Application of storylines for strategy development in flood risk management (FRM)

A case study on the flooding of the island of Dordrecht (the Netherlands)

Nienke Lips, December 2012

Universiteit Utrecht

Deltares

UNESCO-IHE Institute for Water Education

FloodProBE

Application of storylines for strategy development in flood risk management (FRM)

A case study on the flooding of the island of Dordrecht (the Netherlands)

Nienke Lips (3021467)
Department of Physical Geography
Faculty of Geosciences
University of Utrecht
Date: December 2012
Supervised by:
Hans Middelkoop (UU)
Karin de Bruijn (Deltares)
Berry Gersonius (IHE)
Photo cover:
Nigel de Jong

Preface

21 December 2012,

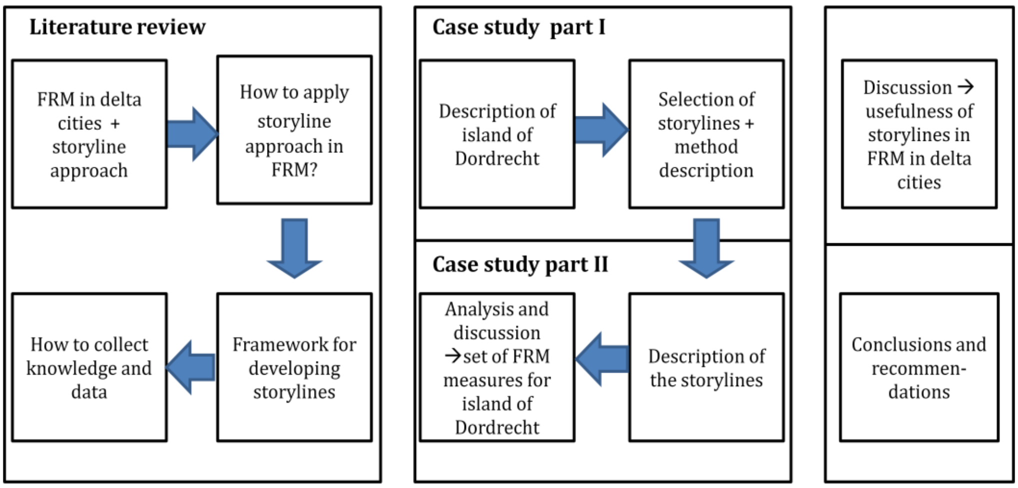
In the summer of 2011, I asked Hans Middelkoop (UU) for a more applied subject to study for my final master research. He just received an email from Karin the Bruijn (Deltares) with a proposal for a study with the objective to work out complete story lines of flood events on the Island of Dordrecht in order to obtain knowledge needed to develop strategies which enable the island to continue functioning even in extreme circumstances. Now, 1.5 years later the final product in the form of this document is finished. First I want to thank my direct supervisors Karin de Bruijn, Hans Middelkoop and Berry Gersonius for their advice and comments on this subject and secondly on their endless patience in the not always smooth process of producing this thesis. I also want to thank the "De Urbanisten" for their very good visualization of my storylines. Finally, I want to thank all the people from Deltares, the municipality of Dordrecht, the safety region, water boards and the experts on critical infrastructure for providing the information and details needed to produce the storylines.

Summary

Background:
During the last decade many countries made a switch in the approach of flood risk management (FRM) towards more integrated approaches that focus on more than one layer of phase of the total flooding process. However, the methods used to develop strategies within FRM do not yet show the need, possibilities, impact and interactions between measures at these different layers or phases. A new method has thus to be introduced in these matters. The storyline method might give insights in these factors and support the development of strategies that contain a consistent set of measures at all layers or phases of an integrated FMR strategy.

Aim of the research:
The aim of the research is to develop and evaluate the storyline method as a tool to develop strategies in an integrated FRM approach.

Approach:
Storylines are development for a case study on the island of Dordrecht (the Netherlands) with the following general approach:



Results:
A storyline is a realistic sequence of incidents and human responses that may happen during a flood event. Storylines should at least exist of 4 actors (water, critical infrastructure, authorities, civilians living inside the dike ring and civilians) and 3 phases (before, during and after the inundation). Three storylines are developed for the case study on the island of Dordrecht. Two for flood events under the current FRM situation (1 worst case scenario) and one for flood events for a future FRM situation with measures taken at more FRM layers.

Conclusions:
Storylines are useful for strategy development for integrated FRM approaches. The method is area specific and cannot be used for comparing areas with each other or for larger areas. It gives insights in the many different components that influence a story, and more important it gives insights in the complexity of these components influencing each other and easily shows knowledge gaps. A disadvantage of the storyline method is that it is a time consuming method.

Table of contents

List of figures and tables

1 Introduction

1.1 Background

Deltas are areas where major floods often occur since these areas are vulnerable for both coastal and fluvial flooding. However, they are also favorable locations for settlements, because they are flat, fertile and close to the sea. There are many countries with major cities in deltas. These countries or cities have developed their own flood risk management (FRM) strategies to cope with these floods. These strategies often result from the awareness that:

- climate is changing and, therefore, floods will occur more often and will be more severe if no action is taken.
- absolute safety is not possible. There will always remain a certain level of flood risk, but this risk can be reduced as much as possible.

Several models are used to develop and describe FRM systems and strategies. The most common models are the Source-Pathway-Receptor-Consequence (S-P-R-C) model, the safety chain and multilayered models. Although there are differences between these models, they are all based on the fact that reduction of flood risk can be accomplished by taking measures at different phases or layers within the flooding process. An example is the fact that flood risk can be reduced by protecting people from flooding by building embankments (protection layer/phase), but also by building waterproof houses (spatial development layer/phase) or by better disaster management. Strategies that take all these phases or layers into account are so-called *integrated* FRM strategies (Gordon and Little , 2009; Lopez, 2006; Kundzewicz and Takeuchi, 1999; IWR, 2011; Dircke et al., 2010; V en W et al., 2009).

One of the countries with high densely populated and economic important areas in a delta is the Netherlands. The Dutch government also has developed an integrated FRM approach. This is the so-called multilayered safety (MLS) approach (V en W et al., 2009). This approach is based on the concept of taking measures that protect the people from the occurrence of floods and at the same time reducing the consequences in case an extreme event occurs. These measures are taken in three “layers” that run parallel to each other. These layers are (V en W et al., 2009):

- protection from floods (i.e. building dikes and storm surge barriers);
- impact reduction/spatial development (i.e. water proofing of buildings);
- crisis management (i.e. up to date evacuation and crisis management plans).

Figure 1 shows these layers. Presently, the application and assessment of this integrated strategy is being studied in many projects in the Netherlands (Slootjes et al., 2010; Van Herk et al., 2011; Kind et al., 2011).

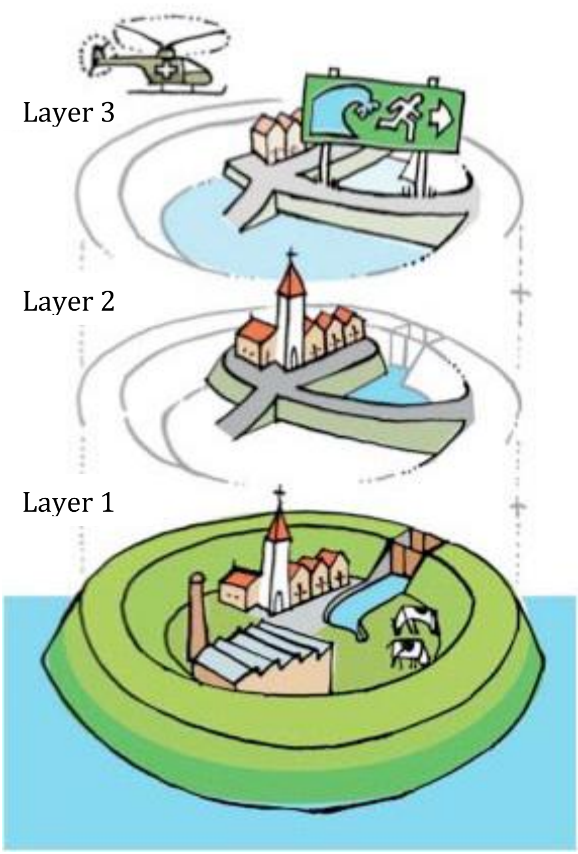


Figure 1: Multilayered safety chain after V en W (2008).

In most countries (especially the Netherlands) different measures and strategies are often compared to each other by risk assessment and/or cost benefit analysis (CBA). These methods compare strategies based on quantitative values that represent implementation and impact costs and loss of lives. These are calculated by loss functions that translate flood characteristics (maximum inundation depth, maximum velocity and rising rate) and the behavior of humans into a certain loss (Beckers and De Bruijn, 2011; De Bruijn and Van der Doef, 2011; Kind et al., 2011). These analyses are very useful, but for developing and analyzing the multilayered strategy (or any other integrated strategy) they do not:

- show the need, possibilities and impact of measures in the second and third layer.
- show the interaction between measures in the three layers.
- give insight in the effect of critical infrastructure on damage, fatalities, extension of impacts to non-flooded areas, and on post-event recovery.

This means that these methods do not support the development of a consistent strategy with measures in all three layers. Furthermore, for communication, preparedness, training and flood crisis management, additional information on the events during a flooding is needed. Therefore, next to the common risk assessments and CBA a more detailed analysis of the sequence of events during a flood is recommended.

A method that may be adequate for this detailed analysis is the storyline method. This method defines a story as a descriptive narrative about the central phenomenon of the study. Storylines are used in for example the field of ethnography, where they are used as a means to communicate research findings. They can also be used as a teaching strategy. Experiences of individuals, groups and communities can be incorporated in stories (Birks et al., 2009; Strauss and Corbin, 1990).

In case of a flood event, storylines can be used in determining and analyzing the sequences of events that can occur during a flood. These give detailed information about the flood process, the decisions which need to be made, responses of authorities and civilians, and to assess critical moments in time. Such insights are extremely useful for developing FRM strategies. Therefore, in this research storylines are developed which explore the whole process of flooding. A storyline is defined here as:

A realistic sequence of incidents and (human) responses that may happen during a flood event.

These storylines thus incorporate (in a simple way) the possible behavior of managers, inhabitants and the collapse of critical infrastructure over time. In case of studying the multilayered approach of Netherlands, storylines may show in which situations measures in the second and third layer (spatial planning and crisis management) are feasible or considerably reduce the potential impacts. The storyline approach is thus not meant to replace flood risk assessments and/or CBA, but to add extra information to them.

1.2 Aim and research questions

Storylines may support the development of strategies that contain a consistent set of measures at all layers or phases of an integrated FMR strategy. A clear example of a country where such a method is needed are the Netherlands that are developing the application and assessment of the multilayered safety approach. However, storylines are rarely used in the field of FRM. The aim of this study was therefore:

To develop and evaluate the storyline method as a tool to develop strategies in an integrated FRM approach.

For this objective the following research question needed to be answered:

How to establish storylines for the analysis of a flood event and developing FRM strategies?

First, the use of the method itself is studied. Second, the study may give more insight in the effect of measures in different layers or phases of an integrated approach. If the method gives satisfactory results for the Dutch multilayered approach it may also be used for FRM research in other countries.

1.3 General approach

The approach of this research was to first execute a literature study on FRM in delta cities around the world and especially the Netherlands. Based on this literature study (Chapter 2) the main knowledge gaps in FRM and the aim of this research were defined.

Secondly, a case study was carried out to test the storyline method. The case study chosen in this thesis is the island and city of Dordrecht, the Netherlands. This case study was selected, because a lot of information and data about the area is already available (Van Herk et al., 2011; De Bruijn et al. 2012; flooding.lizard.net). Moreover, a model that can calculate the flooding of the island of Dordrecht was developed for the studies of VNK (Piek, 2007; Kok et al., 2005; Kok en Van der Doef, 2008) and available to develop and analyze storylines. Furthermore, the island of Dordrecht contains various types of land use; urban, industrial and rural areas. Moreover, the governmental structure is relatively simple: the city is part of one municipality, one water board, one safety region, one province and has one safety standard. This makes it an ideal prototype case for a delta region at risk.

The storylines were developed by first setting up a framework to comprise all information on the island of Dordrecht that can contribute to the sequence of incidents and human responses during a flood. The components of this framework are based on the Source-Pathway-Receptor-Consequence S-P-R-C approach (Samuels and Gouldby, 2009; Sayers et al., 2002). All information was gained from literature, other studies on the island of Dordrecht and talking with experts on the subjects and the area. Secondly, based on this knowledge of the island of Dordrecht, the elements that need to be incorporated to form a realistic storyline were selected. Furthermore, it was determined which flooding scenarios were most relevant to describe in a storyline. Once these elements were determined, the methods and information needed to develop and analyze storylines with different realistic options were described.

Thirdly, the resulting storylines were analyzed. The resulting number of fatalities, the damage, the number of people affected and the number of evacuees were determined. These results were used to compare different measures that may be taken at all layers of the multilayered approach and to develop new strategies. It was discussed to which extent storylines support FRM in the Netherlands. Finally, it was discussed whether the storyline method is suitable for assessing integrated FRM approaches in general/in other countries.

Figure 2 gives an overview of this general approach. It shows the steps taken and the conclusions that need to be drawn from each step.

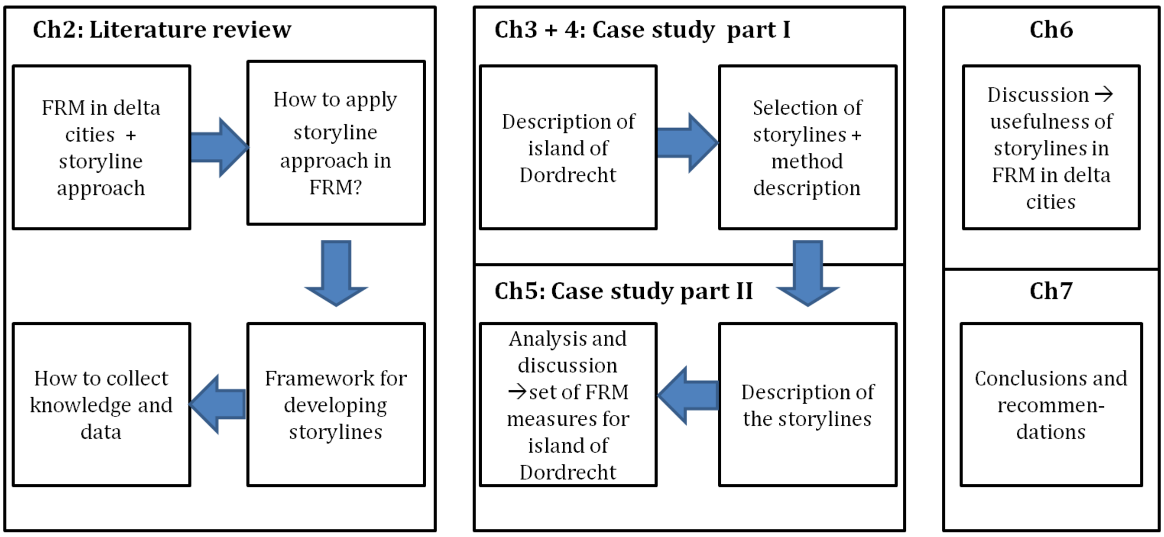


Figure 2: General reading guide of this thesis.

2 Flood risk management in delta cities and storyline approach

This chapter gives a brief review of the literature on FRM in delta cities all over the world and especially the Netherlands. First the current definitions, frameworks and analysis methods and examples of FRM in delta cities are described. Based on this knowledge it is briefly discussed why a new method for analyzing integrated FRM strategies is needed. Hereafter, the theoretical background of the storyline method is described.

2.1 Flood risk management (FRM) in delta cities

2.1.1 Definitions

To study FRM in delta cities first flood risk management itself was defined. The definition used in this thesis is based on the definitions of the studies of De Bruijn, (2005); FLOODsite, (2009) and Hooijer et al., (2004) and as follows:

All activities that aim at maintaining or improving the capability of a region to deal with flood risk.

To further describe this definition of FRM the definitions of flood and flood risk need to be clarified. The definition of a flood is simple and defined as *(*De Bruijn, 2005; Hooijer et al., 2004):

The inundation of an area that is usually dry.

The definition of risk is defined based on different studies (FLOODsite, 2009; RLI, 2011; Samuels and Gouldby, 2009) and as follows:

risk = probability (of the flood) * the exposure (of the area/population) * vulnerability (of the area/population).

Note that the probability of a certain hydraulic load to occur and the probability of failing of the flood defense defense are two different things, but are both used in the definition of probability of flooding. The exposure is the degree to which valuable objects or people are exposed by a flood. The vulnerability is defined as how much harm an object of person suffers due to certain conditions (in the case of flood risk to flood characteristics) (Hoss, 2010). Figure 3 shows the visualization of this definition of risk.

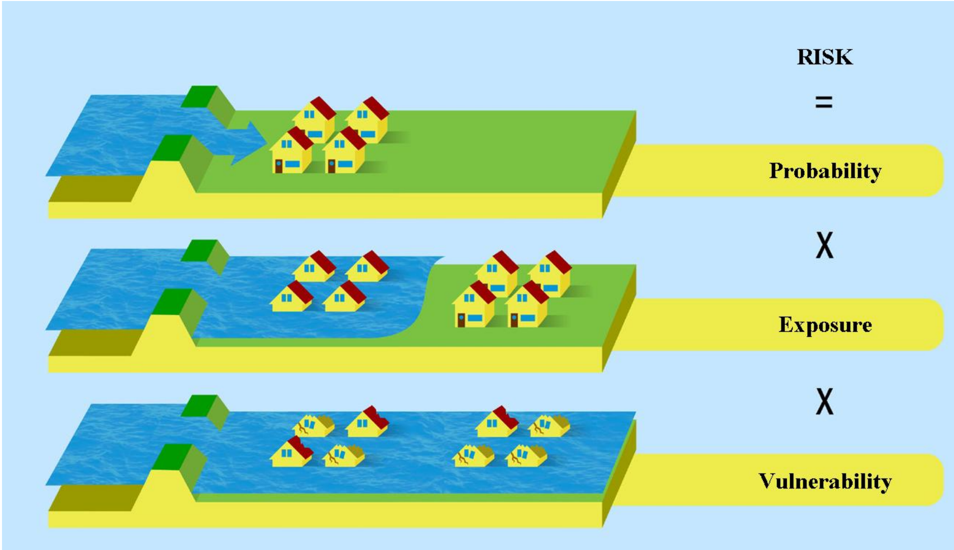


Figure 3: Definition of flood risk from RLI (2009).

Finally, deltas were defined on the following specific characteristics that make them suitable for many economic and social activities, but also make them suffer of high flood risk. These characteristics are (Dircke et al., 2010; Aerts et al., 2010):

- Deltas are low flat areas that, if not protected, are easily flooded from rivers and by the sea.
- Deltas are often densely populated, because land is fertile and connections with other countries through the rivers, over sea and roads are easily feasible.
- Population and economic growth is often fast which increases the vulnerability for floods.
- Deltas are vulnerable for climate change. They are prone to sea level rise and increase in river discharge (often in combination with subsidence of the area).

FRM in deltas consists often of embankments or sometimes storm surge barriers (The Netherlands and the Thames estuary, England), because retention of water often does not result in lower flood water levels. The volume of water that needs to be stored is too large for the space available in the flat areas of a delta. Sometimes, land use adaptation towards flooding is applied (e.g. in Venice and in some Asian cities).

2.1.2 FRM frameworks

To structure FRM in the complex case of deltas several frameworks are used. The most common frameworks used in FRM in the last decade are the Source-Pathway-Receptor (S-P-R-C) model (Samuels and Gouldby, 2009; Sayers et al., 2002), the safety chain (Ten Brinke et al., 2008; Yong et al., 2011) and the multilayered safety model (V en W et al., 2009). These models all describe layers or phases that need to be considered to get towards an integrated (i.e. measures taken at those different layers of phases) FRM approach. For example the S-P-R-C model considers each of the stages that lead from the sources that initiate the hazard to the individuals and assets that suffer the consequences. Analysis of this procedure provides insight into the way hazards occur and how risk may be reduced (Sayers et al., 2002). The safety chain describes 5 different links or phases of risk and crisis management that follow each other in time. When the current system fails, the next will takes over. The five phases of the safety chain are: pro-action, prevention (protection), preparation, response and recovery. For the description of these phases see Ten Brinke et al. (2008). More details of the multilayered safety model are found in V en W et al. (2009).

2.1.3 Analysis of strategies

Methods have been developed to compare different FRM strategies. Examples are cost benefit analysis (CBA) and multi criteria analysis (MCA). These methods compare strategies with different sets of measures with each other and with the business as usual strategy. These comparison methods are often based on risk analysis, because this analysis gives quantitative values that can be directly compared.

Risk analysis

Risk analysis (in the Netherlands) is usually defined by the local individual risk (LIR), the societal risk and the economic risk. LIR is the annual probability of a person dying at a certain location due to a flood event (De Bruijn, 2009). Societal risk is the probability of causing many fatalities in one (extreme) flood event. From a societal point of view, an extreme event with many fatalities is more disruptive than a lot of smaller events that together cause more fatalities (Beckers and De Bruijn, 2011). Finally, economic risk indicates the expected material damage in Euros per year (Hoss, 2010).

These three types of risk are calculated with mathematical functions and thus express the risk in quantitative values only. First, loss functions translate the characteristics of a flood (inundation depth, velocity and raising rate) and the behavior of humans into a certain loss (damage and loss of life). This loss is then translated into a certain risk by multiplying it with the probability of flooding of the area. The details of the loss functions as used in the Netherlands are found in Kok et al. (2005).

2.1.4 Examples of FRM in delta cities around the world

This thesis describes cities in developed countries. Only these cities are considered, because accessibility to resources to develop and implement a certain FRM strategy is very different between developed and developing countries. This makes it more difficult to compare strategies and FRM approaches. It is thus tried to keep the external conditions as similar as possible. Finally, it should be noted that many more (different) examples exist and that only a selection that fitted the goal of this thesis best, is made.

New Orleans (USA)

In the USA FRM is based on the awareness that floods can occur and people have to live with the risk of flooding. Citizens that live in areas with a high annual probability of flooding (> 1:100 years) are required to buy insurance so that it is easy to recover from floods (IWR, 2011). Nevertheless, the federal government does implement flood control measures. According to the Flood Control act of 1936 the federal government in cooperation with states, their political subdivisions and localities should make flood control efforts when benefits outweigh the costs (IWR, 2011).

The delta city of New Orleans is one of the cities in the USA that is treated differently in terms of FRM. Here, the risk and consequences of flooding are more severe, as we saw after hurricane Katrina hit the coast of Louisiana in 2005 (Kok et al., 2006; Gordon and Little, 2009). Integrated FRM strategies for this city have been developed after 2005. One of these integrated strategies is the "multiple lines of defense" strategy. This system is kind of a multilayered system that consists of eleven layers that all act parallel to each other. The layers are definable geographical areas, where natural or manmade features are promoted to reduce the negative impacts of storm surges. The eleven layers are shown in figure 4. More details of this strategy are found in Lopez (2006 and 2009).

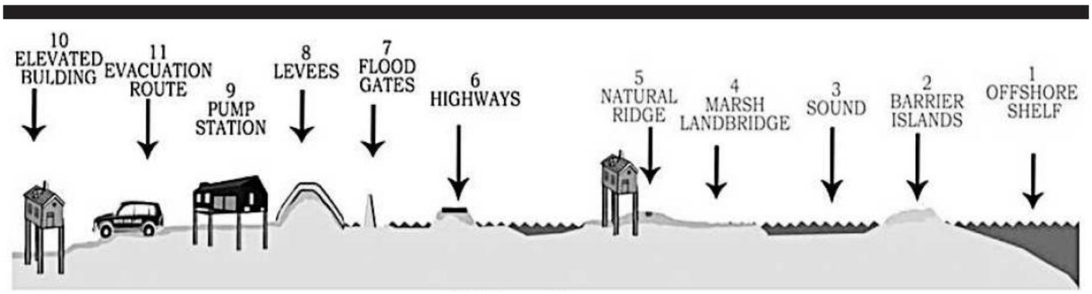


Figure 4: The multiple lines of defense for coastal Louisiana without storm surge from Lopez (2009).

Tokyo (Japan)

In Japan integrated strategies with both structural and non-structural measures have been developed. These strategies are (Kundzewicz and Takeuchi, 1999):

- ***Strategy for large rivers:*** structural measures (dams, levees, upstream sediment control etc.) and non-structural measures (flood forecasting, evacuation, community self-protection teams etc.). Flood risk is assumed to be reduced to an annual probability of 1/100 or 1/200 years by the structural measures.
- ***Strategy for major cities:*** no bank collapse is allowed what results in building of super levees (high and 300-500 m wide).
- ***Strategy for small urban basins:*** retardation facilities (district ponds, underground retardation, drainage pipes), infiltration facilities (ponds, permeable pavement), drainage facilities (pumps) and flood proofing (elevated houses, district walls).
- ***Strategy for environmental concerns:*** the artificial restoration of a hydrological cycle by the enhancement of retardation and infiltration of rainfall.

These strategies incorporate measures that can be taken at all layers of the multilayered safety (MLS) approach. An example of a measure that influences different layers of the MLS approach is the development of super levees in the metropolis of Tokyo. These super levees are embankments that are very wide and can withstand overflow, seepage and earthquakes (protection layer) and are implemented in conjunction with urban development, land rezoning projects or other urban planning (spatial planning layer) and provide shelter during events (emergency layer) (Dircke et al., 2010). Figure 5 shows the idea of constructing a super levee.

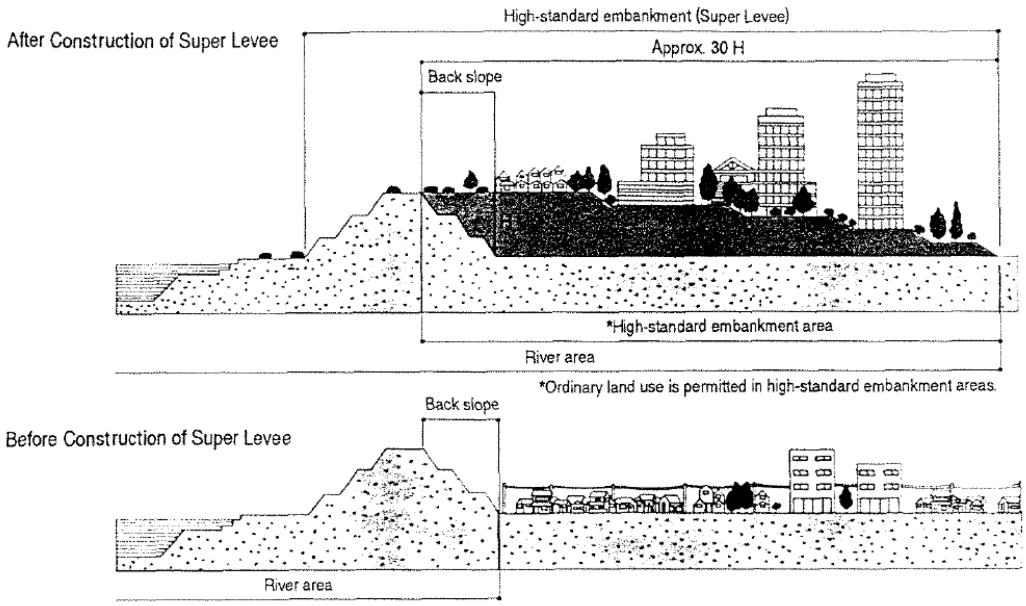


Figure 5: Super levees in Tokyo, Japan from Kundzewicz and Takeuchi (1999).

London (UK)

Before the water management act was implemented in 2010, authorities did not have the legal duty to maintain any particular standard of protection or to invest in FRM. Flood risk was covered by the insurance market that provides packages for owners of domestic properties and small businesses (IWR, 2011; Dawson et al., 2011).

This changed with the act of 2010 which requires authorities to act to the national flood and coastal erosion risk management (FCERM) strategy. This strategy describes the role of government, environmental agency, local authorities, water companies, internal drainage boards and other organizations. Furthermore, the FCERM describes how these authorities should manage risks. The FCERM strategy provides a framework that shows which stages of FRM there are and how the authorities could work together with local communities (IWR, 2011). This framework is visualized in figure 6.

Figure 6: Framework for FCERM from COM (2004).

In the context of FCERM, the city of London started a study after different FRM options that can protect the city of London from coastal flooding until the end of the century. One of the approaches they used is to consider three categories of measures that reduce flood risk. These categories are similar to the layers of the multilayered approach (Dircke et al., 2010):
Defense: embankments/walls
Social: warning, response planning
Standards: property regulations, insurance

An example of a measure taken at the defense layer is the establishing of walkways with a (low) wall along the river. These walkways protect the streets from flooding, but at the same time create a nice recreational area along the river.

Dordrecht (The Netherlands)

The Dutch have been coping with floods for ages and thus FRM has developed since the beginning of civilization. The current FRM strategy that was developed after major floods occurred in the south western part of the Netherlands in 1953 which killed over 1800 people. The Dutch FRM system was reviewed after these floods and based on the recommendations of the first Delta committee, national flood protection standards were developed in the 1960ties. The standards represent a minimum height and strength of the dikes surrounding a certain area that protect that area from flooding. Such an enclosed area is called a dike ring. These standards reflect the annual probability of exceedance of the highest water level that a certain dike ring must be able to withstand. The standards vary from an annual probability of exceedance of 1/1250 years up to 1/10 000 years. Figure 7 shows, which standard corresponds with each dike ring. These standards were included in the flood protection act of 1996. According to this law the dikes are maintained and need to be reviewed every 5 years (in the near future every 6 years) by the water boards (Ten Brinke et al. 2008 and V en W et al., 2009).

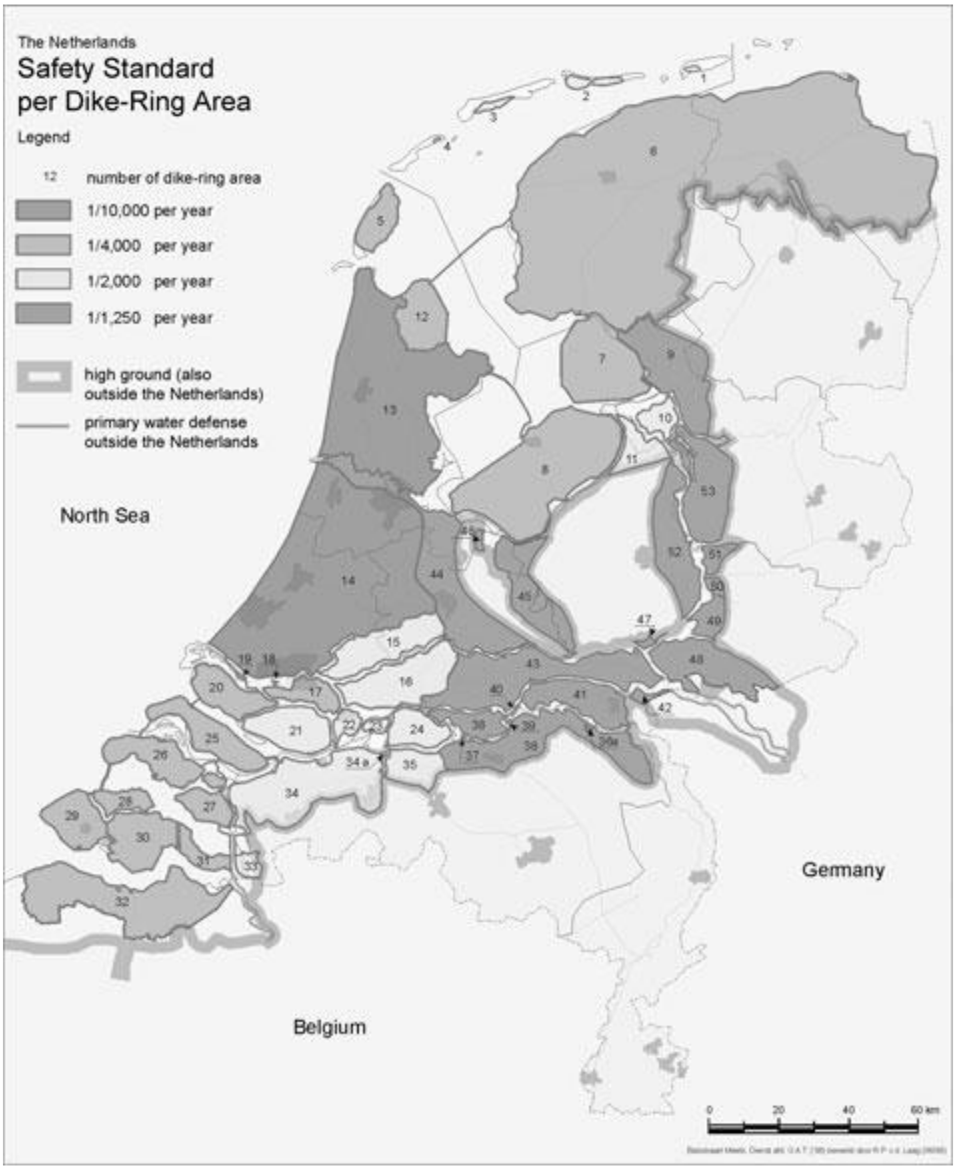


Figure 7: The Dutch dike ring system from RWS (Jonkman et al., 2008).

