A function-oriented methodology of flood vulnerability assessment

By
Zhen Fang

May 2009

Graduation Commission:
Prof. dr. ir. N.C. Van de Giesen, Delft University of Technology
Dr. ir. Pieter van Gelder, Delft University of Technology
Dr. ir. Olivier Hoes, Delft University of Technology
Ir. P.J.N.J.(Pieter-Jeroen) Bart, Oranjewoud

MSc thesis
Water Resources Management, Civil Engineering, Delft University of Technology
This paper presents a flood vulnerability assessment (FVA) model that aims to indicate the interventions at different flood mitigation phases. The flood socio-economic factors are the main concern of this study, regarding their spatial distributive pattern and the overall effects. These concerns are integrated into the main structure of the FVA model along different mitigation phases. Specifically, the social vulnerability index system is reconstructed to feature the spatial distribution pattern, while the flood social impact is evaluated as a complementary part of flood risk assessment at the prevention phase. The use of GIS complemented the FVA model by providing a visual, map-based perspective that identifies the spatial relationships between flood hazards and social vulnerability factors. This model is applied to the area near IJsselmeer in the province of North Holland, the Netherlands. The results of the model not only can help find the distributed vulnerable features for proactive mitigation, but also enables emergency managers to quickly locate the vulnerable hotspots by coupling with different flood scenarios. Moreover, it is found that the flood social impact should be given more attention with regard to their higher impact extent.
Acknowledgements

I would like to thank Pieter-Jeroen Bart and Pascal Vlieghe from Oranjewoud for offering me this topic, for their guidance and encouragement.

I would like to thank my supervisor Olivier Hoes for helping me clarifying the thesis subject, collecting data and advices during the whole study.

I would also like to give my appreciation to my graduation committee members: Professor Nick van de Giesen and Pieter van Gelder for their suggestions and comments.

I would like to thank Maaike van Tuyll and Derk-Christiaan for their advices on flood evacuation programs in the Netherlands.

I would also like to thank Rolf Hut for his great help on the CBS data.

Finally, I will give my special thanks to my family and friends for their love and support during my whole master study.
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## Abbreviations

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<th>Description</th>
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<td>ADRC</td>
<td>Asian Disaster Reduction Centre</td>
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<tr>
<td>CBA</td>
<td>Cost-benefit analysis</td>
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<tr>
<td>CBS</td>
<td>Statistics Netherlands</td>
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<tr>
<td>FVA</td>
<td>Flood vulnerability assessment</td>
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<tr>
<td>GIS</td>
<td>Geographic Information System</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>NAP</td>
<td>Normaal Amsterdams Peil</td>
</tr>
<tr>
<td>SFVI</td>
<td>Social flood vulnerability index</td>
</tr>
<tr>
<td>SoVI</td>
<td>Social vulnerability index</td>
</tr>
<tr>
<td>UNDP</td>
<td>United Nations Development Programme</td>
</tr>
<tr>
<td>UNU-EHS</td>
<td>United Nations University-Institute for Environment and Human Security</td>
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Chapter 1

Introduction

1.1 The problems statement

Flood risk is often defined by probability and consequences. It has been well accepted as the main methodology for flood risk assessment. However, this methodology still has some limitations: firstly in some areas without long time data series, the probability of extreme events is hard to predict. Secondly, the consequences, in most cases, are represented by economic damage without considering the social impact that directly connected with human life, health, environment, etc.

Regarding this, the following two issues should be highlighted in the flood mitigation actions: firstly contingency planning must be developed to cope with the flooding events with low probability but significant consequences. Take Hurricane Katrina as an example, probably the main question is not to what extent the flood can be controlled by human being, but how to maximally protect against the flood. Secondly, the social dimension has to be integrated as a main part of the flood impact.

On the other hand, it is noted that the flood impact is spatially distributed. Different social groups are affected to different degrees by the flood: the financial hardship falls more upon those poor people (Richardson et al. 2005) while people with long-term illnesses are more susceptible to flood diseases. Given temporal and spatial changes in social vulnerability in the future, a one-size-fits-all approach to flood mitigation actions may be the least effective in reducing vulnerability or improving local resilience to hazards. Moreover, from the side of governments and development banks (HM Treasury, 2003), they consider the social distribution deeply rooted in the big social environment which needs to be stressed on to improve the overall effects of projects and try to balance the socio-economic equity (DEFRA & EA, 2004).

To conclude, there are three challenges in front of the current flood risk assessment: first how to include the extreme flood events into consideration? Secondly, how to integrate the social dimension into the flood impact analysis? Thirdly, how to analyze the spatial distribution of the vulnerable social groups?

In order to meet these requirements, in recent years the concept of vulnerability has been proposed by more and more researchers in the field of flood management. The vulnerability assessment has an integrated framework to analyze the risk from both external hazard and internal social fabric. It aims to increase the resilience of the society by strengthening those vulnerable elements depicted by the vulnerable
analysis. Many vulnerability index systems have been proposed in the last decade, but few of them clearly point out the reasoning of the indicators used, and the function of the proposed index system on the end users. Therefore, a practical vulnerability assessment tool is highly demanded to assist the flood mitigation activities.

1.2 Aims of the study

Instead of giving a broad-brush approach, this study aims to develop a flood vulnerability assessment (FVA) tool that identifies with precision the vulnerable communities that will require assistance, support and services at different phases of flood mitigation activities.

In order to achieve this objective, the following study questions will be answered:

1. How to portray different vulnerable communities with social vulnerable index? Who is vulnerable for what at which phases? Where are people with similar vulnerable characteristics located and to how to continuously monitor and assess them?

2. How to clarify the complex index system to better meet the real demand from flood mitigations?

3. How to systematically combine internal social factors and external physical hazard in the FVA model?

4. Which information and coping strategies can be derived to assist the flood mitigation activities?

While these questions are not definitive of all points explored in this report, they are some of the key drivers behind the selection of methodologies, measurement processes and applications. The first question aims to gain a deep understanding of the social vulnerable groups; the second question focused on the modification of the existing social vulnerability index system, to better meet the requirement of future flood mitigation. In other words, it aims to make the index system more function-oriented. The third question pinpoints the relation between external hazard and the internal vulnerability factors. It aims to know which vulnerability indicators can be influenced prior to a hazard impact, and which can be combined with the flood hazard to extract more information. The fourth question aims for the conclusive suggestions for the future flood mitigation actions.

1.3 Outline of the thesis

The thesis is outlined as follows: firstly, the concept of flood impact, flood damage and vulnerability is explained based on extensive literature study; secondly attention is paid to the development of a safety-chain based vulnerability index system which serves as the foundation of the whole vulnerability assessment; thirdly the Flood vulnerability assessment model is constructed with three sub-modules; fourthly the methodology is applied in the area around IJsselmeer in the North-Holland with
Chapter 1. Introduction

consideration on the local situation; lastly the coping strategies and recommendations for future study is suggested.
Chapter 2

Literature Review

2.1 Observation of flood impacts

Flooding encompasses a wide range of harmful effects: it endangers people’s life and health; destroys the buildings and public infrastructures; demolishes cultural heritage and ecological systems, and interrupt people’s daily life. In the flood risk assessment, these impacts are usually quantified by the flood damage. Flood also has differential impacts on the affected people, and the needs generated by the impacts and consequences may persist for long periods. In this section, the flood damage is explained in 2.1.1; then the distributive flood impacts will be additionally explained in 2.1.2.

2.1.1 Flood damage

Flood damage, technically, can be classified into direct damage and indirect damage. The direct damage refers to the damage induced directly by the inundation, while the indirect damage is the damage happens outside the flooded area due to the loss of economic connectivity, and the disruption of the transportation. In addition, depending on whether or not the damage can be specified in monetary term, the damages are classified into tangible damage and intangible damage.

A detailed classification of flood damage is shown in Table 1.

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1 For the interruption of business within the affected area, there are different opinions on categorizing them into direct or indirect damage. In this study, it is classified into the direct damage.
Chapter 2. Literature Review

Table 2.1 The classifications of flood damage (Source: Jonkman et al, 2008)

<table>
<thead>
<tr>
<th>Tangible and priced</th>
<th>Intangible and unpriced</th>
</tr>
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<tbody>
<tr>
<td>Direct</td>
<td></td>
</tr>
<tr>
<td>• Residences</td>
<td>• Fatalities</td>
</tr>
<tr>
<td>• Capital assets and inventory</td>
<td>• Injuries</td>
</tr>
<tr>
<td>• Business interruption (inside the flooded area)</td>
<td>• Inconvenience and moral damages</td>
</tr>
<tr>
<td>• Vehicles</td>
<td>• Utilities and communication</td>
</tr>
<tr>
<td>• Agricultural land and cattle</td>
<td>• Historical and cultural losses</td>
</tr>
<tr>
<td>• Roads, utility and communication infrastructure</td>
<td>• Environmental losses</td>
</tr>
<tr>
<td>• Evacuation and rescue operations</td>
<td></td>
</tr>
<tr>
<td>• Reconstruction of flood defences</td>
<td></td>
</tr>
<tr>
<td>• Clean up costs</td>
<td></td>
</tr>
<tr>
<td>Indirect</td>
<td></td>
</tr>
<tr>
<td>• Damage for companies outside the flooded area</td>
<td>• Societal disruption</td>
</tr>
<tr>
<td>• Adjustments in production and consumption patterns outside the flooded area</td>
<td>• Psychological traumas</td>
</tr>
<tr>
<td>• Temporary housing of evacuees</td>
<td>• Undermined trust in public authorities</td>
</tr>
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2.1.2 The distributive flood impacts

Many field surveys after floods have found that the damage is mainly concentrated on the low income group, as the poor people are more likely to live in the flood zones. The most affected businesses are wholesale, financial, insurance and the retail while those construction and manufacturing factors are better off during the recovery process. The small-size companies, especially those self-owned business, have great difficulty to recover from the flood (Tierney & Dahlhamer, 1996). People who have financial problems are found to have much more difficulty to afford housing, find a job, take childcare and thus hardly recover from the flood compared with other social classes (Cochrane 1975, Gerber 2006).

