Journal of
Flood Risk Management

Risky places in the Netherlands: a first approximation for floods

K.M. De Bruijn and F. Klijn

Deltares, MH Delft, The Netherlands

Correspondence:
Karin M. De Bruijn, Deltares, PO Box 177, 2600 MH Delft, The Netherlands
Email: karin.debruijn@deltares.nl

DOI:10.1111/j.1753-318X.2009.01022.x

Key words
flood-related fatalities; flood risks; risky places; safety; the Netherlands.

Abstract

Flood risk maps are considered useful tools for flood risk management including spatial planning. In the Netherlands, flood risk is usually assessed for large geographical units: at the dike-ring scale. However, within dike rings differences in flood risk are large. Maps that provide information on flood risks and on aspects of flood risks on a more detailed spatial scale are relevant for prioritising flood control measures or land-use planning. The research reported in this paper, therefore, aims at mapping flood risks on a more detailed scale. This paper focuses on the identification of risky places in the Netherlands, i.e. places where many fatalities may be expected due to flooding, because they are both hazardous and vulnerable. The method distinguishes factors that determine the likelihood and number of fatalities into hazard factors and vulnerability and exposure factors. The places that have the highest risk level are the risky places.

Introduction

In the Netherlands – as elsewhere – increasing attention is being paid to the relationships between land use and water and between spatial planning and water management (Min. VROM & V&W, 1997; Commissie Waterbeheer 21e eeuw, 2000; Wiering & Driessen, 2001; Vis *et al.*, 2003; De Bruijn, 2005; Pols *et al.*, 2007). For flood risk management these relationships are essential. Flood risk management involves all activities that aim to reduce flood risks (De Bruijn, 2005; Gouldby & Samuels, 2005). This requires measures that aim to prevent floods, to control the flooding process and to reduce flood impacts or to enhance recovery from flood impacts. Many of these measures are a part of flood risk management or spatial planning, two policy fields that are becoming more and more integrated.

In order to enhance the discussion on logical combinations of spatial planning and flood risk management measures, the spatial distribution of current flood risks should be presented on maps (Pols *et al.*, 2007). The effects of individual measures and comprehensive flood risk management strategies on flood risks can then also be presented on maps. Such flood risk maps not only serve the development of flood risk management, but they are also useful for flood event management.

Because flood risk maps are considered useful tools for flood risk management, the Flood Risk Directive (officially the 'Directive of the European Parliament and of the Council on the assessment and management of flood risks') requires such maps to be made (EU Flood Risk Directive). Flood *hazard* mapping is already a common practice in many countries (see EXCIMAP, 2007), but proper flood *risk* mapping is much less so. In the EXCIMAP atlas one may find excellent examples of flood depth maps for the once in 100 years flood, as well as of maps that combine flood depth and flow velocity in mountainous areas. This atlas also shows various vulnerability maps, such as on population size in the flood-prone area. Risk maps that combine information on hazard and vulnerability are, however, rare. Germany has some examples, and Italy, Spain and Switzerland have official risk zone maps. These combine the probability of flooding with land-use categories. However, no maps that combine all the relevant hazard parameters with different types of vulnerability were found (EXCIMAP, 2007), nor were maps on the likelihood of fatalities.

A review of the demands of the Flood Risk Directive and on the existing knowledge, methods and tools for the Netherlands (De Bruijn, 2007a) revealed that sufficient knowledge and data on flood risks from the sea, main rivers and the IJsselmeer are available, but that these are predominantly shown on the spatial scale level of entire dike rings (protected areas, entirely surrounded by defences and high grounds). For example, Klijn *et al.* (2007) produced flood risk maps for the Netherlands for entire dike rings. These maps do not show differences in risk within these dike rings (see Figure 1). Hence, whereas the flood probabilities and consequences per dike ring are known and communicated, only limited information on the spatial variability of flood

