*GIS & RS in Hydrology, Water Resources and Environment, Volume 1, Chen et al. (eds)*

# Method for he Estimation of Loss of Life Caused by Floods in the Netherlands

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Abstract: Large parts of the Netherlands lie below sea-level, and the hazard of large scale floods leading to extensive damage and loss of life is always present. In this paper a framework for the estimation of loss of life caused by floods in the Netherlands is proposed. The method takes into account the effect of evacuation during the flood and various mechanisms which lead to fatalities during a flood. The method is based on data from the 1953 disaster, which flooded the South Western Part of the Netherlands, and caused 1835 fatalities. In a case study the method is applied to give a first estimate of the number fatalities caused by a dike breach near Rotterdam, leading to a flood of the Central Holland area.

Key words: flood disasters, flood damage, fatalities

## 1 INTRODUCTION

Every year floods cause enormous damage all over the world. In the last decade of the 20$^{th}$ century floods accounted for about 12% of all deaths from natural disasters, claiming about 93,000 fatalities[1]. Floods may also lead to other health effects, and can have various physical as well as psychological impacts (Hajat, 2003; Ohl, 2000; WHO, 2002). These health effects may also result in indirect delayed loss of life due to stress and illnesses. Increased levels of mortality in the year after a flood are for example reported by Bennet (1970). This study focuses on the direct loss of life associated with floods, since relatively little research has been carried out on estimation of loss of life caused by floods. This paper describes the advances in the research on this topic with a special focus on the situation in the Netherlands.

More than half of The Netherlands lies below sea level and would not be suitable for habitation without the protection of dikes, dunes and hydraulic structures. The current safety standards for flood protection (and the dike heights) are based on design water levels which occur with a frequency of once every 1250 to 10000 years, depending on the costs related to recovery of the economics in the affected area. Currently the possibility for a new safety approach is studied which is based on the concept of (flood) risk. In a risk based approach of flood protection probabilities and consequences are considered in coherence. As part of the development of the new approach special studies have been initiated to gain more insight in the various types of consequences of floods. This paper outlines the first findings for the most important damage category, loss of life.

[1] Derived from statistics from OFDA / CRED International Disaster Database, www.cred.be

The final aim of the research program is to develop a method to estimate the number of fatalities for floods in the Netherlands, taking into account the characteristics of the flood and the effect of an evacuation before or during the flood. The developed method can be used to determine the flood risks in the Netherlands and will be an important tool in assessing the safety benefits and the effectiveness of risk reducing measures. In a literature study an overview of existing models for loss of life estimation is given (Jonkman, 2002). However, since it has been concluded in that study that the existing models do not provide a reliable basis for loss of life estimation for floods in the Netherlands, a study is set up to develop a new method. The first results of the research work are summarized in this paper. A framework for loss of life estimation for floods is proposed in section 2. The two main elements of this framework are an evacuation model (section 3) and a method which relates flood mortality to local flood characteristics (section 4). The application of the suggested approach is shown in a case study in section 5 and is followed by concluding remarks in section 6.

## 2 FRAMEWORK FOR LOSS OF LIFE ESTIMATION

The number of fatalities caused by a flood is determined by a large number of characteristics, which can be divided in two groups. The first group of characteristics comprise those of the system or the affected area, i.e.:

- The configuration of the (physical) system: topography, land use, road capacities, etc.
- The human component: the population density, demography, experience with and knowledge of the flood, etc.
- The procedures and organisation to cope with potential floods in the system: warning systems, preparedness for evacuation, rescue facilities, etc.

The second of group of characteristics is concerned with the flood itself, such as breach location and width, that determine the discharge through the breach. Water depths, flow velocities and rate of rise may also be important characteristics in the inundated area.

During the propagation of the flood trough the area, people will start to evacuate and / or flee, either organised or by themselves. The efficiency and progress of the evacuation over time strongly depends on the three system components and the flooding characteristics. The outcome is a description of flee behaviour / evacuation over time under influence of system configuration, procedures and human response.

