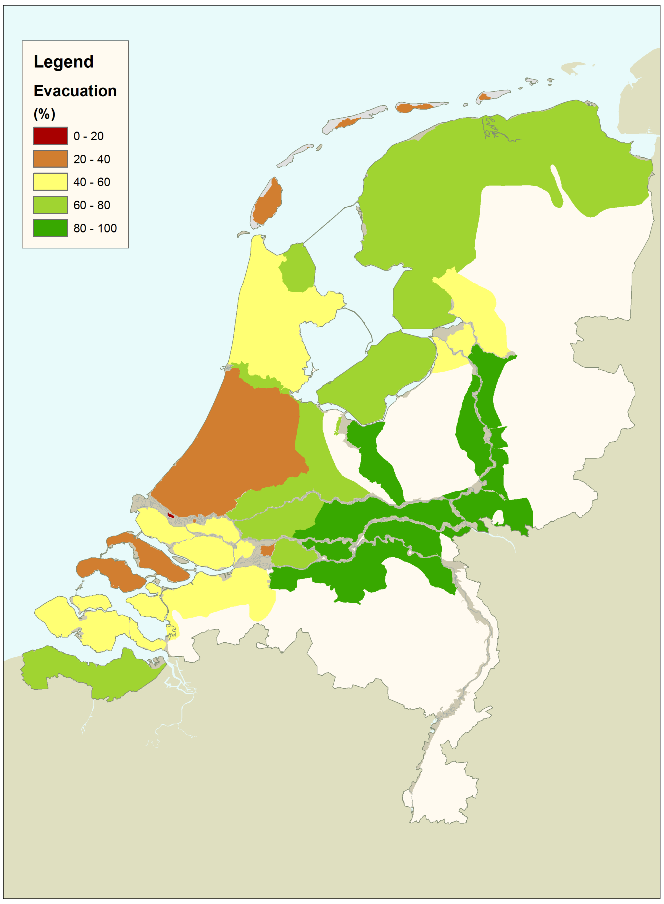

Figure 2.1 *Percentage of the population which may be evacuated before the onset of the flooding (based on Jonkman et al., 2008)*

The relationship between the flooding process and mortality rate

The mortality rate is related to the flooding process. The most important flood variables are the arrival time of the flood water, the maximum flow velocity, the water level rise, and the maximum water depth. The flooding process depends on the outside water level, the location of the breach, the breach growth rate and end-width, the hydraulic roughness of the terrain (land use), the strength of secondary embankments and other obstacles, and the role of regional waterways (who may cause preferential flow and cause the water to spread fast over a larger area) (Klijn *et al*., 2007).

Jonkman (2007) derived mortality functions from data on flood casualties of past floods. These functions have been incorporated in the Dutch Standard Damage and Casualty Model (HIS-SSM). This model first calculates the mortality rate based on the maximum water depth, maximum flow velocity and water level rise rate over the depth range from 0-1.5m. Secondly, it multiplies the found mortality rate for each location with the number of people remaining at that location. The user may reduce the number of people remaining by first assuming a certain evacuation fraction.

The mortality functions of Jonkman (2007) distinguish between three zones in the flooded area (see figure 2.2 and equation 1-3 below). Casualties may occur due to high flow velocities (first equation), high water level rise rates (second equation) or due to other causes (third equation) (see figure 2.3 and 2.4). The equations are based on measured data, so empirically determined. However, the R^2 of the fits were low. This means that the uncertainty involved in these relationships is substantial.

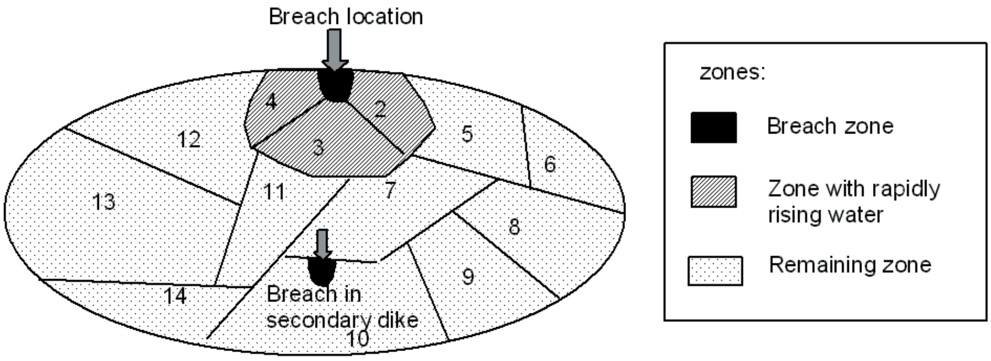

Figure 2.2 Location of the three zones in a flood-plain (Source: Jonkman, 2007)

Flood casualties due to high flow velocities:

$$F_D = 1 \qquad if \quad dv \geq 7m^2/s \qquad and \quad v \geq 2m/s \qquad \text{eq. 1}$$

Due to high water level rise rates: (average rise rate over the water depth range from 0- to 1.5m)

$$F_D(d) = \Phi_N\left(\frac{\ln(d)-\mu_N}{\sigma_N}\right) \qquad \mu_N = 1.46 \qquad \sigma_N = 0.28$$

$$if \quad \left(d \geq 2.1m \quad and \quad w \geq 0.5m/hour\right) \quad and \quad \left(dv < 7m^2/s \quad or \quad v < 2m/s\right) \qquad \text{eq. 2}$$

Due to high water depths

$$F_D(d) = \Phi_N\left(\frac{\ln(d)-\mu_N}{\sigma_N}\right)$$

$$\mu_N = 7.60 \qquad \sigma_N = 2.75 \qquad \text{eq. 3}$$

$$if \begin{pmatrix} w < 0.5m/hour \quad or \\ (w \geq 0.5m/uur \;\; and \;\; d < 2.1m) \end{pmatrix} \; and \left(dv < 7m^2/s \quad or \quad v < 2m/s\right)$$

With:
F_D : Mortality rate (the fraction killed of all people present at the onset of flooding)
Φ_N: de lognormal distribution with parameters μ_N en σ_N;
μ_N: the average of ln (*d*);
σ_N: the standard deviation of *ln* (*d*);
d: water depth;
v: flow velocity;
w: water level rise rate.

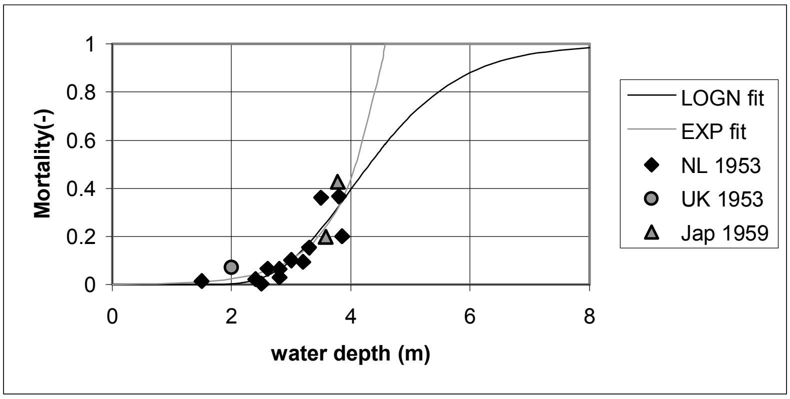

Figure 2.3 Relation between the mortality rate and the water depth for areas with a high water level rise rate (equation 2) (the lognormal relationship is used) (R^2 = 0.76) (Source: Jonkman, 2007)

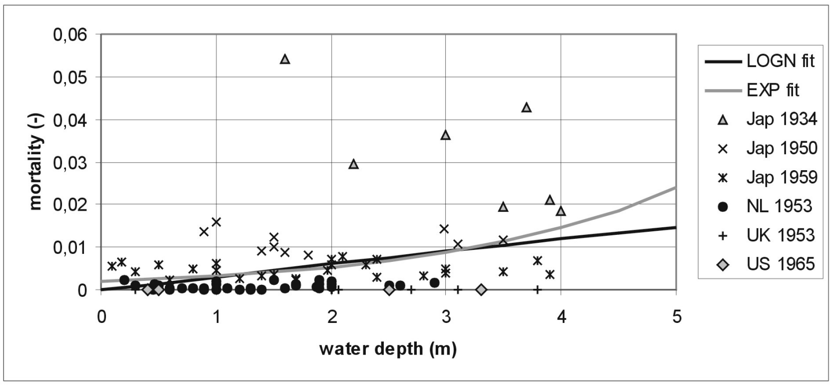

Figure 2.4 Relation between mortality rate and water depth for areas where the water depth does not rise fast (equation 3) (the lognormal relationship is used) (R^2 = 0.09) (Source: Jonkman, 2007).

The mortality functions must be considered as very uncertain:

- they are based on few data;
- the fit of the functions to the available data is poor;
- the current situation is quite different from the situation in 1953 (which was used to derive the functions);
- the parameters used within the functions are disputable.

The functions are derived from historic flood event data, viz. of 1953. It is disputable whether the historic data are still representative for today's casualty flood risks: house quality, the use of cars, population density and communication possibilities have all changed. The historic flood data only cover areas with water depths smaller than 4 m. It is unsure which mortality rates apply for greater depths. The functions do not take into account the variable warning time or water arrival time, although intuitively these are important. Also in an analysis of the 1953 flood in the Netherlands it was found that in areas that were only flooded during the second high tide fewer casualties occurred (Asselman, 2005). The functions include the water level rise rate as an important variable, but the use of this variable is disputable as found by Di Mauro (2009) when she tested the model with data from the 1953 flooding of Canvey Island (UK). The water-level rise rate function results in high mortality rates, when applicable.

This function is used when the water-level rise rate exceeds 0.5m/hour, an arbitrarily chosen threshold. The mortality functions and the resulting casualty estimations must thus be considered with care.

2.3 How to express casualty risk in a quantitative way? Metrics and graphs

2.3.1 Overview

For expressing casualty risks clear indicators – or risk metrics (McGahey & Sayers, 2009) – are required. These indicators should express the probability of occurrence of casualties and the expected number of casualties. In literature on risk assessment a variety of concepts and related indicators is found (cf. Van der Most et al., 2006; Beckers et al., 2008; Jonkman *et al.,* 2008). They all relate to the Locational or Group risk. The Locational and Group risk together cover all aspects of casualty risks.

The Locational Risk is the annual probability of dying due to a flood for an 'average individual' present at that location. This Locational risk can be defined with and without including the possibility of evacuation at the moment that the flood threat becomes imminent.

The Group Risk is related to the probability that many casualties occur. It can be expressed by the expected annual number of casualties (EANC: number of killed persons /yr) or by the annual probability that a certain number of killed persons occurs in one event (e.g. probability that more than 100 persons are killed, or probability that more than 1000 persons are killed) (Vrijling *et al.,* 1998).

These indicators allow comparison of the casualty risk in different places and the investigation of changes of risk in time. Also a well-informed discussion on reconsidering the safety standards for flood risk management may be enhanced by using similar – or the same – concepts and ways of expressing different kinds of risks: external safety risks, flood risks, etc.

Casualty risks may be an important element to take into account in the discussion on new safety standards, as proposed by the Delta Committee (2008). First, it must be discussed what level of casualty risk is acceptable, which requires clear and unambiguous indicators for casualty risks and maps of current casualty risks.

2.3.2 Locational Risk: metrics and maps

The concept of *Locational* risk refers to the probability that a person who is present at a certain location for a year dies due to a dangerous activity in his surrounding (e.g fuel storage). It is a concept used in external safety standards. In the Netherlands, the annual probability to die is on average 10^{-2}. For elderly persons, this probability is higher. The probability to die is lowest for teenagers and young adults: For them the annual probability to die is only 10^{-4}. In external safety policies, this healthy group of young adults is taken as reference. An activity is then considered acceptable if its contribution to the casualty risk is less than 1 % of the basic probability to die, thus if the associated casualty risk is less than 10^{-6} (Ale, 2003).

In flood risk management policy discussions it is debated whether this Locational Risk indicator is also applicable to flood risks. Hazards of fuel storage, chemical factories and transport differ enormously from flood hazards, the most important differences being the time available to warn, evacuate or just run for it as well as the mortality rate. If a factory or fuel storage facility explodes, there no time for warning, evacuation, escape or other sensible reactions: Floods in contrast can sometimes be forecasted days ahead, when the embankment start to fail there still remains time, and in many places the water rises slowly. Moreover, people close to an exploding factory have a high probability of dying. If, instead a flooding occurs only about 1 % of the people remaining in the flooded area actually dies, whereas the others move through the water out of the area, go to a second floor or even the rooftop, or are being rescued by boats or helicopters. Because of the differences, the concept of Locational Risk cannot be applied directly to flood risk.

In this report, we use the term Locational Risk as follows: *The Locational Risk is the probability that a hypothetical person dies on a certain spot because of flooding*. It does take into account sensible behaviour to save ones life and rescue from outside, as well as the possibility of evacuation before the flooding. In practice it thus depends on the probability of flooding, the probability to be evacuated and the mortality rate (the people killed by the flooding as fraction of the people present in the area at the onset of the flooding), (see equation 1).

$$ILR_{x,y} = \sum_i P_i P_P M_i(x,y) \qquad \text{(Eq. 1).}$$

With:

- LR(x,y) = Locational Risk at location x,y [1/yr];
- P_i = Probability of flood inundation scenario I;
- P_P = Probability to be present at the onset of the flooding (equal to (1 minus the probability of being evacuated) (-);
- M = Mortality rate given scenario i (-)

The flood probability of a certain location within a dike ring area depends on all possible flooding events (flood, failure of embankment, flooding process). The number of people present depends on the evacuation effectiveness. This evacuation effectiveness depends on warning time, size of the flood-prone area, population density, capacity of the roads and railroads, etc.

The mortality rate depends on:

- the severity of flooding (depth, flow velocity);
- the time available to escape before or during the flooding process, determined by the arrival time and the water-level rise rate);
- type of houses/buildings;
- the presence of high buildings, shelters, or nearby safe areas;
- individual characteristics (age, health, local knowledge etc.).

Individual characteristics may be neglected in the case of Locational Risk, as this refers to hypothetical persons.

Because evacuation effectiveness is very uncertain and the incorporation of evacuation is disputable (Jonkman *et al.,* 2008) two indicators for Locational Risk may be relevant to consider: one with and one without evacuation. The one without evacuation does include the behaviour of people during the occurrence of a flooding.

Since the Locational Risk primarily depends on the flood hazard characteristics, a map showing this risk is very likely to very much resemble a hazard map. The Locational Risk is especially useful for spatial planning by land zoning.

2.3.3 Group risk: metrics and graphs

Group risks are relevant in the context of policy's desire to prevent large disasters, even when rare (in contrast: Locational Risks are relevant in the context of providing a basic safety for individuals). For example, the planning of new hazardous installations too close to residential areas can be prevented on the basis of group risks, or – the opposite – housing development too close to an existing nuclear power plant.

Group risk can be expressed by one figure: the expected annual number of casualties (EANC) (see De Bruijn, 2005) or the PLL (potential loss of life) (Jonkman *et al.,* 2008), which are essentially the same. To this end flood probabilities and flood consequences are multiplied (or integrated) to achieve this one figure. Events with high probabilities and few casualties are then considered equally serious as rare events with many casualties.

Society and policy makers, however, consider events with large consequences to be so much more disruptive than frequent small events which together cause more casualties, that a special treatment is often called for. Therefore, for hazardous installations different standards for probability apply for events with 10, 100 or 1000 casualties (see BEVI art 1, lid 1). Such a safety policy requires that probabilities and consequences are related to each other. One common way of showing this relationship is by so-called FN curves (Beckers *et al*., 2008). The FN curve shows the exceedence probability of an event with N or more casualties on the vertical axis and the number of casualties on the horizontal axis (see figure 2.5). Both axes usually have a logarithmic scale. The curve can be determined for a certain area (a country, a dike ring, a valley).

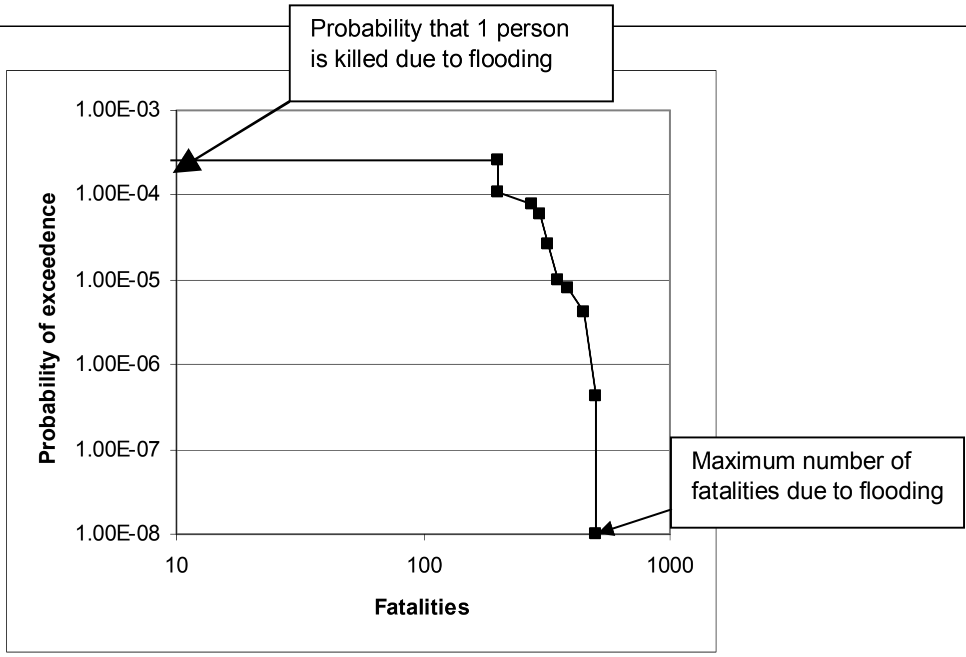

Figure 2.5 Example of an FN curve (hypothetical example)

2.3.4 Mapping risky places

In the former section, quantitative ways of expressing casualty risk have been discussed. Now, we shall go into an approach to indicatively mapping casualty risk, not in quantitative terms, but in relative terms: relatively high versus relatively low.

The text of this section is copied from De Bruijn & Klijn (2009).

What are risky places?
Places are considered risky, when many fatalities may be expected there. Risky places are both *hazardous* and *vulnerable* to floods. Hazardous areas are areas, where flooding is probable, water level rise rates are high or where water depths are high. Hazardous places are thus identified by looking at flood parameters only. Flood depth and water level rise rate determine the survival chances of people and the stability of buildings. Flow velocity is not considered, because in the flat Netherlands the expected flow velocities are very low, except very close to dike breaches. Near breaches the flow velocity may be so high that people become washed away. However, a few hundred metres away from the breach the flow velocity will already be too low to cause danger. Since we focus on the national scale the influence of flow velocity may be neglected (Jonkman, 2007).

Vulnerable areas are areas where many people may be present during flooding. Places which are most vulnerable are those with a high population density, which may be flooded suddenly and from where it is difficult to reach safe areas. The vulnerability is thus determined mainly by the area's characteristics in relation to flood parameters. Vulnerable areas are thus defined here as areas where many people are likely to be exposed to flooding.

Hazard Rating

Similar to the 'Risk to people method' a hazard rating is assigned here to each grid cell in the flood-prone area (See table 2.2). The choice of the parameters to be included was based on the review described above. All factors taken into account in the method proposed here can be traced back to one or several of the approaches discussed above except for 'flood probability'. This factor was added to include the expected flood frequency. The rating scores were assigned by the authors after a thorough investigation of the many flood simulations available for various areas in the Netherlands. The three selected parameters are scored between 0 and 1, and are considered equally important. The resulting hazard rate is also a number between zero and one.

Table 2.2 The criteria and values for the Hazard Rating (HR)

Criterion	**Hazard Rating**
Flood probability rating (FPR)	0-1
Water level Rise rate (RR)	0-1
Water depth rating (DR)	0-1
Hazard Rating (HR)	HR = (FPR + RR + DR)/3

Vulnerability rating

The vulnerability rating is based on expectations about the number of people affected by flooding. The vulnerability rating is calculated based on the following steps:

- Identification of those areas where flooding may occur suddenly, thus where warning time is short;
- Identification of those areas from where it is difficult to reach safe areas because of distance or because of limited capacity of escape routes (bridges);
- Identification of the locations of cities, towns and larger villages.

The information is combined into a vulnerability rating (table 2.3).