The effect of flood on health also varies by pre-existing health status and age (Tapsell et al. 1999, Tapsell et al 2002). Those elder people are more easily to be affected by the damp and dirty conditions after flood, especially those infirm people and people aged 75 years or more. The elder people and disabled people also have big difficulties to find a suitably adapted temporary accommodation, especially if they are reliant on specific medication (Fordham and Ketteridge 1998). For the psychological problems like emotional trauma and anxiety, the single parent, low-income households, and the female shows a higher susceptibility (Tapsell et al 2002).

The minority ethnic groups are found to have difficulty in understanding warnings and receiving advice or support, but their particular cultural needs are sometimes not catered for in evacuation centers (Tapsell et al. 1999).
2.2 Flood Vulnerability Assessment

The concept of vulnerability is introduced in this section. First its initiations and function are introduced in 2.2.1, and then its definition is explained in 2.2.2.

2.2.1 Flood vulnerability assessment vs. Flood risk assessment

In this part, the concept of vulnerability assessment is explained in comparison with the flood risk assessment. As both concepts are highly convoluted, some clarifications are made in terms of initiations and functions.

The initiations

The initiation to introduce vulnerability in flood management was due to the re-recognition of disaster. Instead of linking hazard directly to disaster, the disaster is regarded as the final product of external hazard and internal vulnerability within the social system. Vulnerability focuses on exploring the essential strength and weakness of the elements within the social system. It stresses more on the sustainability of different social groups, the coping capacity of the critical infrastructures, the efficiency of the government, and the robustness of economic structures. Regarding the field of flood management, vulnerability analysis can help identify how robust the social system can cope with the flood and where the inherent weakness are. In comparison, flood risk assessment is more oriented to evaluate the potential consequences of the affected social system with certain flood probabilities. As the consequences are mainly quantified by the economic loss, flood risk assessment is more adopted by cost-benefit analysis (CBA) to evaluate the potential benefit of flood control measures.

The functions

In the field of flood management, both assessments are oriented to assist the flood mitigation activities, but for different aspects. The flood risk assessment to large extent facilitates the prevention phase with the economic loss as the main evaluator; vulnerability assessment tells the government which social elements have a high exposure to flood as well as which elements may exemplify the potential hazard. Thus, it gives more consideration to the social dimension along all the phases.

Moreover, while flood risk assessment analyzes the overall impact of the social system, vulnerability assessment aims to explore the distributive patterns among affected populations and communities, considering that different people or groups can be exposed to different magnitudes and types of loss.

2.2.2 The definition of vulnerability

Although the concept of Vulnerability is potently initiated, its definition is not well

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2 Although recently the integrated flood risk assessment was also proposed to consider the social, economic, ecological and cultural issues, here the most common definition of flood risk assessment is used: the final product of probability and consequences.
Chapter 2. Literature Review

illuminated. In recent years, it has been used as a terminology to describe almost everything. In order to give a broader context of flood vulnerability, some relevant concepts are listed in Table 2.2.

<table>
<thead>
<tr>
<th><strong>Disaster risk:</strong></th>
<th>'a function of the hazard, exposure and vulnerability as follows; Disaster Risk = function (Hazard, Exposure, Vulnerability)'</th>
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<td>---------------(ADRC, 2005)</td>
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<tr>
<th><strong>Exposure:</strong></th>
<th>'Elements at risk, an inventory of those people or artefacts that are exposed to a hazard'.</th>
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<td>---------------(UNDP, 2004)</td>
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| **Vulnerability:**| ‘By vulnerability we mean the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard. It involves a combination of factors that determine the degree to which someone’s life and livelihood is put at risk by a discrete and identifiable event in nature or in society’.
|                   | ---------------(Blaikie et al. 1994)                                                             |

|                    | 'Vulnerability indicates the sensitivity of a system for exposure to shocks, stresses and disturbances, or the degree to which a system is susceptible to adverse effects.' |
|                    | ---------------(IPCC, 2001)                                                                  |

|                    | 'Vulnerability is the intrinsic and dynamic feature of the elements at risk (community, region, state, infrastructure, environment etc.) within the system that both contribute and affected by the harmful events.' |
|                    | ---------------(UNU-EHS, 2004)                                                              |

Table 2.2 The definition of risk, exposure and vulnerability

Based on the concept of vulnerability, ADRC (2005) redefines risk as a combination of hazard, exposure and vulnerability. The vulnerability in this context represents the social fabric that takes into account the community experience with hazard, and community’s ability to respond to, cope with, recover from and adapt to hazards. The social fabric incorporates the economic, demographic and political dimensions. However, this multi-dimension also creates the biggest problem in vulnerability analysis, which is ‘too complicated to be captured by models and frameworks’ (Twigg & Bhatt, 1998)

2.3 The social vulnerability index

3 The community, in this sense, also incorporates various governmental, commercial and non-governmental organizations.
Chapter 2. Literature Review

In order to apply the vulnerability concept into the field of natural hazard, social vulnerability index is proposed to be used as a quantifying tool to analyze the complex social system. From the decade of 1990s, many social vulnerability index systems, like SFVI (Tapsell et al 2002) and SoVI (Cutter et al, 2003) have been developed to depict the complex world by encapsulating a wide range of indicators\(^4\). Among them, SFVI is specially focused on identifying the intangible social impacts of flood.

2.3.1 The problems of the index system

Although these index systems have been developed, their indicative functions are quite doubtable, in the following two aspects:

a) The spatial scales: most of the index systems are imbedded in the national scale, taking the overall governance, social capital, health-care system and the emergency management into account. Although it can allow comparison between different countries, it is too coarse to indicate hazard mitigation activities. It is the trend that vulnerability analysis should be downscaling into the sub-county level (Brooks et al, 2005, Boruff et al, 2005).

b) The convoluted acceptors: the vulnerability index systems combine different social dimensions together without specifically considering their inherent relation. When summing up all the vulnerable dimensions into one single index, it also causes the problem of impairing one dimension by another, and thus leads to loss of information about how different factors that went into making the composite index interact with each other. While giving different weights to the variables may avoid this problem, the weight itself is also questionable for its subjectivity. The statistical tools and expert judgment have been additionally introduced to avoid the subjectivity, but the new question is how robust the result can be without decently understanding the meaning of each element inside. It is argued that the index system should be guided by the demand from the end users, instead of being data-oriented.

2.3.2 The reasoning the social vulnerability index

In order to gain a better understanding of the vulnerable community, in the following part the vulnerable group is explained along with first-hand information collected from previous large-scale flood surveys (A detailed explanation of vulnerable index is listed in Appendix B).

**Physically-vulnerable people**

People with pre-existing health problems, the elder and the disabled are probably the most evident vulnerable group, as a high number of casualties and injuries fall into

\(^4\) For the detailed information of vulnerable indicators, it is recommended to refer to the paper written by Cutter.S (2003).
this group (the relevant data is provided in Appendix A). For the places with a high
collection of these people (like nursing homes and hospitals), it is even more
dangerous as people there are reliant on others for daily care (Dosa et al., 2007).

**The Female**

Many index systems incorporate the female into the physically vulnerable group, but
post-flood fatality tolls doesn’t show big gender differences (Jonkman S.N. 2007).
Instead, the female was found to be vulnerable during the recovery phase with more
psychological trauma and anxiety.

**People without cars**

For people with cars, the exit is much faster than those without who have to rely on
the buses and other public vehicles to send them to the safe shelters (Gerber S. 2006).

**Financially-vulnerable group**

Poor people are considered to be more susceptible to the flood, regarding their
insufficient financial resources to buffer the impact of flood (Walker et al, 2006).
Individuals with good access to resources arguably have a safety net in the case of
natural hazard, allowing them to obtain material and social assistance to maintain their
livelihoods and hence increase their resilience after flood (Ketteridge and Fordham
have less capacity to cope with the hazard. This can be reflected from their
incapability of affording a house outside of the flood zone; lack of money to repair or
reconstruct the house; lack of flood insurance of their houses and contents; and lack of
advice and assistance following the flood.

Two types of index systems are widely applied to portray people’s financial status:
one is material-deprived index and another is poverty index. The Townsend index,
derived by Prof Peter Townsend in 1987, perhaps is one of the most widely applied
material-deprived indices. Based on large-scale field survey, the variables of
unemployment, non-car ownership, non-home ownership and overcrowding (more
than one person per room) are selected to reflect the material exhibition of financial
difficulty. In the Netherlands, the poverty indicator is usually used to evaluate the
financial difficulty. One key indicator of poverty is disposable household income.
Poverty is determined on the basis of two income thresholds: the low-income
threshold and the policy threshold (CBS poverty). As the material-deprived index is
derived from UK, some of the indicators, e.g. house-ownership and overcrowding, are
inappropriate to be transferred in the Netherlands. For example, more than 65%
habitants in UK have the house ownership, which is regarded as kind of social
security. While in the Netherlands, only 55% (CBS, 2005) of the population have their
own houses, and many Dutch rental dwellings are still used by middle income and
high-income households (Saunders, 1990). Thus, the governmental poverty threshold
is used in this study to depict the financially vulnerable group.