When the presence of the inhabitants over time and the flood characteristics are known, an estimation can be given of loss of life. This requires insight in the different mechanisms due to which people die during a flood. These causes can be direct drowning, but also indirect causes such as heart attacks or electrocution. For a better understanding of loss of life caused by floods more insight is required in the causes of death, and their statistical relation with the various individual flood and area characteristics. This type of study requires extensive (quantitative) information from historical floods, for which the availability is in general very limited. Therefore a more simplified approach can be chosen in which the probability of drowning is statistically related to the hydraulic circumstances, based on data from historical case studies. The framework and the elements described above are shown in figure 1.

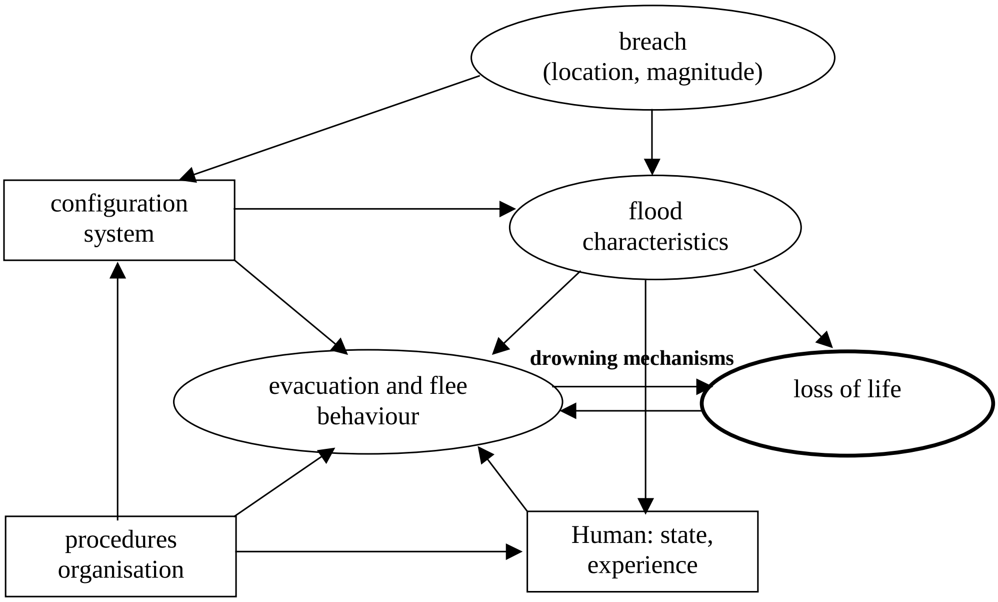


*Figure 1: Framework for loss of life estimation for floods*

This figure forms the basis for loss of life estimations for floods. Two main building blocks of the model can be distinguished. The first part simulates evacuation as a function of system configuration, human presence, procedures and organisation and flood characteristics. Section 3 outlines the developed method to simulate evacuation based on different aspects. The second part of the model combines hydraulic characteristics and the presence of inhabitants in order to determine loss of life, and is described in section 4.

## 3 EVACUATION MODEL

An evacuation of an area threatened by floods can prevent (part of) the loss of human life. A conceptual method has been developed to simulate an evacuation of a flood prone area in the Netherlands (Barendregt, 2002). This model mainly considers preventive evacuation before the initiation of the flood. Further studies will also analyse evacuation during the flood.

A preventive evacuation consists of three stages: the decision making, initiation of the evacuation and evacuation itself. The time factor will be very important: both the required time for evacuation of inhabitants, and the available time before the breach occurs should be taken into account. Based on an investigation of the evacuation, relevant aspects are identified, based on figure 1. The most important aspect of the system configuration is the available infrastructure. The level of preparation and the availability of emergency procedures are taken into account. Finally, the amount of humans trying to escape is taken into account in the traffic volume. Also the effects of traffic management can be taken into account in the model. Decision making and initialisation time are derived with simple assumptions. All these aspects determine the required time for evacuation.

The available time for evacuation will depend on the predictability of the high water, which will be determined by the nature of the hazard. While extreme river discharges in the Netherlands can be predicted up to several days ahead, extreme sea water levels will have a much shorter prediction time (6 – 10 hours). Furthermore the failure mechanism of the water defence will be important. While overtopping can be predicted somewhat in advance, a sudden loss of stability of the dike will be much harder to predict. A typical outcome of the method is shown in figure 2.