Table 2.3 The criteria and values for the Vulnerability Rating

Criterion	**Vulnerability Rating**
Speed of onset of flooding (SF)	0-1
Vicinity of safe places (VS)	0-1
Population density (PD)	Condition
Vulnerability Rating (VR)	VR = 0.5 * (SF + VS) for cities, towns and villages

Risky places

Finally, the hazard and vulnerability rating maps are combined to establish which areas are both hazardous and vulnerable and thus risky. Hazard and vulnerability are combined in two ways:

1. The Hazard Rating and Vulnerability Rating are multiplied (HR * VR);
2. An overlay is made of the hazard rating (HR) map and the vulnerability rating (VR) map and a reclassification is made of those areas which have:
    a. A low hazard and vulnerability;
    b. A low hazard and a high vulnerability;
    c. A high hazard and a low vulnerability;
    d. A high hazard and vulnerability.

Results
The method was applied on the Netherlands as a whole and on the dike ring area ‘Land van Heusden de Maaskant’. The results of the national application are shown in figures 2.6, 2.7 en 2.8.

Figure 2.6 shows the resulting hazard rating map. It was generated by summing the contributions of the flood probability, water level rise rate and water depth to the hazard rating and dividing the total score by three to get a value between zero and one. Figure 2.6 shows that the most hazardous places are located along the rivers, especially in the western parts of dike rings. But also some small polders along the northern coast of the Netherlands classify as hazardous.

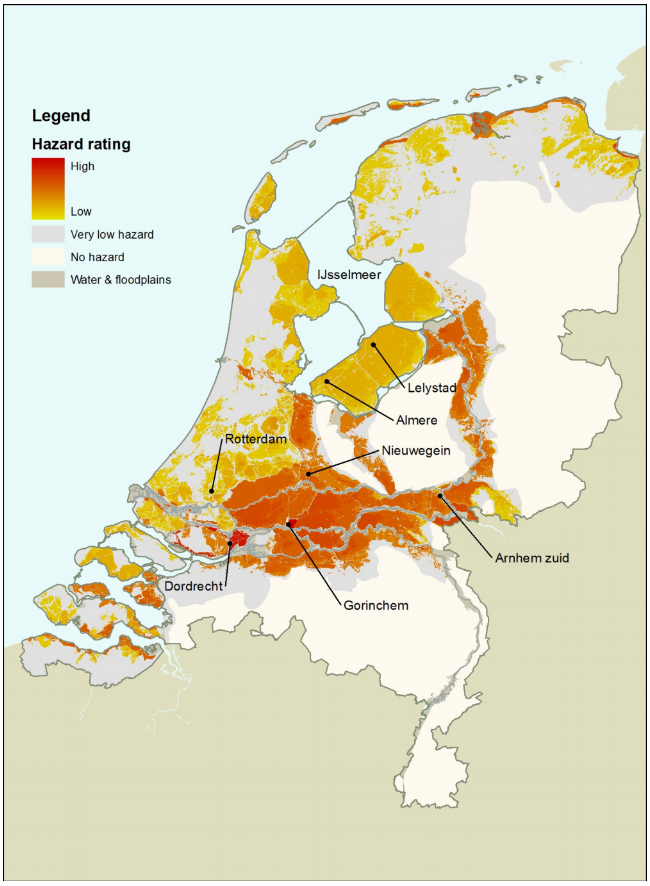

Figure 2.6 The resulting hazard rating map

The vulnerability map is generated by combining maps which indicate:

- areas where flooding may occur suddenly, thus were flood warning time is short;
- areas from where it is difficult to reach safe areas;
- cities, town and villages.

Sudden floods are more likely along the coast and tidal rivers than more upstream along large rivers in the Netherlands and floods may also be more sudden for people living close to dikes which may breach than for people who live further inland. For coastal areas and lakes high water levels cannot be forecasted as long ahead as for large rivers.

It is expected that for coastal areas and estuaries flood forecasts and decision making permit about 12 hours of action before the initiation of the flooding, while for the large rivers 60 hours are available for taking action (Jonkman, 2007). Areas which are situated close to an embankment will have less response time than areas where it will take days before the water will arrive. If we assume that water will flow with 0.5 m/s on average at maximum (0.5 m/s = 1.8 km/h), then people living within 4 kilometres distance from an embankment have only two hours for action between the moment of breaching and the arrival of the water. Flood-prone areas within 4 kilometres from an embankment score 1 and flood-prone areas situated between 4 and 10 kilometres from an embankment score 0.5. The other areas score zero. The thresholds of 4 and 10 kilometres were chosen arbitrarily.

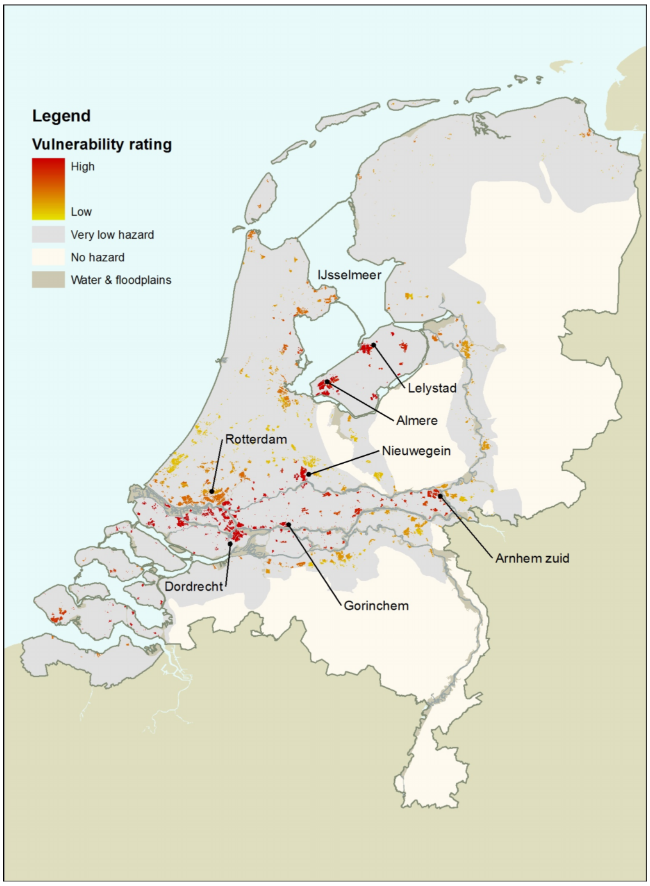

Figure 2.7 The resulting vulnerability rating map

In future, the arrival time of flood water may be derived from flood simulations, although this may require simulating several hundreds of possible events (breach locations) because of the huge length of flood defences in the Netherlands (some 3600 km of primary defences only).

Reaching a shelter or safe area is more difficult if there are no, few, or only very small higher areas or high buildings within reach, or when the distance to an exit is large. For an assessment of the ease to reach safe areas one should consider the number of people present, the existing road capacities, the likelihood that roads can be used during extreme conditions (e.g. severe storm), the availability of shelters (and their accessibility), among other things.

There are various tools available to simulate evacuation (Lumbroso *et al.,* 2008), although most of those also rely on assumptions on the average travel velocity and knowledge on safe areas. For this mapping exercise these sophisticated tools were not used, primarily because they require many data and huge modelling efforts. Instead, the distance to safe ground was considered, assuming that people go to the nearest area which cannot become flooded or to neighbouring dike rings which are not being flooded. Besides, islands which are completely flood-prone and surrounded by water are considered as relatively vulnerable. These islands score 1, and areas where people must travel more than 10 kilometres (measured in a straight line) score 0.5.

Figure 2.7 shows the resulting vulnerability rating map. The cities in the southwest of the Netherlands, Dordrecht, Rotterdam, Gorinchem, Arnhem Zuid, Almere and Lelystad are the most vulnerable. They face relatively sudden floods and are relatively difficult to get away from.

Generation of the maps of risky places
Finally, the hazard and vulnerability rating maps are combined to identify the risky places for large numbers of fatalities. Figure 2.8 (left-hand site) shows the result if the hazard and vulnerability rate are multiplied. It shows that mainly the areas near Dordrecht, Gorinchem and Niewegein are risky. The right-hand side of figure 2.8 shows the overlay version of the risky places map. This version is more illustrative about the causes which make these places risky. It shows that Almere is risky, because the vulnerability is high, caused by the fact that floods may occur suddenly since the city is located close to the embankment of the IJsselmeer and also because people cannot get away easily as Almere lies on an ‘island’, or rather in a polder fully surrounded by water. Dordrecht is both vulnerable and hazardous. In the north of the Netherlands only the hazard is high, but vulnerability is not, as this area is not so densely populated.

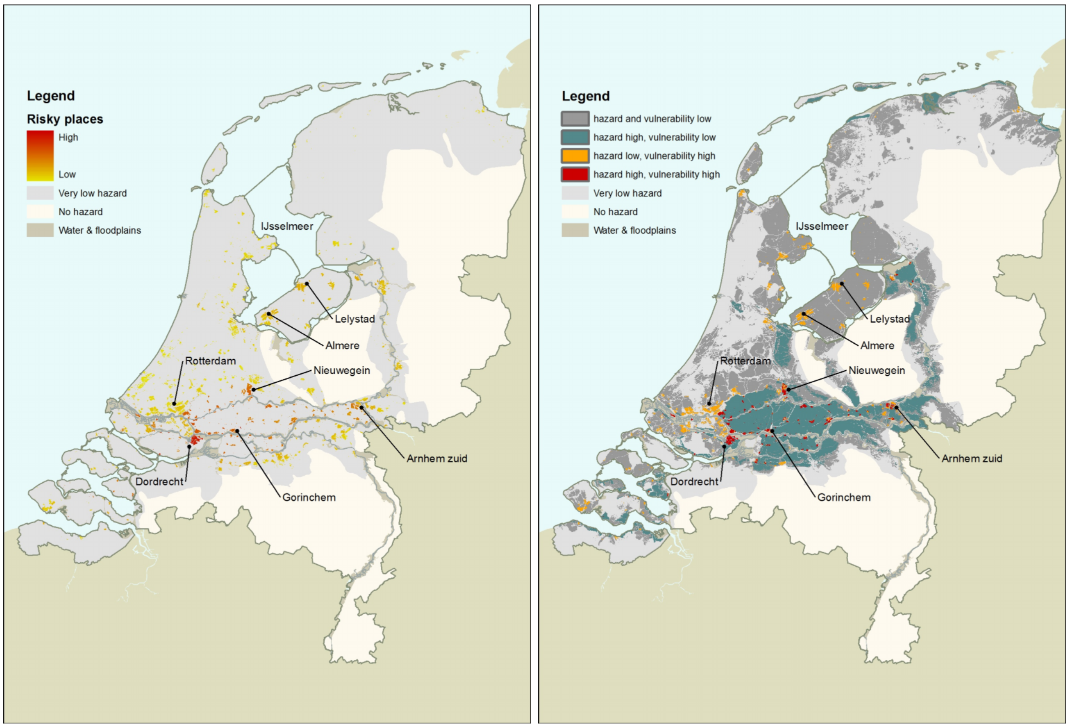

Figure 2.8 First approximation of the risky places in the Netherlands

In contrast to the other described methods, the risky places method does not yield numbers of fatalities, but instead aims at producing a map of those places where the occurrence of many fatalities is likely. Risky places as indicated on the map are less disputable than exact fatality numbers. They also are less likely to change when new knowledge becomes available. Detailed fatality numbers do contain more information than indications of risky places do, but since these numbers are very uncertain and difficult to compare with costs, other risk metrics, or standards, they do not necessarily lead to better decisions. The information on a risky places map already helps spatial planners, flood event managers and flood risk managers a lot. Besides, the whole procedure of making the risky places map provides insight in why the areas are risky and why many fatalities may occur at those locations. This insight supports the selection of flood control measures and spatial planning strategies.

The proposed method requires information on water depths, water level rise rates, flood probabilities, population density, the possibility of sudden floods and the ease to reach safe areas. The method, however, is very open and allows the use of very rough, but also of very detailed information. Therefore, the method can also be applied on areas for which merely a ‘notion’ of these factors exists, but for which a quantitative value is not available. This means that indicative maps of risky places can be drafted also for areas for which adequate flood simulations are absent.

The map provided here is called a first approximation because the input data on which it is based are not very accurate and detailed. Second and further approximations are therefore recommended. The current map is mainly useful for policy making at the national scale. For spatial planning at the municipality scale more detailed analyses should be used. The map shows what may be interesting areas to focus more detailed analyses on or where to focus the development of flood risk management plans and flood emergency plans on. It may also be used in the discussion on flood protection levels: at the most risky places near Dordrecht higher protection levels or local reinforcement of stretches of embankments in order to withstand overtopping might significantly reduce the potential numbers of flood fatalities against relatively low cost

The method thus appears quite acceptable, but the resulting map is somewhat flawed because of the still poor quality of some crucial input maps such as the water depth map. Input maps thus need improvement. Also the assessment of the parameters ‘speed of onset of flooding’ and ‘vicinity of safe areas’ needs improvement. The ‘speed of onset of flooding’ may be derived from the flood water arrival time which can be calculated from flood simulations. And for improving the input maps for ‘vicinity of safe areas’ evacuation models may be used which take into account the presence of high-rise buildings and the effects of shelters on mortality.

It is also recommended to run sensitivity tests for the weights assigned to the factors contributing to the hazard and vulnerability ratings. Regional applications could be used to further test the criteria and input data used.

Furthermore, the results need to be discussed with policy makers and emergency planners in order to achieve improvements on the point of applicability. So far, we only have the experience of the maps being pulled out of our hands, which may be regarded an indication of the huge interest among policy makers from the fields of flood control, spatial planning and emergency planning alike.

3 Indicative casualty-risk mapping of the Netherlands

3.1 Approach

The indicative mapping approach builds on the approach followed in the first approximation (De Bruijn, 2007a) (see section 2.3.4): Relative hazard and relative vulnerability maps were made and combined into relative risk maps. This time, Locational Risk maps and Group risk maps are made in an attempt to converge the indicative mapping approach with the well-known concepts of Locational Risk and group risk. Available data – and especially their quality – does not yet allow a quantitative mapping, so the maps aim to show relative risk levels.

The Locational Risk map has conceptual similarities with the 2007 hazard map, but comprises more exposure characteristics. The group risk map resembles the 2007 risky places map, but is improved because the input used has been improved and the approach has also been improved on various points.

For each variable which determines the Locational and group risk an input map has been derived by (re)classification of the relevant factor maps (or geographical data) and subsequent scaling to values between zero and one. These input maps are then combined into a map for Locational Risk and into one for group risk.

3.2 Locational Risk

The Locational Risk can be considered with and without taking evacuation into account. Both options were elaborated. The Locational flood risk is determined by the (see section 2.3.2 and figure 3.1):

- Flood probability;
- Probability that the individual is evacuated before the flooding starts;
- Mortality rate: the Individual probability of dying if a flooding occurs and if the individual is not evacuated.

Flood probability
The flood probability of any location within a dike ring depends on the load (water level and waves and their probabilities) and the strength of all the embankments, as well as on the characteristics of the location itself. Within dike rings some locations may flood due to dike breaches anywhere along the dike ring, while other locations are expected to remain dry unless very rare circumstances occur.

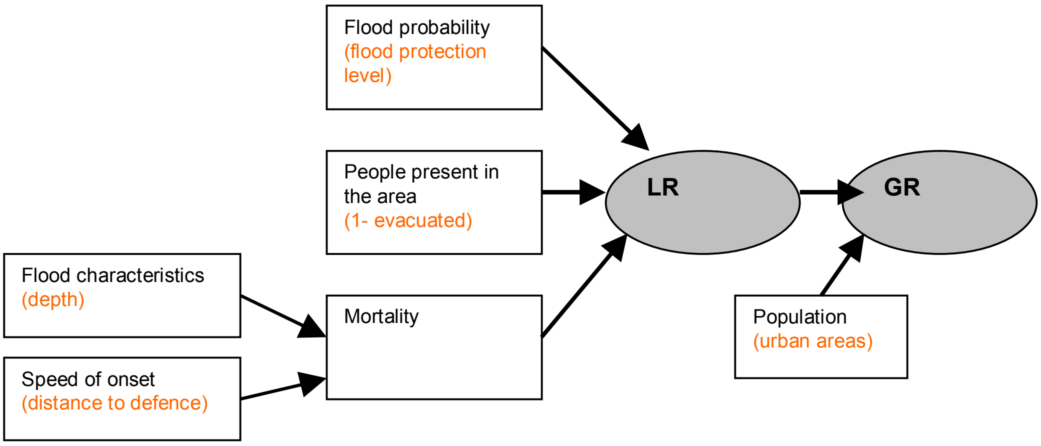

Figure 3.1 Overview on the approach to derive the Locational and Group risk maps (the black words are the parameters, the red terms are the indicators used to quantify the parameters)

For the mapping, it is assumed that the flood probability of each dike ring equals the design probabilities set in the protection standard. This is a gross simplification, however, as the real flood probabilities differ from these design probabilities. Usually, embankments are made somewhat higher and stronger than required, implying that the probability of failure is often lower than the design probability (Klijn *et al.,* 2004). However, their may also be weak spots in which embankments do not comply with the safety standards. The actual flood probabilities are still subject to extensive research and the approaches to establish them are subject to continuous scientific debate. Moreover, the load and strength of embankments changes constantly by climate change and other physical processes and by the effects of flood management measures currently being implemented. In 2015 all embankments are expected to meet the design standards. For this nationwide mapping we (temporarily) use the proxi of protection standards (see figure 3.2). The flood probabilities were scaled to figures between one and zero as indicated in table 3.1.

Table 3.1 The scaling of flood probabilities to numbers between 0 and 1.

The recurrence time (year)	Score
>10000	0.1
5000-10000	0.4
2000-5000	0.5
500-2000	0.8
100-500	1

Individual probability of being evacuated

It is disputable whether evacuation should be included: there may be situations in which unexpected floods occur and in which evacuation is not possible. Therefore, two options were used: one with and one without evacuation. Evacuation percentages were taken from Jonkman *et al* (2008) (see figure 2.1). Figure 3.3 shows the percentage of the inhabitants which is expected to still be present in the area at the onset of the flooding.

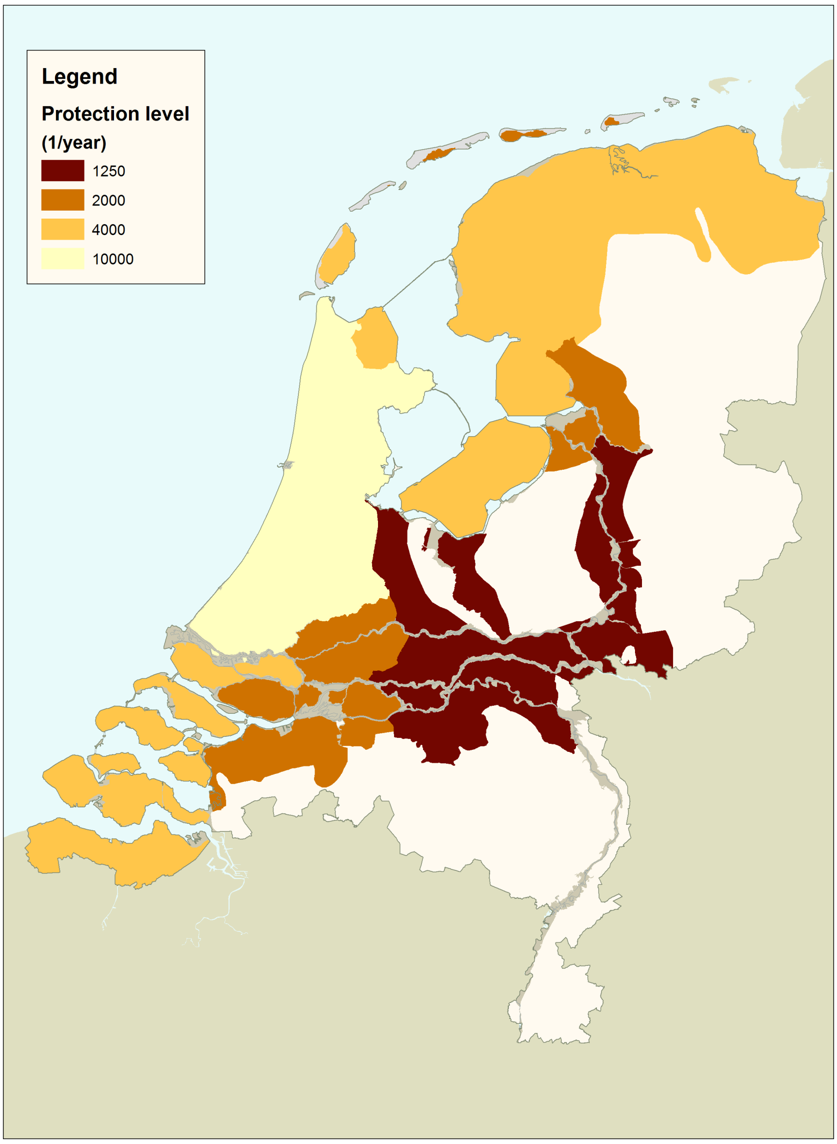

Figure 3.2 Design probabilities (protection standards) of the dike rings

Mortality rate

The third input variable, the mortality rate, is a function of (see section 2.3):

- The severity of the flooding: water depth, flow velocities;
- Speed of onset: if the flooding occurs slower and there is more time available for escape from the lowest areas to higher areas or higher floors.
- Ability to reach a safe place: presence of high buildings and dry areas.