**The ethnic minorities**

The ethnic group, especially new immigrants and tourist, are usually the largest group
which is not aware of the local flood situation and lack of communication channels to
resort help. The culture and language barriers make this group lack sufficient
resources to recover after the flood, as most of them are complained with no advices for reconstruction and financial problems (Bolin, R. Stanford, L. 1998, Cutter, S. 1995). In the case of the Netherlands, the Non-European residents are especially vulnerable on this.
Chapter 3

Methodology

3.1. The modified social vulnerability index

From section 2.3.2, it is noted that the poor people are vulnerable not because they are less capable to escape from the flood, but because they lack of financial resources to recover and rebound from the flood. The aged people are vulnerable not because their financial problems, but the poor mobility and high susceptibility to flood-induced diseases, and their life experiences can even make them more resilient than many younger people during the recover period (Buckle et al 2001). It can be concluded that to some extent people are all vulnerable in certain aspect and what really matters in flood mitigations is which social group is vulnerable for what? Furthermore, it also triggers an essential question: how to differentiate these vulnerable attributes to indicate the intervention actions?

Considering this, the safety net concept is used to help develop a function-oriented FVA tool.

3.1.1 The safety chain concept

Originated in US, the safety chain concept was first introduced to the Netherlands in 1993 to address safety and security concerns on disaster management. There are four phases in the safety chain (Brinke et al, 2008), which are explained as follows:

- **Response**: the phase actually dealing with accidents and disasters (e.g. response teams).
- **Recovery**: the phase for rapid recovery from the consequences of accidents and disasters and ensure that all those affected can return to the ‘normal’ situation and recover their equilibrium.
- **Prevention**: the phase taking measures beforehand that aim to prevent disasters, and limiting the consequences in case such events do occur (both from spatial planning and structural control).
- **Preparation**: the phase taking measures to ensure sufficient preparation to deal with disasters in case they happen (e.g. contingency planning).

5 In the Netherlands, the pro-action is added as an additional phase to separate the spatial planning from structure measures.
Chapter 3. Methodology

It can be seen that the external hazard separates the cycle between the preparation phase and the response phase.

3.1.2 The function-oriented social vulnerability system

Coupled the aforementioned vulnerability indicators with the safety net, the indices can be directly linked with the response and recovery phase, while the ex-ante phase (the period of prevention and preparation) is the phase for emergency agencies to identify and address these demands.

Fig. 3.1 gives a simple explanation on how to link the SVI system with the safety net.

3.2 FVA model

There are three modules in the FVA model: the response module, the social vulnerability module and the damage module. The model structure is shown in Fig. 3.2. The functions of the response module are two fold: firstly it gives a good view of the relations among flood hazards, exposure and social vulnerable elements, based on which the inundation area is divided into different risk zones. Secondly it generates the intermediate outputs for the other two modules. These three modules are all combined and integrated in the environment of Geographical Information Systems (GIS) to identify the spatial distribution pattern.
3.3 The Response module

In this section, firstly a general introduction of response process is given in 3.3.1; then the key elements of response process are explained in 3.3.2, lastly the structure of the response module is presented in 3.3.3.

3.3.1 Introduction of Response process

The response module aims to indicate the mitigation actions during the response phase. There are three main flood mitigation actions during this phase: the evacuation, rescue and sheltering.

Depending on the extent of the flooding, the evacuation can be distinguished by preventive evacuation and forced evacuation (Jonkman, 2007). The preventive evacuation occurs before the arrival of flood while the forced evacuation happens during event development. Both types of evacuation consist of four phases: prediction & decision making, warning, response and actual evacuation. The success of the evacuation is largely influenced by the time available and the time required. Specifically, the time available is the period from flood prediction until the time of flood arrival; the time required is the total of decision making time, the warning time and the response time (see Fig 3.3). The prediction time varies per flood type and failure mechanisms. Generally the prediction time of coastal and lake flood is much less than that of the riverine flood; while the failure mechanisms of inner slope and piping are much less predictable than the dike erosion.

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6 Shelters are those predefined large public buildings that provide enough space and facilities to keep people (e.g. schools, church and sports halls).
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Fig. 3.3 Percentage of evacuation as a function of time (source: FLOODsite, 2009)

Up to now, most of the evacuation models only stress the issue of traffic management, without considering the internal social community patterns and their interplay with the external hydrodynamic conditions. Thus, they cannot identify those preexisting vulnerable area where people need evacuation assistance and rescue help. Due to this ignorance, many areas with high concentration of physically vulnerable people (e.g. hospitals, nursing home) have a much higher fatality during flooding (Jonkman 2007). Moreover, these models fail to indicate the coping capacities of the shelter during the flood, especially for those areas where time is too limited for a complete evacuation. Therefore, a response model that specifically tailored for evacuation, rescuing and sheltering is in high demand.

On the other hand, the emergency agency has its limited capacity. The rescue personnel cannot ensure to save everyone and search everywhere without time delay after the initiation of flooding, while the shelter cannot be built up without knowing its potential demand. There should be a priority order to indicate the demand of the area during the response phase.

3.3.2 Key elements of the response module

In the Netherlands, the aid required from government for large-scale evacuation is mainly determined by the number of threatened persons and the time dynamic (Emergency Response Plan, 2007). The response module in this study, with special focus on the extreme flood events, extends this idea to separate the key elements into dynamic factor and static factor. Apart from the time dynamic, the dynamic factor also includes other flood hydrodynamic parameters, while the static factor also incorporates other socioeconomic factors, not merely population number.

a. Dynamic factor

The dynamic data are derived from flood simulations: the maximum flood depth, the time of arrival and the flood speed. In order to categorize the risk, the following
thresholds are used:

- **d>1m:**
  As most fatality happens when the water depth exceeds 1m (Fig. 3.4), the area with water depth above 1m is defined as the severely affected area.

- **t<5h:**
  For the forced evacuation, it is assumed that no prediction time is available. Then, the time available only depends on the travel time of flood wave to the location under concern. The minimum time required for the initiation of evacuation during unexpected floods usually takes 4 to 5 hours (Jonkman 2007). Thus, for those areas with arrival time less than 5 hours, complete evacuation is neither possible nor feasible.

- **hv>7m²/s or v>2m/s:**
  For the areas with arrival time longer than 5 hours, the life-endanger area is further extracted by the breach zone (Jonkman, 2007) where high velocity and water rising speed can cause the fatality as high as 1. It is found that high flow velocity and rapidly rising water levels are the main causes of mortality. The high velocity in breach zones not only can whirl people away, float the cars, but also can break down buildings. The collapse of building due to high flow velocity will further cause a high rate of fatality which is clearly reflected from the 1953 flood in the Netherlands.

![Fig. 3.4 The relation of flood mortality and rapidly rising water and other causes (source: Asselman & Jonkman, 2007)](image)

**b. The static factor**

The static factors are the social vulnerable elements during the response phase. In this module, four factors are specially considered:

- Physically vulnerable people: one main indicator of SVI
Vulnerable facilities: kindergarten, nursing home, hospital, rest home

Insufficient traffic capacity:
  a) Areas where traffic jams might happen, especially those areas with large population but few transport roads.
  b) Areas that far from the exits

Insufficient vehicles: neighborhoods that have insufficient vehicles to evacuate;

To conclude, three vulnerable aspects are considered: the area with high concentration of the vulnerable people who cannot help themselves during the evacuation; the area with insufficient traffic capacity, and areas with insufficient vehicles. Unlike the other traffic-management-oriented evacuation model which aims to given a quantifiable analysis of the transport network, the index of ‘insufficient traffic capacity’ here emphasis on indicating the area with potential traffic problems during evacuation.

3.3.3 The structure of the response module

In this section, the evacuation module is constructed. This is shown in Fig. 3.5.

There are two main inputs in this module. First is the vulnerable index that related to the response phase (the static factors). It is used to generate predictions during the ex-ante phase. Another is the flood characteristics (the dynamic factors), which divide the inundation area into different risk zones. Finally, the vulnerable hotspots are derived by combining the social vulnerable areas with the risk zones.
During the response phase, both time and resources are limited. It is important for the emergency agencies to allocate their resources to the most demanding area. Specifically, the evacuation managers have to know which areas have more traffic problems; the rescue personnel has to know the distributions of those people who cannot self-help, and whether the local capacity of the shelter can meet the potential demand or not. Accordingly, the hotspots of evacuation are derived by overlaying evacuation zones with areas of traffic problems; the hotspots requiring rescue are derived by overlaying the severe zones with the areas of many physically vulnerable people.

For the shelters, they are separated into the outside shelter (outside the inundation area) and the in situ shelter. The outside shelter serves as the destination of the evacuation while the in situ shelter functions as the safe haven within the inundation area. In this module, the outside shelter is selected from the public facilities with sufficient holding capacities, while the high-rise buildings (more than three-layers) and the buildings located at high land are selected as the in situ shelter.
3.4 The social vulnerability module

Apart from the indicators that have been analyzed in the response module, the other vulnerable components are analyzed in this section: the financially vulnerable group and the minority group.

The distribution patterns of all the indices are further measured by the spatial statistics to check if they are clustered or dispersed. There are two reasons for this: one is because of the restrictions of the classification methods in ArcGIS. By simply mapping the attribute values, the classification methods (Jenks Natural Break, Equal Interval, Quantile, etc.) and the ranges to large extent change the way feature appear to be clustered or not. The statistical tools help identify if the vulnerable index itself is statistically clustered and the degree of the clustering, to ensure that the pattern presented does not differ by the classification factors, thus gives more confidence that the cluster pattern from the map is really a cluster. The second reason is to help the local authorities locate the vulnerable region without the confinement of administrative boundary.