Recently, a second Delta committee studied the current water management strategies against future scenarios. One of the many advices that this committee gave in 2008 was that the protection against flooding has to be improved. The government took the advices of the committee and developed a new Delta Programme (VenW et al, 2009).

According to the National Water Plan (NWP) this new Delta plan should help to change from a protection based strategy to a more comprehensive FRM strategy: the so-called "multilayered safety" (MLS) strategy, which is already described in the introduction of this thesis. Currently, the Delta Programme studies new strategies with measures from the three layers (protection, spatial planning and crisis management).

An example of a city that is involved in the study of the potential of the implementation of measures within all layers of multilayered safety is Dordrecht. Within this project MARE (Managing Adaptive REsponses to flood risk) multiple strategies that contain measures within all three layers of the multilayered safety strategy are developed (Van Herk et al., 2011). One of the possible strategies developed is the idea of the city becoming self-reliant under extreme flooding circumstances. This strategy is based on the idea that no evacuation away from the island should be necessary. Instead, people evacuate to so-called shelters on the island or the first or second floor of their own house. These shelters should be able to provide the first major needs (food, medical care and heat) to people. To meet these goals in the third layer also measures in the second and first layer should be implemented. An example of such a measure is the protection of critical infrastructure, such as communication masts and electricity. Moreover, major roads that connect the shelters with each other and the outside world should remain functioning in case of flood. This can be done by either heighten them or protect them from flooding by walls. The possibility and exact details of this strategy still need to be studied (Van Herk et al., 2011).

2.1.5 Towards a method to analyze integrated FRM strategies

The examples of FRM in delta cities show that integrated (i.e. taking measures for different phases or layers) FRM approaches were developed (or need to be developed) in order to protect society from future floods. Ideally implementing all components of the safety chain or a multilayered safety approach into a FRM strategy is favored, because in this way a back-up system exists if one of the layers of stages fails. However, in practice it seems natural to develop towards an integrated strategy that strongly depends on the measures which were already taken and on the characteristics of the country. Of these characteristics the social and economic activities that lie within the flood prone areas are most important. This can be seen from the examples of implementation of measures. The USA and UK provide insurance packages which focus on the recovery phase of the safety chain. Japan and the Netherlands mainly focus on protection of their densely populated and economic important areas by building strong embankments. The measures selected in FRM thus differ a lot per country.

Since, in many countries FRM focuses on a certain phase, stage or measures within an integrated strategy their risk analysis and strategy development also tend to only focus on that aspect. In the Netherlands, for example, FRM focuses on flood protection, risk analysis and strategy development methods also focus on water levels and embankment strength and not on full risk assessment. A method is thus needed that also includes the effects of measures at other stages or layers of an integrated approach. This method should include all aspects that can contribute to develop new strategies and thus include all aspects, incidents and (human) responses of a flood event.

The current methods available for comparing strategies (in the Netherlands) are Cost Benefit Analysis (CBA) and Multiple Criteria Analysis (MCA) which are based on risk analysis. Risk analysis compares strategies based on implementation and impact costs and are calculated by loss functions. These functions are directly based on the maximum inundation depth, maximum velocity and rising rate and standard for the Netherlands as a whole. This means that it is not easy to use risk analysis to weight the effect on reducing flood risk for measures taken at different layers or phases. Since there is no knowledge on how these measures change the loss functions and thus lower the impact of a flood and with that the flood risk. Furthermore, this type of comparison does not study the duration and different type of processes happening during a flood. These characteristics make risk analysis and thus CBA and MCA inadequate methods in providing detailed information for developing strategies for integrated approaches. This means that a new method should be explored within the field of integrated FRM approaches. This method should be able to provide detailed information on all processes happening during a flood event. One method that seems a promising addition to the risk analysis is the storyline method.

2.2 The storyline method

The storyline method is often used in the field of ethnography, where experiences of individuals, groups and communities are enclosed in stories. Stories can give detailed information about the central phenomena of a study, where a storyline is one conceptualization of a story (i.e. one narrative of one person from a community on a certain event) (Birks et al., 2009; Strauss and Corbin, 1990). The characteristics of a storyline fit the need to provide detailed information on a flooding event in order to develop a set of suitable measures at different layers. A disadvantage of this method is that there is not much knowledge on storylines within the field of FRM and also detailed information on storylines from other fields is difficult to find. However, this also creates the opportunity to develop this method as a useful tool to add additional information for developing FRM strategies.

In FRM there are two methods that use a kind of storytelling. The first one is the method that Haasnoot et al. (2012) use to explore adaptation pathways for sustainable water management in an uncertain future. An adaptation pathway is a sequence of water management interventions implemented over a period of time. Adaptation towards another strategy determines the evolution of the pathway over time. Each developed pathway is a unique storyline with the implementation of different measures at different points in the time sequence. The adaptation and implementation to a new strategy is based on floods or drought events happening during that sequence. A set of pathways is used to identify opportunities, no-regret strategies, dead-ends, and timing of the strategy (Haasnoot et al., 2012).

A second method is the one that is used in the study after worst credible flooding scenarios (EDO's). This study gives scenarios that represent the physical conditions that lead into worst credible floods (RWS and HKV, 2008). Five different areas are defined for the Netherlands that each have a different scenario. The study gives a time line for each scenario that describes the physical conditions such as weather conditions and water level in at sea and in the rivers. These timelines also describe the possibilities for preventive evacuation from the areas at risk (RWS and HKV, 2008).

Both methods give sequences of events which together make up a story (pathway or scenario). They give details at a large scale (time and space). However, they do not show the details of for example one flood event within one dike ring. Furthermore, they show sequences of physical events and human response before a flood event happens (possibilities for preventive evacuation in the EDO's) or after they happen (change of strategy due to a flood in the pathway method), but not the sequences during the events themselves. This makes both methods unsuitable for the purpose of this project as these details are needed to give more insight in the incidents and human responses that may happen during a flood event.

Within this thesis a new method is thus developed and explored that uses storylines within the definition of:

A realistic sequence of incidents and human responses that may happen during a flood event

With this definition storylines should be able to show the differences between measures taken at all layers, since they are directly appreciated in the sequence of events. Furthermore, storylines can be made for the system as a whole (large scale) but also part of the system (small scale) depending on what kind of detail is needed for a certain study. An example of this type of storylines is the following:

"Heavy rainfall in Germany is causing high water levels in the river Rhine. In the meantime a storm is blowing above the North Sea, causing an upset in mean sea level. Due to this combination of factors, water levels in the rivers are rising fast. A river monitoring system provides information about the rising rate of the rivers. Dike guards are sent to the embankments to check them. From the information of the dike guards and the monitoring system, it becomes clear that the situation has become too dangerous and the authorities advice the people of the municipality to evacuate to safer areas. However, due to the stormy weather and heavy rainfall it is hard to evacuate. During this evacuation, suddenly one of the dikes is overtopped and water is flowing into urban areas. People are screaming, running and driving in all directions. Some people cannot go anywhere, because the water has blocked their escaping routes. Others have made it to safer grounds, while some have fled to the first floor of their house. During the flood the electricity goes down, because water has reached the electricity buildings. Therefore, communication through modern means is not possible anymore. In the end everyone is safe, being in their own house or evacuated to somewhere else, but the water level will stay high for another week. This means that the people that are still in the area need to be provided with food, drinking water and medical care. Afterwards, the damage need to be repaired and buildings restored."

2.3 Framework for applying storylines in FRM

In this research the storyline method was developed and applied in integrated FRM. When developing storylines, in general the system studied (in this case a flood event) must be known. When more specifically applying this method on a region of interest, the physical and societal aspects must be explored. To get insights in these aspects and to further develop the storyline from these insights the following framework is used:

1. System exploration:
    - Land use
    - Flood threats
    - FRM strategies and measures
    - Critical infrastructure
    - Potential flood impacts
2. Selection of elements/methods:
    - Selection of realistic flood events and measures to use in different storylines for the current situation
    - Selection of (basic) storyline elements (actors and phases).
    - Selection of methods to analyze the storylines.
3. Description of the storylines for current situation (all events and actions for each area over time).
4. Analysis of the developed storylines for current situation:
    - The results of the storylines (damage, fatalities etc.).
    - The differences between the different storylines.
    - Insights gained for developing a set of FRM measures or new FRM strategies.
5. Description and analysis of new storyline with measures.

In this thesis the area of interest is the island of Dordrecht. In order to do a sufficient system exploration the S-P-R-C framework is used. This framework is commonly used for system exploration. First the geographical location and land use of the island are described. Next the flood characteristics of the island are described. Then the current assessment and research of FRM and the event management plans are discussed.

Hereafter critical infrastructure on the island is described. Finally, the flood impacts are given. The subjects addressed are:

1. The geographical location and land use of the island of Dordrecht
2. Flood characteristics of the island of Dordrecht
3. The current FRM system
4. Current and future flood event management plans
5. Critical infrastructure on the island of Dordrecht
6. Flood impacts for the island of Dordrecht

The required information for these subjects was acquired through multiple ways:

- Collecting literature on all subjects.
- Collecting reports of studies already done on FRM for the island of Dordrecht (for example MARE, VNK, WV21).
- Collecting data (land use, water depths, locations of embankments, CBS information, flooding models etc.)
- Requesting information through email, telephone or meetings with experts on the different subjects (from governmental institutions such as the safety region, the water boards and the municipality of Dordrecht, but also from companies such as Stedin (gas and electricity distributor) or Evides (drinking water company). A list of these experts is found in section 8.3 of this thesis.

3 The island of Dordrecht

The description of the island of Dordrecht follows the order of the questions of the framework used for the exploration of the system.

3.1 Location and land use on the Island of Dordrecht

The island of Dordrecht lies within the western part of the Netherlands and is surrounded by the rivers "Beneden Merwerde" and the "Oude Maas" in the north, the "Dordtsche Kil" in the west and the "Nieuwe Merwede" and "Hollandsch Diep" in the south. On this island lies one city, which is called Dordrecht. This city nowadays counts approximately 120.000 inhabitants and lies at the northern side of the island (figure 8). The island is connected to the main land by only a few bridges and tunnels. The four main important connections are: the "Drecht" tunnel and bridge (train and vehicles) in the north west, the "Merwede" and "Baanhoek" bridges (train and vehicles) in the north, the "Kil" tunnel (vehicles) in the east and the Moerdijk bridge (train and vehicles) in the south west (ANWB and TD, 2004) (figure 8).

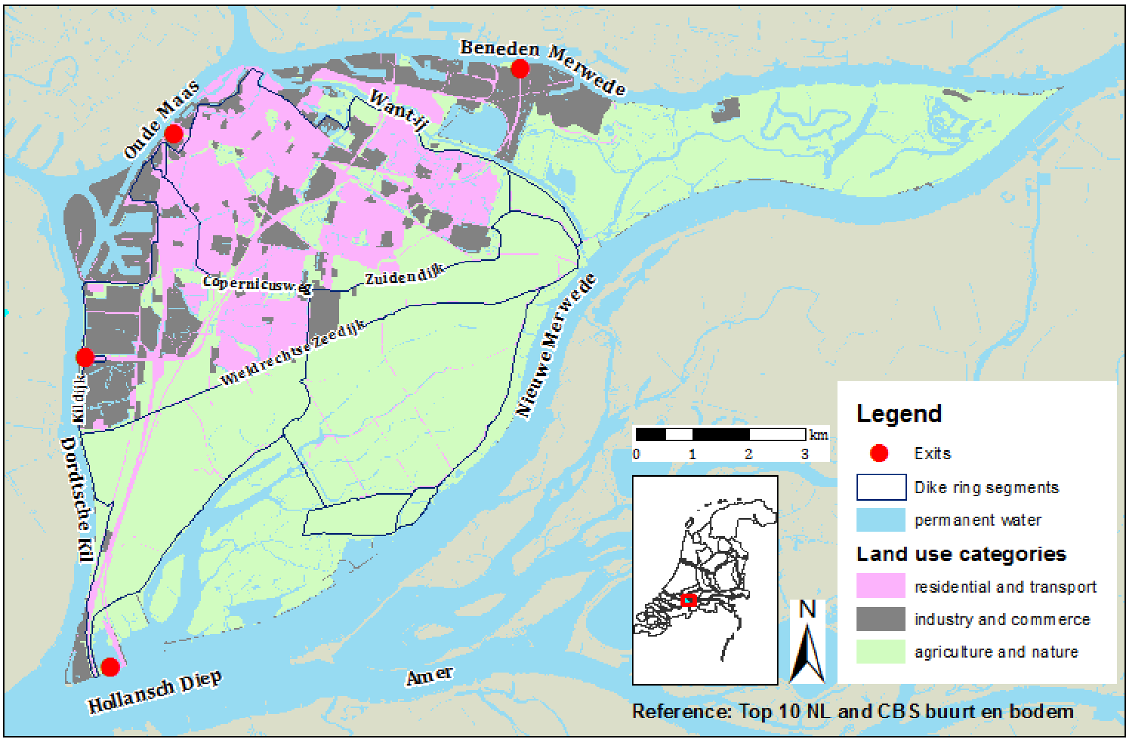


Figure 8: The land use, main exits, river names and names of the main (secondary embankments) of the island of Dordrecht.

Figure 8 shows the three main land use categories of the island of Dordrecht. These categories are residential and transport, industry and commerce and agriculture and recreation (from the CBS data in ArcGIS). The figure shows that most agriculture and recreational areas lie south of the "Zeedijk" and east of the city (the "Biesbosch"), while the residential, industrial and commercial areas lie in the north west of the island. Most industrial areas lie next to the rivers (outside the primary defense system).

3.2 Flood characteristics of the island of Dordrecht

On the island of Dordrecht four areas can be distinguished which all have their own flood characteristics (figure 9). These areas all have their own characteristics such as the height to average high water. Within this thesis the most important characteristic is used to subdivide the island of Dordrecht into two areas (figure 10) (Van Herk et al., 2011):

- The areas that lie within the primary defense system (the areas inside the dike ring).
- The areas that lie outside this defense system (the historical port area, the flanks outside the dike ring and the Biesbosch).

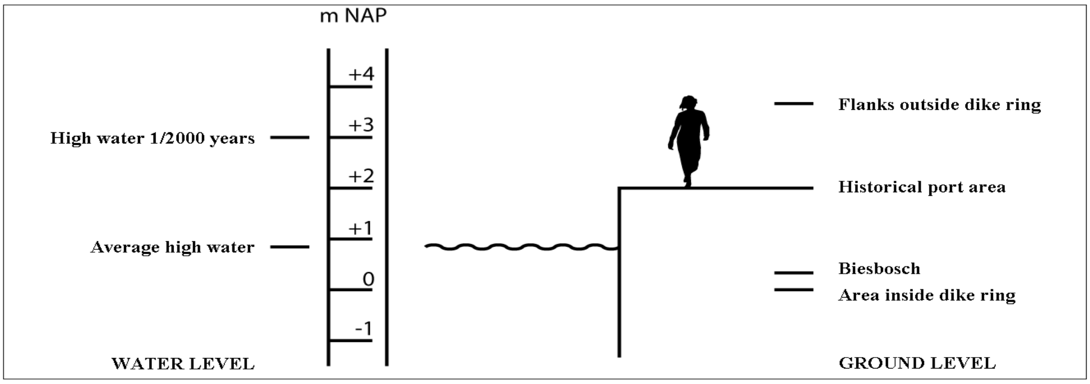


Figure 9: Position of the different areas against mean water level (from: Van Herk et al., 2011).

In the next sections, first the main conditions that can cause the flooding of the island are described. Then the characteristics and patterns of these floods are given for the two distinctive areas.

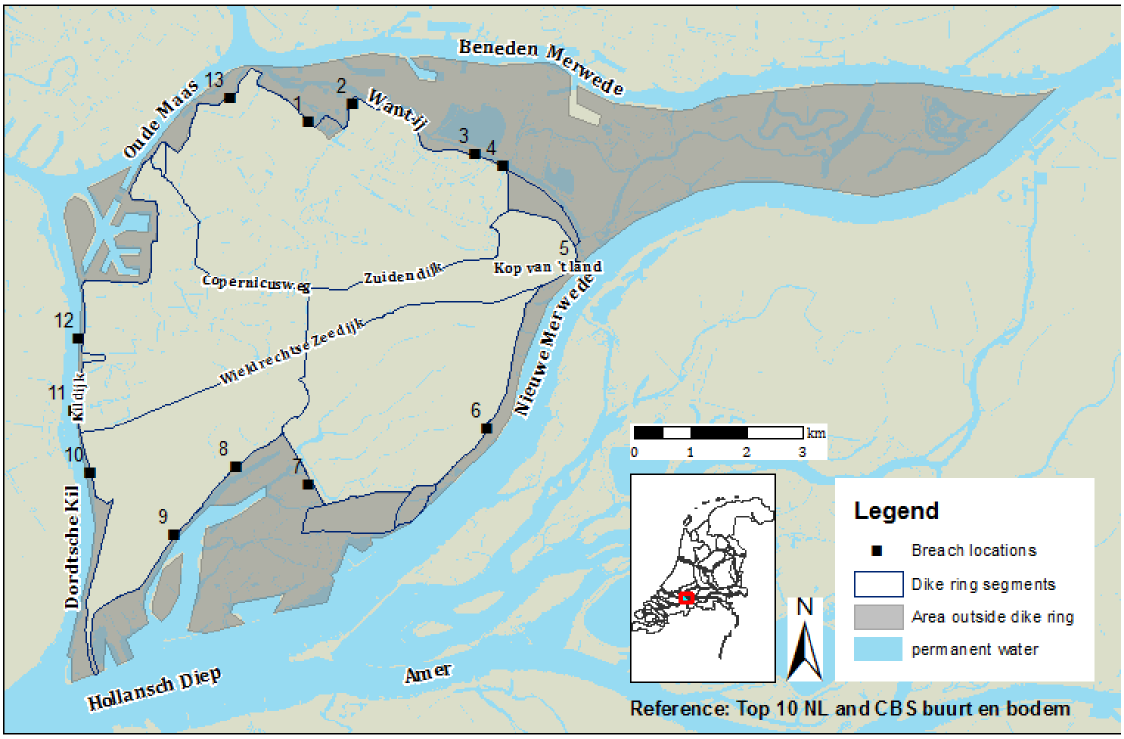


Figure 10: Names of the main (secondary) embankments and the indication of the areas inside and outside the primary defense system.

3.2.1 River and storm surge conditions that can cause the flooding of Dordrecht

Dordrecht is threatened by both river flooding and storm surges. The combination of these two contributes the most to the failure mechanisms of the embankments around the island of Dordrecht. Only the embankments at the "Kop van het Land" (the most eastern part of the island; figure 10) suffer more extreme high river discharges than the combination of a storm surge and a relatively high river discharge (Piek, 2007; Kok and van der Doef, 2008).

The weather conditions that cause high water levels in the rivers around the island of Dordrecht are described in the documentation on the worst possible floods (RWS and HKV, 2008). This document describes a timeline on the combination of weather events that result into high water levels in the river area with tidal influence of the Netherlands for a worst case scenario (RWS and HKV, 2008). This is the area where the city of Dordrecht also resides.

The embankments of Dordrecht are designed to withstand water levels with an exceedance probability of 1:2000 years (the legal standard in the flood protection act of 1996). These are about + 2.6 to + 3.2 mNAP, depending on the location on the island. Fortunately, these water levels have never occurred under the current system of FRM measures, which were established after the storm surge disaster in 1953. The hydraulic conditions needed for the embankments to break under the current FRM strategy thus never occurred and therefore cannot be used for this thesis. However, there are studies that study the flooding of the island of Dordrecht (Kind et al, 2011; De Bruijn and Van der Doef, 2011). These show that water levels that can break or overflow embankments may occur for example due to a river flood wave with the duration of 17 days and a peak discharge of 8000 m^3/s near “Lobith” in combination with a storm surge that causes water levels at the North Sea due to a north western storm event of 35 hours and an average wind speed of 22 m/s (9 Beaufort), which results into a maximum set up of approximately 3.5 meters near the “Maasmond” (Piek, 2007; Slootjes et al., 2010). The conditions that contribute the most to the failure probability of the embankment near “De Kop van het land” are a flood wave along the river occurring for a Rhine peak discharge at Lobith of 16.500 m^3/s and a maximum water level set-up of 1.75 meters near the “Maasmond”, due to south westerly wind with an average speed of 11 m/s (5-6 Beaufort). At the other locations, the conditions dominated by storm surge contribute the most. Figure 11 shows the development of water levels (2.8 – 3.3 +mNAP depending on the location on the island). under the storm surge scenario that reach the water level at which the embankments around Dordrecht are designed.

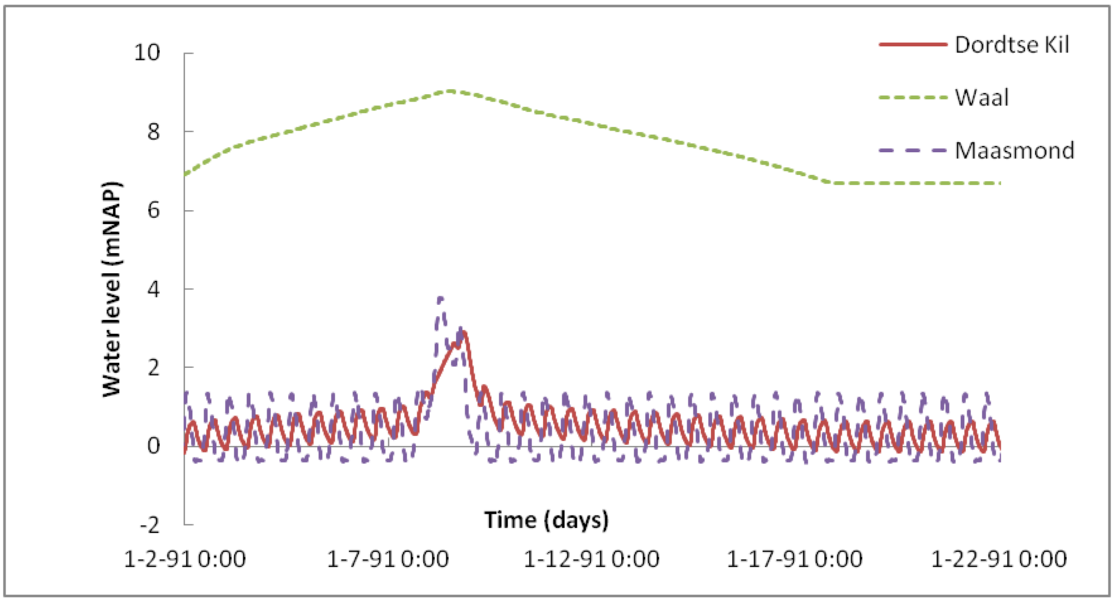


Figure 11: The development of the water levels in the “Waal”(upstream), the “Dordtse Kil” (near island of Dordrecht) and the “Maasmond”(downstream) over time during the storm surge scenario.

3.2.2 Flood characteristics of the areas outside the dike ring

The three main areas outside the primary defense system are the historical port area, in the north west of the island, the flanks outside the dike ring, in the north and the east and the Biesbosch. The historical port area is a small area within the old city centre that contains older public buildings and residential areas. The quay levels in the area are in between +1.7 mNAP and +2.5 mNAP. This area was frequently flooded before the closure of the "Haringvliet" by construction of a dam and sluices in 1970. Nowadays, these quays get flooded by a 1:10 year water level. The elevation outside the dike ring is between +3 mNAP and +4 mNAP. This means that these areas rarely become flooded. Finally, the Biesbosch lies only a few decimeters above NAP, which means that this area inundates every high tide (Van Herk et al., 2011).

Figure 12 shows the once in a 1000 year water depth in the areas outside the dike ring (De Bruijn et al, 2012). This figure shows that the neighborhoods north of the city are only flooded near the edge of the rivers and that the water depth at those locations in general is less than 0.8 meters. One major exception is the "Wantijpark" (ANWB and TD, 2004) that is flooded up to a water depth of 3 meters. The other areas in the east and south that are flooded with a depth of 2-5 meters are all part of the "Biesbosch". The maximum velocities within these areas are in general low. However, velocities within creeks (within the "Biesbosch") or smaller streets can become high. In case of an extreme event the flooded areas will start to drain as soon as the water levels in the rivers drop, and fall dry as soon as the water levels drop below the levels of the land itself.

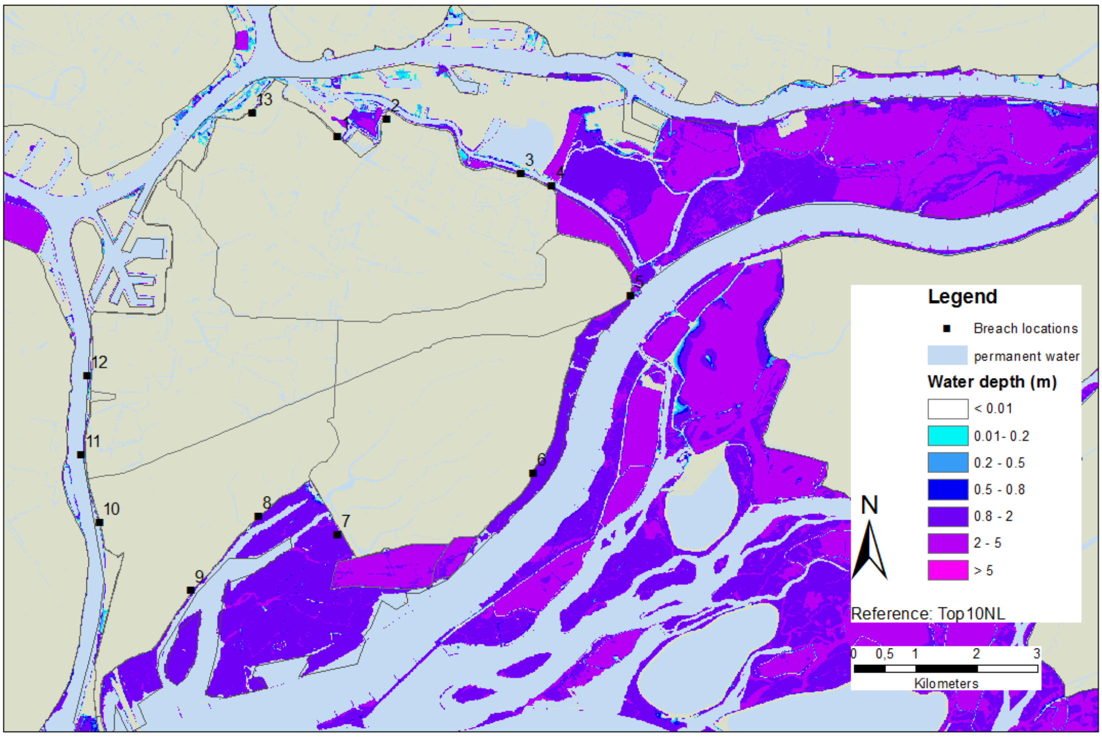


Figure 12: The 1/1000 year water depth in the areas outside the dike ring.

3.2.3 Flood characteristics of the area inside the dike ring

The areas inside the dike ring lie at the elevation of around 0 mNAP. This means that that if not protected by embankments these areas would not exists as land. The projects of VNK-II and VW21 studied the flood characteristics for the area inside the dike ring (Kind et al, 2011; De Bruijn and Van der Doef, 2011). These studies give the maximum water depth and maximum velocities of flooding the island of Dordrecht if the embankment would break at the moment the 1:2000 years exceedance water level is reached. Figure 13 and 14 show the maximum water depth and velocities for a flood from all different breaches at different locations along the embankments of the island. The figures for the maximum depths and velocity of each breach can be found in appendix 1 en 2. These figures show that for the area north of the "Wieldrechtse Zeedijk" (see figure 10) the maximum water depth (from different breaches) lies in between 2 and 5 meters. The maximum water depths south of the "Wieldrechtse Zeedijk" are much lower and lie in between 0.2 and 2 meters. Furthermore, the figure shows that a breach near point 5 "Kop van het land" is the most destructive and inundates the largest area with the highest water depths. Figure 14 shows that the highest velocities are reached near the breach locations and small areas in between higher areas (embankments) that lie within the dike ring. The velocities can be faster than 0.5 m/s near the breaches and in between higher areas, but are generally less than 0.2 m/s.

Another important flood characteristic is the flood duration, because the areas inside the dike ring lie below the average river water level and part of the water has to be pumped out after the breach is closed. The duration of a flood depends on two factors:

- The closing time of the breach(es).
- The time needed to pump the area dry.

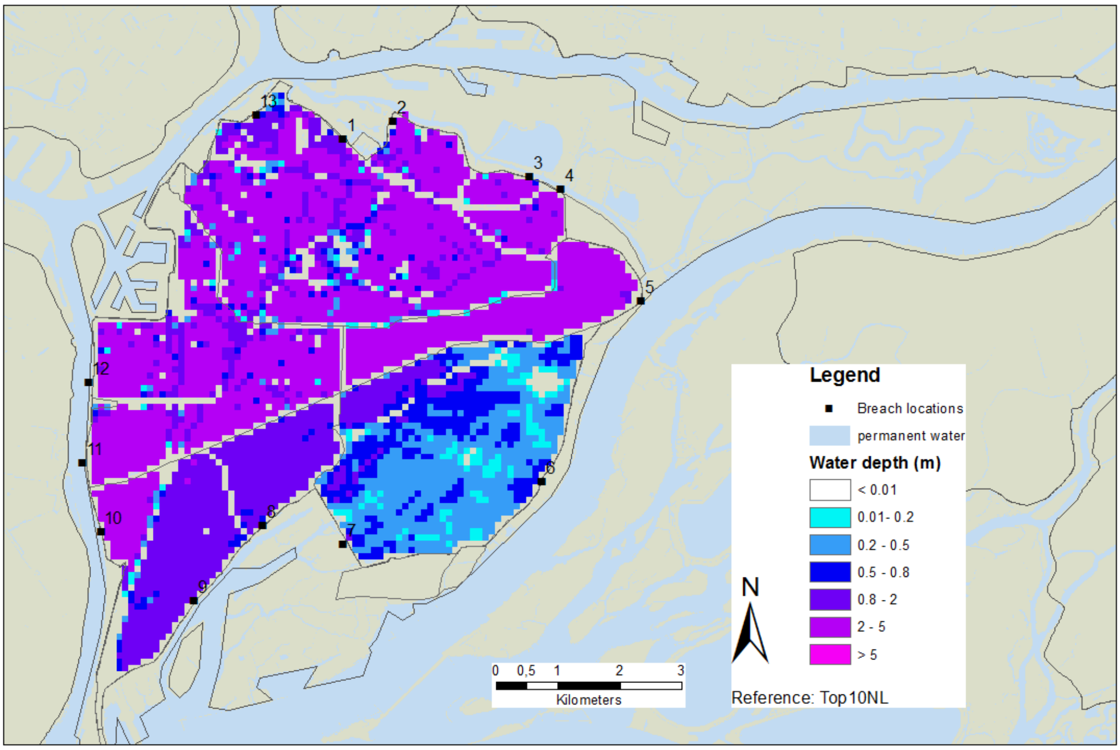


Figure 13: Maximum water depth from all breach locations on the island of Dordrecht.

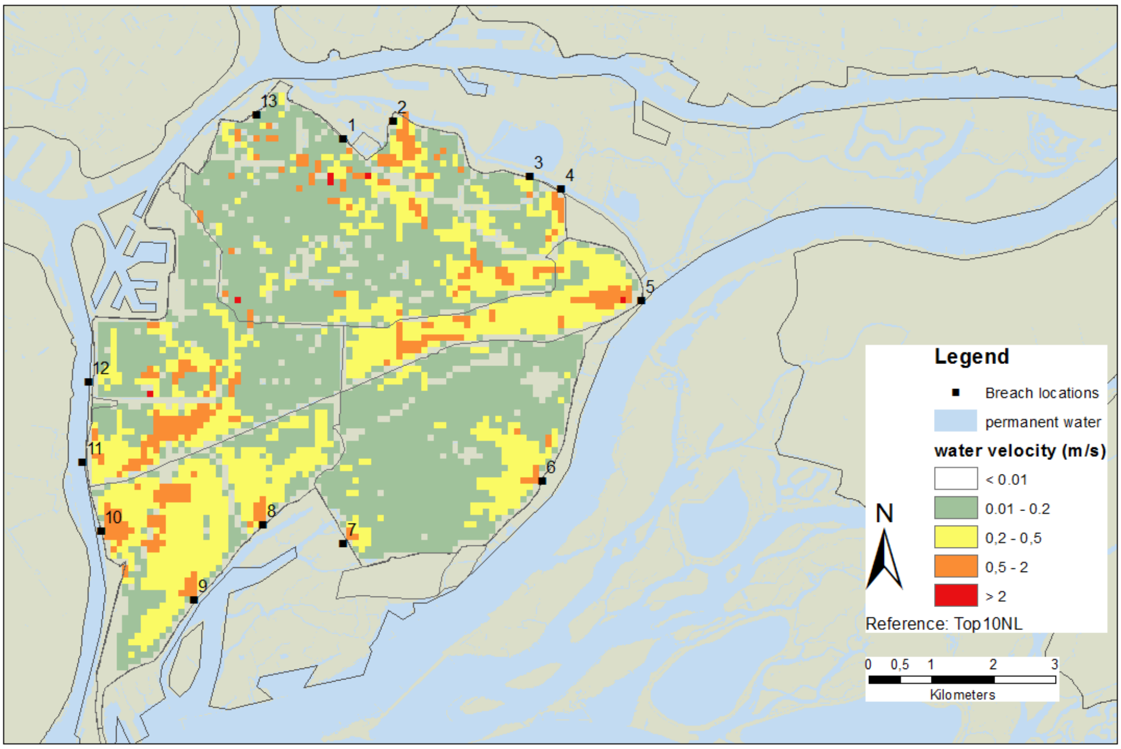


Figure 14: Maximum water flow velocity from all breach locations on the island of Dordrecht.

