

# Evacuation in Flood Threat Scenarios

Improving Methods to Estimate the Required Time for Evacuation

By

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*Paul Christiaan Dannenberg  
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# Executive Summary

When authorities monitor a potential flood they can choose to evacuate the population. Evacuation is defined as the process of alerting, warning, deciding, preparing, departing and (temporarily) removing people, animals, personal belongings and corporate stock and supplies from an unsafe location. Evacuation is a tool to minimise the loss of life and economic damage in (potential) dangerous events. Events prior to the expected onset of a flood can be classified in time periods that are displayed in figure 1. These time periods are:

- Warning issuance delay time: The time it takes for authorities to reach a decision to issue a warning once they have detected the hazard or have been notified of the hazard. [23].
- Warning diffusion: The process of how efficiently information spreads through the population at risk. It is the period after the first warning is issued and the time people receive that warning [22].
- Mobilisation or protective action initiation: The time between when an alert or warning is received by a person at risk and the initiation of a recommended protective action by that person (such as getting in their car) [24].
- Net available time for evacuation: The net available time for evacuation is the period between the beginning of the evacuation and the onset of the disaster. This is the time left for people to reach a shelter or leave the threatened area.

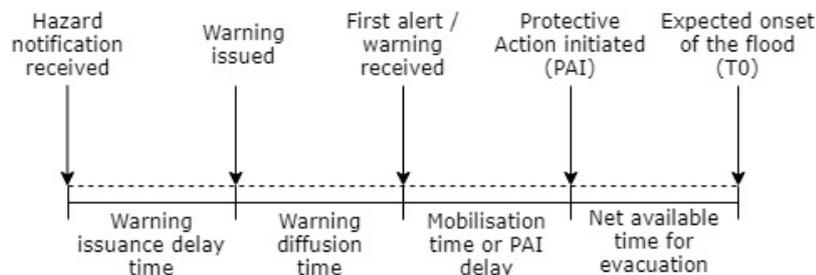


Figure 1: The evacuation time line.

Authorities in the Netherlands are constantly updating and improving their evacuation strategies. These evacuation strategies determine which people should evacuate preventively (move out of the threatened area) and which people should evacuate vertically (move to a safe space within the threatened area). To aid authorities, models are developed that can assess the expected effectiveness of evacuation strategies and the accompanying loss of life.

One area that is constantly updating its evacuation strategy is the island of Dordrecht. How they deal with evacuation in flood threat scenarios is described in their water safety plan. The water safety plan also includes an investment agenda in the field of crisis communication that should increase the evacuation effectiveness in time. Dordrecht uses the PBL evacuation and loss of life model to determine what results can be expected by adopting a certain evacuation strategy. The PBL model is a macro model which means the population is considered as a whole instead of modelling each person separately. In the PBL model the warning diffusion curve and personal action initiation curve are combined into a single departure curve.

However, because mass evacuation are not common in the Netherlands there is little data available to calibrate existing models and methods or develop new insights. Authorities responsible for evacuation in Dordrecht are interested in a method that can translate measures into a shorter warning issuance delay time and faster departure curve. This raises the question upon which this thesis is based, namely:

**"What method can be developed to translate the effects of certain measures in the field of crisis communication following the water safety plan of Dordrecht to an altered warning issuance delay time and departure curve and estimate the effects of these on the required time it takes to evacuate the island?"**

The goal of this study is thus to show what method could be used to translate measures in the field of crisis communication that follow from the water safety plan of Dordrecht into an altered warning issuance delay time and departure curve and what the effects are of these faster curves on the required time for evacuation and loss of life. It will also investigate what the evacuation and loss of life model LifeSim can add to the evacuation strategies developed in the Dordrecht compared to the currently implemented PBL model. LifeSim is a micro level agent based model where every person is modelled separately and followed in their journey to safety. LifeSim includes much more area and personal specific details compared to the PBL model which could result in a "more tailored" estimation regarding the required time for evacuation for different areas.

In the USA mass evacuation are more common than in the Netherlands. The United States Army Corps of Engineers (USACE) collected data from numerous evacuations and defined important factors that influence the warning issuance delay time, warning diffusion time and personal action initiation time. From these studies they developed an assessment method which includes a questionnaire that can estimate the expected warning issuance delay time, warning diffusion time and personal action initiation time for an area. This assessment method is closely interwoven with the evacuation and loss of life model LifeSim. This assessment method combined with LifeSim will be used as the starting point for this thesis and will be applied to a case study, which will be the island of Dordrecht and their water safety plan.

The overall objectives of these reports are:

1. Make a model comparison between the PBL and LifeSim model;
2. Compare the current warning issuance delay time and departure curve of Dordrecht to the USACE assessment method applied to Dordrecht;
3. Develop a case study where Dordrecht will be modelled in LifeSim and the results on the required time for evacuation and loss of life will be compared with the current estimations of the water safety plan;
4. To show what method could be developed to estimate the changes in the warning issuance delay time and departure curve and the consequences of these faster curves on the required time for evacuation.

This thesis found that the USACE assessment method contains valuable information regarding what factors influence the required time for evacuation and can function as a starting point to develop an assessment method applicable to the Netherlands. However, the warning issuance delay time and departure curve (the combined warning diffusion time and personal action initiation time) that followed from this assessment method when applied to Dordrecht were not in line with the current expectations. The differences can be seen in figure 2. The USACE assessment method estimated that the warning issuance delay time is on average 80 minutes whereas it is currently assumed to be 24 hours in the Netherlands. For the departure curve the assessment method estimates that a higher percentage of people will leave and will leave faster, but take longer to reach the max mob rate (the percentage of people that will evacuate preventively). The average mob rate that follows from the assessment method is 98.1% and is reached after 72 hours whereas the mob rate in the Netherlands (with preventive evacuation) is assumed to be 80% which is reached after 16 hours.

These difference can be largely explained by the events and evacuations on which the USACE assessment method is based. They primarily took place in the USA which is affected by threat scenarios not found in the Netherlands such as hurricanes, flash floods and dam breaches. The assessment method also includes data from chemical events. It is assumed that people will behave differently in different scenarios. For example, people will tend to leave faster during a chemical incident that happened an hour ago than to a potential dike breach two days away. This combined with the completely different command structure found in the Netherlands compared to the USA means that adaptations are needed in order to tailor the assessment method to the Netherlands. These adaptations are:

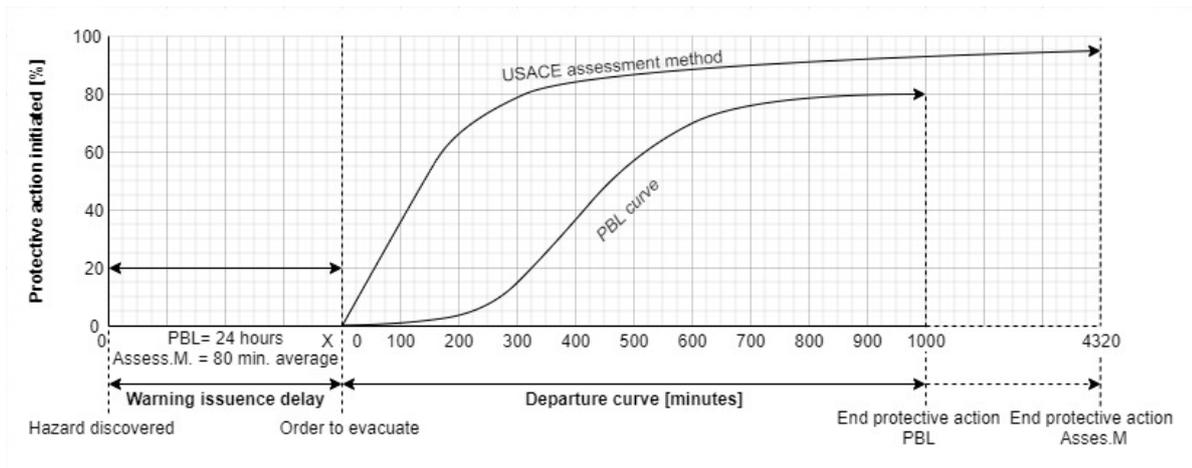


Figure 2: Comparison warning issuance delay time and departure curve following the USACE assessment method applied to Dordrecht and the current expectations in the Netherlands.

1. The decision command structure is currently not taken into account when estimating the warning issuance delay time in the USACE assessment method. The reason is that there was not enough detailed data available to include this parameter in the assessment method. It is expected that this decision command structure is one of the most important parameters that will influence the warning issuance delay time in the Netherlands because of the numerous parties involved in the decision making process. As such, the assessment method developed for the Netherlands has to include a more extensive review of the command structure and how the different parties interact with each other. Because there is not enough data available on evacuations in the Netherlands, the estimations on the warning issuance delay time should be based on expert opinion which can be backed by holding exercises and tests.
2. The departure curve that follows from the USACE assessment method starts of much faster than the departure curve of the PBL model, but takes longer to complete. Like the warning issuance delay time, a possible explanation could be the different threat scenarios found in both countries.

The data of the evacuations that are used to develop the assessment method are also relatively old and primarily come from evacuations in the 1980's and 1990's and therefor does not measure the influence of social media or the internet in the required time for evacuation. The same is true for the departure curve developed in the Netherlands. Like the warning issuance delay time, experts in the field of crisis communication should develop estimations about how the departure curve has changed recent years.

The conclusion of this thesis is accompanied with the following statements:

1. A faster departure curve can result in significant time savings, but only in scenarios where there is little traffic congestion. If there is much traffic congestion traffic jams will develop and the travelling time of the population starts to increase. The time saving of a faster departure curve are nullified because although people will leave faster they immediately enter a traffic jam. This thesis used two road scenarios that follow from the water safety plan of Dordrecht. One where the surrounding roads of Dordrecht are empty and people can leave the island freely and one scenario where the roads that surround Dordrecht are congested because multiple areas in the Netherlands are in the process of evacuation.

The result of the LifeSim simulations showed that in scenarios where there is no congestion on the roads that surround Dordrecht, a faster departure curve is directly translated into a faster evacuation. In roads scenarios where multiple areas are evacuating the time savings of a faster departure curve diminish quickly if larger portions of the population evacuate. For vertical evacuation where 20% of the population of Dordrecht leaves, a departure curve that is 8 hours faster will only result in a four hour faster evacuation. For preventive evacuation where 80% of the population leaves the time savings of a faster departure curve are negligible.

The traffic congestion on the roads surrounding Dordrecht thus form a limiting factor on how fast people can leave the island. Currently areas in the Netherlands develop their own evacuation strategies but this thesis showed that areas cannot be seen as separate in terms of evacuation because they will often be affected by evacuation strategies of other regions. In order to capitalise on a faster departure curve, national collaboration in the field of evacuation strategies and traffic management is needed. If vertical evacuation becomes the standard strategy for a multitude of areas better national traffic management plans can be developed so that the most threatened areas can evacuate faster.

2. This thesis also showed that agent based evacuation and loss of life models add nothing to the evacuation strategies in scenarios with significant road congestion. The travelling time is long relative to the warning issuance delay time and departure curve. A departure curve that is one hour faster in scenarios where it takes more than 48 hours to evacuate the island is negligible. However, if areas manage to (severely) decrease the travelling time of the population by adopting a nationwide vertical evacuation strategy, these agent based models may lead to new insights because they can more easily include area specific information.

# 1

## Introduction

*"Can anyone here give me a reason not to evacuate?"*  
Sheriff of Butte County USA several hours before a potential catastrophic event.  
February 6<sup>th</sup> 2017

In this chapter a general introduction is presented regarding evacuation in flood threat scenarios. It will start with a background introduction and then go to the relevance of the problem. It will then introduce the basic terminology surrounding evacuation and introduce the evacuation and loss of life model that is used in the Netherlands and the water safety plan of the island of Dordrecht, which is used as the case study area in this thesis. And finally, the evacuation and loss of life model LifeSim is introduced.

### 1.1. Background

Three weeks after hurricane Katrina hit New Orleans, and killed more than 1200 people, millions of Texans learned that an even more deadlier hurricane (Rita) was heading to their coastline. With the previous disaster fresh in mind, over 3 million people left Texas which became one of the largest evacuations in the U.S. history. Traffic jams stretched over hundreds of miles and dozens of people died from accidents and heat-related illnesses before Rita even made landfall. Forecasts of where Rita would land where changed numerous times. First it seemed that it would hit Corpus Christi and then Houston, but as the storm continued to progress, it kept moving further and further up the Gulf Coast. It changed course again just before making landfall and was planned to hit near the border between Texas and Louisiana. The constant change in direction meant that even more people hit the road to evacuate their family. Even communities that were not viewed as seriously at risk were evacuating, occupying desperately needed infrastructure. Of the 139 deaths that the state linked to hurricane Rita, 73 occurred before Rita reached Texas. While Rita was destructive, its impact covered a smaller area than previously thought [1].

Natural disasters can be relatively harmless or destructive events that cause massive economic damage and loss of life. In the example presented in the previous paragraph certain potential effects of an evacuation are listed. These include first and foremost, uncertainty about the information regarding the disaster which can change numerous times prior to the expected onset. Making it difficult to assess how, when and where to evacuate. It also shows that people are autonomous. They will not wait around indefinitely for an order to stay or evacuate or even disregard orders from authorities entirely. Even people who are technically not at risk can choose to leave the area. And lastly: infrastructure is limited and extremely important. If all people leave at the same time it can create hazardous events where people are stuck on the highway without any form of shelter or protection.

When authorities monitor future conditions like hurricanes, high water levels or possible failures in, for example, flood defences, they can decide to evacuate the population. Evacuation can be defined as *the process of alerting, warning, deciding, preparing, departing and (temporarily) removing people, animals, personal belongings and corporate stock and supplies from an unsafe location* [9]. Evacuation is a means to reduce the amount of loss of life and potential damage to (movable) goods in case of a catastrophe. However, evacuation

will also disrupt the economic and social processes and often has a base mortality rate due to car accidents or stress experienced by vulnerable people. It can furthermore lead to congested highways, as shown in the first paragraph, if the infrastructure is a limiting factor, in these scenarios people will lack any form of shelter or protection. The capacity of the infrastructure is often a limiting factor of how many people can safely leave an area in time but is also influenced by other parameters. Information about all these factors are therefore key so authorities can make a well informed and weighted decision on when and where to evacuate to minimise the amount of casualties.

To provide the authorities with information, models are developed that can assess the expected effectiveness of evacuation strategies and the potential loss of life in case of a flood. These models are an important tool for authorities to call for an evacuation and how the process of this evacuation is defined. Both in the USA and the Netherlands extensive studies are done to improve the level of accuracy of these models so a better insight can be given about the actual risk for a given area.

There are numerous evacuation and loss of life models available and not all these models operate on the same level and every one has its own purpose. From supporting policy and engineering decisions to providing information to planners and emergency managers to improve and optimise their strategies [6]. In figure 1.1 an overview is presented of different loss of life models. This summarisation distinguishes between the level of detail, located on the Y-axis, which means modelling the fate of each individual to an overall estimation on how an event plays out. And the modelling principles, located on the X-axis. Empirical models apply a mortality rate that is determined by event characteristics on the exposed population whereas mechanistic models include the behaviour of individuals and their cause of death.

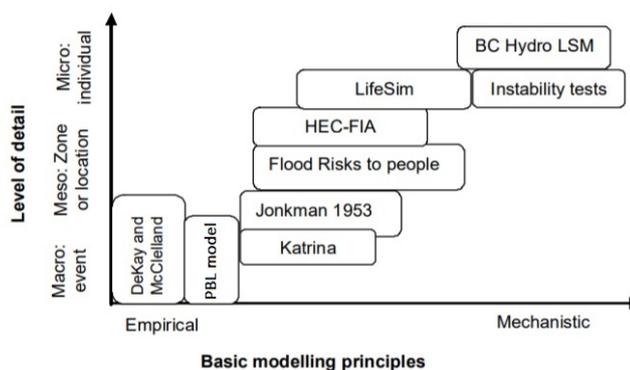


Figure 1.1: Comparison of loss of life models based on Johnstone et al. [4] with the PBL model added

A first quick estimate is generally done with the empirical macro scale models. Simulation models require more time but can be used to verify finding from empirical assessments prior to major investments based on those findings as well as informing decision-making process for selecting measures to reduce potential life loss (e.g. improved warning or evacuation planning) [5].

## 1.2. Relevance of the problem

The Netherlands is a country that is predominantly below sea level. Large areas are protected by flood defences and often contain a high population density. Failure in the flood defences or high water levels could result in a significant loss of life and economic damages. Because of this, the Netherlands sets out standards for flood defences designed to preserve an acceptable level of safety in the Netherlands. In 2017 a new standard for flood defences was developed which was expressed in a different way. It used to be defined as a water level that must be safely guarded against, and as such the standard focused only on the hydraulic load. The new standard is expressed as a probability of flooding. The main reason for switching this focus to the probability of flooding is that it properly reflects the degree of protection from flooding. After all, the probability of flooding depends on both the hydraulic load (water levels and wave action) and on the strength of the defences (height, width, type of material etc.). The new standard is based on the risk of flooding. Risk refers

to both the probability and the consequences of flooding. The possible consequences have been identified more effectively than in the past, with a greater focus on fatalities and victims. For the first time, the loss-of-life risk has played an explicit role in the updating of standards for flood defences. The government has decided that the probability of loss of life due to flooding may not exceed 1/100,00 per year in all protected areas of the Netherlands [25].

Evacuation is a tool to minimise the loss of life. So authorities in the Netherlands are constantly trying to update and improve the effectiveness of their evacuation under programs such as "water and evacuation" and "Wave 2020". One area that is constantly updating their evacuation strategy is the island of Dordrecht. Dordrecht is an island that has a surface of 79 km<sup>2</sup> and has a population 118.654 people. Due to the geographical nature of the the island and their surroundings, it can take multiple days to evacuate the entire island in certain preventive evacuation scenarios. Different papers estimated that in most preventive evacuation scenarios only 15% of the population in Dordrecht can safely leave the island in time [11, 13]. This percentage that can safely leave the island in time is called the **evacuation fraction** and is defined as *the expected number of people who can evacuate outside the dangerous area before a flood hits* [18].

So to limit the effects of flood threat scenarios, Dordrecht uses a concept that combines preventive and consequence limiting measures [20]. This concept is called the multiple later safety approach. This approach consists of three layers: layer 1; prevention (dikes etc.), layer 2; spatial adaptation / land use planning (building shelters, increasing infrastructure) and layer 3; emergency management (or evacuation strategies). This multiple layer safety lies at the basis of the water safety plan of Dordrecht.

This water safety plan of Dordrecht is used as an agenda-setting and connecting document for crisis management, spacial adaptation and communication towards the population and companies. It discusses subjects ranging from how many shelters for the population are needed, suitable places for auxiliaries to set up, where risk objects (electricity companies, drink water, ICT companies etc.) are located and how they should behave during a threat scenario, basic evacuation strategies for different ZIP code areas and so on. The goal of this water safety plan is to develop a self reliant island, which effectively means that people seek shelter within the island instead of evacuating preventively because, as mentioned, in many preventive evacuation scenarios only 10 to 15% of the population can leave the island before the expected onset of the flood. This water safety plan also includes an investment agenda which lists potential opportunities to make the different layers more effective. If implemented, this investment agenda should results in a faster evacuation of the population in a multitude of evacuation scenarios.

However, at the moment there is no method available in the Netherlands that can predict what the precise effects and consequences are of this investment agenda on the time it takes to evacuate the population. One of the reasons that there is little documentation available on this matter is that there are not many mass evacuations in the Netherlands. So it is difficult to calibrate currently used assumptions or to develop new insights. Furthermore, the current evacuation and loss of life model used in the Netherlands, the PBL model, is a macro model, meaning less details surrounding an evacuation and loss of life are included and a more general view on how an event plays out is implemented.

In the USA mass evacuation are more common. The United States Army Corps of Engineers (USACE) instigated numerous studies across many evacuations to investigates what factors play an important part in the process of evacuation, specifically in the required time it takes to evacuate the population prior the the expected onset of a flood. The results of all these studies are combined in the USACE assessment method [14, 15] which consists of two documents. The first one is a guidebook on public alerts and warnings for dam and levee emergencies that list information about how authorities can best prepare themselves for these events, such as how to formalise an evacuation plan and quickly get information across the population. The second document is a questionnaire that check how prepared authorities actually are. The answers given in this questionnaire are converted into scores that can assess the required time for evacuation of a certain area. This assessment method is closely interwoven with the evacuation and loss of life model LifeSim, which is considered a micro model where, compared to the macro PBL model, more details and parameters surrounding evacuations and loss of life are taken into account.

The practical part is that the water safety region South Holland south is interested in a method that shows the changes in the required time needed to complete an evacuation due to investments and measures that follow from the water safety plan and what lessons can be learned from the USACE assessment method. The academic part is what micro level evacuation and loss of life models can add to the evacuation strategies of the Netherlands compared to the current used macro models.

### 1.3. Basic terminology

There are several important basics regarding evacuation and evacuation strategies that will be explained in this sub-chapter.

#### 1.3.1. Evacuation time line

The events prior to the expected onset of a flood can be classified with help of the evacuation time line. The whole evacuation process before this onset can be modelled using four important time periods. It starts when the first notification of the hazard is received and ends at the expected onset of the flood. These time frames are: warning issuance delay, warning diffusion, personal action initiation and the actual evacuation, and are displayed in figure 1.2.

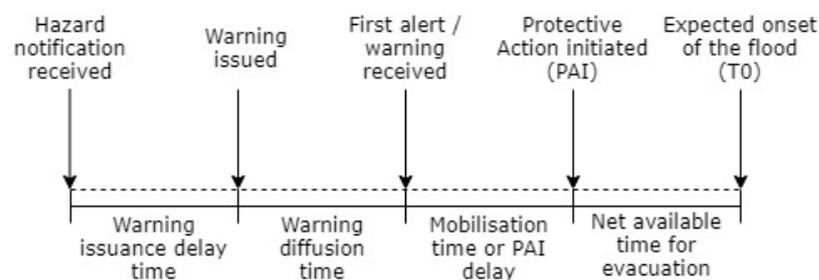


Figure 1.2: The evacuation time line.

- **Warning issuance delay:** The time it takes for authorities to reach a decision to issue a warning once they have detected the hazard or have been notified of the hazard by those monitoring for it or by others who may have observed evidence of the hazard perhaps by chance [23].
- **Warning diffusion:** The process of how efficiently information spreads through the population at risk. It is the period after the first warning is issued and the time people receive that warning [22].
- **Mobilisation or protective action initiation (PAI) time:** The time between when an alert or warning is received by a person at risk and the initiation of a recommended protective action by that person (such as getting in their car). Depending on certain factors the amount of time can be very short or quite long and can have dramatic impact on the potential for an individual to reach safety prior to arrival of an identified hazard at their location [24].
- **Net available time for evacuation:** The available time for evacuation is the period between the beginning of the evacuation and the onset of the disaster. This is the time left for people to reach a shelter or leave the threatened area. It is possible that extreme winds or other circumstances decrease the amount of available time.

Figure 1.2 can be expanded to include several other important definitions of evacuation, including the available time, the required time, the evacuation curve etc. This figure is shown in figure 1.3. The warning diffusion time and mobilisation time are also modelled as a S-curve as shown in [22–24].

#### 1.3.2. Evacuation types

In this thesis a distinction between six different types of evacuation will be presented based on the timing of displacement of people relative to the occurrence of the event and are based on the paper of Kolen [9].

1. **Preventive evacuation:** Evacuation before the occurrence of an event. An example is the preventive evacuation of a flood prone area before a dike breach.
2. **Vertical evacuation:** The organisation and a combined horizontal and vertical movement inside the potentially exposed area before the onset of the disaster or moment of exposure in the following areas:

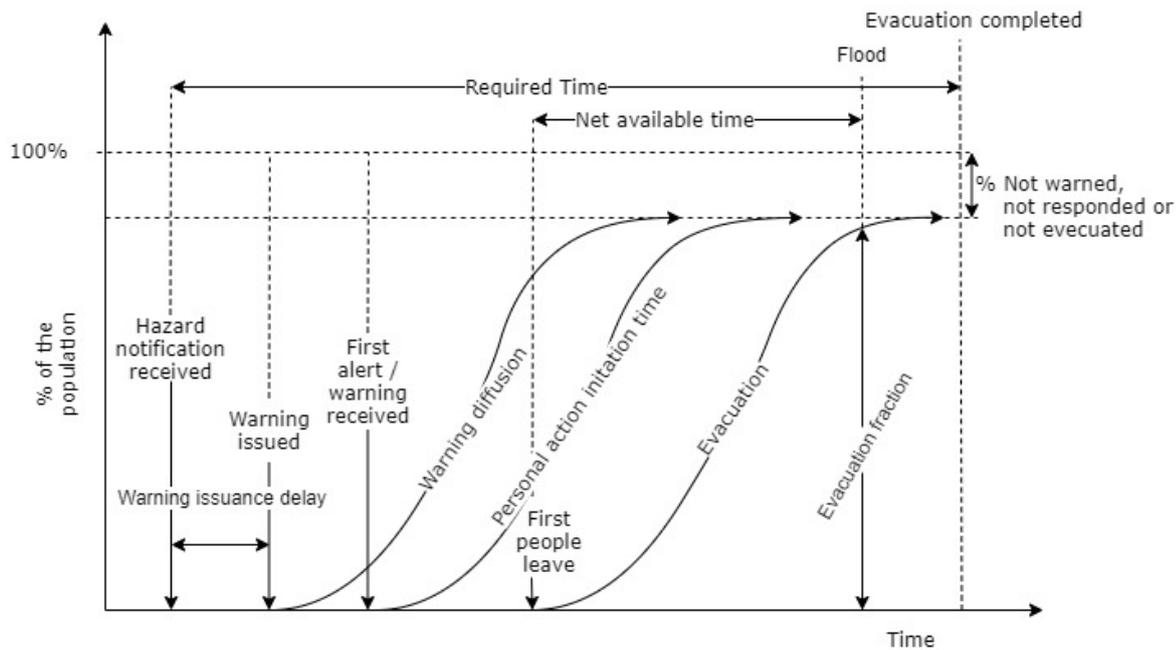


Figure 1.3: Modelling evacuation, available time and required time (adaptation of figure seen in Doef and Cappendijk [2])

- **Shelters:** Strong buildings often governed by the authorities that offer protection for gathered people and goods.
  - **Safe havens:** An area inside the threatened zone that will not be exposed to a flood, such as an elevated area.
3. **Shelter in place:** The organisation and vertical movement to safe locations inside buildings where people live and work before the start of the disaster or exposure, e.g. move to upper floors.
  4. **Acute evacuation:** The organisation and movement of people from a potentially exposed area from a safe location outside this area, initiated after the onset of a disaster and before exposure, controlled by authorities.
  5. **Escape** refers to the movement of people through an exposed area, for example people running through a flooded area. Movement can be impeded by physical effects, e.g. due to limited visibility, reduction of walking speed or sustained injury. Eventually the exposure can lead to death of the escaping person.
  6. **Rescue:** The organisation and removal of people by rescue workers from an exposed area.

### 1.3.3. Threat scenarios and evacuation strategies

The goal of evacuation strategies are to minimise the loss of life. Different possible threat scenarios are developed with matching evacuation strategies. Threat scenarios are characterised by expected water levels, location of dike breaches / river flooding and available time. However, every evacuation strategy takes time to implement and the relation between the available time and required time of an evacuation strongly influences the consequence of evacuation. The available time for evacuation can be defined as: "*the period between the beginning of the evacuation and the onset of the disaster*". It depends on the combination of the availability of (weather) forecasts, time needed for decision making and the implementation of an evacuation strategy. The required time is defined as: "*the period necessary to complete the execution of an evacuation strategy*" [5, 9]. Depending on the relation between the available time and required time, evacuation strategies will change accordingly. In the paper of Kolen [9] an example is shown on how different events warrant different strategies. An adaptation of this example is displayed in figure 1.4.

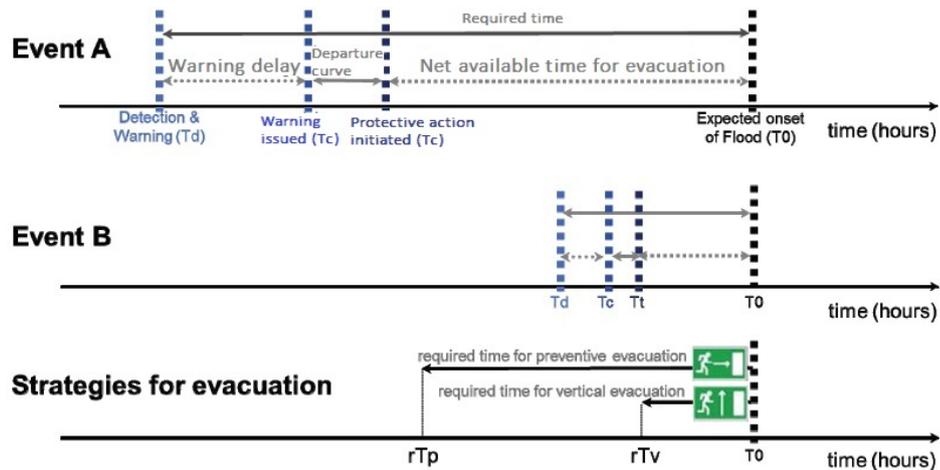


Figure 1.4: Time lines for evacuations for different events. Adaptation of figure seen in [9].

For event A, a potential dangerous event is perceived and relatively much time is available. Authorities have to choose whether they want to wait until more information is available about the event such as information regarding weak points in dikes or expected water levels etc, in order to decreasing uncertainty, or to order an evacuation. This is the decision making process. After a decision is made to evacuate, certain measures have to be implemented before an evacuation begins. Roads can be made one way to increase capacity (reverse laning), important equipment and personnel have to be sent to strategic location etc. This period ends at the transition time where the evacuation actually starts and people will try to evacuate outside the dangerous area. The evacuation ends on the expected onset of the flood.

In event B, the expected onset is relatively soon. Decisions have to be made faster en less time is available to get people out of the threatened area. In this case there is not enough time available for preventive evacuation. Vertical evacuation is a better choice to minimise the loss of life.

### 1.3.4. Decision making process, up-scaling and alarming

Due to uncertainties of a potential hazard, authorities will generally wait till the last possible moment to evacuate due to the societal and economical impact. Prior to this decision authorities already met numerous time to discuss if potential (follow-up) measures should be taken. This is called up-scaling. Whether or not authorities choose to scale up the operations is based on a cost benefit analysis. The consequences and costs of these decisions will increase as more impactful measures are taken. In figure 1.5 a simplification of this decision making diagram is displayed. A call to evacuation consists of the following parts:

1. Up-scaling: crisis teams assemble;
2. Prepare operational measures: people and equipment are prepared and put on strategic places such that, when a evacuation call is given, these resources can act quickly;
3. Call to evacuate: actual call to evacuate. Population will be warned en start to take protective action.

For more information on the national crisis plan of the Netherlands for high water related events and more information on the upscale criteria, see the website of "[www.helpdeskwater.nl](http://www.helpdeskwater.nl)" or the website of the ministry of infrastructure and water management.

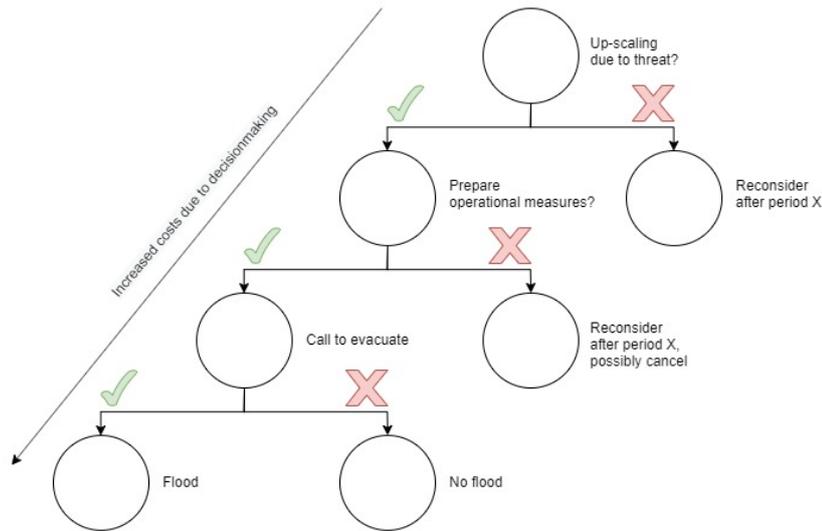


Figure 1.5: Decision making process [10].