Unlike the common statistics, the spatial statistics measures to what extent the value of a feature depends on the values of surrounding features. Specifically, it measures the spatial pattern of feature values based on one notion that nearby features have similar values. The spatial statistics compare the spatial distribution of a set of features to a hypothetical random spatial distribution. The extent to which the observed distribution deviates from the random distribution is the extent to which the pattern is more clustered or more dispersed than the random distribution (the degree of significance).

The high-low clustering tool in ArcGIS is used to analyze the cluster patterns. It uses the general G-statistics to measure within a specified distance how high or low the value are and compare this to a measure of how high or low the values are over the entire study area. The z-score is given as a reference measure of the degree of significance (with mean of zero and standard deviation of 1). The higher (or lower) the Z score, the stronger the intensity of the clustering. A Z score near zero indicates no apparent clustering within the study area. A positive Z score indicates clustering of high values. A negative Z score indicates clustering of low values.

The mathematical calculations are given as follows (Arcgis Desktop, 2009):

The General G statistic of overall spatial association is given as:
\[
G = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} x_i x_j}{\sum_{i=1}^{n} \sum_{j=1}^{n} x_i x_j}, \forall j \neq i
\]

Where:
- \(x_i\) and \(x_j\) are attribute values for features i and j.
- \(w_{ij}\) is the spatial weight between feature i and j.

The z-score for the statistic is computed as:
\[
Z = \frac{G - E[G]}{\sqrt{V[G]}}
\]

Where:
- \(E[G] = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}}{n(n-1)}, \forall j \neq i\)

### 3.5 The flood impact

The flood impact in this study is evaluated from two aspects: the economic impact and the social impact. The damage module is used to quantify the economic damage while the social impact is analyzed by its harmfulness on human life. The loss of life model derived by Jonkman (2007) is deployed to estimate the potential fatality from the flood.

#### 3.5.1 The damage module

In the current state-of-the-art flood damage evaluation, various stage-damage functions that derived from previous field surveys are used. In the Netherlands, HIS-SSM (Schade en Slachtoffers Module; Huizinga et al. 2005) has been developed as a standard method of flood damage evaluation as a part of the Flood Management System (Hoogwater Informatie Systeem; HIS). Figure 3.7 shows the main conceptual components of the model.
Fig. 3.7 The conceptual diagram of the HIS-SSM model

In HIS-SSM, 11 relative depth-damage functions have been developed for certain land use type (Table 3.1). By coupling the land use map with the inundation depth, the amount of damage that occurs at different flood depth can be calculated as a ratio (between 0 and 1) of the replacement assets value. The flow velocity is used as a complementary factor in calculating the residential property, as large amounts of fabric damage is caused by high flow velocity as well. Imbedded in the GIS system, the amount of tangible damage for each grid cell can be calculated by the formula:

$$S = \sum_{i=1}^{n} \alpha_i n_i S_i$$

Eq. 3-4

With

- $n_i$: number of units in category $i$
- $S_i$: maximum damage per unit in category $i$
- $\alpha_i$: damage factor category $i$

The damage module in this study comprises four main categories of HIS_SSM: business, dwelling, infrastructure and agriculture. The replacement value is directly adopted from HIS-SSM (Huizinga et al. 2005).
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The social impact

Based on the flood risk zones derived from the evacuation module, four elements are accounted in the social module:

- The people at risk: the number of people directly affected by the flood;
- People severely affected: the number of people who reside in the severe zone;
- The life-endangered population: the number of people who are located within the non-evacuation zone with little response time and extreme hazards;
- Collapsed buildings: the number of buildings that face a high potential to collapse during the flood;

Moreover, the loss of life model developed by Jonkman (2007) is used to estimate the potential casualties for both scenarios. Based on the previous flood data (mainly the 1953 flood in the Netherlands), Jonkman derived three sets of fatality functions for three inundation zones: the breach zone, the zone with rapidly rising water and the remaining zone. These three zones are captured by their hydrodynamic factors of flood velocity, depth, and water rising speed. The numbers of exposed people in each zone are calculated by subtracting people who saved by evacuation, rescue and sheltering from the total population. The evacuation model developed by HKV (2005) is used to calculate evacuated fraction; the rescue capacity is determined by the expert judgment, and the sheltering capacity is determined by the numbers of high-rise building within the inundation zone. Due to the large uncertainties of the emergency interventions, the potential fatality without intervention actions is calculated by this fatality model.
Chapter 4

Case study

4.1 Study area

4.1.1 The North Holland and IJsselmeer

The area of North-Holland that borders Lake IJsselmeer is selected as the study area (Fig. 4.1). Most of the areas in North Holland lie at or below sea level, except the eastern part where higher lands with minor hills exist. The lowest parts are within those reclaimed polders, like Wieringermeer, Schermer, Beemster and Schaalsmeer (with the elevation between -1m to -3.4m). North Holland contribute one fifth of the national product. The triangle between Haarlem, Amsterdam and Schiphol Airport is the economic heart of the country and riddled with modern office buildings (North Holland, 1998). Like the other parts of the Netherlands, the main business type in North Holland is service which account for 77% of the work force. The Province’s main agricultural activities are bulb-growing and seed production.
Chapter 4. Case study

North Holland is bordered on IJsselmeer and connected with Friesland through Afsluitdijk. IJsselmeer is a freshwater lake, which locates in the central Netherlands, with an area of 1250 km² and depth of 5 to 6 m. It was created in 1932 when the Zuiderzee (an inland sea) was closed by the Afsluitdijk. It boards Markermeer, the former southern part of the IJsselmeer and now hydro-logically separated from IJsselmeer. For years, the water level of IJsselmeer has been kept at -0.2m NAP in the summer (1 April to 1 October) and -0.4 meters NAP in the winter (rest of the year), due to the requirement of water quantity management (Wikipedia IJsselmeer, 2009).

Discharged by River IJssel, IJsselmeer serves as the main freshwater resources of the Netherlands. Considering the future water shortage and sea level rise, the Delta Committee suggested increasing the lake level by maximally 1.5 meter until 2050 in order to facilitate the gravity flow and create the largest possible fresh water reservoir. This action will enable IJsselmeer with multiple functions of water management, but it also brings the threat of flooding on the surrounding areas, especially considering its direct link to North Holland.

4.1.2 The cities near IJsselmeer

Hoorn is the major city within the area near IJsselmeer, with 68,170 inhabitants and the highest population density (3355/km²). Hoorn is the hub of West Frisian business, with around 3,000 businesses and 30,000 employees. Hoorn is also the transportation
hinge within this area, because of its excellent location on the highway A7 and good rail connections to and from Amsterdam and Schiphol airport. Compared to the other cities, Hoorn has a much higher concentration of non-westerners (12%).

Wieringermeer, on the contrary, has the most sparsely distributed population (65/km²), with only four small towns located inside. Reclaimed by 1930, 60% of the total land use in Wieringermeer is agriculture and green natural area. The main crops are grains and sugar beets, but the main occupations are cattle rising and dairy farming (Wikipedia Wieringermeer, 2009).

The study area congregates the greenhouse business, among which, Heerhugowaard has the largest share. The railway transverses in the south of the area, covering Koggenland, Hoorn, Drechterland and Enkhuizen.

4.2 The data preparation

4.2.1 The land use data

The TOP10NL land use map of the Netherlands is used for this study. It incorporates specific land use information of the agriculture, transportation lines, green areas and elements within the urban area. Different land use types are extracted according to the land categories in HIS_SSM. Specifically, the whole road network is classified into four types: the railway, the highway, the regional and the local roads; the agriculture is classified into common crops and greenhouse; the urban area is specified into the residential area and the commercial area. The vulnerable buildings (hospitals, nursing home, and rest home) are extracted from the building map. In addition, the holding capacities of public buildings are identified from the Riskokaart to select the suitable shelter location.

4.2.2 The socio-economic data

The ‘Wijk- en-buurt kaart 2007’ from Statistics Netherlands (CBS) are used as the main source of socioeconomic data. It is the smallest census unit that is published by CBS, with the resolution at neighborhood scale. The index system derived in section 2.2.3 is modified by the actual data that is available in CBS. The results are shown in Table 4.1
The active people\textsuperscript{7} receiving governmental subsidies are used to capture the financial deprived group, since in the Netherlands, financial subsidies are allocated to those people below national poverty line, like the unemployed, households on a minimum income, and homeless people (SZW). The minority group is captured by the foreigners, for their culture and language barriers (HWWI 2008). Although flood insurance is regarded as a crucial factor in flood mitigation, it is not included in this study case. The reasons are the flood insurance is regarded to be uninsurable in the Netherlands since the catastrophic flood in 1953. From 1998 onwards, the Dutch government passed Calamities and Compensation Act (WTS) which provides the compensation for flood damage. But the flood induced by storm surge is excluded in this compensation scheme, considering its considerable economic loss (Botzen and Van de Bergh, 2008).

The numbers of employees are distributed from the municipality scale by the proportion of company numbers at each neighborhood, as the employee numbers are not available at the neighborhood unit. In consistent with the CBS data, the business is classified into three sections: the production, commercial and non-commercial sections\textsuperscript{8}. Accordingly the replacement value of these three economic sections is averaged among their sub-sections listed in HIS-SSM.