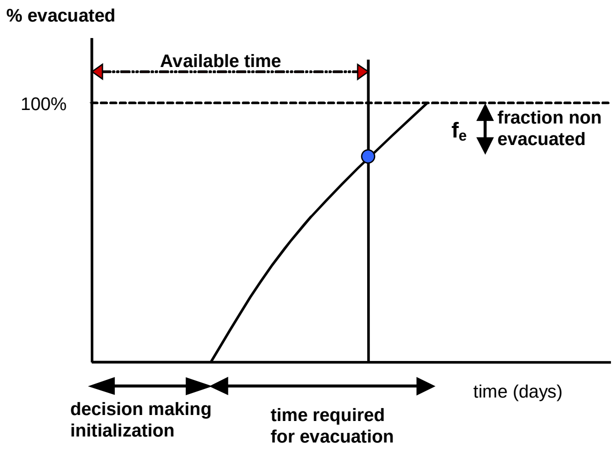


*Figure 2: Development of an evacuation as a function of time [Barendregt, 2002]*

Figure 2 shows the percentage of the inhabitants evacuated as a function of time. At a certain point in time the dike breaches and the flood occurs (in the figure after *available time*). A certain fraction of the inhabitants ($f_e$) will still be present in the area and these persons will be exposed to the flooding conditions.

It is important to realize that this conceptual model schematises the evacuation problem on a general (macro) level. Some specific issues are fully schematised in the described model. Evacuation may in some cases result in an increase of the number of fatalities, for instance when a traffic jam of persons fleeing for the flood, is overwhelmed by the incoming flood wave. This issue should be dealt with in a more detailed evacuation simulation, which takes into account the state and location of individual (or groups) of vehicles. This is not possible with the present evacuation model.

## 4 FLOOD LOSS OF LIFE ESTIMATION

### 4.1 Derivation of a method for loss of life estimation based on the 1953 flood in the Netherlands

After application of the evacuation model, the number of persons present in the area at the time of inundation is known. The number of fatalities can now be estimated using the flood characteristics. A relationship is proposed for the estimation of loss of life as a function of hydraulic flood characteristics. The development of a flood mortality relationship should be preferably based on realistic data, derived from historical case studies. Therefore an investigation of available information from historical floods was carried out. So far, detailed data on drownings for the 1953 floods in the Netherlands have been retrieved from Waarts (1992). During this flood a storm surge from the North Sea inundated large parts of the southwest of the Netherlands. This event caused enormous damage and shock, moreover 1835 persons were killed due to this disaster. Based on the available information on drownings it was investigated whether a relation between hydraulic flood characteristics and flood mortality could be found. In this case the effects of evacuation are neglected: the disaster struck unexpectedly at night, no evacuation could be carried out. Following the framework of figure 1 the loss of life can directly be related to the presence of persons at different locations and the hydraulic flooding circumstances.

Based on the collected data from the 1953 flood the following approach is proposed to relate flood mortality (i.e. the fraction of inhabitants in an area that lose their life in the flood) to hydraulic circumstances of the flood. Three categories of flood deaths are distinguished:

- Drownings due to rapidly rising water

- Drownings due to high flow velocities
- Deaths due to other causes, such as hypothermia, heart attacks, shock, failed rescue, etc.

In the analysed data it has been recorded to which of these causes the fatalities per location can be attributed. The distribution of the numbers of flood deaths is shown in table 1.

*Table 1: Distribution of flood deaths of the 1953 disaster in the Netherlands over the categories for 1726 of the 1835 recorded flood deaths (based on Waarts, 1992)*

| **Cause** | **Number of deaths** | **Percentage** |
|---|---|---|
| Rapidly rising water | 1054 | 61% |
| High flow velocities | 254 | 15% |
| Others causes | 427 | 25% |

The table shows that rapidly rising water, was the main cause of death during the unexpected 1953 flood. This information on drowning categories is used to propose criteria for each of these three categories to estimate the contribution to total loss of life.