### 1.3.5. Risk

Risk is the cornerstone of when and where to evacuate and is defined as *"the probability of the event happening multiplied by the consequences"*. In Kolen [9] a default evacuation diagram is displayed (figure 1.6) that can assess if evacuation is the rational choice with an incoming flood based on costs and benefits. It takes into account the 1) the minimal conditional probability of flooding (based on forecast levels), 2) loss of life and economic losses, which can be prevented in case of a flood by evacuating during the available time and 3) the loss of life and economic losses which are caused by evacuation. When less time is available for an evacuation, less people can be saved, so the minimal conditional probability of flooding that is necessary to call for an evacuation decreases based on an economic approach.

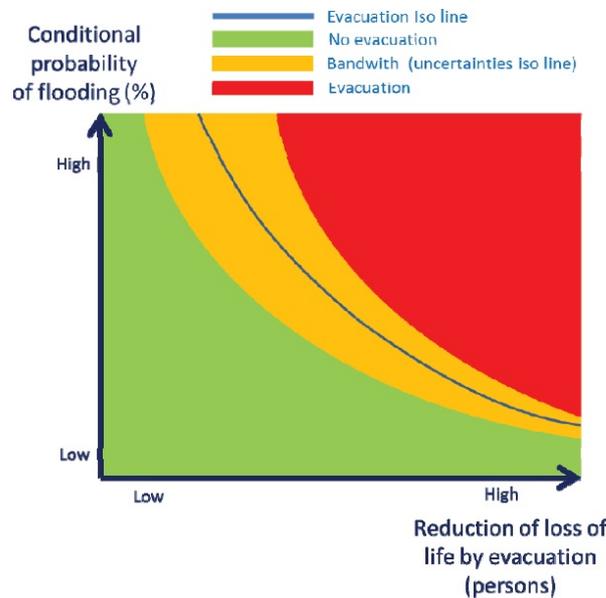


Figure 1.6: Evacuation diagram (seen in [9]).

The evacuation isoline shows the minimal conditional probability of flooding, and the amber zone shows an uncertainty range. The red zone in the graph shows when a call has to be made based on economic rational approach. The green zone indicates when evacuation is not profitable based on an economic approach. Following this figure, it can be concluded that the frequency of a flood will be less than the frequency of evacuation. Studies conducted by Kolen [9] show that a chance of only 5% is sometimes enough to call for an evacuation. This thesis however will not look at which conditional probabilities of flooding are acceptable or how these are determined but rather on how you can increase the efficiency of evacuation given a certain decision.

#### 1.4. Water safety plan Dordrecht

As mentioned in the opening chapter of this thesis, the water safety plan of Dordrecht is used as an agenda-setting and connecting document for crisis management, spacial adaptation and communication towards the population and companies in case of flood threat scenarios. It discusses subject like the different evacuation strategies in certain flood threat scenarios, upscale criteria and decision diagrams etc. However, the base evacuation strategy in every flood threat scenario is always the same. It starts with vertical evacuation and when enough time is available, additional measures will be taken such as evacuating the most threatened areas.

The water safety plan also includes an investment agenda for the island of Dordrecht that should positively affect the evacuation effectiveness in time. These investments listed in table 1.1 and are focused around the different layers of the multiple layer safety approach. In theory, these investments should result in a lower warning issuance delay time, a faster warning diffusion curve and a faster personal action initiation curve. However, at the moment no documentation or method is available that can precisely predict the changes that some of these investments have on the required time for evacuation and what the consequences are for how many people can leave the area in a certain amount of time.

<b>Focuses on flood probabilities</b>	<b>Focuses on spatial adaptations</b>	<b>Focuses on crisis management</b>
Prepare estimates conditional probability of flooding	Shelters	Information preparation
Updating of consequence scenarios	Risk objects	Specific risk communication about the base evacuation strategy
Review of scaling criteria	People in need of help and healthcare institutions	Fast and transparent crisis communication
	Evacuation Routes	Preparing decision making
		Training directors and their advisers
		Agreements on continuity of the electricity and IT in the threat phase
		Shelters and landing place
		Evacuation routes

Table 1.1: Investment agenda as displayed in the water safety plan of Dordrecht [10]

## 1.5. Introduction to evacuation modelling

In the opening paragraphs of this thesis a short introduction is already presented on the different evacuation and loss of life models available. Every model provides a different results regarding the expected location of the population and the loss of life.. In Jonkman et al. [7] an example is presented to show these wide ranges of outcomes. In this paper the 1953, Katrina and LifeSim model are applied to a case study, which represents the 'Natomas Basin' (an area in the USA), to determine the loss of life (see figure 1.7). The difference of results can be related to the modelling principles and level of detail. Different models use different assumptions regarding their parameters. For example, the loss of life functions of the 1953 model are sensitive to rise rates of water whereas the LifeSim model is sensitive to flood depths.

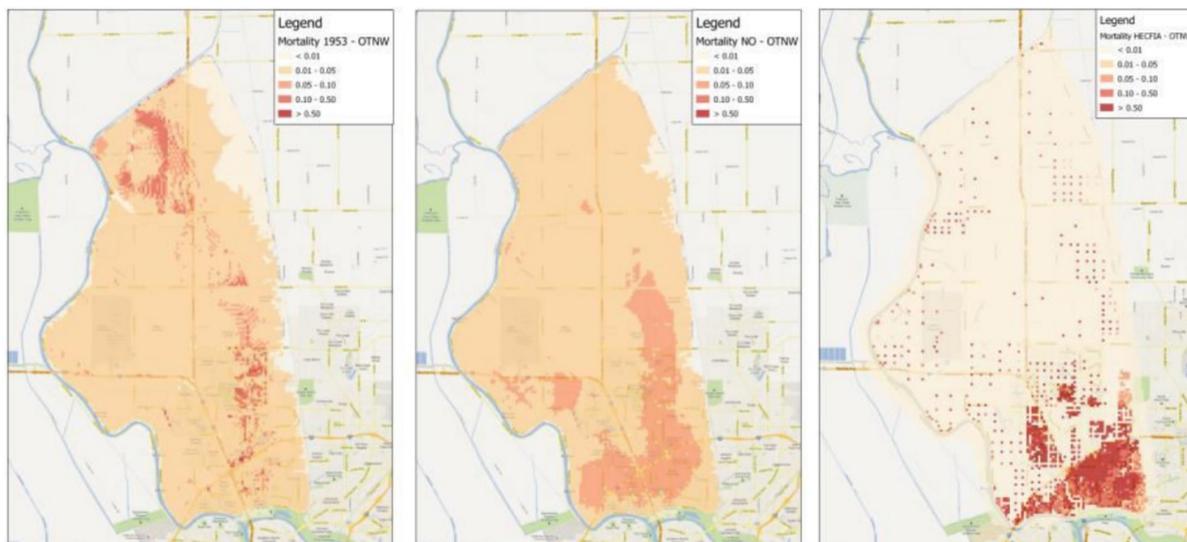


Figure 1.7: Location and mortality rates for Natomas Basin case for different evacuation and loss of life models (left 1953, centre Katrina, right HEC-FIA) as seen in [7]

When interpreting the results that these models provide it is thus important to be aware of **why** and **how** certain parameters are defined. These parameters are a simplification of reality and different circumstances warrant different way of simplifying these parameters. Where the Netherlands is a low lying country protected by flood defences with a large population per km<sup>2</sup> the USA is affected by different situations like hurricanes and dam breaches. Where hypothermia is a dangerous parameter affecting loss of life in the Netherlands, the water is often warmer in the USA, but contains more debris.

## 1.6. Introduction PBL and HIS-EC models

The PBL model is the evacuation and loss of life model that is used in the Netherlands to substantiate choices for a certain evacuation strategy and spatial adaptation to minimise the loss of life. The PBL model is closely interwoven with the HIS evacuation calculator software which is used to estimate how many people can leave an area in a certain amount of time (required time for evacuation). This sub-chapter will provide a quick introduction to the PBL model and the HIS evacuation calculator. In chapter §3.1 a more in-depth approach of the PBL model is presented which will also discusses the loss of life parameters.

The PBL model can be categorised as an empirical macro model that divides the population over several victim categories that are based on the expected location of the victim. Each victim category then receives a specified mortality rate which is based on the paper of Jonkman [5]. The different victim categories are:

1. **Victims due to preventive evacuation** (traffic accidents, stress on vulnerable people);
2. **Victims hit by a flood during evacuation;**
  - (a) *Overtaken by the flood:* Victims that are overtaken by the flood during evacuation.
  - (b) *Shelter in surroundings:* Victims that are overtaken by the flood, but manage to find shelter in their surroundings at the last possible moment (houses or high ground).

3. **Shelters:** Population that is hit by the flood while in a predefined public shelter;
4. **Those staying at home:** The population that does not evacuate and stay in their own home or in the home of others. A distinction is made between people who are prepared and unprepared for the incoming flood.

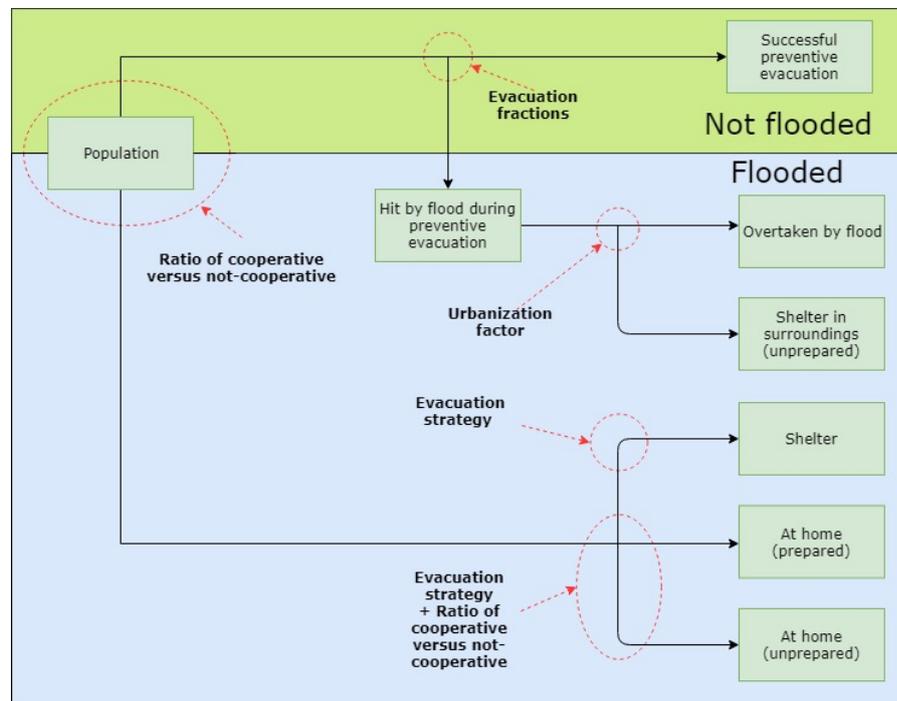


Figure 1.8: Outline of the PBL model as seen in [18]

In figure 1.8 the outline of the PBL model is presented. With the PBL model it is possible to determine the loss of life caused by a flood while incorporating different evacuation strategies like preventive and vertical evacuation as a function of time. In the PBL model ZIP code areas are used as the smallest entity, meaning a certain ZIP code area can only evacuate preventively or vertically. In a city or area, these two evacuation strategies can thus be mixed for an optimal expected result. Where the most threatened areas will evacuate and less dangerous area's shelter in place.

### 1.6.1. Evacuation fraction

The evacuation fractions determine the expected number of people who can evacuate outside the dangerous area before a flood hits [9]. The evacuation fraction for different areas within the Netherlands are represented as a single number in the "Deltaprogramma" and are used for the norm of the different dikes throughout the Netherlands. However, this single evacuation fraction is actually an average expected value of multiple evacuation fractions that are the result of many different scenarios, uncertainties and assumptions. So if specific scenarios are modelled, different estimations can be used like a two or three days available time or different degrees of evacuation success.

These different estimations are presented in an "event tree", presented in figure 1.9. An event tree displays which end result (evacuation fraction) can be expected as a certain initial event is followed by the occurrence of certain other follow-up events. In this case, the event tree start with a expected amount of available time which is followed by how effective the evacuation plays out. By combining these events with probabilities a probability density function can be determined. The **preventive evacuation** fractions that are used in the Netherlands are based on the paper of Maaskant et al. [13] whereas the evacuation fractions when **vertical evacuation** is the strategy are described in Kolen et al. [11]. However, the evacuation fractions used in the Deltaprogramma are only based on preventive evacuation. This is because evacuation strategies in the Netherlands used to be based around preventive evacuation (and in many cases still are). So only information

about preventive evacuation was available. Now that areas start including vertical evacuation as a strategy, it is worth to investigate on how vertical evacuation changes the evacuation fractions.

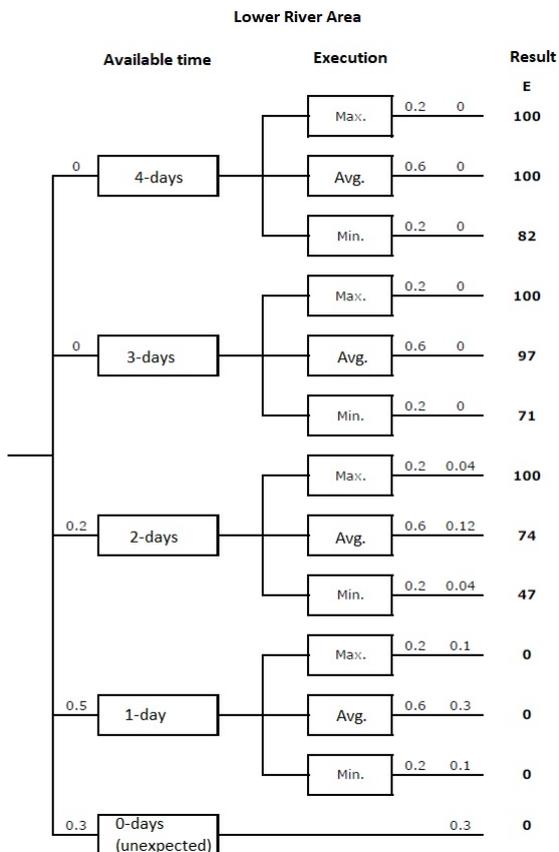


Figure 1.9: Evacuation tree for the lower river area for preventive evacuation [8].

To estimate the evacuation fraction in a certain scenario, traffic models are used. These traffic models estimate the number of people that can leave an area in a certain amount of time. Two methods of modelling the traffic flow are available, a static and dynamic traffic approach. The static approach in the PBL model is based around the HIS-EC whereas the dynamic approach is based around OmniTRANCE. The evacuation fractions in the Deltaprogramma are based purely on calculations made with the HIS-EC.

### 1.6.2. HIS-EC and OmniTrance

The HIS-EC is a traffic model that simulates the evacuation effectiveness by means of a static traffic simulation approach. With this static approach an average spread of the population is assumed and the details of the road network are not directly taken into account. With the dynamic traffic model OmniTRANCE, the details of the road network are taken into account, meaning that when more traffic is present on a lane, the flow rate of the traffic will decrease and the amount of vehicles per lane will increase. Dynamic traffic models are generally more costly and time consuming to run and is only be used to control finding from the HIS evacuation calculator for certain areas. Both traffic models include an exit capacity and departure curve of the population.

This exit capacity denoted as cars per hour is an important parameter in the evacuation fraction calculation in the Netherlands because it simulates the fact that when a certain area evacuates, it is often not the only area that is evacuating. Every evacuating area takes up capacity of the major highways throughout the Netherlands. This exit capacity limits the outflow of the population to simulate the fact that the major highways are congested.

A departure curve simulates the fact that not the entire population leaves at the same time. Instead people leave as a function of time. The departure curve is discussed in paragraph §1.6.3.

To summarise, the HIS-EC is used to determine the evacuation fraction of the Netherlands. The process of the the HIS-EC can be defined by three distinct part which are displayed in figure 1.10. The first part is how fast people will get into their car (departure curve). The second part determines the travelling time by means of an average travelling speed and the last part is how fast these people can leave a certain area by including an exit capacity.

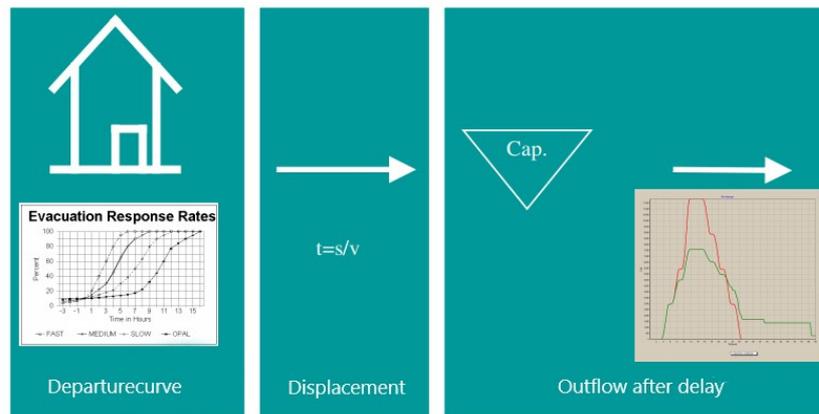


Figure 1.10: Conceptual model of the HIS-Evacuation [26].

### 1.6.3. Departure curve

In the Netherlands the warning diffusion curve and protective action initiation curve are combined into a single departure curve. Like the warning diffusion curve and personal action initiation curve the departure curve is S-shaped and determines how many people get into their car as a function of time.

The departure curve used to estimate the evacuation fractions in the Netherlands was developed by the University of Twente in 2004. Data was collected from hurricane events in the USA and different departure curves were formulated. The reason that evacuation response rates from the USA were used and not of Dutch scenarios is due to the fact that (mass) evacuations are a rare phenomenon in the Netherlands. Not enough data was available to develop a departure curve. Data had to be collected from somewhere else. The results of this departure curve is as follows [2]:

- The departure curves show a S-like character such as a logistic curve;
- From 20 to 80% the departure is linear;
- The amount of departures between 20 and 80% is strongly dependent on the circumstances.

A distinction was made between a "fast" and "slow" departure curve. The fast curve is the dotted line in figure 1.11 and the slow curve the continuing line. Due to the sensitive nature of evacuation, and the lack calibration data in the Netherlands the slow curve is used in all evacuation fraction calculations of the Netherlands. The fast curve is reserved for sensitivity analyses.

It is important to notice that the departure curve is unaffected by outside parameters like day or night, an expected or unexpected flood or safety measures taken by authorities. The reason that the Netherlands has not invested in a more "detailed" departure curve is a combination of two things. The first one is, as already mentioned, a lack of data. Mass evacuations are not common in and it is therefore not possible to develop new estimations or calibrate old graphs with data.

The second reason has to do with the travelling time of the population to reach safety. The evacuation strategies incorporated by the Netherlands are primarily based on preventive evacuation. Traffic modulations however showed that there will be large traffic jams in most scenarios, hindering the speed of which people can

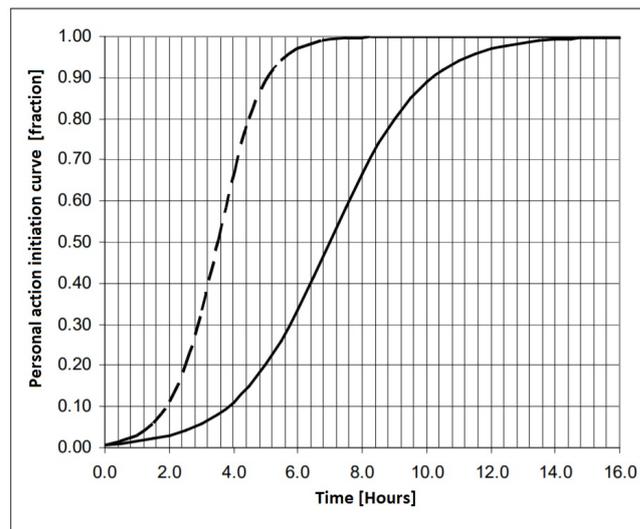


Figure 1.11: Departure curves developed by the University of Twente. The slow departure curve is used in the PBL model.

leave a certain area. In the paper of Kolen and Huizinga [10] an example is presented that shows that in normal conditions (day to day life) the travelling time out of the island of Dordrecht only takes a maximum of 1 hour. However, in worse conditions this can increase to 7-12 hour or even to 48 hours in the most extreme scenarios. Evacuations are generally categorised by these worst scenarios (bad weather, numerous people on the roads, traffic jams). In these scenarios it is pointless to include much detail in the departure curve in the form of investments and measures. A departure curve that is 10, 20 or even 50% faster makes little difference. However, now that safety regions start to include vertical evacuation into their strategies, it is possible that the roads will be less congested and travelling times remain relatively low, meaning a faster departure curve can increase the evacuation effectiveness significantly.

## 1.7. LifeSim model

In the USA the evacuation and loss of life model LifeSim is used and can be described as a mechanistic micro model. In LifeSim each individual person is modelled and accounts explicitly for the impact of warning issuance time, warning diffusion time, the population at risk's behaviour and evacuation potential, detailed flood dynamics and loss of shelter on loss of life [17]. Each individual is tracked throughout the warning and evacuation process. It incorporates a Monte Carlo sampling technique to capture the natural and model uncertainty in the warning and evacuation process. LifeSim is closely interwoven with the USACE assessment method as described in §1.2 to estimate the warning issuance delay, warning diffusion time and mobilisation time. In figure 1.12 an example is presented of how a LifeSim model run could look like. In this example an imaginary dam breach is modelled in the city of Deming USA. In this example the people and infrastructure that are still safe are denoted blue, whereas houses and people that are compromised by the flood are red.

By importing six data sets an estimation is given on an evacuation will play out. These sets in turn include many parameters that will influence the model run. The six data sets are:

### 1. Hydraulic Data:

This data set contains the flood characteristics. It can be imported in several ways but at the least needs a time series of depth and velocity to execute a model run. This can be complemented with the rise rate or quality of water (debris, temperature etc.).

### 2. Structure Inventories:

A structure inventory represents geospatial points that contain damageable elements (typically structures like homes). It is used to estimate direct economic damage, loss of life due to collapsing buildings and an estimation on how many people live in a certain location.

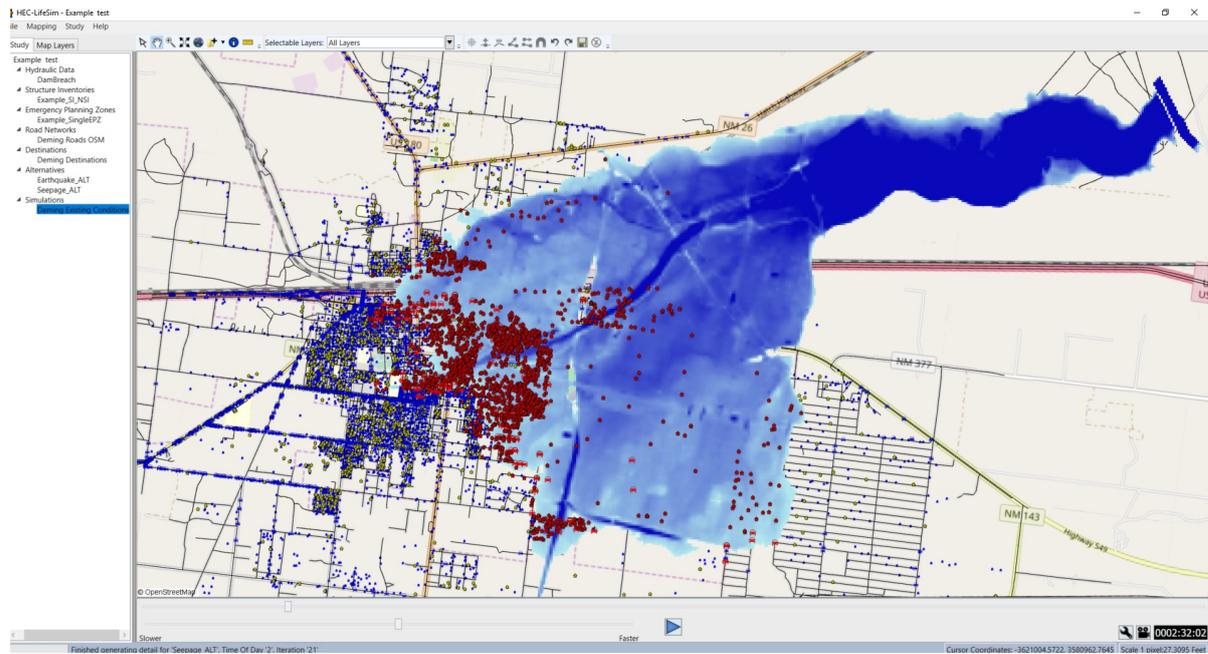


Figure 1.12: Example of a LifeSim model run.

### 3. Emergency Planning Zones:

This data set contains the overall evacuation effectiveness as seen in Sorensen and Mileti [22, 23, 24]. It will contain the warning issuance delay, warning diffusion and the personal action initiation curve for any given area.

### 4. Road Networks:

This data represents the possible evacuation routes that people can take during an evacuation. It accounts explicitly for different road types and their features like capacity, free flow speed and speed in case of a traffic jam. The traffic model is considered a dynamic traffic model.

### 5. Destinations:

The destination data represents possible evacuation locations during flood events. It can either be a shelter in the dangerous area or locations outside the flooding. It is often represented as a point on a highway that, once reached, counts as a successful evacuation.

### 6. Alternatives:

An alternative allows the user to define the input data sources and parameters that will make up the simulation computations. For example, many roads are one way, but what if the authorities counter flow several roads, meaning more cars can leave the area. The alternative tab is used to define multiple alternatives (or simulation) to compare the effects of operational changes.

# 2

## Problem Definition

### 2.1. Problem analysis

The safety region of South Holland south who are responsible for the island of Dordrecht in terms of crisis management in flood threat scenarios use the water safety plan of Dordrecht as an agenda setting and connecting document for crisis management, spacial adaption and communication towards the population. In this water safety plan evacuation strategies for different flood threat scenarios are elaborated. However, the base evacuation strategy is always vertical evacuation. Depending on the available time and threat scenarios additional measures can be taken such as preventive evacuation of the most threatened areas. In this water safety plan measures and investments are also introduced that should positively effect the warning issuance delay time and the departure curve of the population, which should result in less required time to complete an evacuation strategy.

However, at the moment no documentation or method is available that can show the safety region the effects of certain measures and investment following the water safety plan on the warning issuance delay time and departure curve of the population. Or what the effect of these two curves are on the required time for evacuation.

### 2.2. Goal and objectives

The goal of this study is to show what method could be used to translate certain measures and investment in the water safety plan of Dordrecht to a faster warning issuance delay time and departure curve and what the effect of these curves are on the required time it takes to complete an evacuation and the corresponding loss of life. It will furthermore investigate which parameters could also be used to influence this required time for evacuation. The starting point of this thesis is the USACE assessment method in combination with the evacuation and loss of life model LifeSim. The current estimations are gathered from the water safety plan of Dordrecht which are calculated with the PBL evacuation and loss of life model.

The overall objectives of this report are to:

1. *Make a model comparison between the PBL and LifeSim model;*
2. *Compare the current warning issuance delay time and departure curve of Dordrecht to the USACE assessment method applied to Dordrecht;*
3. *Develop a case study where Dordrecht will be modelled in LifeSim and the results on the required time for evacuation and loss of life will be compared with the current estimations of the water safety plan;*
4. *To show what method could be developed to estimate the changes in the warning issuance delay time and departure curve and the consequences of these faster curves on the required time for evacuation.*

## 2.3. Research questions

To fulfil the research objective of this study, the main research question will be:

*"What method can be developed to translate the effects of certain measures in the field of crisis communication following the water safety plan of Dordrecht to an altered warning issuance delay time and departure curve and estimate the effects of these on the required time it takes to evacuate the island?"*

The sub research questions are formulated as follows:

1. What are the fundamental differences between the PBL and LifeSim evacuation and loss of life models?
2. What are the differences between the warning issuance delay time and departure curve used in the Netherlands and the assumptions of the USACE assessment method?
3. Can the USACE assessment method be used to estimate the warning issuance delay time and departure curve of Dordrecht and include the effects of investments following their water safety plan?
4. What are the effects of an altered departure curve on the required time of an evacuation in certain evacuation scenarios of Dordrecht?
5. How does a faster decision making process relate to a faster departure curve in terms of required time for an evacuation for Dordrecht?
6. Are the results generalizable to other areas in the Netherlands?

## 2.4. Methodology and report structure

The objective of this thesis is addressed by a combination of two things. First the USACE assessment method is discussed with two experts from the safety region South Holland south. This should provide the warning issuance delay time, the warning diffusion curve and protective action initiation curve. After this interview, several LifeSim models will be developed that resemble scenarios taken from the water safety plan of Dordrecht. After these base simulations, sensitivity analyses will be introduced where important parameters are altered to see the effect on the required time for evacuation. The results from these simulates will be compared with the current expectations that follow from the water safety plan of Dordrecht. The structure of the thesis is as follows:

- **Chapter 3: Literature review:**

In this chapter a literature review is conducted in order to describe the fundamentals of both the PBL model and LifeSim, followed by an introduction to the USACE assessment method and information on the water safety plan of Dordrecht. The result of this literature review will be used to determine the boundary conditions of future LifeSim models and how to interpret the results.

- **Chapter 4: Result USACE assessment method:**

The USACE assessment method is discussed with two expert of the water safety region South Holland south, the safety region responsible to carry out the evacuation strategies of Dordrecht. The result of the USACE assessment method will be compared and discussed with the warning issuance delay and departure curve used in the PBL model.

- **Chapter 5: Case study:**

In chapter 5, three reference models are introduced for LifeSim and their results compared and discussed with the PBL model. These reference models are developed by using information following the literature review. This chapter is also accompanied with sensitivity analyses where important parameters are changed and a reflection on the LifeSim models.

- **Chapter 6: Conclusion and recommendations:**

In this chapter the main research question is answered in combination with the sub-questions. It will furthermore include recommendations that follow from the conclusions.

# 3

## Literature Review

This literature review will consist of five sub chapters which will discuss the following subjects: the PBL model, the USACE assessment method, the LifeSim model, the water safety plan of Dordrecht and the conclusion of the literature review. The first part will focus on why and how certain parameters of the PBL model are defined in a certain way and investigates the different parameters of the PBL model so boundary conditions can be developed that future LifeSim models runs must meet. Then the USACE assessment method is introduced, which will discuss the parameters included in the assessment method and the data on which it is based. After this, the LifeSim model is investigated more closely so important parameter options within LifeSim are known so potential differences between the different parameters of the PBL model and LifeSim can be addressed. Then the water safety plan of Dordrecht is discussed so different model scenarios can be developed and finally a summary of the literature review is presented.

### 3.1. PBL model

This section will further discuss the PBL model introduced in chapter §1.6. As a reminder the outline of the PBL model is repeated in figure 3.1.