### 4.2.3 Normalization of the index

As the indicators obtained from CBS have different units, it is difficult to make composite index from them. For this reason, the original values are standardized to a

\textsuperscript{7} The active person means those people between the age of 15 and 64, who are supposed to have capability to work.

\textsuperscript{8} Specifically, the industry incorporates the construction, the mineral and the industry; the commercial incorporates the trade and hotel, the communication and transportation, the bank and insurance, and the utility companies; the non-commercial section includes the government and health-care.
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ratio between 0 and 1, using the Averaging of normalized observations (Briguglio 2003)

\[ R_{ij} = \frac{X_{ij} - \text{Min}X_j}{\text{Max}X_i - \text{Min}X_i} \]  
Eq. 4-1

Where:
- \( R_{ij} \) stands for the standardized index to be computed, with regard to component i, for location j;
- \( X_{ij} \) stands for the observed value of the same component for the same location;
- \( \text{Max}X_i \) and \( \text{Min}X_i \) stand for the maximum and minimum value of the observed range of values of the same component.

For those components which are vulnerable in the negative direction, the function is modified as follows to insure that positive loadings were associated with increasing vulnerability.

\[ R_{ij} = \frac{\text{Max}X_{ij} - X_{ij}}{\text{Max}X_i - \text{Min}X_i} \]  
Eq. 4-2

4.3 Flood scenarios and simulation

4.3.1 Flood scenarios

The Netherlands is a low-lying country, with about 27% of its area and 60% of its population located below sea level (Rosenberg, Matt, 2008). Although it has the highest standard of flood defense system all over the world, it does not mean the chance of flooding is zero. The hurricane Katrina gave the wake-up warning to Dutch government that the extreme flood event can be fateful. The government has installed for two years a Cabinets Taskforce Management Flooding to prepare safety regions, government, citizen and businesses for the worst credible flood scenario. Relevant evacuation and capacity strategies are under developed to increase the national safety and security. Correspondent to this, the study case here aims to identify the weak elements of the social system that should be enhanced to maximally protect the society against the extreme events.

The safety standards of flood defenses are indicated in Fig. 4.2, where the inferior dike is colored by blue and the dike with good condition is colored by green. It can be seen that the dike around Wieringermeer is not well-maintained compared to other dike segments of the area. In order to make an extreme scenario, three breaches are selected at different dike segments (Wieringermeer, Onderdijk and kerkbuurt) with different safety standards.
Fig. 4.2  Dike conditions of North-Holland, source: Delta committee report (2008)

As there is no real-time record of the storm surge level in IJsselmeer, the estimation is made based on the empirical formula of wind set-up in a closed basin (Angremond and Van de Velden, 2001). Based on the maximum hourly wind speed found near IJsselmeer (25.4m/s), an extreme scenario (SN_{+1.5}) is made as follows\(^9\): the lake level is set to be 6.5 m (including the increase of 1.5m); the storm surge is set to be 1.4m lasting 24h; the three breaches are set to be 3days, assuming that after 3 days the breach would be closed. To allow comparison, the same storm surge condition with the current lake level (with water depth of 5m) is used as the reference scenario (SN_{ref}).

\(^9\) The detail calculation of storm surge is presented in Appendix C.
4.3.2 Hydraulic simulations

Hydraulic simulations of the floods are carried out with the 2D Sobek_rural model. In the Sobek model, the two-dimensional data terrain height and roughness of the terrain (2D) are coupled with the water system (1D) to simulate the dynamic flow process. The Verheij-vdknaap function is used to simulate the flood due to dike breach. In the end, the output of maximum flood depth, maximum flood velocity, time of flood occurrence, and the rising speed of water level are generated (see Fig.4.3).
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Fig. 4.3 The simulation result of SN+1.5 (Left) and SN_ref (Right)

From the SN+1.5, it can be seen that the most seriously flooded area is Wieringermeer (the main city within Dike ring 12) because of its low elevation (between -3m to -0.25m NAP). The secondary dike that separates the Dike ring 12 and 13 has a high protection to the further inland, as it holds most of the flooded water within the Wieringermeer. On the other hand, it also means that if some breaches happen on the secondary dike, more inland cities will be flooded.

Compared with SN+1.5, the affected area of the reference is mainly restricted within the city where breach occurs and the flood progresses much slower.
Chapter 5

Results and analysis

5.1 Results of the flood impact

5.1.1 Results of the flood damage

The total damage of $\text{SN}_{+1.5}$ is 7 billion euro (2% of GDP, 2005), the largest fraction of which (52%) is from the residential damage, followed by the business (24%), transportation (13%) and agriculture (11%).

For $\text{SN}_{\text{ref}}$, the total damage is 7 times less. Dramatic changes are found in the residential damage and the agriculture damage: instead of being the first, the residential damage reduces sharply to a share of 16%; the agriculture damage, instead, takes up almost half of the total damage (42%). The businesses and transport shares almost the same quotient in both scenarios. The specific damage results are presented in Appendix F.

![Graph showing damage of two flood scenarios](image_url)

**Table 5.1** The damage of the two flood scenarios: the red line represents $\text{SN}_{\text{ref}}$, the blue
The distributive damage maps among affected municipalities are given in appendix F. It shows that in SN_{ref}, the damage is mainly restricted within the city where breach happens. Among them, Wieringermeer takes up almost 75% of the total damage, followed by Wervershoof, Andijk and Medemblik which together account for 21%. By increasing the lake level, the flooding progresses further inland, making the damage more spread out. Wieringermeer is still the most damaged city (38% of the total), followed by Hoorn, Medemblik, Drechterland and Stede Broec.

5.1.2 Results of the social impact
Compared with the economic damage, the social impact is more severe for the SN_{+1.5}(see Appendix F). The increase of total affected people is comparable with the total flood damage (increased by 7 times), but the severely affected people are 10 times higher. Moreover, the result from the loss of life model shows that the fatality of SN_{+1.5} can be even 30 times higher.

5.2 The results of the response module
5.2.1 Ex-ante prediction

Fig. 5.1 Areas of physically vulnerable people: red spots (vulnerable facilities): a) the normalized index of inundation area; b) the percentage of physically vulnerable people in the city Hoorn (%)

Fig. 5.1 gives the distribution of physically vulnerable people. It shows that the most vulnerable city is Hoorn, where the percentage in some neighborhoods can be as high as 48%, and many vulnerable facilities are concentrated there. When zooming into each municipality, the vulnerable area is more identifiable for assistance planning at each neighborhood.

In the same way, the vulnerable areas with insufficient vehicles and traffic difficulty are depicted in Fig 5.2 and Fig 5.3 respectively. It is found that the main city with
insufficient vehicles are Hoorn, Stede Broec, and part of Medemblik that near the IJsselmeer. Coincidently, the traffic difficulty also shows to be a big problem in the city of Hoorn and Stede Broec but more spread around the eastern part. However, it has to be noted that if Markerwaarddijk, the dike links the eastern part of the study area to the western part of the lake, can still function during the storm, the emergency of these areas can be much reduced.

Fig. 5.2 The number of cars per household: Left: the whole inundation area; Right: Stede Broec (up) and Hoorn (down)

Fig. 5.3 The normalized index of areas with traffic difficulty: Left: the whole inundation area; Right: cities on the eastern part of the area (up) and Hoorn (down)
Chapter 5. Results and analysis

Among the three breach locations, the one near Andijk has more difficulty of evacuation, as the area around it has large amount of people but few traffic lines to cope with it. Although Hoorn locates relatively far from the hazard, one neighborhood (Buurt_33_06) is unexpectedly high for its limited traffic capacity.

The General G method is applied at both the municipality scale and the whole North-Holland for the three indices. The results exhibit that the physically vulnerable people and the households with insufficient vehicles are highly clustered at 0.01 confidence level, with z-score at 3.84 and -6.12 respectively.

5.2.2 Risk zoning of inundation area

Fig. 5.4 shows four hazard zones: the building endangered, the non-evacuation zone, and the evacuation zones (constituted by the severe zone and the less severe zone). In SN\(\_1.5\), most of the areas are severely flooded. As the flood progresses extremely fast within the first 5 hours, the non-evacuation zone covers almost the whole city where breach occurs. The high flow speed occurs around the breach location which generates a big threat to the buildings around. Because of the low elevation, the water rising speed is significantly high within Wieringermeer, which makes evacuation an even tougher task to undertake.

Considering the large non-evacuation zone, especially the area with large amount of residents, it may be best to raise awareness of high-rise buildings that are suitable to function as in situ shelters; for the roads that are more easily to be flooded, it is important for traffic managers to give signs that they are not safe routes to take during
flooding.

Risk zoning is a very context-specific method of identifying those at-risk. Even though they can be employed immediately to identify vulnerable people, the extent of these zones depends on the nature of the disaster and the breach locations. It is necessary for the emergency managers to run several flood scenarios with different flood magnitude to better categorize the study area. As this case study is to exemplify the function of the FVA model, only one extreme flood scenario is used.

5.2.3 Results of the vulnerable hotspots at response phase

Vulnerable hotspots of rescue and evacuation

For the extreme flood scenarios, the emergency actions have to consider their efficiency and feasibility and the resources have to be allocated to the right place and the right person. The rescue actions should give more attention to people who cannot help themselves (physically vulnerable people and facilities), while the evacuation management has to focus on those areas with transport difficulties (lack of vehicles and insufficient traffic capacity). The in situ shelter is considered to be the main resource for those areas where neither rescue nor evacuation is possible during the initiation time.