© 2009 The Authors
Journal Compilation © 2009 Blackwell Publishing Ltd

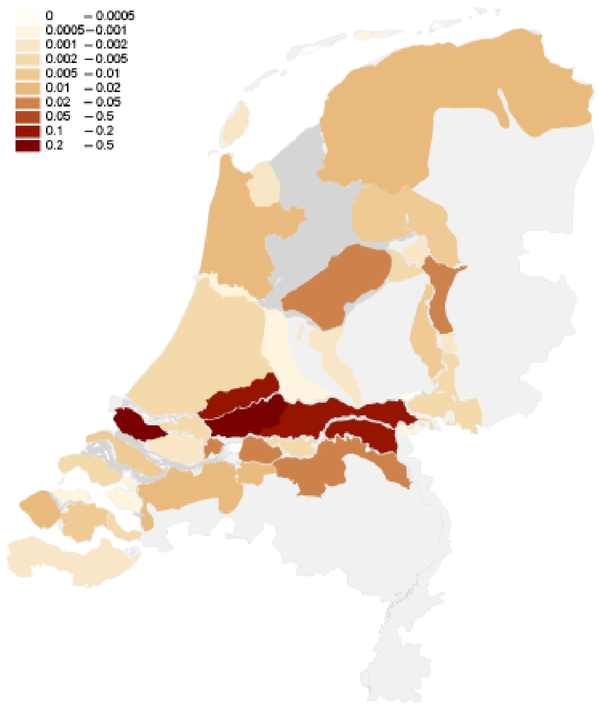

Figure 1 The expected annual number of fatalities per dike ring due to flooding (situation 2005) (Klijn *et al.*, 2007).

hazard characteristics and flood risks *within* dike rings is made available. It is recognised that there are large differences in expected flood depths, flow velocities and flood consequences between different locations within dike rings, but this information is seldom published. De Bruijn (2007a) concluded that information on differences in flood risks and about various aspects of flood risks on a more detailed spatial scale than dike rings is useful for the discussion on differentiating protection levels, for the consideration of compartmentalisation, for spatial planning – especially behind dikes – and for flood event management.

This paper, therefore, aims to show a method for mapping flood risks on a spatial scale that allows differentiation within dike rings and that is consistent for the whole country. It focuses on one type of risk, namely the risk of fatalities within the flood-protected parts of the country. It does not estimate the number of fatalities, but instead it aims to depict geographically which areas are more risky and why they are more risky. The paper provides a first approximation of risky places in the Netherlands.

The paper first defines the main concepts used, and then it discusses the most important factors that determine fatality risks, and based on these, it proposes an approach to establish risky places. Next, this approach is applied to the Netherlands. Finally, conclusions and recommendations are given.

Fatality risks of floods

Flood, flood risks and flood impacts

A flood is a temporary covering of land by water outside its normal confines (Gouldby & Samuels, 2005). There are many different types of floods, for example flash floods, river floods, estuarine floods, coastal floods, floods from lakes, floods from canals or regional waterways, urban sewer floods and floods due to groundwater logging (De Bruijn, 2007a). The relevance of these flood types differs per region. This paper focuses on the Netherlands and especially on river, estuarine and coastal floods that may cause the failure of dikes or other defences. These flood types are selected, because they are dangerous from a public safety point of view. Groundwater logging, sewer floods and floods from regional waterways may cause substantial damage and nuisance, but they are not expected to cause death in the Netherlands.

This paper does not study floods, but flood risks. Flood risks are defined as ‘the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event’ (Flood Risk Directive, 2007). Thus, to establish flood risks, both flood probabilities *and* consequences must be considered or – alternatively – flood hazard and the vulnerability of the flood-prone area (Gouldby & Samuels, 2005).

Flood hazards are characterised in terms of flood probability, flood depth, flow velocity, water level rise rate, etc. Flood impacts comprise both direct and indirect flood impacts, on tangibles (usually property and economy) and intangibles, such as people (fatalities, injuries, psychological damage, etc.) and ecosystems (Table 1). Generally, in flood impact assessments, flood damage and fatalities are considered first.

Table 1 Negative flood impact categories (from De Bruijn, 2005)

Category		Tangible	Intangible
Primary	Direct	Capital loss (houses, crops, cars, factory buildings)	Victims, negative effects on ecosystems, pollution, monuments, culture loss
	Indirect	Production losses, income loss	Social disruption, emotional damage, psychological stress
Secondary		Production losses outside the flooded area, unemployment, migration, inflation	Emotional damage, damage to ecosystems outside the flooded area
Induced		Costs for relief aid and information services	Evacuation stress

© 2009 The Authors
Journal Compilation © 2009 Blackwell Publishing Ltd

The analysis and assessment of flood fatalities and damage differs significantly. For fatalities factors such as warning time, evacuation effectiveness and water level rise rate are extremely relevant, while for damage the maximum water depth and flood duration are relatively more important. The analysis of flood fatalities and flood damage is thus different.