Individual differences were not incorporated: healthy young adults probably have a lower mortality rate than children, ill, handicapped, and elderly people. The risk maps apply to average persons

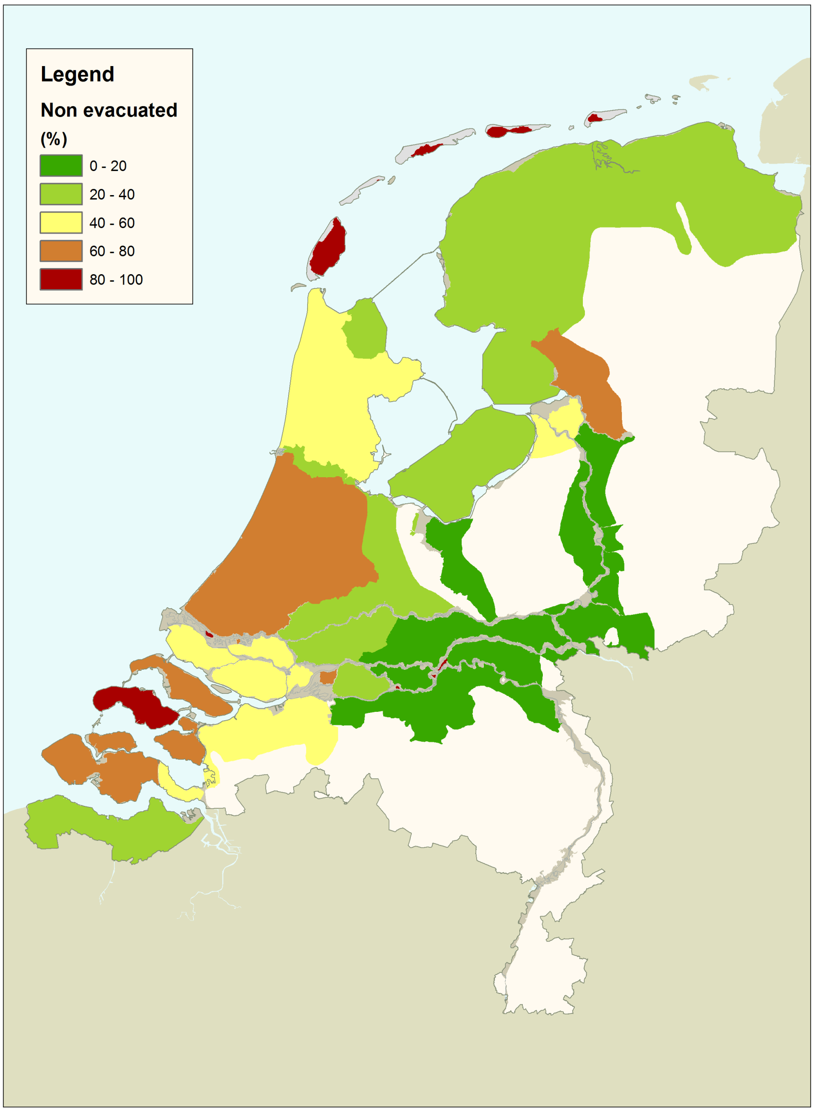

Figure 3.3 *Percentage of people per dike ring who are not evacuated and thus present at the moment that the flooding starts (based on Jonkman et al., 2008)*

Severity of flooding

The flow velocities in the Netherlands are generally less than 0.5m/s and almost never exceed 2 m/s. Therefore, the influence of flow velocities on casualties may be neglected. The water depth then is the most important factor. The maximum water depths are provided in figure 3.4.

The water depth map was scaled to values between zero and one as indicated in table 3.2. Areas which are situated outside the flood-prone area score a 0. Areas within the flood-prone area, but which are not likely to flood score a 0.01. The water depth map used is based on a large set of flood simulations with various assumptions, but it is possible that flood-protected areas which appear to remain dry in this map do become flooded.

The water depth boundary of 0.5 m was chosen, since floods shallower than 0.5 m are considered not life-threatening; people may go upstairs or climb upon a table. Above 2 m people must move to a second floor to be safe. Above 4 m, also a second floor is dangerous.

Table 3.2 Classification of water depths from 0 to 1

Water depth (m)	**Score**
outside dike ring	0
0	0.01
0.01-0.5	0.1
0.5-2	0.2
2-4	0.5
>4	1

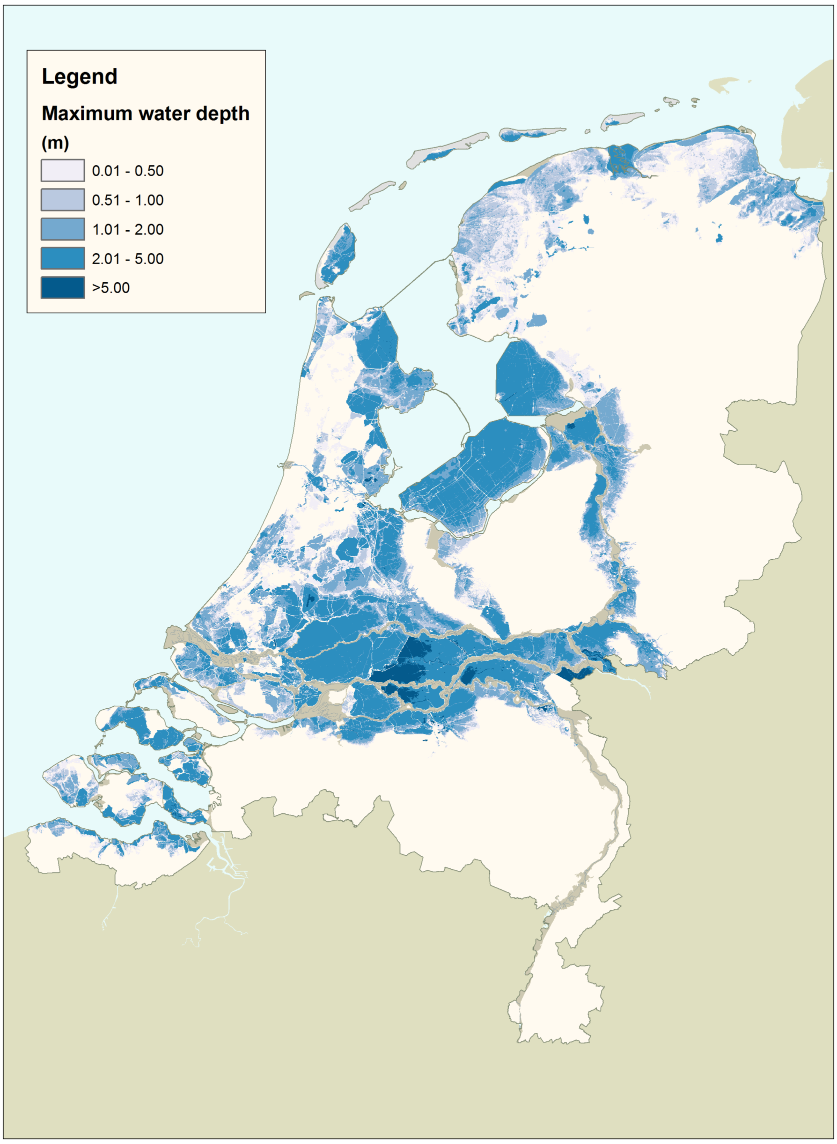

Figure 3.4 Maximum water depth map (based on the combined provincial flood risk maps)

Speed of onset of flooding

The speed of onset of flooding depends on the arrival time of the water at a certain location. Because no representative arrival times for the whole country have been established yet, the distance to the embankments was used as proxi Figures 3.5 and 3.6). The closer to an embankment, the faster water may arrive if a dike breach occurs. This assumption is of course a gross simplification again, since the arrival time does not only depend on the distance to an embankment only, but also on the land use, the spreading through water ways, the presence of obstructions, etc. Therefore, it is recommended to use flood simulations and water arrival times for more detailed regional analyses (see also chapter 4)

A function was used to classify the distances to a value between zero and one (see figure 3.5) based on table 3.3. These points are identical to those used earlier for the speed or onset by De Bruijn (2007a).

Table 3.3 Classification of the speed of onset of flooding to values between 0 and 1

Distance to an embankment	Score
< 0.01	1
4	0.5
10	0.2
20	0.001

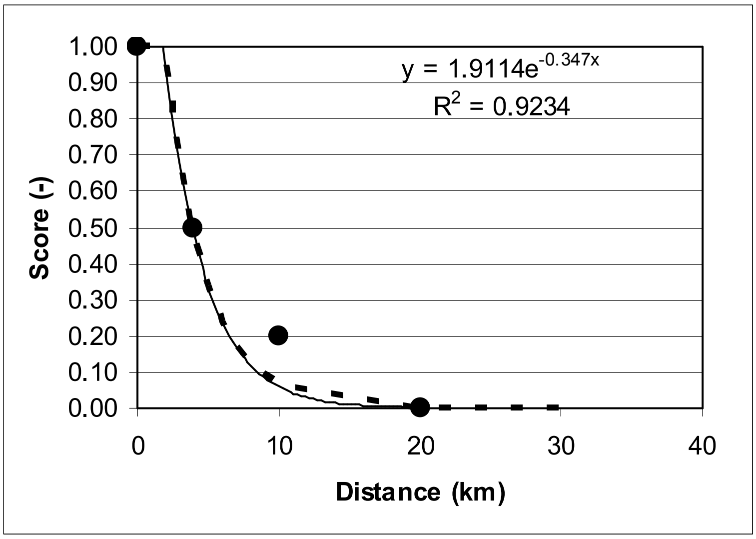

Figure 3.5 Classification of the distance of an embankment to values between 0 and 1

High buildings and safe areas

The third variable, the presence of high buildings and dry areas, has not been taken into account for the nationwide mapping. It is thus assumed here that all persons have an equal ability to reach safe buildings or safe locations. This may need to be improved in the future.

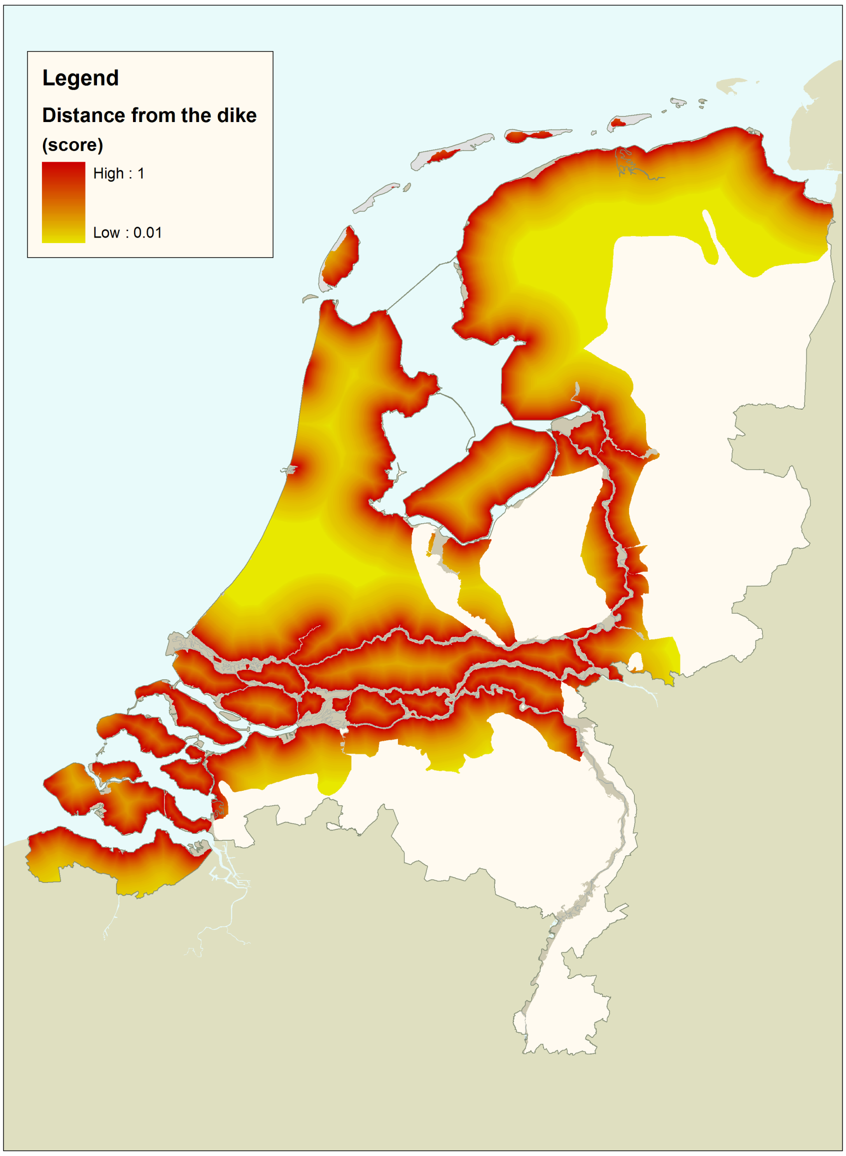

Figure 3.6 Distance to an embankment expressed by values between zero and 1

Resulting mortality map

The mortality map was made by multiplying the map with the scored distance to the embankments with the scored water depth map. Figure 3.7 shows the result. The mortality is largest in the flood-prone areas along the rivers, because the distance to embankments is generally smaller there than in the coastal areas, whereas also large water depths may occur.

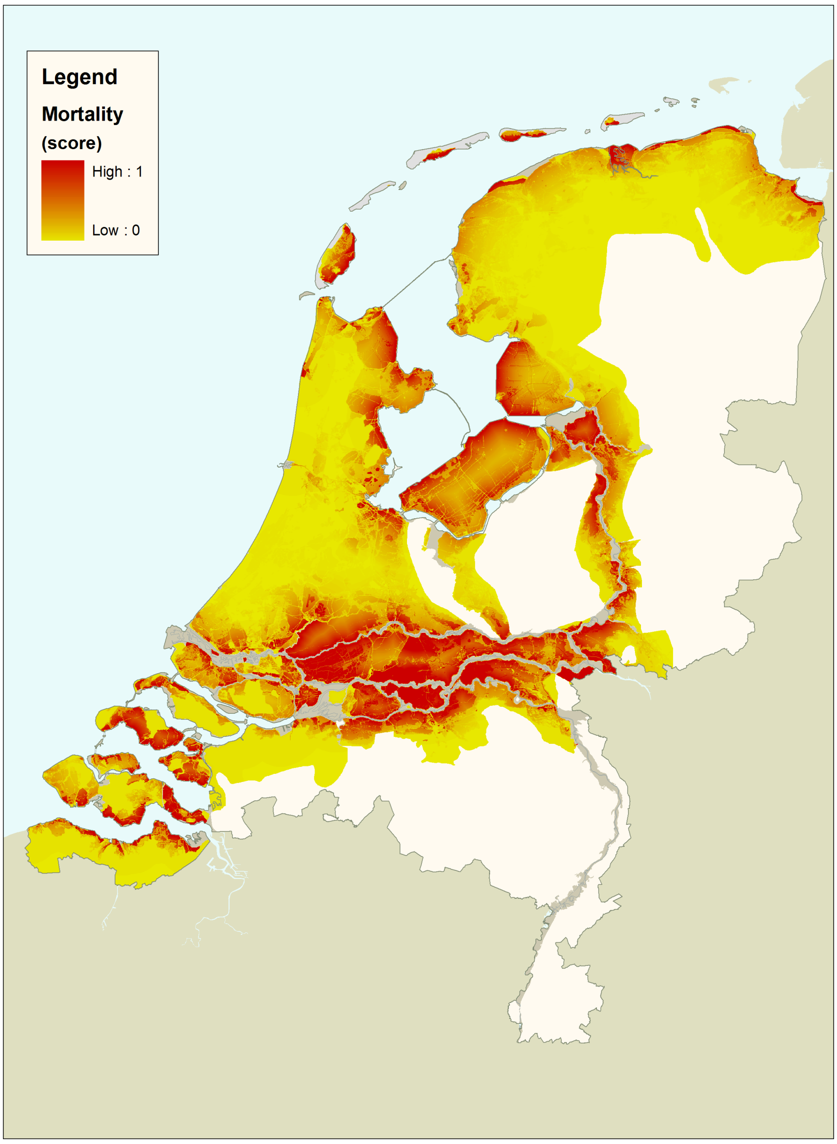

Figure 3.7 The resulting indicative flood mortality map

The resulting LR map
The most important input maps to be combined into the indicative Locational Risk map are thus the flood probability map, the evacuation probability map, and the mortality map (based on the potential water depth map and the speed of onset map) (see Figure 3.7). They are combined by multiplication of two or all three maps

Figure 3.8 shows the map for the LR *with* evacuation – the combination of three maps – and figure 3.9 shows the result *without* evacuation – the combination of two maps only.

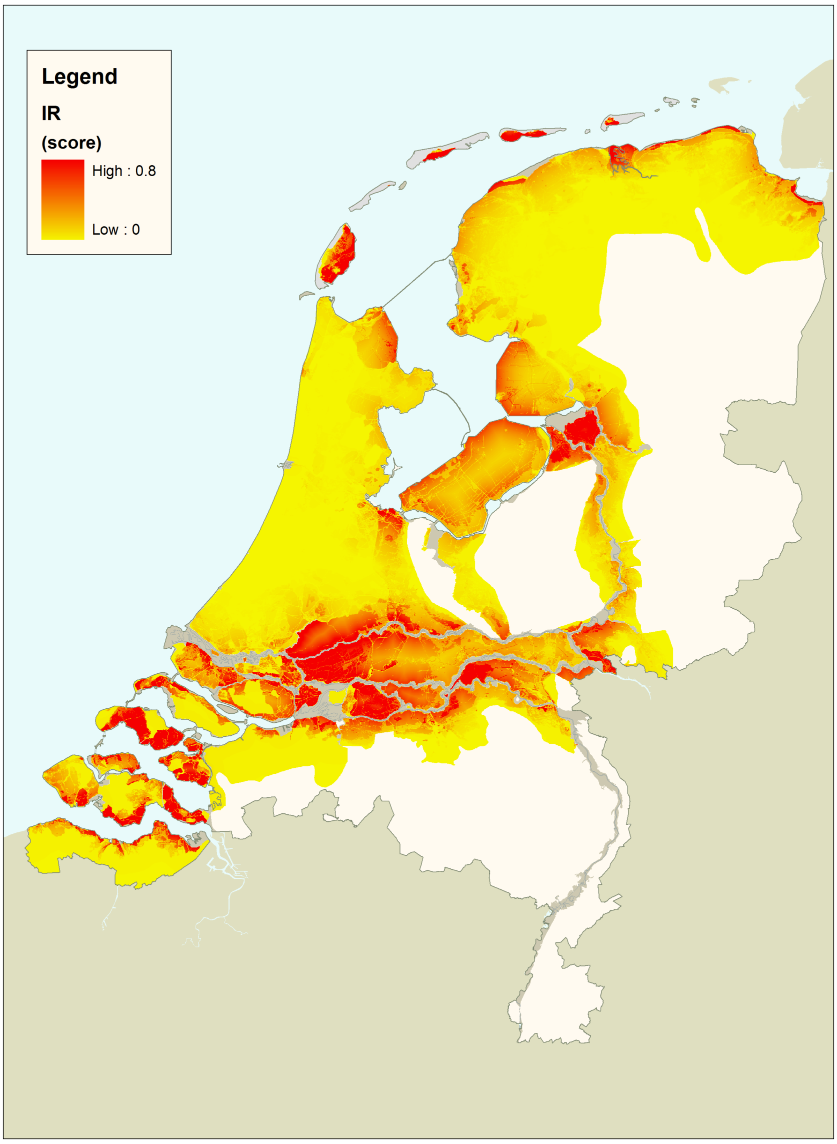

Figure 3.8 The indicative Locational Risk map with evacuation

The LR map shows that the Locational Risk is highest in the areas threatened by river floods. This is caused by the relatively high flood probabilities of those areas (1/1250 or 1/2000 while the coastal area has 1/4000 to 1/10000). Especially the river threatened areas which face large water depths score high (e.g. the Alblasserwaard, the western part of the Betuwe and the Land van Maas en Waal, Rijnstrangen area, Mastenbroek). The islands in the north and the coastal areas in the southwest score high because of their high mortality rate (due to large water depths and high speed of onset) and the low evacuation probabilities of those areas.