**Drownings due to rapidly rising water**

When the water rises rapidly, dangerous situations will occur. People will not be able to reach high grounds or even to reach the higher floors of buildings. It is expected that especially the combination of water depth and rate of rising causes the danger, since dangerous situations will especially occur in higher water depths. The fatalities caused by rapid increase in water depth during the 1953 flood are shown in figure 3. From this figure it can be seen that mortality increases with water level. The following function is derived:

$$f(h)_{rise} = 9.18 \cdot 10^{-4} \cdot e^{1.52 \cdot h} \qquad f(h)_{rise} \leq 1 \tag{1}$$

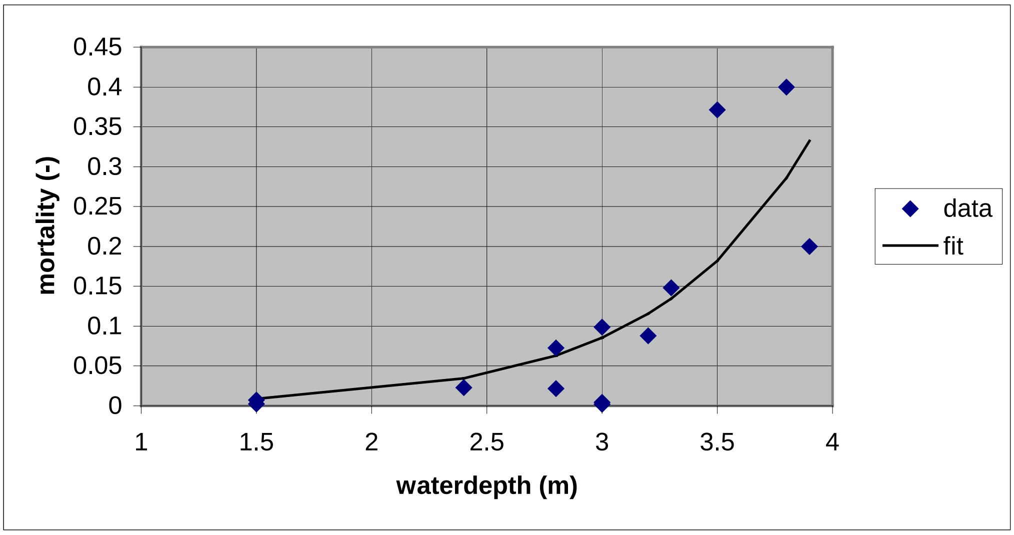



*Figure 3: Proposed function for estimation of flood mortality for rapidly rising water*

Based on the known values of the rate of water level rise it is assumed that this function should be applied if the water rises with 1 m/hr or more.

**Drownings due to high flow velocities**

Due to high flow velocities people can lose their stability, fall into the water and drown. Also, buildings can collapse. Tests on the stability of humans in flows have been carried out by Abt et al. (1989). A criterion for the damage to buildings in flow conditions is proposed in the Rescdam project (Rescdam, 2000). Total damage to masonry, concrete & brick houses will occur if the product of water depth and flow velocity exceeds the following criterion:

$$h \cdot v \geq 7 m^2 / s \qquad and \qquad v \geq 2 m / s \tag{2}$$

Where v – flow velocity (m/s)
h – water depth (m)

Since it is assumed that most persons will not enter the flow during the flood and that persons will drown when the building collapses, this criterion is proposed to estimate the contribution of deaths due to high flow velocities.

**Deaths due to other causes**

If fatalities are not caused by rapidly rising water levels or high flow velocities, other causes may also result in casualties. These causes can be for example hypothermia or fatigue of persons, collapse of building after a long period of hydraulic load. Also, indirect causes of death, such as heart attacks and electrocution, can be relevant. For the 1953 flood the reported mortalities for other causes are shown in figure 4.