Flood risk mapping and the flood risk directive

In order to gain an insight into the spatial distribution of flood risk, maps are useful. 'Flood risk map' is a term used for a wide variety of maps, including maps on flood hazards and floods impacts. In this paper we distinguish between flood hazard maps, vulnerability and exposure maps, and flood risk maps (cf. FLOODsite, http://www.floodsite.net; Gouldby & Samuels, 2005). Flood hazard maps are maps with information on the maximum flood extent, flood depths, flow velocities and other flood-related parameters. Vulnerability maps and exposure maps are maps with information on land use, number of inhabitants, potential number of affected persons, or maps with vulnerable locations or objects (such as schools, hospitals, chemical factories, electricity plants, public water supply plants, etc.). Flood risk maps are maps that combine information on hazards and vulnerability by a simple 'overlay', by reclassification or by expressing the results of model calculations. They may contain, for example, the number of affected persons or fatalities per year, the expected annual damage or areas that are risky because they are both hazardous and have a high impact potential (cities, towns, villages, industrial areas and vital infrastructure).

Risk maps are necessary for the coordination of different actions. They are a planning tool and ensure that all actors have the same information on the potential spatial extent and severity of hazards, vulnerabilities and risks. Flood hazard, flood vulnerability, exposure and flood risk maps may be useful for flood control, spatial planning, the determination of insurance fees, for increasing public awareness among inhabitants and for emergency planning. The users of flood risk maps can thus be divided into two distinct groups:

- *Professionals*: flood risk managers, policy makers and governmental organisations who base their flood risk management policies, spatial planning policies or evacuation plans and measures on such maps.
- Inhabitants of flood-prone areas who use the maps to get an idea of the flood risk they face.

These two groups may need different information. The first group wants to know how many people run a risk ('collective' or 'group risk', cf. Beckers *et al.*, 2008), whereas the second is primarily interested in the 'locational risk', i.e. the risk they may individually run at a certain place (x, y, z). The information they need may also have to be presented differently. Therefore, this distinction is an important one. This paper focuses on the first group of users, namely the flood risk management professionals, and thus on establishing where many casualties may occur. The hazard map, which is required to find out where the risky places are, does, however, reflect the 'locational risk' and may hence be useful for the second group of users too.

The Flood Risk Directive requires EU countries to consider flood risks and to make maps. Article 1 of the Directive states the Flood Risk Directive's purpose as: 'to establish a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the community'. The Flood Risk Directive identifies three steps to reach the goal of flood risk reduction:

1. Preliminary flood risk assessment to identify those areas where the potential flood risk is significant.
2. Generation of flood hazard maps and flood risk maps for those areas.
3. Development of flood risk management plans, setting objectives on flood risk reduction and describing measures that will be adopted to achieve this.

The preliminary flood risk assessment serves to identify the areas where the next steps should focus on. For those areas that were identified as being at a significant risk, Member States have to prepare flood hazard maps and flood risk maps at an 'appropriate scale'. Flood hazard maps have to show flood extents, water depths or water levels and, where appropriate, also flow velocities. Flood risk maps have to indicate the potential adverse consequences associated with floods. These consequences have to be expressed in (a) the indicative number of inhabitants potentially affected, (b) the type of economic activity of the area potentially affected, (c) installations that might cause accidental pollution in case of flooding and Natura 2000 areas (a network of nature areas that should be protected; defined by the EU to protect valuable European species and habitats) and (d) other information that the Member State considers useful such as the indication of areas where floods with a high content of transported sediments and debris flows can occur. In the third step flood risk management plans must be developed for the areas with significant flood risks. These plans should include 'appropriate objectives' that focus on either the reduction of the likelihood of flooding or on the reduction of potential adverse consequences, as well as measures for achieving the established objectives.

The Flood Risk Directive does not define which risk level is 'significant', nor does it require the precise calculation of flood risk. And the Flood Risk Directive only requires hazard maps and vulnerability maps and indicative

© 2009 The Authors
Journal Compilation © 2009 Blackwell Publishing Ltd

combinations of those to be made, without any further prescriptions on method or output. However, it may be valuable to make true flood risk maps that reflect the definition of flood risk as a function of hazard and vulnerability.

This paper focuses on fatality risks and the mapping of risky places: places where many fatalities may occur, because they are both hazardous and vulnerable. Such a map is obviously only one of the many kinds of maps that qualify as a risk map according to the Flood Risks Directive.