In the map in figure 3.8 the Locational Risk of the river threatened areas is even higher, because the high success rate of evacuation there has not been taken into account.

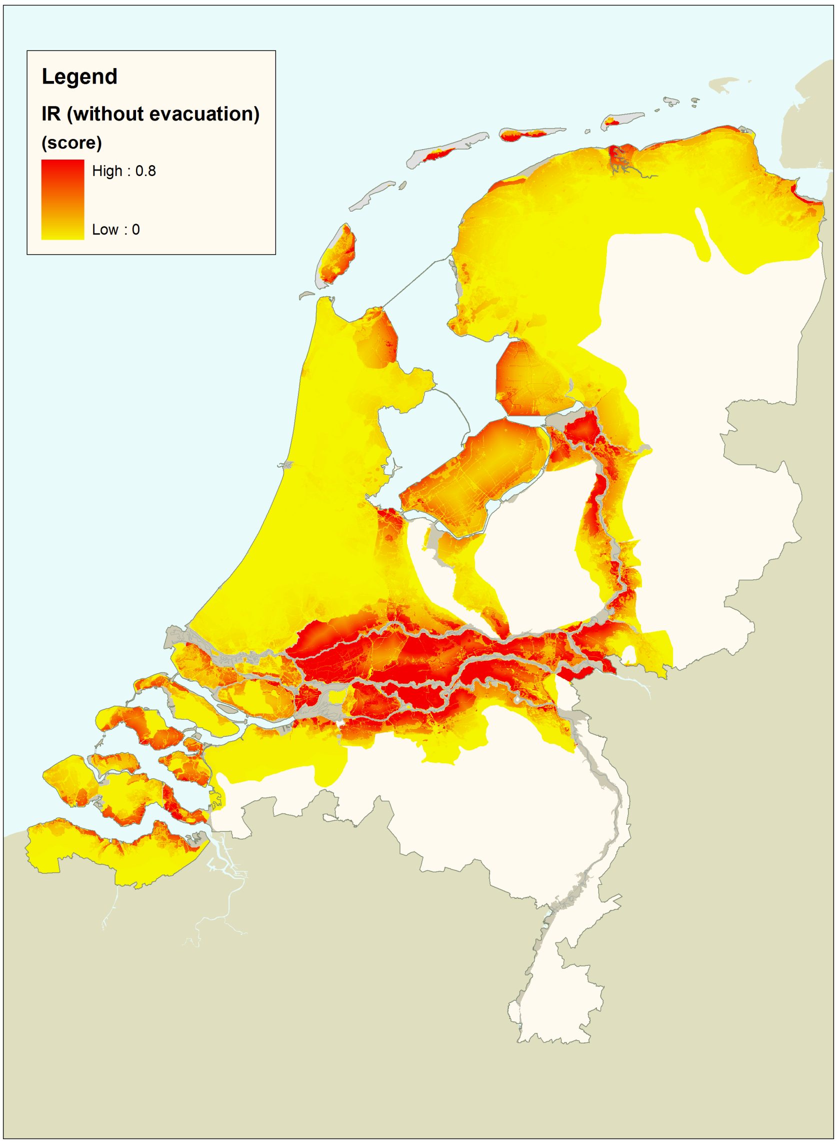

Figure 3.9 The indicative Locational Risk map without evacuation

3.3 Group risks

The indicative group risk map was made by combining the Locational Risk map with a map on actual population density (n/ha). Figure 3.10 shows the resulting GR map. The scores in figure 3.10 are the same as the scores in figure 3.8. However, they are provided only for the urban areas. This map shows that the cities Dordrecht, Ridderkerk, Rotterdam-IJsselmonde, Spijkenisse, Den Bosch and Vlissingen have a higher Locational Risk than other cities.

The resulting indicative group risk map does not give expected numbers of casualties, which would require the use of quantitative data on sufficient quality (see Chapter 4).

However, it combines information on flood probabilities, flood depths, speed of onset of flooding, evacuation possibilities and the location of urbanized areas. Therefore, it can be used to obtain insight into the spatial distribution of group risk.

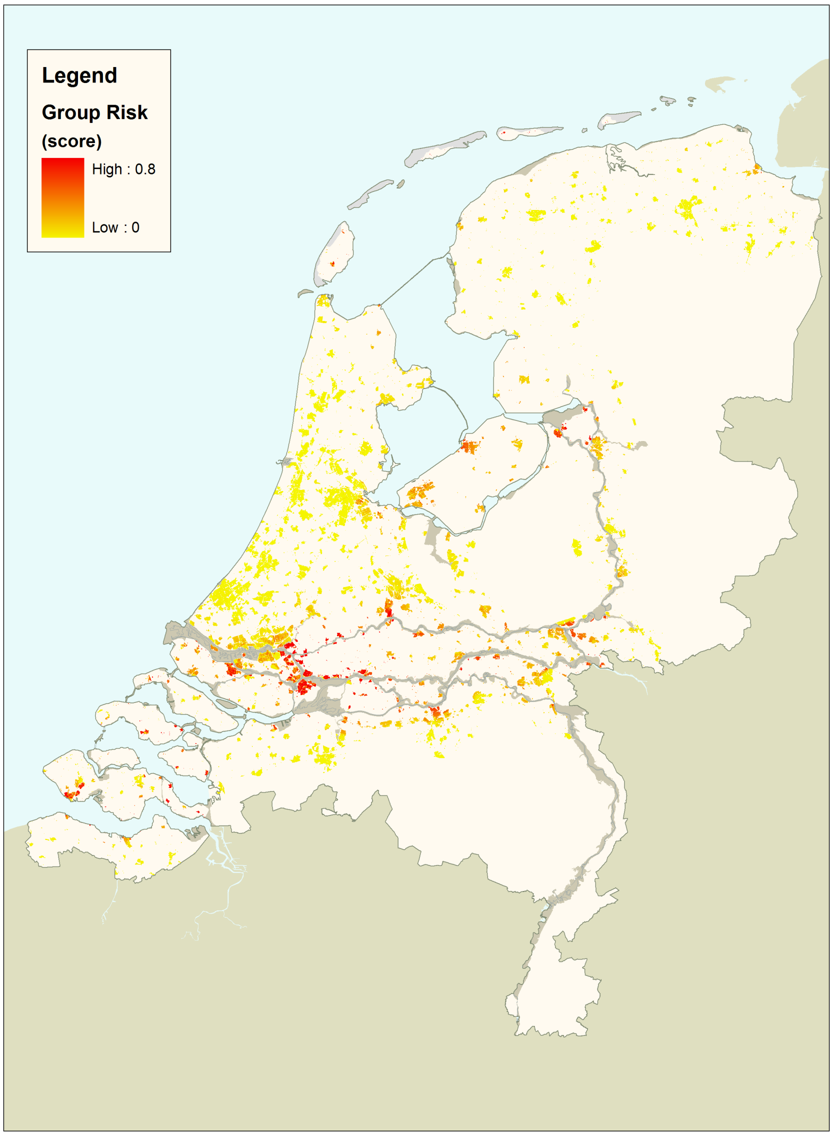

Figure 3.10 The resulting indicative group risk map for the Netherlands.

3.4 Discussion

The risky places found

The resulting indicative LR and GR map show the most dangerous, respectively riskiest places in the Netherlands, i.e. the places where flood casualties are potentially (LR) or actually (GR) most likely. The LR map provides a nationwide image of hazard (or ‘potential risk’), which is relevant for spatial planning, while the GR map shows actual risk, which is obviously confined to urbanized areas only, where flood protection and/or evacuation planning require attention.

The LR map shows that mainly Mastenbroek, the Alblasserwaard, the Lopikerwaard and Krimpenerwaard, and the coastal compartments in the south west are dangerous. The GR map shows that the cities Dordrecht, Hoogvliet, Spijkenisse, Ridderkerk, Lelystad, and Vlissingen are riskiest.

The risky places found in the indicative group risk map correspond with expectations and with the result of the risky places method of 2007 (see section 2.3.4). If, however, the LR map is compared to the hazard map made earlier (De Bruijn, 2007a), some large differences are found. In the LR map evacuation and the speed of onset are included, while in the hazard map only flood probability, water level rise rate and flood depth were incorporated. By including the speed of onset (distance to the embankment) and the evacuation rate in the LR map, the spatial differences are more outstanding than in the hazard map of 2007. In the 2007 first approximation the two mentioned variables were incorporated in the vulnerability map; now they have moved to constitute the LR map, which can be regarded a kind of combined hazard and potential exposure map.

The effect of assumptions and uncertainty
The maps shown in the previous section were based on data, calculations and expert judgement. The choice for the parameters and indicators, the scoring of the indicators and the weighing of the indicators was mainly based on expert judgement and experience with flood inundation simulations and risk assessments. The results are obviously sensitive to the choices made.

To obtain more insight in the sensitivity of the Locational Risk map for flood probability the Locational Risk map was also compiled for the likely flood probabilities of the dike rings as estimated by Van Velzen (2008) instead of for the protection levels (see figure 3.11).

The estimated flood probabilities apply for the situation in 2015 when all embankments are intended to at least comply with the legal protection levels. Figure 3.12 shows that the resulting Locational Risk map looks different: The southern part of Flevoland, The Betuwe and other flood-prone areas along the rivers, the northern islands and the south-western coastal area appear considerably less risky. Mastenbroek, Eiland van Dordrecht, IJsselmonde, and Voorne-Putten remain as very risky areas.

Knowledge of actual flood probabilities is thus very important for the identification of actually risky places. Unfortunately, the current flood probabilities are not sufficiently well known. In 2010 the FLORIS II project is providing more knowledge on failure probabilities of embankments and flood probabilities of locations within dike rings. Their results will be based on the situation in 2002.

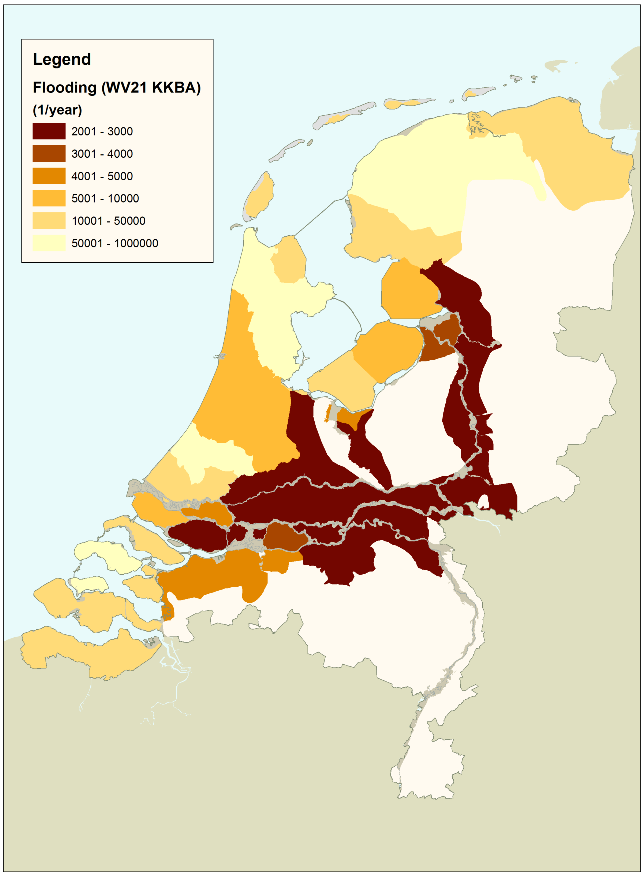

Figure 3.11 Actual flood probabilities as from 2015 onwards as estimated by Van Velzen (2008)

The *evacuation fractions* are unsure as well. They were based on some evacuation modelling results, but not on empirical data. In those models expert judgement and assumptions were combined with data on the area. However, the evacuation input map gives an impression of differences of evacuation possibilities within the different areas. The estimations were made on the spatial scale of dike rings. For detailed LR maps, more precise estimates are needed.

The mortality rate was found by combining the depth map and the speed of onset map. The depth map is based on the maximum value per cell found in all available flood inundation simulations made for design conditions. The speed of onset map was based on the distance of a location to an embankment and a function to score this distance to a value between zero and one. If this function is changed, the result will change slightly.

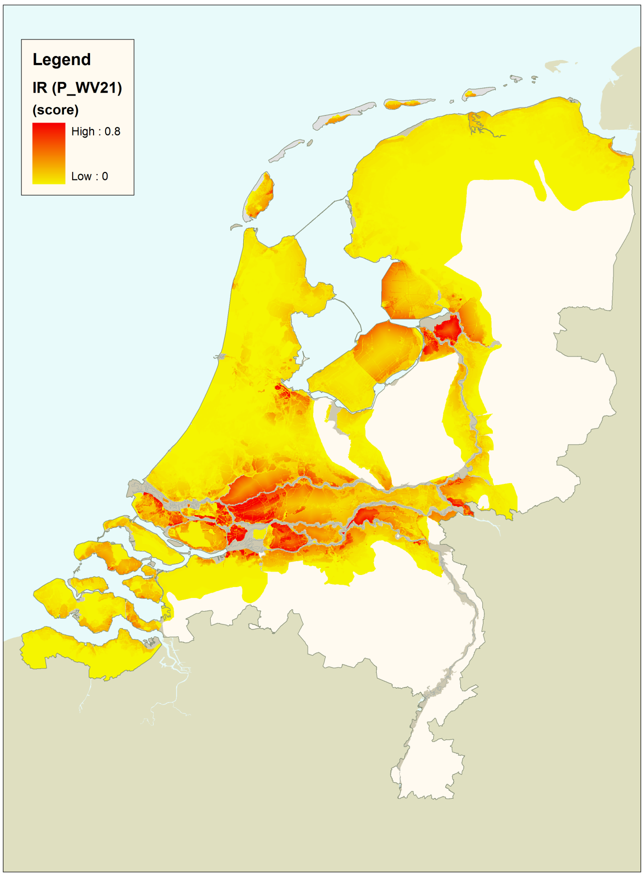

Figure 3.12 The Locational Risk map based on the likely flood probabilities as calculated by Van Velzen (2008) for 2015

Applicability of the maps
The maps are indicative, but informative. They show which locations are expected to have a high LR and why: because of their probability, potential flood depth, speed of onset, or evacuation possibilities or because all of them are relatively important. They clearly indicate spatial differences in risk within dike rings. They may also be used to select case study areas for flood risk management studies, or for flood event management studies.

The risky places partly depend on the flood probabilities. Because current flood probabilities are uncertain, the resulting risk map gives an indication only. However, the risk maps are very useful to determine where flood probabilities should not be allowed to increase, because that would result in a high casualty risk. Those locations may be considered for extra dike strengthening. Especially embankments which cannot break, because they are resistant to overflow, could be considered for those locations. Based on the GR map, locations can be selected where these embankments may be considered first.

Since these maps do not provide absolute figures, they cannot be compared with existing standards for LR from the domain of external safety.

4 Quantitative casualty risk analysis: case study Drechtsteden

4.1 Introduction

4.1.1 The case study area

The focus on a case study allows a more quantitative approach than the indicative method discussed in the previous section. The Drechtsteden area was selected, since this comprises several of the riskiest places in the Netherlands (see chapter 3).

The Drechtsteden area is located southeast of Rotterdam (see figure 4.1). It comprises three islands: dike ring 17 (IJsselmonde), dike ring 21 (Hoekse Waard) and 22 (Island of Dordrecht) which are surrounded by large tidal rivers. Land use in the case study area consists of agriculture, urban areas and industries. The most densely populated areas are concentrated south of Rotterdam and in the city of Dordrecht in dike ring 17 (IJsselmonde) and 22 (Dordrecht).

The area was found to be risky because it is threatened by storm-driven floods which leave little time for evacuation, high potential water depths, and because it is difficult to reach safe areas from the islands (De Bruijn, 2007a). Safe areas are difficult to reach, because the islands are connected with the mainland by a few bridges and tunnels with a limited capacity. The most important roads are the A15, A4, A16 and A29.

Evacuation from this area is expected to take between 17 and 24 hours (depending on traffic jams etc.) (Goudappel & Goffenk, 2008): This is slow compared to the expected time available, which is less than a day. Jonkman *et al.* (2008) estimated that about 50% of the population could be evacuated before flooding would occur. This figure is uncertain and depends on the lead-time of the forecast, the efficiency of decision-makers and the behaviour of the inhabitants. Also the weather circumstances are relevant: if the storm is too strong, driving may become dangerous or accidents may occur causing traffic jams. It may also be possible to only evacuate certain dangerous parts or to advise people to go to safe higher buildings or safer locations with the dike rings. This has not been assessed yet.

The three islands are protected from flooding by high embankments which are designed to withstand water levels and waves with a probability of once in 2000 (dike ring 21 & 22) and once in 4000 years (dike ring 17 Island of Dordrecht). If extreme conditions would cause an embankment to breach then it would probably result in flooding of a part of an island. The location and extent of the flooding depends on the breach location, the outside water levels and wave conditions, and the presence and strength of the many secondary embankments in the area (Figure 4.2). The outside water levels and wave conditions also depend on the functioning of the storm surge barrier ‘Maeslantkering’.

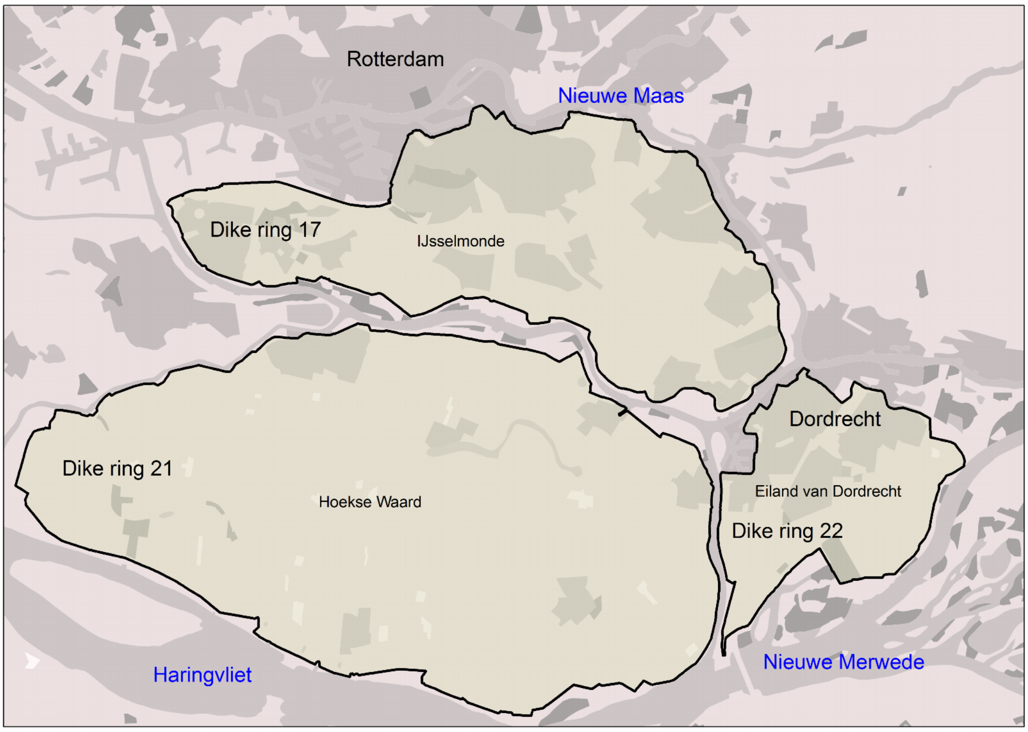

Figure 4.1 *The case study area with the three islands IJsselmonde (17), Hoekse Waard (21) and the Island of Dordrecht (22)*

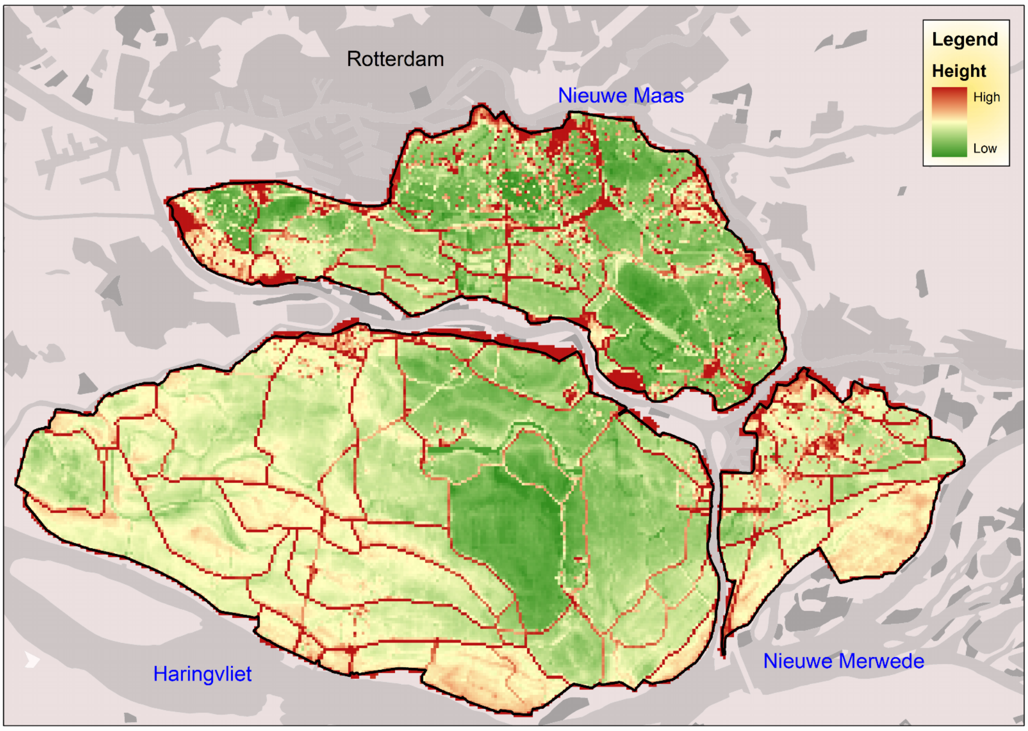

Figure 4.2 *The elevation of the Drechtsteden area. The presence of many secondary embankments reduces the flood extent in case of a flooding*

4.1.2 Aim and research questions

The case study aims to:

1. To develop flood casualty risk maps for the Drechtsteden area. A quantitative method is used to make this flood risk map;
2. To gain more insight into the influence of the flood mortality functions on the outcomes and their sensitivities.