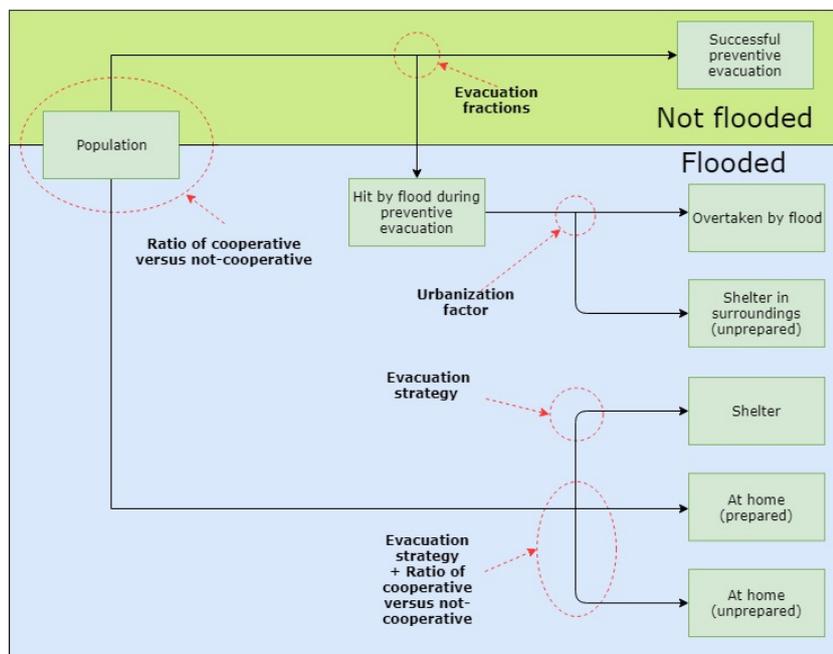


Figure 3.1: Victim categories of the PBL model as seen in [18]

### 3.1.1. Evacuation strategy and cooperation

The smallest zones of control that are considered with the PBL model are ZIP code areas. This effectively means that an entire ZIP code area can only evacuate vertically or preventive. Mixing these strategies provides a valuable asset when infrastructure proves a limiting factor. Areas that are in danger such as houses located directly next to a dike breach or low lying parts of the city can evacuate, whereas areas where it is safe to shelter can shelter in place.

Ideally, the population will always follow the evacuation strategy of the authorities. However, different events showed that not all people will act according to the instructions provided by the authorities [9, 16]. In the PBL model this is taken into account by the cooperation factor. In most area's a 80-20 rule is applied, meaning 80% of the population will follow the instructions of the authorities and 20% will do the opposite. So if preventive evacuation is the strategy, 80% will try to leave the threatened area and 20% will stay. Along rivers this is changed to 90-10% because people can see the water rising and thus have a higher incentive to leave.

### 3.1.2. Expected location of the population and urbanisation factor

The location of the population is determined by dividing the population over the different victim locations by means of (fixed) fractions. In Pleijter and Kolen [18] some examples are presented. If users estimate different results due to, for example, measures, particular evacuation strategies or available shelters, these fractions can be altered. In table 3.1 a summary is displayed of the fractions used in Pleijter and Kolen [18] for preventive and vertical evacuation. In figure 3.2 and example is presented for vertical evacuation. These estimations also include the urbanisation factor which is important when more people try to leave a threatened area than the evacuation fraction allows. In that scenario people will be hit by the flood during evacuation. In the PBL model it is assumed that these people will try to get themselves to safety (like a higher area or building) at the last possible moment. In urban areas it is assumed that 90% will reach a safe area in time and 10% will be overtaken by the flood, thus resulting in a correction factor of 10. People who manage to reach a safe area receive are put in the "at home unprepared" location. In rural areas this correction factor is 67%, .

	<b>Preventive</b>	<b>Vertical</b>
<b>Successfully evacuated</b>	Maaskant et al. [13]	Kolen et al. [11]
<b>Caught by flood</b>	Percentage preventive evacuation minus evacuation fraction	Percentage preventive evacuation minus evacuation fraction
<b>Overtaken by flood</b>	Caught by flood / urbanisation factor	Caught by flood / urbanisation factor
<b>Shelter in surroundings</b>	Caught by flood minus overtaken by flood	Caught by flood minus overtaken by flood
<b>Shelter</b>	10%	50%
<b>At home</b>	90% (80% prepared, 20% unprepared)	50% (80% prepared, 20% unprepared)

Table 3.1: Example of fractions used for preventive and vertical evacuation of the population. Found in Pleijter and Kolen [18]

### 3.1.3. Assumptions regarding the evacuation fractions

In the opening paragraphs of this thesis it was already mentioned that the evacuation fractions in the Deltaprogramma are actually a combination of multiple scenarios and assumptions. If specific scenarios are modelled, event trees can list what result can be expected in certain scenarios. However, each event tree is the result of different assumption which will be discussed below:

- **Different areas:** The first assumption is that not every area in the Netherlands has the same area characteristics. The location of a dike ring area plays an important part in the process of a possible evacuation. The Netherlands is divided into separate areas that take into account overlapping infrastructure needed during evacuation in a specific flood threat scenario. An example of a division into separate areas can be found in Slomp et al. [19] and is displayed in figure 3.3.

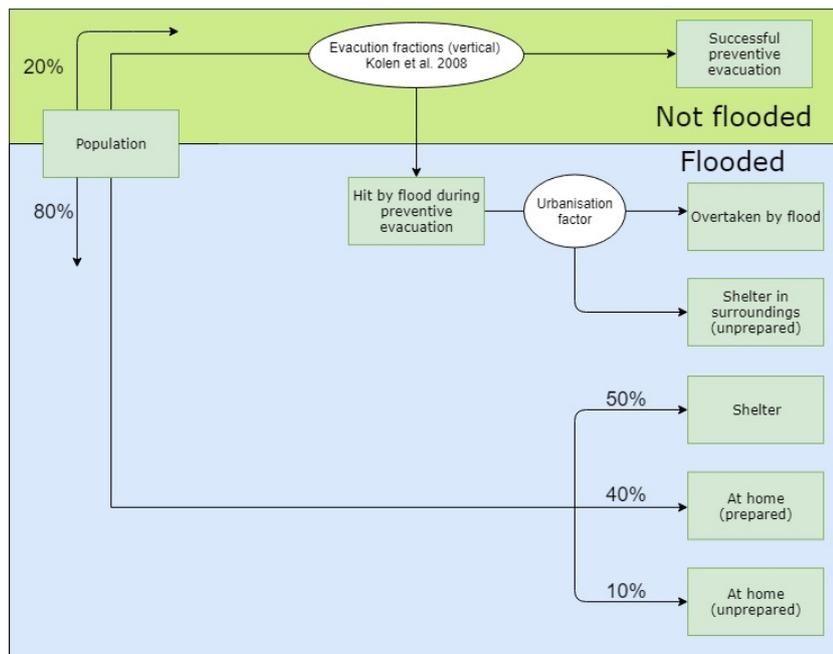


Figure 3.2: Example of fractions used for vertical evacuation. Found in [18]

- Available time:** The available time for evacuation depends among others on the weather expectation prior to a flood and the treat scenario. When an area is threatened that is affected by extreme river discharges, the weather almost never limits the ability to evacuate. So river areas can evacuate till the expected onset of a flood. However, areas located along the coastline are affected by extreme winds which will hamper the ability to evacuate, decreasing the available time for evacuation. In table 3.2 the hours that are unavailable for evacuation for different areas are listed. Dordrecht is part of the lower river area.

Evacuation area	Time prior to a breach that is not available
1. Friesland and Groningen	24 hours
2. North- and South Holland	24 hours
3. Zeeuwse and South- Holland islands	24 hours
4. Zeeuws-Vlaanderen	24 hours
5. Flevoland and surroundings	-
6. Lake area	6 hours
7. River area	-
8. Lower river area	24 hours (in storm related flood scenarios, otherwise 0)

Table 3.2: Hour that are unavailable prior to an evacuation due to extreme weather conditions [13].

- Conditional chances for available time:** In the evacuation trees conditional chances are included for the amount of available days. For certain areas the conditional chances for three or four days available time is estimated to be zero. This has to do with the fact for these areas, the necessary time for a complete evacuation is less than three or four days. For this reason it is highly unlikely that authorities will give an order to evacuate due to the massive economical and social impact.

An exception is made for the lower river area. This area is located behind the Maeslantkering (a large floor barrier) which closes if dangerous water levels or storms are predicted. That is why the conditional chance for four and three days is zero because authorities count on the barrier to close. However, this mechanical flood barrier also has a chance to malfunction (1% per closure). This means that the conditional chance for an unexpected flood in the lower river area is higher than in the other areas. This unexpected malfunction results in scenarios where little time is left for preventive evacuation.

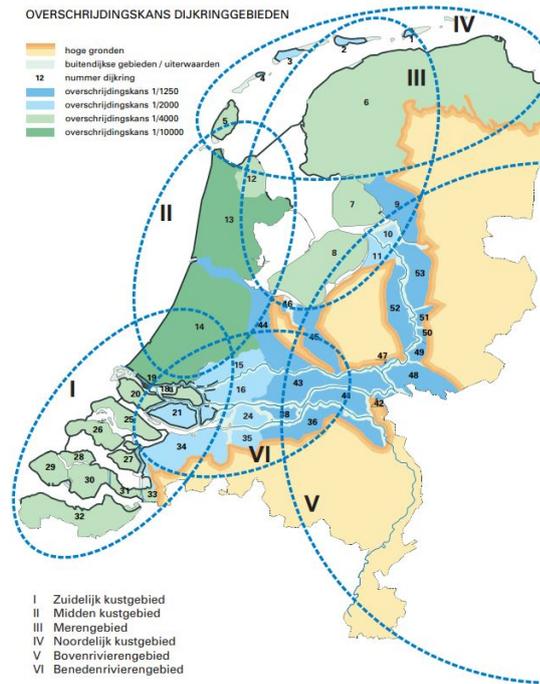


Figure 3.3: Area layout for supraregional floods found in Slomp et al. [19] (in Dutch).

- **Execution:** How well an evacuation is executed has a large influence on how many people can leave the area. This success depends on the circumstances during the evacuation, traffic management, coordination between organisations and choices of the population and will differ in each evacuation. In the event tree a distinction is made between a maximum, average and minimum effectiveness.

### 3.1.4. Traffic modulation & HIS-Evacuation calculator

The required time for evacuation in the Netherlands are based on the static traffic model HIS-EC. The HIS-EC makes a distinction between general and dike-ring specific information. It furthermore includes traffic management options. The general parameters are:

- Amount of people and cattle that has to be transported;
- Available road network;
- Road capacity;
- Amount of vehicles that are on the road;
- When people leave (departure curve)
- The time period that needs to be taken into account;
- Non-response factor;
- People car equivalent (people per car);

The dike ring specific options include information about where the people come from, go to (exits) and the capacity of these exits. This exit capacity simulates the effect that surrounding roads that are not part of the model are also congested by other evacuating areas. It is also possible to include traffic management options to simulate an uncertainty range in how effective the traffic flows. These traffic management options are:

- **Reference:** It is assumed that the evacuees distribute themselves evenly over the predefined exits of the area.
- **Near:** It is assumed that every evacuee leaves the area via the nearest exit, regardless of the road capacity of this exit. This strategy gives the highest priority to minimising the vehicle kilometres and knows it only converging traffic flows and therefore no intersecting traffic flows.
- **Traffic management:** Here the evacuees are distributed according to the road capacity. The goal is to minimise the amount of vehicle kilometres.

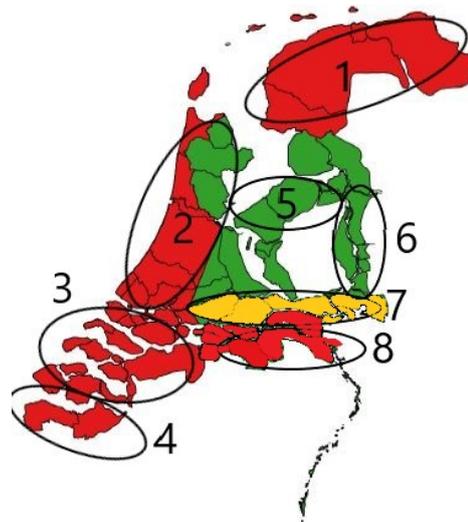


Figure 3.4: Areas in the Netherlands with less available time for evacuation (red and yellow) in wind related flood scenarios, based on Maaskant et al. [13].

### 3.1.5. Mortality

The mortality in the PBL model is a slightly altered approach of the model developed in the paper of Jonkman [5]. Jonkman proposed a model for which the mortality in situations that are typical for Dutch areas can be estimated. In his paper it is concluded that most fatalities occur directly behind a breach or in areas with rapid rising water. Locations further away from a breach have a better survival rate. As such, areas affected by a dike breach are divided into three areas.

- Breach zone: Due to the inflows through the breach, high flow rates are generally measured directly behind the breach.
- Zones with rapidly rising water: Due to the rapid rising water, people are often not able to reach shelter on higher ground / buildings. This is particularly dangerous in combination with larger water depths.
- Remaining zone: In this zone the flood conditions develop more slowly ( $<0,5$  m/hr), offering higher change to find shelter.

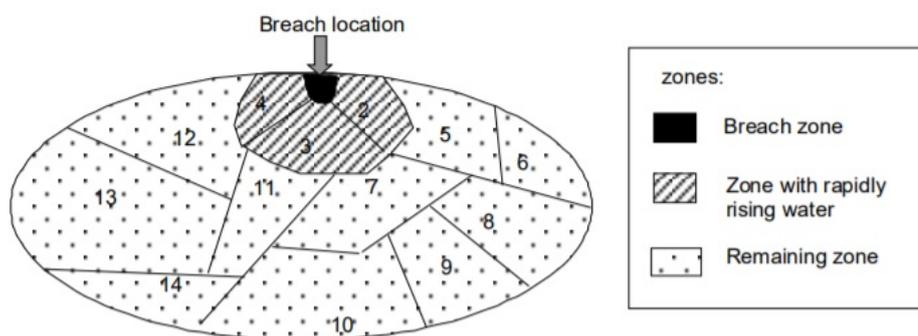


Figure 3.5: Proposed hazard zones Jonkman [5]

The mortality functions in these different zones are developed by combing the results from historic flood from around the world. The data is taken from data sets that include import information regarding the flood such as: event characteristics (name, location, date), flood characteristics (depth velocity, rise rate), information regarding warning, evacuation, shelter and collapse of buildings and more descriptive information regarding circumstances and vulnerabilities of floods fatalities. The mortality rate for these different zones are:

- Breach zone: For the population located in the breach zone a mortality of 100% is assumed.
- Rapidly rising water zone: In figure 3.6 the mortality function of the rapidly rising water zone is displayed.
- Remaining zone: In figure 3.7 the mortality function of the remaining zone is displayed.

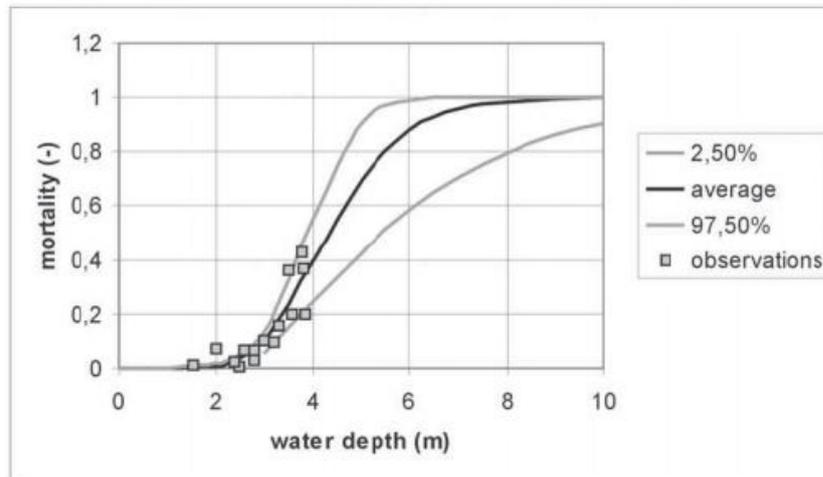


Figure 3.6: 2.5% and 97.5% confidence intervals of the rapid rising zone Jonkman [5]

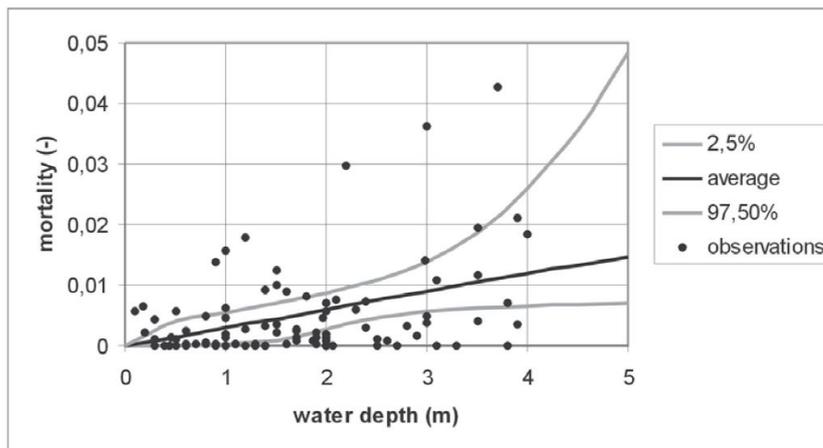


Figure 3.7: 2.5% and 97.5% confidence intervals of the remaining zone Jonkman [5]

The PBL model uses the mortality functions of these different zones by linking it to a specific location of the population. Meaning that the location of the population is not determined by means of modelling an area into separate flood zones, but rather by means of a global differentiated method. Meaning that the population is divided over the different victim locations by means of fixed fractions and coupled with the mortality rates seen in Jonkman [5]. This results in the following mortality rates for the victim locations of the PBL model:

- Successful preventive evacuation: Mortality rate of 0.001%
- Overtaken by flood: A mortality rate of 5 times the average mortality rate in the area.
- Shelter in surroundings: Same mortality as the "at home - unprepared" location.
- Shelter: Mortality rate of 0.05%
- At home: For the population at home the upper limited of the rapid rising zone (figure 3.6) is used to estimate the mortality of the "at home unprepared" population whereas the lower limit of this function is used to estimate the mortality of the people that are "at home prepared".

### 3.2. USACE assessment method

The answers of the questionnaire provided by the USACE assessment method are quantified to scores that can be used to generate the warning issuance delay, warning diffusion time and personal action initiation curves. The curves generated from this assessment method include an uncertainty range of which an example is displayed in figure 3.8. In this paragraph the USACE assessment method is discussed including the data behind the USACE assessment method.

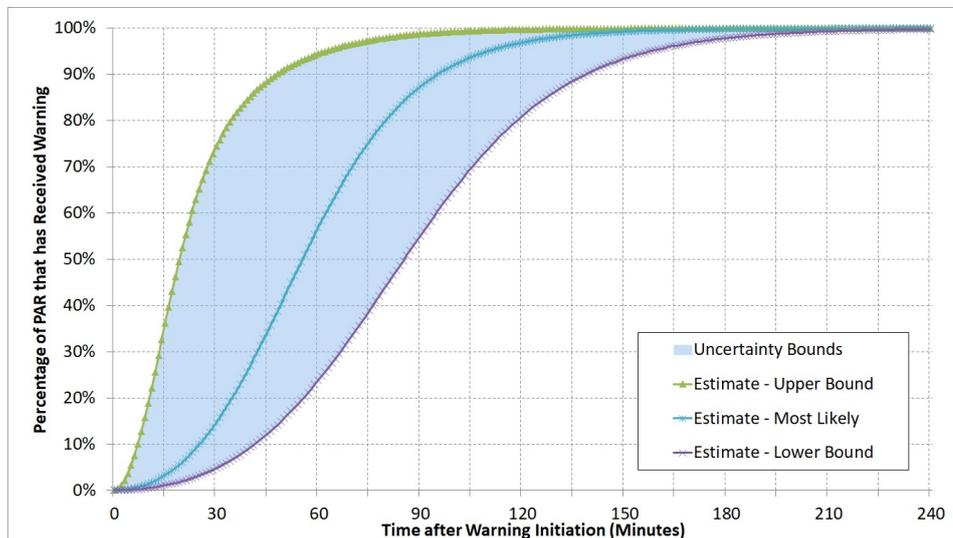


Figure 3.8: Example of a curve (warning diffusion curve) generated by the USACE assessment method.

#### 3.2.1. Warning issuance delay

The warning issuance delay time is the time it takes for decision makers to reach a decision to issue a warning once they detected the hazard or have been notified of the hazard by those monitoring for it. In Sorensen and Mileti [23] the theory and data behind the warning issuance delay that is used in the USACE assessment method is listed. Sorensen and Mileti found that there are four major categories that influence this warning delay.

- The first one is the formalisation of planning and implementation procedures. Communities that have thought through the warning decision process and prepared plans, procedures and the relevant tools for arriving at rapid decisions will perform better than those communities who have left warning decisions to be made in an ad-hoc manner. Sorensen and Mileti mention that although many communities have adopted an incident command decision structure, it is unclear what impact this type of structure has on the timing of warning issuance.
- Second are the performance and interpersonal relations factors. Having been trained on the warning issuance process and exercised it on a periodic basis will improve the effectiveness of the decision process. Moreover, understanding the communications process and knowing the people one is communicating with will also reduce issuance time. Flexibility in adapting to new and unforeseen situations will also reduce delays.
- Third are system performance factors. Having hardened and redundant communications can prevent technology failures from interfering with making decisions.
- Fourth are situational factors. Some of these can be effectively controlled; others require adaptive planning procedures to overcome detrimental effects. Warnings are delayed when incidents occur during the night versus during the day. If the event that caused the emergency impacts electricity supply in or the physical infrastructure of the community, delays may be unavoidable. Environmental cues such as the lack of rain during a flood event may cause decision makers to delay decisions. The urgency of the need to make a decision can be a strong motivation to reduce delays in warning.

These four mayor categories can be further divided into separate parameters that are listed in table 3.3. Sorensen and Mileti do note that a lack of data means that it is not possible to estimate how strong each single factor influences the warning delay time. Rather, they argue that as more factors that are associated with reducing the delay are present, the warning delay time will decrease.

The warning issuance delay that follows from the USACE assessment method is rather straightforward. The assessment method provides a minimum and maximum estimation of the warning issuance delay in combination with a most likely (mean) time.

<b>Factor</b>	<b>Importance</b>
<b><i>Formalisation of planning and implementation procedures</i></b>	
-Standard warning plan is written down	High
-Standard operating procedures are written down	High
-Warning thresholds are in place (matrix)	High
-Succession planning is detailed within standard operating procedures	Low
-Responsibilities are identified	Moderate
-Clearly define authority to issue warnings	Moderate
-Interagency communication follows rules and procedures	High
-There is two-way communication among organisations	Low
-Threat verification procedures are defined	Low
<b><i>Performance and interpersonal relations</i></b>	
-Standard operating procedures practice is conducted (drills or exercises)	Moderate
-Personal knowledge of communicating personnel	Low
-Frequency of interaction	Low
-Ability to improvise	Low
<b><i>System performance factors</i></b>	
-Failsafe communication mechanisms are in place	Low
-Redundancies in communications are in place	Low
<b><i>Situational factors</i></b>	
-Day or night	Moderate
-Power availability (electricity)	Low
-Damage to infrastructure	Low
-Environmental cues	Low
-Time to impact	Moderate
-Number of people involved	Moderate
-Experience of community	Low

Table 3.3: Factors that influence first alert and / or warning issuance delay, found in [23].

### 3.2.2. Warning diffusion time

The warning diffusion represents the process of how efficiently information spreads through the population at risk. In Sorensen and Mileti [22] the data behind the USACE assessment method regarding the warning diffusion is discussed. Sorensen and Mileti found that there are different factors that influence the diffusion time, which can be divided into two mayor categories.

- The first one is sending the first alert. Sending a first alert can come from an formal notification system, informal notification or from cues directly from a persons environment. It can either be an alert (signal) or a notification (message). Signals indicate something out of the ordinary is happening and serve as a cue for seeking further information.
- The second one is receiving the first alert warning. The receipt of a first alert is also influenced by the characteristics of people for whom the alert is intended. These are divided into the categories of the activities that people are engaged in when a first alert is issued, where they are located, time of day, first alert reception impediment and personal resources available to first alert recipients.

In table 3.4 the parameters and their importance are displayed. Sorensen and Mileti do note that the data on which they based their warning diffusion time model is relatively old and were obtained before availability and use of many of the modern first alert diffusion technologies that are in place today such as wireless emergency alerts, social media opportunities etc. They could not include empirical data on which to estimate what first alert diffusion might actually be like in today's modern world. They estimate that by including more recent data the uncertainty is reduced and will improve the confidence in estimating the diffusion curves.

Factor	Importance
<b><i>Sending the first alert / warning</i></b>	
-Channels - types of technologies	High
-Channels - disruption to infrastructure	Low
-Number and mix of channels	High
-Frequency of distribution	High
-Informal notification	Moderate
-Environmental and social cues	Low
<b><i>Receiving the first alert warning</i></b>	
-Activity - task (task is warning other people)	Moderate
-Activity - location and proximity to the hazard	Moderate
-Activity - time of day	High
-Impediments - sensory (hearing, visual)	Moderate
-Impediments - linguistic and cultural	Low
-Resources - access to technology	Moderate
-Social media participation	Low
-Social- economic status	Moderate

Table 3.4: Factors that influence the warning diffusion time, found in [22].

For the warning diffusion curve that follows from the USACE assessment method after completing the questionnaire, the assessment method makes a distinction between a day and night curve where the warning diffusion is slower in the night. It furthermore includes an uncertainty range. For simulations in LifeSim the user can then choose at what time the warning will be sent to the population (for instance 2 a.m.). These nighttime warnings may form an important factor if dangerous events are unannounced such as dam failures or flash floods.

### 3.2.3. Protective action initiation curve

The protective action initiation is the time between when an alert or warning is received by a person at risk and the initiation of a recommended protective action by that person. In Sorensen and Mileti [24] the data and important parameters on which the USACE assessment is based are discussed. In that paper Sorensen and Mileti show that mixes of different factors influence the effectiveness of the protective action initiation time. These factors can be separated into three mayor categories.

- The first one is the warning message characteristics. The warning message characteristics influences how much time people delay in initiating a protective action. These message characteristics are divided into content, style, delivery and the type of recommended protective action.
- The second one is the receiver characteristics. These represent how people interpret alert and warning differently. These include personal attributes, role characteristics (being responsible for others such as children or pets), personal preparedness, pre-event knowledge and experience and membership in a socially isolated group.
- And lastly, the context characteristics represent what context factors influences how people interpret alert and warning differently. The context characteristics represent how context influences people on how they interpret alert and warning differently.

The different factors and parameters that influence the protective action initiation curve in the USACE assessment method are displayed in table 3.5. It is important to note that the data that was used to estimate the important parameters influencing the protective action initiation curve is primarily based on chemical accidents and hurricanes. The data for flooding events is limited. Furthermore, most data used to generate the

curves is relatively old, coming from the late 1980's and early 90's. Sorensen and Mileti assume that the basic social processes associated with initiating a protective action have not changed in the last 25 years. Also, all empirical data on the personal action initiation curve comes from events where preventive evacuation is the recommended protective action, There is no empirical data on vertical evacuation. And lastly, Sorensen and Mileti assumed that changes in emergency management practises that may impact the factors in table 3.5 have not changed, although they expect that this is not the case. Meaning that some measures may lead to an improved content of warning messages which in turn leads to a faster personal action initiation curve.

<b>Factor</b>	<b>Importance</b>
<b>Message characteristics</b>	
-Appropriate content	High
-Style	High
-Message length adequacy	Moderate
-Personal	High
-Delivery (frequency)	High
-Protective action type	Moderate
<b>Receiver characteristics</b>	
-Status attributes	Moderate
-Role characteristics	High
-Personal preparedness / planning	Low
-Pre-event knowledge	Low
-Experience	Moderate
-Membership in a socially isolated group	Moderate
<b>Context characteristics</b>	
-Environmental cues	High
-Social cues	Moderate
-Location / activity	Moderate
-Day versus night	Low
-Time to impact	High
-Impact intensity	High

Table 3.5: Factors that influence the protective action initiation curve, found in [24].

In the results that follow from the USACE assessment method, the protective action initiation curve takes into account different "initial perception" zones, effectively meaning how the population will think about the dangerous event and how it will effect them. People living directly in the path of, for example, a hurricane will evacuate in greater numbers and at a faster rate than people that life in an area that lies on the outskirts of the predicted hurricane path. The different perception zones are:

- Likely to impact
- Unlikely to impact
- Unknown

These perception zones will determine the maximum "mob rates" (the percentage of people that will leave their home). The mob rates are further influenced by the available time. If the available time is short (<8 between warning issuance and flood) less people will leave their home than when the available time is, medium (8<24hours) or (long >24 hours). These mob rates are similar to cooperation factor of the PBL model.

### 3.3. LifeSim

In this chapter the basics of LifeSim are discussed. It is already mentioned that a LifeSim simulation consists of six data sets. Not every parameter within these data sets will be discussed in this chapter for reasons of brevity. Instead it will focus on the most important parts of LifeSim.

### 3.3.1. Traffic modulation

LifeSim incorporates a dynamic traffic model in which the road network itself is imported as a line shapefile. In that shapefile, roads can be defined as one way and can include a vertical offset, meaning that if water starts to rise, certain roads may remain dry. Every road has its own CFCC code. This CFCC code defines what kind of road it is and is generally defined as A16 or N217. Every CFCC code has parameters attached that determine the amount of lanes, free flow speed (km/h), jam density (vehicles/km), break away density (vehicles/km) and stop and go speed (km/h). The definition of these parameters is presented below:

- Free flow speed: How fast a car can go if there is no traffic (maximum speed).
- Jam density: The amount of cars that can fit on one mile stretch road in one lane if traffic is bumper to bumper.
- Break away density: How many cars can move in one lane at the free flow speed on a one mile stretch of road.
- Stop and go speed: The speed that vehicles will travel when traffic jam conditions are met.

LifeSim then couples these parameters into a speed density function that will then determine how fast cars can go in certain conditions. An example speed density function is presented in figure 3.9.

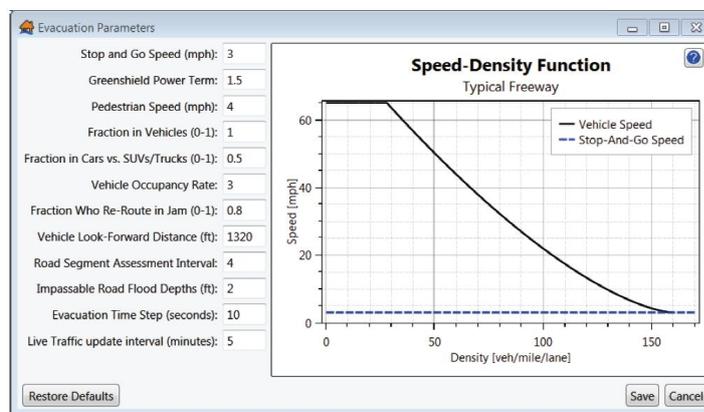


Figure 3.9: Example of a speed density curve of a typical highway.

These road parameters are coupled with road behaviour of the population under the alternative option data set. These include

- Fraction who re-route in jam.
- Vehicle look forward distance: Distance in front of a vehicle that is used to define the traffic density.
- Effective vehicle length: The effective length of a vehicle that determines load limits.
- Non-evacuation depth: Depth at a structure where people no longer attempt to evacuate away from a structure.

### 3.3.2. Location of the population

In the LifeSim model the location of the population is not determined by means of fixed fractions like the PBL model but by an interaction between all the different data sets and uncertainties included in the LifeSim model. These uncertainties mean that in each iteration of the simulation the location of the population will differ. The possible locations of the population are presented below:

- Successfully reached a destination
- Overtaken by flood
- In a structure (the user can include numerous different buildings such as hospitals, schools, homes, factories etc.)

It is important to mention that LifeSim does not include a sort of urbanisation factor, meaning a way of getting people who are in a car but have no chance to get of the island (surrounded by water or in a large traffic jams minutes before the flood hit) into a safe area. As soon as people get into their car they will drive until they either found an exit or are hit by the flood.

However, although the user can define multiple building types, it is difficult to include shelters within the threatened area with LifeSim. It lacks an option to define a destination point that functions as a shelter since destination points always function as an exit. Meaning a user cannot include a capacity (a maximum amount of people that can enter a shelter). Also, if this destination point were to be placed within the city centre for example to function as an exit capacity, people will go to this destination point since it has the shortest travelling time. There are some modelling methods to only allow certain people to use an exit, but these are time consuming to model and do not change the fact that "a shelter destination point" has the same mortality function as an exit destination point.