Factors that influence the occurrence of flood fatalities

The identification of relevant factors to be taken into account in the mapping of risky places can be derived from earlier research on flood fatalities due to flooding (cf. Jonkman, 2007). In addition, De Bruijn (2007b) reviewed a number of methods that aim to determine the expected number of flood fatalities. Three approaches were reviewed, viz. those of Klijn *et al.* (2007), HR Wallingford, FHRC and Risk & Policy Analysts (2006) and the one of Kok *et al.* (2005) (also Jonkman, 2007). The first one is based on logical reasoning and expert judgement, the second one on indices derived from correlative research and statistical regression and the third method is a semiquantitative approach based on mortality functions that relate flood characteristics to mortality rates.

During flooding, people may die due to drowning, hypothermia, by being trapped in a collapsing house or due to stress and diseases. They may drown when they are swept away or when they are in a car that is being swept away. Jonkman (2007) found that on average (world-wide) about 0.5% of all persons present in an area that is flooded from a river (excluding flash flood rivers) die due to this flooding. For flash floods the figure is 3.6% and for large-scale coastal floods it is about 1%. These figures reflect the importance of the time and speed of onset of a flood, as well as of flow velocity. How easily people become swept away also depends on the height and weight of the person. HR Wallingford, FHRC and Risk & Policy Analysts (2006) recognised a value of 0.5–1 for the product of water depth (m) and velocity (m/s) as a threshold for being swept away.

The 'expert judgement method' of Klijn *et al.* (2007) was intended to obtain expected annual numbers of fatalities for all dike rings in the Netherlands in the current situation and in various future situations. The approach consisted of the following steps:

1. For each dike ring the percentage of the area that may become flooded and the number of inhabitants in that area are determined based on knowledge of flood patterns available from flood simulations and knowledge on the population distribution.
2. For each dike ring, the percentage of the people who can be evacuated before the dike breaks is estimated. This estimation is based on area characteristics, the type of flood threat and the expected warning time.
3. The most likely mortality rate was estimated as 0.3% of the people who remain in the area at the initiation of the flooding. Because this figure is very uncertain, fatalities were also determined with a minimum and a maximum mortality rate of, respectively, 0.1% and 1%.
4. The number of inhabitants of the flooded area (found in step 1) was multiplied by the estimate of evacuation effectiveness (step 2) and the mortality rate (step 3) to obtain the expected number of fatalities, as well as a lower and an upper estimate.

HR Wallingford, FHRC and Risk & Policy Analysts (2006) developed the 'flood risks to people' method for DEFRA/Environment Agency, which allows one to estimate the number of injured persons and the number of fatalities due to floods. The method relies on three groups of factors that cause death or injury to people during floods:

- Factors that determine the flood hazard, viz. flood depth, flow velocity and the presence of debris, combined into a *hazard rating* (HR).
- Factors that determine the chance of exposure of people to the flood, as a function of the effectiveness of flood warning, speed of onset of flooding and the nature of the area (including types of buildings), combined into *area vulnerability* (AV).
- Factors that determine the individual vulnerability of those exposed and their ability to respond effectively to flooding. As an indicator for these factors, together called 'people vulnerability (PV)', the percentage of residents who are either suffering from long-term illness or aged 75 or over is used.

The expected number of fatalities is calculated as a function of HR, AV and PV.

Jonkman (2007) and the Dutch Standard Damage & Casualties Module (HIS-SSM) (Kok *et al.*, 2005) calculate the number of affected persons and the number of fatalities due to floods based on mortality functions for expected water depths, flow velocities and water level rise rates. This approach primarily considers the effect of flood parameters on the number of fatalities, but also implicitly incorporates knowledge on people's vulnerability. Expert judgement on warning and evacuation effectiveness may be added by the user to obtain more realistic fatality numbers.

The three methods together provide an insight into the main factors that determine fatality numbers. Obviously, all three methods start with the number of people present when the flooding begins. The second and third methods include various flood hazard parameters (depth, velocity and water

© 2009 The Authors
Journal Compilation © 2009 Blackwell Publishing Ltd

level rise rate), whereas the first one only takes into account the flooded area as a proxy. The third method primarily considers flood hazard characteristics, while the very important evacuation effectiveness must be included as expert judgement. Only the 'risk to people' method includes building type and takes into account differences in the vulnerability of individual people, as it was developed for application at the local and regional scale. In the other two methods, which were designed for the large regional to national scale of the Dutch polders, these factors are implicitly encompassed in the evacuation effectiveness and the mortality functions, respectively, neglected.

The insight that was thus gained on the relevance of the various factors is used for the mapping of risky places in the next section.