In Fig 5.5, the predefined vulnerable indicators are coupled with different flood zones to indicate the demand of rescue and evacuation. In the map of rescue, the physically vulnerable group is mainly coupled with the seriously affected area, as the flood hazard probably will not directly endanger people's life in the less-severe zone. Apart from the most dangerous non-evacuation zone (depicted by the red color), the physically vulnerable people and facilities are mainly located in Enkhuizen and Medemblik where rescue assistance is highly demanded. In the map of evacuation,
Chapter 5. Results and analysis

the eastern area around Stede Broec and Enkhuizen are highlighted for their insufficient traffic capacity. The emergency extent of Hoorn is reduced by its low exposure to the hazard. If traffic can be managed well in advance, evacuation would not be a problem for this area.

**The suitable shelters**

![Diagram](a) the suitable public buildings that can serve as shelter; b) the suitable shelter in the inundation zone (SN+1.5)

As no pre-designated shelters exist in the study area, the public buildings with holding capacity larger than 500 persons are first selected to be the potential shelter. In the whole North-Holland, 326 buildings meet this criteria (Fig 5.6 a), but most of them are located further inland, especially near Amsterdam. In the area around IJsselmeer, only one shelter is available for each city, except for Hoorn.

In order to identify the suitable in situ shelter, these shelters are further examined by their elevation. The result shows that only 17 pre-selected shelters are located on the highland within the inundation area (of SN+1.5), and even so, most of them are within the less-severe zone. For the most demanding area--non-evacuation zone, only two are available. It means that under extreme situation, their capacity can hardly meet the potential demand.

The high-rise building is usually regarded as the safe haven for those areas where rescue assistance can not arrive at the first time, but this is not the case for the study area. In the inundation zone, almost no high-rise building exists. By extracting the building height from the elevation map, the buildings with elevation above 0m are identified in the Fig. 5.6 b with purple color. Again, most of them are located in the less-severe zone. Although some can be found within the non-evacuation zone, their location is just behind the dike, with a high exposure to the hazard.

Moreover, special attention needs to be given to Wieringermeer. Despite of its expansive area, only one shelter is available there. Due to its low elevation, the high
5.2.4 Concluding remarks

1. The ex-ante prediction uses the social vulnerable index to identify the potential vulnerable area during response phase. It is found that the physically vulnerable people and households with no vehicles are spatially clustered. The neighborhood scale used in this study provides a high resolution for emergency managers and local community to locate these vulnerable areas and derive relevant response planning. Combined with the risk zoning map, the hotspots with different assistance demands can be visualized from the map.

2. The breach location can make huge differences on the overall flood impact. It is found that the breach near Andijk would be several times more serious than the breach near the less populated Wieringermeer. On the other hand, although Wieringermeer can maximally store water and impede further encroach of flood, the three villages within Wieringermeer are very vulnerable for their high exposure and isolation.

3. The increase of the lake level can make the surrounding area more vulnerable during the first response phase. There are no high buildings within the cities near IJsselmeer, and the shelter capacities are found far less capable to deal with the extreme event. If the lake level is increased by 1.5m, neither evacuation nor in-situ sheltering can be relied on for those areas near the breach location. Moreover, if the socio-economic scenario in 2050 is also considered, the flood impact might be more severe, since more residents and economic values will be added. It further indicates that the lake level cannot be just simply increased without in phase development of the surrounding region. For example, the building regulations and relevant shelters have to be strengthened and established for those areas near the dike, extra pumping stations should be built up for fast draining, and the human settlement near the dike have to be strictly regulated.

5.3 The Results of the social vulnerability module

5.3.1 The identification of vulnerable hotspots
Chapter 5. Results and analysis

The financially vulnerable group is scarcely distributed among the inundation area, but more concentrated in Hoorn, wervershoof, and Enkhuizen; the minority group is centered in Hoorn, with high spatial cluster (z-score of 9.33) at the 0.01 significance level. Thus, flood information and post-flood subsidies should be tailored for these areas.

5.3.2 The interplay of damage and financial resource

The flood damage calculated before only represents the economic loss of flooding, but it cannot reflect to what extent the damage affects the local economy. In order to examine the damage extent among different neighborhoods, the local economic condition should be taken into account. This is the same for the residential damage. The financial resources are the main stimulator for the post-flood recovery, and the interplay between household damage and their financial condition determines their damage extent. In this study, the damage extent is expressed by dividing the total household damage with the total household income. The results are shown in Fig. 5.8.
Chapter 5. Results and analysis

The two graphs reflect two different damage patterns. It can be seen that by integrating the financial factors, the damage pattern becomes much clearer among the affected areas. In the SN$_{+1.5}$, the cities where breach occurs (Wieringermeer, Memdemblik, and Andijk) are highlighted as the most damaged cities.

5.4 The comparison with the composite index system

In order to compare the results of this study with the other composite index systems, all the indicators are combined together to represent their composite feature. The final map is represented in Fig. 5.9.

![Fig. 5.9 The map of composite vulnerable index: a) the whole inundation area; b) Hoorn](image)

It is found that the hotspots highlighted in the map incorporate different dimensions. Take Hoorn as an example (see Fig. 5.9b), all three hotspots have different vulnerable dimension. Location 1 is concentrated by the physically vulnerable people (R=0.98); location 2 is highlighted by both physically vulnerable group (R=1) and financially vulnerable group (R=0.95), while the location 3 is the combination of large minority group (R=1) and people with financial problems (R=1). Therefore, although hotspots can be depicted from the composite map, the single map cannot transmit direct information to the end users. It can be expected that if more irrelevant indicators are incorporated in the system, the final result would be more inaccurate. Compared to this, the function-based vulnerable index system is more robust and practical to indicate the mitigation agencies.
Chapter 6

Conclusions and suggestions

6.1 The conclusion

In this study, a practical FVA model is developed to link the services of flood mitigation actions directly to the demand of different vulnerable people. Imbedded in the GIS environment, this model can identify with precision the spatial distribution of vulnerable people at different phases of the flooding.

The three modules of the FVA model are developed along with the four phases of the flood mitigation activities. The response module is employed to indicate the three actions during the response phase: evacuation, rescue and shelter; the social vulnerability module focuses on indicating the other vulnerable groups that related to the post-flood subsidies and information transmission; while the flood impact module can indicate the post-flood recovery and reconstruction by analyzing the damage extent of the area.

Compared with the flood risk assessment, the FVA model focuses on increasing the inherent resilience of the social system through identifying and modernizing those vulnerable elements. Thus, it can better protect society against those extreme flood events. The FVA model also takes special care of the socioeconomic factors, in the aspect of overall social impact and spatial distribution of those vulnerable areas.

Compared with the other vulnerability index systems, this study stays at the neighborhood scale which provides a high resolution for the local mitigation actions. Moreover, instead of trying to combine different vulnerable components together, this study distinguishes the vulnerable groups according to their vulnerable features at different phases of the flooding. In this way, the mitigation programs can be precisely tailored to the demand of each vulnerable group.

The case study of IJsselmeer shows that spatial distribution pattern varies among different vulnerable groups, and the vulnerable hotspots are different for different mitigation actions. Since most of the social vulnerability factors are spatially clustered, their locations can be more precisely identified beyond the barriers of administrative segmentations. The increase of lake level makes the flooding progress much faster and farther inland. This hazard extent is far beyond the current capacity of social
systems: the non-evacuation zone is so large that hardly any in situ shelters could be found inside, and the available time is so limited that huge tension would be exerted on the transport lines. Moreover, the increase of lake level induces a much sharper increase of the social impact than the economic damage. Although social information used in this study is restricted at a coarse scale, it is undoubtedly appropriate for identifying areas requiring pre-flood planning and post-flood remedial work.

6.2 Suggestions

6.2.1 The study of vulnerability index

The previous flood vulnerability studies referenced in this report, alongside many other studies of vulnerability to natural hazards, continuously highlight the complex issues of vulnerability. This study acknowledges these concerns, and also makes the following three suggestions on this study:

Firstly, the deep meaning of vulnerable indicators is the foundation of any vulnerability index study. It not only ensures the index system is developed on a meaningful foundation, but also helps avoid some unnecessary work that leads to the wrong direction. For example, Brooks and Kelly (2005) used the mortality data as the impact factor to select vulnerable indicators. From the result, he found that the GDP is unexpectedly out of the list, and Bangladesh has even a low composite vulnerability score. It is argued that this correlation-based selection can be erroneous in this case as the flood mortality is inappropriate to be linked with the economic-related vulnerable index, like GDP. For the same reason, it would not be surprised to find that there was no correlation between the frequencies of presidential disasters and the SoVI index scores of the study in Cutter.S (2003). Compared to the other FVI model, this study only uses the indicators that have been proved and verified by the previous large-scale field surveys. With a lack of the full recognition of flood impact, the field survey result is probably the most reliant data source in this aspect. Moreover, one has to be aware that the vulnerable group features are not always visible enough to be identified from previous flood events. The recovery information is more difficult than assessing the flood damage, as it not only relates to the financial states of the household but also to the local economic structures and coping strategies.

Secondly, it is suggested to derive an index system that tailor made for explicit needs of the end user than one which is almighty for all. It is inappropriate to combine all the indicators together and take it for granted that it can identify hotspots for all the end users, as different social factors come into play in different phases of a flood event.

Thirdly, an integrated system is required to incorporate different stakeholders working together. Social vulnerability, deeply rooted in the complicated socio-economic contexts, is not restricted within the field of social science or water management, but more imbedded in a broad social network, which needs the contribution of various
Chapter 6. Conclusions and suggestions

stakeholders.