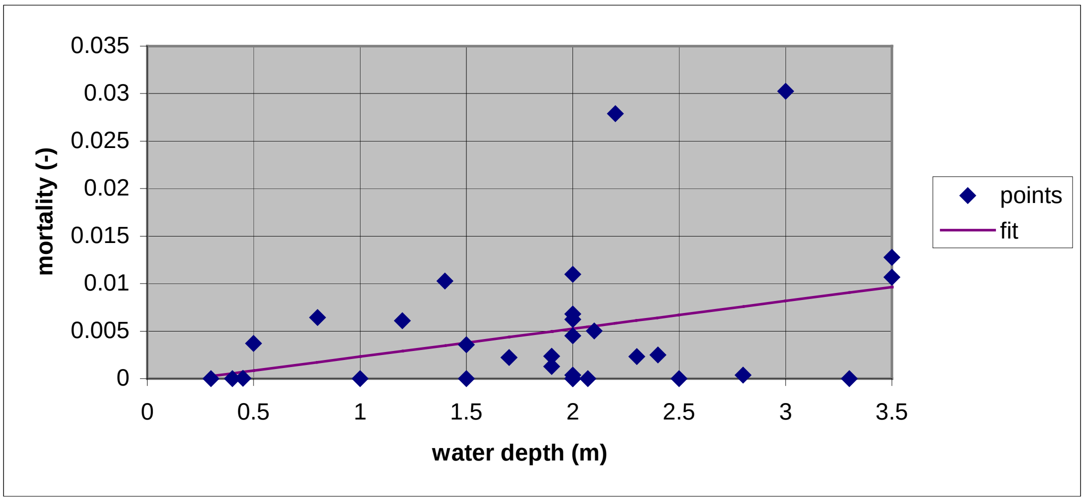



*Figure 4: Proposed function for flood mortality estimation due to other causes*

The following function has been derived:

$$f(h)_{other} = 1.41 \cdot 10^{-3} \cdot e^{0.59 \cdot h} \qquad f(h)_{other} \leq 1 \tag{3}$$

## 4.2 Application of the framework

Criteria for loss of life estimation are derived from data for the 1953 flood disaster in the Netherlands. It has to be stated that these functions are based on data from 1953 and that it is expected that the circumstances during a flood nowadays will be significantly different. For example, disaster preparedness and communication systems are expected to have been improved since, and the evacuation possibilities have increased due to the increase in availability of motorised transport. In 1953 many people died due to the collapse of buildings. Since 1953 building quality has been improved and the introduction of high rise buildings has provided new shelter places.

Aspects related to evacuation are taken into account in the evacuation model described in section 3. In addition to it, the effect of the presence of high rise buildings can be taken into account by assuming that people living in these buildings can be considered as 'safe'. The procedure for loss of life estimation can now be summarized as follows:

- Estimate the number of evacuated persons in the area with the evacuation model
- Determine the number of persons present in high rise buildings, consider them as evacuated

For every location the number of fatalities for the non evacuated persons can be estimated as follows:

- If the local rate of the rising of the water exceeds 1 m/hr, the fraction of the persons drowned can be estimated with:

$$f(h)_{rise} = 9.18 \cdot 10^{-4} \cdot e^{1.52 \cdot h} \qquad f(h)_{rise} \leq 1$$

- If the local rate of rising of the water is smaller than 1 m/hr, the fraction of the persons drowned can be estimated with:

$$f(h)_{other} = 1.41 \cdot 10^{-3} \cdot e^{0.59 \cdot h} \qquad f(h)_{other} \leq 1$$

- Deaths due to high flow velocities will occur if the water depth- flow velocity product exceeds $7m^2/s$ and if the flow velocity is larger than 2 m/s

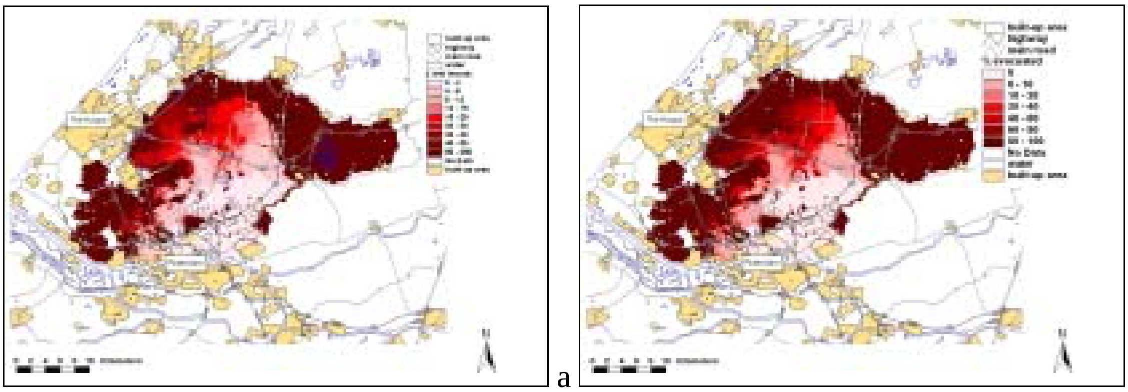
This model is only based on data from the Netherlands from 1953. An update of the model with more recent information from international floods is recommended.