The closure time of a breach depends on many factors, such as the scale of the damage to the embankments, the accessibility to the breach, the type of breach (lowest level of breach below or above average water level, influence of tides) and the priority to close the breach (in case of multiple breaches). There is no real time data from closing breaches along the island of Dordrecht, but data from the flooding of New Orleans in 2005 and "Zeeland" in 1953 is available. The majority of the breaches in New Orleans and "Zeeland" areas were closed with emergency repairs in 15 and 100 days respectively. However, some single breaches were repaired within one day, by for example sinking a ship into the breach and then dump sand bags behind it (Morra, 1954; Van der Veen, 1954; U.S. Army Corps of Engineers, 2005; Wagenaar, 2012).

The time needed to drain the area after closure of the breach(es), depends on the volume of water in the flooded area and the available pump capacity. Stone (2011) made an estimation of the time needed to drain the water from the flooding of the island of Dordrecht through a breach near the "Kop van het land". This estimation assumes that the pumps on the island are not destroyed by the flood, water cannot drain from the area through the breach and no other resources are used to drain the water. It then takes 2.5 months to pump the whole water body of 60 million m^3 with a total pump capacity of the 5 major pumping station of 583 m^3/min.

3.3 Flood risk management (FRM) on the island of Dordrecht

The municipality of Dordrecht has the protection of people from flood risk high on their priority list. They are involved in many (research) projects that involve flood risk management. Furthermore, they actively provide the civilians with information on flood risk at the municipality website. Within this section first the present FRM measures and characteristics that fit the 1st and 2nd layer of multilayered safety strategy are described. Next the present crisis management plans (3rd layer of MLS) are given. Finally, current research and future plans for FRM on the island are described.

3.3.1 Present FRM measures for the 1st and 2nd layer of MLS

Measures for areas outside the dike ring

Flood risk management outside the dike ring is not regulated by law. There are thus no legal protection standards for these areas and no high embankments were built. However, due to the city's history with major floods in the past many buildings are already protected against water. This protection is reached with measures such as higher first floor levels and waterproof facades (Van Herk et al., 2011). Furthermore, flood risk is further reduced for these areas by actions and measures taken during extreme water levels by the crisis management team(s) as described in the next section.

Measures and their characteristics for the areas inside the dike ring

Dike ring 22 is designed to protect the hinterland against extreme events with an annual exceedance probability of 1/2000 years according to the Dutch water act (wetten.overheid.nl). The primary defense system along the island consists of different types of embankments. These types are: the historical city dike, city dike, park dike, polder dike, river dike and a wide dike. An overview of the primary defense and the different types of embankments can be found in figure 15 (Hinborch, 2010; Van Herk et al., 2011).

The historical city dike lies within the old city centre, is densely built upon and has a gentle slope at the inside of the dike. The city dike is also a dike on which houses are built, but does not lie in the old city centre. The park dike is a wide dike with a gentle slope and composed by terraces. The polder dike is a small dike with steep slopes and trees on top. The river dike contains a standard dike profile and directly borders the river. Finally, the wide dike contains a high area between the river and the dike, which in fact broadens the whole dike zone. The different types of embankments have different strengths in the context of possible breaching during times of high water levels in the rivers. This is also seen from the test result of the review of the primary embankments every five years by the water boards (see figure 16). These figures show the strongest embankments are the (historical) city dike and the park dike. The weakest embankments are the "Kildijk" (river dike) in the west and the one near the "Kop van 't land" (polder dike).

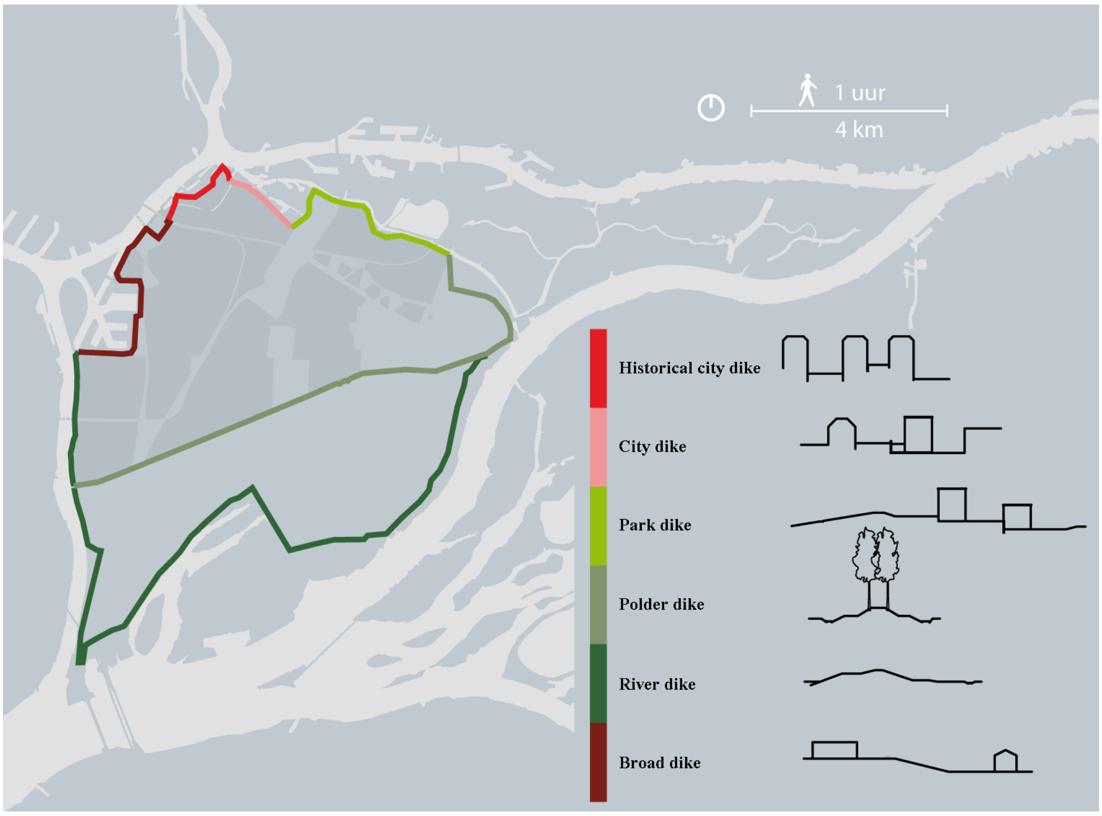


Figure 15: Types of dikes at the island of Dordrecht from Van Herk et al. (2011).

3.3.2 Crisis management and evacuation plans (measures 3rd layer)

There are several documents that describe the crisis management and evacuation plans in case of an extreme high water (flood) event on the island of Dordrecht. The first document "Regionaal Basisplan Overstromingen" (VRZHZ, 2009), RBO, is established by the governmental body called the safety region "Zuid Holland Zuid"(ZHZ) and describes the procedures for the authorities on the island of Dordrecht in case of the occurrence of extreme water levels and possible embankment overtopping or breaking. Thresholds for the warning system and up-scaling towards a higher state of emergency are determined based on the water levels predictions in the rivers around the island and water depths on the island (VRZHZ, 2009). The second document, "Hoogwater bestrijdingsplan", HB, (Gemeente Dordrecht, 2012) describes the actions taken by the crisis management team in case of flooding of the areas outside the primary defense. Also in this document water level thresholds are used to scale up towards a higher state of emergency. Finally, the risk map of the Netherlands (www.risicokaart.nl) describes all kinds of risk in the region including potential water depths and consequences of flooding. The site describes what type of floods can be expected in a certain area and what civilians can do to rescue themselves given a certain water depth and flow velocity. These thresholds for water depth and velocity are also described Van de Pas et al. (2011) and can be found in table 1.

Figure 16: The results of the 5 year review of the embankments by the water boards of 2006 from Van Herk et al. (2011).

Table 1: Thresholds for water depths and velocity and the possibilities for people and authorities to execute certain actions based on Van de Pas et al. (2011):

Tresholds	**Actions that still can be performed**
Max water depth:	
0 - 0.2 m	People can walk and low damage
0.2 – 0.5 m	Cars can drive and higher damage
0.5 – 0.8 m	Army vehicles can drive and high damage
0.8 – 2 m	People can evacuate safely at the first floor and maximum damage
2 – 5 m	People can evacuate to their roof and maximum damage
> 5 m	People are not safe anywhere and maximum damage
Water velocity	
< 0.5 m/s	People are still able to walk
> 0.5 m/s	People are not able to walk
Arrival time or raising rate of water (areas inundation > 1.5 m)	
< 6 hours	Almost no time to flee the area (island of Dordrecht
6 – 24 hours	Short time period to flee (only regionally)
> 24 hours	Enough time to flee (also nationally)
Duration of inundation	
< 2 weeks	Area can recover itself in short time period
> 2 weeks	Area is not accesible for a longer time period

The RBO and HB describe 3 stages for emergency management that are based on the warning system from "Rijkswaterstaat", RWS. These stages each describe different measures that need to be taken by the water board, the municipality of Dordrecht or the safety region. The stages are entered based on the forecasting and monitoring of the water levels in at the "Oude Maas" near Dordrecht by RWS. The stages are entered 16-12 hours before the corresponding water levels are expected. The stages are:

1) Pre- warning: expected water level of + 1.8 meters above NAP
2) Warning: expected water level of + 2,5 meters above NAP
3) Alarm: expected water level of +2,8 meters above NAP

The measures and actions that are taken for each stage by the authorities involved can be found in appendix 3. The most important among them are monitoring of the water levels in the rivers, monitoring of the embankments, arranging of a crisis centre, the closing of movable protection measures, closing of the connections in the sewer system between the areas outside and inside the dike ring and warning of the civilians (VRZHZ, 2009; Gemeente Dordrecht, 2012).

The RBO divides the inundated areas, in case of a flood, into 3 different crisis management zones. These zones are:

1) safe areas (water depth < 0.05 m)
2) areas where measures and emergency operations still take place (water depth = 0.05 m – 0.8 m)
3) unsafe areas (water depth > 0.8 m)

In the case of an inundation of the areas inside the primary defense of the island, there are no specific details about the actions of the authorities in the crisis management plans. These actions will be formulated during the crisis. Only responsibilities are recorded. However, during these crisis situations the authorities have information available on how water levels and depths can develop in the next hours after a breach occurred (VRZHZ, 2009).

Finally, it should be noted that studies are done on the possibilities of evacuation of the whole tidal river area (Maaskant et al., 2009) and recently specifically on the island of Dordrecht (Hoss et al, 2011). These studies show that due to the few main escaping routes (main high ways), the limited available time for the evacuation (24 hours before the highest water levels it is not possible to evacuate anymore due to the fact that for most breach scenarios a heavy storm is blowing over the area) and the high number of people that need to be evacuated (densely populated area) on average only 15% of the people living in the area can be evacuated. However in case of a river flood with no storm and thus more time to evacuate this percentage can be up to 79% for the island of Dordrecht. These studies assume that 20% of the people living in the area would not evacuate if the authorities asked them to (Maaskant et al., 2009; Hoss et al., 2011). Appendix 4 shows the possible evacuation scenarios for the island of Dordrecht and the probabilities and percentages coupled to these scenarios.

3.3.3 Research and future plans for FRM

To date, maintenance of embankments is still the most important element of FRM on the island of Dordrecht. However, new FRM strategies are developed based on the idea of applying the multilayered safety approach and the possibility of eventually changing the term and regulations of the standards in the law (Ten Brinke et al., 2008; V en W et al., 2009). At the moment two main studies are carried out that may influence FRM strategies on the island of Dordrecht. The first one is MARE in which the possibility of applying multilayered safety on the island of Dordrecht is considered (Van Herk et al., 2011; RWS, in prep). The second is a sub-programme of the 2nd delta programme that studies the possibilities for integrated water management for the area of "Rijnmond Drechtsteden". Dordrecht resides in this area (RWS, in prep; Slootjes et al., 2010; Hinborch, 2010).

The study of the project of MARE

Within the project of MARE a distinction is made between areas inside and outside the primary defense system. For these areas measures are proposed at all layers of the MLS strategy. In the areas outside the embankments measures such as waterproofing of buildings or building a collective water defense system along the quays of the city of Dordrecht are proposed (Van Herk et al. 2011; Hinborch, 2010).

The areas lying inside the dike ring can best be protected by creating a more robust embankment system, since a large scale re-arranging of the low-lying areas inside the dike ring seems not realistic. Studying the embankments along the island shows that parts of the embankments (historical city embankment, city embankment, park embankment) on the northern part of the island show characteristics of wide strong delta embankments. This means that these embankments can easily transformed towards strong unbreakable embankments. The southern part of the island has a secondary embankment (the old sea embankment) that can act as a compartmentalization embankment that also prevents water from flowing into the city. The study also shows that that the embankments near "De kop van het land" and along the "Dordtsche Kil" are the weak points on the primary defense system of the island. (Van Herk et al., 2011).

These characteristics for the island were used to develop two extreme strategies for the island of Dordrecht. The strategies are used to explore the possibilities of realistic strategies for the island of Dordrecht. Furthermore, they are used to explore the potential for the island to become self-reliant under extreme circumstances. These strategies are (Van Herk et al., 2011; RWS, in prep):

- Evacuation strategy, where no additional measures are taken at the first (protection) layer but all non-self-reliant people in case of an extreme event are evacuated to shelters on the island itself. All other people have to evacuate by themselves to high dry parts. For this strategy additional measures need to be taken at the second and third layer. Examples of such measures are building and maintenance of raised roads that connect the shelters with the outer world and the improvement of communication to the civilians of Dordrecht during these extreme circumstances.
- Prevention strategy, where additional measures are taken at the first layer only, and the embankments around the whole northern part of the island are converted into delta embankments. The old sea embankment that divides the island in two parts acts as compartmentalization embankment that is strong enough to not break under the hydraulic pressure of the water levels that occur due to breaking of the primary defense in the southern part of the island.

Within this context a shelter is a building or part of building that is designed to withstand the hydraulic load associated with a flood event. It functions as a multi-use facility that provides multiple functions (such as health care, distribution of food, shelter for people) before, during and after the flood event (Blom et al., 2012).

The general conclusion on these two strategies is that the evacuation strategy does not reduce the damage but reduces the number of fatalities by 66%. The prevention strategy reduces both damage and fatalities by 95 – 97 % respectively, but costs around 10 times more than implementation of the prevention strategy. Still, these numbers are rough estimates and should be used as an indication of the differences between these strategies. Further research is needed to give specific details on these strategies (Van Herk et al., 2011).

Sub-programme (of the 2nd delta programme) "Rijnmond Drechtsteden"

The programme of "Rijnmond Drechsteden" carried out a risk analysis on all areas within the region of the programme with scenarios that include climate change in the future (Slootjes et al., 2010; Hinborch, 2010; RWS in prep). Based on this risk analysis strategies are developed for these areas that lower the water levels in case of extreme events in the future. The strategies developed for this area could have major consequences for the FRM strategies on the island of Dordrecht. For example one of the proposed strategies is the so-called "Afsluitbaar Open Rijnmond" (Usually open, occasionally closed "Rijnmond") concept. Figure 17 shows a possible solution for this concept. When extreme water levels are expected at sea, the total area is closed off with the "Maeslant" barrier, "Hartel" barrier, "Haringvliet" sluices and four new barriers in the "Spui", the "Oude Maas", the "Dordtsche Kil" and the "Merwede". High river discharges are diverted towards the southern delta via the "Hollandsch Diep" and the "Haringvliet", along the island of Dordrecht. The advantages of this concept are that the whole area of "Rijnmond Drechtsteden" acts as dike ring, and less embankment strengthening is needed within this area to cope with flood risk in the future. However, this concept can cause very high water levels at the bifurcation point of the "Beneden Merwerde" and the "Nieuwe Merwerde". This bifurcations point lies next to the southeastern part of the Island of Dordrecht and high water levels at that point threaten the embankments of "Kop van het land". This means that if this concept is carried out the "Kop van het land" becomes the main focus area for FRM on the island of Dordrecht (Slootjes et al., 2010; Hinborch, 2010.)

Figure 17: The "Afsluitbaar Open Rijnmond" concept from Ties Rijcken, TU Delft and HKV lijn in water (from Hoss, 2011).

3.4 Critical infrastructure on the island of Dordrecht

Critical infrastructure is very important in the continuation of functioning of a certain area. Without these critical functions, the area and the people living there cannot survive; failure of these functions causes at least social and economic dislocation in that area (BZK , 2005). However, less is known about critical functions in case of flooding. Therefore, this section about critical infrastructure is somewhat more comprehensive than the other sections and also contains a short literature study on critical infrastructure. This section starts with the definitions for critical infrastructure in general and for this thesis. Hereafter the defined critical functions are described in terms of failure during floods. Finally, the most important locations and assumptions of failure during floods of critical functions on the island of Dordrecht are given.

3.4.1 Introduction in and definition of critical infrastructure

Before critical infrastructure (CI) can be described it is needed to know what CI exactly is. BZK (2005 and 2009) define infrastructure as critical if at least one of the following criteria can be applied:

- Disruption or failure of a critical sector, service or product causes economic or social dislocation on a (inter)national scale.
- Disruption or failure of a critical sector, service or product results directly or indirectly into the death of many people.
- The dislocation is long term, recovery takes relatively much time and during the recovery no alternatives are available.

The disruption or failure of critical sectors, services and products can have many causes from technical failure and organizational failure, via natural hazards up to conscious human action (terrorism). Another definition of critical infrastructure is given by Luijjf et al. (2003), who describe critical infrastructure as an infrastructure that is essential to the economic security, the smooth functioning of the government at all levels and society as a whole. Furthermore, Luiijff (1999) already stated that the interrelated trio of electricity, communications systems are the most important critical functions, because without them the security, safety, economy and ways of life cannot function anymore. BZK (2005 and 2009) describes twelve categories that are critical based on above definition. These categories are further subdivided into 31 critical sectors, services and products. In 2009 BZK draws the most important six out of this list. These are:

- Electricity: Almost all other critical categories are depending on electricity.
- Gas: Electricity strongly depends on gas supply and almost all other categories do depend on electricity.
- Drinking water: Humans and animals cannot survive long without drinking water.
- Telecom/ICT: important technical systems (such as certain emergency systems) do depend on Telecom/ICT.
- Protection and management of surface waters: Major floods can be disastrous for human society and almost all critical categories.
- (Road) Transport during crisis situations: almost all other critical categories do depend on road supply systems of goods, products and services.

Similar lists are made by the Province of Utrecht (2010), by Syncera (2007), Huizinga et al. (2011) and by DHV (2011). Syncera (2007) also found that today's crisis management assumes that if a flood occurs all critical functions do not function anymore. Furthermore, they found that the critical water depth for which the critical functions no longer continue to operate is difficult to determine, and strongly depends on the location of critical objects.

In this thesis the functions that are defined as critical infrastructure are the following:

- Electricity network
- Gas supply network
- Drinking water network
- (Crisis) telecommunication network
- Road network

These functions include all functions that are crucial for the survival and recovery of a certain area from floods. Electricity is considered critical, because many other functions do depend on electricity, such as gas supply, communication network and drinking water. Secondly the gas supply network is a critical infrastructure, since most heating systems in households depend on the heating of gas and people cannot survive cold days without any heating in their homes. Thirdly, pure and safe drinking water is very important for the health of all people. They cannot live more than a few days without drinking water. Fourthly, crisis telecommunication networks are important for the communication between emergency services and other authorities. Communication is important for fast and smoothly execution of emergency rescues and crisis management plans (BZK 2005; Syncera 2007). Finally, the road network is a very important critical infrastructure during floods. People need to rely on roads in order to be able to evacuate from an area. Furthermore, roads are needed for emergency services to enter the hazard area and for fast recovery activities in the area (DHV 2011, Provincie Utrecht 2010).

3.4.2 Electricity

The electricity network in the Netherlands is divided into three levels that transport electricity at a certain voltage and are connected to each other through transformers (www.wikipedia.nl; www.tennet.nl; de Kort ,2012; DHV, 2011):

- The high-voltage (>110 kV) network is constructed in ring structures and generally consists of mast with transport cables high above the ground, but also in the deep underground. Furthermore, the network is built redundant (www.tennet.nl).
- The medium-voltage (<10 kV) network is constructed in both ring as finger structures that generally transport electricity through cables underground. The electrical cabinets, where the network divides, are situated at ground level.
- The low-voltage (400/230 V) network is constructed in finger structures and deliver electricity directly to buildings. Generally the cables are constructed underground and the electrical cabinets are placed at ground level.

Electricity supply occurs in a step-wise lowering of the voltage from the high-tension national 380 kV network down to a medium-voltage network of 13kV and finally to the low-voltage network to use on the island of Dordrecht (pers. Comm. Verschuren – Dordrecht Municipality). If contacted to water during a flood, electricity can fail. Therefore, electricity companies disrupt the electricity supply when a flood with a water depth of more than 20 cm is expected. This is done to avoid electrocution of people and to avoid damage of the system (DHV, 2011). The chance of failure due to floods of the high voltage-network is very low. Water and cables do not interact, which therefore does not cause failure. This network can only fail when masts collapse, but this scenario is neglected in this study. Furthermore, the network is built redundant which means that if one part fails it can be replaced with another part. (Syncera 2007 and Provincie Utrecht 2010; De Kort 2012). The cables underground that are part of the medium- and low-voltage networks do not fail due to floods. However, the networks comprise components where water can interact with electricity and thus can cause failure of the system. This can already happen at a water depth of 30 cm for the low-voltage cabinets and at a water depth of 50 cm for the medium-voltage cabinets according to De Kort (2012) and experts from Stedin. Other components where water can interact with electricity are the underground supply to street lights and the fuse boxes of buildings. These components do fail at a water depth of respectively 35 cm and 150 cm (new buildings) or 30 cm (old buildings) (De Kort 2012, Syncera 2007, DHV 2011). Electrical cabinets in the areas outside the primary defense are heightened to prevent them from flooding.

3.4.3 Gas supply

The gas network in the Netherlands is more or less built up the same way as the electricity network. High pressure pipes transport the gas from its source towards the station where gas is distributed towards pipes with lower pressure that feed households etc. The high-pressure network (40 bar) of Gasunie delivers gas to the high pressure network (8 bar) of Stedin on the island of Dordrecht. Stedin lowers to pressure towards 100 mbar that can be distributed towards the households. Gas supply is important, because civilians and companies rely on gas supply in order to warm their houses/buildings (DHV 2011, www.wikipedia.nl, Provincie Utrecht, 2010). Gas pipes can withstand a water column of 150 cm (including the depth they lay below surface) according to De Kort (2012) and 180 cm according to Huizinga et al. (2011), otherwise water may leak into the pipes. Furthermore, the gas distribution stations can withstand a flood of 100 cm, afterwards the pressure-control valves are closed off which can lead to high pressures and explosions. Also, the addition of an artificial essence to the gas at the distribution stations can fail due to flooding, which makes gas not safe to use (De Kort 2012, Provincie Utrecht, 2010). Finally, the control system of gas supply depends on electricity. Therefore, gas supply will probably fail if electricity fails. When gas pipes become flooded with water the whole system becomes completely destroyed (DHV 2011, Syncera 2007).

3.4.4 Drinking water

The drinking water system contains of the following elements (DHV, 2011):

- Water winning: 250 places in the Netherlands were water from the ground and rivers is purified into drinking water
- Water basins: Basins where unpurified water is stored before the purification process.
- Pumping stations: The stations were pressure is build up in the pipes to transport drinking water to the households.
- Drinking water system: Closed system containing pipes that transports water towards the households.

The drinking water system in the Netherlands is not very vulnerable for floods. The pipes can withstand a water column of 20 meters (i.e. the pressure in the pipes is higher than the pressure due to 20 meters water column). However, after a flood pipes may break due to consolidation of the soil after flooding (De Kort, 2012; Syncera, 2007; Provincie Utrecht, 2010). Furthermore, the pumps for pumping drinking water through the network depend on electricity. If electricity fails, generators are available at the pumping stations. However if the flood reaches these pumping stations, the pumping system will fail, due to failure of the generators (DHV, 2011; Syncera, 2007; Provincie Utrecht 2010). Flooding can also cause pollution of the water in the water basins and thus a disruption in the purification process. According to the drinking water act (July 2011) water companies are obliged to represent a plan that describes the guarantee and continuity of delivery of drinking water to households in the Netherlands. This means that according to this act all drinking water companies need to be able to be self-reliant on energy and chemical supply for at least 10 days (DHV 2011; Huizinga et al. 2011; the expert from Evides).

3.4.5 (Crisis) telecommunication network

The main network that needs to continue working during floods is the C2000 network. This network is the communication network of the Dutch emergency services. This network has its own transmitters and receivers on so-called TETRA masts (480 units) and cross connection centers (15 units). The TETRA network has its own transmitting and receiving frequency and the network is built with redundancy. The masts of this network are not vulnerable for floods, however the technical (support) system is placed in a cabinet at the bottom of the mast and thus very vulnerable to floods. Furthermore, the network depends on electricity. So if electricity fails, this network will fail too (De Kort, 2012; Provincie Utrecht 2010; DHV 2011; Jasperse 2011). The experts from the C2000 network itself made clear that during the building of the C2000 network, the network was not built waterproof. This is intentionally done, because it is very hard to realize and the extra costs do not out weight the low risk that damage indeed occurs due to flooding. Furthermore, the more negative esthetic aspect of placing cabinets on higher mounds or higher foundations does not out weight the avoidance of damage due to the low risk of flooding. Other telecommunication networks (mobile network, internet, television network etc.) that are intensively used by civilians and companies are very vulnerable for floods. These networks are highly redundant, but all the equipment and cables lie around ground level and thus damage if floods occur. Like the C2000 network the other networks also depend on electricity. This means that the telecommunication networks will fail in the flooded area. However the emergency services may then communicate by satellite phones (DHV 2011, De Kort 2012, Syncera 2007,Provincie Utrecht 2010).

3.4.6 Road network

People can drive with their own car up until a water depth of 20 cm. However a flooded street forms a certain risk, because obstacles and sudden depths are hidden below the water (De Kort, 2012, Syncera 2007). Furthermore, it is not possible to pass tunnels anymore, when water fills these lower points during a flood. Finally, if electricity fails during floods, traffic lights, track points and traffic control will not function anymore and therefore traffic is not smoothly regulated (DHV 2011, Syncera 2007).

3.4.7 Critical infrastructure on the island of Dordrecht

The most important information and locations of critical infrastructure on the island of Dordrecht are gathered from different organizations and experts, such as Stedin (electricity and gas), the municipality of Dordrecht, Evides (drinking water company), C2000 (crisis communication network) and the water board (Hollandse Delta). Unfortunately, due to confidential and safety issues of the involved organization and companies, data on the precise locations of critical infrastructure is not available. The municipality of Dordrecht was the only that provided the most important locations for critical infrastructure on the island. Figure 18 shows these locations. Furthermore, a summary of the conditions under which critical infrastructure fails can be found in appendix 5.

The locations showed in figure 18 for the electricity networks are the locations where electricity is transformed from the high-voltage network (Tennet) to the medium-voltage network (Stedin). The gas deliver points that are showed, are the points on the island where the main network (Gasunie) with high pressure is distributed towards a secondary network (Stedin) with lower pressure. The locations of Evides and are mainly water storage basins. Furthermore, an important group of valves that closes of the pipes of the main gas network in the Netherlands is shown. Finally some locations on main KPN (telecommunication) hotspots and the waste combustion and sewage treatment plants are showed. The road network is available from the data of the Topographical Survey (www.kadaster.nl (TOP10NL). Figure 19 shows this road network. The two main connections on the island are the A16 (the high way in purple) that represents the main north-south connection on the island and the N3 (in red) the main west-northeast connection on the island.

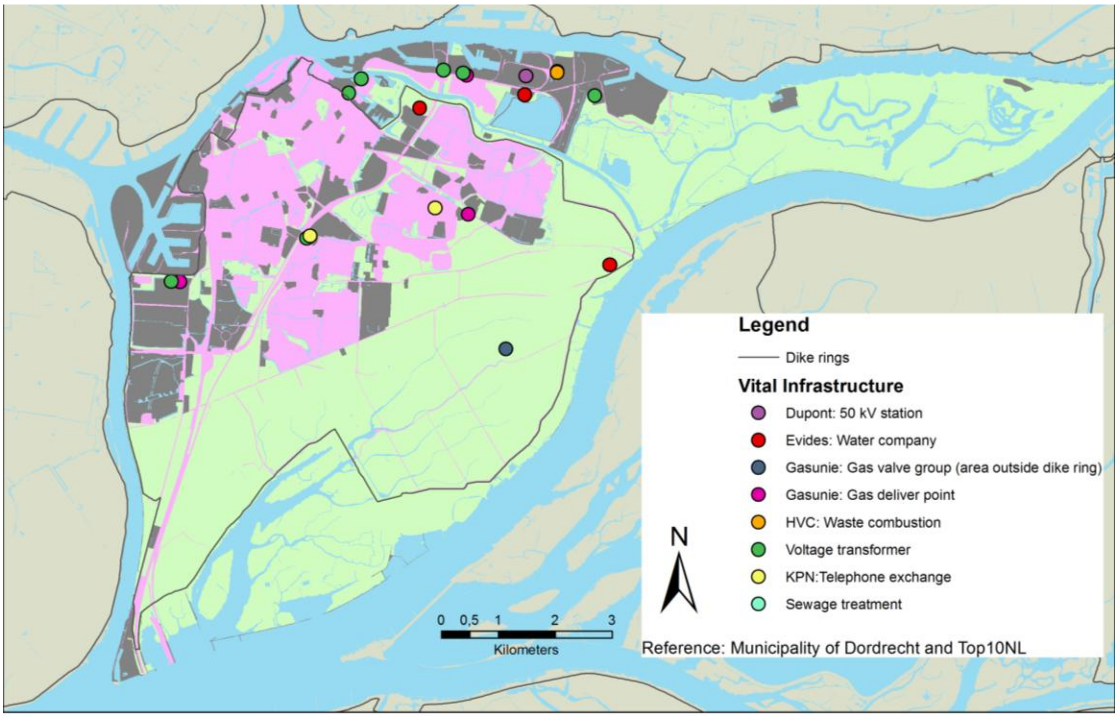


Figure 18: The locations of the most important critical infrastructure locations on the island of Dordrecht.

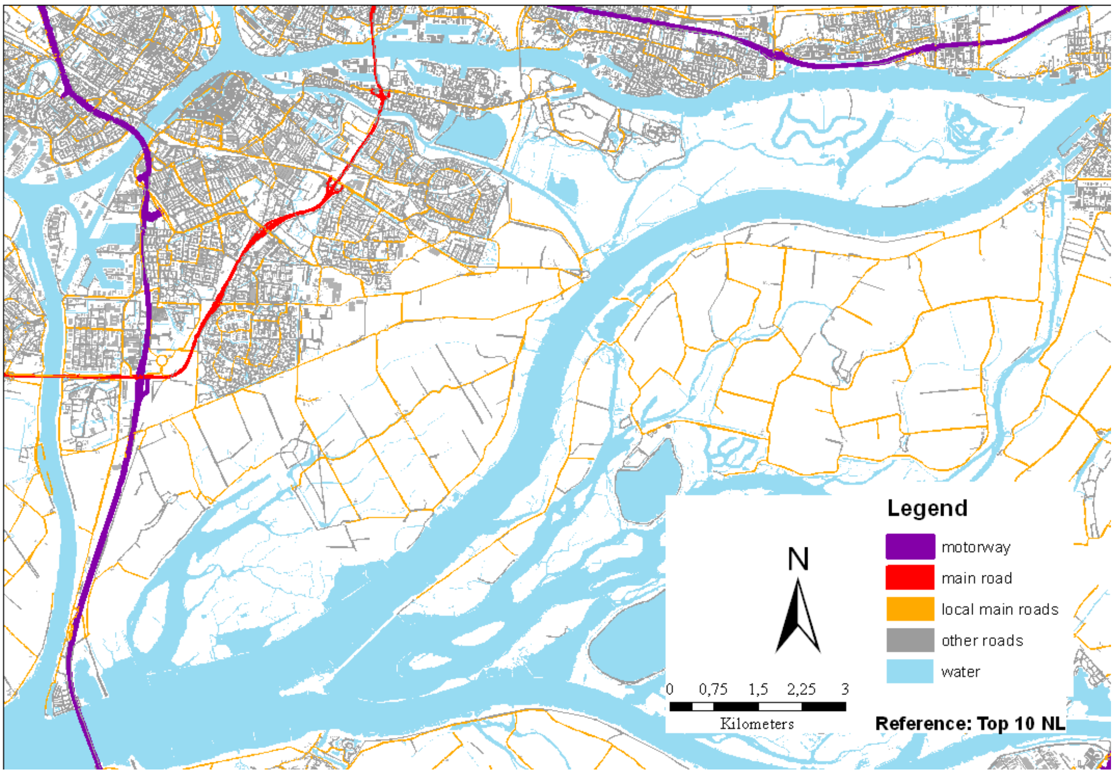


Figure 19: The road network on the island of Dordrecht.