6.2.2 The modernization of the model

The scenario-based planning is considered to be a flexible strategic planning mode for an uncertain future. It is suggested to run several flood scenarios with different boundary conditions to identify those vulnerable hotspots and test if the current capacities can meet the requirement of potential flood. The development of Dynamic Decision Support (DDS) system would be necessary to consider these various flooding circumstances into account, and ensure a fast and more robust result.

6.2.3 Coping strategies for the flood mitigation

Considering the future challenge of flood hazard, it is advised to have a systematic flood mitigation planning, taking into account the full needs of residents before, during and after the flooding event and provide follow-up services during the long-term recovery periods. It is believed that the hazard cannot be controlled by human being, but the vulnerability can be relieved and managed by human society. A potential storm might not be controlled but by various flood mitigations the social system can be better able to cope with and reduce the potential risk. Specifically, the following issues can be done during each mitigation phase:

Response phase

It is necessary to have a real-time risk zoning map to indicate the emergency response. For the non-evacuation zone, sufficient warning and evacuee information should be provided for the local residents, while at the same time, the rescue and in situ shelter should be timely initiated.

Recover and reconstruction phase

During this phase, it is important for the local government to differentiate and prioritize the demand of the flood victims, especially the financially vulnerable group, in order to derive a socially just recovery and reconstruction planning.

Ex-ante phase

The ex-ante phase probably is the most important phase that needs to be stressed in flood mitigation, as preventative action is always more acceptable and supported by the society. It is within this phase that the flood mitigation strategies have to be planned to cope with the potential flooding event. Three main challenges are pointed out as follows:

a. The channels of flood risk educations should be improved: firstly public campiness and excises should be initiated to improve people’s flood awareness and teach people how to protect themselves during flood events. This has already been done in some countries like UK and USA. In the Netherlands, large-scale campaigns have been also under plan in the national security programme (BZK a). Secondly, the minority
groups, like tourists and foreigners should not be overlooked in this aspect. Instead, flood warnings and information should be targeted for these minorities, considering that most of them have language barriers to access the information provided by the government. Thirdly, different social communities, especially those identified social vulnerable group, should be involved in the planning process to allow communication between different stakeholders.

b. The need for robust communication system linking all regional and national crisis centers is strongly addressed in the Netherlands, in order to achieve ‘greater uniformity in the management and provision of information’ (BZK b). To ensure the services to be delivered efficiently and timely through the system, the local council should identify and register the vulnerable group and housing in order to deliver relevant services as precisely as possible (A list of people with specific needs are listed in Appendix G, correspondent with relevant organizations and agencies). The self-help and neighborhood help should also be advocated among local communities, considering that the emergency actions cannot cover all the affected area during large-scale flooding.

c. The flood risk assessment should take the social dimension and vulnerability concept into account, to gain a better insight for the potential flood impact.
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(UNU-EHS) United Nations University, Institute for Environment and Human
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Appendix

Appendix A  Fact sheet

“Of the four deaths attributed to the storms in northern England in January 2005, two were elderly women who died in flooded properties in Carlisle and another was a 63-year-old man crushed after a barn collapsed on his caravan in Cumbria”.

------- Tapsell et al (1999)

During the 1953 flood, the fatality rate in the Netherlands (Jonkman 99, 1997) and UK (Pollard, 1978) increase sharply over the age of 60. In catastrophic hurricane Katrina, 70% fatalities are over the age of 60 while 85% are over 50, and a high mortality occurred in the nursing home in the South East of the St. Bernard. At Canvey Island, 42 out of 58 fatalities were aged over 60. At Jaywick, 28 of the reported 34 fatalities were over 60, and in south Lynnm all 14 fatalities were over 60.

------- Jonkman (2007)

The single parent families with only underage children¹, the low occupation and people dependent on governmental assistance are more financially vulnerable.


Table A-1 Fact sheet on the social vulnerability

¹ Underage children are defined as children under the age of 18. 
Fig. A-1 Comparison of distribution over the age categories for fatalities of the 1953 flood disaster and the 1953 population; Source: Jonkman (2007)

Fig. A-2 Age distribution among the fatalities in Katrina; Source: Jonkman, (2007)

Fig. A-1 shows that the fatality becomes prominent after the age of 50 and increases sharply after age 60 in the 1953 flood in the Netherlands. The same pattern also is shown in Fig A-2 in the Hurricane Katrina in the USA.
## Appendix B  The reasoning of the social vulnerability index

<table>
<thead>
<tr>
<th>Category</th>
<th>Indicators</th>
<th>Literature source</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physically vulnerable people</td>
<td>The elderly</td>
<td>Tapoel et al. 2002</td>
<td>A sharp increase in the incidence and severity of illness that is sensitive to the damp, cold and environmental conditions that would follow a flood event.</td>
</tr>
<tr>
<td></td>
<td>The disabled</td>
<td>Dosa et al., 2007</td>
<td>Most of them are dependent on others for daily care.</td>
</tr>
<tr>
<td></td>
<td>Pre-existing health</td>
<td>Tapoel et al. 2004; Tapoel et al. 2002</td>
<td>High morbidity and mortality during and post flood because of limited mobility and reduced hearing and visual capacities.</td>
</tr>
<tr>
<td></td>
<td>problems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Financial deprivation</td>
<td>Unemployment</td>
<td>Townsend et al. 1999</td>
<td>The outcome of lack of financial resources.</td>
</tr>
<tr>
<td></td>
<td>Overcrowding</td>
<td>Townsend et al. 1999</td>
<td>The outcome of lack of financial resources.</td>
</tr>
<tr>
<td></td>
<td>Non-car ownership</td>
<td>Townsend et al. 1999</td>
<td>Townsend index / People that rent are either transient or do not have the financial resources for home ownership. They often lack access to information about financial aid postflood and do not have insurance on their property.</td>
</tr>
<tr>
<td></td>
<td>Non-home ownership</td>
<td>Townsend et al. 1998; Heinz Center for Science, Economics, and the Environment 2000</td>
<td>Wealth enables individuals to absorb and recover from losses more quickly using insurance, social safety nets, and entitlement programs.</td>
</tr>
<tr>
<td></td>
<td>social dependence</td>
<td>Morrow (1999) and Tobin and Ollnerburger (1993)</td>
<td>People who are totally dependent on social services for survival are already economically and socially marginalized and require additional support in the post-disaster period.</td>
</tr>
<tr>
<td></td>
<td>Occupation</td>
<td>Heinz Center for Science, Economics, and the Environment (2000), Hewitt (1997), and Puerto (1999)</td>
<td>Some occupations, especially those involving resource extraction, may be severely impacted by a hazard event. Self-employed fishermen suffer when their means of production is lost and may not have the requisite capital to resume work in a timely fashion.</td>
</tr>
<tr>
<td></td>
<td>Lone parents</td>
<td>Tapoel et al. 2003</td>
<td>This group tends to suffer more stress and trauma as they tend to have less income and must cope single-handedly with both children and the flood impacts.</td>
</tr>
<tr>
<td>People with communication problem</td>
<td>Education level</td>
<td>Heinz Center for Science, Economics, and the Environment (2000).</td>
<td>Higher educational attainment affects lifetime earnings, and limited education constrains the ability to understand warning information and access recovery.</td>
</tr>
<tr>
<td></td>
<td>Race and ethnicity</td>
<td>Bolin 1996 and Cutter 1995</td>
<td>Language and cultural barriers that affect access to post-disaster funding and residential locations in high hazard areas.</td>
</tr>
</tbody>
</table>
Appendix C  The calculation of storm surge

As there is no real-time record of the storm surge level in IJsselmeer, the empirical formula of wind set-up in a closed basin is used for estimation:

\[ i = c \frac{U^2}{gh} \]  
Eq. C-1

In which, 
- \( i \) = gradient of the water surface,
- \( U \) = wind speed in m/s,
- \( g \) = acceleration of gravity in m/s\(^2\),
- \( h \) = water depth in m,
- \( c \) = empirical coefficient (3.5 to 4*10\(^{-6}\))

The water depth in IJsselmeer is around 5m. Depends on the wind direction, the fetch length of the lake varies from 30km (30°) to 35km (60°). The first weather stations around IJsselmeer have the wind speed records only since 1960 (Leeuwarden), while the rest were built after 1970s (De Kooy, Stavoren and Wijdenes).

During these four decades, it was found that most of the extreme wind events were from the South-west, while only one was recorded from the North East on February 14 of 1979. During this event, the hourly averaged wind speed that above 19.1m/s has lasted for 7 hours and the maximum wind speed arrive at 25.4 m/s.
Appendix

Based on this event, an extreme storm surge scenario is assumed as follows:

- The wind direction: 60 degree (with the length of 35km);
- The wind speed: 25.4m/s (the extreme event)
- The lake depth: 6.5m (considering the increase of 1.5m)
- The storm surge period: 24h

The scenario is an extreme case in three aspects: firstly the maximum hourly wind speed is used for the whole storm events; secondly instead of 7 hours in the previous event, the storm surge is assumed to last for 24 hours; thirdly the wind direction from the North West itself is already an extreme case, as among 40years records, only one such case has been found around IJsselmeer.