### 3.3.3. Mortality

The mortality in LifeSim is determined by the location that a person finds him or herself in. Depending on the location of the person, he or she is classified in a high or low hazard zone. Each zone has its own loss of life parameters. Where the dose response function differ in comparison with the PBL model is that in LifeSim the loss of life parameters are a function of the **relative frequency of exceedance** and **proportional life loss**. The relative exceedance represents the probability of receiving a particular fatality rate whereas the proportional life loss represents the fatality rate. In figure 3.10 the default mortality function of the high hazard zone is displayed.

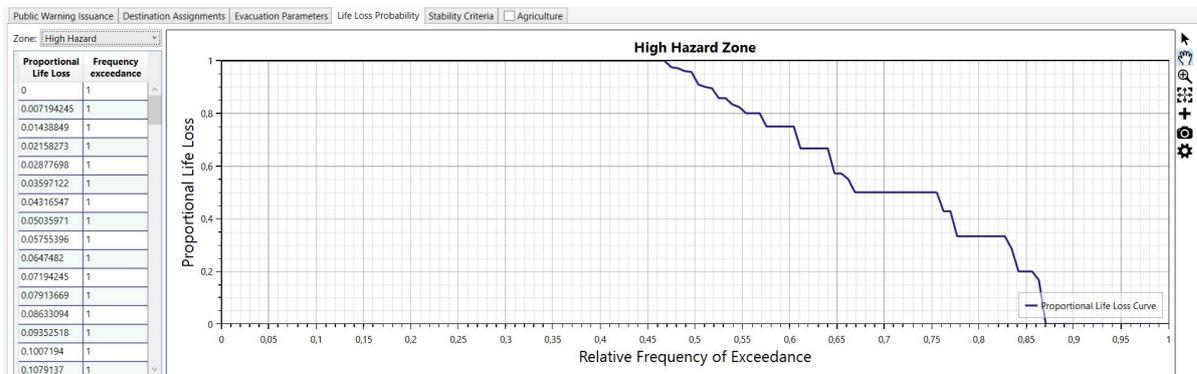


Figure 3.10: Default LifeSim mortality in the high hazard zone

## 3.4. Water safety plan Dordrecht

In this sub-chapter important topics from the water safety plan that have not yet been introduced will be discussed. It will start by introducing the different flood threat scenarios, then the different possible evacuation strategies, the expected available time and the required for certain strategies and finally list the roads capacity assumed in different scenarios.

### 3.4.1. Threat scenarios

Different flood threat scenarios warrant different evacuation strategies. The different flood threat scenarios that can affect Dordrecht are displayed in figure 3.11 and the corresponding consequences and evacuation strategies in table 3.6. These flood threat scenarios are based on the current strength of the flood defences and the historical water levels. These threat scenarios represent the possible severity of an event, given a certain return period.

### 3.4.2. Evacuation strategies and mortality

The evacuation strategy of Dordrecht is always based around vertical evacuation. If enough time is available, additional follow up measures will be taken such as evacuating the most threatened part. However, to gain insight in the expected loss of life value for some scenarios five different evacuation strategies for each threat scenario are elaborated, meaning the amount of people that are affected by the flood, the evacuation time needed for different ZIP code areas and the loss of life. The different calculated evacuation strategies are:

1. The basic approach (vertical prepared) where everybody shelters in their own home after informed. There is also enough time for people to take certain preparatory measures.

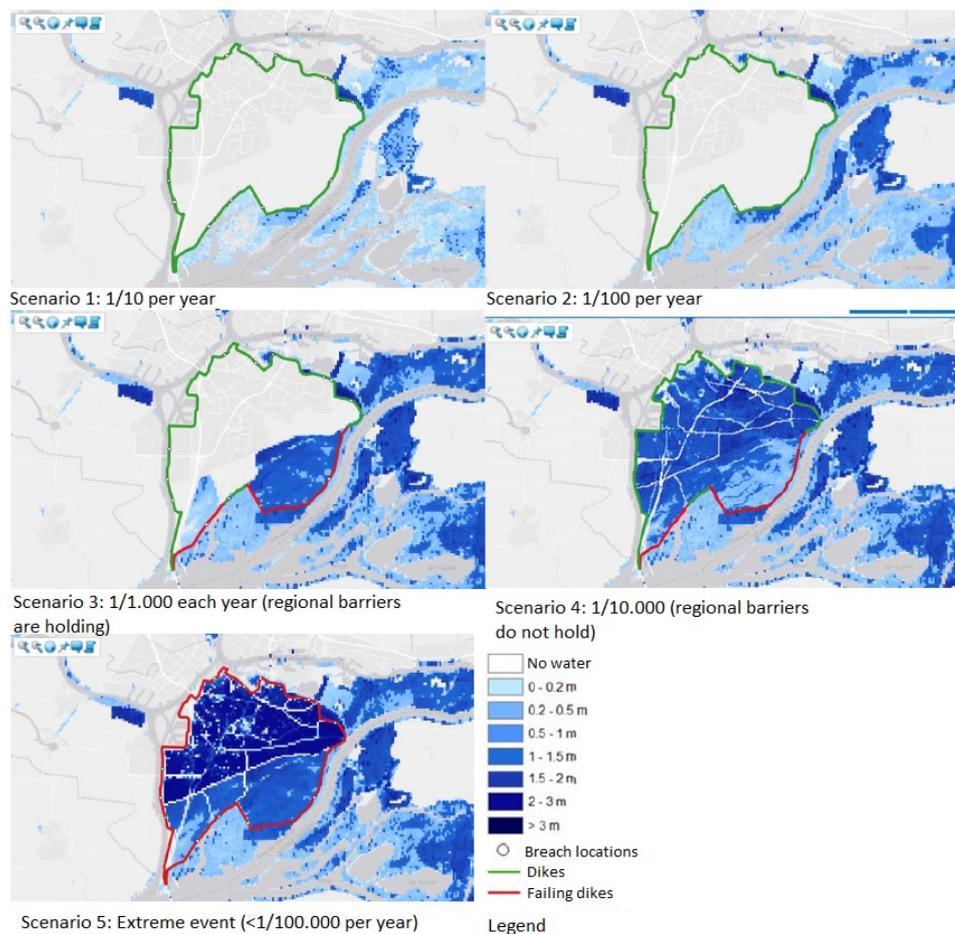


Figure 3.11: Different threat scenarios as seen in Kolen and Huizinga [10].

2. Shelter (based on current availability)
3. Shelter (based on the necessary availability)
4. Preventive evacuation (with enough available time)
5. Vertical unprepared. In this situation no decision is made to evacuate and the flood comes 'unexpected'. People will evacuate vertically but are less prepared.
6. Preventive evacuation with little time (wrong call). This scenario is only applicable in threat scenarios 4 and 5 because in the other scenarios the untreated area is still available.

In table 3.7 the loss of life for the different evacuation scenarios in threat scenario 5 for different ZIP-code areas is presented.

### 3.4.3. Available time

Based on the available time before the breach (remember, wind can further reduce the available time) it is possible to determine which strategies can be applied. The available time following from the water level expectations is between two and five days. In case that the Maeslantkering fails (1% per closure), the available time is limited to several hours.

The available time to the onset of the flood is expected to be somewhere between two days and an almost unexpected event (0+ hours). Because extreme wind is also a factor the flood is unexpected in 30% of the cases (no time to prepare). In 50% of the cases there is one day available time and in 20% of the cases there are two days available with one day used to implement measures, see figure 3.12.

	Consequences on Dordrecht	Surroundings	Evacuation strategy
Sc.1	Problem limited to outside of the dike	Limited	Vertical evacuation, when necessary relocate people to other parts on the island.
Sc.2	Problem limited to outside of the dike	Limited	Vertical evacuation, when necessary relocate people to other parts on the island.
Sc.3	Problems outside of the dike + flood threat rural area	Storm + flooding danger at weak points	Vertical evacuation, when necessary relocate people to other parts on the island. For the southern part people will evacuate to the northern part of Dordrecht.
Sc.4	Problems outside of the dike + flood threat rural area and inhabited area	Storm + large flooding danger in entire area	Vertical evacuation and possible preventive evacuation.
Sc.5	Problems outside of the dike + flood threat city and rural area. (breaches in multiple locations)	Storm + large flooding danger entire area	Vertical evacuation and possible preventive evacuation.

Table 3.6: Composed threat scenarios for the island of Dordrecht as seen in the water safety plan of Dordrecht [10].

Loss of life with strategy:	ZIP code area											Total
	3311	3312	3313	3314	3315	3316	3317	3318	3319	3328	3329	
Base (shelter in place)	25	40	<5	60	75	5	65	25	40	60	5	400
Shelter (current availability)	9	10	20	35	55	20	20	10	30	50	15	274
Shelter (required availability)	9	10	5	20	20	5	20	10	15	20	5	139
Preventive evacuation	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	0
Shelter at home unexpected	45	75	<5	115	140	5	120	50	80	120	10	760
Preventive with little time (wrong call)	310	1010	<5	640	2555	45	680	275	1100	840	85	7540

Table 3.7: Loss of life for different evacuation strategies in threat scenario 5 as seen in the water safety plan of Dordrecht [10].

#### 3.4.4. Required time

The required time for a **preventive evacuation** of Dordrecht in scenario 4 and 5 is based on the paper of Maaskant et al. [13] and the accompanying paper of Kolen et al. [12]. In the water safety plan of Dordrecht it is assumed that the whole lower river area also evacuates and thus also uses the surrounding rounds of Dordrecht. These estimations are based on traffic models where the different degrees of evacuation success are taken into account. The uncertainty range is set up by taken into account a reduced impact of the wind and by implementing other evaluations of better and worse execution of the evacuation. These estimation on how many people can leave Dordrecht in a certain amount of time is displayed in figure 3.12. This figure shows that it is almost never possible to preventively evacuate the whole island in time and that there is a large chance that many people remain on the island.

#### 3.4.5. Traffic model and required time for relocation

The travelling time of the population of Dordrecht is influenced by the congestion on the roads surrounding Dordrecht and the threat scenario. In threat scenarios 1, 2 and 3 the travelling time is usually not significant since most people stay on the island. In threat scenarios 4 and 5 where the whole island is flooded, the travelling time becomes significant due to the number of people that have to leave the island in combination with the limited exit capacity. This limited exit capacity is the result of multiple areas in the Netherlands that are evacuating. A distinction between two road scenarios is used which are an optimistic and realistic road scenario.

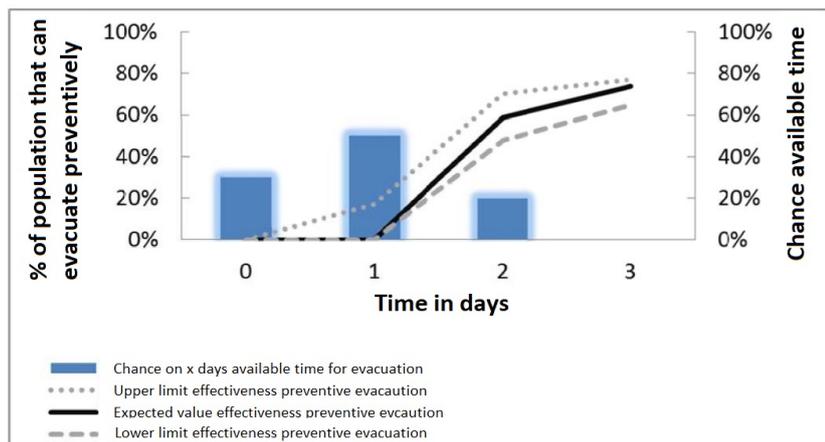


Figure 3.12: Required time for preventive evacuation due to dike failures set against the chance for a certain chance on available time [10].

- Optimistic:** In this situation the load on the road network in the area itself and surrounding areas is limited. A reduction of 50% of the road capacity is assumed compared to normal conditions. This 50% is used to represent the negative effects of the weather and other effects on the road capacity. It is assumed that the total exit capacity of the island is 12600 cars an hour. A breakdown of the capacity from specific exits is presented in table 3.8. In this case an average of 2.2 people per car is assumed.

Exits	Road capacity (cars / hour)		
	Lanes	Good weather (normal conditions)	Bad weather (evacuation condition)
N3 bridge over Beneden-Merwede	2x	4400	2200
Bridge over Oude Maas	1x	1800	900
A16 tunnel	4x	8800	4400
N217 tunnel under Dordtsche Kil	2x	3600	1800
A16 bridge over Hollands Diep	3x	6600	3300
<b>Total road capacity leading out of the area</b>		<b>25200</b>	<b>12600</b>

Table 3.8: Road capacity in optimistic scenarios as seen in Kolen and Huizinga [10].

- Realistic:** In this situation the road network surrounding Dordrecht is overloaded, which is the result of multiple areas in the Netherlands that are evacuating. In these cases the capacity of the different exits is strongly limited, meaning traffic jams are bound to happen. The total exit capacity in these scenarios is estimated to be 1100 cars / hour.

### 3.5. Conclusion literature review

By now it should be clear that both models operate on a fundamental different level (macro vs micro) from each other. They both approach and handle important subject like mortality, traffic simulation and expected location of the population differently. This is because they are both tailored to what their users expect of an evacuation and loss of life model. The inclusion or lack of certain options therefor does not make a model better or worse than other models, it only makes it better suited for certain scenarios. A summary of some important differences between the models is presented in table 3.9 and will be discussed in the following paragraphs.

	<b>PBL model \ HIS-EC</b>	<b>LifeSim</b>
<b>Modelling level</b>	Macro level	Micro level
<b>Including warning issuance delay time</b>	Indirectly by estimating available time	Yes
<b>Including Warning diffusion curve</b>	Part of departure curve	Yes
<b>Including protective action initiation curve</b>	Part of departure curve	Yes
<b>Different victim locations</b>	6	3
<b>Different loss of life functions</b>	5	2
<b>Traffic model</b>	Static	Dynamic
<b>Calculating people per car</b>	Direct control (user defined)	Indirect control
<b>Including exit capacity of area</b>	Yes	No
<b>Can stop evacuation (to simulate extreme weather)</b>	Yes	No

Table 3.9: Several differences between the PBL model and LifeSim.

### 3.5.1. Victim locations, mortality rate and flexible evacuation strategy

Where the PBL model distinguishes between six different victim locations and five mortality rates, LifeSim differentiates between three victim locations with two mortality functions. Although it can be argued that LifeSim includes many more different victim locations because the user can define building types such as hospitals, houses and factories that each has its own parameters such as stability criteria and if people are warned at the same time. However, it is denoted as three because LifeSim does not differentiate in mortality between a dry story of a hospital or a dry story at home. Also, in the results the loss of life can only be displayed in total loss of life, loss of life in structures, loss of life on roads and loss of life for people who are not at risk.

This difference in victim locations and mortality rates results in the PBL model being better equipped to directly show the outcome of a flexible evacuation strategy. Users can assume more shelter capacity or better prepared people that shelter in place. In LifeSim it is more difficult to directly see the result of a flexible evacuation strategy because there are only two mortality functions and no (easy) option to include a shelter located within the threatened area.

### 3.5.2. Traffic model and average people per car

The HIS-EC is a static traffic model whereas LifeSim incorporates a dynamic traffic model. Within the HIS-EC users can also include an exit capacity to limit the amount of people that can leave an area. This is used to simulate the fact that surrounding roads are often congested because multiple areas in the Netherlands are also evacuating. LifeSim does not include this option. They differ on how the amount of people per car is determined.

The HIS-EC determines the amount of people per car by a predefined number set by the user which can also include decimal points. Within LifeSim, the user sets the amount of people per car for each type of building, meaning a single family home, hospital, flat etc. This can only be a whole number. However, LifeSim does not bundle different types of houses together so this average is reached. What this effectively means is that if the average people per car is set to 2 for a certain building type but there are 100 **separate** houses where only one person lives and one flat where 20 people live there will be 100 cars with only 1 person and 10 cars with 2. Which will not average out to two people per car. This will result in the user having less control over the amount of people per car in LifeSim than in the Netherlands.

### 3.5.3. Extreme weather

Evacuation scenarios in the Netherlands are often accompanied with extreme weather which will hamper the ability to evacuate, in the case of Dordrecht, shortening the available time with 24 hours. In the HIS-EC this is modelled by setting a simulation run time. After this set amount of time, the user can then determine how many people reached an exit and how many people are still in the process of evacuating. In LifeSim, this available time is a little more nuanced. The user can also determine how many hours prior to the expected onset of a disaster a dangerous event is identified, but it will not stop an evacuation on or prior to the onset of a disaster.

What this effectively means for Dordrecht is that in case of a dike breach, people will still evacuate as long as the non evacuation depth is not reached around their house. If a dike has breached that is located at the west side on the island, people in will still evacuate on the east side. Even when there are huge traffic jams and no possible way to reach an exit before a mortal water level is obtained.

#### **3.5.4. Warning delay, warning diffusion and personal action initiation**

The USACE assessment method and LifeSim distinguish between a separate warning delay time, warning diffusion curve and personal action initiation curve. These curves (generally) also can include an uncertainty range. In the Netherlands however, the warning issuance delay time is not taken **directly** into account in the model simulations, but rather indirectly when estimating the time left till the onset of the disaster. It is assumed that a period of 24 hours has preceded the decision to evacuate and a model simulation start when authorities "press the button". These traffic model of the PBL model is run with the HIS-EC.

Another difference is that the warning diffusion curve and personal action initiation curve in the Netherlands are combined into a single departure curve. This departure curve has no uncertainty. Meaning whether it is day or night or a threat is announced or unannounced, the departure curve remains the same.



# 4

## Result USACE Assessment Method

### 4.1. Introduction

The questionnaire and the corresponding answers of the USACE assessment method following the expert interview are displayed in Appendix A. The results of the assessment method will be discussed in the following paragraphs. It is important to note that at this point no changes have been made to the different options within the curve generator. After the results potential differences will be discussed including an explanation on why they differ. LifeSim includes an option to show the issuance to initiation graph which is a combination of the warning diffusion and personal action initiation curve. This issuance to initiation graph is used to compare the results of the USACE assessment method to the departure curve of the PBL model.

#### 4.1.1. Warning delay time

The warning issuance delay time is the time it takes for decision makers to reach a decision to issue a warning once they have detected the hazard or have been notified of the hazard by those monitoring for it or by others who may have observed evidence of the hazard perhaps by chance [23]. The warning delay time that follows from the USACE assessment method is displayed in figure 4.1. If this graph is imported by means of a triangular distribution, the warning delay time is somewhere between 0 minutes and 240 minutes, with a most likely (mean) time of 80 minutes. This means that in an average simulation the time it takes for a dangerous situation to be observed to the point that a warning is sent to the population is 80 minutes.

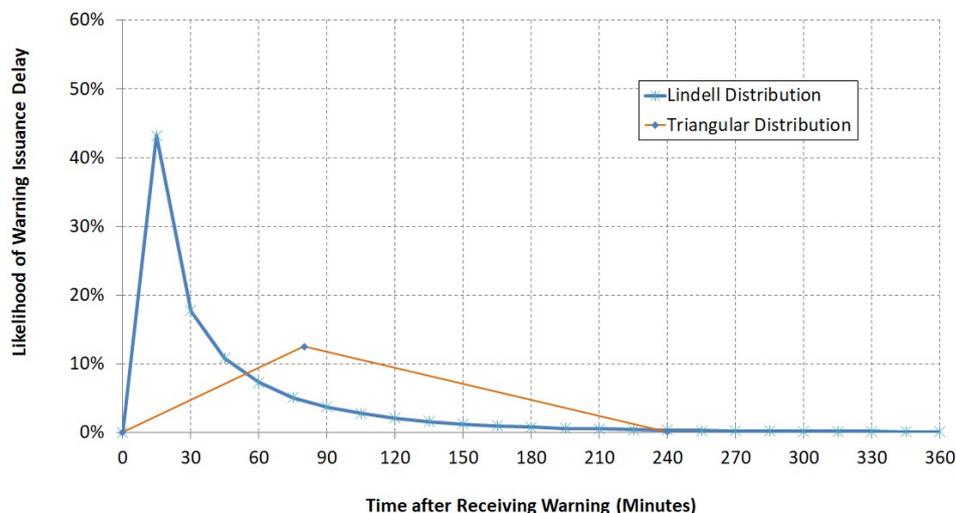


Figure 4.1: Warning delay time for Dordrecht according to the USACE assessment method.

### 4.1.2. Warning diffusion time

The warning diffusion time measures how efficiently a warning spreads through the population and can be described as the period after the first alert / warning is issued and the time people receive that warning [23]. The warning diffusion time that follows from the USACE assessment method when applied to Dordrecht is displayed in figure 4.2 and represents the warning diffusion time during day time (left) and night time (right).

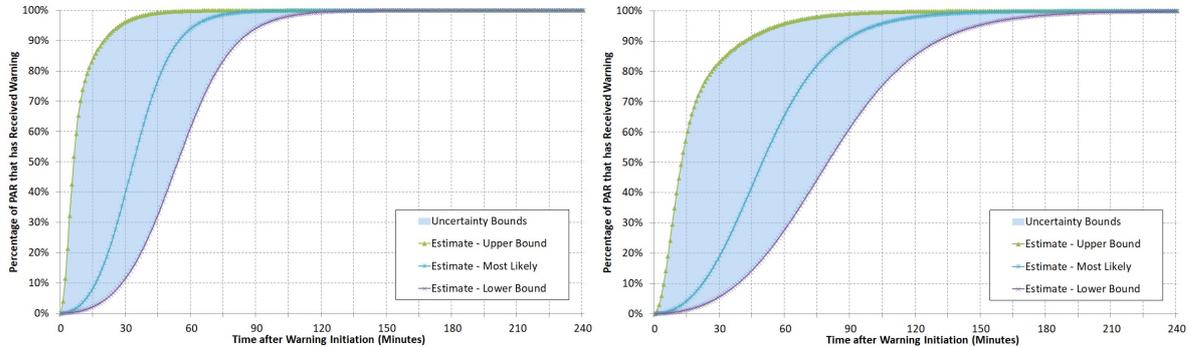


Figure 4.2: Warning diffusion curve during daytime (left) and nighttime (right) alert.

### 4.1.3. Protective action initiation

Personal action initiation time is the period after receiving the first alert or warning and the initiating of a protective action. In this time period most people take a range of actions to implement a protective action, such as getting into their car [24]. For floods in Dordrecht (especially in flood threat scenarios 4 and 5) it is assumed that everybody perceives themselves to be impacted. The protective action initiation curve is thus only displayed for "likely to impact" zone. The expected max mob rates for Dordrecht are displayed in table 4.1. In table 4.2 and figure 4.3 the protective action initiation curve is displayed.

Initial Perception	Warning time	Upper Estimate	Best Estimate	Lower Estimate
Likely to impact	Short (<8 hours)	96	85	75
	Med (8-24 hours)	98	94	90
	Long (24-72 hours)	99	98	97

Table 4.1: Expected mob rates of Dordrecht following the USACE assessment method.

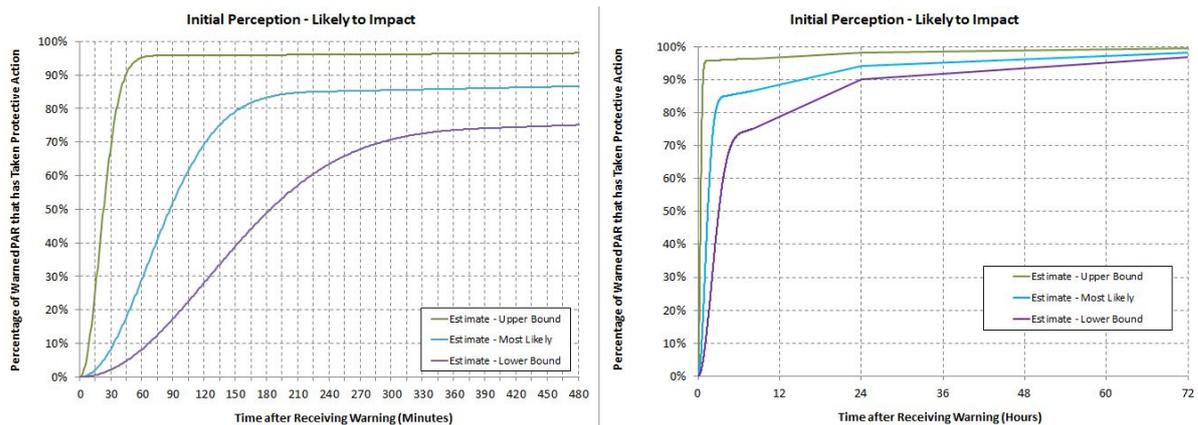


Figure 4.3: Protective Action initiation curve of Dordrecht following the USACE assessment method.

Minutes	Most likely	Lower bound	Upper bound
0	-	-	-
10	1,00	0,25	12,87
20	3,92	0,98	42,00
30	8,57	2,19	69,63
40	14,64	3,84	86,25
50	21,73	5,91	93,17
60	29,45	8,36	95,23
70	37,36	11,15	95,68
80	45,11	14,22	95,73
90	52,38	17,51	95,75
100	58,96	20,99	95,77
110	64,70	24,58	95,79
120	69,56	28,24	95,81
180	83,30	49,01	95,92
240	85,06	63,46	96,04
300	85,45	70,77	96,15
360	85,83	73,55	96,27
420	86,22	74,42	96,38
480	86,61	75,09	96,50
1440	94,25	90,14	98,36
4320	98,18	96,89	99,48

Table 4.2: Values protective action initiation curve.

## 4.2. Including the investment agenda in the USACE assessment method

After discussing the questionnaire with the two experts of the water safety region and discussing the results of this questionnaire, it is concluded that the USACE assessment method could not include the investment agenda following the water safety plan of Dordrecht and estimate the effect on the warning delay time, warning diffusion curve and the personal action initiation curve.

This has to do with how the questions in the USACE assessment method are formulated. Questions are more formulated such as: do you have access to warning method X or Y, do you have personnel that is available 24 hours per day and do you have any backup systems etc. Reflecting this to the investment agenda of Dordrecht, little has changed with regard to new warning methods or new personnel, some assets and communication strategies are just made more efficient.

However, this does not mean that the USACE assessment method does not deem the measures of the investment agenda of Dordrecht unimportant. On the contrary, the parameters that will be made more effective following this investment agenda broadly resemble parameters found by Sorensen and Mileti [22–24] to be influencing the warning delay time, warning diffusion time and personal action initiation time (remember that the USACE assessment method is based on their research). Some examples of the investment agenda that closely resemble parameters found by Sorensen and Mileti are displayed in table 4.3.

Investment agenda Dordrecht (crisis management)	Important parameters found by Sorensen and Mileti
Information preparation	Formalisation of planning and implementation of procedures
Preparing decision making	Standard operating procedures are written down Warning thresholds are in place Succession planning is detailed within standard operating procedure
Training directors and their advisors	Standard operating procedures practise is conducted (drills or exercises)
Agreements on continuity of the electricity and IT in threat phase	Power availability

Table 4.3: Examples investments of the water safety plan of Dordrecht that should improve factors deemed important by the papers of Sorensen and Mileti [22–24]

Explanations on why the USACE assessment method does not necessarily measure the investments following the investment agenda although they improve factors deemed important by Sorensen and Mileti **may** be found in the following explanations:

- The first explanation may be the expected user base of the USACE assessment method. The USA is a large country with numerous cities, counties and other small areas. Especially within these small counties and areas it is possible that a single sheriff or small organisation comprising of only a handful of people are responsible for organising and starting an evacuation. These kind of organisations often do not have extensive preparations in place or data on the required time for evacuation in different threat scenarios.

The USACE assessment method is also developed for usage by these kind of organisations (the data on which the assessment method is based also includes many evacuations in these smaller areas). It seems that the goal of the assessment method is to test whether or not certain systems are in place to estimate the evacuation curves instead of measuring how well these systems are implemented.

- The second explanation could come from a lack of available (detailed) evacuation data. As mentioned in §3.2 of the literature review, Sorensen and Mileti mention in their different papers that it is often difficult to find detailed and complete data surrounding mass evacuations. For instance, in their warning issuance delay paper [23] they mention that it is unclear what the impact is of single factor on the warning issuance delay and instead argue that if more factors are presents the warning delay time will decrease, or how a specific command decision structure influences this warning delay. So it is possible that the USACE assessment method is kept global just because there is not enough data available to include more detailed questions.

### 4.3. Comparison USACE results and Dutch estimations

The warning issuance delay curve estimated by the USACE assessment method ranges between 0 and 240 minutes with a mean time of 80 minutes. In the Netherlands it is assumed that a period of 24 hours preceded a call to evacuate.

The issuance to initiation graph (including uncertainty) following from the USACE assessment method for Dordrecht is displayed in figure 4.4 and 4.5. In this figure the slow departure curve of the PBL model (for preventive evacuation) is also drawn. What stands out is that, like the PBL departure curve, the issuance to initiation graph also starts as a S-shaped graph. However, it increases much faster but has a longer tail, meaning it takes longer to get to the maximum mob rate mark (compliance rate). In table 4.4 the results that follow from the USACE assessment methods are presented on when the issuance to initiation graph reached the 50%, 80% and 100% mark and a % per hour when the line is straight. In table 4.5 the values of the preventive evacuation departure curve are presented.

Response	Time in hours			% per hour in linear part	Mob rate
	50%	80%	100%		
Slow curve	3.7	13.3	78.0	~20.0%	96.9%
Expected curve	1.8	4.3	78.0	~33.0%	98.1%
Fast curve	1.0	1.7	78.0	~64.0%	99.4%

Table 4.4: Amount of hours to reach a certain evacuation fraction threshold and the accompanying mob rate following the issuance to initiation curve.

Response	Time in hours			% per hour in linear part	Mob rate
	50%	80%	100%		
Slow curve	7.0	9.0	16.0	15.0%	80.0%

Table 4.5: Amount of hours to reach a certain evacuation fraction threshold and the accompanying mob rate of the PBL model.

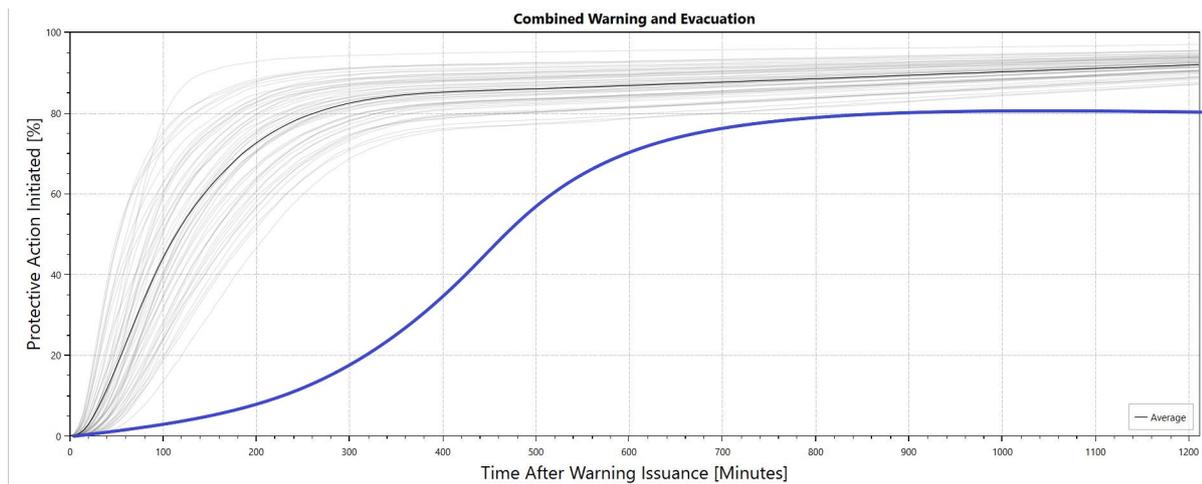


Figure 4.4: Issuance to initiation curve following the USACE assessment method (left) combined with the (preventive evacuation) departure curve used in the Netherlands (right).