The flood casualty risk maps will provide insight into flood casualty risks in the Drechtsteden area and they may be used to 'validate' the indicative mapping method of chapter 3.

To reach these aims, the following research questions have been studied:

- What happens in the scenarios: what are flood extents, depths, velocities, water level rise rates and how many casualties may occur per flood event (and what is the mortality)? Which events or which breach locations are the most dangerous?
- What causes people to die according to the mortality functions: flow velocities, water level rise rates or high water depths?
- How can the results of the individual flood simulations be combined into one map per variable: one maximum depth map, one water level rise rate map, etc and in one map for the resulting mortality and for the expected number of casualties at a location.
- How can the local Locational casualty risk with and without evacuation be calculated and how is it spatially distributed in the case study area?
- How can the group risk be calculated and how is it spatially distributed in the case study area?
- To what extent do the resulting risk maps correspond with the maps generated by the 'indicative mapping method'?
- Are the resulting maps useful for FRM, Spatial planning and flood event management?
- Does the case study give insights about the outcomes of the mortality functions and their sensitivities for the water level rise rate threshold and water depth threshold?

4.1.3 Approach

Flood Risk Maps
One of the goals of the Drechtsteden case study was to develop quantitative flood casualty risk maps from two angles: from the perspective of the Locational Risk and from the perspective of Group Risk (see chapter 2). Group risk can be thought of as a spatial estimate of the number of deaths expected within a dike ring or for an event or country. To estimate the group risk (GR) the personal risk needs to be multiplied by the number of inhabitants within each grid cell.

This can be expressed as follows: $GR(x) = LR(x) * N(x)$,
where N(x) is the number of people present at location x.

The challenge was to find one representative flood risk map on the basis of various potential breach scenarios. This was carried out by first analyzing the water levels, water rise rates, flow velocities, and mortalities resulting from various breach scenarios and then combining these results to one map.

Mortality Functions within HIS-SSM

The second aim was to gain more insight into the reliability of the flood mortality functions included in HIS-SSM (see section 2.3.2). Three mortality functions are contained within HIS-SSM; which function is applied to a cell is contingent upon water level rise rate (*w*), flood velocity (*v*), and water depth (*d*). The result of having three discrete functions is that small changes in *w, v,* or *d* may result in large differences in mortality. The extent of this discontinuity was one of the focus points of the research into the mortality functions.

Steps taken

1 Flood simulation results for various breach scenarios along dike rings 17, 21, and 22 (see Figure 4.1) were obtained from the Province Zuid-Holland. These results included water depth, flood velocity, and the time of arrival of water for each 100x100 meter cell of the study area.

2 The HIS-SSM module was used to calculate the flood casualties corresponding with the flood patterns. The number of casualties as well as the economic damage per dike breach scenario were tabulated and plotted. This showed which breaches were most important. (See section 4.3).

3 The HIS-SSM module produces not only the number of casualties, but also the number of casualties that can be attributed to different causes of death. The causes were classified into three categories: high flood velocity, high water rise rate, and other. As an indicator for ‘other’ the water depth is used. The causes were plotted per dike breach scenario.

4 Methods were developed, and tested to combine the input data and the resulting casualties of the individual events to one map for each input parameter and one casualty and one flood mortality rate map and to a Locational and group risk map. The preferable method was identified and applied.

5 The resulting maps were analysed to judge their credibility, their meaning for the region, and to compare them with the results of the indicative mapping method.

4.2 Analysis of flood patterns and the resulting number of casualties

The dike breaches along dike rings 17, 21, and 22 may result in casualties and economic damage. These values were collected and are presented in the following sections to shed light on which breach scenarios contribute most to the flood risks. For each of three dike rings under consideration a section is provided with information on the potential flood patterns and flood impacts.

4.2.1 Dike ring 17 (IJsselmonde)

A dike breach in dike ring 17 results in a partial flooding of the dike ring and in damage and casualties.

With the mortality functions of Jonkman (2007) (see chapter 2) flood casualties were determined. To this end, first it was assumed that no evacuation would occur whatsoever.

Assuming that the simulated breach locations are equally likely, the average number of casualties of a flood event is 251, the minimum 0, the maximum 2761 and the median 11 casualties. These values indicate that consequences differ significantly per breach location.

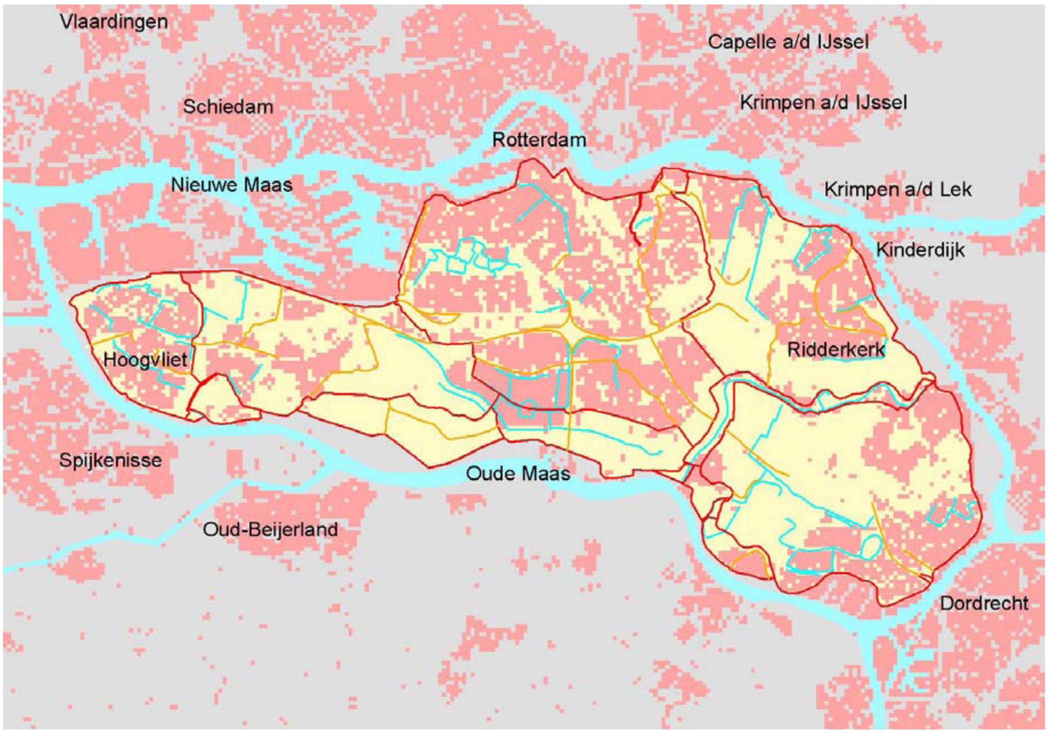

Figure 4.3 Overview over dike ring 17: IJsselmonde (Tonk & Kolen, 2005)

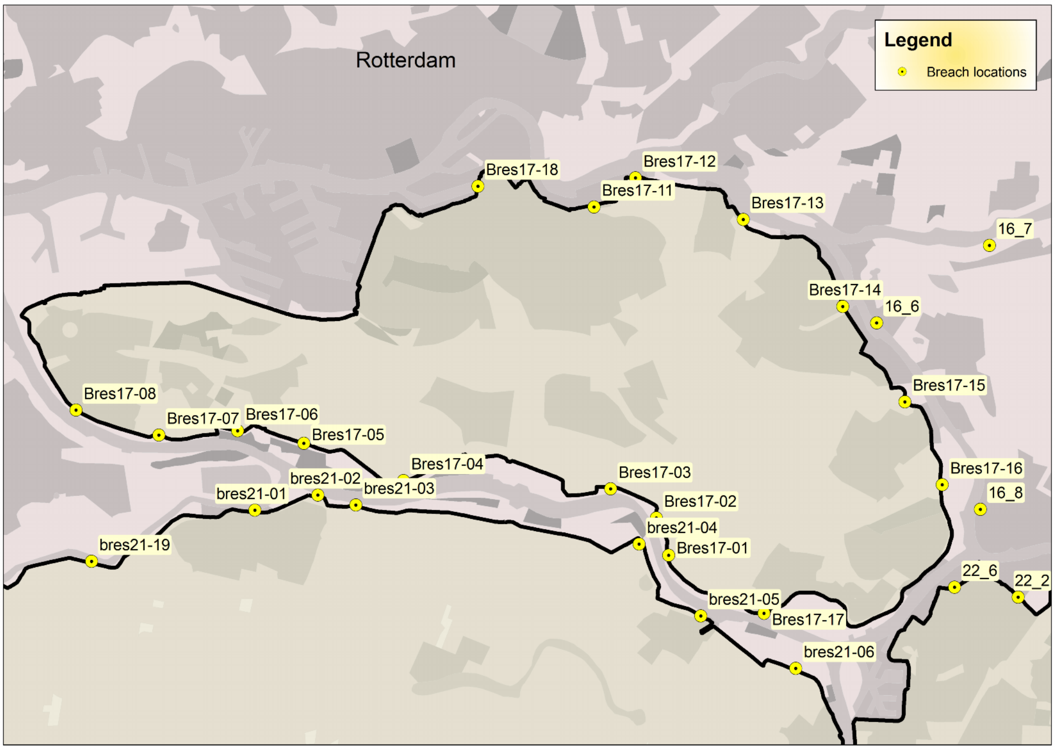

Figure 4.4 Investigated breach locations along dike ring 17

A breach in the northeast (east of the A16) (e.g. dike breach 17-12, 17-13 and 17-15) is most dangerous, because it results in high water level rise rates near the breach and in flooding of urban areas (Rotterdam-IJsselmonde, Ridderkerk). Breaches at the southern locations 17-1, 17-4 and 17-5 do not cause casualties because these cause the flooding of small rural areas only. Breaches in the south-west in Hoogvliet do cause casualties, but not as many as in the north (see figures 4.3, 4.4 and 4.5).

In two scenarios many casualties are likely due to high water level rise rates (17-13 and 17-12). In contrast, in the other 14 scenarios most casualties occur due to high water depths.

The damage and casualties in this dike ring cannot be related to one representative breach location. A worst case scenario for casualties and damages is the same and would be 17_13 (see figure 4.4). Any scenario in the south east not close to a city is a 'best case' scenario. Table 4.1 shows the casualties and economic damage resulting from each of the dike breaches in dike ring 17. Figure 4.6 presents the same information.

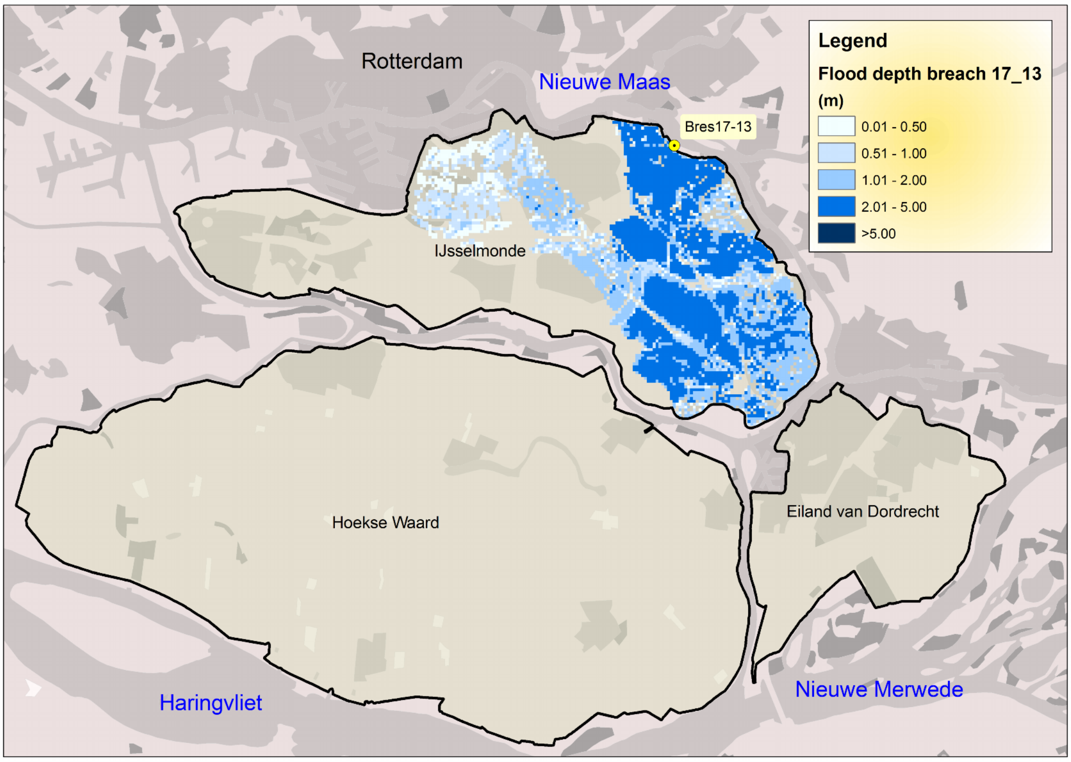

Figure 4.5 Flood depths corresponding with breach 17_13

Table 4.1 Flood consequences of the breach scenarios of dike ring 17: IJsselmonde

Breach	Casualties	Damage (10^6 M€)	Flooded area	Barrier
17-01	0	1	Small rural	Closed
17-02	3	36	Small rural	Closed
17-03	8	142	Small rural	Closed
17-04	1	15	Small rural	Open
17-05	0	14	Small rural	Open
17-06	14	193	Small urban (Hoogvliet)	Open
17-07	0	0	Small	Open
17-08	92	932	Medium urban Hoogvliet	Open
17-11	3	51	Small urban	Open
17-12	350	1929	Large urban (IJsselmonde)	Open
17-13	2761	8107	Very large urban	Open
17-14	62	969	Medium urban	Open
17-15	567	4314	Large urban	Closed
17-16	1	34	Small rural	Closed
17-17	28	385	Medium rural/urban	Closed
17-18	122	1758	Medium urban Rotterdam	Open

* All scenarios used the design conditions as boundary conditions

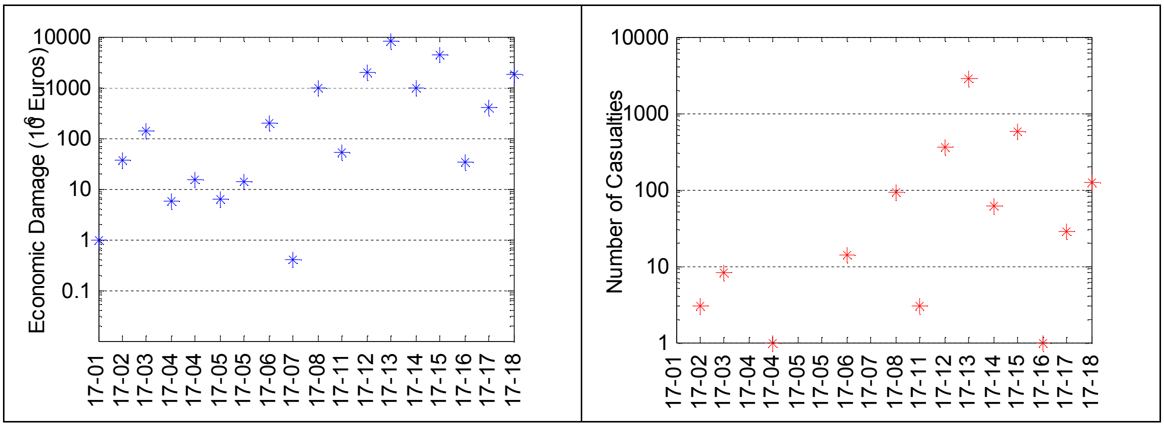

Figure 4.6 Economic Damage (M€) and Number of Casualties for dike breaches along dike ring 17

4.2.2 Dike ring 21 (Hoekse Waard)

As with dike ring 17, different breaches result in different casualty numbers and economic damage based on both the flood extent and the population density of the flooded area. Table 4.2 and Figure 4.7 present the result of the simulated flood events. The number of casualties and economic damage resulting from floods in dike ring 21 are considerably less than in dike ring 17. On average there are 7 casualties, the maximum is 44, the minimum is zero and the median is 2. The flooded areas are much smaller due to the presence of many secondary embankments and the area is less densely populated. The differences between the scenarios are also much smaller.

Table 4.2 Flood consequences of the breach scenarios of dike ring 21: Hoekse Waard (figure 4.8 shows the breach locations)

Breach	**Casualties**	**Damage (10^6 M€)**	**Barrier**
21-01	20	84	Open
21-02	1	125	Open
21-03	7	71	Open
21-04	9	89	Closed
21-05	44	485	Closed
21-06	21	288	Closed
21-07	12	70	Closed
21-08	5	94	Closed
21-09	0	6	Closed
21-10	1	15	Closed
21-11	2	31	Closed
21-12	0	12	Closed
21-13	0	9	Closed
21-14	0	7	Closed
21-15	0	6	Closed
21-16	2	42	Closed
21-17	0	11	Closed
21-18	0	11	Closed
21-19	7	130	Closed

* All scenarios used the design conditions as boundary conditions

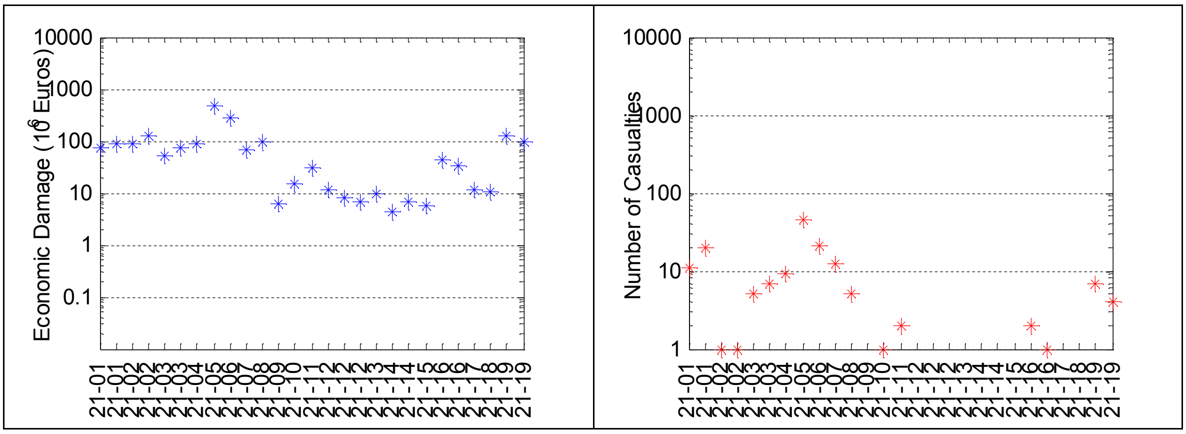

Figure 4.7 Economic Damage (M€) and Number of Casualties for dike breaches along dike ring 21.