With the Eq. C-1, the resultant storm surge from this scenario is 1.41m.
Due to the data limitation, no probability value is specifically given for the boundary conditions mentioned above. Considering that this scenario is mainly used as the input to depict the extreme flood condition, its uncertainty will not distort the main objective and results of this study. For a decent drawing of flood scenario, three aspects of hydraulic boundary conditions should be given more attention: the extreme storm surge data series, the failure mechanisms of the dike, and the weak spots (the breach location) along the dike.
Appendix D  Socio-economic condition of the study area
Fig. D-1  The socioeconomic conditions of the North-Holland: a) the population density; b) the total population numbers; c) the component of companies: blue: industry, green: non-commercial, yellow: commercial; d) the total company numbers; e) the area of common crops; f) the green house area

Source: based on the wijk-en-buurt 2007, CBS
Appendix E  Facts of evacuation

In the Netherlands, not many previous data is available for the evacuation. Slager (1992) reports that for the 1953 flood in the Netherlands most people were rescued within the first 48 hours. In 1995, 250,000 people in the Netherlands were evacuated from the Limburg region, south of Nijmegen and from Zeeland, around Rotterdam (The Rhine Floods, 2009), and some detailed information is listed in Table E-1.

<table>
<thead>
<tr>
<th>Region</th>
<th>Number of people</th>
<th>Evacuation time</th>
<th>Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Province of Gelderland</td>
<td>240,000</td>
<td>+/-36h</td>
<td>C.O.T. (1995)</td>
</tr>
<tr>
<td>Ooijpolder, Land van Maas en Waal, Bommelerwaard</td>
<td>95,000</td>
<td>80% (76,000): 20h; 100% (95,000): n/a</td>
<td>NRC Handelsblad (1995a)</td>
</tr>
<tr>
<td>Tielerwaard, Culemborgerwaard</td>
<td>100,000</td>
<td>95% (95,000): 17 h; 100% (100,000): n/a</td>
<td>NRC Handelsblad (1995b)</td>
</tr>
</tbody>
</table>

Table E-1 The evacuation time during the 1995 floods in the Netherlands. Source: Frieser, B. (2004)

Barendregt et.al in 2005 used the expert judgment to estimate the time required and available during evacuation process. It concludes that the prediction time in IJsselmeer can vary between 7 to 45 hours (depends on the failure mechanism), while the time required for evacuation initiations is 6 hours (decision making: 2 hours; warning of population: 2 hours; response of population: 2 hours). However, this judgment is based on the preventive evacuation. For the forced evacuation where prediction time is extremely limited, the decision making time and the response time will be reduced coordinately. Therefore, in this case study, the time required is set to be 5 hours that derived from previous observations of unexpected flooding events.

<table>
<thead>
<tr>
<th>Water System</th>
<th>Time required to initiate evacuation [hours]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rivers</td>
</tr>
<tr>
<td>Evacuation Process</td>
<td></td>
</tr>
<tr>
<td>Decision Making</td>
<td>4</td>
</tr>
<tr>
<td>Warning Population</td>
<td>3</td>
</tr>
<tr>
<td>Response Population</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
</tr>
</tbody>
</table>

Table E-2 Estimates of time required to initiate evacuation  (Source: Barendregt et.al, 2005)
Appendix F  The results of the flood impact

<table>
<thead>
<tr>
<th>Economic impact</th>
<th>SN_{+1.5}</th>
<th>SN_{ref}</th>
<th>SN_{+1.5}/SN_0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total damage (€)</td>
<td>7.04E+09</td>
<td>9.57E+08</td>
<td>7</td>
</tr>
<tr>
<td>Dwelling</td>
<td>3.71E+09</td>
<td>1.50E+08</td>
<td>25</td>
</tr>
<tr>
<td>Business</td>
<td>1.66E+09</td>
<td>2.50E+08</td>
<td>7</td>
</tr>
<tr>
<td>Industry</td>
<td>1.19E+09</td>
<td>1.79E+08</td>
<td>7</td>
</tr>
<tr>
<td>Commercial</td>
<td>3.57E+08</td>
<td>5.64E+07</td>
<td>6</td>
</tr>
<tr>
<td>non-commercial</td>
<td>1.11E+08</td>
<td>1.51E+07</td>
<td>7</td>
</tr>
<tr>
<td>Transport</td>
<td>8.80E+08</td>
<td>1.50E+08</td>
<td>6</td>
</tr>
<tr>
<td>Railway</td>
<td>1.90E+08</td>
<td>0.00E+00</td>
<td>Na</td>
</tr>
<tr>
<td>Highway</td>
<td>9.15E+07</td>
<td>2.97E+07</td>
<td>3</td>
</tr>
<tr>
<td>National and local roads</td>
<td>4.95E+08</td>
<td>9.14E+07</td>
<td>5</td>
</tr>
<tr>
<td>Other roads</td>
<td>1.04E+08</td>
<td>2.84E+07</td>
<td>4</td>
</tr>
<tr>
<td>Agriculture</td>
<td>7.88E+08</td>
<td>4.08E+08</td>
<td>2</td>
</tr>
<tr>
<td>crops</td>
<td>7.02E+08</td>
<td>3.91E+08</td>
<td>2</td>
</tr>
<tr>
<td>greenhouses</td>
<td>8.60E+07</td>
<td>1.63E+07</td>
<td>5</td>
</tr>
<tr>
<td>Social impact</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total people directly affected</td>
<td>197657</td>
<td>30157</td>
<td>7</td>
</tr>
<tr>
<td>People seriously affected</td>
<td>99811</td>
<td>11000</td>
<td>9</td>
</tr>
<tr>
<td>Number of buildings collapsed</td>
<td>178</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>Life-endangered people</td>
<td>22343</td>
<td>2246</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Potential Fatality</th>
<th>SN_{+1.5}</th>
<th>SN_{ref}</th>
<th>SN_{+1.5}/SN_0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total fatality</td>
<td>5816</td>
<td>197</td>
<td>30</td>
</tr>
<tr>
<td>Fatality in the breach zone</td>
<td>165</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Fatality in the severe zone</td>
<td>5210</td>
<td>115</td>
<td>45</td>
</tr>
<tr>
<td>Fatality in the remaining zone</td>
<td>441</td>
<td>68</td>
<td>6</td>
</tr>
</tbody>
</table>

Table F-1  The overview of the flood impact
Fig. F-1  The damage component of the flood scenario: a) the SN_{1.5}; b) the SN_{ref}
Appendix

Fig. F-2   The municipality damage of SN+1.5
Appendix

Fig. F-3    The municipality damage of SNref
Appendix

Appendix G  Organizations which can help identify those with specific needs

<table>
<thead>
<tr>
<th>People with specific needs</th>
<th>Organisations and Agencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pupils with special educational needs/disabilities or medical needs</td>
<td>LEA schools through local authorities, and non-LEA schools through their governing body or proprietor.</td>
</tr>
<tr>
<td>Those dependent on medical support within hospital</td>
<td>Hospitals (public, private or charitable) will have lists of their own patients who should be subject to the hospital's own evacuation plan.</td>
</tr>
<tr>
<td>Those dependent on medical support (but not within hospital) (Potentially a large group encompassing not only those that need regular medical attention (eg dialysis, oxygen or a continuous supply of drugs) but those with chronic illnesses that may be exacerbated or destabilised either as a result of the evacuation or because prescription drugs were left behind.</td>
<td>Local health authorities, including district nurses and GPs should have visibility of this group. (GPs in particular may be able to assist with those dependant on medical support at home).</td>
</tr>
<tr>
<td>Those that are dependent on carers or other forms of social care</td>
<td>Care and nursing homes offering non-residential 'home-visit' care should be able to assist.</td>
</tr>
<tr>
<td>This encompasses those who need assistance with basic activities such as dressing and washing.</td>
<td>Social services in combination with local health authorities (mental health trusts, community psychiatric nurses) and voluntary sector and community groups (for example mental health charities) should have visibility of most of this group.</td>
</tr>
<tr>
<td>Those with a lack of understanding of what is taking place (some people with severe physical or mental disabilities, senility or mental illness)</td>
<td>Social services in combination with local health authorities, GPs, private and charitable hospitals and nursing homes and British Red Cross.</td>
</tr>
<tr>
<td>Those with mobility difficulties</td>
<td>Social services in combination with local health authorities, GPs, private and charitable hospitals and nursing homes and British Red Cross.</td>
</tr>
<tr>
<td>Those with sensory Impairment</td>
<td>Local health authorities, GPs, district nurses, voluntary sector and community groups.</td>
</tr>
<tr>
<td>The elderly and frail</td>
<td>Those who may be able to assist include: care and nursing homes, GPs and district nurses, health visitors, and voluntary organisations providing local support to the aged (eg Help the Aged, British Red Cross).</td>
</tr>
</tbody>
</table>
### Appendix

<table>
<thead>
<tr>
<th>People with specific needs</th>
<th>Organisations and Agencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destitute asylum seekers who are not in reception/detention centres</td>
<td>The Home Office’s Immigration and Nationality Directorate (IND) run the National Asylum Support Service (NASS) which provides accommodation and subsistence through local authorities and private landlords.</td>
</tr>
<tr>
<td>Visitors and refugees, and non-English speaking communities</td>
<td>Most major emergencies have an international dimension which can present particular challenges. Foreign embassies, community centres and the immigration service should be able to assist and the Red Cross’ International Messages and Tracing Service may be of help. (Clearly, it is unlikely to be either feasible or appropriate to maintain a standing list of this group.)</td>
</tr>
<tr>
<td>Those dependent on state benefits</td>
<td>The Department for Work and Pensions is developing guidance for local authorities on benefits and qualifying conditions which may be relevant post-emergencies. Job Centre Plus should hold information on those in the area that are receiving benefits – this may also be a useful source of information on other vulnerable groups (e.g., those receiving incapacity benefit or disability allowance).</td>
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