How to find risky places

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 are washed away. However, a few hundred metres away from the breach the flow velocity will already be too low to cause danger. Because 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 that 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.

HR

Similar to the 'Risk to people method' an HR is assigned here to each grid cell in the flood-prone area (see Table 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 0 and 1.

Table 2 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

Table 3 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

Vulnerability rating (VR)

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

- Identification of those areas where flooding may occur suddenly, and 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 VR (Table 3).

Risky places

Finally, the hazard and VR 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 HR and VR are multiplied (HR × VR).
2. An overlay is made of the HR map and the VR map and a reclassification is made of those areas that 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.

© 2009 The Authors
Journal Compilation © 2009 Blackwell Publishing Ltd

Application to the Netherlands

The method was tried and fine-tuned and then applied on the Netherlands as a whole and to one example dike ring (De Bruijn, 2007b). Here the application on the Netherlands as a whole is discussed. Because only existing and available nation-wide data and expert judgement were used, the result must be considered as a first approximation.

Generation of the hazard map

The hazard map was generated by considering the selected hazard factors: flood probability, water level rise rate and flood depth. Only flood-protected areas were considered, because from a Dutch perspective, the flooding of the unprotected floodplains is not a public safety issue. Still, there are relevant differences in flood probability within the protected areas in the Netherlands. For the hazard map two flood probability classes were distinguished:

- Areas outside the flood-prone area and areas protected by defences with a safety standard of 1/4000 or 1/10 000 a year.
- Areas protected by defences with a safety standard of 1/1250 or 1/2000 years.

If water levels rise fast, fatalities are more likely. According to Kok *et al.* (2005), the water level rise rate of the first 1.5 m of water is important. If the water level rise rate of that first 1.5 m exceeds 0.5 m/h, fatalities are more likely. Water levels may rise fast in very small dike rings. Water levels will also rise fast when the water cannot spread because of obstacles such as secondary embankments. Important secondary embankments are mainly found along the coast in the southwest and north, but also near Rotterdam.

The maximum water depth is also important. A preliminary maximum water depth map, representing the envelop of all available flood simulations for design conditions, was used. It was classified into areas with water depths below 0.5 m, between 0.5 and 2 m, between 2 and 4 m and above 4 m. The threshold of 0.5 m was used because walking, cycling and driving lorries in deeper water is practically impossible. Above 2 m people need to go to a second floor and above 4 m even the second floor may become dangerous.

The HR map was generated by summing the contributions of the flood probability, water level rise rate and water depth to the HR and dividing the total score by 3 to obtain a value between 0 and 1. Figure 2 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.

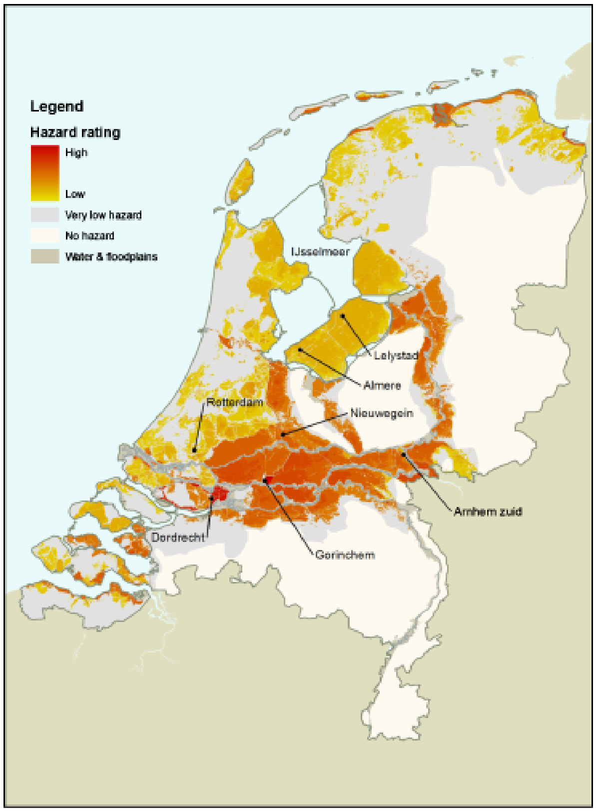

Figure 2 The resulting hazard rating map.