3.5 Flood impacts

The flood impacts on the island of Dordrecht vary across the island. Two important indicators for the impact of a flood are the number of fatalities and the damage caused by a flood. Table 2 shows the damage and fatalities on the island of Dordrecht as calculated for the study of WV21 (Nelen en Schuurmans, 2010). This table shows the damage caused by inundation through breaches at different locations along the embankments of the island. From this table it is seen that the damage is high for the breaches that cause inundation of areas that contain residential areas (the breach near the "Kop van het land" and the breaches that occur along the city dikes and park dike in the north) and/or industrial functions (breaches along the "Kildijk" in the west). The damage is low for the breaches that mainly inundate agricultural and nature areas (breaches south of the "Wieldrechtse Zeedijk". The number of fatalities is high in residential areas, while it is lower in areas with an industrial function. Furthermore, damage and fatalities are higher in areas that face a bigger water depth (Nelen en Schuurmans, 2010). The areas with the largest potential flood impacts lie at the northern side of the island.

These flood impacts are visualized in figure 20 that shows five flood impact categories for the island of Dordrecht. The flood impact categories are categorized based on the water depth, land use type, population density and the trend in the curve for damage against water depth for industrial, agricultural and residential areas (RBO (VRZH, 2009; Kok et al., 2005; Beckers and De Bruijn, 2011). Table 3 shows which flood impact category is defined for each combination of land use and water depth.

Table 2: The damage per breach from Nelen en Schuurmans (2010):

Breach name	Number of fatalities	Damage (millions of €)	Number of victims
1	82	1093	59310
2	137	1472	63760
3	134	1372	60182
4	134	1374	59584
5	566	4781	95167
6	0	13	107
7	0	8	223
8	0	5	159
9	0	17	28
10	6	21	253
11	65	782	20417
12	31	627	20097
13	18	308	17532

To calculate these numbers the most important regional waterways are included as are the main secondary embankments that are assumed to not break. Furthermore, the evacuation fraction is assumed to be 15% and high flats are not safe. The price level for the damage represents the year 2000.

Table 3: Definition of each flood impact category based on water depths and land use categories:

Water depth (m)	Land use category	Flood impact category
<0.05	Agriculture and nature	0
0.05 – 0.8	Agriculture and nature	1
> 0.8	Agriculture and nature	1
<0.05	Residential and transport	0
0.05 – 0.8	Residential and transport	3
> 0.8	Residential and transport	4
<0.05	Industrial and commerce	0
0.05 – 0.8	Industrial and commerce	2
> 0.8	Industrial and commerce	3

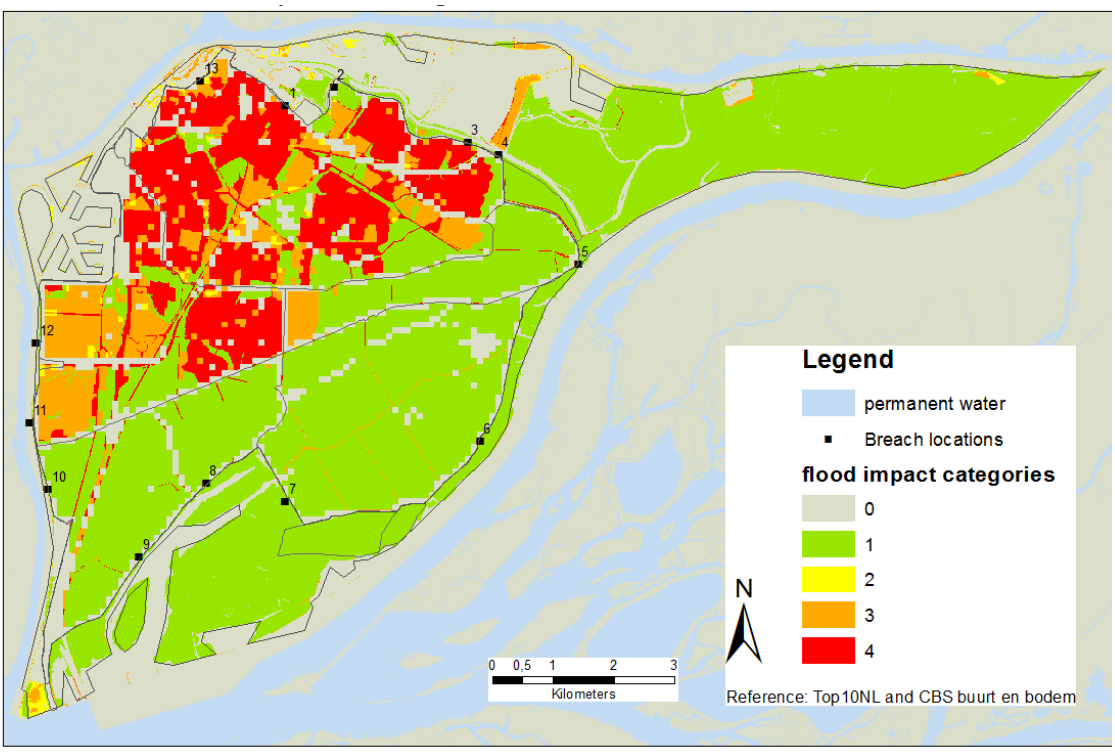


Figure 20: Flood impact categories for the island of Dordrecht.

Flood impact also includes the time needed for full recovery of the area. The recovery phase is the process of restoring, rebuilding, and reshaping the physical, social economic and natural environment through pre-event planning and post-event actions (Smith and Wegner, 2006). Unfortunately long term recovery (LTR) from disasters is the least understood phase of a disaster circle and not many studies have addressed this subject (Rubin, 2009; Chang, 2010). Therefore, it is difficult to implement the LTR phase into the flood impact for the island of Dordrecht. The only indication that can be used in this study is that the few studies on this subject show that there are four phases in LTR. These phases are (Rubin, 2009; Haas et al., 1977):

- Emergency (rescue, shelter, feeding of people)
- Reconstruction (return of functions and people (fast solutions))
- Recovery I (return to pre-disaster levels)
- Recovery II (improved and developed beyond pre-disaster levels)

In general the time needed for the next phase is 10 times the time needed in the preceding phase.

One of the factors in determining the time needed for full recovery of the area is the failure and thus recovering of critical infrastructure. As long as critical infrastructure fails, inhabitants cannot live within that area and thus the impact of floods on an area is extremely high. Critical infrastructure is very vulnerable for floods, because CI fails when water depths become higher than 30 cm. Most of the main locations of critical infrastructure as given in figure 18 lie in the areas outside the primary defense system and are not flooded during the extreme circumstances that represent the water levels that occur with an annual probability of 1:1000 years (see figure 12). This means that although vulnerable, the flood impact on these main elements of critical infrastructure on the island of Dordrecht is low. However, although most critical infrastructure within the dike ring could not be shown, the general knowledge on critical infrastructure shows that many important elements also lie within the primary defense system of the island of Dordrecht. This means that many critical elements such as electricity, gas supply and communication networks will fail if flooded, since water depth becomes higher in all areas than the average water depth of 30 cm on which most critical infrastructure fails. The recovery time on these elements is estimated by the experts from a couple of months to over a year.

4 Methods of establishment and analysis of storylines

Storylines were developed based on the knowledge from the previous chapters. The selection procedure and main elements that need to be incorporated in a storyline are described in this chapter. Subsequently, the methods for analyzing the storylines are described.

4.1 Selection of storylines

Each storyline describes a sequence of events that may happen over time during a flood event. It is chosen to develop storylines for an event with one embankment breach at a certain location within the primary defense system, despite the fact that in practice the hydraulic load on the other embankments does not necessarily decrease due to the breaking of one of the embankments in the dike ring. This means that multiple breaches could occur during one high water event. However, in each storyline there is assumed that there is one weakest spot. The embankment break is defined as the 0 hour on the timeline that describes each storyline. Most incidents that determine the outcome of a storyline happen just before or after that moment.

For this study the following three storylines were developed and described:

1. A breach along the "Kildijk"
2. A breach near the "Kop van het land"
3. Multilayered Safety strategy with breach along the "Kildijk"

The first two storylines were developed for two breach locations, for a breach near the "Kop van het land" and for a breach near the "Kildijk" (locations 5 and 11 in figure 10). These breach locations were chosen on the fact that they are the weakest points within the current embankment system (showed in figure 16 for the review of the embankments by the water boards every 5 years). This means that if embankment breaches occur during extreme circumstances, it will be it is most likely on these locations. The third storyline was developed to represent a future case where measures are implemented based on the idea of the island becoming self-reliant. This storylines was developed after the analysis of the first two storylines. These three storylines are assumed to represent the most realistic (wide) range within the events that can happen on the island under the current and future FRM.

Storyline 1 on a breach in the "Kildijk" represents an event under the current FRM circumstances (the current defense measures and crisis strategies). In this storyline not all areas of the northern part of the island are inundated. Furthermore, storylines for this case could also represent storylines for breaches along the embankments north of the city of Dordrecht. The figures in appendix 1 show that if breaches along these embankments occur, the flooded area and maximum depths are in the same order of magnitude as the breach along the "Kildijk".

Storyline 2 on a breach near the "Kop van het land" represents a worst case scenario where the northern part of the island with most economic and social functions inundates with large water depths. This storyline is also worked out under the current FRM circumstances.

Storyline 3 also represents a scenario with a breach along the "Kildijk", but in this storyline measures in the first, second and third layer are implemented that reduce the impact of the inundation. This storyline was developed based on the strategies that followed from the first conclusions of the analysis of the first two storylines.

Furthermore, this strategy was also proposed in the project of MARE (Van Herk et al., 2011; RWS, in prep). Figure 21 shows a representation of this strategy.

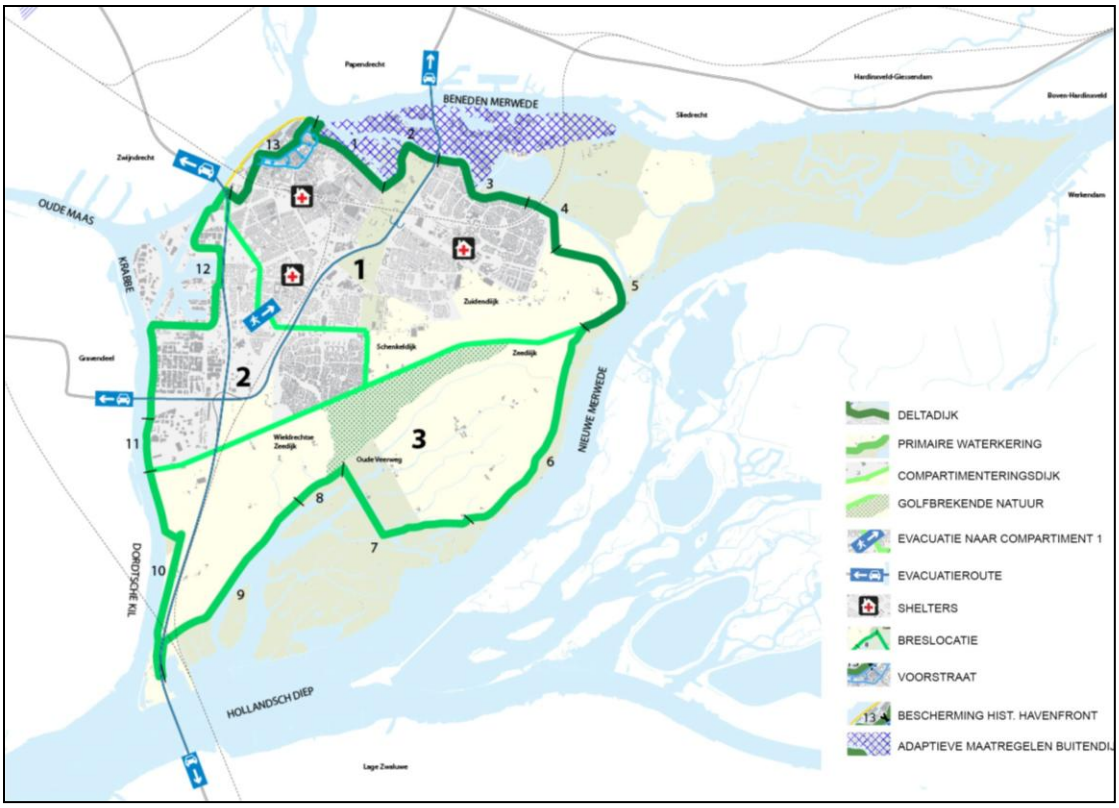


Figure 21: Figure showing multilayered layered strategy for the island of Dordrecht with different compartment from RWS (in prep).

4.2 Main elements for storylines

The storylines were described with 5 different actors that act in 3 different phases. The actors determine the incidents that happen during a flood. They are the basic elements that at least need to be included otherwise the storyline is assumed not to be realistic. The actors are determined from describing the island of Dordrecht and divided into two groups. The first group is based on physical processes and the second group is is based on human behavior. The actors are:

- Water (physical processes)
- Critical infrastructure (physical processes)
- Authorities (human behavior)
- Civilians living outside the dike ring (human behavior)
- Civilians living inside the dike ring (human behavior)

These actors all behave differently over time, but they do influence each other. For example, the civilians inside the dike ring react to the fact that water levels becoming very high and decide to flee from the water. Another example is that the civilians react based on the fact that the authorities give the advice to stay inside.

The authorities include the water board, the safety region and the municipality of Dordrecht. The national government and “Rijkswaterstaat” (RWS) are not included in the authorities’ line, because they do not directly influence in the sequence of events within the authorities line. They are seen as external factors that can give advice to the authorities. However, there is one important element that directly influences the choices and actions made in the authorities’ line. These are the warnings for extreme water levels from RWS which the authorities in the endangered areas use to take certain precaution measures.

The behavior of the civilians is split into two different groups, because the behavior of civilians living outside the dike ring is considered to be different from those who live inside the dike ring. The civilians that live in the low lying areas of “Dordste Biesbosch” are not taken under consideration, because those areas inundate with every tide and not many people live there. The civilians that live outside the dike ring are used to the fact that inundation occurs with water depths that occur with a chance of 1:10 years, while civilians inside the dike ring are not. Furthermore, the civilians outside the dike ring live in an area that is relatively high and thus inundations depths do not become large, while they may be up to meters in the areas inside the dike ring.

The storylines are divided into different 3 different phases. These phases mark different conditions in time where at the transition from one phase to another a major change in acting of one (or more) actor(s) takes place. The phases are:

- Build-up phase: The beginning of the build-up of the storm and high water levels and inundation of the areas outside the dike ring until the moment the embankment breaks.
- Inundation phase: The embankment breach and the inundation of area inside the dike ring until the breach is closed.
- Recovery phase: Drainage of the area and recovery of the area until the area is fully recovered.

It is clear that the exact behavior of the actors is not exactly known. This means that different types of behavior may be equally realistic. An example is the behavior of authorities when an embankment breaks. The authorities can advise to evacuate the civilians or advise them to stay inside their houses. Furthermore, the actions of one actor do influence other actors. This means that along with the fact that there are already different options of behavior for one actor more options for behavior of one actor are introduced. Therefore, even when arising from the same dike breach location, many different storylines can be considered realistic ‘realisations’ of the subsequent series of events. To structure and manage all these different options for storylines it is chosen to only describe the most extreme choices of behavior of the actors. In this way the most extreme range for the results is tested and results of all other options will fall within this range. Storyline 1 was described extensively. The other options for behavior were described in storyline 2 and 3 or the result is shortly discussed during the analysis of the storylines.

To easily describe the different storylines a code system was developed. The code consists of 4 numbers and letters. These describe the phase of the storyline (Roman number), the actor (capital letter), the option for the action of the actor (number) and the time at which the warnings from RWS for high water are given to the authorities (lower case letter). The actions of each actor determine also the actions for other actors if they are directly influenced by this choice. The interactions between actors are represented by the vertical dotted lines that result into the same change in code for another actor. The meaning of the letters and numbers is found in tables 4 and 5.

Table 4: Definitions of the codes for the different phases and actors:

Part of code	Definition
Phases:	
I	Phase 1
II	Phase 2
III	Phase 3
Actors:	
W	Water
A	Authorities
C	Critical infrastructure
Co	Civilians living outside dike ring
Ci	Civilians living inside dike ring

Table 5: Definitions of the codes for the behavior or event happening for each actor:

Part of code (options per actor)	Definition
Water (W):	
1	Breach 11
2	Breach 5
Authorities (A):	
3	Evacuate from island
4	Advise civilians to stay inside
5	Advise civilians to flee from water
6	Evacuation of non-self-reliant people to shelters and advise others to stay inside
Critical infrastructure (C):	
7	Critical infrastructure in flooded areas fails
8	Critical infrastructure on the whole island fails
All actors:	
0	No choices/splitting point in actions are made yet in the current phase
a	Time pre-warning from RWS
b	Time warning from RWS
c	Time alarm from RWS
d	Time breaking of embankment

4.3 Methods used to analyze the storylines

The storylines were analyzed to determine the results in:

- Fatalities in the flooded area
- Total damage in the flooded area
- Time available to flee from water → number of evacuees
- Details of flooding pattern → new set of measures that reduces flood risk

The storylines were analyzed with a flood inundation model, a damage assessment and procedures in excel and ArcGIS to determine the number of self-reliant people and evacuees.

4.3.1 SOBEK model for flooding the island of Dordrecht

The flooding of the island of Dordrecht is calculated with a SOBEK1D2D model that is developed for the studies of VNK and WV21 (Piek, 2007; Kok and Van der Doef, 2008). This model includes the whole river area in the Netherlands that is still under the influence of tide. The lower boundaries lie at the North Sea near the “Maasmond” and the “Haringvliet”. The upper boundaries lie along the three major rivers (Maas, Waal and Lek) near the towns of “Tiel”, “Hagenstein” and “Lith”. See also figure 21.

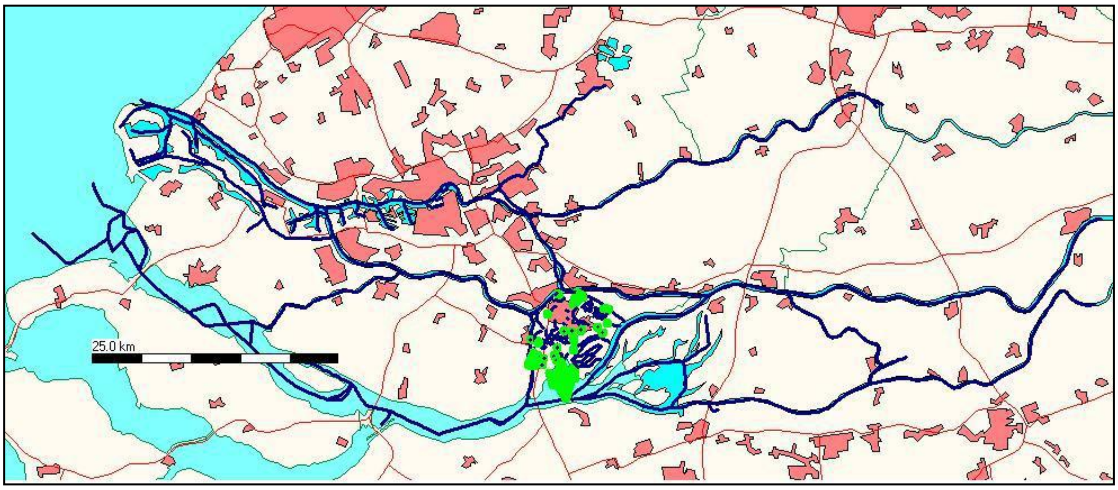


Figure 22: the representation of the network used in the SOBEK model (from Piek 2007).

The model consists of two parts: A part that calculates all variables in the rivers (1D) and a part that calculates the variables in the inundated areas within the embankments of the island (2D). The embankments of the island in the model break at the moment that the top water level occurs of an event that causes water levels that correspond with the protection standard of the dike ring as described in the Water Act (wetten.overheid.nl). This standard is 1/2000 years for the island of Dordrecht. This hydraulic load at a certain location is defined by the location of the dike ring segment, the river discharge, the water level at the North Sea, the wind speed and direction and the most likely mechanism of embankment failure at that location (Piek, 2007; Kok and Van der Doef, 2008). The boundary conditions that cause this 1:2000 years event are described in section 3.2.1.

The final flooding pattern within the dike ring does depend on many factors, such as:

- *Location of the breach* → from the VNK scenarios (figure 10)
- *Water level in the river near the breach* → depending on the scenario used for each breach (variable over time). The same scenarios as those of VNK are used (figure 11).
- *The duration of extreme water levels* → 35 hours of higher water levels.
- *Width of the breach* → depending on the velocity of water through the breach and strength of the embankment. The strength of the embankment depends here on the soil structure. An embankment of sand was modeled.
- *The moment of failure of an embankment* → is set at the top of the high water level
- *Embankments within the area of the dike ring* → these embankments can be set to withstand water permanently or temporarily. Here, the embankments are assumed to break when water levels reach the top of the embankment. Otherwise they do not fail.
- *Combination of multiple breaches* → for this thesis only one breach per storyline is assumed.
- *The digital elevation model within the dike ring* → represented on a grid of 100 x 100 meter.
- *Calculation time step* → 10 minutes

The model can calculate many variables. The ones used in this thesis are:

- Water depth (maximum and for each time step)
- Water velocity (maximum)
- River discharge and level near the breaches (for each time step)
- Time at which the cell first became wet
- Time at which the cell reached its maximum water depth
- The width and depth of the breach (for each time step)

4.3.2 Damage assessment with HIS- SSM (High water information system – damage and fatalities module)

HIS – SSM is a module that calculates the damage and fatalities due to a flood in a certain area. Damage is expressed as economic damage (in Euros) and consists of three categories:

- Direct damage: damage on objects, capital and real-estate goods due to direct contact with water.
- Direct damage due to business interuption: damage resulting from downtime of businesses.
- Indirect damage: damage due to cut-off of trading routes and damage on businesses outside the flooded area that depend on businesses inside the flooded areas.

The damage and fatalities are calculated with so-called damage functions. Damage is calculated with the maximum water depth, maximum velocity and the presence of waves. Fatalities also depend on the rising rate of the water level. The damage functions are different for each damage category. For example the damage function for a house is different from that of a highway or a factory. Furthermore, the population of an area determines the number of fatalities for that area. The exact functions for damage and fatalities are found in Kok et al. (2005).

The damage calculated as a result of the storylines is the maximum damage that contains all three categories. These results are compared to the results of the studies of VNK and WV21. The fatalities that are calculated as a result of the storylines depend on the number of people that is still in the area at the end of the storyline. This number is represented in HIS-SSM with an evacuation percentage (percentage of people that made it out of the inundated area).

4.3.3 Procedures in Excel and ArcGIS

In this thesis also some models were constructed in excel and ArcGIS to easily calculate the following:

- The time available to flee from the water per neighborhood
- The time needed to get the area water free again
- The number of people that need to be sheltered
- The number of people still residing the area after inundation of the areas reached it maximum. This is used as an input to calculate the number of fatalities with HIS-SSM.

The parameters used to calculate these numbers are the number of non-self-reliant people, evacuation speed, evacuation distance and pumping capacity.

Many of these parameters are very uncertain, because not much is known on these subjects. Assumptions for these parameters were made on the best source available or on common sense if no source was available. Sometimes more options were explored with different results for one storyline. The values used for these parameters are found in appendix 5.

5 Description and analysis of the storylines

This chapter describes the storylines in a narrative way. The descriptions are indicated with a code that is described in section 4.1 and tables 4 and 5. After description of the storylines the analysis and the results per storyline are shown. The assumptions for the actors used in these storylines are based on the information collected and described in Chapter 4. The assumptions used in the storylines are found in appendix 5.

5.1 Storyline 1: A breach along the "Kildijk"

This storyline is described most extensively. Appendix 6 shows the representation of this storyline (and the others) at A0 format with the choices made for the actions of each actor. This representation is designed by "De Urbanisten" following the sequence of storytelling in this research.

5.1.1 Phase I: Actor water

Figure 10 shows the position of the dike breach (location 11). The representation of the water levels during phase one over time for this storyline is found in figure 11. Figure 12 shows the inundation depth of the areas outside the dike ring.

IW1:

End of December 2011: Depressions with rain are transgressing over the catchment areas of the river Rhine and Meuse. Due to the heavy rainfall the first signs of high water in the Rhine become available from Germany. Models forecast high water levels forecast at the 1^{st} of January (-8 days on the timeline). The high water level forecast becomes more accurate with time.

Six to five days before the occurrence of extreme water levels: rainfall is still falling in the catchment of the Rhine and the weather forecast still indicates more rainfall in the next week. It becomes clear that the water levels in the Rhine can develop towards a high but not extreme flood wave. In the meantime a heavy storm is developing above the North Sea. However, it cannot yet be said if this storm is actually a threat to the Dutch coast.

Four to two days before the occurrence of extreme water levels: Water levels in the upstream area of the Rhine rise. RWS gives a high water level forecast with a precision of 25 centimeters for the island of Dordrecht. Two days before maximum water levels occur, it becomes clear at which part of the day the storm is the heaviest, but still the precise location of the area that will be most severely hit by the storm is not known.

One day before the occurrence of extreme water levels: It is known which area will be hit the most severely by the storm. From now on it is clear that water levels are rising to the extreme in the rivers around the island of Dordrecht, because the moment the storm hits the coast the heaviest will coincide with the passage of the river flood wave along the island of Dordrecht. The prediction of an average wind speed of 22 m/s (9 Beaufort) is also given.

IW1a:

Around 2 pm at January the 7^{th} (-31 hours on the timeline) the pre-warning for high water levels (above + 1.8 mNAP) from RWS is given with a lead time of 12 hours.

IW1b:

This warning is followed by an official warning for high water levels at 8 pm (-26 hours on the time line), 12 hours before the water level reaches a height of + 2.3 mNAP (at this moment it is also already know that levels will rise above +2.5 mNAP).

IW1c:

At midnight (-21 hours on the time line) the official alarm for extreme water levels is given at the moment the “Meastlantkering” and the “Hartelkering” are closed. Around 3.30 AM at January the 8th the water levels rise above the lowest quays of the island of Dordrecht. From now on the areas outside the dike ring start to inundate.

During January the 8th water levels rise to an extreme and in the evening of January the 8th the unfortunate happens. At 8.50 pm the embankment along the “Dordste Kil” breaks (figure 10, location 5).

5.1.2 Phase I: Critical infrastructure

IC0:

During the hours where the storm is becoming heavier and water levels rise, critical infrastructure (CI) on the island continues to function well. Critical infrastructure is protected against water in the areas outside the dike ring (as stated in Chapter 3.4) and thus does not fail during the inundation of these areas. The areas inside the dike ring are not inundated during this phase and thus CI does not fail. An exception is the fact that the roads in the areas outside the dike ring that are inundated with a water depth of more than a few centimeters are not safe to drive anymore. This is due to the fact that it cannot be seen where for example a road is ending into a harbor. At smaller scale critical infrastructure can be disrupted. Examples are the failure of small electricity masts or cables due to the heavy wind speed during the storm or the blockage of roads due to collapse of trees or flying roof tiles.

5.1.3 Phase I: Actor authorities

This section describes the sequence of actions that are performed by the authorities of the island of Dordrecht in narrative form. The main actions are described, but detailed tables of actions performed by the authorities are found in appendix 3.

IA0:

At the latest two days before extreme conditions can occur the authorities of Dordrecht are being informed by RWS about the fact that water levels are rising in the river Rhine in Germany and that furthermore a storm is developing above the North Sea which can cause extreme water levels. They get prepared for the fact that an alarm for extreme events can be given by RWS. It becomes clear that evacuation of people from the island is not realistic, because at the moment it becomes certain that extreme levels can occur, there is not enough time left for evacuation. Furthermore, the stormy conditions impede and endanger the evacuation.

IA0a:

At the 7th of January around 2 pm, fourteen hours before the occurrence of a water level of +1.8 mNAP the authorities receive a pre-warning for high water from RWS. Due to this pre-warning the water board starts to monitor the water levels itself and prepares itself for a potential up-scaling to another emergency state. The municipality of Dordrecht opens all bridges and takes preparations to close off roads in the area outside the dike ring and informs civilians to move their cars to safe parking areas. The authorities also provide sand bags to the civilians living there. Furthermore, the sewer system is closed off outside the embankments.

IA0b:

Around 8 pm the municipality of Dordrecht gets the official warning from RWS for the occurrence of high water levels. The authorities notify the civilians living outside the dike ring about the high water levels and the chance that the quays and other streets will get inundated. The roads in these areas are closed and sand bags are provided to the civilians to protect their houses from flooding. In the meantime a warning and action center is built up, so it could be immediately used if the conditions become more extreme. Furthermore, the embankments around the island are from now on monitored by employees of the water board. In the meantime the storm is becoming heavier which sets up water levels fast near the "Maasmond" and makes the conditions for the authorities to work outside the shelter of buildings difficult.

IA0c:

Around midnight of January the 7th to January the 8th RWS decides that the "Measlantkering" will be closed. With this closure the authorities of the island of Dordrecht receive an official alarm for extreme water levels. The water board immediately occupies the action center and sets up a system of extensive monitoring of the embankments and water levels at multiple locations along the island. Furthermore, all water defense systems are checked and all removable water defense systems are closed. An example is the wooden bars along the "Voorstraat" to heighten the primary defense level. All valves in pumping stations are closed as well as the weirs and the embankments of the secondary embankments.

IA4:

The flood threat for the people in the flood-prone areas is now clear. However, it is too late for safe evacuation. Wind is blowing with force and the surrounding areas are also threatened by flooding. All civilians of the island are recommended to stay inside their houses under these circumstances. This advice is given during the day of January the 8th (around – 10 hours on the time line).

5.1.4 Phase I: Actor civilians living outside dike ring

ICo0 :

The first warnings of extreme water levels that reach the civilians are from the daily weather forecast and news that reports about extreme rainfall in Germany and a storm entering from the Atlantic Ocean. On the 7th of January they see the water levels in the rivers rise. The people know the procedure for the inundation of the quays near their houses. They prepare themselves for an inundation by transporting most valuable items to safe places in their houses.

ICo0b:

At 10 pm of the 7th of January, two hours after the authorities received a warning for high water levels from RWS, all civilians living outside the dike ring are warned by the authorities. The civilians use sand bags to protect their houses from flooding and cars are moved from the quays to higher and safer places.

ICo4:

The civilians get the advice (from the authorities) to stay inside while the storm becomes heavier and the area gets inundated. All civilians follow this advice and stay inside. At January the 8th around 3.30 am, the first quays inundate and the majority of the inhabitants (approximately 4000) are safe inside their houses. A few cellars get inundated, but no severe damage occurs.

5.1.5 Phase I: Actor civilians living inside dike ring

ICi0:

The first sign of extreme circumstances that the civilians inside the dike ring get are the same as the ones outside the dike ring get. They are warned through daily weather forecast and news. With the storm building up, wind speeds becoming faster, rainfall becoming heavier and water levels rising in the rivers most people stay inside their houses. It becomes too dangerous and uncomfortable to go outside.

ICi4:

The authorities advise the civilians to stay inside their houses. Unfortunately some civilians get scared due to the fact that the embankments are monitored by the authorities and water levels become really high. Therefore 10% of the civilians (approximately 11500) decide to flee by car, despite the bad weather, to safe areas in other parts of the Netherlands. Then at January the 8th at 20.50 the embankment along the “Dordtse Kil“ breaks.

5.1.6 Phase II: Actor water

IIW1:

Areas outside dike ring: The embankment along the “Dordste Kil” breaks at the moment water levels in the rivers around the island are highest. The storm passes by and in the next hours the water levels in the rivers around the island drop fast. At 2 am at January the 9th (+ 5 hours on the time line) water levels in the rivers around the island already drop below the pre-warning level of +1.8 mNAP. From now on water levels at the “Oude Maas” slowly drop further until they reach normal levels after several days. The development of the water levels around the island is shown in figure 11. The water depths at the areas outside the dike ring are directly related to the water levels in the rivers around the island. As soon as water levels start to drop the water depths also drop. Around 2.20 am at January the 9th water levels fall below the height of the lowest quays and the areas outside the dike ring are no longer inundated anymore.