## 5 APPLICATION OF METHOD IN GIS MODEL: CASE STUDY

In order to study the applicability of the proposed framework, a case study is carried out for a flood of the Central Holland area in the Netherlands. Central Holland is the largest flood prone area in the Netherlands. It is inhabited by about 3.5 million persons and includes major cities such as Rotterdam and The Hague. The area is threatened by floods both from the (North) sea side and from the south by the river Nieuwe Maas. In the selected case study a breach in the river dike east of Rotterdam is studied. The breach width is 250 m. The discharge through the breach varies from more than 5000 $m^3/s$ immediately after failure to about 1000 $m^3/s$ several hours later. The inflow remains high as the difference between water levels in the river and the elevation of the inundated polders is large, i.e. about 9 m. The inflow continues for about 10 days.

Propagation of the flood through the area is simulated with a 2 dimensional hydraulic model. The model results provide information on hydraulic characteristics of the flood which form the basis for the evacuation simulation and the loss of life estimation.

The possibility to evacuate on a certain location depends on  the moment of warning and the time that the flood arrives. The flood is expected to occur relatively unforeseeable so no pre warning is assumed. The percentage of the inhabitants that can be evacuated at a certain location therefore depends on the time that the water arrives there. As no detailed evacuation model was available for this area, an evacuation curve as shown in Figure 2 was used. The curve is based on earlier evacuation studies carried out for different area. Here, the time for decision making and initialization was assumed to be 6 hours. The total time needed for evacuation was 50 hours. The time of arrival of the flood in hours after failure of the river dike is shown in Figure 5a. The percentages of the persons evacuated in the inundated area are shown in figure 5b.



a b

*Figure 5* *In- and output of the evacuation model a) time of inundation (hours after failure of the river dike), b) percentage of inhabitants that can be evacuated*

Now that the number of persons still present at different locations within the inundated area is known, loss of life can be estimated with the proposed model (Eq. 4 and 5, chapter 4.2). The flooding conditions follow from the hydraulic simulations. As model input water depth and flow velocities are used, computed with the hydraulic model (Figure 6). The model output comprises estimations of the number of casualties as well as the main cause of death (figure 7).

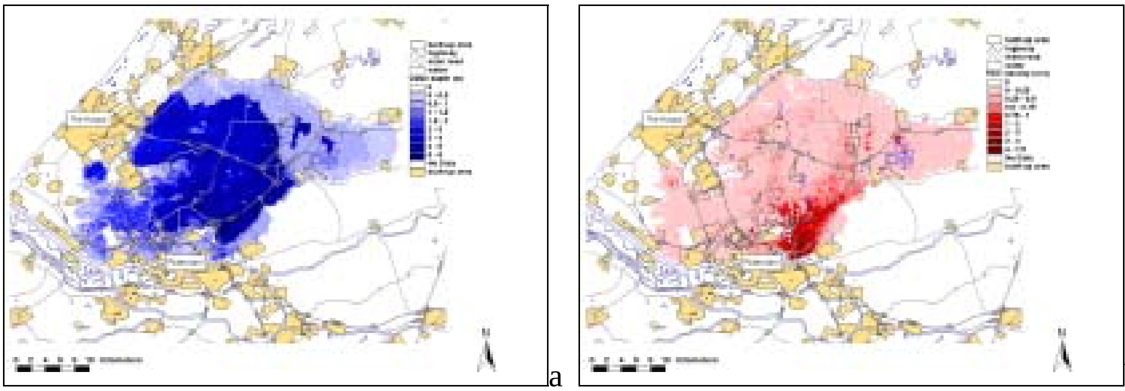


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*Figure 6* *Model input: a) water depth, b) flow velocities*