Generation of the vulnerability map

The vulnerability map is generated by combining maps that indicate:

- Areas where flooding may occur suddenly, and thus where 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 that 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 h of action before the initiation of the flooding, while for the large rivers 60 h are available for taking action (Jonkman, 2007). Areas that are situated close to an embankment will have less response time than areas where it will take days before the water arrives. 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 a 4 km distance from an embankment have only 2 h for action between the time of breaching and the arrival of the water. Flood-prone areas within 4 km from an

© 2009 The Authors
Journal Compilation © 2009 Blackwell Publishing Ltd

embankment score 1 and flood-prone areas situated between 4 and 10 km from an embankment score 0.5. The other areas score 0. The thresholds of 4 and 10 km were chosen arbitrarily.

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) and 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 these 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 considerable data and huge modelling efforts. Instead, the distance to safe ground was considered, assuming that people go to the nearest area that cannot become flooded or to neighbouring dike rings that are not being flooded. Besides, islands that 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 km (measured in a straight line) score 0.5.

Figure 3 shows the resulting VR 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 VR maps are combined to identify the risky places for large numbers of fatalities. Figure 4 shows the result if the hazard and vulnerability rate are multiplied and reclassified. It shows that mainly the areas near Rotterdam and Dordrecht, and Almere and Lelystad are risky. Figure 5, the overlay version, is more illustrative of the causes that make these places risky. It shows that Almere is risky, because the vulnerability is high, due to the fact that floods may occur suddenly because 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. Rotterdam and Dordrecht are 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.

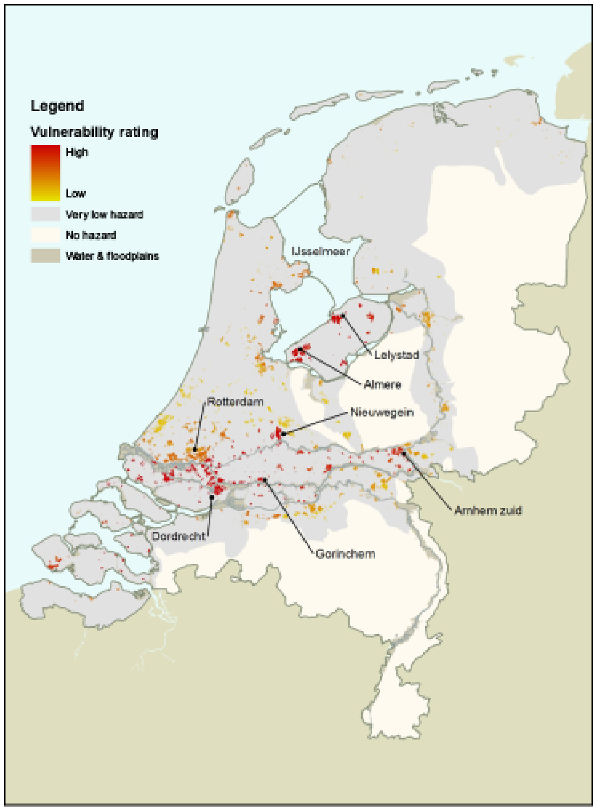

Figure 3 The resulting vulnerability rating map.

Discussion and conclusions

The research described in this report aimed to identify and map risky places in the Netherlands from the viewpoint of public safety and primarily intended for policy makers in the fields of flood control, spatial planning (new developments) and flood event management (evacuation planning). To our own surprise, *no* such map existed for the country as a whole and with sufficient detail (cf. also EXCIMAP for other countries; EXCIMAP, 2007), *nor did a method to draft one.* Against this background, risky places were defined as places where many flood-related fatalities might occur.

On the approach

The method developed considers all important factors that determine the risk of fatalities by taking into account factors that characterise the hazard on the one hand, and factors that determine the exposure and vulnerability of the place on the other. The hazard is characterised mainly by flood probability, water depth and the rate of water depth rise. The vulnerability and exposure are primarily determined by the population density and by the warning time and the vicinity of safe areas. The hazard and vulnerability factors are each scored separately and then combined into a score that indicates the risk level.