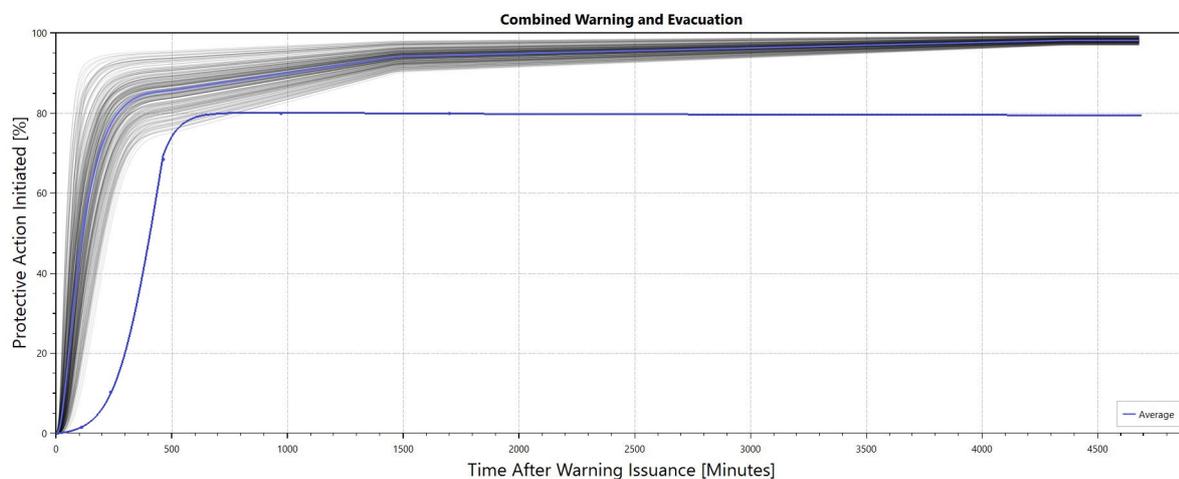


Figure 4.5: Issuance to initiation curve following the USACE assessment method (left) combined with the (preventive evacuation) departure curve used in the Netherlands (right).

The logical explanation for these differences may be that every country (or even region) has its own method of preparing for possible evacuations and is effected by different threat scenarios. The USACE assessment method is based on scenarios found in the USA, meaning that it includes scenarios such as dam breaches, flash floods and other flood scenarios not found in the Netherlands. The data behind the personal action initiation curve of the USACE assessment method furthermore includes chemical events. People and organisations will react differently to a imminent dam breach, flash flood or chemical event only hours away than to a storm several days away. Other differences may be explained by the assumptions in the papers of Sorensen and Mileti [22–24].

- For the difference in the warning issuance delay, as already mentioned in paragraph §4.2, Sorensen and Mileti do not include the command decision structure in their estimation for the warning issuance delay. The command decision structure is arguably one of the most important parameters in the Netherlands influencing this warning delay. This has to do with the up-scale process and multiple parties that are included in this decision making process. This method of reaching a decision to evacuate differs greatly from examples found in the USA where it is sometimes a decision of a single sheriff.

- The difference between the departure curve in the Netherlands and the combined warning diffusion and personal action initiation curve may be explained by what evacuation events are chosen to develop the estimations. The departure curve of the Netherlands is developed by using data of evacuations during hurricane scenarios in Alabama, which experts expect to closely resemble a storm scenario. This data is thus based on a single region with only one threat: hurricanes. The warning issuance delay and personal action initiation curve of the assessment method is based on many more areas and many more threat scenarios (including chemical ones), which inevitably leads to different results. Both models use data that is relatively old, meaning they do not include the effects of internet and social media in the estimations.

#### 4.4. Conclusion USACE assessment method applied to Dordrecht

This chapter showed that there are large differences in what is currently expected in Dordrecht and what the USACE assessment method expects regarding the warning issuance delay time, warning diffusion time and personal action initiation curve. In figure 4.6 these differences are displayed. Remember that in the Netherlands the warning diffusion curve and personal action initiation curve are combined into a single "departure curve". This departure curve starts at the same time as the warning issuance delay time. LifeSim has an option to combine the warning diffusion time and protective action initiation time into a single curve called the issuance to initiation graph. This graph is the equivalent of the departure curve and is also used this figure.

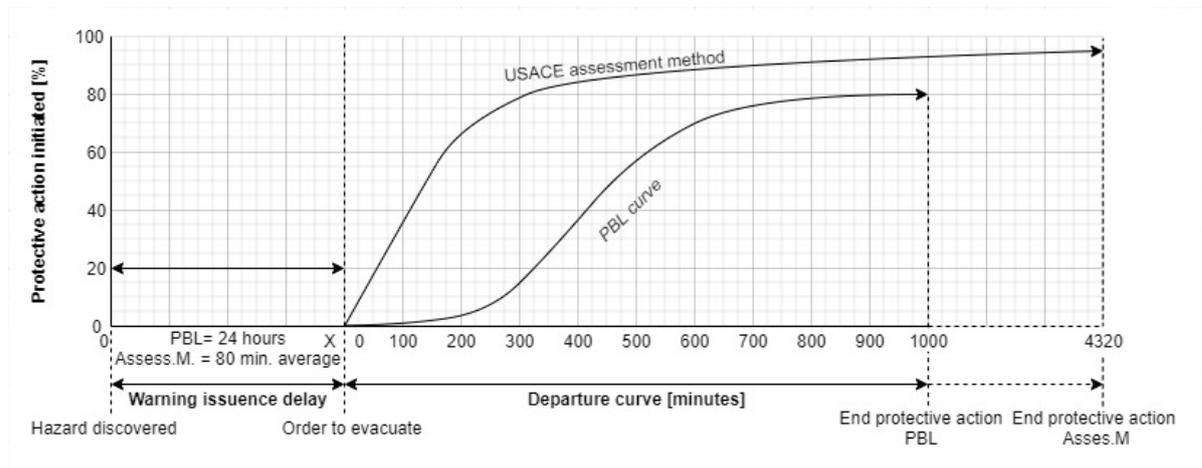


Figure 4.6: Differences between the warning issuance delay and departure curve of the PBL model and the USACE assessment method.

It is concluded that the USACE assessment method cannot be applied to the Netherlands directly because the results are too different from the data currently used and expected in the Netherlands, as is shown in paragraph §4.3. Although the direct result of the assessment method cannot be applied directly to the Netherlands, there is still valuable information stored within the USACE assessment method document. This is because it is one of the few methods available that combines the data of numerous mass evacuees together and from this data determines the important parameters that influences the warning delay time, warning diffusion time and personal action initiation curve. It is a good start to inventorise what safety regions have currently done in terms of evacuation, the warning methods available, the amount of experience that a region has and what factors are important for the required time for evacuation. To translate this assessment method for Dutch usage several adaptations are needed which be discussed below:

- **Warning issuance delay:** for estimating the warning issuance delay time greater emphasis should be placed in the interaction between the responsible parties and the meetings that precede a call to evacuate (up-scale process). Currently a period of 24 hours is assumed, but experts of the safety region South Holland south estimated that recent preparations will (severely) decrease this expected time. How certain preparations will influence this warning delay should be discussed with experts in the field of crisis management and communication and safety regions so a estimation can be developed where each preparation is translated into a shorter warning delay time.

- **Departure curve:** the current departure curve was developed in 2004 with data from hurricane Opal in Alabama USA. This curve has not changed since then and has not included possible changes due to innovation or new warning methods. For example, social media and the internet were not nearly as large a factor during hurricane Opal (1995) as nowadays, which may or may not influence the departure curve. Although there have been some evacuation drills and the current departure curve is backed up by expert opinion, there has been little calibration data with real mass evacuation in the Netherlands. The reason that this departure curve has not been reevaluated was because the evacuation strategies were primarily based on preventive evacuation, meaning a faster departure curve had little impact on the required time for evacuation because roads were often congested. However, now that vertical evacuation is the base strategy of Dordrecht, the departure curve may have a bigger influence. Like with the warning issuance delay, a lack of data means that expert opinions should form the basis of this "new" departure curve. And experts in the field of crisis management communication and responsible parties with respect to evacuation should come together and estimate what they expect how certain investments, new technologies etc. influence the departure curve.

Because this large difference in results, the choice has been made to not use the results of USACE assessment method in the case study of chapter 5 to determine the warning issuance delay, warning diffusion and personal action initiation. Instead, an alternative approach is proposed which is based on the PBL method. That is, the warning issuance delay time will be set to zero hours. This means that a simulation will start when "authorities press the button". The warning diffusion time is modelled so that the population is instantly aware of the warning and finally the protective action initiation curve is modelled to represent the departure curve of the PBL model. By using this approach, the results of the case study are also better comparable to the results of the water safety plan of Dordrecht. In chapter 5 a more extensive explanation is provided.



# 5

## Case Study

### 5.1. LifeSim models

In this chapter the LifeSim models are introduced and the results of the required time and loss of life are discussed and compared to the estimations of the water safety plan of Dordrecht. It will furthermore include sensitivity analyses of important parameters. The three base scenarios that will be used are displayed in table 5.1. It can generally be assumed that options to change parameters within LifeSim are left at default unless otherwise specified.

		<b>Evacuation strategy</b>	
<b>Available time</b>	<b>Road capacity</b>	<i>Base (shelter in place)</i>	<i>Preventive evacuation</i>
2 Days	<i>Optimistic</i>	Alternative 1	x
	<i>Realistic</i>	Alternative 2	Alternative 3

Table 5.1: Different reference models.

The available time is set to two days, which is the maximum available time to evacuate according to the water safety plan of Dordrecht (three days minus 24 hours due to extreme weather). Two road scenarios are included, which are an optimistic (12600 cars / hour) and realistic (1100 cars / hour) scenario. It is assumed that an optimistic scenario is only a possibility when vertical evacuation is to chosen evacuation strategy. And lastly, the modelled evacuation strategies are shelter in place (vertical evacuation) and preventive evacuation. There are several assumptions made which affect all scenarios where the most important are:

- 80% of the population (~93.500 people) will follow the instructions of the authorities whereas 20% (~23.500 people) will not.
- There is an average of 2.3 people per car.
- The traffic network is completely empty and wholly available at the start of the evacuation.
- There is no incoming traffic, people will only try to leave the island.
- No disturbances are included in the road network as a result of accidents or other factors.
- Simulations start when authorities made a decision to evacuation, meaning the warning issuance delay is set to 0 hours.

As mentioned in the previous chapter, the results of the USACE assessment method proved too different from what is currently assumed in the Netherlands. So the slow and fast departure curve are imported. The fast departure curve is used to estimate the effects of a faster departure curve. The departure curves are modelled by setting the warning diffusion time to 1 minute (population is instantly notified) and manually modelling the different departure curves in the personal action initiation curve.

However, in LifeSim, the user can only plot and distinguish between the different iterations of a simulation by means of loss of life, economic damage or % of the population that is warned, mobilised or cleared (see figure 5.1).



Figure 5.1: Different options to plot the summary data within LifeSim.

So the information that is needed, namely which departure curve is used in a certain iteration and the accompanying time it takes to complete an evacuation cannot be collected if an uncertainty range is included in the personal action initiation curve. So to control what particular departure curve is used, the alternatives are run separately with either a slow or a fast departure curve. This combined with a fixed amount of people that try to evacuate effectively eliminates most uncertainty within a single simulation as the result of how fast people can leave the island will be roughly the same in each iteration.

The results of the simulations will be displayed in cumulative evacuation outflow graphs. These graphs contain two functions, a mobilised and reached safety graph. The mobilised graph is defined as the number of people who have gotten into their car as a function of time (departure curve) and the reached safety graph shows how many people have reached a destination as a function of time. This area between these graphs can be used to estimate the travelling time of the population and collect information about the congestion on the roads. An example evacuation outflow graph is presented in figure 5.2.

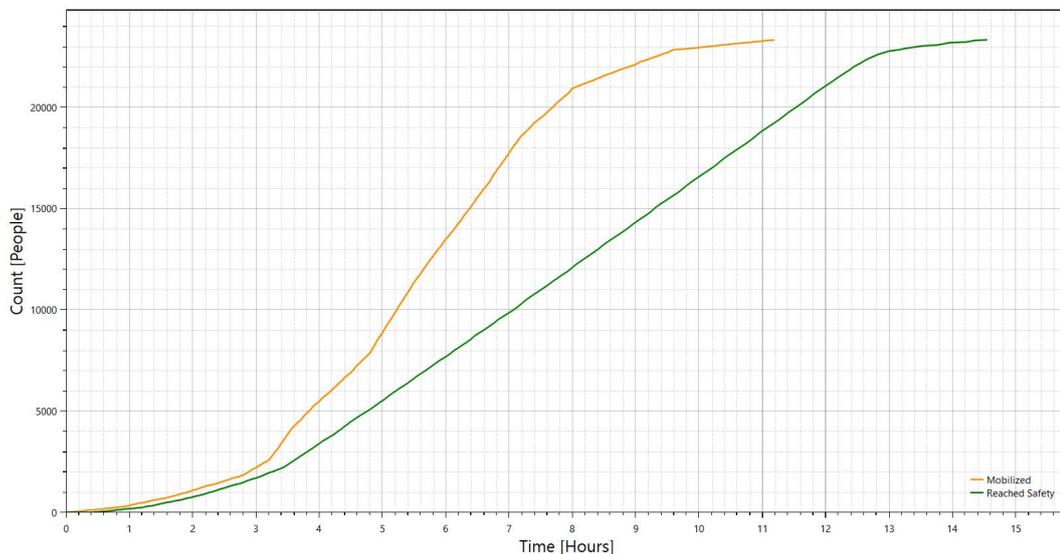


Figure 5.2: Example of an evacuation outflow diagram of LifeSim

## 5.2. LifeSim datasets

In the following paragraphs the different data sets are introduced that are developed for the simulations.

### 5.2.1. Hydraulic Data

For the hydraulic data, LifeSim is closely interwoven with the "Hydraulic Engineering Center's River Analysis System" (HEC-RAS) which is also distributed by the USACE. This software allows the user to directly import the results of a flood scenario from HEC-RAS into LifeSim. At HKV however the hydraulic modelling program SOBEK is used. SOBEK will summarise the hydraulic data to ASCII files which can be converted to TIFF files with help of QGIS and imported in LifeSim as GRID files.

A normative scenario breach in bress 22-05, displayed in figure 5.3 is taken as the default hydraulic situation. This threat scenario is comparable to threat scenario 5 of the water safety plan discussed in chapter §3.4.1 but are not exactly the same which means some differences in the loss of life results are expected. In threat scenario 5 there are multiple breaches in the dikes surrounding Dordrecht, whereas the scenario of a breach in bress 22-05 only includes 1 breach. However, the water levels between both scenarios are relatively similar and a normative scenario in breach 22-05 was chosen because the data was readily available to implement.

However, for some unknown reason the TIFF files had trouble to be imported LifeSim, which may be the result of a currently used Beta build of LifeSim. The entire flood scenario displayed errors upon importation, however one scenario that could be imported were three TIFF files containing the data of the highest water level and the accompanying flow rate at that time step. This means that the entire flood scenario is not taken into account and is only based on the highest water level and flow rate.



Figure 5.3: Location of bress 22-05

### 5.2.2. Structural inventories

The structural inventories shapefile as needed for LifeSim is not readily available in the Netherlands and has to be produced manually by combining data from different sources. This (shapefile) data set contains 13 fields:

1. Occupancy Type
2. Number of Stories
3. Construction Type
4. Foundation Height
5. Ground floor height (ft)
6. Above ground floor height (ft)
7. Attic height (ft)

8. 2AM Population Under 65
9. 2AM Population Over 65
10. 2PM Population Under 65
11. 2PM Population Over 65
12. Structure Value
13. Content Value
14. Other Value
15. Vehicle Value

### **Location of the structures**

First the location the structures is determined. For this, the structural database of "<http://3dbag.bk.tudelft.nl/downloads>" is used. This data set includes information on all structures of the Netherlands including the location, area surface and their respected height. The following steps are taken to reduce the shapefile to the necessary size and form:

1. Deleting unnecessary structures: all structures except the ones located on the island of Dordrecht are deleted.
2. Deleting unpopulated buildings: Because this data set also includes carports, sheds and other unpopulated structures, the following two steps are applied:
  - Deleting all polygons with a height of less than three meters.
  - Deleting all polygons with an area less than 20 m<sup>2</sup>.

### **Number of stories**

The height of each building is divided by three to determine the amount of stories, rounded up or down to whole numbers. So it is assumed that a building of 4.49 meters has one story and a building of 4.5 meters two stories.

### **Damage category and Occupancy type**

The occupancy type is simplified and only determined by the number of stories:

- 1 Story: RES1-1SNB, Single family residential structure that is 1 story tall with no basement.
- 2 Stories: RES1-2SNB, Single family residential structure that is 2 stories tall with no basement.
- 3 Stories: RES1-3SNB, Single family residential structure that is 3 stories tall with no basement.
- 4 stories: RES3B, Multi Family Residence - 3 to 4 units.
- 5 & 6 stories: RES3C, Multi Family Residence – 5 to 9 Units.
- 7 stories: RES3E, Multi Family Residence – 20 to 49 Units.
- 8 - 24 stories: RES3F, Multi Family Residence – more than 50 Units.

### **Construction type**

It is assumed that the velocity and depth during a breach in bres 22-05 is not large enough to damage buildings in Dordrecht. It is thus not necessary to differentiate between building types (wood, concrete etc.) and all buildings are given the masonry construction type. Masonry structures are strong enough to withstand the max depth and velocity recorded after a breach in bres 22-05.

### **Foundation height**

A foundation height of 10 cm is assumed which is based on Pleijter and Kolen [18].

### **Ground floor, above ground floor and attic height**

Each floor is estimated to be 265 cm.

### **Population data**

The population data will be collected from the CBS which contains the population data of 2014 in raster form of 100 by 100 meter. Each raster contains the number of people under 65 years and number of people over 65 years old. With help of the USACE the population of this raster is divided equally over the points (structures) located within this raster. For a visual representation see figure 5.4:

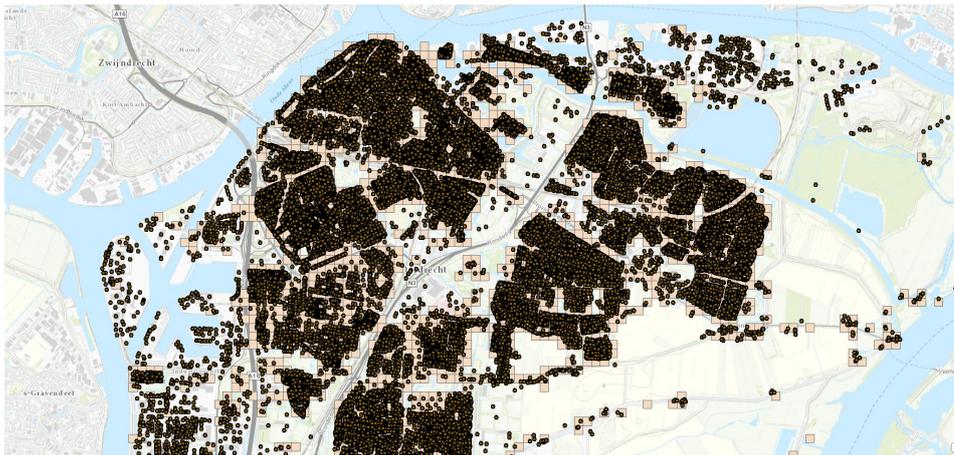


Figure 5.4: Grid data CBS and location buildings

After dividing the population over the structures, around 9% of the buildings did not receive any population data. These can either be structures that were not located within a population grid, or located in a grid with less population than number of buildings, meaning that a building cannot contain 0.5 people. In the population data 97.215 people are under 65 years old and 19.590 people are over 65 years old. Meaning in total there are 116.805 people. This is comparable to the population found in the water safety plan which is based on 118410 people of which 19940 people are over 65 years.

#### Structure, content, vehicle and other values

The different value parameters are not taken into account in this thesis and are switched off.

**Parameters occupancy types** After importing the structural data set, LifeSim has the option to alter economic- evacuation- submerge- and other parameters for each type of occupancy type (such as the RES1-1SNB).

- Economic damage: For all different occupancy types the economic damage is turned off.
- Evacuation parameters:
  - Population in structure warned at the same time & population in structure takes protective action at the same time: For RES1-1SNB, RES1-2SNB, RES1-3SNB the population in the structure will be warned at the same time and will take protective action at the same time to simulate that these are single family homes. In RES 3B, RES3C, RES3E and RES3F people will not be warned at the same time and will not take protective action at the same time because these occupancy types generally represent flats or other multiple residents areas.
  - Fraction of population that evacuates in vehicles vs. on foot: default value of 1 (same for every occupancy type).
  - Evacuating group size (e.g. number of people per evacuating vehicle): Can only be whole numbers so the 2.26 of the PBL model should be rounded down to 2, however, preliminary model runs showed that the actual average number of people per car in these cases is 1.7 not 2. This is because of how LifeSim divides the population over the different vehicles. If an average of three people per car is assumed the actual average is 2.3, which is a close approximation of the value used in the PBL models.
- Submerge criteria: left at default.
- Other parameters: left at default.

#### 5.2.3. Emergency planning zone and departure curve

Dordrecht is modelled as a single entity with an exception of ZIP code areas 3317 and 3318. This is because preliminary model runs showed that the exit "A16 brug over HollandsDiep" was only used after a few hours (shown in 5.5). This has to do with the fact on how people choose a destination. They will take the shortest travelling time for them, unless traffic or obstructions has them re-route. This situation where one exit is

completely negated is unlikely to happen in real life. By modelling ZIP code areas separately they can be linked to a certain exit (meaning it is the only exit people from this area can use) which in combination with slightly altering the destination of the exits results in a more realistic spread over the different exits. The rest of the population of Dordrecht can use every exit available.

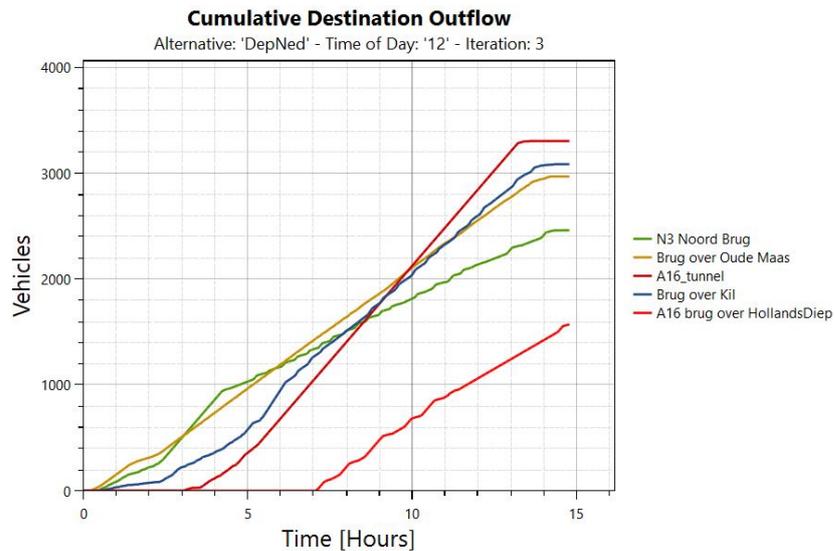


Figure 5.5: Example of an exit that is not used in the beginning when no traffic management is included.

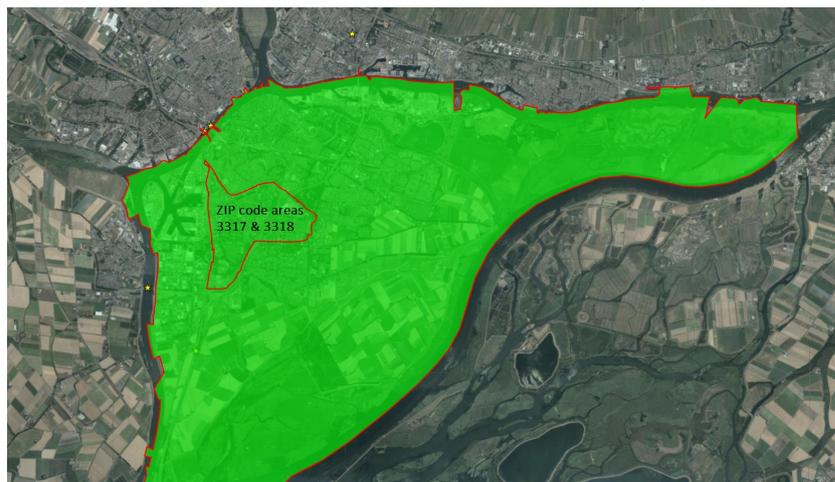


Figure 5.6: ZIP code areas 3317 and 3318.

#### 5.2.4. Road network

The road data set file that will be used in the reference model is based on the 'Nationaal wegenbestand (NWB)' of Rijkswaterstaat version 2014. This shapefile contains the road number and travelling direction (one way or two way). The 4 default roads are displayed in table 5.2.

The following changes have been made to the NWB:

- More roads are displayed than necessary, roads are deleted that run further than the different exits points of Dordrecht.
- After visual inspection the one-way parameter has to be updated. Roads are changed to one-way where applicable. In consultation with the USACE the road network is not too detailed so simulation times remain manageable. Generally only highways and important inner roads are modelled one way.

WEGNUMMER	Represents:
"	All smaller & inner roads located in Dordrecht
003	The N3
016	The A16 running through Dordrecht
N217	The N217 located southwest of Dordrecht

Table 5.2: Different roads as displayed in the NWB roadfile.

- "" Roads are renamed to inner roads to avoid confusion.
- Because LifeSim does not include an option to include exit capacity, the last 100 meters of road leading to the 5 different destinations receive a different CFCC code denoted "Const" from Constraint. These roads can then receive different parameters so they can function as some sort of resistance and limit the amount of people then can reach an exit.

In realistic road scenarios the inner roads of Dordrecht use the default settings of LifeSim for comparable roads. Except the free flow speed is divided by two to represent the bad weather conditions and the stop and go speed is changed from 6.4 to 0.5 km/h. The reason that this stop and go speed is altered is due to the constraint that are included. Preliminary model runs showed that if the constraints have a free flow and stop and go speed of 0.5 km/h and other roads also have a stop and go speed of 0.5, then the outflow is approximately 1100 cars per hour. However, if the stop and go speed of the inner roads is higher than that of the constraint, the constraints are (largely) ignored.

For an optimistic road scenario, the constraints are managed so that they do not interfere with the simulation. They receive a high free flow speed, amount of lanes and stop and go speed. However, the stop and go speed remains the same as in a realistic road scenario. The values for the different roads under both optimistic and pessimistic scenarios are displayed in table 5.3.

Type of road	Optimistic				
	Lanes	Free flow speed (km/h)	Jam density	Break away density	Stop and go speed (km/h)
Inner roads	1	10	99	9	0.5
003 (N3)	2	40	99	14	0.5
N217	2	40	90	14	0.5
016 (A16)	3	50	99	17	0.5
Constraint	3	50	99	9	50
Pessimistic					
Inner	1	10	99	9	0.5
003 (N3)	2	40	99	14	0.5
N217	2	40	99	14	0.5
016 (A16)	3	50	99	17	0.5
Constraint	1	0.5	99	9	0.5

Table 5.3: Parameters of the different roads under optimistic and pessimistic scenarios.

### 5.2.5. Destinations

The destinations represent the different exits of Dordrecht. The default exits are taken from Huizinga [3] and presented in table 5.4. However, the destinations are altered slightly so a more natural spread of the population is obtained (for the same reason as discussed in the emergency planning zone paragraph). This is done by the "N3 Noord Brug" and the "A16 brug over Hollandsdiep" closer to the island. In figure 5.7 the different destinations are displayed.

Rank	Name	Latitude (Y)	Longitude (X)
1	N3 Noord Brug	51.8234597	4.7058952
2	Brug over Oude Maas	51.8111718	4.649884
3	A16 tunnel	51.8097695	4.6474847
4	Brug over Kil	51.7726888	4.6266643
5	A16 brug over HollandsDiep	51.718849	4.6357789

Table 5.4: Location of the exits as seen in Huizinga [3]

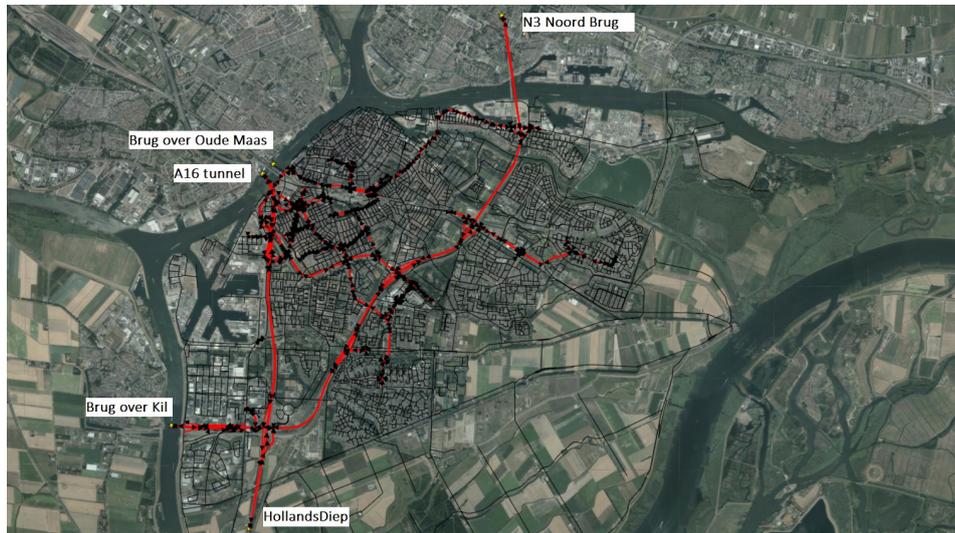


Figure 5.7: Roads and destinations of the LifeSim models.

### 5.2.6. Alternatives

In the alternative data set the public warning issuance and destination options are altered.

#### Public warning issuance

- Hazard identified relative time in hours (time before the onset of a disaster): set to -48 hours.
- Hazard communication delay in hours (time it takes to notify emergency managers after the hazard is identified): set to 0 hours.

#### Destination assignments

All ZIP-code areas can use all exits except for areas 3317 and 3318 which are linked to the exit "Brug over Kil".

## 5.3. Results base simulation

Here the result of the base simulations are presented and discussed. First the required time for evacuation in the base scenarios are discussed and compared to the water safety plan followed by the loss of life and finally the sensitivity analysis.

### 5.3.1. Required time for evacuation

The time it takes for different percentage of the *evacuating* population to reach an exit is displayed in table 5.5. Remember that for vertical evacuations only 20% of the population evacuates which amount to approximately 23.500 people, whereas in preventive evacuation 80% of the population will try to leave the island which amounts to approximately 93.500 people. So the 100% means either 20% or 80% of the total population.

	Slow departure curve				Fast departure curve			
	25%	50%	75%	100%	25%	50%	75%	100%
<b>Alternative 1: Vertical optimistic</b>	~5.5	~7.5	~9	~16.3	~3	~4	~5	~8.35
<b>Alternative 2: Vertical realistic</b>	~6	~9	~11.5	~18.15	~3.5	~6	~8.5	~14.25
<b>Alternative 3: Preventive realistic</b>	~10.5	~19.5	~29	>48	~9.5	~18.5	~27.5	>48

Table 5.5: Evacuation time for different percentages of the **evacuating population** following the reference models.

In the water safety plan of Dordrecht, only an estimation of a preventive evacuation with a realistic road scenario is displayed, which was discussed in paragraph §3.4.4. So it is difficult to make a direct comparison between all alternatives and what is currently expected for Dordrecht. However, if the values of the preventive evacuation that follow from the water safety plan of Dordrecht are compared with the values of preventive evacuation in a realistic roads scenario from LifeSim (displayed in figure 5.12, the results are relatively similar as shown in table 5.6. Do note that this table shows the percentages of the total population instead of the evacuating population.