Areas inside the dike ring: As soon as the embankment along the “Dordste Kil” breaks water starts flowing through the breach. The breach grows under the hydraulic circumstances. Although water levels in the rivers start to drop water continues to flow through the breach, because the crest level of the breach at the end is lower than the water levels in the river. The figures in appendix 7 represent the inundation of the areas inside the dike ring. In the first hours after the breach occurred water flows into the neighborhood of “Dordste Kil III” (see 23) for the locations of the neighborhoods). The elevated areas around this industrial neighborhood prevent the water from directly flowing into other areas. Water depths in “Dordste Kil III” are increasing fast until they stagnate around 2.5 m. After two hours water levels reached the top of the elevated fundaments of the N3 (secondary road) and starts flowing into the neighborhoods of “Sterrenburg 3”and Crabbehof and the other industrial areas of “Dordtse Kil”. Water is spreading north and east wards and after 8 hours after the breach occurred, all above named neighborhoods all have been inundated with water levels from 0.05 to 2.8 meters. Water continues to flow into the area and water depths continue to raise and spread northwards. After 16 hours the neighborhoods of “Sterrenburg 3” and “Krispijn” are inundated with depths from 0.1 to 2.7 meters (see also figure 23 and 24 and appendix 7) and in many neighborhoods water depths have reached their maximum. From this time onwards water is still flowing into the area, but water levels are not rising very fast anymore and after 32 hours water is not inundating dry areas anymore. All maximum water levels have been reached after 36 hours. As long as the breach is not closed water continues to flow in and out the area directly behind the breach as water levels outside the dike ring rise and fall with tide.

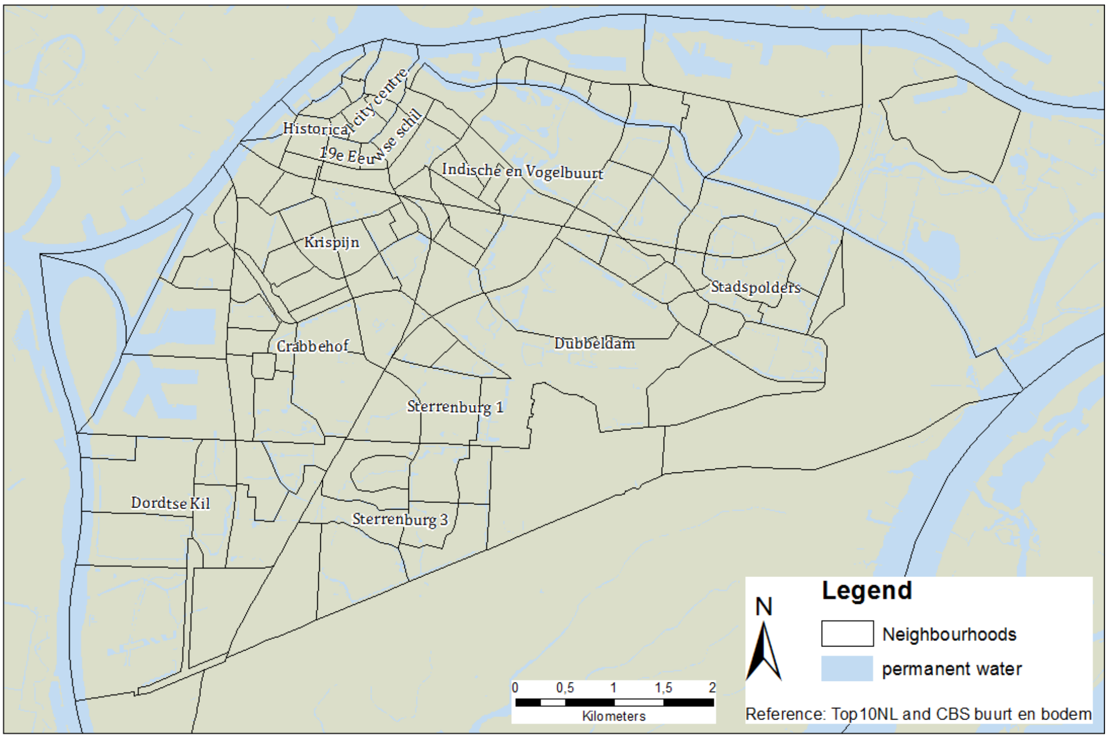


Figure 23: Names of neighborhoods within the city on the island of Dordrecht.

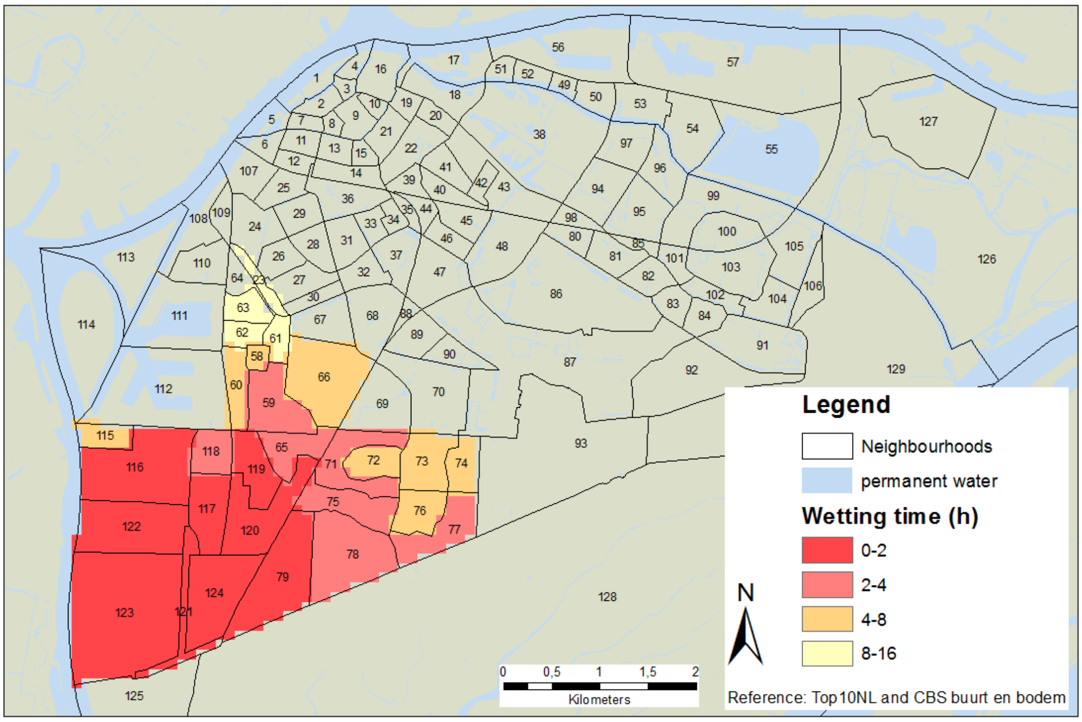


Figure 24: Time at which the first cell in the neighborhood is inundated in hours after the embankment break.

5.1.7 Phase II: Actor critical infrastructure

IIC0:

Areas outside the dike ring: The areas outside the dike ring are already inundated by the time the breach along the "Kildijk" occurs. The water levels and depths reached by this time are the highest that occur in these areas and critical infrastructure is not threatened by these water depths as most of them are adapted towards high water levels. Therefore, all critical functions will continue functioning in the areas outside the dike ring during the inundation. One exception is the critical function of roads. This is already explained in the section of *IC0*. Five hours after the breach occurs the area outside the dike ring is water free and reparations may start.

IIC7:

Areas inside the dike ring: As soon as water is flowing into the areas behind the dike ring electricity within the areas behind the dike ring is shut down by Stedin to avoid the electrocution of people. This is done in the neighborhoods that are directly threatened from the water. This means that the whole island is shut down. The will restart electricity in the neighborhoods that are not inundated by the time that it becomes clear that the maximum inundation depths are reached (after 36 hours). The communication network fails with the failure (closing off) of electricity. The network depends on electricity and do not have any back-up system. Drinking water distribution is not threatened. Its distribution center lies at height in the area outside the dike ring and is not flooded and the water pipes that lie within the area of the dike ring can withstand a pressure column of 20m. Gas does not fail directly, but will fail as soon is water depths in the area will become above 150 cm or if electricity fails (most boilers work on electricity). So as the inundation off the island continues the gas supply will fail in more and more neighborhoods. With the inundation of the island roads get flooded and traffic lights do not function anymore. Therefore this critical function is highly disrupted as soon as an area gets flooded. Furthermore, the first night after the breach occurs the stormy weather is still causing problems for traffic as well.

5.1.8 Phase II: Actor authorities

IIA4:

At the moment the embankment breaks, the person who is monitoring at that location will notify the action center. At that moment all emergency services are warned and in the next hours they try to help and safe anyone in direct danger of dying. The coordination of these rescue actions is from the action center. The location of the action center of the water board lies at the "Baanhoekseweg" in the area outside the dike ring in the north of the island. They use the results of the models for the inundation of the area inside the dike ring with a certain breach location to decide which actions are taken to avoid as many victims and damage as possible. Based on studying these models and receiving real-life information from the field the following main actions are taken during the first hours after the breach occurs:

- The advice for all civilians to stay inside and move to the first floor of their home if possible, still applies. This advice is communicated towards the civilians as soon as possible.
- They warn the civilians that live in the areas that according to the models get inundated over time.
- They are busy with creating plans to close the breach as soon as possible and multiple attempts are carried out, but are not successful immediately.

After the night and the storm have passed by, the authorities start to rescue all the people that were not in direct danger and did survive, but are trapped in their houses because of inundation of the area they live in (about 22600 people). In this storyline it is assumed that these people get rescued with boats and vehicles available from the army and other emergency services. However it is not know what the capacity of these rescue facilities is and how much time it will take to rescue these people. It is assumed that it will not take any longer than a few days. In the meantime the first plans are made to take further damage control and to recover the inundated area as fast as possible. The inundated area will be closed off and no-one is allowed to enter the area without permission of the authorities. Finally, one week after the breach occurred it is closed and recovery of inundated areas is started.

5.1.9 Phase II: Actor civilians living outside dike ring

IICo4:

At the moment the breach occurs the civilians outside the dike ring are safe in their homes and the area around their houses is still dry or water depths are not higher than 0.5 meter. The inhabitants see water levels dropping fast, while the storm passes by. At January the 9th around 2am the area outside the dike ring is dry again. The inhabitants start to inspect and clean up their houses in the daylight of the next morning. As the majority of the critical infrastructure in this area is still running, they can also start repairing the damage at their houses and clean up the streets as fast as possible. It is assumed that most of these repairs do not take more than a few days. Furthermore, they try to help others in the inundated areas inside the dike ring as much as possible. For example they offer their homes to family and friends that live in inundated areas.

5.1.10 Phase II: Actor civilians living inside dike ring

IICi4:

As soon as the embankment breaks and water is flowing fast through the breach there is total chaos. People that are still on the streets see water coming and they try to run or drive away from the water towards higher and safe areas and most of them succeed. The people that are inside their houses (approximately 24500) notice that something is wrong due to the fact electricity and other critical infrastructure fail. The people that live close to the breach area also see water flowing and rising fast in the streets. Most of them stay inside, because it is dangerous to go outside and leave the shelter of their own house. They move to the first or second floor of their house. However, 10% (approximately 2450) of the civilians still in their houses get scared and try to flee from the flood in their car. Traffic is chaos due to fact that some roads are blocked by fallen trees and tiles and traffic lights do not work. Still the majority of them finds a safe place and do not die. During the night most people that are in there homes and are in direct danger of dying try to rescue themselves by moving to the roof of their homes or flee by boat if they have one available. There they wait until they are rescued by the emergency services or die in the process. At January the 10^{th} people still residing in the inundated areas (approximately 22 500) will rescue themselves by boat or car, depending on the water depths in their residential area. Or they are rescued by the emergency services. The capacity of the rescues facilities (boats, army vehicles, helicopters) is not exactly known. It is however assumed that eventually two days after the embankment breach all civilians did leave the inundated areas. The majority is assumed to be sheltered by family or friend either in the functioning parts of the island or elsewhere in the Netherlands.

5.1.11 Phase III: Actor water

IIIW1:

Areas outside dike ring: Water levels in the rivers around the island of Dordrecht are rising and falling with tide and do not increase to extreme levels anymore. The high lying areas outside the dike ring are dry and are not inundated in the near future.

Areas inside the dike ring: The breach is closed by the authorities one week after the embankments broke. This means that from now on water is pumped away from the island. This is done with the pumps from the drainage network that already exists on the island and some emergency pumps from the water boards and RWS. The calculations with the capacity of these pumps show that if all pumps work the total inundation volume of 9.9 million m^3 can be pumped out in approximately 5 days. However the majority of the capacity of these pumps is from the emergency pump of RWS. If these are not available it will take approximately 25 days to pump out this water volume. The exact calculations are found in appendix 8. After all water is pumped from the island and cleaning of sediment and mud can start. Hereafter, an inventory is made of what the damage is on the houses, roads etc. and how this can be repaired. This process can be taken up to months or even years.

5.1.12 Phase III: Actor critical infrastructure

IIIC0:

In the beginning of the third phase, critical infrastructure in the areas outside the dike ring and inside the dike ring that are not inundated does fully function.

IIIC7:

Critical infrastructure in the areas inside the dike ring that are inundated is fully disrupted and severely damaged, because the elements of the electricity and communication network are highly sensitive for contact with water. The gas and road network is less damaged, because these elements are less sensitive for water, but still need to be repaired. An exception is the drinking water network that still fully functions, because the pipes are not vulnerable for water pressure and the distribution center lies in a dry area outside the dike ring. As soon as water is pumped out of the area after the breach is closed, restoration of critical infrastructure starts. At first, emergency repairs are made to get the functions back as soon as possible. Then, all damaged cabinets, cables, pipes etc. are replaced with new ones. In the end it takes multiple months to a year before all critical infrastructures are fully recovered.

5.1.13 Phase III: Actor authorities

IIIA0:

A week after the embankment breach did occur; the authorities were able to close it. This means that from now on the area is pumped dry. In the meantime the authorities make an inventory of what need to be repaired and restored. They order contractors to execute the first repairs in order to return to daily life on the island as soon as possible. Firstly emergency repairs are done, while hereafter more sustainable solutions are introduced. The authorities will continue to do this work until the whole area is recovered and civilians can return to their houses and work. It is not exactly known how much time this whole process will take. It is assumed that is will take months to years.

5.1.14 Phase III: Actor civilians living outside dike ring

IIICoO:

The civilians that live in the area outside the dike ring already started with cleaning their houses and street as soon as water was gone. This process is fast and within a few weeks, because damage due to the flood is not high. After cleaning and repairing their houses they go back to their normal life as soon as possible. However some of these civilians suffer the consequences of the flooding of the area inside the dike ring. They cannot go back to normal life easily if grocery stores, office buildings and schools are closed due to the flooding. People that suffer these consequences are looking of jobs and schools either on the not inundated areas of the island or elsewhere.

5.1.15 Phase III: Actor civilians living inside dike ring

IIICi0:

The houses and personal belongings of the civilians that live in the inundated areas are severely damaged. Furthermore, most critical functions have failed. Inhabitants cannot live in these conditions and can only return to their houses if these buildings and critical functions are repaired. The exact duration of this process is not known, but it is assumed taking a couple of months to years. In the meantime these civilians have to live and find jobs elsewhere to. Some of these civilians do not return to the island, because they build a new life elsewhere.

5.2 Storyline 2: A breach near the “Kop van ‘t land”

The event and actions of actors for this storyline that are different from storyline 1 are described while the actions and event that are the same are referred to. For this storyline the first division is made based on the actors and the second division is made base on the phases. This storylines shows the events happening for an event that with a breach near the “Kop van ‘t land” (figure 10, location 5) and shows a worst case scenario under the current FRM. Appendix 6 shows the representation of this storyline at A0 format.

5.2.1 Actor water

IW2:

End of December 2011: Depressions with rain are transgressing over the catchment areas of the river Rhine and Meuse. Due to the heavy rainfall the first signs of extreme high waters in the Rhine become available through the models of the high water forecast at the 1st of January. The high water forecast becomes more accurate with time before the actual high water.

Six to five days before the occurrence of extreme water levels: heavy rainfall is causing trouble in the catchment of the Rhine and the weather forecast still indicates more rainfall in the next week. It becomes clear that the water levels in the Rhine can develop towards extreme high waters.

Four to two days before the occurrence of extreme water levels: Water levels in the upstream area of the Rhine rise and cause flooding in Germany. RWS gives a high water level forecast with a precision of 25 centimeters and a warning for an extreme high flood wave is given to all water boards and safety regions that lay along the upstream Rhine branches. The water boards, there, fight to maintain the embankments and they succeed.

January the 8th (day of extreme high water levels): Weather in the Netherlands is not sunny but not stormy either. However, due to the flood wave traveling along the Rhine, water levels in the rivers around the island of Dordrecht start to rise to extreme heights. The areas outside the dike ring slowly get inundated. Around 10 am in the morning the water levels near the “Kop van het land” reach the levels that correspond to water levels of the standard for the island of Dordrecht in the water act. And then the unfortunately happens. The embankment near the “Kop van het land” breaks.

IIW2:

During the next days the flood wave passes by and the water levels outside the dike ring drop. However, water is entering the island of Dordrecht through the breach. The crest level of the breach has dropped to -0.51 mNAP and water can enter this breach also when water levels are back to normal after a couple of days. The figures in appendix 9 show the inundation of the island of Dordrecht through the breach near the “Kop van ‘t land”. First the area in between the higher lying “Zeedijk” and the “Zuidendijk”starts to inundate (figure 10 and appendix 9). After 11 hours the water finds its way over the “Zuidendijk” and the residential areas of “Stadspolders”, “Sterrenburg”and “Dubbeldam” (see figure 23 for names of the residential areas) start to inundate. Water is spreading westward and 18 hours after the breach occurred the N3 is passed. The residential areas of the “Crabbehof” and “Indische en Vogelbuurt” get inundated. Water is spreading northwestward to the other parts of the old city centre. In the south the N3 and the “Zuidendijk en Copernicusweg” prevent water from flowing into the areas of “Sterrenburg 3” and “Wielwijk”. However after 36 hours also these areas start to inundate as well. Water is flowing westwards until the water body stagnates behind the A16. Unfortunately, in the end the height of this highway cannot prevent the western industrial areas (Dordste Kil) from inundating. This inundation starts around 54 hours after the breach occurred. By the time these areas get inundated the other areas have long reached their maximum water depths. These water depths lay in between 2.3 and 3.3 meters. After 80 hours water depths in all areas do not change anymore.

IIIW2:

The sequence of events happing in this phase is the same as that of storyline 1. After one week the authorities are able to close the breach near the "Kop van het land". From now on the total volume of 60 million m^3 is pumped out from the island. After approximately one month the island could be pumped dry if the emergency pumps of RWS are available. If these are not available the island is pumped dry after approximately 3 months (see appendix 8 for the calculations).

5.2.2 Actor critical infrastructure

The sequence of events for critical infrastructure is the same as in storyline 1. However the damage on critical infrastructure is much higher, because the inundated area is much larger and thus more critical infrastructure is damaged. Therefore, the time needed to repair critical infrastructure in the third phase is also much larger. The majority of the critical infrastructure in the areas outside the dike ring is still working because here most elements are protected against water and the main delivering stations of gas and electricity are lying at the dry parts of the areas outside the dike ring and are thus not disrupted.

5.2.3 Actor authorities

5.2.4 IA0:

The authorities get their information on high water levels through the same media as in storyline 1.

IA3:

Three days before the flood waves enters the river areas under the influence of tide, the authorities are notified about the fact that the threat of a flood wave that can break any embankment is high. They decide to start the procedure of evacuating the civilians from all areas along the Rhine and Meuse branches. A couple of million civilians get advised to evacuate. All army, police and firemen and other emergency services are deployed to structure this evacuation at large scale. However Dordrecht's evacuation does not start before the upstream areas are empty. So there is at most 2 days available to evacuate these people. Furthermore, because all people of the emergency services were already staged elsewhere in the upstream river area and the population density in the areas around the island of Dordrecht is high, the evacuation process is chaotic. Everyone on the island of Dordrecht is advised by the authorities to go.

IA3abc:

The three stages of warning for extreme high water levels are entered at once on January the 7th (- 1,5 days on time line). The measures taken during these stages are the same as described in section IA0abc of storyline 1.

IIA3:

The actions of the authorities in this phase are partly the same as in phase 2 of storyline 1. They try to rescue as many people as possible in the already inundated areas and get them to safe areas outside or on the island. As also said in the first storyline the precise capacity of emergency vehicles and facilities (such as helicopters) is not known. In the evacuation of the island is still going at the moment the breach occurred. Models of the inundation of the island of Dordrecht show that all residential areas will get inundated in time. Therefore, the authorities decide continue the evacuation of people from the island to get as many persons out as possible. Although this evacuation process becomes more chaotically due to the fact that in this phase electricity on the island fails and does traffic lights etc. do not work anymore.

IIIA0:

The actions of the authorities are the same in this phase as they are in the section of IIIA0 of storyline 1.

5.2.5 Actor civilians outside dike ring

The civilians that live outside the dike ring are acting the same way as they do in storyline 1. It is assumed that these people are part of the 20% that decide to stay in their homes when everyone is advised to evacuate, because they know that their cellars can get inundated, but they can survive extreme water levels.

5.2.6 Actor civilians inside dike ring

ICi0 and ICi3:

The civilians in the first phase first act the same as they do in storyline 1. After the civilians are notified by the authorities to evacuate, 80% of the people pack their bags and get into their cars and try to drive from the island, the others (approximately 23700) stay behind. The evacuation process goes slowly, because of the many cars that are travelling at the same time. Traffic jams result into the fact that evacuation speed (on the high ways) only has an average of 20 km/h. In the residential areas itself it is even lower due to the small streets and few main roads to the high way.

IICi3:
At the time the embankment breaks most people are on the road in their cars. The majority will continue the evacuation process, because they are not yet notified about the fact that the embankments broke. Other people decide that trying to get away from the water is not possible anymore and decide flee to their house or nearby houses and evacuate vertically to the second floor. This process is chaotic, because now cars are trying to turn or people leave their cars and walk back towards home. As water continues to flow onto the island of Dordrecht, some of the people that are still in the streets or in their house and in direct danger are rescued by the emergency services (same assumptions for vehicle capacity etc. as in storyline 1). These processes continue until all residential areas are inundated after approximately 2 days. However as time progresses less and less people are still in the area and streets are emptier. So after one day it is easier to drive away from the water than it was the day before. More and more people get out of the area now they still can, since all facilities and critical infrastructure in the area will become severely damaged and thus you cannot live there after the inundation. In the end it is assumed that 59% (approximately 70 000) of the people did get from the island (based on the evacuation models in Hoss et al., 2011). The other 41% of the people (approximately 48000) are trapped in their houses and thus need to be

rescued by the authorities (same assumptions on the capacity as for storyline 1). It is assumed that at the moment the breach is closed after a week all civilians were rescued and not in the area anymore.

IIICi0:

The civilians act the same in the third phase as they do in storyline 1.

5.3 Analysis of storylines 1 and 2

For each storyline damage and number of fatalities is given. Furthermore, the most important elements of the (flooding) pattern that determine the results of the storyline are discussed. Hereafter, the results of the different storylines were compared to each other. Finally, the patterns of each storyline were used to give recommendations on measures that change the storylines the sequence of events in such a way that the results improve (less people die or damage is reduced).

5.3.1 Analysis of storyline 1

Damage, fatalities and affected people

Table 6, figure 25 and 26 show the damage and fatalities corresponding with storyline 1. The total amount of damage is almost 742 million euro whereof the direct damage is an amount of about 707 million euro. Figure 25 shows in which areas on the island damage is highest.

Table 6: HIS-SSM results for storyline 1:

Number of fatalities	**Number of victims**	**Total damage (millions of €)**	**Direct damage (millions of €)**
67	20415	742	707

To calculate these numbers the most important regional waterways are included as are the main secondary embankments that are assumed not to break. Furthermore, the evacuation fraction is assumed to be 0% and high flats are safe. The price level for the damage represents the year 2000. The complete report of HIS-SSM can be found in appendix 10.

The results of HIS-SSM show the number of fatalities that result from this flooding under the condition that every citizen was in the area at the time of flooding and persons living in buildings higher than the second floor are safe. Under these conditions the number of fatalities is 67. These people do not die from causes as high water raising rates (> 0.5 m/h) or fast flowing velocities (near the breach) (> 2 m/s) but from other causes as for example drowning or under cooling.

However, during storyline 1 people reacted to the raising water and on the advice of the authorities. Therefore, not all inhabitants were in the area at the time of flooding. Table 7 shows the percentages and number of people who fled the area and the number of persons left behind. The values of the parameters behind these calculations are found in appendix 5.

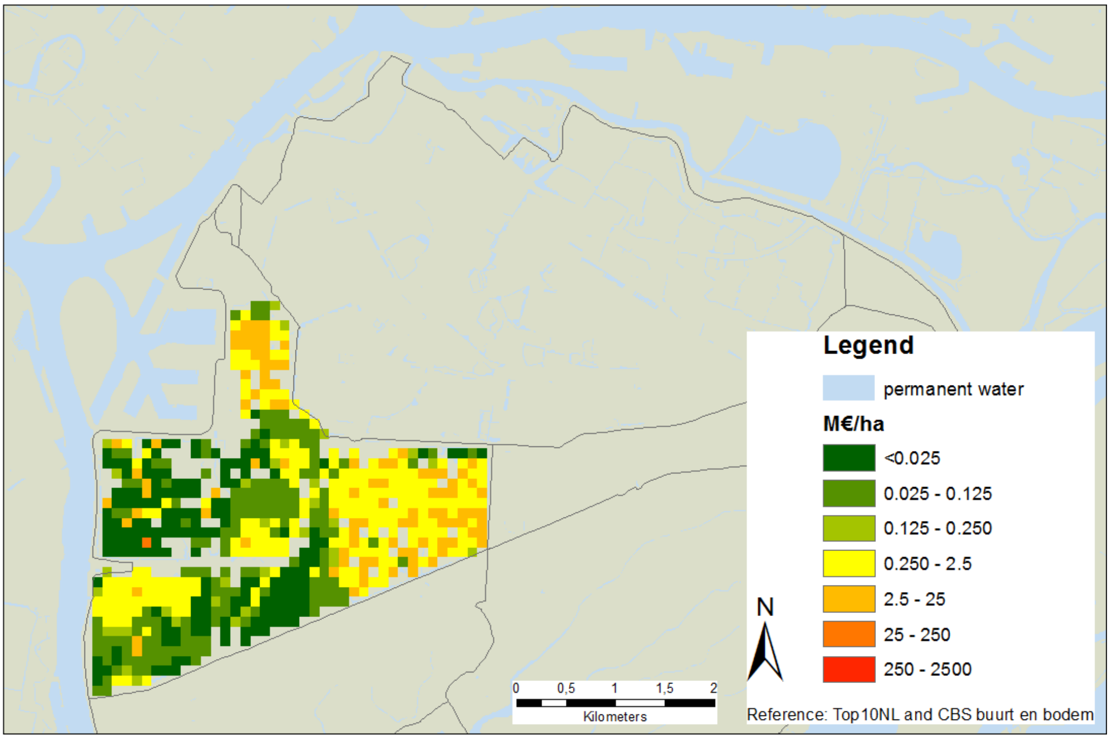


Figure 25: the total damage in M€/ha for storyline 1.

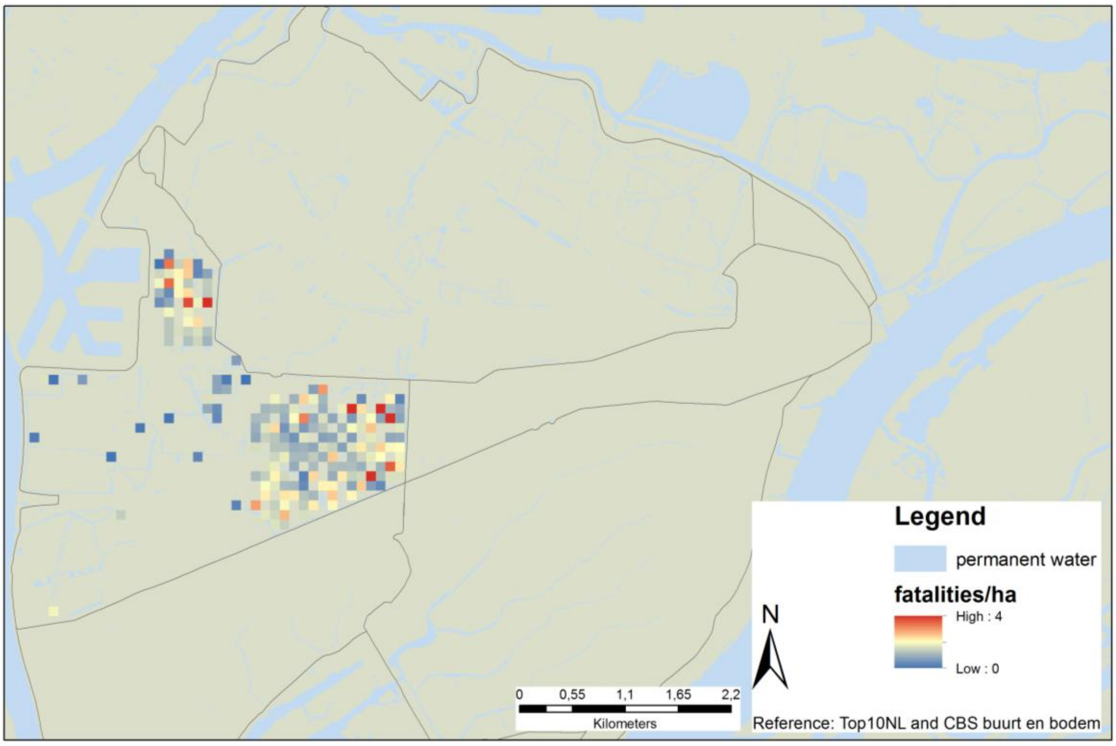


Figure 26: Fatalities per ha for storyline 1 without preventive evacuation.

Table 7: The numbers refugees, the ones left behind and fatalities for storyline 1:

	% of civilians that fled and where safe in time	Number of refugees (that were safe in time)	Number of fatalities	Number of people left in the area (which will be rescued)
Phase I				
whole dike ring	10	11430	0	0
inundated area	10	2786	0	0
Phase II				
Inundated area	10	2470	54	22546

The number of fatalities was calculated with the percentage of people that were left in the area at the end of the storyline. This number was calculated by taking the time available to flee from the water (see figure 24) per neighborhood and the time needed to get to safe areas on the island itself. The assumptions for these calculations are found in appendix 5. The calculations on this percentage show that only the people that live in the areas near the breach in the neighborhoods of “Tweede Tol, Dordtse Kil III and Oostkil” (see figure 23 and 24) did not have enough time to flee during the second phase. However, the number of inhabitants of these three neighborhoods (in total 420) is low and of these inhabitants only 37 (10 % of the people that were in these neighborhoods at the beginning of phase 2) persons tried to flee (and failed). These 37 people are assumed to still be in the area at the end of phase 2 and thus either die or are safe and need to be rescued.

Analysis of (flooding) patterns that determine the results of the storyline

The most characteristic pattern in the first phase that determines the end result of the storyline is the number of people that are left behind in the area of inundation. This number determines the number of fatalities. The number of people left behind directly results from the fact that no pre evacuation is executed. There is simply not enough time and the stormy conditions under which this evacuation needs to take are not favorable.

In the second phase the most notable pattern that determines the end results is the inundation pattern of the areas inside the dike ring. The flooding pattern determines the results in two ways; first, it determines the time before certain areas get inundated and secondly it determines which areas are inundated or not. The time available before an area is inundated directly determines if the people that try to flee within this storyline have enough time to get to safe grounds, while the area that gets inundated directly determines the total number of fatalities, damage and affected people. This is explained in the following examples.

The flooding pattern shows that water first enters the industrial areas of the “Dordtse Kil” (see figure 23) which have low population density. In this area water is rising relatively fast as the water body stagnates behind the main roads N3 and A16 and the “Wieldrechtse Zeedijk” (see figure 10). It takes a couple of hours before the residential areas directly behind these roads and old embankments are flooded. This means there is time for most people that decided to flee to get off the area. It shows that this gives the opportunity for the authorities to properly warn the civilians within the areas that will get flooded and they can prepare themselves for this flood. The flooding pattern also shows that especially the residential area “Wielwijk” is not flooded until 10 hours after the breach occurred. This means that there could be opportunity to get the inhabitants out of these areas before they become inundated. Especially, since the storm has passed by the time these areas get inundated and it thus is easier to travel.

Secondly the flooding pattern shows the importance of the accuracy of the model on the strength of the secondary embankments and higher elevated areas. If the assumptions for the strength of these elements are wrong, a totally different flooding pattern and thus actions from authorities and civilians would arise. For example if these secondary embankments break (they are now assumed not to until water levels reach the crest of the embankments) water will flow into certain areas much faster and thus less time is available to flee. The breaking of the secondary embankments can also influence the flooding pattern in such a way that water flows into areas that were not inundated in this storyline, which results in different water depths, fatalities and damage.

Another notable pattern in the second phase that determines the results of the storyline is the assumption that almost all critical functions in the inundated areas fail. This results in the need of everyone in the inundated areas to be brought elsewhere within a couple of days, since they cannot survive without these functions and these functions will not function anytime soon. This directly influences the behavior of the civilians and authorities.

Finally, also the behavior of the civilians within the dike ring determines the outcome of the number of fatalities. The assumed small number of people that decided to flee the area and did this successfully is herein the most important factor, since it directly determines how many civilians were in the area at the time of the flooding. Furthermore, the capacity of the authorities on vehicles and other transportation modes to rescue the civilians in their houses is important to determine the time that civilians at least have to survive in their homes. It thus determines whether distribution of additional survival packages is needed or that they can be rescued before they have to depend on these packages.