© 2009 The Authors
Journal Compilation © 2009 Blackwell Publishing Ltd

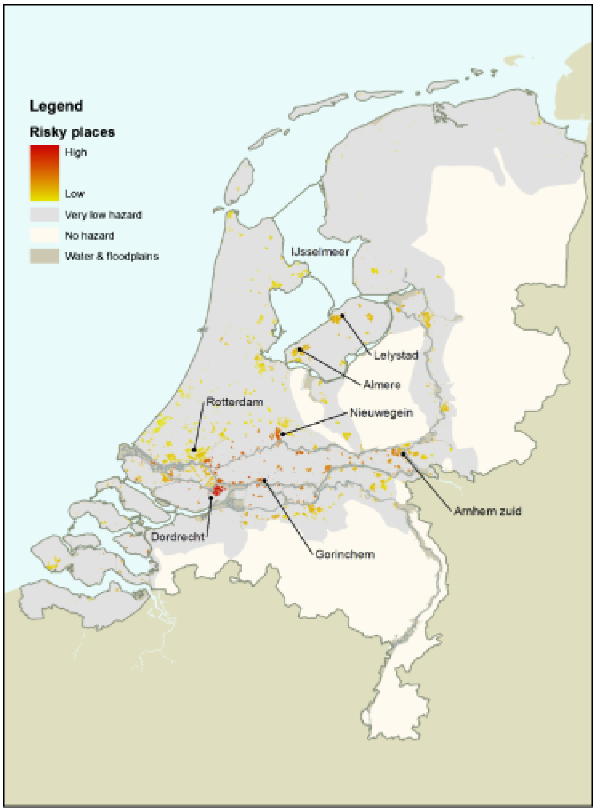

Figure 4 First approximation of the risky places in the Netherlands.

Figure 5 Risky places as overlay of vulnerability and hazard rating.

The factors used to determine the risky places largely correspond with the ones included in the three approaches discussed in chapter 2. Any deviations are related to the nature of the study area, scale of application (national) and availability of data. All factors used in the 'expert judgement approach' (Klijn *et al.*, 2007) are incorporated. Although 'evacuation effectiveness' is not mentioned as such, it is covered by the factors 'speed of onset' and 'vicinity of safe places'. Not all factors included in the 'flood risk to people approach' (HR Wallingford, FHRC and Risk & Policy Analysts, 2006) were included. Of the HR only those factors that are relevant for the Dutch situation are included. Of the AV two factors, viz. speed of onset and flood warning, are included in this first approximation under the headings of 'rise rate' and 'speed of onset', but not the 'type of buildings'. However, it is recommended to study as to where high-rise buildings predominate and where there are low-rise buildings. High-rise buildings may be used as shelters. The PV has not been taken into account, because of the scale of analysis (nationwide) and considering that each village and/or quarter contains a school, a home for elderly people, etc.

The scoring of the parameters in this first approximation was carried out by the authors. It was based on the review of research on flood fatalities. The scores cannot be validated on recent data because no major flooding has occurred in the Netherlands since 1953. The flood disaster of 1953 and its lessons for the current situation have, however, been thoroughly considered (see e.g. Asselman, 2005; Jonkman, 2007). Notwithstanding, the scoring and weighing of the parameters remains difficult. The resulting maps are, however, not severely affected by varying the scoring, as we established in various trials. Changes in the scores for and weighing of the parameters do affect the result, but the general picture of where the most risky areas lie remains the same.

In contrast to the existing methods that we reviewed, the method proposed here does not yield the 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 are also less likely to change when new knowledge becomes available. Detailed fatality numbers do contain more information than indications of risky places do, but because 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 considerably. Besides, the whole procedure of making the risky places map provides an insight into why the areas are

© 2009 The Authors
Journal Compilation © 2009 Blackwell Publishing Ltd

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 also be drafted for areas for which adequate flood simulations are absent.

Practical applicability in flood risk management

The applicability of the method was shown by discussing the nationwide application. The map of the risky places in the Netherlands shows that the method yields relevant results. The map shows areas that are more and less risky. It also indicates areas that are more hazardous and/or more vulnerable. The risky places map is considered understandable and clear and matches intuition and thus serves as an adequate first approximation. However, the input maps need further improvement, especially on the water level rise rate and the vicinity of safe areas.

How and by whom the method and the resulting risky places maps can be used depends on the accuracy and spatial scale of the input data. By showing and discussing the input maps, the uncertainty of the result becomes at least clear. If rough input data are used, the derived maps can only provide a rough indication of those areas that deserve more attention in emergency planning, flood control and spatial planning. If high-quality input data are available, the resulting maps could be used for the more precise planning of flood risk management measures. The maps can then be used to identify those embankments that require very high protection levels or should be 'fail-safe' even if overtopped. Because the map shows risk differences within dike rings it allows consideration of flood risk management measures that are less uniform and more tailor made than the current Dutch flood protection scheme allows for.

The map provided in this paper 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 Rotterdam, Dordrecht and also near Almere, 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 a relatively low cost.