% of total population that has evacuated	Time in hours			
	12	24	36	48
<b>Water safety plan Dordrecht</b>	~25%	~60%	~70%	~78%
<b>LifeSim</b>	~23%	~50%	~70.5%	~79%

Table 5.6: Evacuation percentages of the **total population** for preventive evacuation on different time intervals between the water safety plan of Dordrecht and the LifeSim model.

#### **Alternative 1: vertical evacuation in a optimistic road scenario.**

In this scenario the 23.500 people try to leave the island without a constraint on the different exits. The results of a simulation with a slow departure curve is displayed in figure 5.8 and in figure 5.9 with a fast departure curve. With a slow departure curve an evacuation takes a little over 16 hours, whereas an evacuation with a fast departure curve takes approximately 8.35 hours. In this scenario a departure curve that is 8 hours faster is indeed translated into an evacuation that is 8 hours faster.

Although only 20% of the population is evacuating, the travelling time is already increasing slightly if a faster departure curve is assumed. This means that the inner roads start to form a slight constraint on how fast people can leave the area.

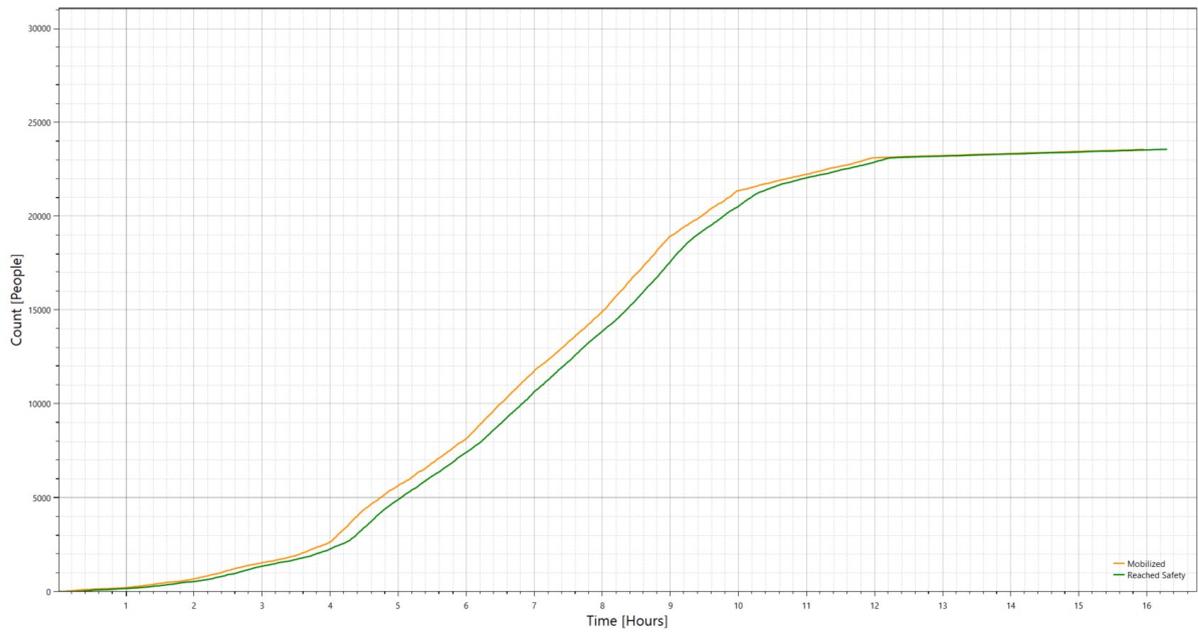


Figure 5.8: Cumulative evacuation outflow for a vertical evacuation strategy with a slow departure curve in an optimistic road scenario.

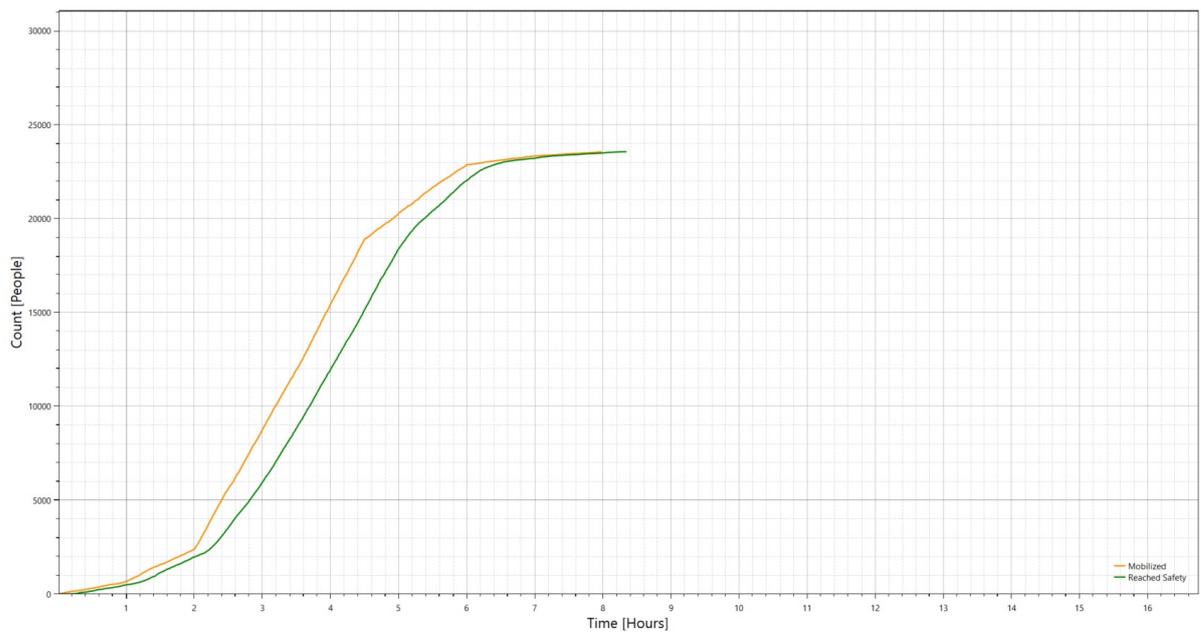


Figure 5.9: Cumulative evacuation outflow for a vertical evacuation strategy with a fast departure curve in an optimistic road scenario.

**Alternative 2: vertical evacuation in a pessimistic road scenario.**

In this scenario 23.500 people try to leave the island while a constraint of 1100 cars per hour is applied on to the different roads leading to an exit. The simulation with a slow departure curve is displayed in figure 5.10 and takes a little more than 18 hours to complete whereas the simulation with a fast departure curve is displayed in figure 5.11 and takes approximately 14 hours to complete. Comparing the results it can be concluded that in these scenarios the exit capacity start to limits the effectiveness of a faster departure curve on the time it takes to complete an evacuation. A departure curve that is 8 hours faster is not translated into an evacuation that is 8 hours faster.

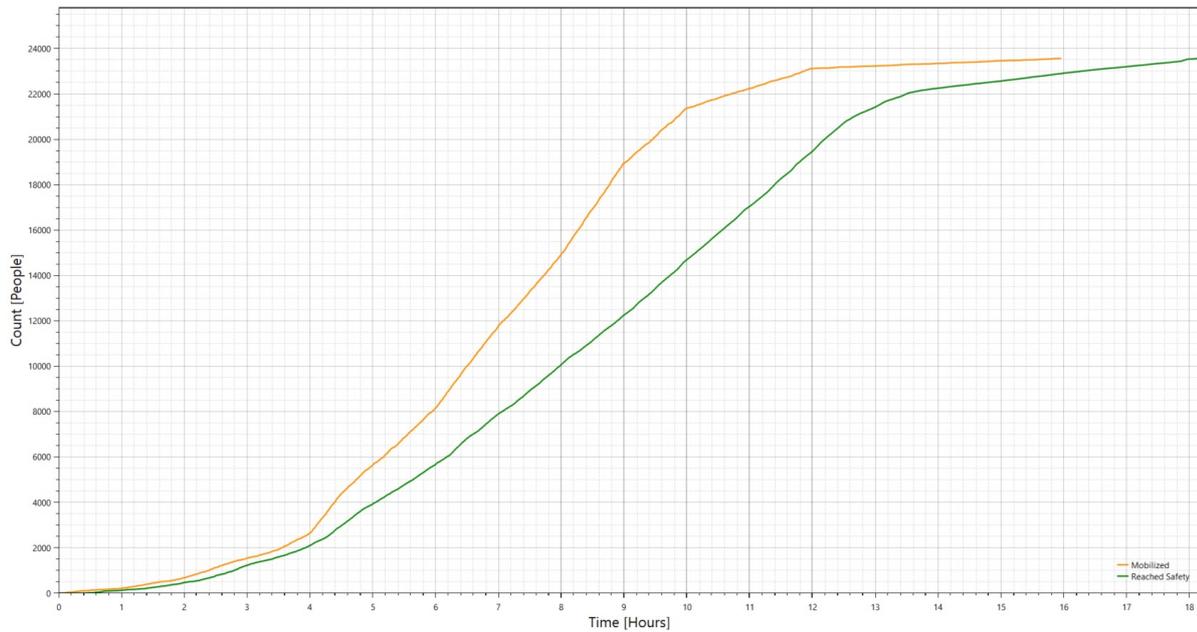


Figure 5.10: Cumulative evacuation outflow for vertical evacuation strategy with a slow departure curve in a pessimistic road scenario.

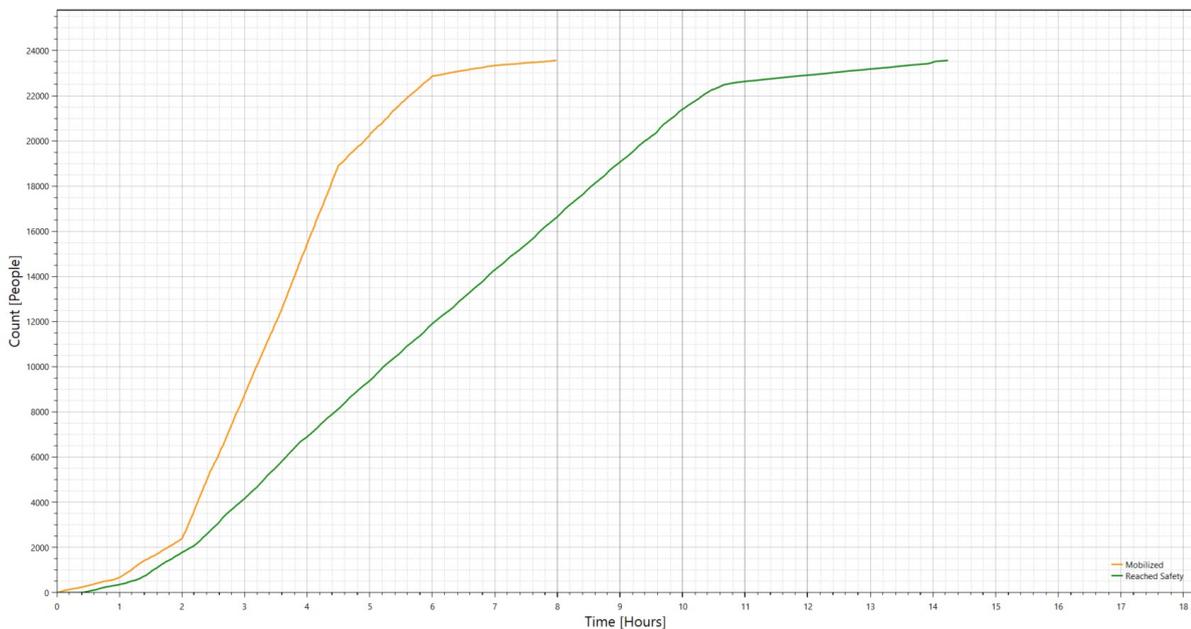


Figure 5.11: Cumulative evacuation outflow for vertical evacuation strategy with a fast departure curve in an optimistic road scenario.

### Alternative 3: preventive evacuation in a pessimistic road scenario.

In this scenario 93.500 people try to leave the island while an exit capacity of 1100 cars per hour is applied. In these scenarios it is not possible to completely evacuate 80% of the population within 48 hours. In figure 5.12 the results with the slow departure curve are displayed and in figure 5.13 the results of a fast departure curve. It can be concluded that a faster departure curve has almost no influence on the total time it takes to preventively evacuate the population while an exit capacity is in place.

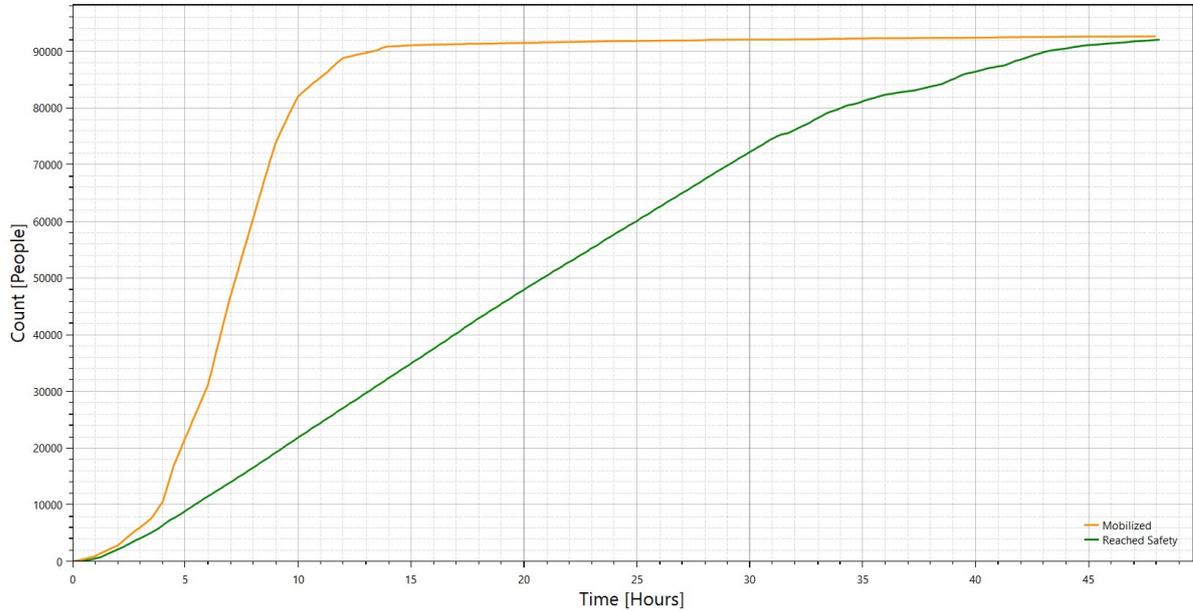


Figure 5.12: Cumulative evacuation outflow for preventive evacuation strategy with a slow departure curve in a pessimistic road scenario.

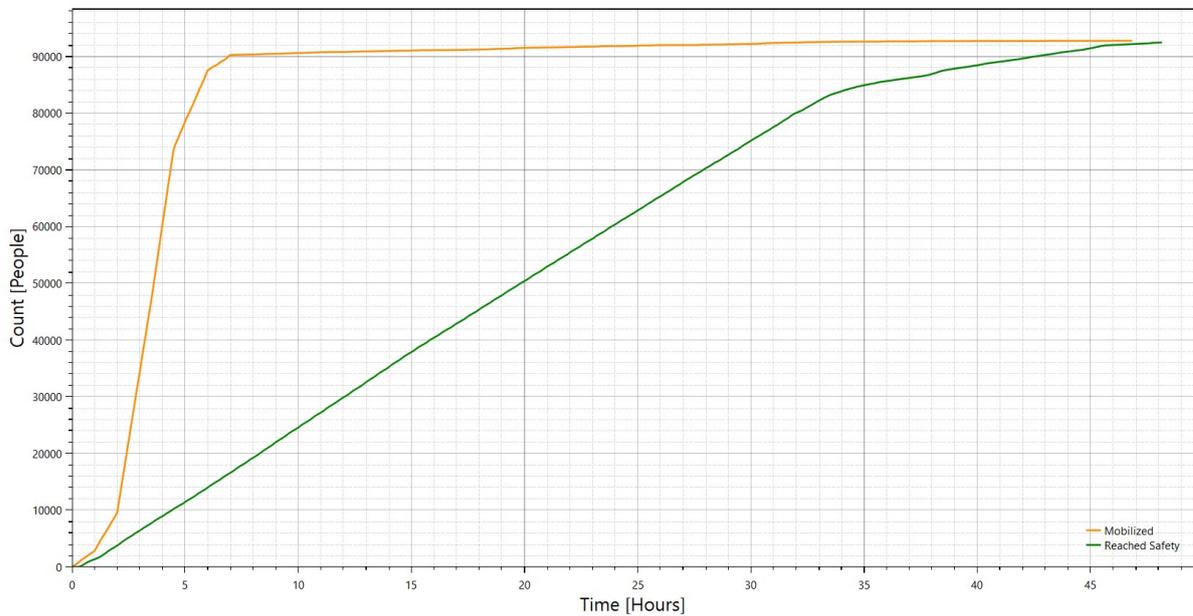


Figure 5.13: Cumulative evacuation outflow for preventive evacuation strategy with a fast departure curve in a pessimistic road scenario.

### 5.3.2. Loss of life comparison

The loss of life in the different ZIP code areas of Dordrecht for threat scenario 5 of the water safety plan for vertical and preventive evacuation is displayed in table 5.7. The loss of life following from the LifeSim model of vertical evacuation is displayed in figure 5.14 and in figure 5.15 for preventive evacuation. In the vertical scenario 80% of the population remains on the island (~93.500 people) and 20% has left the island (~23.500 people). With preventive evacuation this is the opposite and 80% has left the island successfully and 20% of the population remains.

In both LifeSim simulations of preventive evacuation and vertical evacuation the entire loss of life was observed to be in structures. No loss of life was perceived on roads or in the population not at risk (reached an exit). Also the option to show the exact location of the population when caught by the flood or in which structures and zone the loss of life took place was not working at the moment so it is not included in the discussion.

Strategy	Zip code area											Total
	3311	3312	3313	3314	3315	3316	3317	3318	3319	3328	3329	
Vertical ev.	85	530	<5	195	1410	25	240	95	615	330	45	<b>3570</b>
Preventive ev.	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<b>0</b>

Table 5.7: Loss of life in threat scenario 5 of the water safety plan of Dordrecht for vertical and preventive evacuation.

Evacuation strategy		Loss of life
Vertical	<i>Water safety plan</i>	3570
	<i>LifeSim</i>	Average ~83
Preventive	<i>Water safety plan</i>	0
	<i>LifeSim</i>	Average ~21

Table 5.8: Differences in loss of life between the water safety plan and the LifeSim

There are large differences in the loss of life between both models which is displayed in table 5.8. This can be explained largely by the model characteristics and the modelling choices in the case study. Taken into account these differences and modelling choices it is concluded that the loss of life between these models may not be compared directly with each other. These reasons are:

- First of, the flood scenario in the case study is not the same as the flood scenario of the water safety plan (scenario 5). Although the water depth and flow rate are comparable, in threat scenario 5 there are multiple breaches surrounding in the different dikes surrounding the island, whereas the threat scenario imported in LifeSim was a single breach in bress 22-05. This was done because the data of a breach in bress 22-05 was readily available.
- Secondly, the mortality rates were left at default for LifeSim, meaning they are calibrated to US data and threat scenarios. As discussed in paragraph §1.5 different evacuation and loss of life models are sensitive to different flood characteristics. How LifeSim handles the mortality function differs from the PBL model but the exact differences are not known or investigated in this thesis. Developing mortality function for LifeSim based on Dutch data was also outside of the scope of this thesis.
- Lastly the location of the population differs from the data of the water safety plan. In the LifeSim models there are no shelters located within the threatened area, meaning that people who in the PBL model are located in a shelter are modelled at home in the LifeSim simulations. This combined with the fact that LifeSim only includes two mortality functions means that LifeSim is less suited to implement the flexible evacuation strategy of Dordrecht.

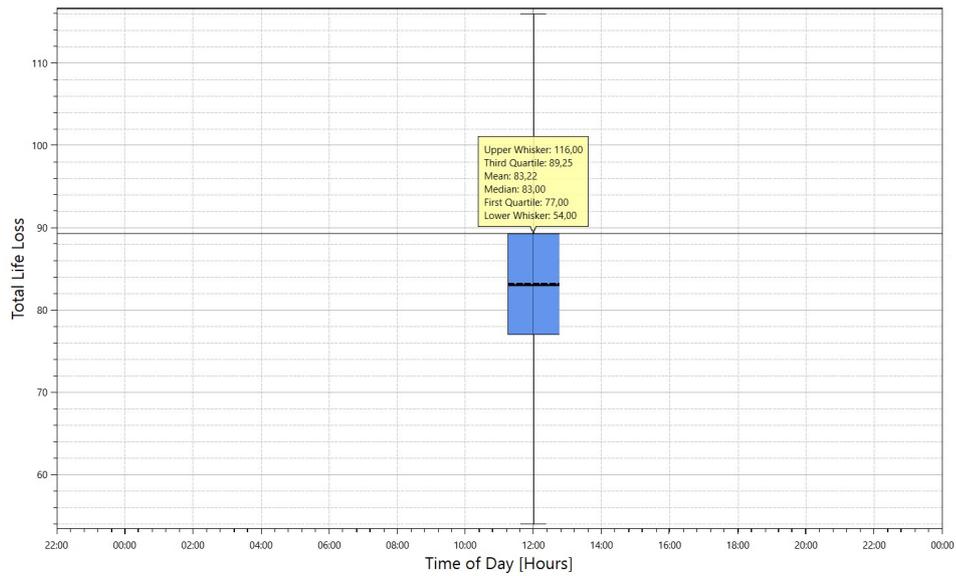


Figure 5.14: Loss of life in a successful vertical evacuation scenario in LifeSim.

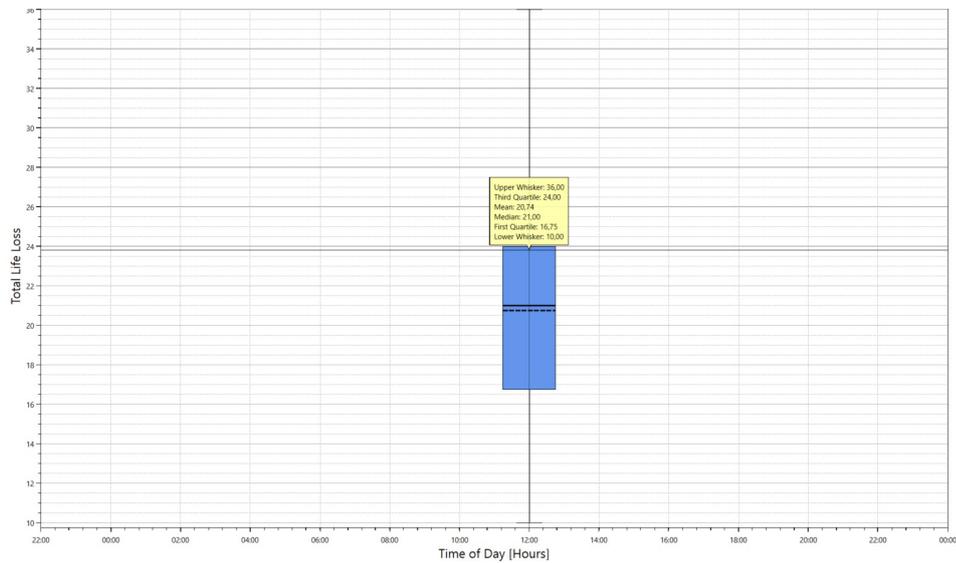


Figure 5.15: Loss of life in a successful preventive evacuation scenario in LifeSim.

One consideration on the calculation of the loss of life in the LifeSim models. Due to the Monte Carlo simulations, the USACE recommends to run at least a 1000 iteration in a given simulation. However, in the preventive evacuation scenario the amount of iterations is only 100. This is because the simulation times for preventive evacuation proved unmanageable. A single iteration took up to 10 minutes. The reason for this long simulation times will be further discussed in chapter six. However, because a lot of uncertainty is not taken into account, such as in the mob rates, the warning issuance delay time, the warning diffusion and personal action initiation curve the standard deviation of the loss of life should be less than in a "normal" LifeSim simulation, meaning it is not necessary to adhere to the normal 1000 iterations advised by the USACE.

### 5.3.3. More available time

As mentioned in the literature review, one conclusion of the water safety plan of Dordrecht was that the up-scale criteria are sometimes reached to late. The safety region South Holland south is interested in what the effect is of more available time to evacuate. So to estimate what the effect is of more available time, tables are presented where at different time intervals the evacuation fraction is presented. As in the previous paragraph, the percentage displayed in the tables represent the evacuating population, not the total population. In table 5.9 the effect of more available time for vertical evacuation in an optimistic road scenario is presented, in table 5.10 for vertical evacuation in an realistic road scenario and in table 5.11 the results for a preventive evacuation in as realistic road scenario. The accompanying graphs are the same as the results of the reference scenarios discussed in paragraph §5.3.1

		<i>Hours</i>								
		<b>Slow departure curve</b>								
		<i>2</i>	<i>4</i>	<i>6</i>	<i>8</i>	<i>10</i>	<i>12</i>	<i>14</i>	<i>16</i>	
<b>Alternative 1</b> <b>Vertical optimistic</b>		2%	10%	32%	58%	97%	98%	99%	99.9%	
	<b>Fast departure curve</b>									
			<i>2</i>	<i>4</i>	<i>6</i>	<i>8</i>	<i>10</i>	<i>12</i>	<i>14</i>	<i>16</i>
		8%	29%	50%	71%	91%	97%	99.9%	100%	

Table 5.9: Percentage of the evacuating population that has reached a destination after a certain amount of hours for alternative 1.

		<i>Hours</i>									
		<b>Slow departure curve</b>									
		<i>2</i>	<i>4</i>	<i>6</i>	<i>8</i>	<i>10</i>	<i>12</i>	<i>14</i>	<i>16</i>	<i>18</i>	
<b>Alternative 2</b> <b>Vertical realistic</b>		2%	9%	24%	43%	63%	83%	94%	97%	99%	
	<b>Fast departure curve</b>										
			<i>2</i>	<i>4</i>	<i>6</i>	<i>8</i>	<i>10</i>	<i>12</i>	<i>14</i>	<i>16</i>	<i>18</i>
		8%	29%	50%	71%	91%	97%	99.9%	100%	100%	

Table 5.10: Percentage of the evacuating population that has reached a destination after a certain amount of hours for alternative 2.

		<i>Hours</i>										
		<b>Slow departure curve</b>										
		<i>5</i>	<i>10</i>	<i>15</i>	<i>20</i>	<i>25</i>	<i>30</i>	<i>35</i>	<i>40</i>	<i>45</i>	<i>50</i>	
<b>Alternative 3</b> <b>Preventive realistic</b>		9.5%	23.5%	37.5%	52%	65%	78%	87.5%	93.5%	98%	100%	
	<b>Fast departure curve</b>											
			<i>5</i>	<i>10</i>	<i>15</i>	<i>20</i>	<i>25</i>	<i>30</i>	<i>35</i>	<i>40</i>	<i>45</i>	<i>50</i>
		12%	27%	41%	54%	68%	78%	92%	95%	99%	100%	

Table 5.11: Percentage of the evacuating population that has reached a destination after a certain amount of hours for alternative 3.

## 5.4. Sensitivity analyses

To estimate the effect what certain parameters have on the simulation, sensitivity analyses will be run. First, the average people per car will be adjusted, then the exit capacity of the island and finally a simulation is run with an instant departure curve. The accompanying evacuation outflow diagrams are displayed in appendix B.

### 5.4.1. People car equivalent

The average people per car in the base simulations was 2.3. The different alternatives are now run with an average of 2.8 people per car. In table 5.12 the results are presented.

	Slow departure curve				Fast departure curve			
	25%	50%	75%	100%	25%	50%	75%	100%
<b>Alternative 1: Vertical optimistic</b>	~5.5	~7.5	~9	~16.15	~3	~4	~5	~8.25
<b>Alternative 2: Vertical realistic</b>	~6	~8.5	~10.5	~18	~3.5	~5	~7	~11.15
<b>Alternative 3: Preventive realistic</b>	~10	~18	~26.5	>48	~9	~17	~25.5	>48

Table 5.12: Evacuation time for different percentages of the population for the different alternatives if there are 2.8 people per car.

- For alternative 1 the total time it takes to evacuate 20% of the total population in both the slow and fast departure curve scenarios roughly remains the same compared to the base simulation. This shows that if the exit capacity is no limiting factor the amount of people per car has almost no influence on the time it takes to evacuate the population, which is as expected. The travelling times of the population is short and how fast they can leave the island is primarily determined by the departure curve.
- For alternative 2 the amount of time it takes to evacuate 20% of the population with a slow departure curve remains relatively the same compared to the base simulations, whereas with a fast departure curve this process is significantly faster. The results of the simulation with the slow departure curve were somewhat unexpected since the base simulations showed that the exit capacities were the limiting factor. Meaning that if there are more people per car, it should in theory influence the required time of an evacuation. The reason why this is not the case in the slow departure curve simulation cannot be determined.
- For alternative 3 the differences between the time it takes to evacuate the population if there are 2.8 people per car compared with the base simulations of 2.3 people per car is also less then expected. Why this is the case is unknown.

### 5.4.2. Increased exit capacity

In the base simulation the exit capacity was modelled to be 1100 car/hour. In this sensitivity analyses the exit capacity is set to roughly 2200 cars/hour for alternative 2 and 3. This is done by setting the free flow speed and stop and go speed of the constraints to 2.15 km/h.

	Slow departure curve				Fast departure curve			
	25%	50%	75%	100%	25%	50%	75%	100%
<b>Alternative 1: Vertical optimistic</b>	-	-	-	-	-	-	-	-
<b>Alternative 2: Vertical realistic</b>	~5.5	~7.5	~9	~16.25	~3	~4.5	~5.5	~8.4
<b>Alternative 3: Preventive realistic</b>	~7.5	~11.5	~16.25	~29	~5.5	~10.25	~15	~29

Table 5.13: Evacuation time for different percentages of the population for the different alternatives with an exit capacity of 2200 cars per hour.

For both alternative 2 and 3 a larger exit capacity has a significant influence on the time it takes to evacuate the total population compared to the base simulations.

- In alternative 2 the exit capacity is now large enough to facilitate the evacuating population and the evacuation time closely resembles the departure curve. In these scenarios a faster departure curve can contribute to a faster evacuation.
- For alternative 3 the travelling times remain long and a faster departure curve has no influence on the total required time compared with a slow departure curve.

### 5.4.3. Instant departure

This scenario shows what the results are if an instant departure curve is assumed in alternative 2. This is a completely unrealistic scenario but is done to investigate if there is a limit to what a faster departure curve can do for the required time for evacuation.

	<b>Instant departure curve</b>			
	25%	50%	75%	100%
<b>Alternative 1: Vertical optimistic</b>	-	-	-	-
<b>Alternative 2: Vertical realistic</b>	~2.5	~5	~7	~11.5
<b>Alternative 3: Preventive realistic</b>	-	-	-	-

Table 5.14: Evacuation time in hours for different percentages of the population for alternative 2 with an instant departure curve.

The total time it takes to complete an evacuation with an instant departure curve is still faster than the fast departure curve in the base simulation of alternative 2. It can be concluded that as long as vertical evacuation strategy is adopted in these models, the total time it takes to evacuate the population will decrease if a faster departure curve is assumed, albeit with an increasing travelling time of the population.

## 5.5. Reflection LifeSim models

LifeSim misses some options that makes it difficult to model evacuation scenarios of Dordrecht that are found in their water safety plan. There were also some errors that limited the amount of data that could be collected from the LifeSim simulations. The missing options and the effects on the model will be discussed below.

### Including hydraulic data and loss of life

As already mentioned in paragraph §5.2.1 the hydraulic data generated by SOBEK had some trouble to be imported into LifeSim. For some reason the entire hydraulic scenario could not be included but only the TIFF files with the highest water level and flow rate. This did not affect the model runs in this thesis because in the loss of life calculations it was assumed that the evacuation strategy was successful, meaning there where no people on the road.