The most important factor in the third phase that determines the result of the storyline is the time needed to get the area water free. Emergency reparations cannot start when water is still in the area. The assumptions for the pumping capacity and closing of the breach are thus very important. Furthermore, the time needed to get all the failed functions back is important. This determines the indirect impact of the flood on the economy of the area and areas or companies that depend on functions within the inundated area. Unfortunately not much is known yet about the time needed to restore these functions. The indications for critical infrastructure lies within a few months to over a year, depending on the total water depths and the flood extent.

5.3.2 Analysis of storyline 2

Damage, fatalities and affected people

Table 8 shows results of storyline 2. These results are from WV21 (Nelen en Schuurmans, 2010) and are based on the same scenarios developed for VNK-II (Piek, 2007) with year 2000 for the price level. They show that with this flooding pattern the total damage is 4781 million euro whereof 4684 euro is direct damage. In total 566 people die. Within this number it is assumed that 15% of the people evacuated before the breach occurred. Most of them (~ 85%) die due to other causes than water velocity near the breach or water level rising rates in the transition zone. The others die in the transition zone. Figures 27 and 28 show the total damage and fatalities for storyline 2. This is thus a catastrophic event, both in terms of fatalities and damage.

Table 8: The HIS-SSM results for storyline 2 after Nelen en Schuurmans (2010):

Number of fatalities	Number of victims	Total damage (millions of €)	Direct damage (millions of €)
566	95167	4781	4684

To calculate these numbers the most important regional waterways are included as are the main secondary embankments that are assumed to not break. Furthermore, the evacuation fraction is assumed to be 15% and high flats are safe. The price level for the damage represents the year 2000. The complete report of HIS-SSM can be found in appendix 11.

However within this storyline other percentages are used for the evacuation of the inhabitants than the 15% that is showed in table 8. These percentages result into another number of fatalities and affected people. Table 9 shows these percentages and numbers.

Table 9: The numbers evacuees, the ones left behind and fatalities for storyline 2:

	% of civilians that tried to evacuate	Number of evacuees (that were safe in time)	Number of fatalities	Number of affected people that need to be rescued
Phase I + II				
whole dike ring	80	69903 (59%)		
inundated area	80		273	48304

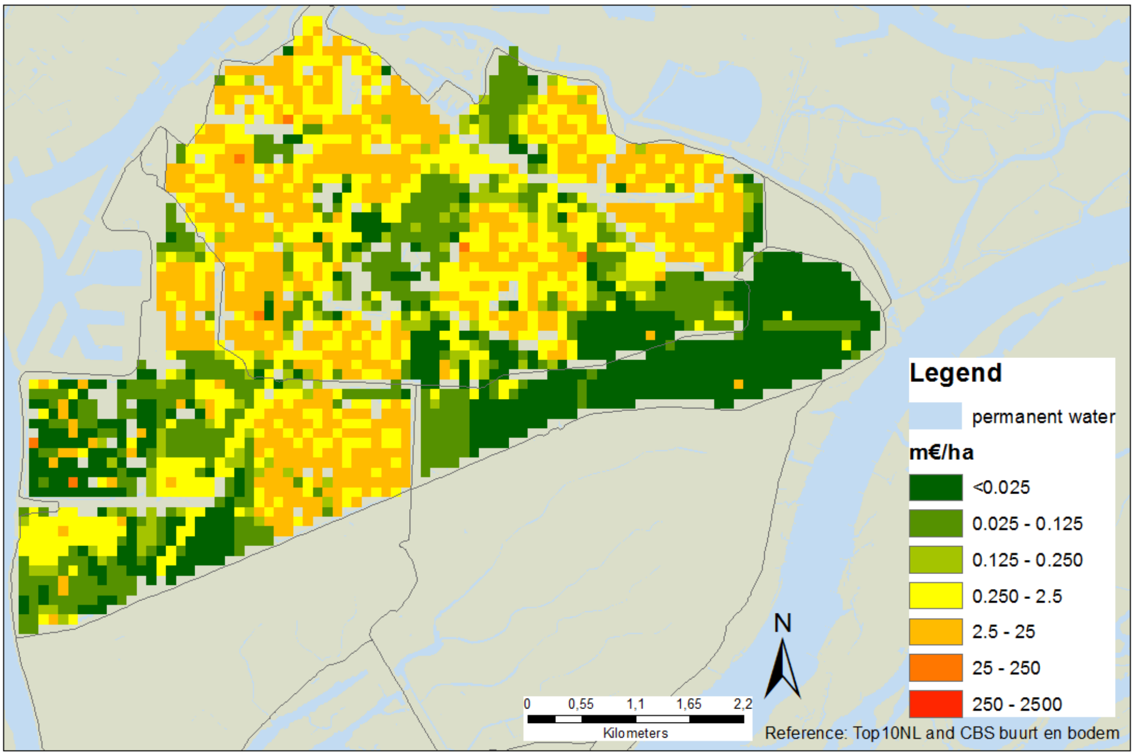


Figure 27: Total damage storyline 2.

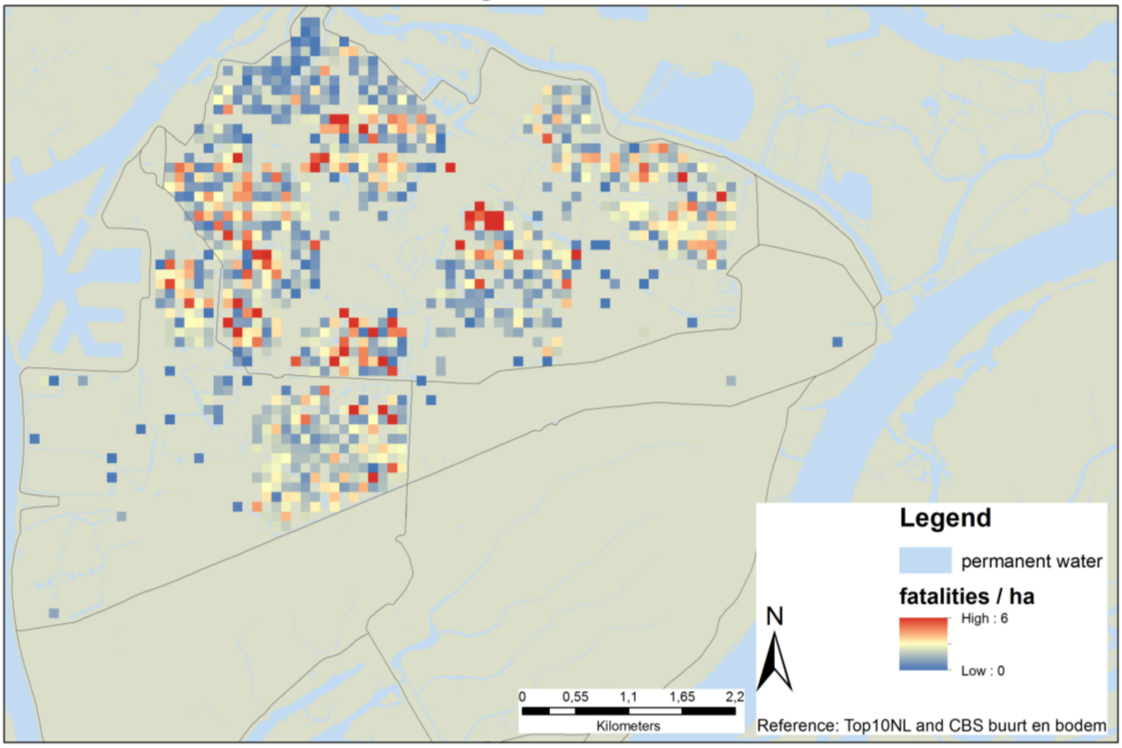


Figure 28: Fatalities per ha for storyline 2 without evacuation.

Analysis of (flooding) patterns that determine the results of the storyline

Also in this storyline the number of people that are still in the area when it becomes inundated determines the number of fatalities. The number of people still residing in the area is mostly depending on the assumptions made for the percentage of people that could evacuate in time, which depends on the time available between the moment the authorities decide to evacuate the island and the first residential areas get inundated. Furthermore, the percentage depends on the capacity of roads and vehicles available for this evacuation.

Another important factor that determines the results is the flooding pattern. In this storyline the flooding pattern results into major damage and many fatalities. However if for example the assumption for the "Wieldrechtse Zeedijk" (see figure 10) not to break does not hold true, water flows towards the southern part of the island and the damage and fatalities patterns would be totally different. This again notes the importance of a correct representation of the strength of the secondary embankments and heights in the model and the assumptions on the evacuation processes.

Finally this storylines shows that in time all critical infrastructures become disrupted (except for drinking water). Furthermore, the economical and social heart of the island is inundated with water significant water depth (< 2m) and it will take months to get the water out of the area and repair all damage. This means that is not possible to normally live on the island for at least a couple of months. This shows that the recovery phase is very important for the end result of the storyline in the meaning of going back to the situation before the extreme event occurred.

5.3.3 Comparison of storylines 1 and 2

The storylines for the two different breaches show major differences in total damage and total fatalities. These differences depend on the total flooded area, the water depth and rising rate and the land use of the flooded area. Furthermore, the flooding depth and area depend on the hydraulic conditions at the moment of breaking of the embankment and the assumptions for the strength of the secondary embankments and heights within the dike ring. These differences and causes were already known from the VNK-II and WV21 studies and described in Chapter 4.

Besides these differences storyline 1 and 2 show similarities in the fact that the total number of fatalities depends mostly on the flooding pattern. As said this pattern determines the final flooded area and depths but also the time available to flee or evacuate from the water after the breach occurred. This time represents the possibilities of the people to flee or evacuate from the water. Calculations for storyline 1 show that with an average evacuation speed of 5 km/h and 1 hour response time after the breach occurs 98.5 % of the inhabitants that wants to flee from the final inundated area has enough time to get to safe areas on the island itself. For storyline 2 is argued that 59% of all people are able to evacuate from the island before the major residential areas are inundated.

In conclusion the flooding pattern is very important for the storylines. The pattern determines:

- The (total) flooded area which determines total damage
- The (total) depth which determines total damage and fatalities
- The time available to flee from water which determines fatalities
- Rising rate and speed of water which determines fatalities
- The time needed to get the area dry which is important for the recovery phase

5.3.4 Useful insights for developing a set of measures at different layers of MLS in Dordrecht

The main conclusions drawn from the comparison of the different storylines are used to give advice on measures that can be taken at all layers of multilayered safety. For the island of Dordrecht the following 4 types of measures and strategies are proposed at the second (spatial planning) and third (crisis management) layers. These strategies are not tested on feasibility in terms of cost benefit analysis (implementation costs versus risk reduction).

Strengthen secondary higher elevated elements

The first measure proposed is to maintain or improve the strength of the higher elevated elements within the dike ring, such as the A16 the N3 and the “Wieldrechtse Zeedijk”. All three storylines showed that these embankments delayed the water from flowing into major residential areas. The figures (see figure 27 and 29) that show the fatalities for each storyline show that almost all fatalities occur within these residential areas (see figure 8), while the number of fatalities in the rural and industrial areas is low. Furthermore, the damage in these rural areas is also low compared to the residential areas. So theoretically it would be preferred to only have these areas inundated after a breach occurred along one of the embankments that are next to industrial or rural areas (as the breaches in storyline 1 and 2 do).

By strengthening or heightening the higher elevated elements and they, therefore, do not break it can prevented that water flows into the residential areas. This would reduce the amount of damage and number of fatalities. It also means that most critical infrastructure does not fail. Furthermore, it will reduce the time needed in the third phase to restore the damage on the island as less damage did occur and more people can continue living in their own homes. Implementing these measures would reduce risk by spatial planning.

To see whether the implementation of these measures is feasible, the following should be studied:

- The strength of these elements in present-day situation.
- The possibilities of strengthening or heightening (without adding major additional costs).
- How to set a standard that weights the reduction in flood risk caused by implementing these measures.
- A cost benefit analysis between the extra reduce in flood risk and the costs to strengthen these elements.
- To check if these measures would not affect the flooding pattern from other breaches than tested in this case study in such a way that the results are more devastating than the result from the current models.

Evacuate people from potentially inundated areas
The second proposal of measures is to delay water from flowing into the major residential areas as much as possible and in the meantime evacuate the people out of these areas. Storyline 1 and 2 showed that there time available before water is flowing into the major residential areas. If it is possible to delay this process with a couple of hours there might be time to evacuate the people from the areas that potentially become inundated. It is already showed that in both storyline 1 and 2 the This measure is different from the first one proposed, because in the first proposal water is prevented from flowing into major residential areas by measures taken before the actual extreme event occurs. In this proposal water is delayed by measures taken during the extreme events.

To implement this idea, measures should be taken at the first layer, second and third layer of the MLS system. Temporary measures should be taken to prevent water from flowing into the residential areas. This can be done by simple measures as temporarily strengthen the embankments with sand bags. The second measure that should be taken, is at the third layer. The crisis management teams must be prepared for the evacuation of people in a short amount of time and thus an evacuation plan is needed. To prepare these teams and to see whether this strategy is feasible the following questions should be (further) studied:

- Who is coordinating which process (i.e. who is responsible for the evacuation of which residential areas, for adding the sand bags on the high elevated elements)?
- Whereto should the evacuees be brought?
- What is the easiest way to evacuate all these people (i.e. which residential area goes first, people need to drive or walk)? Creation of an evacuation plan.
- What are the actual evacuation speeds?
- Is evacuation possible under bad weather conditions?
- How do the evacuees get from the island to long term shelter after they were sheltered for a couple of days?
- Is it certain that breaking water can delayed long enough by temporarily strengthen primary and secondary embankments with sand bags?

For the question to which location on the island these people need to be brought, the possibilities of shelters as mentioned in one of the strategies of the project of MARE (Blom et al., 2012) can be studied.

Finally, it is important to study whether it is possible to evacuate the people under the conditions of storyline 1, where a storm is chasing the island. A consideration should be made between the possibilities of getting the people out of their houses before water enters the area or the advances of having people safe in their homes and thus cannot be harmed due to the stormy conditions. However, the conditions during this storm are of an average of 22m/s second (9 Beaufort), which are conditions that occur every year along the coast of the Netherlands, which normally does not cause major disruptive problems and people are still able to drive and walk under these conditions.

Breaking the "Wieldrechtse Zeedijk"

The third proposal for a FRM strategy is to study the possibilities on breaking the "Wieldrechtse Zeedijk" (figure 10) in case of a breach near the "Kop van het Land". If it is possible to break this secondary embankment before the "Zuidendijk" breaks, water will flow into the rural area of the island and this will lower the hydraulic pressure on the secondary embankments that prevent water from flowing directly into the residential areas of the island.

Ultimate multilayered safety strategy

Finally, it is argued that above proposed strategies can be combined in the means of proposing a strategy where a breach along the "Kop van 't land" is not allowed to break (too many damage, fatalities and recovery time, as seen in storyline 2), but a breaking of the "Kildijk" can occur and measures in the 2nd and 3rd layer (strengthening of the secondary embankments and evacuation of residents) are taken to reduce the damage and fatalities in the area that inundates through this breach. This is also a strategy that was already proposed and calculated to be cost beneficial within the project of MARE (Van Herk et al, 2011; RWS, in prep). To show the differences between storylines under the current situation and a storyline where measures are implemented a third storylines is created based on the above described strategy and is briefly described and analyzed in the next section.

5.4 Storyline 3: Multilayered Safety strategy with breach along the "Kildijk"

This storyline is based on storyline 1. However, in this storyline it is assumed that the island of Dordrecht is self-reliant. This is realized by taking measures on all three layers of MLS. This means that a breach near the "Kop van het land" is less likely occur, because of strengthening of the embankments at this point into a so-called delta dike. The weakest point of the island is then the "Kildijk" (figure 10). A breach of this embankment does not result into the inundation of the whole island, because it is also assured that the secondary embankments are strong enough to resist the hydraulic pressure of the water levels in the inundated area. The civilians that live in the area that can get inundated have to evacuate to the safe compartments on the island. The non-self-reliant are brought towards shelters. These shelters can shelter non-self-reliant persons for a week or two before they are transferred to other facilities. Furthermore, these shelters can provide first aid support to possible other victims. Finally, all civilians are well informed beforehand about the fact that the island is self-reliant under extreme circumstances. Figure 21 shows a representation of this strategy. This storyline is described in less detail. The same flood event occurs as in storyline 1. Only the actions that differ from the previous storylines are discussed. The figures that represent the actions within this storyline are showed in appendix 6 at A0 format.

5.4.1 Actor authorities

IA0 and IA5abc:

The authorities are executing the same procedures for the different stages of the warning system for extreme high waters as in storyline 1. However in the meantime they start to evacuate all non-self-reliant people (approximately 700) to shelters. These people are not able to survive in their house when they are inundated and critical functions fail nor are they able to evacuate or flee in cars by themselves. The evacuation of these people starts at the moment the warning stage (IW1c) is entered. This means there is 21 hour to evacuate. The authorities advise the others (approximately 24500) to evacuate by themselves to the safe compartment.

IIA5:
During this phase the authorities try to rescue the people left in the area in the same way as in storyline 1 and 2.

IIIA0:
The third phase follows the same sequences of events as they did in storyline 1.

5.4.2 Actor civilians inside the dike ring

ICi0 and ICi5:

The civilians start to notice the possibility of extreme high water levels around the island through the usual media. The civilians that are living in the compartment that can get inundated prepare themselves for evacuation towards the safe compartment. At the moment the authorities advice to evacuate, 80% of the inhabitants (approximately 22308) leaves the area the others stay behind. Of this 80%, 15% tries to get off the island while the other 85% finds shelter in the safe compartment. The majority of the people evacuate by car, despite the fact that a storm is blowing which slows down the evacuation process. It is assumed that these people can get out of the unsafe compartment before the embankment breaks. The non-self-reliant people (approximately 700) are evacuated to the shelters by the emergency services. This is done by ambulances and other cars and buses available.

IICi5:
The majority of the people is already in the safe compartment during this phase. The people that stayed in their houses are rescued from their house by the authorities under the same circumstances as in storyline 1. However, they now can be brought to one of the shelters on the island. It is assumed that after 2 days no one is left in the inundated area.

IIICi0:

This third phase is again the same as in storyline 1.

5.4.3 Analysis of storyline 3

Damage, fatalities and affected people

The results of this storyline are found in tables 6 and 10. This storyline results into the same damage as for storyline 1. However, the number of fatalities is smaller due to the fact that the non-self-reliant people were evacuated to shelters before the embankment break and the majority of the others in the unsafe compartment evacuated themselves.

Table 10: The numbers refugees, the ones left behind and fatalities for storyline 1:

	% evacuees that were safe in time	**Number of evacuees (that were safe in time)**	**Number of fatalities**	**Number affected people that need to be rescued**
Phase I				
Unsafe compartment	80	22308		
Phase II				
Unsafe compartment			13	5564

Within the storyline the assumptions made on the measures taken within this example of a multilayered strategy determine the final results. Especially the assumption the fact that some compartments are safe and others are not is important. It should however be discussed and studied if these assumptions and measures are feasible in the near future or if this storyline is not a realistic option.

6 Discussion

This chapter discusses first the results of the island of Dordrecht and the uncertainties in the methods and assumptions used to develop the storylines. In the next part a discussion is held on the usefulness and value of the storyline method in developing new strategies for island of Dordrecht, the Netherlands and other cities in the world.

6.1 Results for the island of Dordrecht

6.1.1 Factors that determine the flooding pattern

The flooding pattern that determines the outcome of the results in several ways depends on many factors. It is thus important that following factors are represented correctly within the flooding model:

- The strength and ability of secondary embankments and other high elevated elements within the dike ring to withstand a certain water level.
- The local drainage pattern in the form of small ditches and canals.
- The elevation grid of the model

Representation of the secondary embankments in the flooding model

Both the study of MARE and WV21 (Van Herk et al., 2011; Nelen en Schuurmans, 2010) are not certain that all higher lying elements within the dike ring are able to withstand a certain water level and do not fail before water reaches the crest of these elements, which is the way these elements are now reflected in the flood model. Especially the strength of the "Wieldrechtse Zeedijk" is not secured (Van Herk et al., 2011).

The importance of this representation of secondary elements is found in the example for the storyline of the "Kop van het land", where the "Wieldrechtse Zeedijk" does not hold and breaks although it is not being overtopped. This causes water to flow southwards into the rural areas of the island. This scenario will lower the hydraulic pressure on the other secondary embankments that surround the residential areas (such as the "Zuidendijk") (see figure 10) and will therefore probably not break. This prevents water from flowing into the residential areas. In case they still break, the process of water flowing into these areas is delayed by another few hours and thus more time is available to evacuate or rescue the inhabitants in the residential areas.

This stresses the need for further study on strengths of the secondary embankments and higher elevated elements such as the fundaments of the A16 and N3 to determine the most correct representation of these elements in the flooding model. It should be noted that the exact flooding pattern is never known, because in practice it is never sure which of these secondary embankments and higher elevated elements within the dike ring will break or not.

This shows that the flooding patterns of the created storylines are two of many possible flooding patterns that can occur if the dike ring breaches at the "Kop van het land" or along the "Kildijk". To avoid making thousands of storylines it is proposed to determine what the worst, but still realistic flooding pattern is. This way measures and strategies are developed that reduce the number of fatalities and amount of damage in this worst case scenario of a certain breach. Generally this means that also the damage and fatalities are reduced for less worse scenarios.

The local drainage pattern

For this study it was tried to produce a flooding model that could also drain the flooded area. In this model the drainage network of the regional water model of the water board was included. Despite the fact that this model did not work properly to calculate the draining time it showed the importance of the representation of the drainage network on the island for the flooding pattern. The network of tranches and ditches used in this drainage model differs from the network used in the original flooding model. Figures 29 shows the two different networks used for the different models. Figure 30 shows the maximum water depths for the model including the emptying network for a scenario that uses the same embankment breach and the same boundary conditions as the VNK model does. The maximum water depth for the breach along the "Kildijk" resulting from the VNK model is found in appendix 1.

The two figures with maximum water depths (figure 30 and appendix 1) show clearly a different flooding pattern. The correct representation of the drainage network is thus important for the flooding pattern. Which of these representations of the drainage network on the island is best is not known for this thesis. However, the experts of the water board probably know which of these different representations of the drainage network on the island is best. They do also know where trenches can be closed off so that water is not transported through these channels from one part of the island to another. This means that the representation of the channels and trenches in the VNK model could be correct if these connections do exist and were closed off. This also shows the importance of closing these channels, which should be incorporated in emergency response plans. Within this field it should also be checked if the sewer system can also transport water from one compartment to other and if these connections can be closed off.

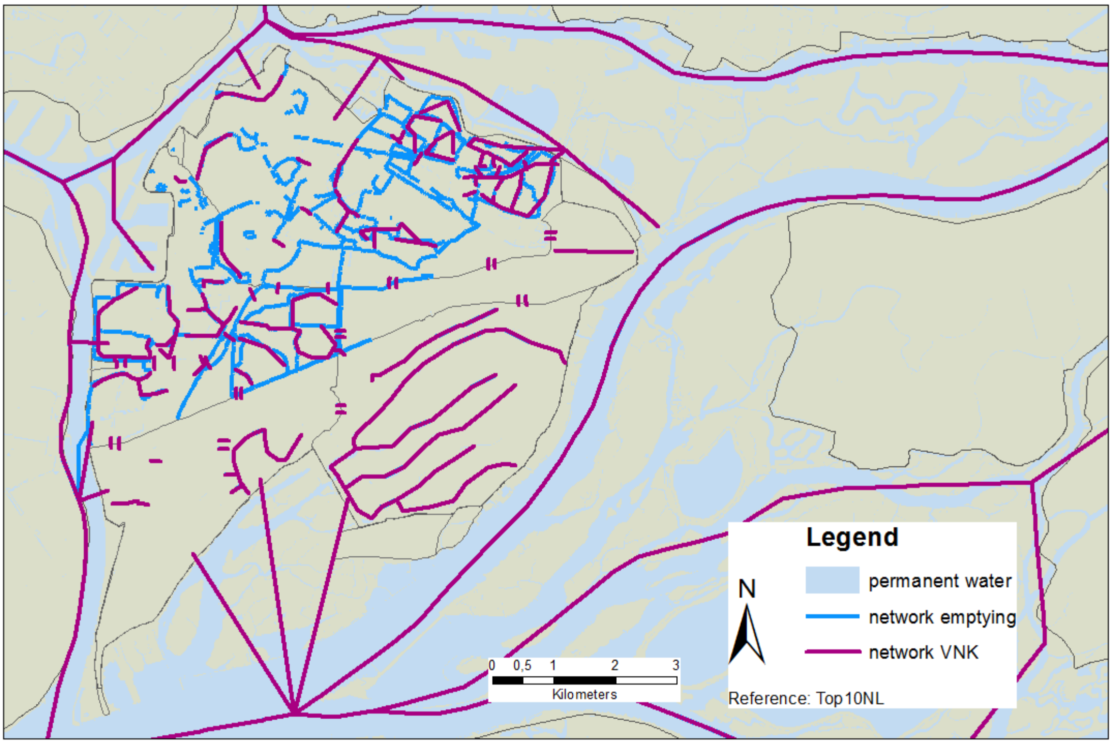


Figure 29: The difference between the two networks used in the VNK model and the model for pumping water from the inundated area.

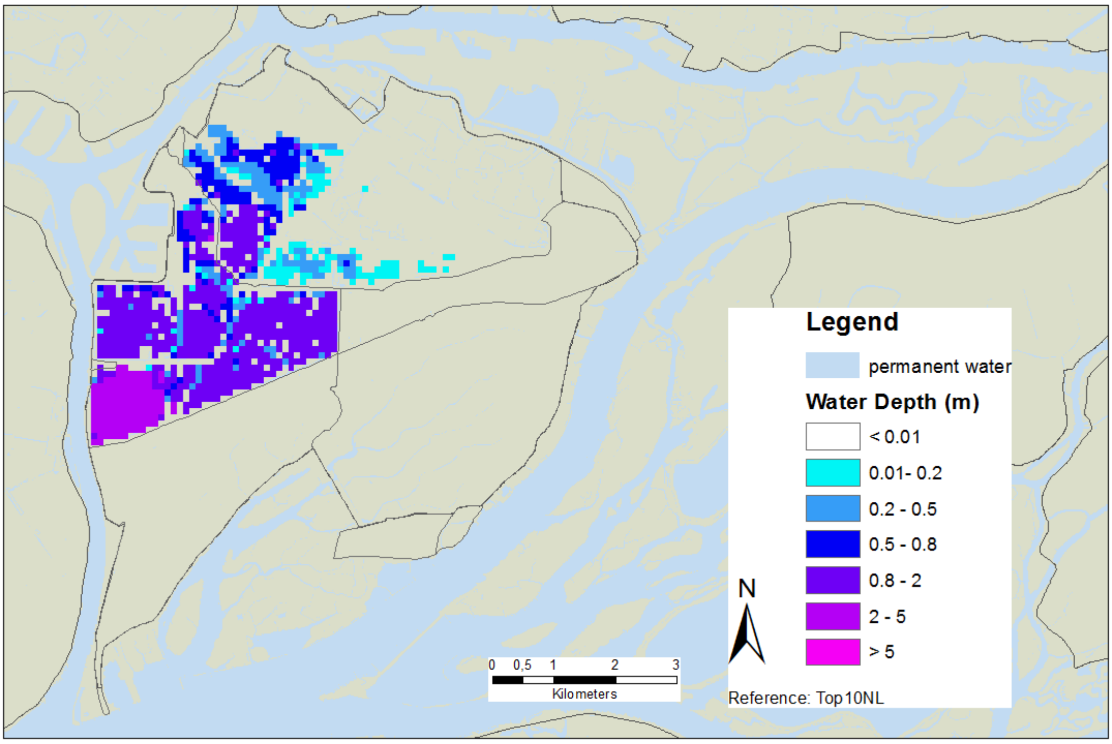


Figure 30: The maximum water depth resulting from the model used for emptying the island after inundation through the breach along the "Kildijk".

The elevation grid

The elevation grid is used in the calculation of the water depths, velocities and rising rates. The grid is represents the elevation in cell of 100x100 meters. The higher elevated elements are represented well on this grid, because the highest elevation is given to the whole cell when major differences occurred within one cell. If no major differences occurred the average is attached to the cell. In this way the average water depths could be represented well. However major errors arise in the calculated water flow velocity. Most streets within the residential areas are much smaller than 100 meters. Within these small streets high velocities can occur in real life that are not calculated on a grid of 100x100 meters.

The influence of these differences in velocity in the results of the storyline becomes clear from the fact that the damage and casualty functions in HIS-SSM depend on these velocities. The velocity of 2 m/s is often a threshold in these functions (Kok et al., 2005). Especially, if people are in the streets instead of their houses they may die of drowning, because they can't swim against the flow. Also buildings are more severely damaged under the influence of high velocities.

On the other hand it can also be argued that during the the majority of the inundation time the majority of people stay in their houses and thus they do not experience these higher raising rates and velocities. Therefore the average for these rates on a cell of 100x100 meters represented the situation well. Still, high flow velocities may also destruct or undermine walls and houses. Also in this case it is thus not certain which representation fits the storyline best and again more options should be calculated and explored to take into consideration of developing new and better FRM strategies.

6.1.2 Calculation of final damage and fatalities

Within this section the following two topics are discussed:

- The use of HIS-SSM to calculate the final results
- The uncertainty in the assumptions made for the storylines

HIS-SSM

Within this study the final results on damage and fatalities are calculated with the HIS-SSM. Within this study this works, because no storylines were tested that incorporate measures that changed these functions. However, if in future studies storylines are developed that include measures taken in the field of for example waterproofing buildings these functions must be changed.

A second fact that should be noted is that the functions used in HIS-SSM are generalized for the whole country, while storylines are created for a specific case in one dike ring. This means that to get more detailed insights in the local damage it should be considered if the functions represent the local land use sufficiently.

Uncertainty in assumptions

Within storyline 1 and 2 assumptions are done for the parameters used to calculate the final number of people left in the area at the end of the inundation phase. All the assumptions made to do these calculations were a best guess based on the available information. However, some of these assumptions are very uncertain and other values could be as true as the values used in the created storylines. This especially applies to:

- The percentage of people that tries to flee even if the authorities advice otherwise.
- The response time between the time of the trigger (embankment breach or advice authorities) to flee and the actual time people got on the road.
- The evacuation/flee velocity (due to weather conditions, road blockages, traffic jams).
- The time available to evacuate (in the second storyline).
- The percentage of people that eventually evacuate (in the second storyline).
- The time needed to recover the area.

These factors all involve human actions. It is very difficult to predict human behavior in general, and especially for the field of human reactions towards flooding and recovery from flooding which only recently became a field of interest within FRM. This also shows that these topics should be further studied in other to determine if the strategy proposed in storyline 3 is feasible. Especially, the assumption that the majority of the civilians living in the unsafe compartment will evacuate towards the safer grounds must be checked.

In conclusion the discussed uncertainties in human behavior and flooding pattern show that one storyline represents a possible sequence of events that can occur, but that another storyline could be equally true. However, this is also the definition of the storyline method and thus the results and definition used for the method show that more different storylines should be made to include every aspect of a story. There are no wrong or right stories, at most very unlikely storylines. In order to developed FRM strategies at least the range of most likely storylines should be covered.

6.2 Evaluation: lessons for strategy development FRM

6.2.1 Storylines useful method for strategy development in Dordrecht?

The development and analysis of storylines for the island of Dordrecht resulted into proposals for new strategies. In this way it could be said that developing storylines indeed are a useful method to develop insights for new strategies in FRM. These strategy development results mainly from the following advantages of the method that became clear during the development of the method:

- It forces to select the details of an event that are most important for the results of the event.
- It gives insights in the many different components that influence a story, and more important it gives insights in the complexity of these components influencing each other.
- It is easily showed what the main knowledge gaps and uncertainties within understanding of a flood event are.
- It can be easily used to explore specific scenarios (such as worse case or scenarios with measures taken).
- It allows for sensitivity analysis with different assumptions for the parameters that determine the number of people that left behind in an area after inundation.
- It is area specific.

Insights in all these factors are needed to develop a strategy. The storylines developed for the island of Dordrecht showed that much is not known yet for the island and blanks need be filled to select the ultimate feasible FRM strategy. However, the method showed in which component the knowledge gap exists and it also gives an indication of the factors that always will be uncertain, such as the behavior of humans.

The main disadvantage of the method is that it takes a lot of time to gather all information needed for all different components of the method if it is done by only one person. However, this problem can be solved if a meeting or workshop is organized where all experts on the different components are present. At these workshops blanks can be filled in fast or if information is not yet available on one subject the experts on that subject can study these blanks themselves.

At December the 17th, such a workshop was organized for MLS strategy development for the island of Dordrecht. At this workshop the three storylines developed in this thesis were presented. The storyline method was received positively. During the workshop it also became clear that the storyline method has another big advantage; namely that of enhancing the discussion for strategy development directly at the important details and knowledge gaps. An example hereof was the discussion about the feasibility (especially, on socially explain this strategy) of the MLS strategy described in the third storyline.