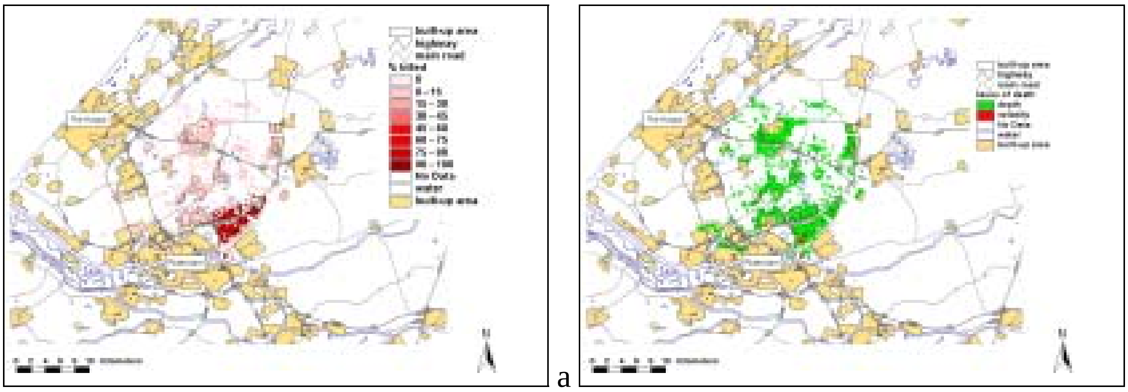

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*Figure 7* *Model output: a) percentage of inhabitants killed, b) most important cause of death*

Because of the uncertainty in the time needed for evacuation, the simulations were repeated with different evacuation curves. The results in Figures 5 and 7 are based on a total required time of 50 hours. Table 2 shows the results of this case.

*Table 2 Number of casualties, estimated using different evacuation curves.*

| | Time needed for evacuation (hours) |
|---|---|
| | 50 |
| Total nr of inhabitants | 3.6 $10^6$ |
| Nr of inhabitants effected by flood | 0.9 $10^6$ |
| Nr of inhabitants killed | 71800 |

The influence of the total required time was investigated for values of 25 and 100 hours. Differences in estimated numbers of casualties are small. This is due to the fact that most casualties are expected to occur in the south eastern part of the area where water depths are large. This area is inundated within a few hours after failure of the river dike. Evacuation of inhabitants therefore is impossible regardless of the total time needed for evacuation. Lives in this area can only be saved by evacuation beforehand. The high number of fatalities in the South Eastern Part can be attributed to the combination of fastly rising water and high water depths. Following formula 1 (and figure 3) high casualty numbers are obtained for these circumstances. It has to be noted that the choice of extrapolating the curve for higher water depths >3.9m, for which no data points are available, has much influence on the final death toll. The elapse of the function for higher water depths has to be analyzed more in-depth.

## 6 CONCLUDING REMARKS

In this paper a framework for the estimation of loss of life caused by floods in the Netherlands is proposed. The method takes into account the effect of evacuation during the flood and various mechanisms which lead to fatalities during a flood. The method is based on data from the 1953 disaster, which flooded the South Western Part of the Netherlands, and caused 1835 fatalities. In a case study the method is applied to give a first estimate of the number fatalities caused by a dike breach near Rotterdam, leading to a flood of the Central Holland area.

However, this method is a first proposal based on limited data. Several aspects should be further investigated to improve the estimate of the model. Firstly, the evacuation method should be improved and linked with traffic simulation models. The estimation of the number of casualties is based on relations obtained from one event, the 1953 disaster. The model should be improved and updated with more recent information from international floods. However, systematic data on health effects and mortality from flood events is rare. Therefore centralized and systematic reporting for deaths and injuries from floods using standardized methodology is strongly recommended (Hajat, 2003).

The developed method may also be of practical relevance. Decision makers can benefit from the evacuation model as a tool in their disaster management planning. The methods developed within the loss of life and evacuation research will provide information on the reduction of impacts of floods and the effectiveness of various measures.

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