### Location of the population

The option to show the traffic flow during evacuation and the location of the loss of life of the population could not be included in this thesis. The option was not working in the LifeSim models during this thesis.

### Including exit capacity

The way the exit constraint are currently modelled in LifeSim are not ideal and have an effect on the simulation. These effects are:

- First of, the exit capacity in the different simulation were measured with help of cumulative destination outflow graphs. These show the amount of cars that reached a particular exit after a certain amount of time. In figure 5.16 an example is presented of the evacuation outflow diagram for preventive evacuation in a pessimistic road scenario.

It was expected that the shape of the evacuation outflow for the different exits would be somewhat similar since every constraint has the same amount of lanes, free flow speed and stop and go speed. However this evacuation outflow diagram shows that this is not the case. One possible explanation could be that if there are many people on a road and suddenly the capacity drops significantly, LifeSim overwrites certain parameters so these people can still be facilitated. However, for every simulation run in this thesis the evacuation outflow diagrams are checked to make sure that the combined capacity never exceeds 1100 cars per hour.

- Another limitation of the current modelling method of the exit constraints is that the total exit capacity is not shared between the exits. Meaning that if one exit is not used, the capacity of another exit goes up. This is also shown in figure 5.16. Some exits are not used while other still are. This will result in slightly longer evacuation times compared to simulations with a more even distribution.

### Including uncertainty

LifeSim includes an uncertainty range in the results by means of a Monte Carlo approach. The USACE advised to generally run each simulation with a 1000 iterations. Due to the uncertainty in the warning issuance delay, warning diffusion, personal action initiation and loss of life each iteration has a different result. This gives an uncertainty range of what different results that can be expected.

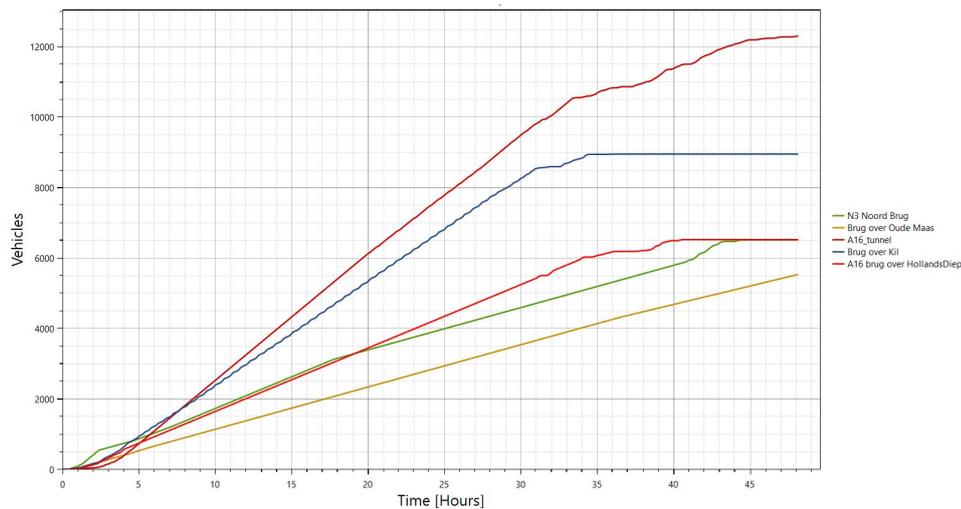


Figure 5.16: Cumulative destination outflow graph example.

However, with how the LifeSim models are currently defined this Monte Carlo approach does not influence the results. The models do not include a warning issuance delay, the warning diffusion is instant and finally the personal action initiation curve is modelled after either the slow or the fast PBL departure curve which do not include an uncertainty range. This means that the result of each iteration is roughly the same since almost all uncertainty is taken out of the model.

### Preventive evacuation

LifeSim had trouble with simulation where a large number of people will try to reach a destination but where the road capacity is limited. In the base simulations of preventive evacuation with a realistic roads scenario, one iteration could take up to 15 minutes to run with an additional 10 minutes to generate a detailed output to show the cumulative evacuation outflow graph and cumulative destination arrival graph.

These long simulation times are the results of large traffic jams and a low outflow of the population due to the exit constraints. If 40.000 cars are driving at a particular moment that re-rout constantly and influence each other with this rerouting LifeSim has trouble simulating each car. With these simulation-times of 15 minutes, simulating 1000 iterations for each different departure curve is unfeasible.

This problem however was solved by the approach in the previous paragraph by excluding the uncertainty within the model. Because of this reason only one iteration was needed to show the required time for evacuation of either a slow or fast departure curve.

# 6

## Conclusions and Recommendations

### 6.1. Conclusion

The purpose of this thesis was to investigate how Dordrecht could translate the investment of their water safety plan into an altered warning issuance delay and departure curve and to estimate the effects of these faster curves. The corresponding main research question is presented below. An answer in this chapter is provided to the following main question:

*"What method can be developed to translate the effects of certain measures in the field of crisis communication following the water safety plan of Dordrecht to an altered warning issuance delay time and departure curve and estimate the effects of these on the required time it takes to evacuate the island?"*

A method that could be used, is a method that is based on the USACE assessment method. Although the USACE assessment method cannot be used directly to estimate the warning issuance delay time and departure curve for case studies in the Netherlands, there is still a wealth of information that can be collected from this document. It is one of the most complete assessment methods available and is based on data from numerous evacuations throughout the USA. There are certain steps that can be made to tailor this approach so it can be applied in the Netherlands.

For the warning issuance delay time: The warning issuance delay time for Dordrecht following the USACE assessment method is estimated to be somewhere between 0 and 240 minutes with a mean time of 80 minutes. This is considered to be unrealistically high for the Netherlands. The explanation for this difference is a combination of things. First of: the command structure between both countries differs greatly. In some counties of the USA a single sheriff is responsible for a call to evacuate, whereas in the Netherlands it is a decision making process between multiple parties. Secondly, the threat scenarios on which the USACE assessment method is based include dam breaches, chemical leaks, flash floods, hurricanes and dike breaches. It can be assumed that the decision making process is faster in chemical leaks and dam breaches only hours away compared to flood threats days away.

So in order to get a better estimation for Dutch scenarios, more questions should be included that focuses on the up-scaling process and the interaction between different parties in the Netherlands while threatened by flood scenarios. However, the large difference in the estimated warning issuance delay between the USACE assessment method and the current estimations in the Netherlands does show that that there is much to be gained in this particular area.

Regarding the departure curve, the difference between the departure curve used in the Netherlands and the warning diffusion graph and personal action initiation graph that follow from the case study of Dordrecht are large. The assessment method estimates a much faster initial response of the population, but a longer overall time for the personal action invitation curve to be completed compared to the departure curve. A possible explanation of this difference is the same as the warning issuance delay time. The threat scenarios on which the USACE assessment method is based includes events not found in the Netherlands. Another consideration is that the data of the USACE assessment method is only based in preventive evacuations.

That said, both the USACE assessment method and the departure curve used in the Netherlands use relatively old data, meaning that new innovations such as social media and internet are less well represented. The data used in the development of the USACE assessment method primarily comes stems from 1980 till 1990, whereas hurricane Opal, on which the departure curve is based, comes from 1995.

The advise is to reevaluate the current departure curve and estimate if the initial response is larger than previously thought or that the departure curve takes longer to complete as seen in the USACE assessment method. Meetings should be organised where experts on evacuation issues gather with safety regions and other responsible parties can be used to determine what they think the effects are of recently taken investments and measures on the departure curve. The values of the USACE assessment method can then be adjusted to better represent the Netherlands.

The conclusions of the previous paragraphs should be accompanied with the following statements:

1. A faster departure curve can result in significant time savings, but only in scenarios where there is little traffic congestion. If there is much traffic congestion traffic jams will develop and the travelling time of the population starts to increase. The time saving of a faster departure curve are nullified because although people will leave faster they immediately enter a traffic jam. This thesis takes into account two road scenarios that follow from the water safety plan of Dordrecht. One where the surrounding roads of Dordrecht are empty and people can leave the island freely and one scenario where the roads that surround Dordrecht are congested because multiple areas in the Netherlands are in the process of evacuation.

The result of the LifeSim simulations showed that in scenarios where there is no congestion on the roads that surround Dordrecht, a faster departure curve is directly translated into a faster evacuation. In roads scenarios where the surrounding roads of Dordrecht are congested the time savings of a faster departure curve diminish quickly if larger portions of the population evacuate. For vertical evacuation where 20% of the population of Dordrecht ( 23.500 people) leaves, a departure curve that is eight hours faster will only result in a four hour faster evacuation. For preventive evacuation where 80% of the population leaves (93.500 people) the time savings of a faster departure curve are negligible.

The traffic congestion on the roads surrounding Dordrecht thus form a limiting factor on how fast people can leave the island. Currently areas in the Netherlands develop their own evacuation strategies but this thesis showed that areas cannot be seen as separate in terms of evacuation because they will often be affected by evacuation strategies of other regions. In order to capitalise on a faster departure curve, national collaboration in the field of evacuation strategies and traffic management is needed. If vertical evacuation becomes the standard strategy for a multitude of areas better national traffic management plans can be developed so that the most threatened areas can evacuate faster.

2. This thesis also showed that agent based evacuation and loss of life models add nothing to the evacuation strategies in scenarios with significant road congestion. The travelling time is long relative to the warning issuance delay time and departure curve and when people leave their home they immediately enter a traffic jam. However, if areas manage to (severely) decrease the travelling time of the population by adopting a nationwide vertical evacuation strategy, these agent based models may lead to new insights because they can more easily include area specific information.

The sub question that accompanied the main research question will be discussed below.

#### **Sub-question 1: What are the fundamental differences between the PBL and LifeSim model?**

Both model operate on a different modelling principle of each other. The largest differences between the models are:

- **Traffic modulation and exit capacity:** The PBL model is based on the HIS-EC which is a static traffic model with an option to include an exit capacity model, LifeSim includes a dynamic traffic model but does not include an option to include an exit capacity.

- **Victim location & mortality:** The PBL model distinguishes between six different victim location and five mortality rates whereas LifeSim distinguishes between three victim locations and two mortality rates. This three victim locations of the LifeSim model are a simplification because the user can include numerous different buildings such as schools, factories, hospitals, one story buildings, two story buildings etc. and can assign certain unique parameter to these building types such as the average people per car, stability criteria, or if people leave at the same time. So it can be argued that there are not three victim location but a lot more. However, LifeSim treats people on a dry story at home the same as people located in a hospital. Also within the options it does only show the loss of life in the structures. So for simplifications it is denoted as three.

The different victim locations of the PBL model are:

1. Successful preventive evacuation
2. overtaken by flood
3. Shelter in surroundings
4. Shelter
5. At home prepared
6. At home unprepared

The different victim locations of LifeSim are:

1. Successfully reached a destination
  2. Overtaken by flood
  3. In a structure (the user can include numerous different buildings such as hospitals, schools, homes and factories)
- **Inclusion of extreme weather:** In the HIS-EC extreme weather is included by setting a certain simulation time, meaning the evacuation stops at that moment. In LifeSim it is not possible to stop an ongoing evacuation. The evacuating population will continue to evacuate until a non-evacuation depth is reached.
  - **Determining people per car:** The people per car in the HIS-EC is determined by a predefined number defined by the user. In LifeSim the average people per car are determined for each building. However, LifeSim does not bundle buildings together to reach this average. So the average people per car of the total population will often be less than what the user defines.

These differences make the LifeSim model less suited for modelling flexible evacuation strategies in Dutch evacuation scenarios. This is because certain parameters that are deemed important for Dutch evacuation to estimate the result in the required time and loss of life with a certain strategy cannot be included. Firstly, the lack of a direct option to include an exit capacity makes it difficult to get a grip on how many people can leave the island. The inclusion of exit constraints as used in this thesis are time consuming to include and have some drawbacks.

Secondly, because LifeSim only includes two mortality functions, it is difficult to see the results in loss of life of additional measures following the base strategy of evacuation for Dordrecht. For the loss of life it does not matter if people evacuated preventively, reached a shelter or remain in a dry story within their house. Consequently, people that do not have a dry story are put in the same mortality function as people who are swept away by the flood.

#### **Sub-question 2: What are the differences between the warning issuance delay time and departure curve used in the Netherlands and the assumptions of the USACE assessment method?**

In the Netherlands the warning issuance delay time is not included in the model simulations. A model starts when a call to evacuate is given. However, it is taken into account indirectly by estimating the expected time till the onset of a flood. It is assumed that a period of 24 hours preceded this call to evacuate. The USACE assessment method (and consequently LifeSim) do take into account this warning issuance delay in the model simulations.

In the Netherlands, the warning diffusion time and personal action initiation curve are combined into a single curve called the departure curve. The departure curve used in the Netherlands was developed in 2004 with data of hurricane scenarios of Alabama USA. It does not differentiate between day or night or an expected or unexpected flood. This departure curve takes 16 hours to complete. This is in stark contrast with the USACE assessment method that does estimate that there are numerous factors that influence how the warning diffusion curve and personal action curve are defined and include the difference between a day and night cycle, the cooperation factor of the population compared to the relative warning time and how the population perceives themselves to be impacted.

**Sub-question 3: Can the USACE assessment method be used to estimate the warning issuance delay time and departure curve of Dordrecht and include the effects of investments following their water safety plan?**

After completing the questionnaire of the USACE assessment method with the water safety region South Holland south, who are responsible for the island of Dordrecht with respect to evacuation, it is concluded that what the assessment method predicts differs greatly than what is currently assumed in the Netherlands. The warning issuance delay time following the assessment method is estimated to be somewhere between zero and four hours with an most likely (mean) time of 80 minutes. In the Netherlands this time is expected to be significantly longer. This is because in the Netherlands there are multiple parties involved in the decision making process. Furthermore, the decision to evacuate is often not a singular decision, but rather a series of decisions to scale up with the end decision to evacuate. So before the actual call to evacuate, there have been numerous meetings between different parties to prepare followup measures. This whole process of up scaling will take up more than 80 minutes.

Another difference is that the assessment method predicts that the majority of the population will take a defensive action much faster than what is currently assumed, but takes a lot longer for the total population to reach 100%, that is, 100% of the people that will evacuate of the island which in Dutch scenarios is either 20% or 80%. For example, the assessment method predicts that in an average scenario 50% of the population will have left after 1.8 hours, whereas the departure curve in the Netherlands estimates that this is seven hours. In figure 6.1 the issuance to initiation and the slow departure curve of the Netherlands are combined in one graph.

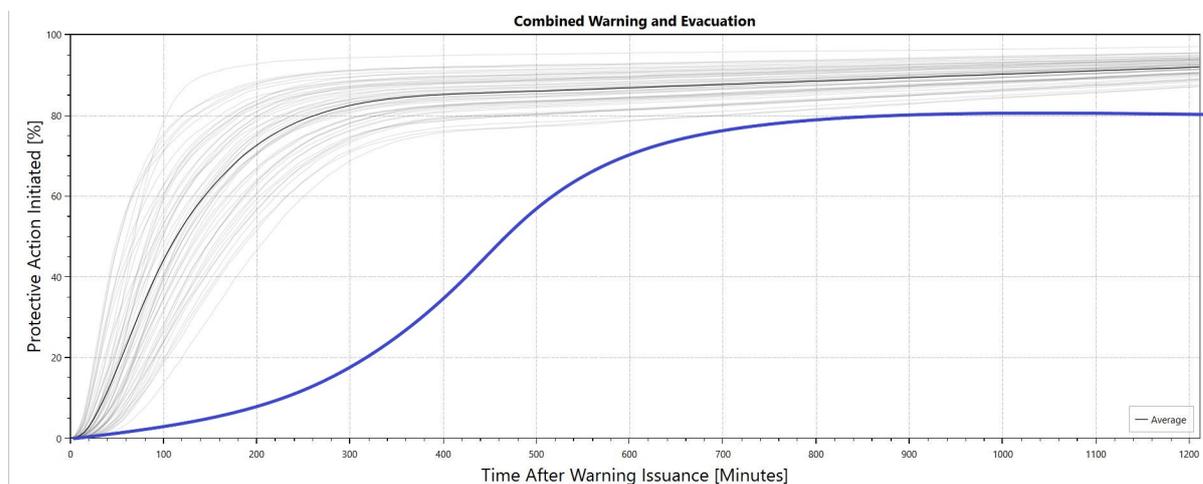


Figure 6.1: Issuance to initiation curve following the USACE assessment method (left) combined with the slow departure curve of the Netherlands (right).

The difference between the warning issuance delay curve and the issuance to initiation curve (which is a combination of the warning diffusion curve and personal action initiation curve) compared to the assumptions in the Netherlands may be explained by the differences between the two countries. Firstly, the different threat scenarios. In the USA they are threatened by hurricanes, dam breaches, flash floods etc. People will react differently to a possible dam breach than to a dike overflow. Another factor is evacuation experience. The Netherlands are rarely affected by evacuations, whereas it is more common in the USA, and lastly, how evac-

uation is arranged. In the Netherlands there are numerous parties involved that meet several times before a call to evacuate is given where in the USA, especially in the smaller counties, it is often the responsibility of the sheriff to give an order to evacuate [21].

Another conclusion following from the USACE assessment method is that it could not measure the improvement of the investment agenda of the water safety plan of Dordrecht. The questions in USACE assessment method were more applicable to make a one time estimation of the situation than to measure small increases in the evacuation efficiency due to investments and measures. Questions in this assessment method were focused on subjects such as which warning methods are available and if a person is available 24 hours a day that can be reached if a dangerous situation is established. In the case of Dordrecht, they have not hired new people or installed new warning methods, they just made the whole decision making process and warning process more efficient.

**Sub-question 4: What are the effects of an altered departure curve on the required time of an evacuation in certain evacuation scenarios of Dordrecht?**

An altered departure curve can have a large influence on the required time of evacuation, but only in situations where the population is not limited by an exit capacity or road congestion. Three base simulations were developed following the water safety plan of Dordrecht. Each simulation was run with a slow departure curve that takes 16 hours to complete and is currently the standard in the Netherlands and a fast departure curve which takes 8 hours to complete. Also a distinction was made between the road capacity of the surrounding roads of Dordrecht. In an optimistic scenario the surrounding roads of Dordrecht are empty, whereas in a realistic scenario the surrounding roads are heavily congested. The different simulations were:

- **Alternative 1: A vertical evacuation strategy with an optimistic road scenario.**

In this situation, 20% of the population of Dordrecht, which amounts to approximately 23.500 people will try to leave the island. It is assumed that the surround roads of Dordrecht are completely empty, meaning that people can freely leave the island. In this simulation a faster departure curve is completely converted into a faster evacuation. However, this is a scenario that is unlikely to happen in real life scenarios because other areas are also evacuating, limiting the exit capacity of the island.

- **Alternative 2: A vertical evacuation with a realistic road scenario.**

In this scenario other areas in the vicinity of Dordrecht are also evacuating, meaning that the exit capacity of Dordrecht is limited. The assumed exit capacity is taken as 1100 cars per hour and like alternative 1, approximately 23.500 people will try to leave the island. In this scenario time savings following a faster departure curve are primarily the result of people leaving their homes faster. But additional time savings are limited by the exit capacity. The results are that an eight hours faster departure curve only amounts to a four hours faster evacuation.

- **Alternative 3: Preventive evacuation with a realistic road scenario.**

In this scenario 80% of the population of Dordrecht will try to leave the area, which amounts to 93.500 people. Like alternative 2, the roads surrounding Dordrecht will be congested and this is modelled using an exit capacity of 1100 cars per hour. This scenario shows that according to LifeSim it is not possible to completely evacuate the island in 48 hours, which is the maximum amount of available time according to the water safety plan of Dordrecht. In this scenario a faster departure curve is also negligible.

**Sub-question 6: How does a faster decision making process relate to a faster departure curve in terms of required time for an evacuation for Dordrecht?**

In the Deltaprogramma the warning issuance delay time is not directly taken into account to determine the evacuation fractions of the different areas in the Netherlands. Rather it is taken into account in the available time for evacuation where 1, 2, 3 or 4 days time is assumed between the order to evacuate and the onset of a disaster. It is assumed that 24 hours warning issuance delay time has preceded this decision to evacuate. The safety region South Holland south estimates that they are faster than is currently assumed. This thesis showed that a faster decision making process result in a higher percentage of people that can evacuate before the expected onset of a flood. This is because the warning issuance delay time directly effects the net available time for evacuation. The USACE assessment method showed that there is still significant possibilities to

increase the efficiency of this warning issuance delay. However, one consideration is that the USACE assessment is based on different threat scenarios and command structures than found in the Netherlands. So some differences in the warning issuance delay time are expected.

**Sub-question 7: Are the results generalizable to other part of the Netherlands?**

In other areas that are also effected by heavy traffic congestion and have similar evacuation strategies, it can be argued that the results are generalizable. In these scenarios the faster departure curves will be limited by the traffic congestion and travelling time. However, in situations where the safe destination of the population is in close proximity of their starting point, a faster departure curve can be directly translated into a faster evacuation time.

## 6.2. Recommendations

The following recommendations are based on the study findings and experiences while performing this study:

1. LifeSim currently misses some options to make it an effective tool to calculate the results of a flexible evacuation strategy of Dordrecht. However, if several options could be implemented within this model it could be a valuable tool for future estimations on the required time for evacuation and loss of life of areas in the Netherlands. These options include: implementing an exit capacity option, include the option of modelling shelters within the threatened area and the inclusion of more mortality rates. If these options are included, LifeSim could be better suited for calculating a flexible evacuation strategy.
2. Following the answer of the main research question, the USACE assessment method provides a valuable basis for the Netherlands to develop their own assessment method. However, several steps have to be taken to tailor it for usage in the Netherlands. Firstly, a Dutch assessment method should focus more on the decision making process. Secondly the warning diffusion curve and personal action initiation curve should be calibrated to Dutch expectations and threat scenarios. Due to a lack of data this is primarily done by holding meetings where experts in the field of crisis management and communication meet with safety regions and other responsible parties to investigate what they think the expected change in a departure is following investment and measures. This can be combined with tests and exercises.
3. Start working together on national scale with respect to developing evacuation strategies. At the moment authorities are primarily focused on their own territory. However, this thesis showed that different areas cannot be seen as separate since they all influence each other by using the major infrastructure throughout the Netherlands. The influence of measures and investments taken by certain areas is nullified by the evacuation strategy of other areas. If vertical evacuation could be made the default strategy for a majority of the Netherlands, new national traffic management options will present themselves and the most threatened areas could be evacuated faster. However, threat scenarios will always be accompanied by uncertainty on the precise location and arrival time. So what exactly is a threatened area may be difficult to determine a few days prior to a disaster.
4. Both LifeSim and the PBL model have a place in developing evacuation strategies. The PBL model which is classified as a macro model is simpler and better suited if there is relatively little data available regarding evacuations or when the travelling time of the population is long compared to the warning delay, warning diffusion and personal action initiation time. LifeSim on the other hand could give a more "tailored" estimation on the required time for evacuation by taking area specific parameters into account. This thesis showed that for areas in the Netherlands that are effected by traffic congestion during evacuation (such as Dordrecht) then the PBL is better suited. However, there are also areas in the Netherlands where a safe location is relatively close to the starting point of the population, for instance, in flood scenarios caused by high river discharges. In these scenarios the LifeSim or other agent based models may provide new insights in the required time for evacuation.

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# **Appendices**



# A

## Questionnaire USACE assessment method

Question	Response
1	Which of the following flood threats could affect your community:
1-a	Dam breaches? No
1-a	Controlled dam releases? No
1-c	Levee breach or overtopping? Yes
1-d	Flash flooding? No
1-e	Riverine flooding? Yes
1-f	Other flood types? Yes
1-g	(IF YES) What other flood types? _____
2	Are the boundaries identified for the areas of your community that would be flooded for the full range of potential flood scenarios? Yes
3	Do you have a general emergency plan? Yes
4	Do you have a general warning plan or annex to a general plan? Yes
5	Do you have standard operating procedures for warnings? Yes
6	Do you have a hazard-specific warning plan for flooding including breach scenarios? Yes
7	Do you have a hazard-specific standard operating procedures for flooding including breach scenarios? Yes
8	Is a particular person or position responsible for getting a first alert or warning out to the public? Yes
8-a	(IF YES to 8) What is their name and title? _____ Incident voorlichter
8-b	(IF YES to 8) Do they have legal authority to do so? Yes
8-c	(IF NO to 8) What is the name and title of who does? _____
8-d	Is the responsible person or position written down? Yes
8-e	(IF YES to 8d) Where? _____ Procedures (RCP)
9	Would responsibilities pass from one person to another if someone were not available to perform their first alert or warning roles? Yes
9-a	(IF YES to 9) How would it be done? _____ Pilot
9-b	(IF YES to 9) How would the people involved know how to do it? _____ Training
9-c	(IF YES to 9) Is how to do it written down? _____ Plan
9-d	(IF YES to 9c) Where? _____ Beleidsplan
10	Do you have a staffed contact point that operates 24 hours per day 7 days a week to receive threat information from those who might detect it? Yes
11	Do your plans, procedures, or other written documents classify threat levels into different categories (for example, flood watch and flood warning), and specify different public actions for each level? Here's an example (SHOW MATRIX CARD) of what I mean. Yes
12	What would trigger sending a first alert or warning to the public? _____ Besluitvorming
12-a	How would you know when the trigger is reached? _____ Mandaat Operationeel Leider
12-b	Is anything about the trigger written down? Yes
12-c	(IF YES to 12-b) Where? _____ Wetgeving
13	Would you seek to confirm the flood threat before distributing a first public alert or warning? Yes
13-a	Are there written procedures about threat confirmation? Yes
14	Would you communicate with the agency responsible for the dam or levee before distributing a first public alert or warning, for example, so you could ask questions and get answers? Yes
14-a	(IF YES to 14) How would it be done? _____ Afspraken / overlegstructuur
14-b	(IF YES to 14) How would you know how to do that? _____ Planvorming
14-c	(IF YES to 14) Is how to do it written down? Yes
14-d	(IF YES to 14c) Where? _____ Beleidsplan
15	Are the name(s) and number(s) of the people to talk with in the agency responsible for the dam or levee written down and readily available? Yes
15-a	(IF YES to 15) Where? _____ Beleidsplan
16	Do you have redundant technologies available for communicating with people in the agency responsible for the dam or levee? Yes
16-a	(IF YES to 16) What are they? _____ Generator / drie typen internet
16-b	(IF YES to 16) Would any work if the electricity were out? Yes
16-c	(IF YES to 16) Would any work if the community were damaged? Yes
17	Do the people who would issue a first alert or warning routinely communicate with the people responsible for the dam or levee? Yes
17-a	(IF YES to 17) How often? _____ (times/year) 6
18	Are the people who would issue a first alert or warning allowed to get that job done in innovative ways if circumstances keep them from doing it according to procedures? Yes
18-a	(IF YES to 18) Is their ability to do this part of your written procedures? Yes

19	Do you have unique ways to provide first alerts or warnings for events in which impact could occur in an hour or less, for example, send a first alert or warning out without getting clearance from anyone?	Yes
19-a	(IF YES to 19) How would it be done? _____	Procedure (spoed)
19-b	(IF YES to 19) Is how to do it written down?	Yes
20	How many people would likely be involved in deciding and/or approving issuing a first alert of warning? _____	4
21	Do the people who have a role in getting a first alert or warning to the public practice doing that job, for example, in drills or exercises?	Yes
21-a	(IF YES to 21) How often? _____ (times/year)	6
22	Which of the following ways to disseminate alerts and warnings would you use to get the first alert or warning to the public?	
22-1	Route alerting	No
22-2	Fixed location loudspeakers & public address systems	No
22-3	Wireless emergency alerts that use the WEA opt out system	Yes
22-4	Wireless emergency alerts that use an SMS opt in system like Everbridge	No
22-5	Radio	Yes
22-6	Television	Yes
22-6	NOAA Weather Radio	No
22-9	Tone alert radios dedicated to dam or levee emergencies	No
22-10	Audio sirens and alarms	Yes
22-11	Broadcast voice sirens	No
22-12	Message signs	Yes
22-13	Aircraft	No
22-14	Visual alerting	Yes
22-15	Email to the public	Yes
22-16	Text messages not including WEA	Yes
22-17	Social media, e.g., Twitter and Facebook	Yes
22-18	Website(s)	Yes
22-19	Reverse auto-dial telephone distribution system	No
22-20	Tdd/Tyy	No
22-21	Other _____	No
22-22	ADD FOR TOTAL # EXCLUDING TDD/TYY= _____	10
23	The following questions help to gauge the effectiveness of each warning system identified above. (ONLY ASK ABOUT ITEMS SELECTED IN QUESTIONS 22)	
23-a	How many patrol cars and officers would be dedicated to route alertings?	-
23-c	What percentage of the population has NOAA Weather Radio or dedicated tone alert radios?	0%
23-d	Would a significant portion (large percentage or those closest to hazard) of the at risk population be alerted by audio or broadcast sirens or fixed location loudspeakers?	Yes
23-e	Have you successfully issued warnings or alerts through the WEA system in the past?	Yes
23-f	How many aircraft would be dedicated to spreading warnings?	-
23-g	What percentage of the public is engaged with your social media activities?	50%
23-h	What percentage of the public has signed up their cell phone number in the reverse autodial system or email notification system?	0%
23-i	How many calls/hour can the reverse autodial system make?	-
24	If an update to a warning message were not needed, would the original message be repeated more than once?	Yes
24-a	(IF YES to 24) How frequently would it be repeated? _____	2x per uur per middel
25	Do you have ways to monitoring what other organizations or people in the public might be saying about the threat to each other, for example, over social media?	Yes
25-a	(IF YES to 25) How would it be done? _____	Crisisfunctie
25-b	(IF YES to 25) Would you attempt to correct wrong information? _____	Yes
26	Could there be a significant number of people engaged in any of the following activities, in any of the following locations, or in any of the following groups when alerts or warnings are issued, and do you have special ways to provide them with a first alert or warning?	Sig#/Ways to Warn
26-a	Boating	Yes/No
26-b	Camping	Yes/No
26-c	Hiking	Yes/No
26-d	Recreational activities near water	Yes/No
26-e	Hospitals	Yes/Yes
26-f	Group homes	Yes/Yes

26-g	Prisons	Yes/Yes
26-h	Shopping centers	Yes/Yes
26-i	Schools	Yes/No
26-j	Agricultural workers in fields	Yes/No
26-k	Transients	Yes/Yes
26-l	Homeless	Yes/No
26-m	Unique subcultures, e.g., the Amish	Yes/No
		-3
27	Do you have a special way to deliver a first alert or warning message to people very close to the dam and/or levee?	No
27-a	(IF YES to 27) How would it be done? _____	
28	Do you have a way to wake people up at night when they might be sleeping to provide them with a first alert or warning?	Yes
28-a	(IF YES to 28) How would it be done? _____	Alarm
29	Do you have a way to deliver alerts and warnings to people who are hearing impaired?	No
29-a	(IF YES to 29) How? _____	
29-b	(IF YES to 29) What has been done to assist the hearing impaired in obtaining the specialized equipment or technology they need to be able to receive alerts and warnings? _____	
30	Do you have a way to deliver alerts and warnings to people who are visually impaired?	No
30-a	(IF YES to 30) How? _____	
30-b	(IF YES to 30) What has been done to assist the visually impaired in obtaining the specialized equipment or technology they need to be able to receive alerts and warnings? _____	
31	Do you provide alerts and warnings in foreign languages for people who only speak a foreign language?	No
31-a	Are you missing any languages that make up a significant portion of the population? _____	Yes
32	Do you have the plans and technology in place to alert and warn people if infrastructure were disrupted, for example, from a lack of electricity, damage to streets that might be used for route alerting, or damage to an outdoor siren system?	Yes
32-a	(IF YES to 32) What are they? _____	Social media, omroepen hebben noodstroom
33	Do you have example alerts, warnings and/or emergency press releases or templates to use as guides during an event?	Yes
33-a	(IF YES to 33) What does each of them say? _____	Afhankelijk van bericht
33-b	(IF YES to 33) May I have copies of them? _____	
34	Have you recently issued any alerts, warnings and/or emergency press releases to the public?	Yes
34-a	(IF YES to 34) When and for what? _____	Chloordampen. Zelfde partijen verantwoordelijk dus wordt getest
34-b	(IF YES to 34) May I have copies of them? _____	
35	Would you name a source in the public alerts, warnings, and press releases that you issue?	Yes
35-a	(IF YES to 35) Who would be named including job title and affiliation? _____	Grote centrale, dus niet specifiek
36	Would you recommend in alerts, warnings and press releases that the public take specific protective actions, for example, evacuate, move vertically, or check local media?	Yes
36-a	(IF YES to 36) What specific public actions would be recommended for each flood threat level? _____	
37	Would the alerts, warnings and emergency press releases you issue tell the public about any of the following?	
37A	The consequences of the flood and why taking the recommended protective action(s) would reduce them?	Yes
37B	The time people should begin and complete taking the recommended protective action?	Yes
37C	The boundaries of the areas that would be flooded?	Yes
37D	Why people who are safe, but located close to an area being evacuated have no reason to evacuate?	Yes
37E	What parents should do about their children who might still be in school?	Yes