Finally, it should be noted that in developing the storylines for the island of Dordrecht only 5 main actors were selected that influence each other. These actors were based on the knowledge and insights available from exploring the island of Dordrecht. During the further process of developing the storylines it became clear that more lines can be considered. One of these lines is a line for media (news on radio and television, but also social media sites as twitter and facebook) that influences the human response to the events, especially the first phase. One other important element that could be included is that of (chemical) industry. They can be important during the second and third phase if they contaminate the environment and the water.

6.2.2 Storylines useful for strategy development in the Netherlands?

One of the goals of using the storyline method was to not only focus on one layer or phase within a certain strategy, but on all phases and layers. The method should link or connect the three layers and help finding a consistent set of measures for FRM in a certain area. This goal was certainly met in case of the island of Dordrecht as different strategies with measures at different layers were proposed. Creating storylines for the island of Dordrecht clearly showed the advantages of using storylines in strategy development to add more insights next to the already existing methods such as risk analysis and cost benefit analysis. Therefore it is recommended to use this method also in other areas in the Netherlands.

However it should be noticed that the method is suitable for strategy development in specific areas and not for general strategy development for the Netherlands as a whole. The strength of the method is that it provides lots of details on all elements and their interactions within an event. It would be difficult to generalize events into ones with less detail, without losing this advantage of the method. Furthermore, it would take too much time to gain all details on all considered areas in the Netherlands.

Finally, it should be noted the island of Dordrecht is a nice example of an area where taking measures at different layers can be more cost beneficial than only taking them on the first layer (strategy used in storyline 3 (RWS, in prep)). However it should be noted that in other areas, even though the storyline method is used to consider every aspect for strategy development at all layers of FRM, the chance exists that the best cost beneficial solution could still be the one with measures taken at the first layer of the MLS strategy. This is due to the fact that most measures in the past have been taken at this layer and it is often cheap to adjust this layer compared to take new measures within another layer. Also most important economical and densely populated areas often lay low, with means that breaking of the primary defense (first layer) is a worst case scenario that everyone wants to avoid.

6.2.3 Storylines useful for strategy development in other countries?

Within other countries that have delta cities the storyline method could certainly be used to develop strategies as it can explore all details of an event independently from the location in the world. The storyline method could be applied using the 5 main actors used in this thesis. These actors should in greater or lesser extent also apply to other countries in the world as they are general actors that are everywhere in the world. Except for the two different civilian actors, in other part of the world no division is made in areas in and outside a certain dike ring. This leaves 4 main actors (water, critical infrastructure, authorities and civilians) for executing the storyline method in other parts of the world. During the system exploration to fill in the details for these actors other lines that apply for the specific situation in a certain country can be found.

It should be noted that in order to apply the storyline method relatively fast, sufficient detailed information on the flooding pattern and other factors should already be available at different companies or governmental bodies. If these details or models to get these details are not yet available the storyline method becomes a very time consuming method. Time is needed to develop models and gain detailed information. In this case it should thus be considered if the researchers are willing to take this time. If this is the case the storyline method could be used as a method to identify which information is most important in order to get a generally correct view of the event.

The usefulness of the storyline method for strategy development can for example be found in the multiple lines of defense strategy in the USA (see Chapter 2). This strategy implies that measures can be taken at 11 layers that all act parallel to each other. The storyline method would show the importance of each layer in the sequence of events happening under extreme circumstances. Furthermore, it can show the interaction between these layers. The storyline method can provide insights to see if you need measures in all these layers or you can also find strategies that only use a couple of them.

Furthermore, the examples in Chapter two from the USA and England also show that often FRM lies in the hands of local authorities and communities. This automatically means that the development of strategies is always on local scale at which the storyline method is a useful to use. In Japan the storyline method could be used to explore the possibilities for different options in FRM for new built residential areas, as found in the example of the super levees. In this case maybe the storyline method should be adapted to not only look to what is needed during an extreme event, but also during normal circumstances. An example is the need for recreational areas that can be combined with defense measures.

7 Conclusions and recommendations

7.1 Conclusions

Within this thesis the following aim was studied:

To develop and evaluate the storyline method as a tool to develop strategies in an integrated FRM approach.

For this objective the following research question has been answered:

How to establish storylines for the analysis of a flood event and developing FRM strategies?

The research showed that it is indeed possible to develop storylines and use these storylines to develop strategies within an integrated FRM approach. This was successfully done for the case study on the island of Dordrecht. However, it is also concluded that developing storylines is a time consuming method, as it takes time to gain all detailed information needed to tell a story. It is thus only a useful method in studies that need these details to develop strategies and not in studies that compare areas or studies on large areas. The storyline method seems suitable for developing strategies in countries all around the world.

The research concluded that the main advantages of the storyline method are the following:

- It forces to select the details of an event that are most important for the results of the event.
- It gives insights in the many different components that influence a story, and more important it gives insights in the complexity of these components influencing each other.
- It is easily showed what the main knowledge gaps and uncertainties within understanding of a flood event are.
- It can be easily used to explore specific scenarios (such as worse case or scenarios with measures taken).
- It allows for sensitivity analysis with different assumptions for the parameters that determine the number of people that left behind in an area after inundation.
- It is area specific
- It enhances discussion at the right detailed level.

To establish storylines first an area exploration needs to be executed to determine what the most important actors and phases in the storyline for a flood event are. The actors and phases used in this research are assumed to be general for all flood event storylines, extra actors or phases can be added for specific situations. The actors and phases used in this research were the following:

- Actor: Water
- Actor: Critical infrastructure
- Actor: Authorities
- Actor: Civilians living outside the dike ring
- Phase: Build-up (before inundation/breach)
- Phase: Inundation (during the inundation)
- Phase: Recovery (after the inundation)

The analysis of the storylines for the island of Dordrecht showed that the flooding pattern is the most important characteristic for the end result of the storylines. This flooding pattern determines:

- The (total) flooded area which determines the total damage
- The (total) depth which determines the total damage and fatalities
- The time available to flee or evacuate from water which determines the number of fatalities
- Rising rate and speed of water which determines the number of fatalities
- The time needed to get the area dry which is important for the recovery phase
- The disruption extent for critical infrastructure which is important for the recovery phase.

As the flooding pattern is an important characteristic the model used to develop the flooding pattern should be as accurate as possible.

Other factors that determine the results such as the behavior of humans are uncertain. Often there are many options for the assumptions made on these factors and more different storylines should be considered in order to develop a strategy.

The strategies that were developed during this research should be further studied as must the assumptions on the storylines that resulted into these proposals. The recommendations for further study are given below.

7.2 Recommendations

Following from the discussion on the factors that determine the end result of the storylines, many characteristics that are important for each proposed strategy should be further studied. These characteristics are:

- The strength and ability of to withstand a certain water level of secondary embankments and other high elevated elements within the dike ring.
- The location and the capacity of the drainage network (including sewer system) within the dike ring.
- The elevation of the area within the dike ring.
- The percentage of people that tries to flee even if the authorities advice otherwise.
- The response time between the time of the trigger (embankment breach or advice authorities) to flee and the actual time people got on the road.
- The evacuation velocity (due to weather conditions, road blockages, traffic jams).
- The possibilities of breaking the “Wieldrechtse Zeedijk” to avoid water from flowing into the residential areas in case of a breach near “de Kop van ‘t land”.
- The availability of vehicles, boats, helicopters to evacuate people from their home towards the shelter and from the shelter towards safe areas in the rest of the Netherlands.

More general recommendations are:

- Study the feasibility of proposed strategies for the island of Dordrecht.
- Explore if more actors are important in the storylines used for developing strategies on the island of Dordrecht (for example a line for (social) media and (chemical) industry).
- Study the third phase of the storyline, as not much is known about the recovery phase yet (Kim Annema is studying this in her current project).

8 References

8.1 Memo's, books, articles and reports:

Aerts, J., Major, D.C., Bowman, M.J., Dircke, P. and Marfai, M.A. (2010). Connecting delta cities; Coastal Cities, Flood Risk Management, Adaptation to Climate Change. VU University press. 48p.

ANWB and Topografische Dienst Kadaster (TD) , 2004. ANWB Topografische Atlas Zuid-Holland 1:25.000. ANWB Media en Bart Bennis. Papendrecht 101 p.

Beckers, J. and De Bruijn, K.(2011). Analyse van Slachtofferrisico's Waterveiligheid 21e eeuw. Deltares; projectnr. 1204144-005; 58p.

*Birks, M., Mills, J., Francis, K. and Chapman, Y. (2009).*A thousand words paint a picture: The use of storyline in grounded theory research. Journal of Research in Nursing 2009 14: 405; pp.405-417.

Blom, E.T., Zevenbergen, C., Gersonius, B. and Van Son, E. (2012). Smart Shelter Strategies – Cost effective flood preparedness. Project of FloodRisk 2012. 7p.

BZK, Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (2005). Rapport bescherming criticale infrastructuur. Den Haag. 69 p.

BZK, Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (2010). 2de inhoudelijke analyse bescherming criticale infrastructuur. Den Haag. 45 p.

Chang, S.E. (2010). Urban disaster recovery: a measurement framework and its application to the 1995 Kobe earthquake. Disasters 34(2); 303-327 pp.

COM (2004) 472 final. Communication from the commission to the council, the European parliament, the European economic and social committee and the committee of the regions; Flood risk management; flood prevention, protection and mitigation. 11p.

Dawson, J.R., Ball, T., Werritty, J., Werritty, A., Hall, J.W. and Roche, N. (2011). Assessing the effectiveness of non-structural flood management measures in the Thames Estuary under conditions of socio-economic and environmental change. Global Environmental Change 21; pp. 628-646.

De Bruijn, K.M. (2005). Resilience and flood risk management; A systems approach applied to lowland rivers. DUP science; Delft. 210p.

De Bruijn, K.M. (2009). Slachtofferrisico's door overstromingen, Voorstel voor indicatoren voor gebruik in de discussie over nieuwe normen voor de waterkeringen. Deltares rapport 1200165-002.

De Bruijn, K. and Van der Doef, M.(2011). Gevolgen van overstromingen – Informatie ten behoeve van het project Waterveiligheid in de 21e eeuw. Rapportnummer: 1204144-004. Deltares, Delft. 78 p.

De Bruijn, K., Kind, J. Slager, K., Van Buren, R., Van der Doef, M. (2012). Verbetering van de gevolgen van overstromingen buitendijks in de regio Rijnmond-Drechtsteden. Projectnummer 1206053-000, Deltares, Delft. 51 p.

De Kort, R. (2012). Kwetsbaarheid in het buitendijkse gebied; analyse van de gevolgen van overstroming op criticale infrastructuur en stedelijke functies in Rotterdam. Gemeente Rotterdam, afdeling Ruimtelijke Ordening en Stadsontwikkeling. 50p.

Dircke, P., Aerts, J. and Molenaar A. (2010). Connecting delta cities; sharing knowledge and working on adaptation to climate change. City of Rotterdam. 159 p.

DHV BV, Van Ark, Ronald, Baltissen, Jan, De Boer, Steven (2011). Weerbaarheid criticale infrastructuren en objecten; Strategieën in relatie tot overstromingen. Conceptrapport. In op dracht van Ministerie I&M; Deelprogramma nieuwbouw en herstructurering. Dossiernummer: BA3384-101-100. Amersfoort. 35p.

FLOODsite (2009). Flood risk assessment and flood risk management; An

introduction and guidance based on experiences and findings of FLOODsite (an EU-funded Integrated Project). Deltares| Delft Hydraulics; Delft. 139p.
Gemeente Dordrecht (2012). Hoogwater Bestrijdingsplan; januari 2012. 33p.
Gordon, P. and Little, R.G. (2009). Rethinking flood protection: Options an opportunities for New Orleans. Public Works Manangement Policy 14; pp. 37-54.
Haas, J.E., Kates, R.W. and Bowden, M.J. (1977). Reconstruction Following Disaster. Cambridge, MA: MIT press. 331 p.
Haasnoot, M., Middelkoop, H., Offermans, A., Van Beek, E. and Van Deursen, W.P.A. (2012). Exploring pathways for sustainable water management in river deltas in a changing environment. Climatic Change, DOI 10.1007/s10584-012-0444-2.
Hinborch, M. (2010). Flood defense town centre Dordrecht. Master thesis TU Delft. 139p.
Hooijer, A. Klijn, F. Pedroli, G.B.M. and Van Os, A.G. (2004). Towards sustainable flood risk management in the rhine and meuse River basins; synopsis of the findings of IRMA-SPONGE. River Research and applications 20; pp. 343 – 357.
Hoss, F. (2010). A comprehensive assessment of Multilayered Safety (Meerlaagsveiligheid) in flood risk management. Master thesis TU Delft. 167p.
Hoss, F., Ter Horst, W., Jonkman, B. and Maaskant, B. (2011). Multilayered Safety Strategies in Dordrecht. Analysis of risk to life. TU Delft, Faculty of civil engineering and geosciences. 65p.
*Huizinga, J., Nederpel., A, De Groot, K. and Batterink, M. (2011).*Risicomethode buitendijks: Methodiek ter bepaling van risico's als gevolg van hoog water. Provincie Zuid Holland, Arcadis, HKV lijn in water. 55p.
IWR (2011), Flood Risk Management Approaches: As being practiced in Japan, Netherlands, United Kingdom and United States. IWR report No: 2011-R-08. 124p.
Jasperse, M.H.V. (2011). Algemene beschrijving C2000 radionetwerk; versie 2.0. Voorziening tot samenwerking Politie Nederland. 9p.
Jonkman, S. N., Kok, M. and Vrijling, K.J. (2008). Flood Risk Assessment: A case study for dike ring South Holland. Risk Analysis 28(5); pp.1357 – 1372.
Kind, J. et al. (2011). Kosten-Baten analyse Waterveiligheid 21e eeuw. Een economische analyse ten behoeve van nieuwe normen voor de bescherming tegen hoogwater. Deltares, Delft.
Kok, M., Huizinga, H.J., Vrouwenvelder A.C.W.M. and Van den Braak, W.E.W. (2005). Standaardmehtode2005 Schade en Slachtoffers als gevolg van overstromingen. HKV Lijn in water en TNO Bouw in opdracht van Rijkswaterstaat DWW; PR999.10. 33p.
Kok, M., Theunissen, R., Jonkman, B. and Vrijling, H. (2006). Schade door overstroming: Ervaringen uit New Orleans. TU Delft; HKV lijn in water. 43p.
Kok, M. and Van der Doef., M. (2008). Leidraad overstromingsberekeningen voor VNK2. Ahv "Uitgangspunten voor overstromingsscenario's in VNK2 uit 2006". 35 p.
Kundzewicz, Z.W. and Takeuchi, K. (1999). Flood protection and management: quo vadimus? Journal of hydrological science 44(3); pp. 417-432.
Lopez, J.A. (2006). The multiple lines of defense strategy to sustain coastal Louisiana. Lake Pontchartrain Foundation. 21p.
Lopez, J.A. (2009). The multiple lines of defense strategy to sustain coastal Louisiana. Journal of Coastal Research, SI (54); pp. 186-197
Luiijff, H.A.M. (1999). Inofrmation assurance and the information society. In EICAR 1999 best paper proceedings; ISBN 87-987271-0-9. Aalborg.
Luijff, E.A.M., Burger, H. and Klaver, H.A. (2003). Critical infrastructure protection in The Netherlands: A Quick-scan. In EICAR conference best paper proceedings;ISBN 87-987271-2-5. Copenhagen. 19p.
Maaskant, B., Kolen, B., Jongejan, R., Jonkman, B. Kok, M. (2009). Evacuatieschattingen Nederland. Projectnummer: PR1718.10, HKVlijninwater.

Morra, R.H.J., (1954). De onmiddelijke gevolgen van stormvloed en enkele aansluitende beschouwingen.; Ramp en herstel 1953. Haarlem, Stam, 1954. Polytechnisch tijdschrift uitg. B. Jg. 9, no. 31-34.

Nelen en Schuurmans (2010). WV-21 gevolgenspoor; Rapport 4- deeldijkringen 21_1 tot 28_1. In opdracht van Deltares. 56 p.

Piek, R. (2007). Hydraulische Randvoorwaarden Overstromingsscenario's VNK-II Provinciale Risicokaart Provincie Zuid-Holland 1e concept. PZH-2007-336478. 58p.

Provincie Utrecht, Egas. W., Luyendijk, E., Booltink, M., Visser, W., Van Kruining, M., De Bruin, E., Tromp, E., and Asselman, N. (2010). Handreiking overstromingsrobuust Inrichten; samen maken we Utrecht mooier. Utrecht. 73 p.

RLI (2009). Tijd voor waterveiligheid; strategie voor overstromingsrisicobeheersing. OBT bv; Den Haag. 90p.

Rubin, C.B. (2009). Long term recovery from disasters – The neglected component of emergency management. Journal of homeland security and emergency mangament; Volume 6: Issue 1, Article 46. 17p.

RWS (Rijkswaterstaat) and HKVlijninwater (2008). Overstromingsscenario's voor rampenplannen; Benedenrivierengebied. Lelystad. 6p.

RWS (Rijkswaterstaat) (in prep). Gebiedsrapportage "Eiland van Dordrecht". Inzichten over de wateropgaven, kansrijke maatregelen, kansen en knelpunten. Concept van 30 november 2012. In het kader van het Deltaprogramma Rijnmond-Drechtsteden. 35p.

Samuels, P. and Gouldby, B. (2009). Language of Risk; Project Definitions (second edition). FLOODsite. 56p.

Sayers, P.B., Hall, J.W. and Meadowcroft, I.C. (2002). Towards risk-based flood hazard management in the UK. Civil Engineering 150; pp. 36-42.

Slootjes, N., Jeuken, A., Booterhuis, T. and Gao, Q. (2010). Resultaten MHW berekeningen t.b.v. probleemanalyse en verkenning hoekpunten; voor het Deltaprogramma Rijnmond-Drechtsteden. Deltares en HKVlijninwater; 1202134-016. 73p.

Smith, G.P. and Wenger, D. (2006). Sustainable disaster recovery: operationalizing an existing agenda. Chapter 14 in Handbook of Disaster research, edited by H. Rodriguez, E. L. Quarantelli and R. Dynes (NY: Springer); 234 -274 pp.

*Syncera B.*V. (2007). Quick scan Halve meter ramp. In opdracht van V&W and DG-water. Projectnummer: W06A0243. 18p.

Stone, K. (2011). Memo: Rapportage kostenberekeningen MARE MLV gebiedspilot. To: Van Herk, S. and Ter Horst, W. 15 juni 2011. 15p.

Strauss, A.L. and Corbin, J.M. (1990). Basics of qualitative research: Grounded theory procedures and techniques. Newbury Park; CA. Sage publications. 270p.

Ten Brinke, W.B.M., Saeijs, G.E.M., Helsloot, I. and Alpen, J. (2008). Safety chain approach in flood risk management. Municipal Engineer 161; ME2; pp. 93-102.

U.S. Army Corps of Engineers (2005). NEWS RELEASE: Corps overcomes huge hurdles; New Orleans begins to see results of recovery operations. September 11th, 2005. 3p.

Van de Pas, B., Slager, K., Bruijn, K. and Klijn, F. (2011). Overstromingsrisicozonering; Fase 1: Methode voor het identificeren van overstromingsgevaarzones. Deltares; 1204144-019. 97p.

Van der Veen, J., (1954). De schade en herstelwerkzaamheden in de provincie Zuid-Holland; Ramp en herstel 1953. Haarlem, Stam, 1954. Polytechnisch tijdschrift uitg. B. Jg.9, no. 31-34.

Van Herk, S., Kelder, E.T.G., Bax, J.H., Van Son, E., Waals, H., Zevenbergen C.,

Stone, K. and Gersonius, B. (2011). Gebiedspilot meerlaagsveiligheid Eiland van Dordrecht; Tussenrapportage ter inspiratie. 65p.
VRZHZ (Veiligheidsregio Zuid Holland Zuid), (2009). Regionaal Basisplan Overstromingen Zuid Holland Zuid; specifiek deel dijkring 22, Eiland van Dordrecht. Versie: RBO ZHZ v2.7. 25p.
V en W. (2008). Concept Nationaal Waterplan. Den Haag
V en W, VROM and LNV (2009). Nationaal Waterplan 2009- 2015. Den Haag. 280 p.
Wagenaar, D. (2012). Master thesis: The Significance of flood duration for flood damage assessment. 104p.
Yong, R., Luo, H. and Guo, D. (2011). Visual system design for independent safety management in petrochemical enterprises. Communications in Computer and Information science; Education and management; International symposium ISAEBD; Proceedings part III; pp. 239-246.

8.2 Websites:

www.wikipedia.nl
www.tennet.nl
www.risicokaart.nl
flooding.lizard.net
www.cbs.nl (population file of 2011 for ArcGIS)
www.kadaster.nl (topographical files of 2011 for ArcGIS)
http://wetten.overheid.nl/BWBR0025458/geldigheidsdatum_26-11-2012
(latest version of the Dutch water act)

8.3 Specialists and companies:

C2000 system:
- Peter Pijper

Evides (drink water network for the island of Dordrecht):
- Lydia Barm

Stedin (gas- and electricity network on the island of Dordrecht):
- Lion van der Heijden
- Agnes van den Ouden

Waterboard Hollandse Delta:
- Hans Waals
- Niels Robbemont

Municipality of Dordrecht:
- Ellen Kelder
- Martin Hulsebosch
- Annette Verschuren

Safety region Zuid Holland Zuid
- Nico van Os

Province Zuid Holland
- Renée Piek

UNESCO-IHE institute for water education:
- Berry Gersonyus
- Kim Annema

Deltares:
- Karin de Bruijn
- Karin Stone
- Dennis Wagenaar

University of Utrecht:
- Hans Middelkoop

Duravermeer:
- Edwin Blom

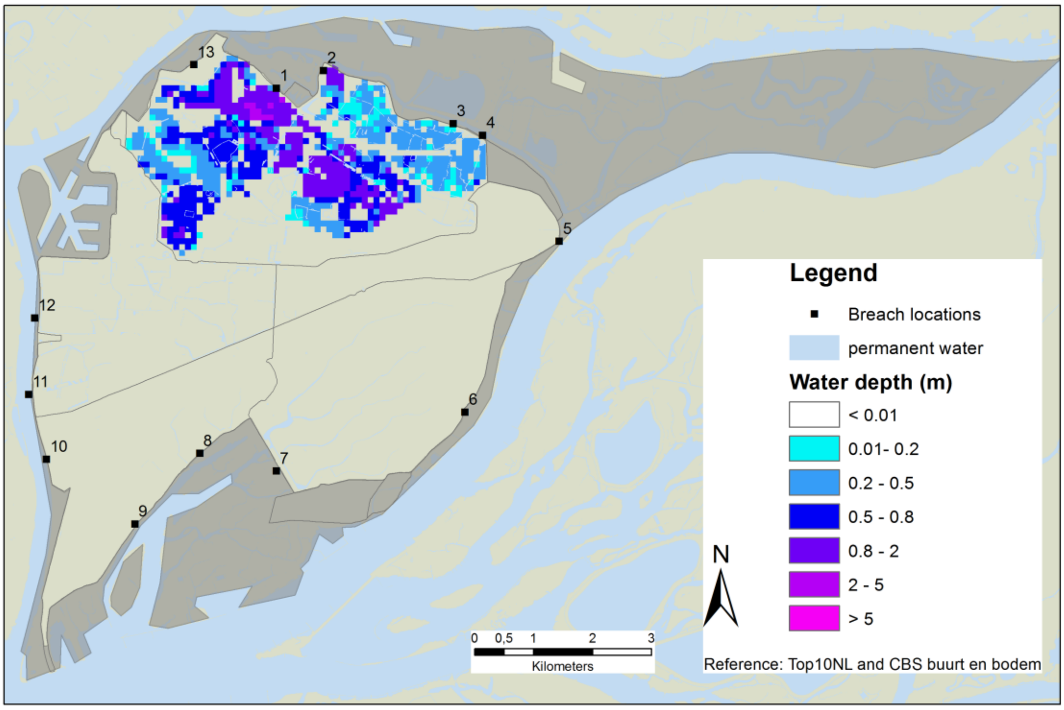
De Urbanisten:
- Auke Wissing
- Florian Boer

9 List of appendices

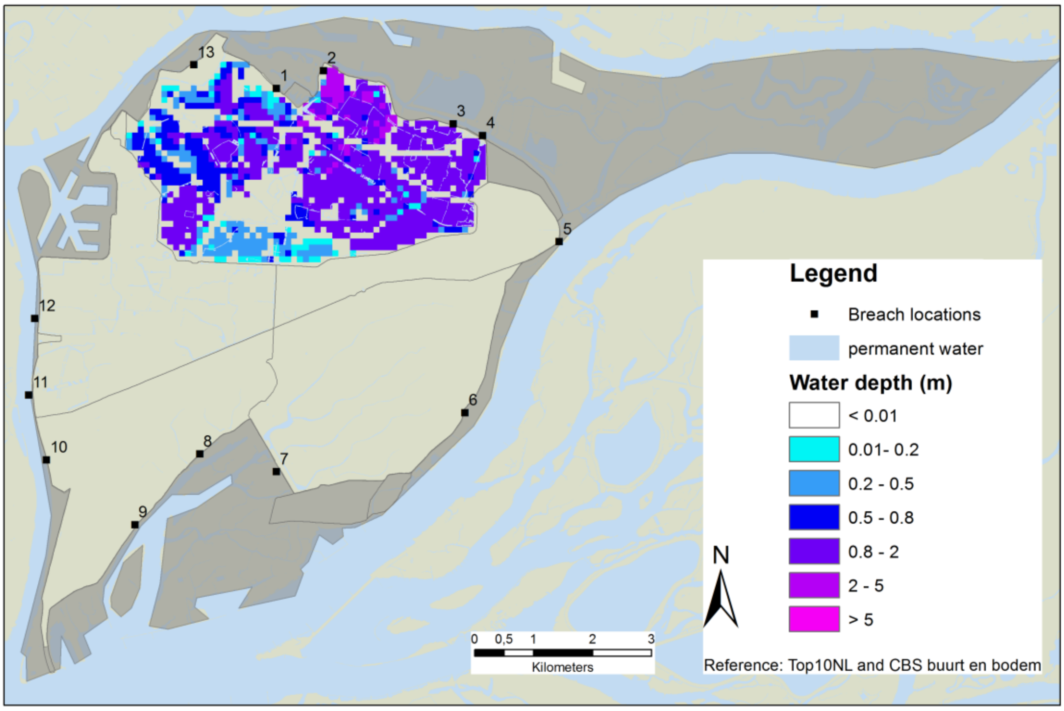
Appendix 1: Maximum water depth per breach
Appendix 2: Maximum velocity per breach
Appendix 3: Tables with measurements taken by the authorities
Appendix 4: Evacuation scenarios and percentages
Appendix 5: Assumptions used for the results of the storylines
Appendix 6: Figures representing storyline 1, 2 and 3
Appendix 7: Inundation through the breach along the "Kildijk"
Appendix 8: Calculations on draining the island for the two storylines
Appendix 9: The inundation of the island through the breach near the "Kop van 't land"
Appendix 10: HIS-SSM report for the breach along the "Kildijk"
Appendix 11: HIS-SSM report for the breach near the "Kop van 't land"