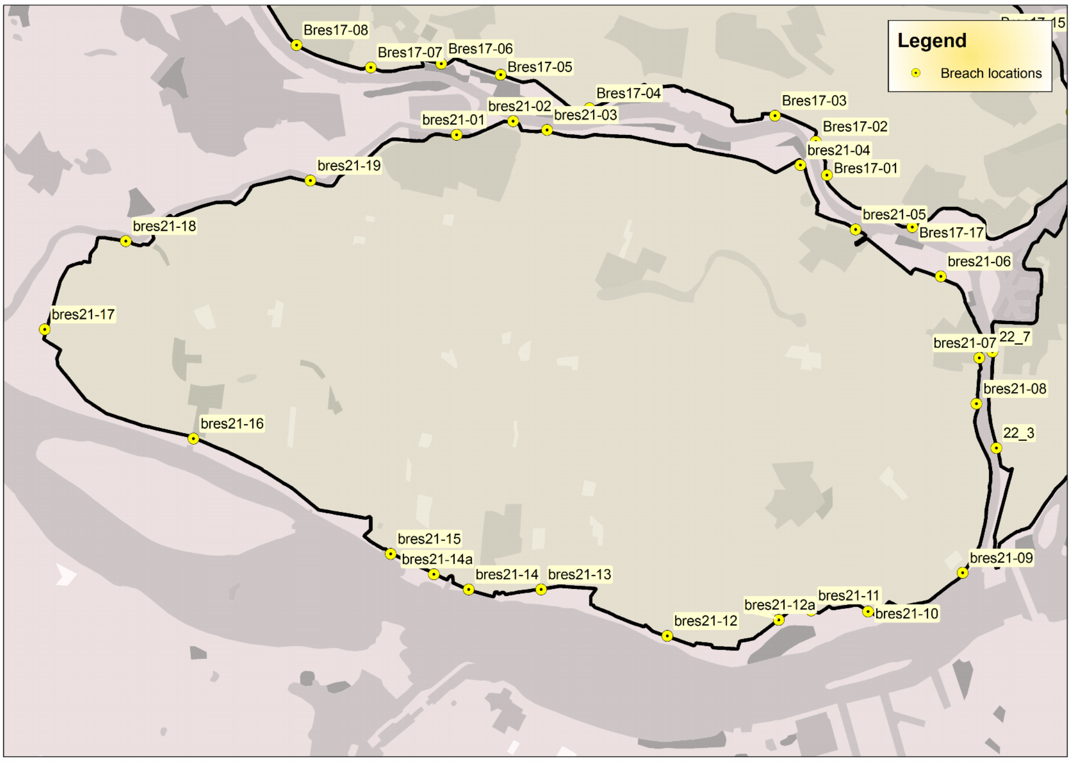

Figure 4.8 Investigated breach locations along dike ring 21 (Hoekse Waard)

4.2.3 Dike ring 22 (Island of Dordrecht)

In dike ring 22 one extreme breach scenario results in more than 7,000 casualties. The other scenarios are comparable to what was observed in dike ring 21 (see table 4.3, figure 4.9, 4.10 and 4.11). The average number of casualties is 1245, the maximum is 7.24, the minimum is 1 and the median is 64. The difference between the scenarios is thus very large.

Table 4.3 The casualties and flood damages associated with the breach scenarios in dike ring 22

Breach	Casualties	Damage (10^6 M€)	Affected persons	Mortality	Barrier
22_1: KopVanTLand	7247	7224	98079	0.0739	Open
22_2: Noordendijk	72	913	49174	0.0015	Closed
22_3: OudeBeer_ev	2	7	303	0.0066	Closed
22_5: Stadspolder	1	12	3664	0.0003	Closed
22_6: VoorstraatA	89	1095	44329	0.0020	Closed
22_7: Wieldrecht_	56	753	20248	0.0028	Closed

* All scenarios used the design conditions as boundary conditions

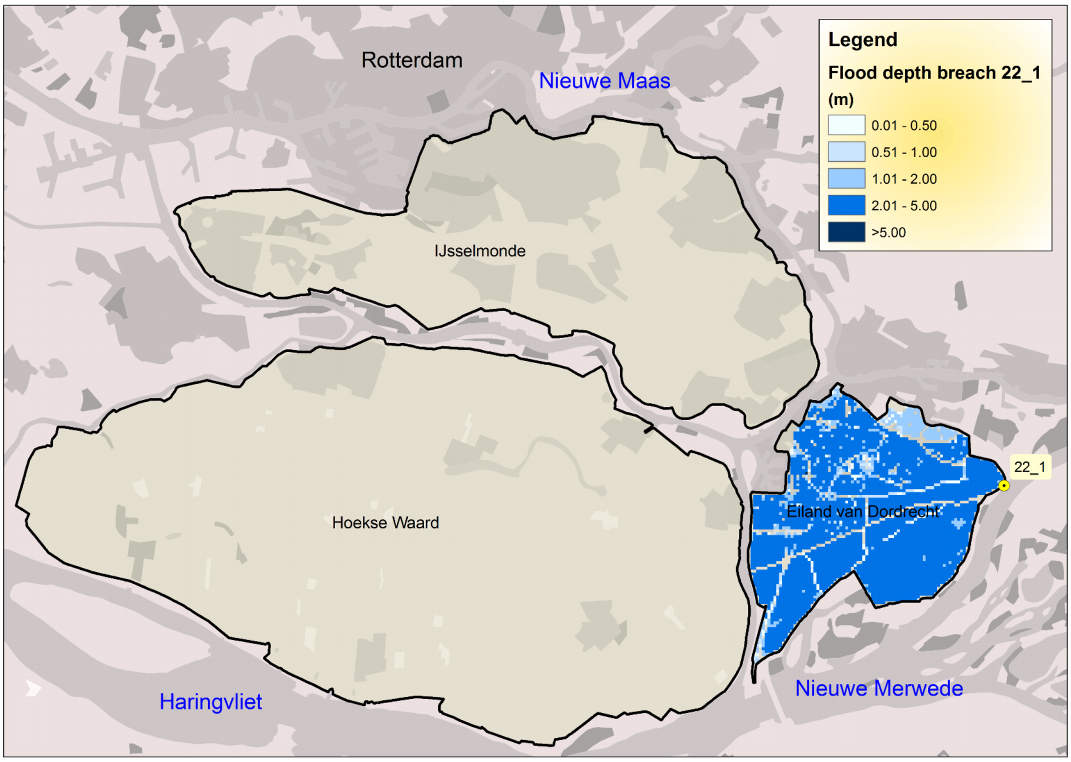

Figure 4.9 The flood pattern corresponding with scenario 22_1

Figure 4.10 Investigated breach locations for dike ring 22 (Island of Dordrecht)

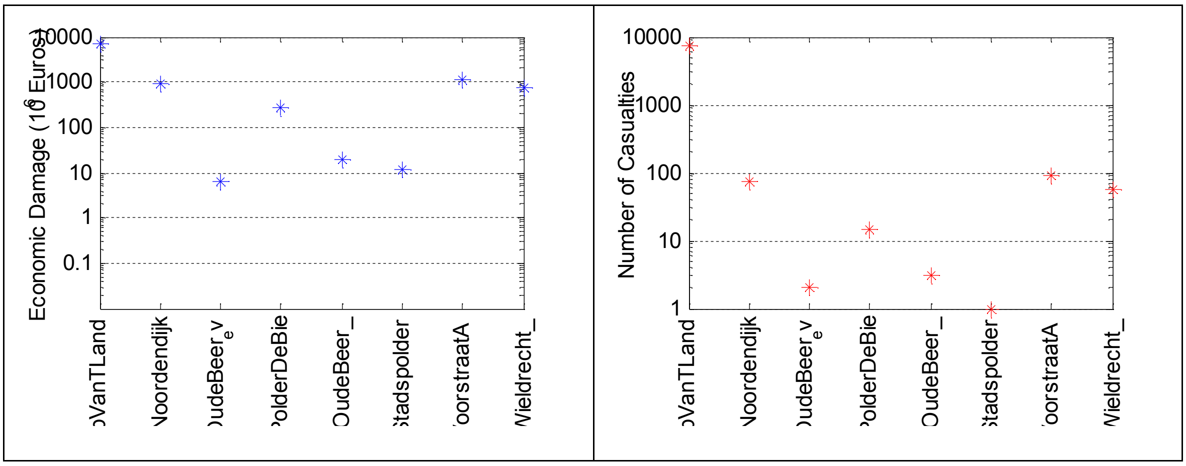

Figure 4.11 Economic Damage (M€) and Number of Casualties for dike breaches along dike ring 22

4.2.4 Summary and analysis of all three islands together

The results of the three islands were combined into figure 4.12, which shows the dike sections that are related to high casualty numbers if they would breach. They show that the north-east of IJsselmonde and the east of Dordrecht are most dangerous. The Hoekse Waard is considerably less dangerous. This map may be very helpful for the selection of local measures: both for flood defence (dikes should not break at the red and orange stretches) and for spatial planning and flood event management: the areas behind the red and orange stretches must be considered for adaptation measures and emergency plans should be ready for those areas. Appropriate measures may thus be:

- Flood prevention measures: embankment strengthening, constructing embankments which do not break when overtopped, possibly in combination with elevated areas for housing, industries, recreation or other purposes.
- Flood consequences mitigation measures: Elevation of the area, elevated buildings, removal of compartmentalisation embankments, etc. and improved evacuation plans and/or creating safe heavens and shelters.

Table 4.4 shows the results for each individual dike ring. In dike ring 21 the mean and median are close, showing a smaller spreading than in the other dike rings. In both dike ring 17 and 22 scenarios are possible in which zero to 1 casualty is expected and disasters are possible with thousands of casualties.

Table 4.4 Number of casualties per island (based on table 4.1, 4.2 and 4.3)

Island	Average	median	max	min
17_IJsselmonde	251	11	2761	0
21_Hoekse Waard	7	2	44	0
22_Dordrecht	1245	64	7247	1

* All scenarios used the design conditions as boundary conditions

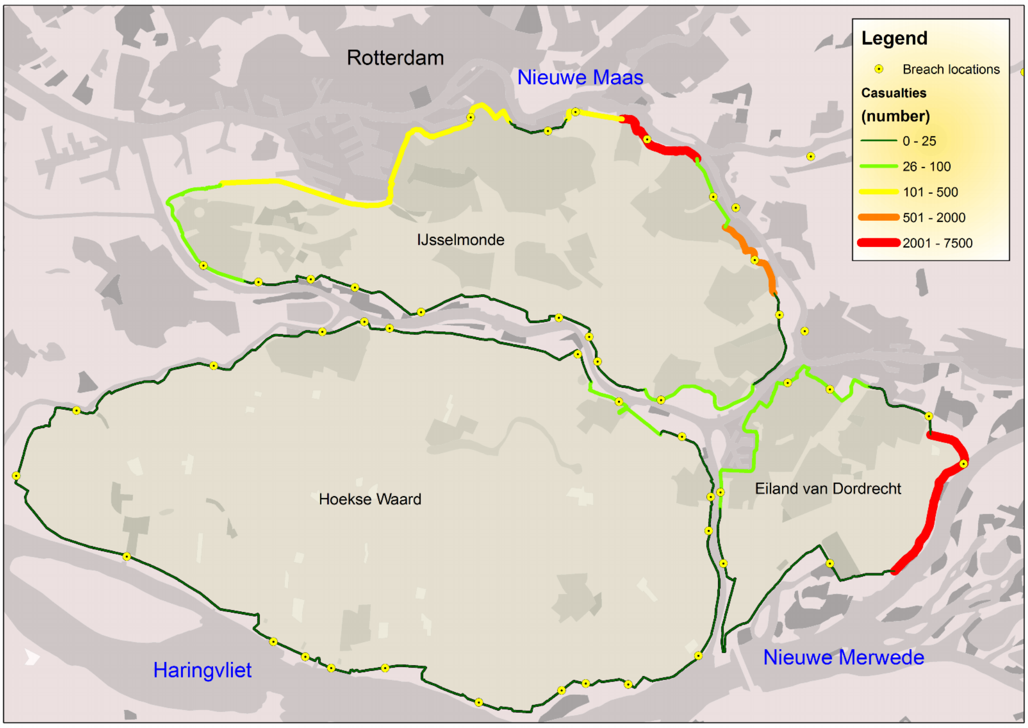

Figure 4.12 The dike stretches and the number of casualties which may occur if the dike breaches there (based on the scenarios obtained from the Province of South Holland in October 2008, the HIS-SSM version 2.4 and without considering evacuation, breaches are supposed to occur due to outside water conditions which correspond with design conditions)

Table 4.5 shows the cause of the casualties (according to the mortality functions of the HIS-SSM). No casualties occur due to high flow velocities and in most scenarios the majority of casualties occur due to high water depths (others). In some scenarios the water level rise rate results in many casualties, to such extent that is was decided to further study the sensitivity of the results for the rise rate function (see next section).

Table 4.5 Number of casualties per breach scenario differentiated according to the cause of depth for the scenarios with casualties

Breach	High Velocity	HighRiseRate	Other	SUM
17-02	0	2	1	3
17-03	0	0	8	8
17-04	0	0	1	1
17-06	0	0	14	14
17-08	0	0	92	92
17-11	0	0	3	3
17-12	0	114	236	350
17-13	0	2139	622	2761
17-14	0	0	61	61
17-15	0	0	566	566
17-16	0	0	1	1
17-17	0	0	28	28
17-18	0	0	122	122
21-01	0	16	3	19
21-02	0	0	1	1
21-03	0	0	7	7
21-04	0	6	3	9
21-05	0	0	44	44
21-06	0	4	17	21
21-07	0	10	2	12
21-08	0	0	5	5
21-11	0	0	2	2
21-16	0	0	2	2
21-19	0	0	7	7
22_1	0	6781	466	7247
22_2	0	0	72	72
22_3	0	2	0	2
22_5	0	0	1	1
22_6	0	1	88	89
22_7	0	5	52	57
SUM	**0**	**9080**	**2527**	**11607**

* All scenarios used the design conditions as boundary conditions

4.2.5 Sensitivity of the mortality functions

The water-rise-rate condition is derived from data from the 1953 storm surge disaster in the Netherlands. It is applied to locations with a water level rise rate higher than 0.5m/h and a water depth larger than 2.1m (see section 2.2.3 equation 2). The threshold value of 0.5 m/hr was based on the data of 1953: It was the lowest observed water-rise rate where casualties resulted from high water level riser rates. The next lowest water-rise rate observed in the 1953 historical event was 4 m/hour. Based on the 1953 data a threshold somewhere between 0.5 and 4 m/hour might have been used. The choice made in the mortality functions for 0.5 m/hour is, therefore, somewhat arbitrarily. The depth threshold of 2.1m is chosen because at that depth the mortalities found with equations 2 and 3 are equal.

Condition 2: w > 0.5 m/s and d > 2.1 m
Function 2: $M = \Phi_N\left(\frac{\ln(d) - \mu_N}{\sigma_N}\right)$

Where $\mu_N = 1.46$ and $\sigma_N = 0.28$ are the mean and standard deviation of log-transformed water-depth values from historical events. Note that function 2 is a lognormal distribution. The operator Φ_N is the cumulative normal distribution, operating on the log-transformed values of water depth.

Sensitivity to the water level rise rate threshold

It was investigated how sensitive the mortality rates are to the water-rise rate threshold value. Two scenarios were examined: the most extreme scenario for which water depth, water velocity, and water-rise rate were available, and a less-extreme scenario. Breach 17-13, along dike ring 17, was the most extreme scenario for which the necessary information was available. Breach 17-08 represented a less extreme flooding scenario. The purpose of investigating a less extreme flooding scenario is to gauge whether the sensitivity to changes in the water-rise-rate and water-depth criteria is dependent on the severity of the event.

Breach scenario 17-13 resulted in 2,761 fatal casualties, 2,139 due to high water rise rates, and 622 due to high water depths. Breach scenario 17-08 resulted in 92 fatal casualties, all of which resulted from high water depths.

The water-rise-rate threshold was incrementally increased from 0.0 m/hr to 4 m/hr. It was found that in breach scenario 17_13 most cells with a high water level rise rate are located in the zone which floods within 6 hours after the initiation of the breach. Table 4.6 shows that in breach scenario 17_13 the results are sensitive to changes in water-rise rate between 0.5 and 1.5 m/hr. This indicates that more research needs to be done to find a water-rise-rate threshold that best represents the ‘cutoff ‘between the two mortality functions. For breach scenario 17_08 the changes in water-rise-rate threshold had no effect on the number of cells falling into either of the conditions. Water depths were lower than 2.1m, which means that the water level rise rate was not considered.

Table 4.6 Number of cells in which conditions correspond with a certain hazard zone and the mean mortality rate in those cells (for various water level rise rate thresholds) for scenario 17_13

Water-rise-rate Threshold	Zone with high water level rise rate	Remaining zone
0.0	2340	1317
0.5	1118	2539
1.0	276	3381
1.5	82	3575
2.0	47	3610
2.5	16	3641
3.0	4	3653
3.5	3	3654
4.0	3	3654

Thus: the total number of casualties is very sensitive to the threshold for the water level rise rate. This threshold is very uncertain. It is, however, difficult to validate this threshold, because of a lack of empirical data.

4.3 Combination of the results of the individual flood event

For flood risk mapping the results of the individual flood events must be combined. The next section describes the combination of the flood related parameters.

4.3.1 Combining the flood related parameters

Because it is unknown which scenario is more likely and since they all represent breaches at conditions which correspond with design conditions, it was decided to combine the individual events by taking the maximum value in each cell. The resulting maps thus show possible depths, flow velocity and rise rates. The map as a whole is thus not possible in one event!

The maximum water depths lie around 3.5 m. Near Dordrecht and IJsselmonde and in the small compartments in the south of the island IJsselmonde the highest water depths can occur (see figure 4.13).

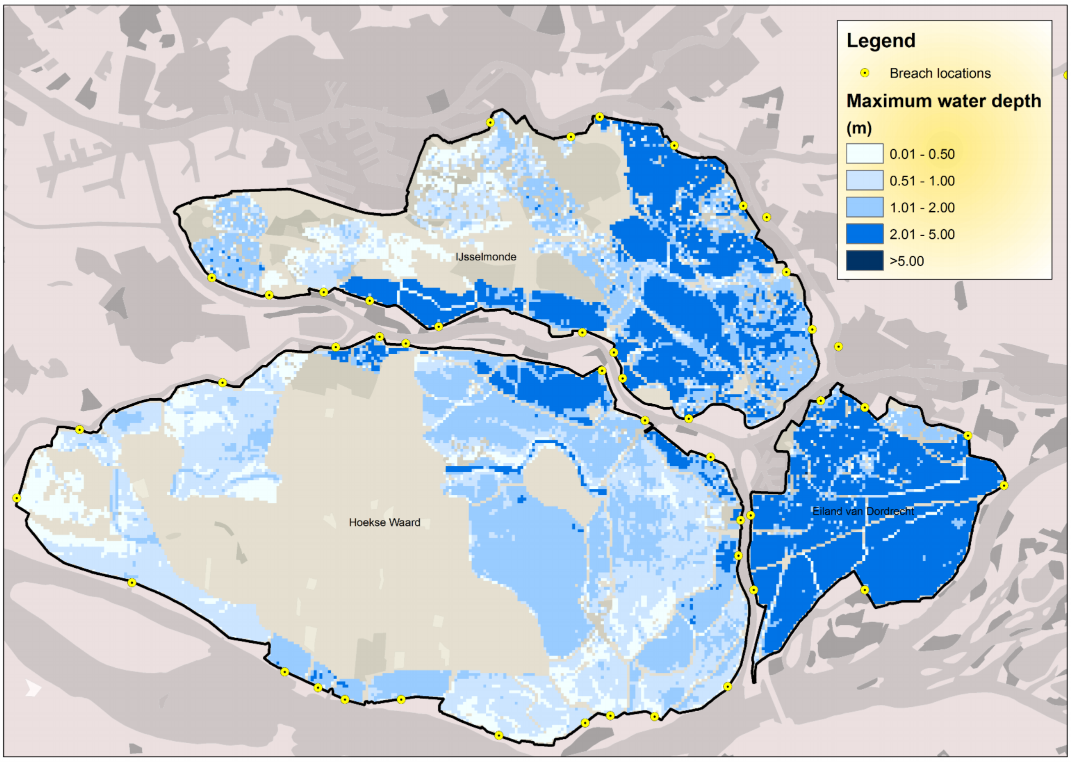

Figure 4.13 The maximum water depth for each cell derived from the breach scenarios

The maximum flow velocity found was 3.8 m/s (see figure 4.14). However, in most areas the velocity lies below 0.5 m/s. Near the breaches the flow velocity is higher, but flow velocities above 2 m/s are very rare. This was reflected by the finding that according to the mortality functions no one died due to high flow velocities (see previous section).