37F	What to do with pets and animals when taking a protective action?	Yes
37G	The weather outside if a flood was happening on a sunny day?	No
38	Would the alerts, warnings and emergency press releases you issue have either of the following characteristics?	
38A	Would they be specific, for example, if people are asked to evacuate by describing the details of evacuation such as the routes they should take, what boundaries they should cross to reach safety, and the time by when they should get there?	Yes
38B	Would they be clear, for example, by not using words like probable maximum flood, uncontrolled release, and breach, and instead use words that everyone can understand?	Yes
39	Would the alerts, warnings and emergency press releases you issue say anything different for people who might be close to where the flooding would begin versus people who are far away?	Yes
40	Would the alerts, warnings and emergency press releases you issue be different if impact is imminent, for example, within minutes to an hour?	Yes
41	Would you work with other flood threatened political jurisdictions, for example, other counties or cities, to coordinate the content of public alerts, warnings and/or emergency press releases?	Yes
41-a	(If YES to 41) How would you do that? _____	Nationaal / Regionaal crisisplan
42	Do the people who write and issue public alerts, warnings and press releases practice doing so in drills, exercises or in other ways?	Yes
43	Do you have a program in place to provide public education to motivate household preparedness among people in your community who live in areas that could flood?	Yes
43-a	(If YES to 43) Please describe that public education program and any material that might be part of it? _____	Overstroomik.nl
44	Would you say people in your community who live in areas that could flood are adequately prepared?	No
45	Has your community experienced a flood in the last 20 years?	No
45A	(If YES to 45) In what year did it happen?	
45B	How severe was it?	
45C	Were members of the public asked to evacuate?	
45D	(If YES to 45C) What percentage of the total population that could be at risk to flooding in your community were asked to evacuate? _____	
45E	What percentage of the population asked to evacuate did so? _____	
45F	How many hours did it take to accomplish the evacuation? _____	
45G	Did you encounter any problems in managing the emergency?	No
45H	(If YES to 45G) What were those problems? _____	
45I	What have you done to correct for those problems since then? _____	
45J	Have you made other emergency management changes since then that would influence your response to a future emergency?	Yes
45J-a	(If YES to 45J) What were they?	
46	Have warnings been issued in your community recently about an impending emergency including floods and other types of hazards that asked people to take some sort of protective action?	Yes
46-a	(If YES to 46) How many times? _____	2x per jaar
46-b	(If YES to 46) When? _____	Brand 2019, stankincident 2018
47	If a flood event were to occur in your community, what percentage of the people advised to take the following actions would you expect to actually do so?	
47A	Move vertically? _____%	80
47B	Evacuate out of the flood inundation area? _____%	80
48	What percentage of your at risk population did not graduate from high school? _____%	7%
49	What percentage of your at risk population are unemployed? _____%	8%
50	What percentage of your at risk population have a median annual before tax household income below the poverty level, which is \$23,850 per year for a family of four? _____%	6%
51	What percentage of your at risk population are homeless? _____%	0%
52	Are there members of your at risk population who live in a neighborhood that is cut off from everyone else in your community for reasons that might include extreme poverty, race, religion, lifestyle, or other factors?	No

# B

## Evacuation outflow graphs

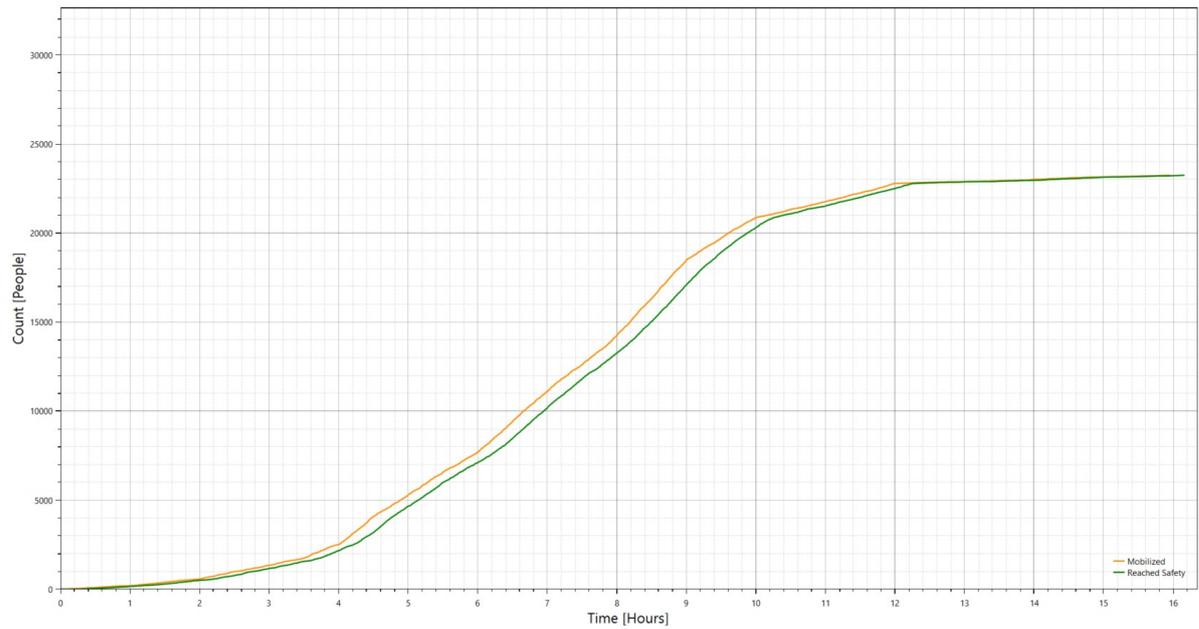
**Evacuation outflow graphs sensitivity analysis 2.8 people per car, vertical optimistic.**

Figure B.1: Evacuation outflow graph of a vertical evacuation in a optimistic road scenario with a slow departure curve.

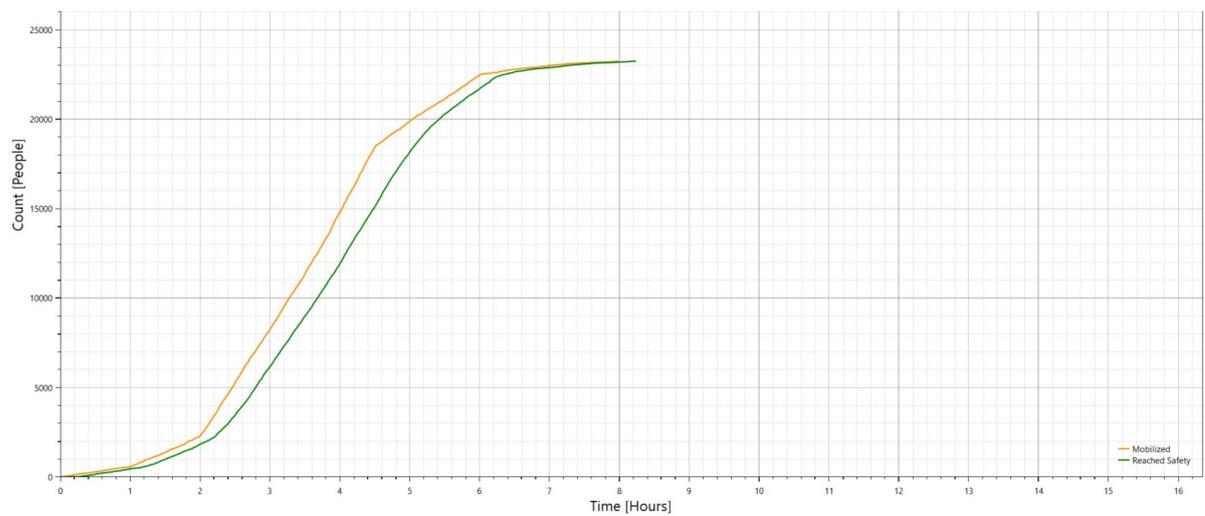


Figure B.2: Evacuation outflow graph of a vertical evacuation in a optimistic road scenario with a fast departure curve.

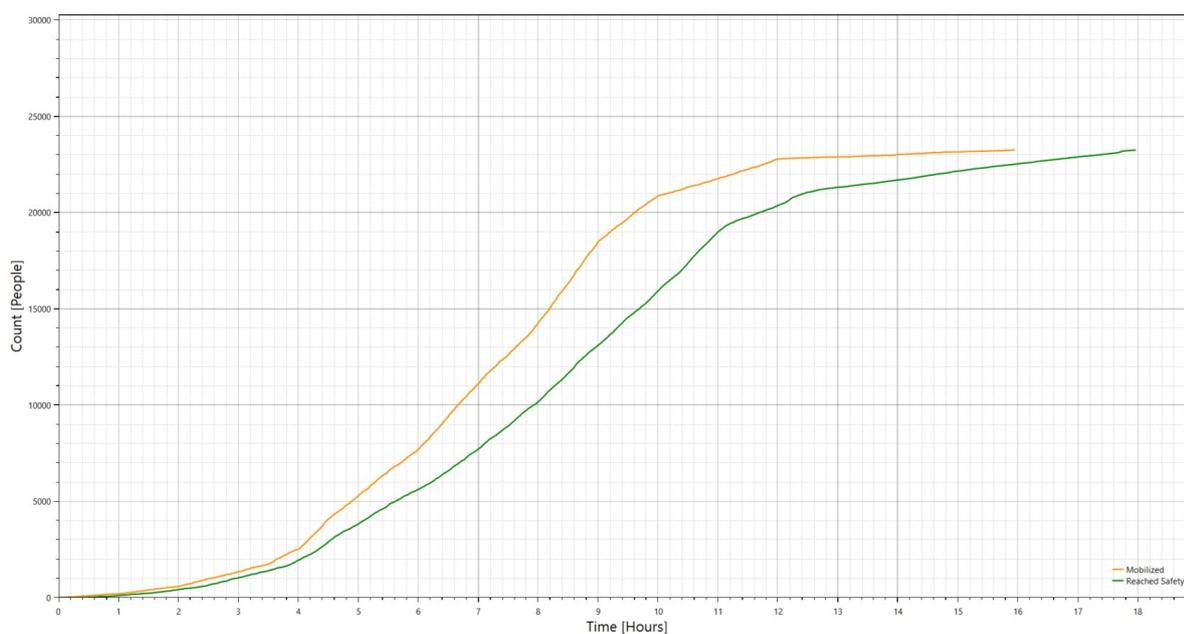
**Evacuation outflow graphs sensitivity analysis 2.8 people per car, vertical realistic.**

Figure B.3: Evacuation outflow graph of a vertical evacuation in a realistic road scenario with a slow departure curve.

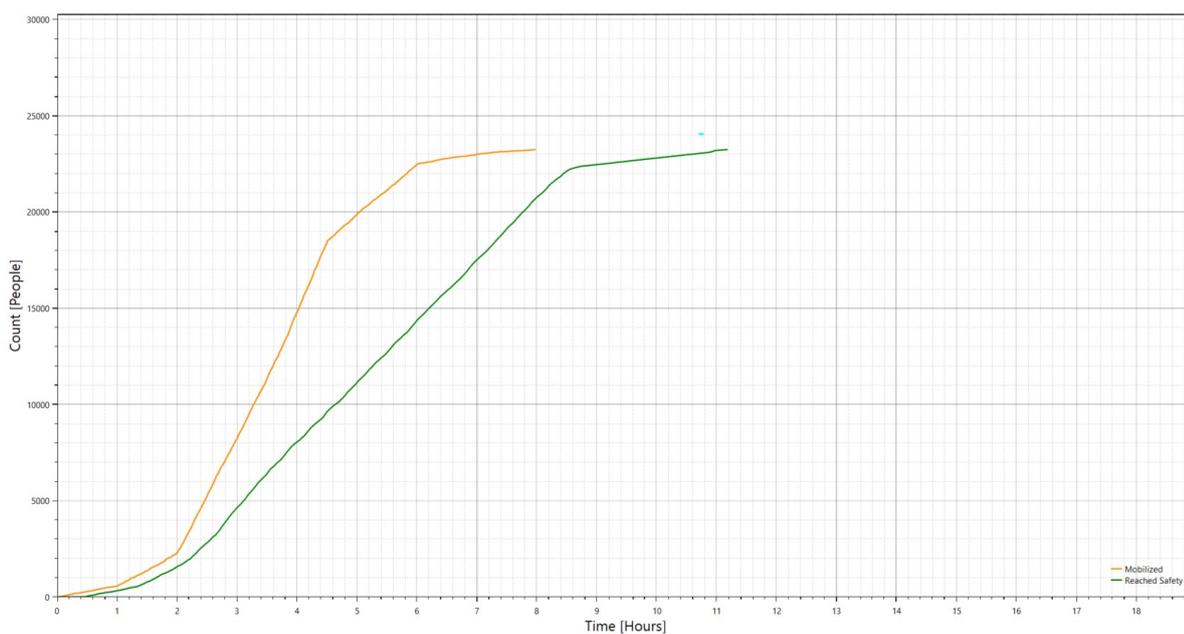


Figure B.4: Evacuation outflow graph of a vertical evacuation in a realistic road scenario with a fast departure curve.

**Evacuation outflow graphs sensitivity analysis 2.8 people per car, preventive realistic.**

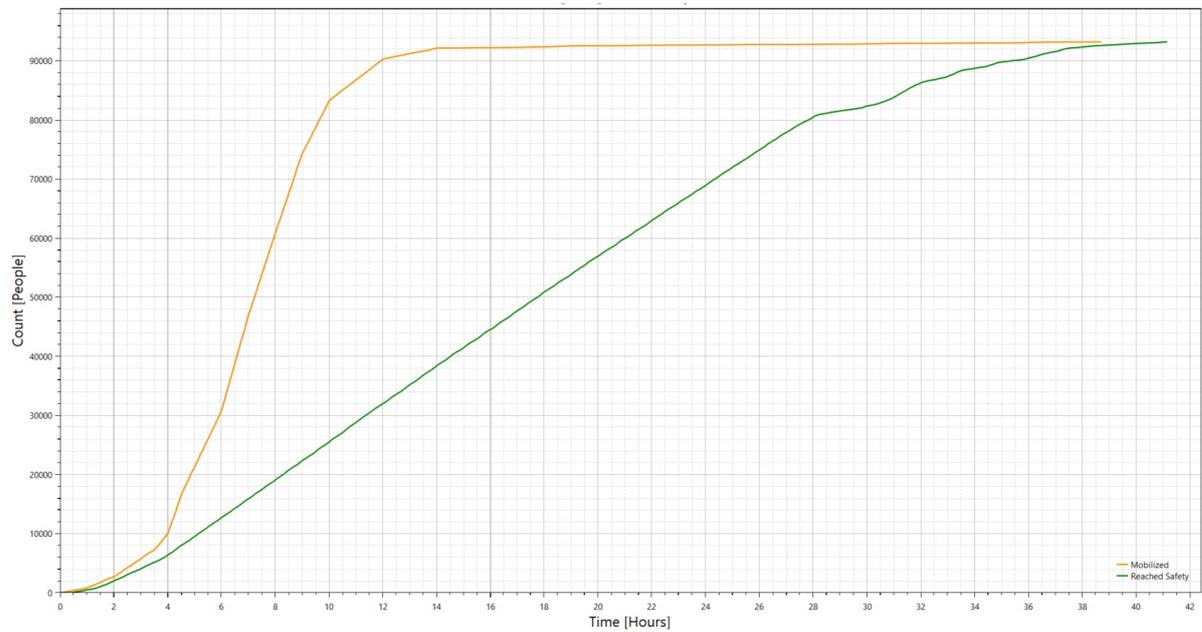


Figure B.5: Evacuation outflow graph of a preventive evacuation in a realistic road scenario with a slow departure curve.

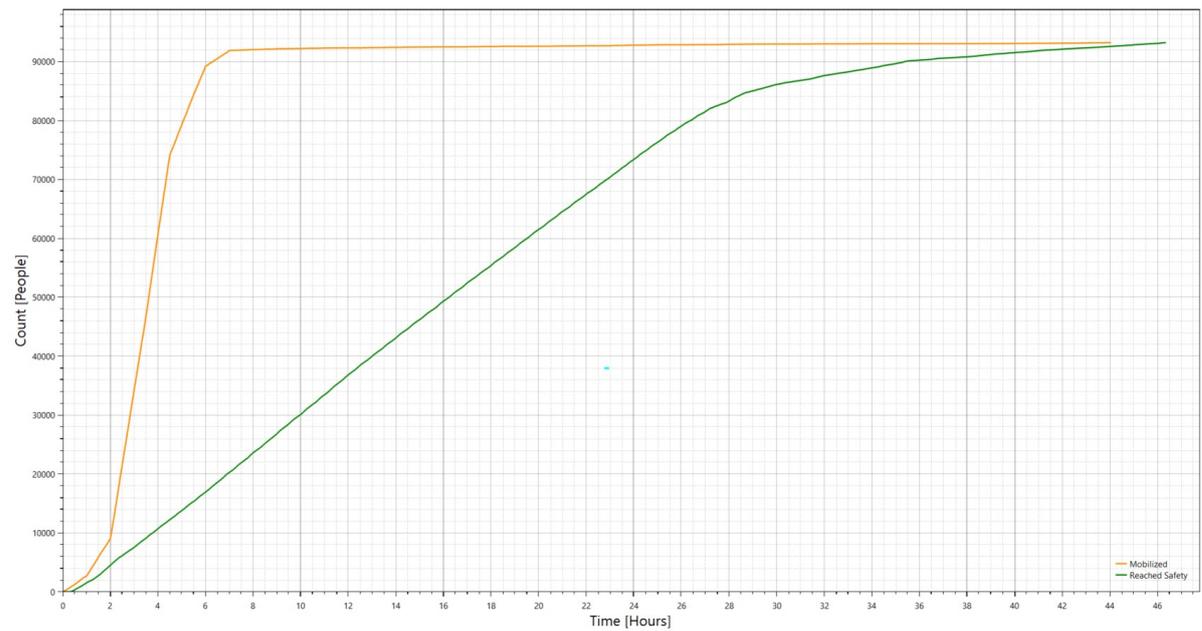


Figure B.6: Evacuation outflow graph of a preventive evacuation in a realistic road scenario with a fast departure curve.

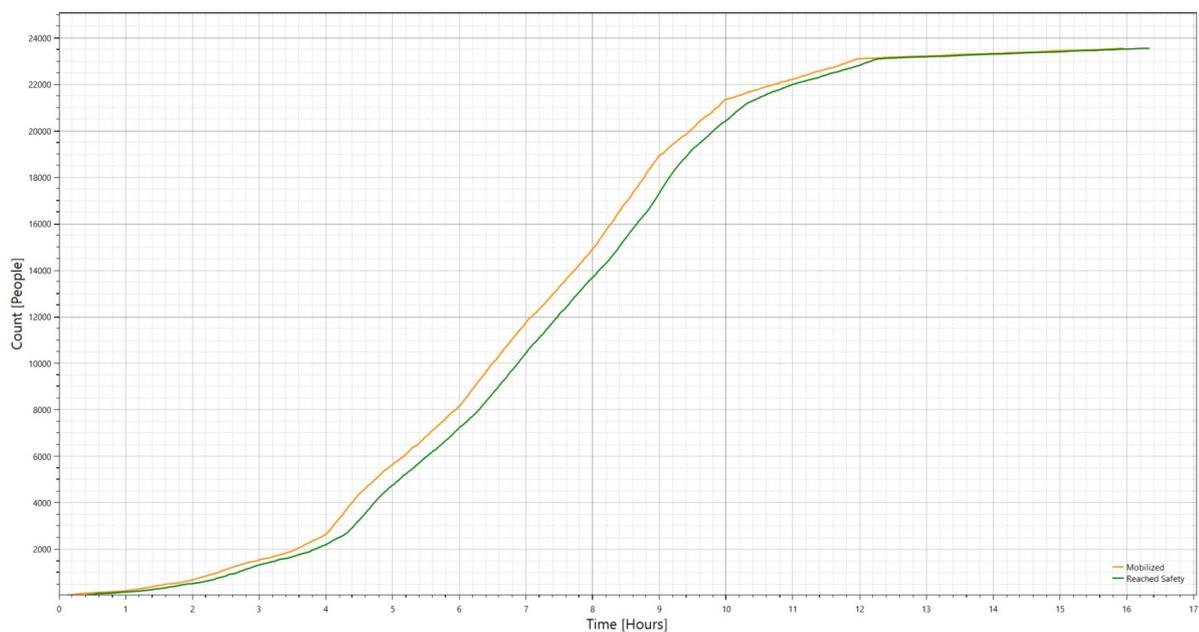
**Evacuation outflow graphs sensitivity analysis 2200 cars per hour exit capacity, vertical.**

Figure B.7: Evacuation outflow graph of a vertical evacuation in a realistic road scenario with a slow departure curve.

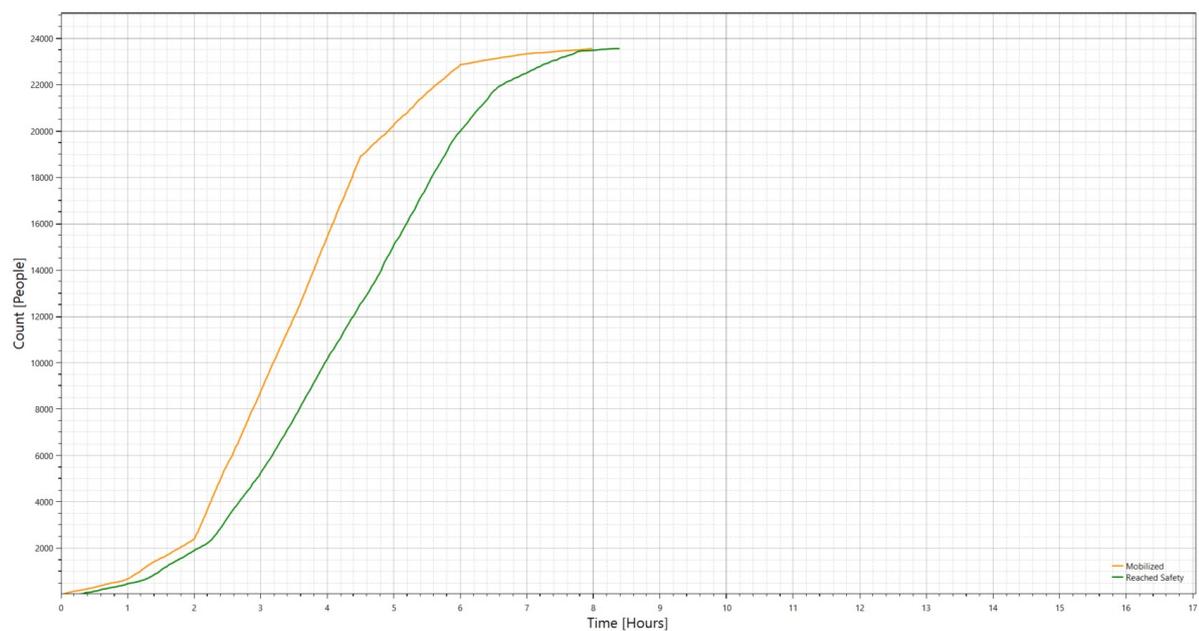


Figure B.8: Evacuation outflow graph of a vertical evacuation in a realistic road scenario with a fast departure curve.

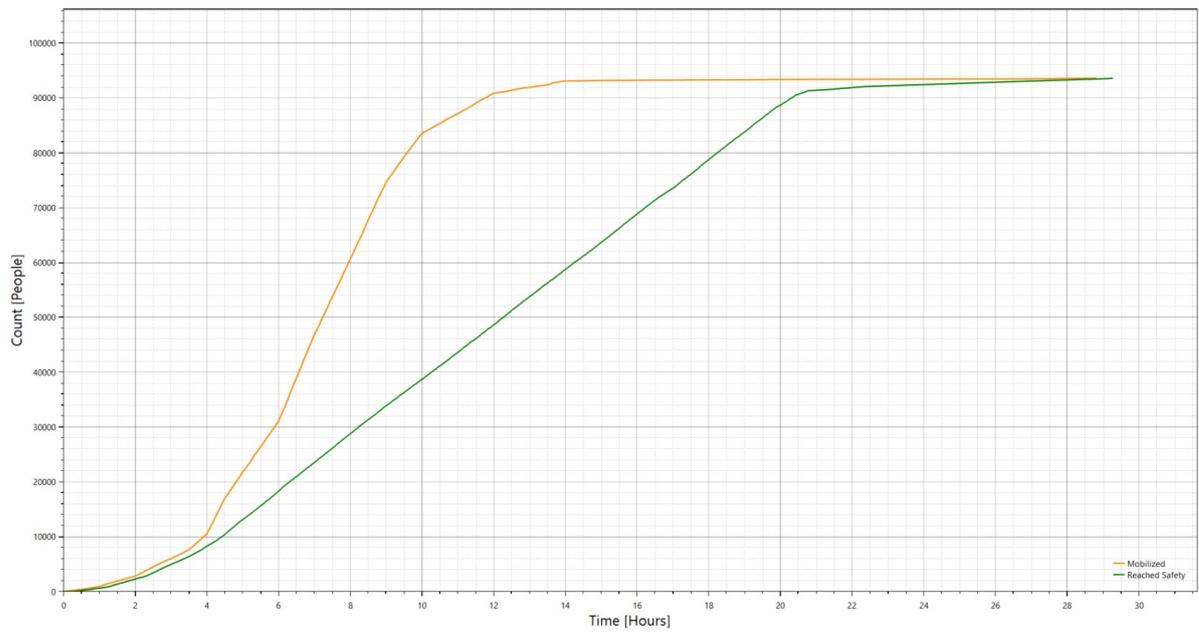
**Evacuation outflow graphs sensitivity analysis 2200 cars per hour exit capacity, preventive.**

Figure B.9: Evacuation outflow graph of a preventive evacuation in a realistic road scenario with a slow departure curve.

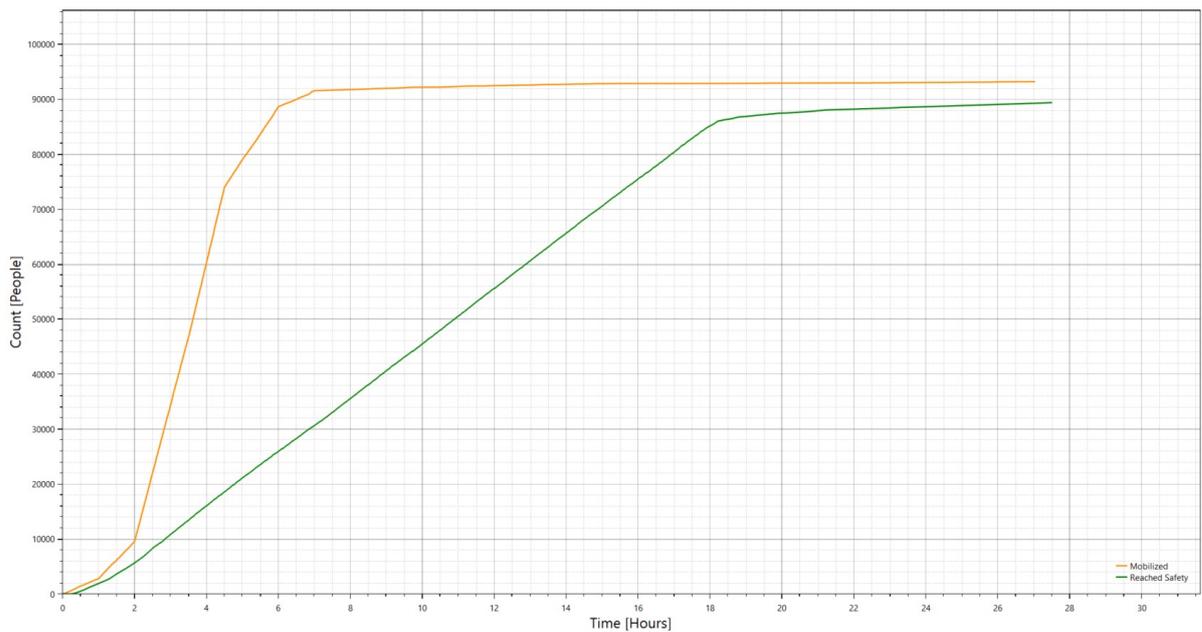


Figure B.10: Evacuation outflow graph of a preventive evacuation in a realistic road scenario with a fast departure curve.

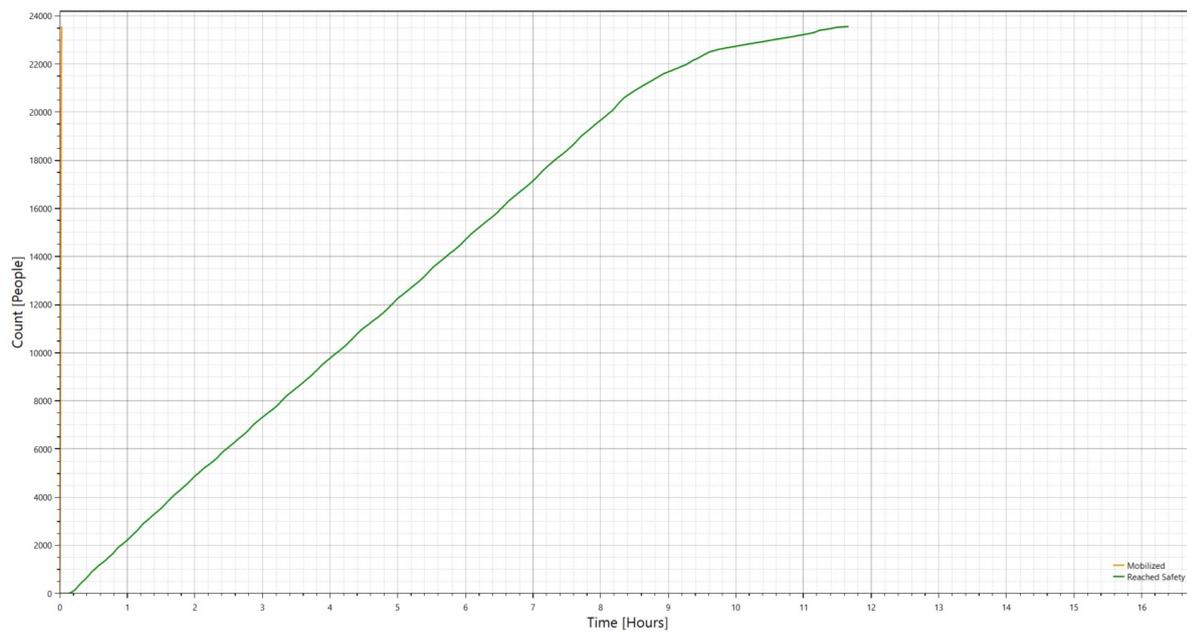
**Evacuation outflow graph sensitivity analysis instant departure curve, vertical realistic.**

Figure B.11: Evacuation outflow graph sensitivity analysis instant departure curve, vertical realistic.