Recommendations

The method and results presented here are a first approximation. The method appears quite acceptable, but the resulting map is somewhat flawed because of the 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' and 'vicinity of safe areas' needs improvement. The 'suddenty 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 that 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 HR and VR. 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 as an indication of the huge interest among policy makers from the fields of flood control, spatial planning and emergency planning alike.

Acknowledgements

The paper is based on research carried out within Delft Hydraulics, now Deltares. The first ideas originated from a co-operation with the Netherlands' Environmental Assessment Agency (MNP), whereas inspiration for the approach was found among partners within the FLOODsite project (contract no. GOCE-CT-2004-505420).

References

Asselman N.E.M. Consequences of floods. Damage to buildings and casualties. Delft Hydraulics report Q3668, Delft, the Netherlands, 2005.

Commissie Waterbeheer 21e eeuw (Commissie WB21). *Waterbeleid voor de 21e eeuw. Geef water de ruimte en de aandacht die het verdient*. The Netherlands: Kwak & Van Daalen & Ronday, 2000 (in Dutch).

Beckers J.V.L., Mens M.J.P. & en Timmers P.G.J. *Groepsrisico's van overstromingen. Deltares rapport T2505*. Delft, the Netherlands: Deltares, 2008 (in Dutch).

© 2009 The Authors
Journal Compilation © 2009 Blackwell Publishing Ltd

De Bruijn K.M. Resilience and flood risk management. A systems approach applied to lowland rivers. PhD thesis, Delft University of Technology, Delft, the Netherlands, 2005.

De Bruijn K.M. *Review on existing knowledge and tools for flood risk mapping. Project Q3668*. Delft, the Netherlands: WL|Delft Hydraulics, 2007a.

De Bruijn K.M. *Risky places in the Netherlands: a first approximation for floods. Project Q3668*. Delft, the Netherlands: WL|Delft Hydraulics, 2007b.

EXCIMAP. Atlas of flood maps. Examples from 19 European countries, USA and Japan. EC workgroup EXCIMAP. Available from http://ec.europa.eu/environment/water/flood_risk/flood_atlas/pdf/flood_maps_ch1_3.pdf, 2007 (Accessed 8 February 2009).

Gouldby B. & Samuels P. Language of risk. Project definitions. Report T32-04-0, FLOODsite project, 2005.

HR Wallingford, FHRC and Risk & Policy Analysts. *Flood risks to people phase 2. The flood risks to people methodology. Flood and Coastal defence R&D programme*. London, UK: DEFRA, 2006.

Jonkman S.N. Loss of life estimation in flood risk assessment. Theory and applications. PhD Thesis, Delft University of Technology, Delft, the Netherlands, 2007.

Klijn F., Baan P., De Bruijn K.M. & Kwadijk J. *Overstromingsrisico's in Nederland in een veranderd klimaat. Verwachtingen, schattingen en berekeningen voor het project Nederland Later*. Delft, the Netherlands: WL|Delft Hydraulics, Delft, 2007 (in Dutch).

Kok M., Huizinga H.J., Vrouwenvelder A.C.W.M. & Van den Braak W.E.M. Standaardmethode 2005. Schade en slachtoffers als gevolg van overstromingen. Rapport 999.10, HKV Lijn in Water, Lelystad, the Netherlands (in Dutch), 2005.

Lumbroso D., Gaume E., Logtmeijer C., Mens M. & van der Vat M. Evacuation and traffic management. FLOODsite Task 17 report number T17-07-02, HR Wallingford, Wallingford, UK, 2008.

Ministeries VROM & V&W. *Beleidslijn Ruimte voor de Rivier*. Den Haag, the Netherlands: Ministeries VROM & V&W, 1997 (in Dutch).

Pols L., Kronberger P., Pieterse N. & Tennekes J. *Overstromingsrisico als ruimtelijke opgave*. Den Haag, the Netherlands: Ruimtelijk Planbureau, 2007 (in Dutch).

Vis M., Klijn F., De Bruijn K.M. & Van Buuren M. Resilience strategies for flood risk management in the Netherlands. *International Journal of River Basin Management* 2003, **1**, (1), 33–40.

Wiering M.A. & Driessen P.P.J. Beyond the art of diking: interactive policy on river management in the Netherlands. *Water Policy* 2001, **3**, (2001), 283–296.

© 2009 The Authors
Journal Compilation © 2009 Blackwell Publishing Ltd