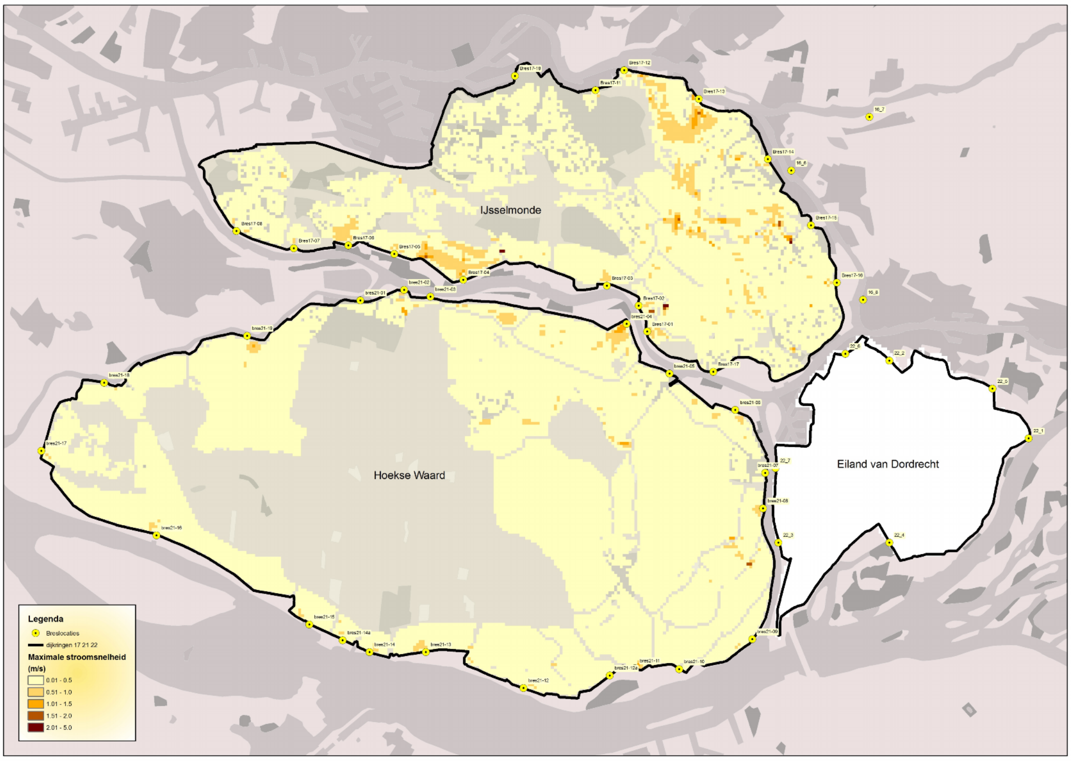

Figure 4.14 The maximum flow velocity for each cell derived from the breach scenarios

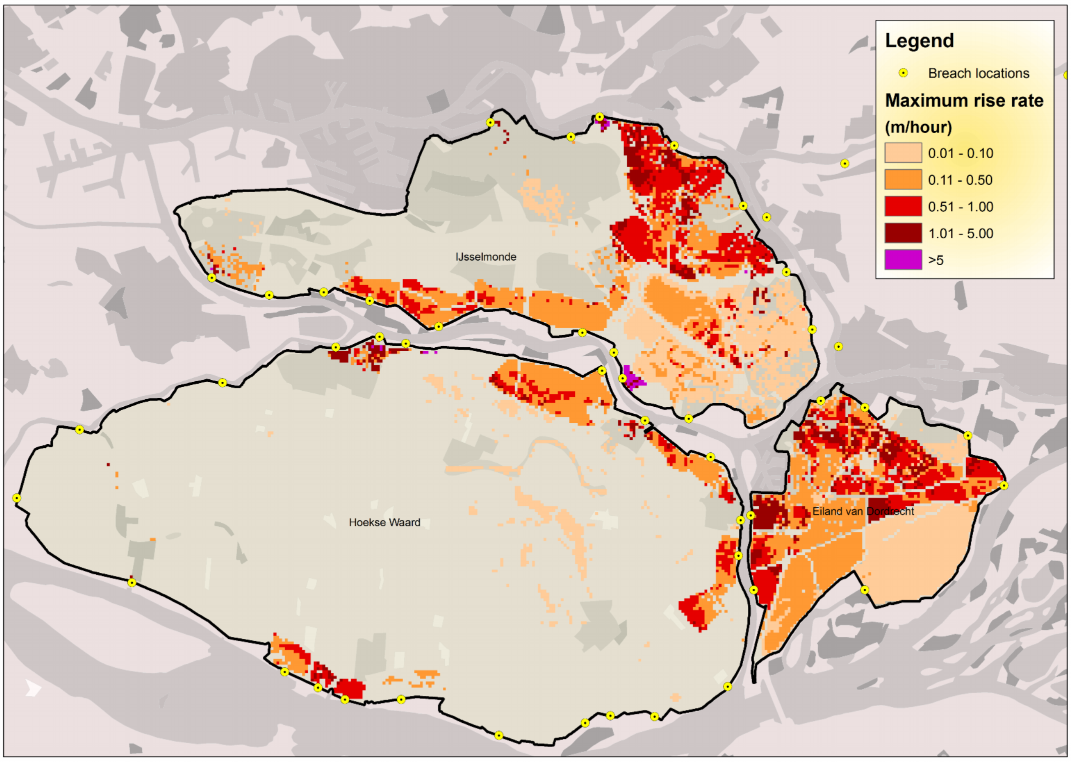

Figure 4.15 The maximum rise rate for each cell derived from the breach scenarios

The water level rise rates in some areas, such as the northeast of IJsselmonde and the northeast of the island of Dordrecht are very high (see figure 4.15). This is caused by the secondary embankments. This means that the second relationship of the set of mortality functions is used for those areas. This explains the high number of casualties estimated for those areas.

If a dike breaches, the water fills the first compartments near the breach almost immediately. The water arrival time in the compartments near the breaches is generally less than 1 hour after the breach (see figure 4.16). This means that the available time to escape the water after the dike breach is very limited in those compartments. Since it is expected that only one or a few breaches will occur, the other compartments do have more time available.

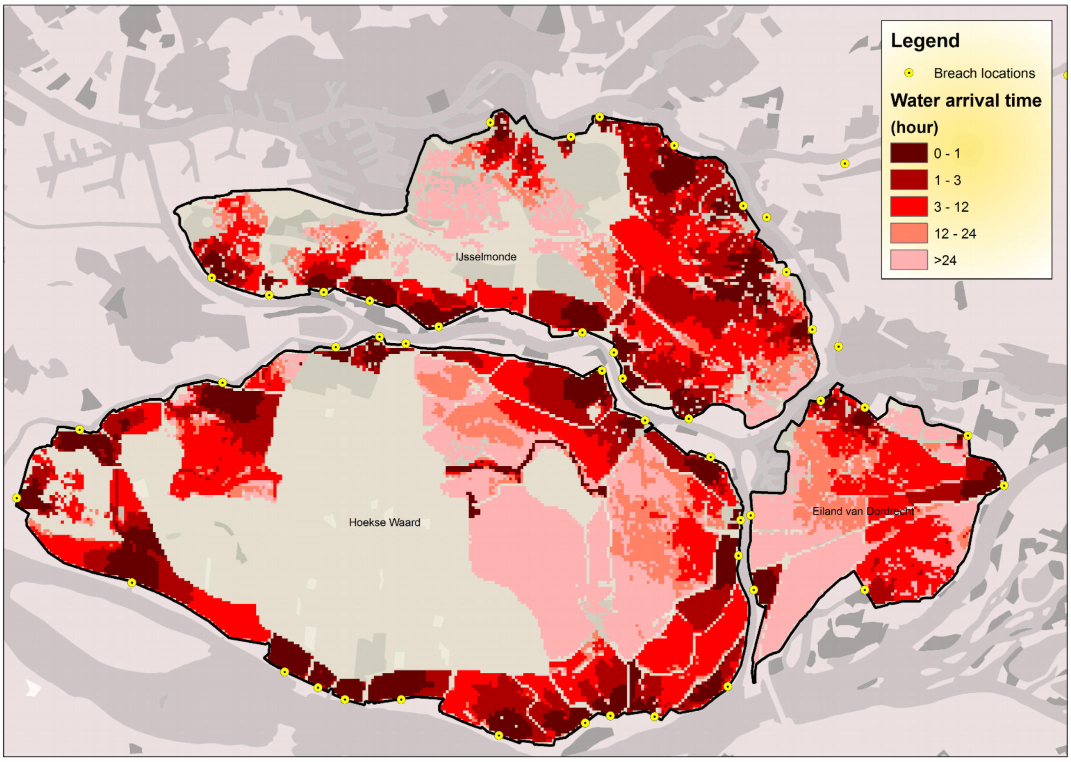

Figure 4.16 The minimum time of arrival for each cell derived from the breach scenarios

The areas are not equally dangerous: some areas are flooded due to only one breach location. Some due to 2 or even 4 breach locations (see figure 4.17). The latter are more dangerous. Since there are so many areas that only become flooded from one breach, it is difficult to define a representative breach location or flooding simulation.

The mortality rate is high in the locations where water level rise rates are high and water depths are large. These areas correspond with the areas with a short water arrival time (see figure 4.18).

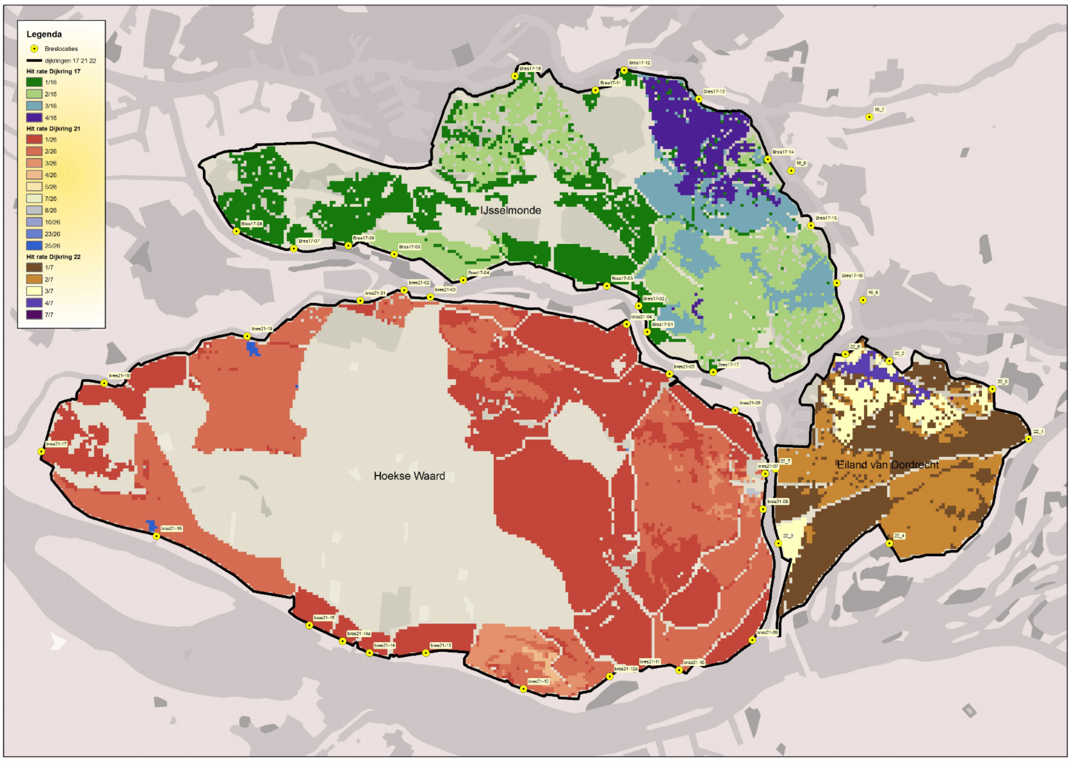

Figure 4.17 The hit rate: the number of scenarios in which the cell becomes flooded

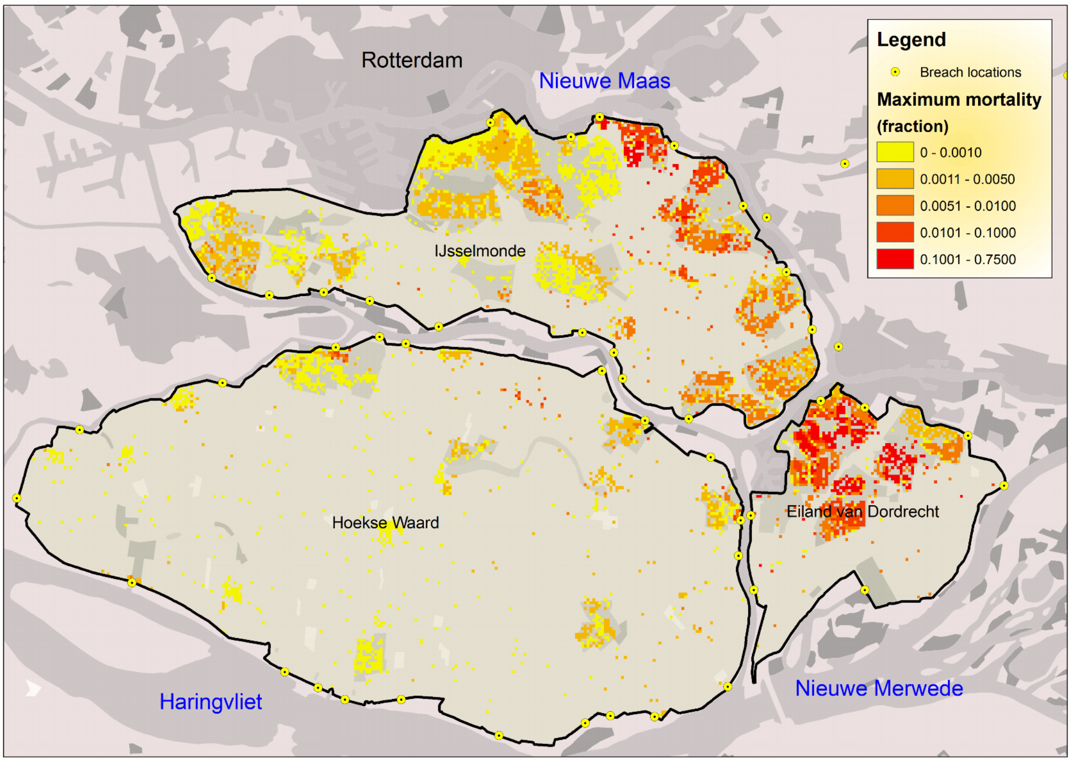

Figure 4.18 The mortality rate per cell at locations where people live derived from the breach scenarios by taking the maximum

Figure 4.18 is based on the maximum mortality rate. If the scenario probability is taken into account, it is also possible to assess a kind of mean mortality rate. To estimate this, it was assumed that the scenario probability depends on the length of the dike for which the scenario is representative. (In reality it depends on the dike length, on the dike strength and on the local characteristics of the load such as wave attack and local water levels). The resulting average mortality is shown in figure 4.19. Figure 4.20 shows the number of inhabitants per hectare and figure 4.21 the number of people killed per hectare. This was calculated by multiplying the maximum mortality with the number of inhabitants.

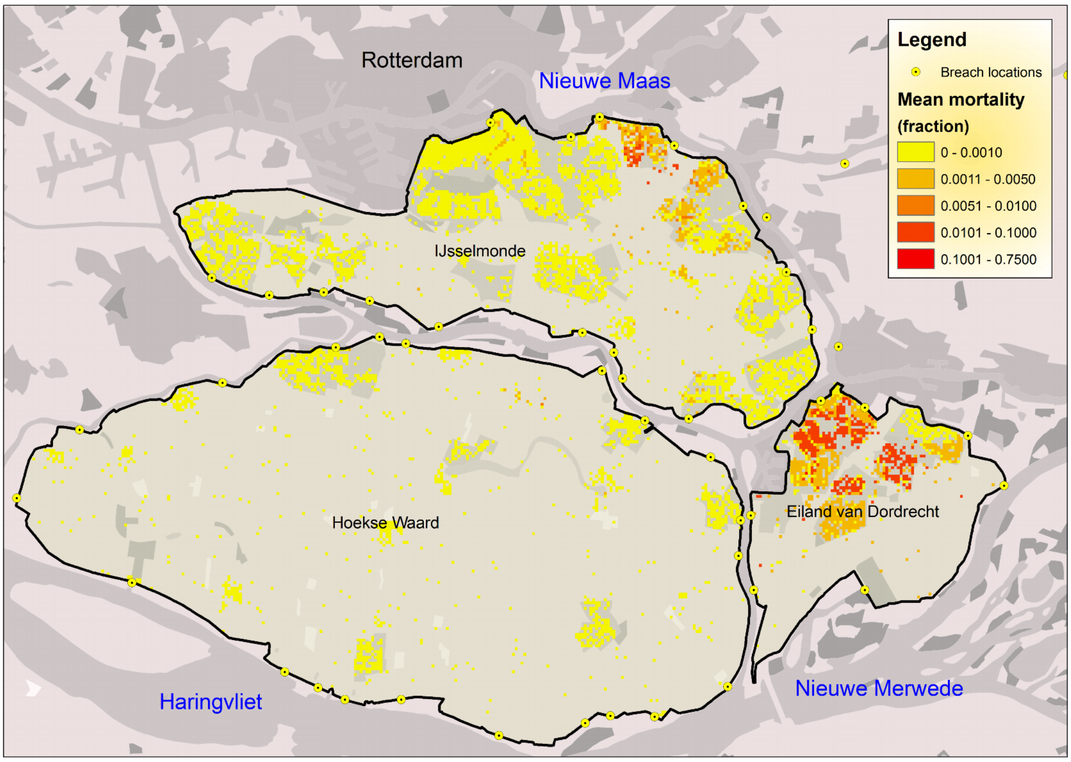

Figure 4.19 Average mortality rate within the scenarios. The scenarios are weighed according to the length of the embankment of the compartment in which they are situated

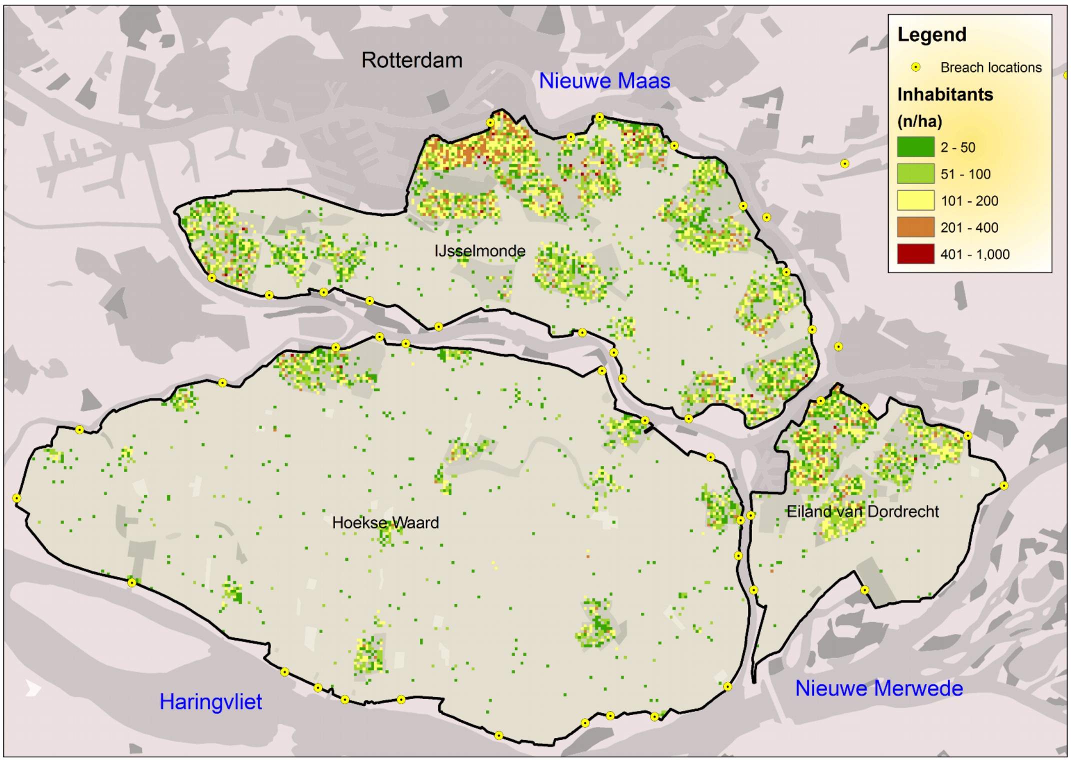

Figure 4.20 Number of inhabitants per hectare

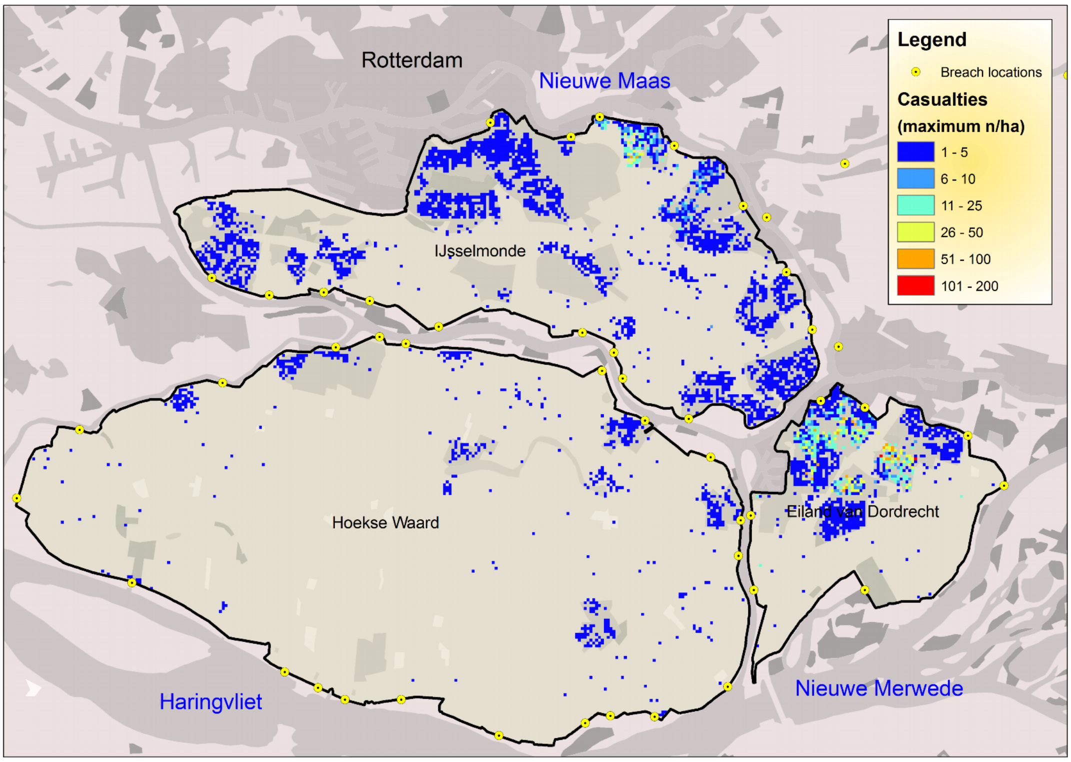

Figure 4.21 The maximum number of people killed derived from the breach scenarios

4.3.2 Locational and Group risk

The calculations discussed in the previous section are used to assess the Locational (LR) and Group Risk (GR). The approach followed resembles the approach used in the indicative mapping method. However, the speed of onset was not based on the water arrival time, but instead, on the water level rise rate and also the flow velocity was considered (but with no effect).

Since the probability of the breach scenarios is unknown it was assumed that the flood probability is equal to the protection level. At the end of 2010 probabilities of the breach scenarios (for the reference situation of 2002) will be available from the FLORIS II project. For evacuation the percentages provided by Jonkman *et al.* (2008) (50%) were used. Figure 4.22 shows the approach, figure 4.23 the resulting LR map and figure 4.24 the GR map.

In contrast to the indicative mapping method of chapter 3, this approach results in quantitative figures: the LR map shows the probability of dying due to a flood. while the GR map shows the expected number of persons killed annually per hectare.

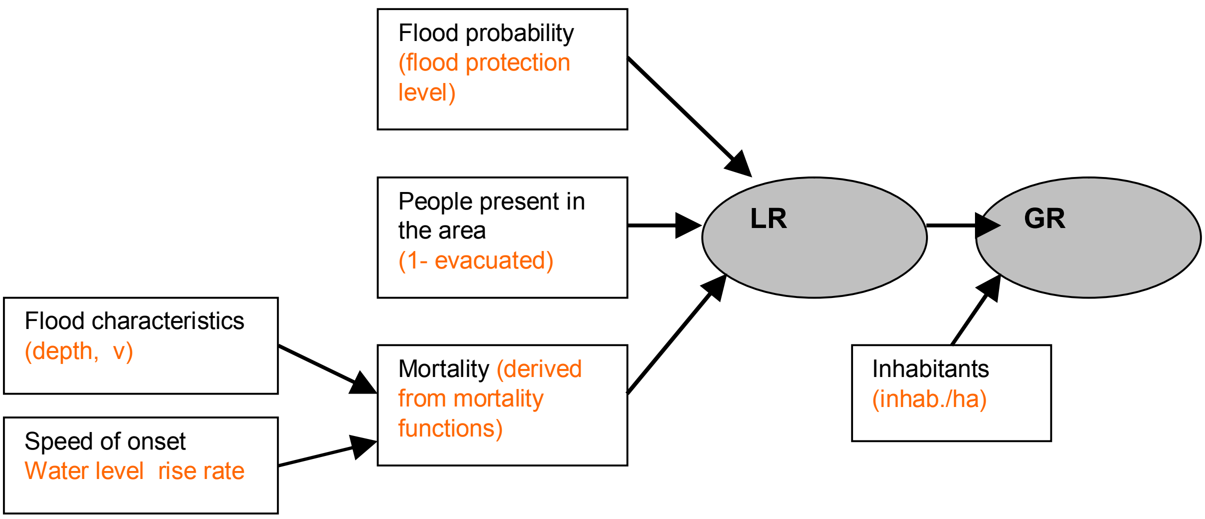

Figure 4.22 The approach followed to calculate the LR and GR map used for this case study

The resulting Locational and Group risk maps show that the spatial differences in casualty risks in this area are large. Some areas have Locational Risks of more than $3.5 * 10^{-4}$, but generally it is lower than 10^{-5}. The GR map shows the expected annual number of casualties due to floods per hectare. It is highest near Dordrecht and IJsselmonde and lowest in the Hoekse Waard. These figures must be considered with care since they are based on the flood protection level and not on the actual flood probabilities. If the embankments comply with the current safety standards, flood probabilities are lower than the protection levels. Most embankment sections comply with the safety standards, some are much stronger, but there may also be weak spots with higher flood probabilities.

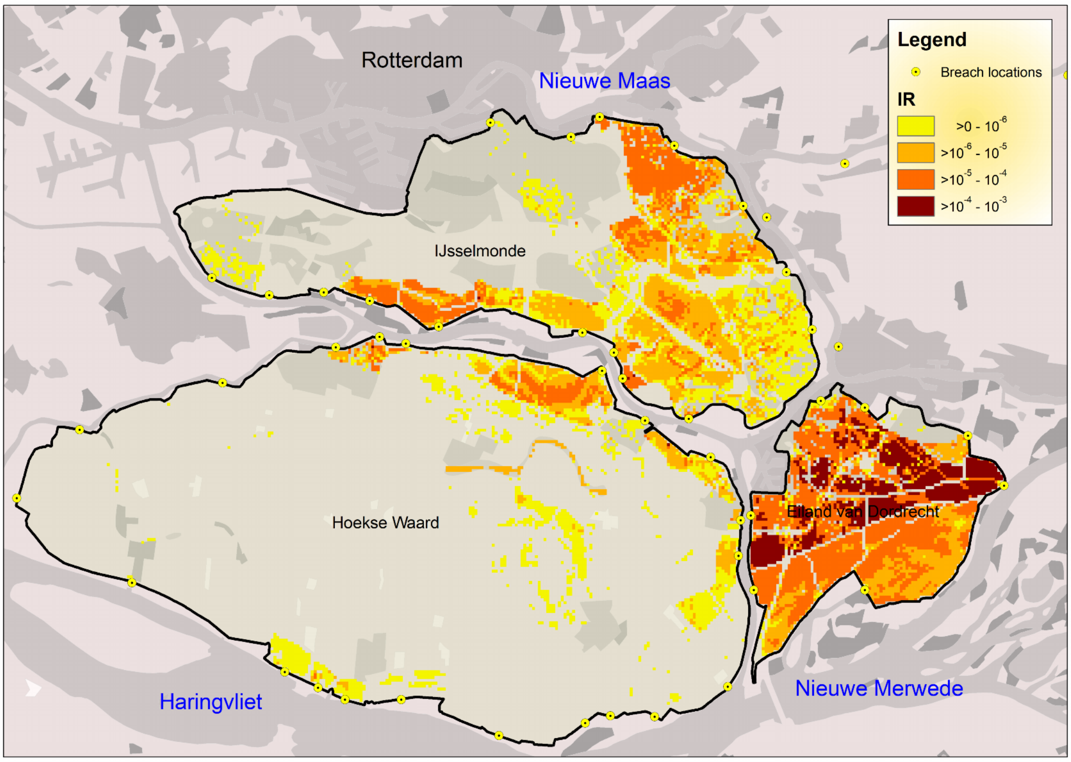

Figure 4.23 LR calculated by multiplying the mortality rate with the protection level

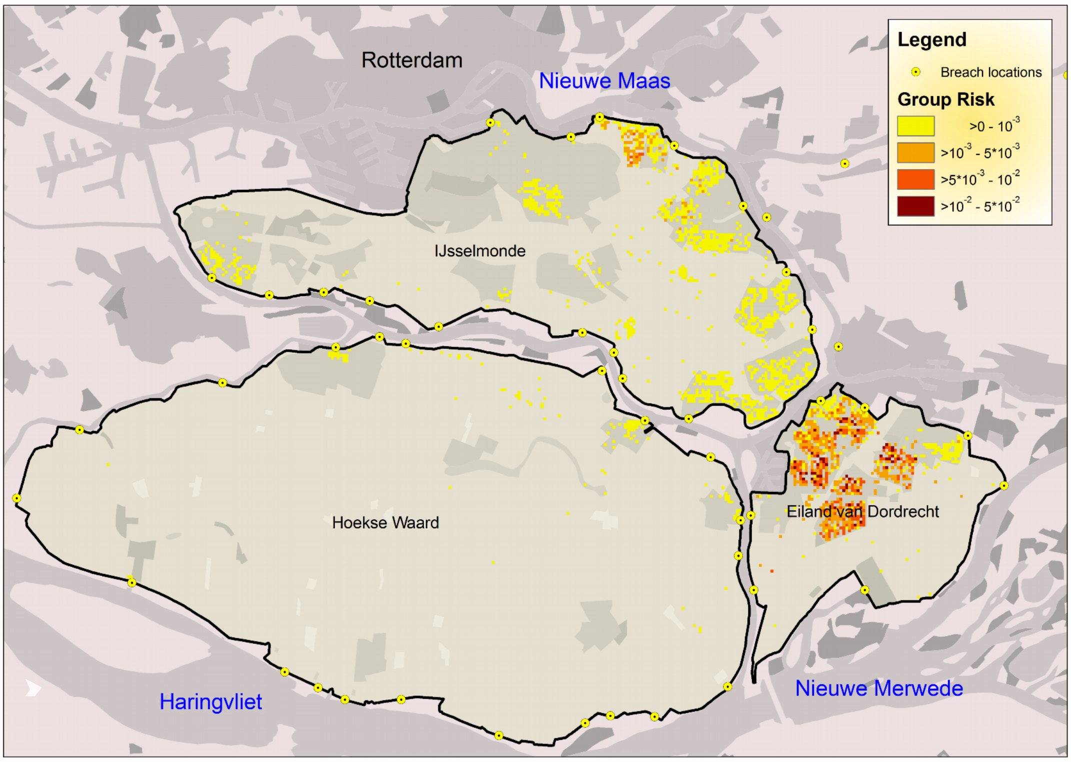

Figure 4.24 GR (indicated by the EANC per hectare) calculated by multiplying the LR with the number of inhabitants per hectare

4.4 Summary and discussion

The case study aimed to:

- Provide insight into flood casualty risks in the Drechtsteden area and to develop quantitative flood risk maps;
- To 'validate' the indicative mapping method with this quantitative approach;
- To gain insight in the influence of the flood mortality functions on the results.

Although the case study area is considered one of the riskiest places in the Netherlands, the risk differs substantially in space. In the cities Dordrecht, Rotterdam-IJsselmonde, and Hoogvliet, the Locational and Group risks are relatively high indeed. However, in other areas the Locational Risk is a factor of 100 lower. Mapping these risks shows that even in small areas large spatial differences occur.

The flood risks are high in Rotterdam-IJsselmonde and Hoogvliet because secondary embankments prevent spreading of the water over larger areas. This results in high water level rise rates and large water depths. Also, residential areas are situated close to the embankments. Risks could be lowered by embankment strengthening (e.g. by making them fail-free or by raising the surface of the areas near the embankment, by making strong houses and by not using the ground floor). In Dordrecht the high casualty risks can be attributed to the expected water depths and the high water level rise rate. Since this is an island, evacuation is difficult.

The resulting maps correspond very well with the results of the nationwide indicative mapping, which was not based on individual scenarios. This is partly explainable, since this map was partly based on the same data: the same flood probability, water depth and evacuation percentage. One of the differences is the use of the water arrival time versus the water-level rise rate. The use of both seems intuitively correct, but it is difficult to establish the relationship of these variables with the mortality.

The largest difference between the indicative mapping method and the quantitative method used for this case study is, however, that the latter results in quantitative figures instead of relative classes. However, since the flood probability is unknown and the evacuation is considered in a simple way, and since the relationship between the flood parameters and the mortality is very uncertain (R^2 of the depth-casualty relationship is only 0.09) the quantitative results should be considered a very rough estimate only. If the probabilities of the inundation scenarios would be known, then the advantages of the quantitative method would be clearer.

For flood risk management the map shown in figure 4.12 is highly informative as well, as it shows exactly which embankment sections result in the highest casualty numbers. These embankment sections should preferably not fail. Such a map is thus useful for prioritisation. The analysis showed that the casualty risks found are sensitive to the water level rise rate threshold. According to the mortality functions, the water level rise rate causes large numbers of casualties in some scenarios. These casualties mainly occur within the first hours after a breach and they happen in small very deep areas. This is plausible. The exact shape of the mortality functions and the mortality rates cannot be validated by these scenarios, since no recent flooding occurred in this area. The analysis also showed that the flow velocity criterion was not met in any scenario.
It is recommended to study the water level rise rate threshold in future, which may be done based on the 1953 and New Orleans flooding.

5 Discussion, conclusions and recommendations

The project aims to make flood casualty risk maps for the Netherlands and for the Drechtsteden area. In chapter 3 indicative nationwide Locational Risk and Group Risk map were made and in chapter 4 quantitative casualty risk maps for the Drechtsteden area were developed.

The indicative mapping method applied to the Netherlands
The nationwide indicative Locational Risk map was based on a flood probability map, an evacuation percentage map and a mortality map. This mortality map was derived from a potential flood inundation depth map and a speed of onset of flooding map (see figure 3.1). The LR map shows that the highest Locational Risks are found at the Alblasserwaard, the western part of the Betuwe, The Rijnstrangenarea and the Ooijpolder, the Western part of the Land van Maas en Waal and the areas along the embankments in the south west of the Netherlands, the north of the Netherlands and along the Meuse River.

The GR map shows that the riskiest cities are Dordrecht, Den Bosch, Rotterdam-IJsselmonde, Spijkenisse, Ridderkerk, and Vlissingen. The GR map was made by extracting the values of the LR map for all urban areas. The values of the LR and GR map are thus the same, but only the urban areas are shown in the GR map. This shows the casualty risk in the densely populated areas. To express the the Group Risk in one figure or one curve for the Netherlands as a whole the number of people who may be killed *per event* should be considered. This was considered too difficult in this approach. For that a more quantitative approach is needed.

This map was made with and without including evacuation. However, for most purposes, evacuation must be included, because it is most likely that part of the population is being evacuated in time. Not including the evacuation means that areas where evacuation is a realistic option are considered as dangerous as areas where evacuation is more difficult. It is, therefore, recommended to include evacuation in the LR and GR maps. In this project, evacuation was included in a simple way by one percentage per dike ring. This must be improved, especially when more detailed maps are being made, or when regional maps are made. Evacuation may be more feasible for areas further from the embankment or closer to a safe area. This should be incorporated in the analysis.

The LR and GR map depend on the flood probabilities used. Currently, flood probabilities of locations within dike rings are not known. Therefore, safety standards were used. These protection standards are defined as the probability of water levels which embankments should be able to resist, thus they differ from the flood probabilities of areas. If all embankments would (at least) comply with the safety standards, dike failure probabilities would be lower than the probabilities of the design water levels. Since not all areas within a dike ring become inundated by any breach in that dike ring, local flood probabilities may be much lower.

The regional quantitative method
The quantitative method resulted in quantitative flood casualty risk maps for the Drechtsteden area. The resulting LR and GR map show that the spatial differences in risk are significant.

The cities Dordrecht, Rotterdam-IJsselmonde and Hoogvliet are much more dangerous than the areas in the Hoekse Waard. Locational Risk values higher than 3.5 $*10^{-4}$ were found locally, but in other areas the LR was a factor of 100 lower. The figures must be considered with care, since they are not based on flood probabilities, but on protection standards. Not only the LR and GR map, but also the map which shows the link between a dike failure along a certain dike stretch and the expected number of casualties is considered very informative (see figure 4.12). This map clearly shows which embankment stretch should be made very strong, since failure may result in thousands of casualties. Strenghtening of these sections should be prioritized from the point of view of casualty risks.

The Group Risk map provides the expected annual number of flood related casualties per hectare. This number varies from zero in the villages in the Hoekse Waard to 0.047 casualty per hectare per year in Dordrecht. This group risk map cannot be converted to a Fn Curve for the Group Risk directly. For that the relationship between probabilities of exceedence of events and the number of casualties associated with those events are needed.

Safety standard discussions
For safety standard discussions, risk maps could be made assuming a situation in which all areas comply with the proposed safety standards (such as the preliminary map based on the probabilities of Van Velzen (2008) in figure 2.13). Because this does not require precize knowledge on the exact failure probabilities of dike sections, this is easier than making maps of the actual Locational Risk. For nationwide analyes the indicative mapping method could be used. This would, however, not show which areas comply with possible acceptable levels, since the indicative risk mapping approach only results in indicative values between zero and one. To find areas which do not comply with potential acceptable risk levels, the quantitative method discussed in chapter 4 could be used (if all input data is available).

The discussion on flood safety standards in the Netherlands will be based on economic flood risks and casualty risks. Which indicators will be used for casualty risks is still not clear. However, there is a clear tendency to use indicators which show both the Locational Risk and the Group Risk. Discussions focus on whether to incorporate evacuation or not, at what scale Locational and Group Risks need to be calculated, how they can be converted to other scales (e.g. from dike ring to the country as a whole or vice versa) and how to express Group Risks. From this report it can be learned that absolute casualty risk figures will be very uncertain and depend on assumptions made. Absolute risk figures must thus always be considered with care. Differences between areas, however, can be made clear. These may be useful in the safety standard discussion.

Next to LR and GR figures also other maps are informative, such as maps which show the number of casualties associated with dike failure of certain stretches and mortality maps.

The selection of a certain acceptable casualty risk level is subjective and cannot be done by scientists or engineers. However, scientists may support decision makers by showing different possibilities and by providing insight into the consequences of their choices. Casualty risk maps may help in this process of defining acceptable levels of casualty risks and thinking on flood protection standards.

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