Appendix 1: Maximum water depth per breach

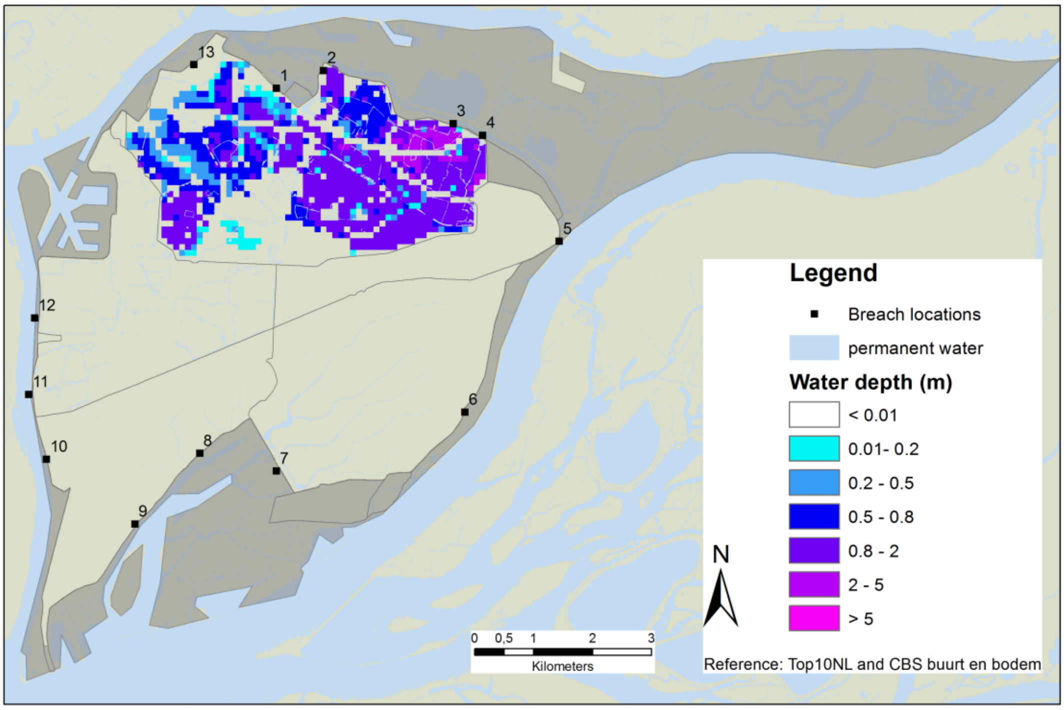
Maximum water depth breach 1



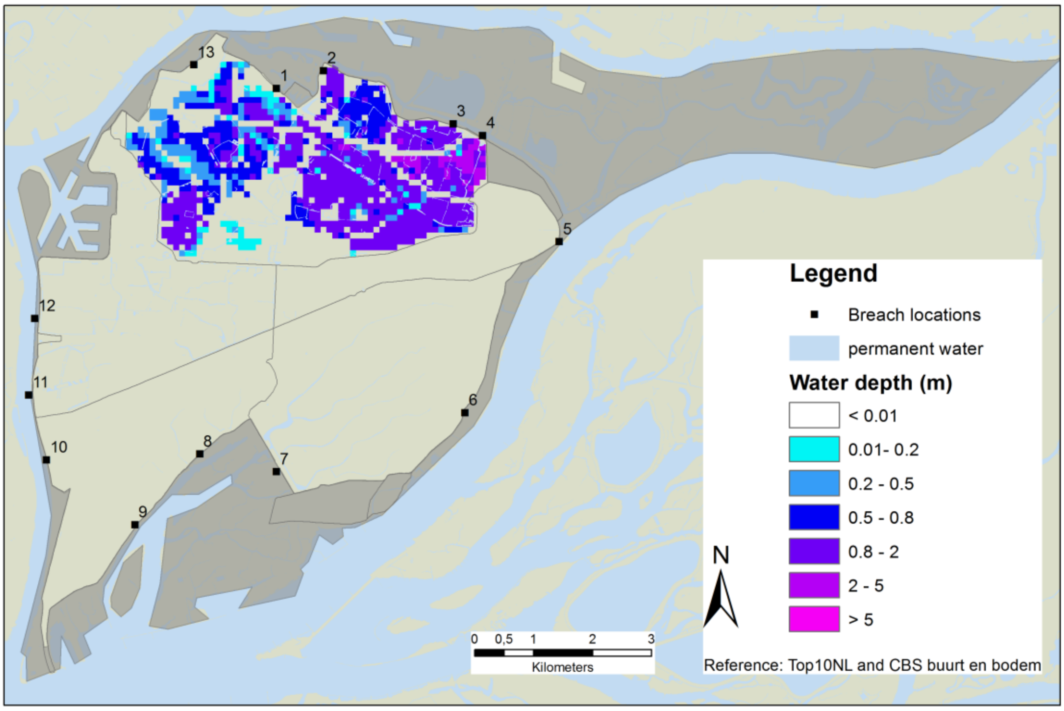
Maximum water depth breach 2



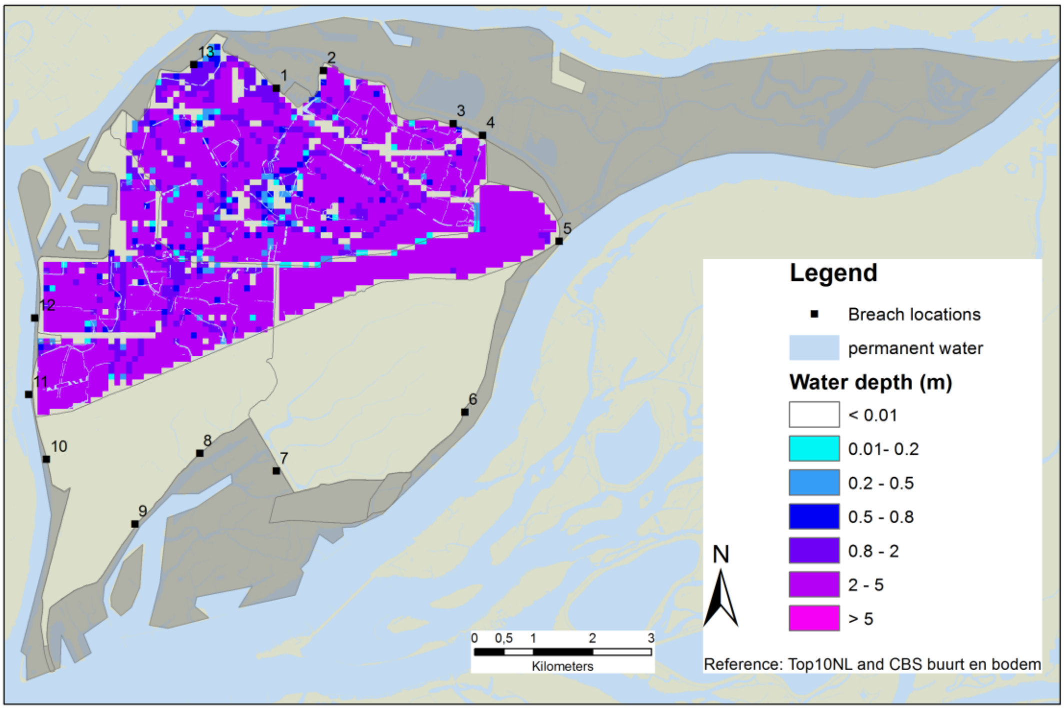
Maximum water depth breach 3



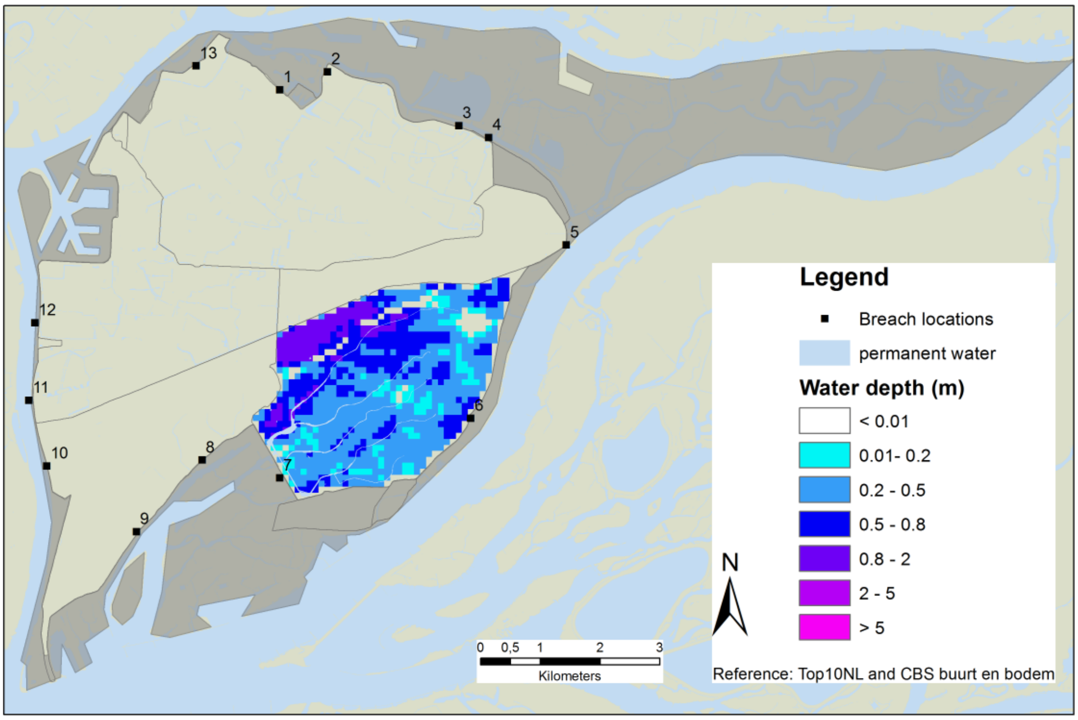
Maximum water depth breach 4



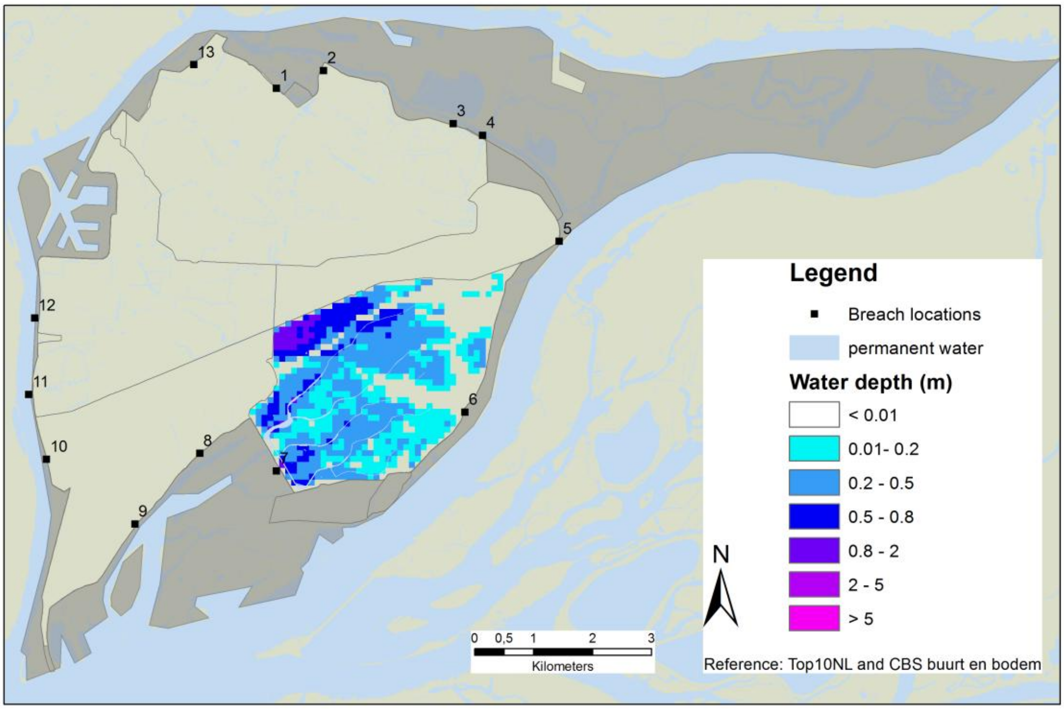
Maximum water depth breach 5



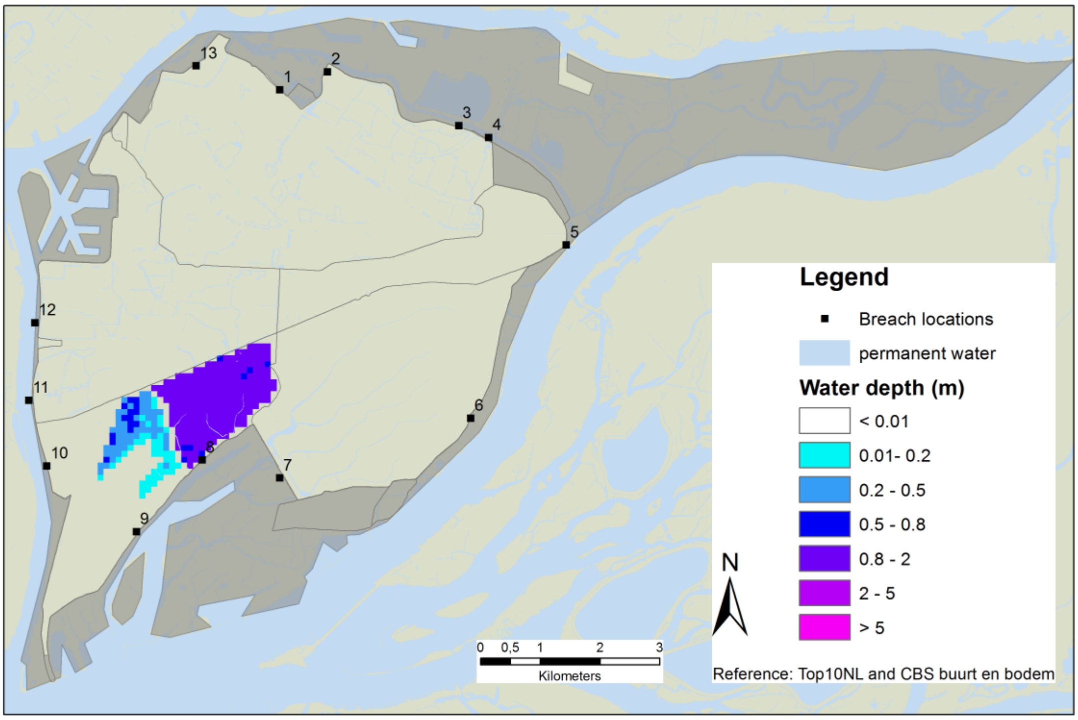
Maximum water depth breach 6



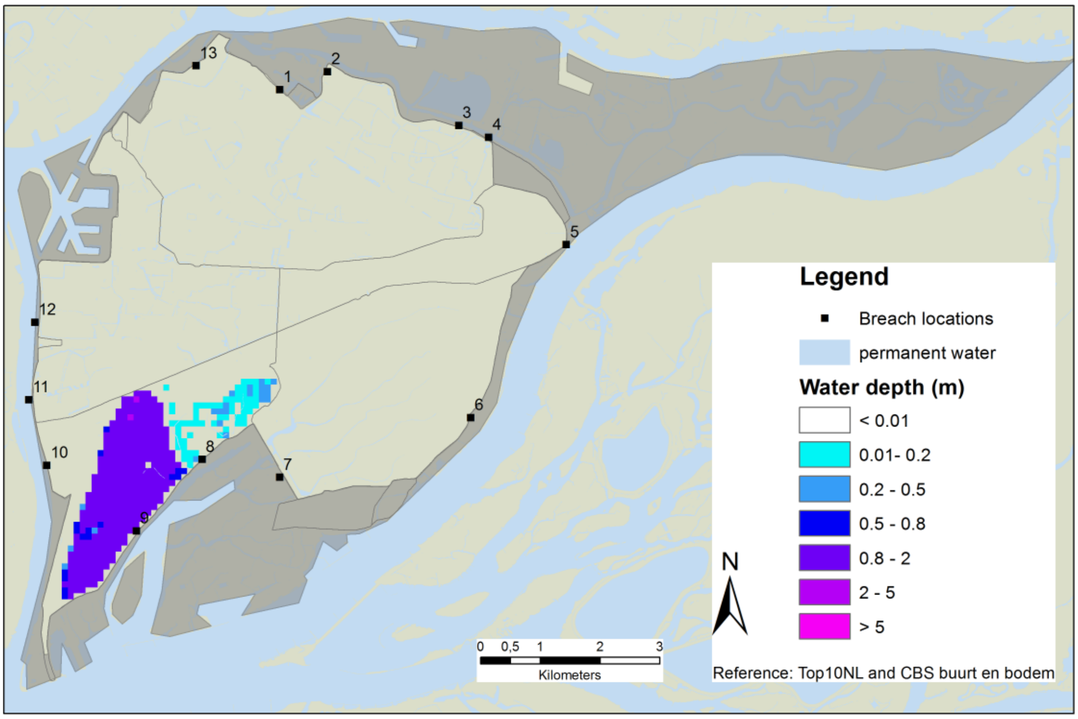
Maximum water depth breach 7



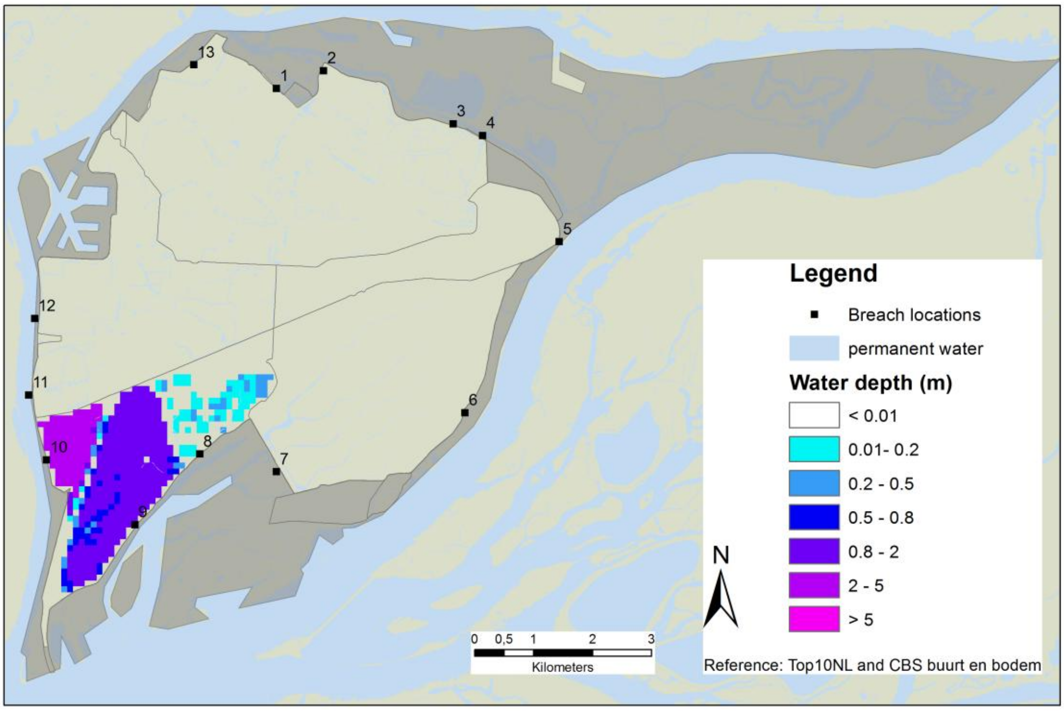
Maximum water depth breach 8



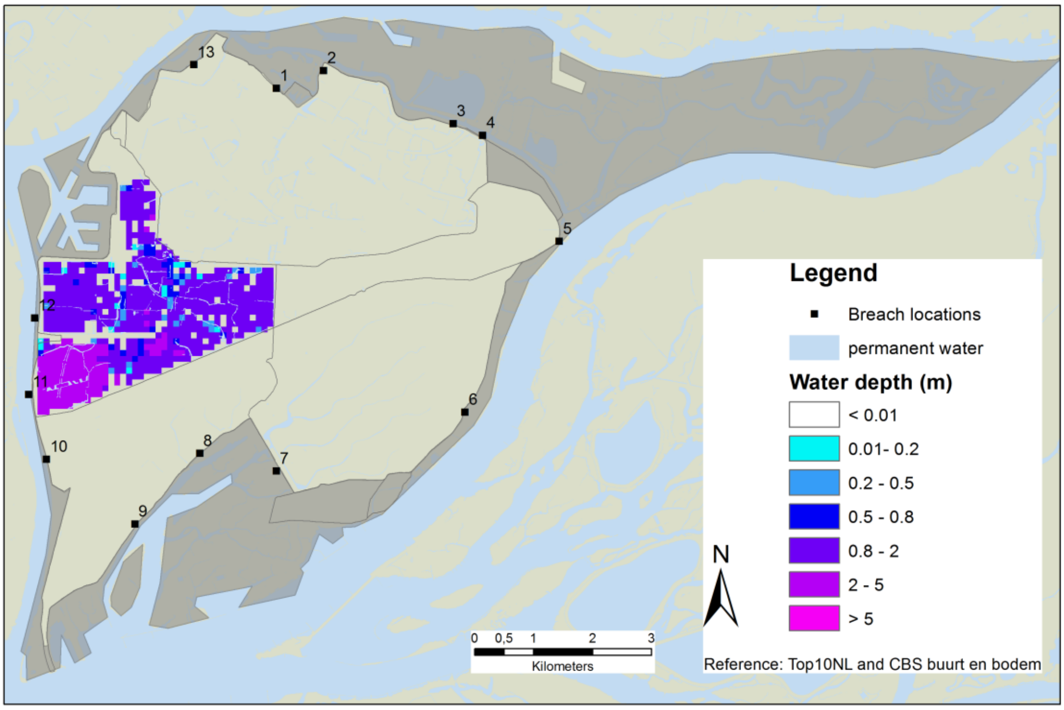
Maximum water depth breach 9



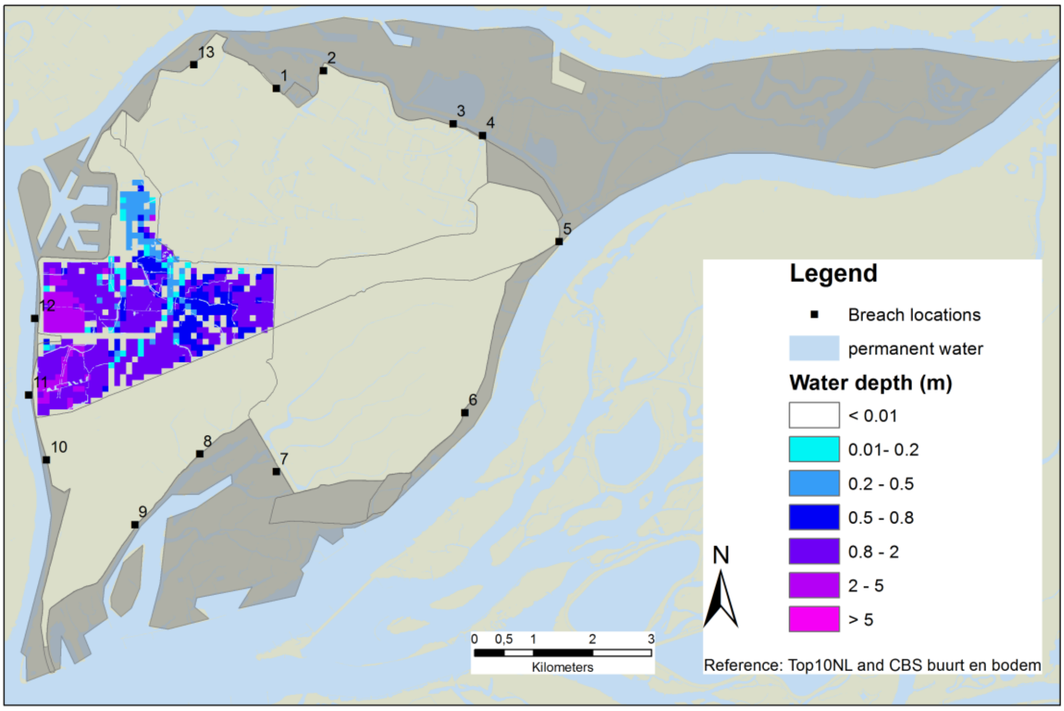
Maximum water depth breach 10



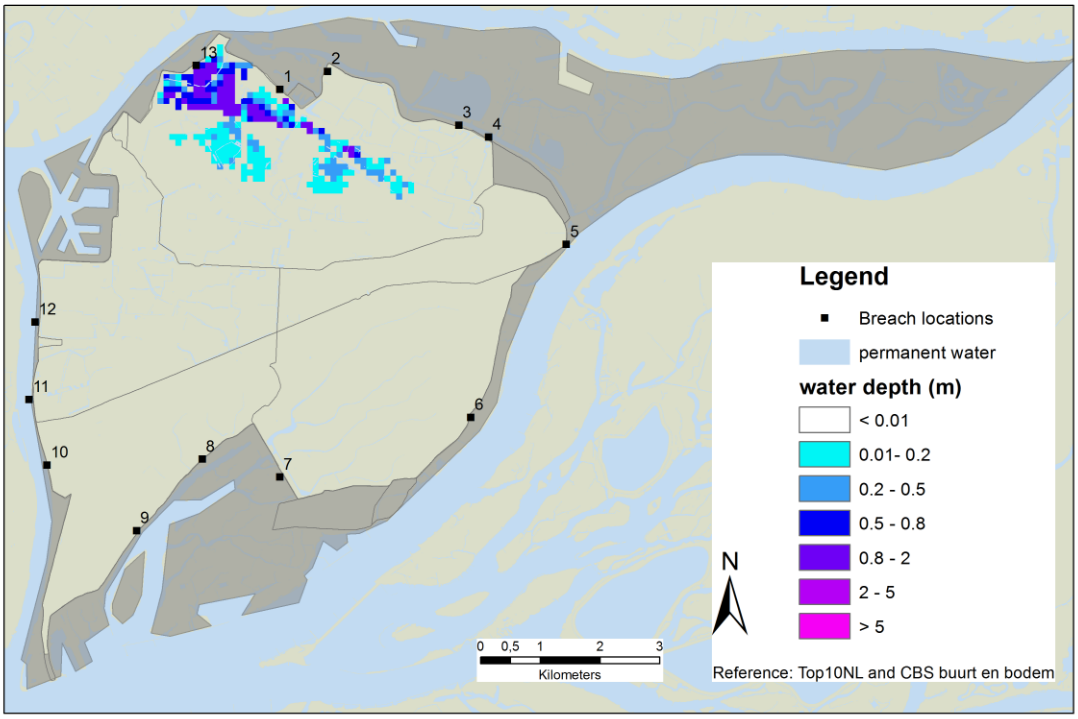
Maximum water depth breach 11



Maximum water depth breach 12

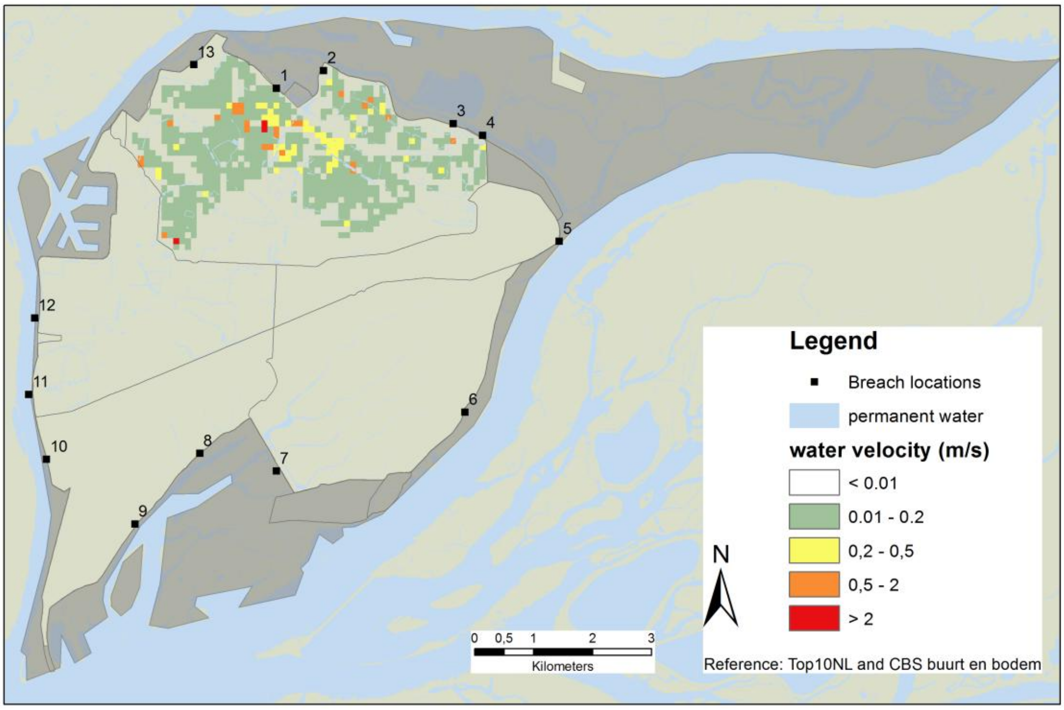


Maximum water depth breach 13

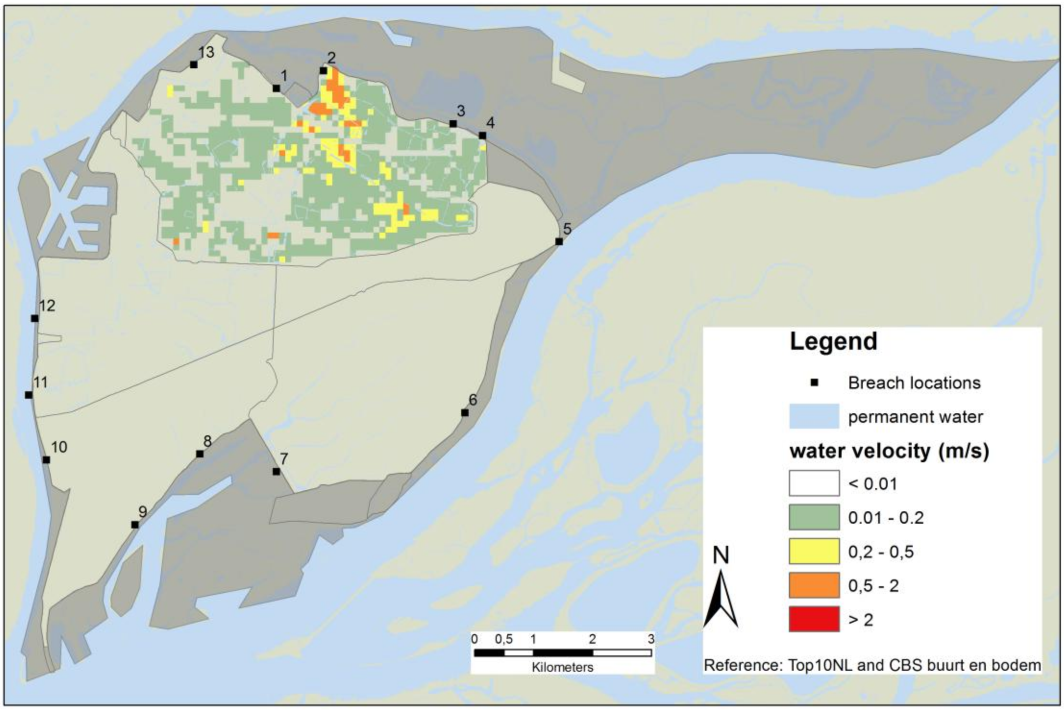


Appendix 2: Maximum velocity per breach

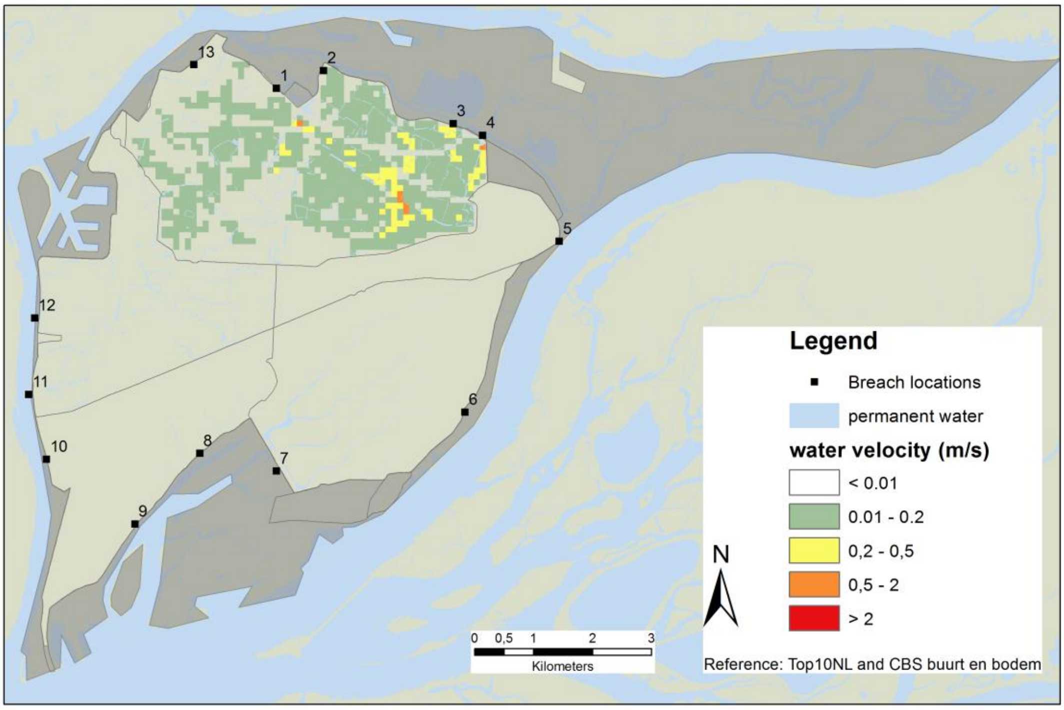
Maximum flow velocity breach 1



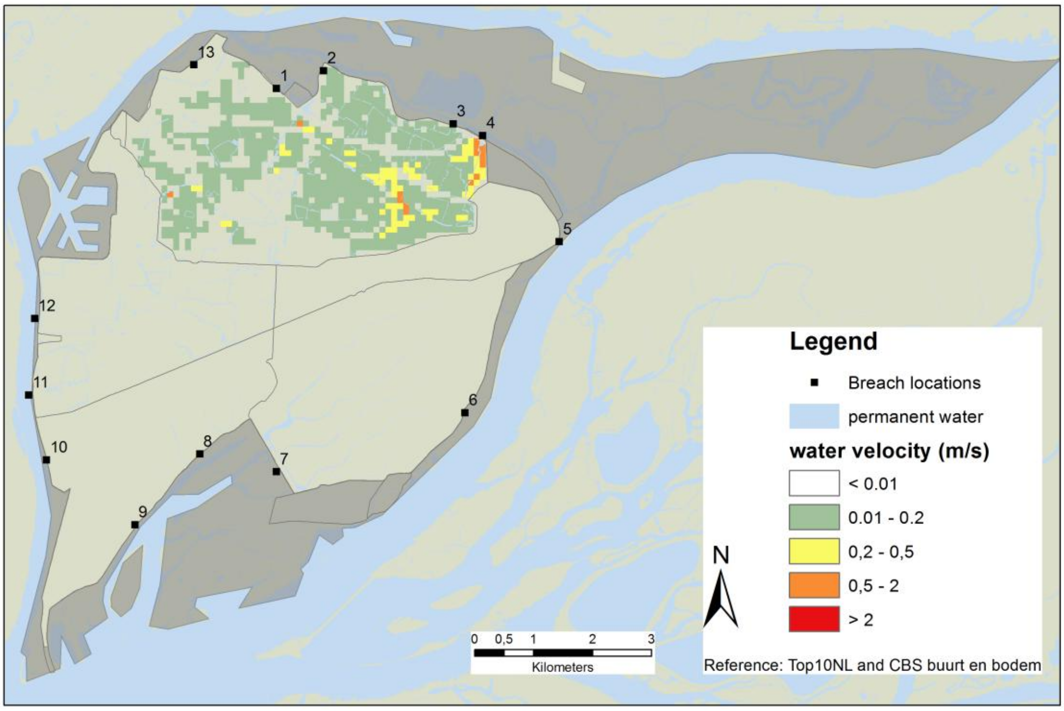
Maximum flow velocity breach 2



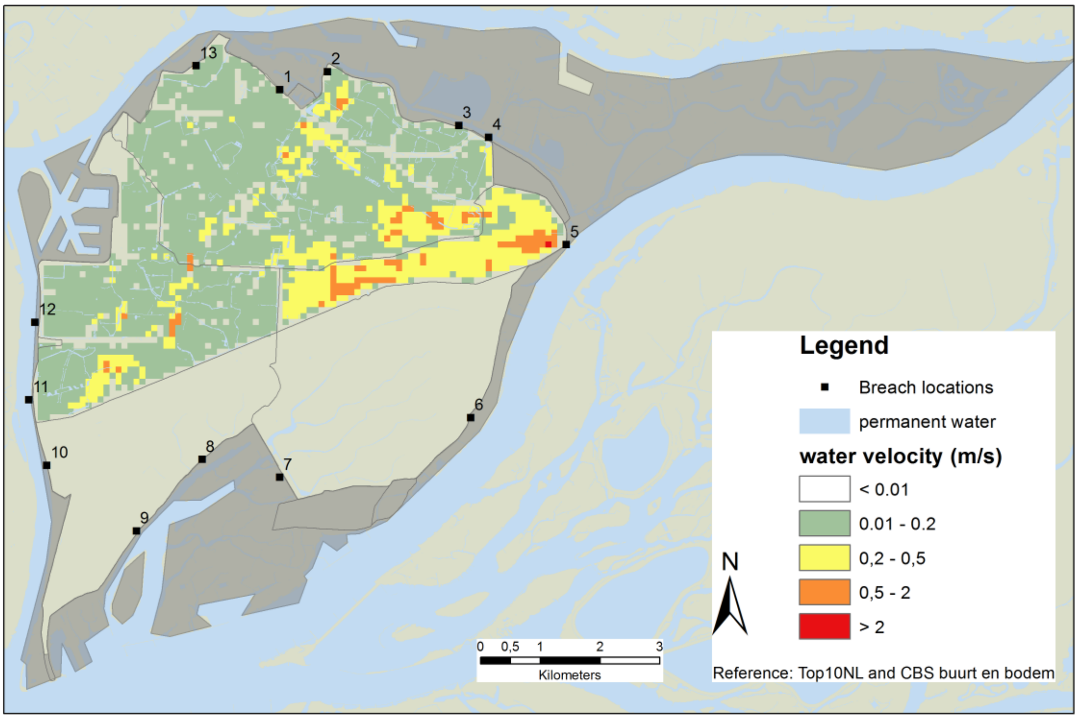
Maximum flow velocity breach 3



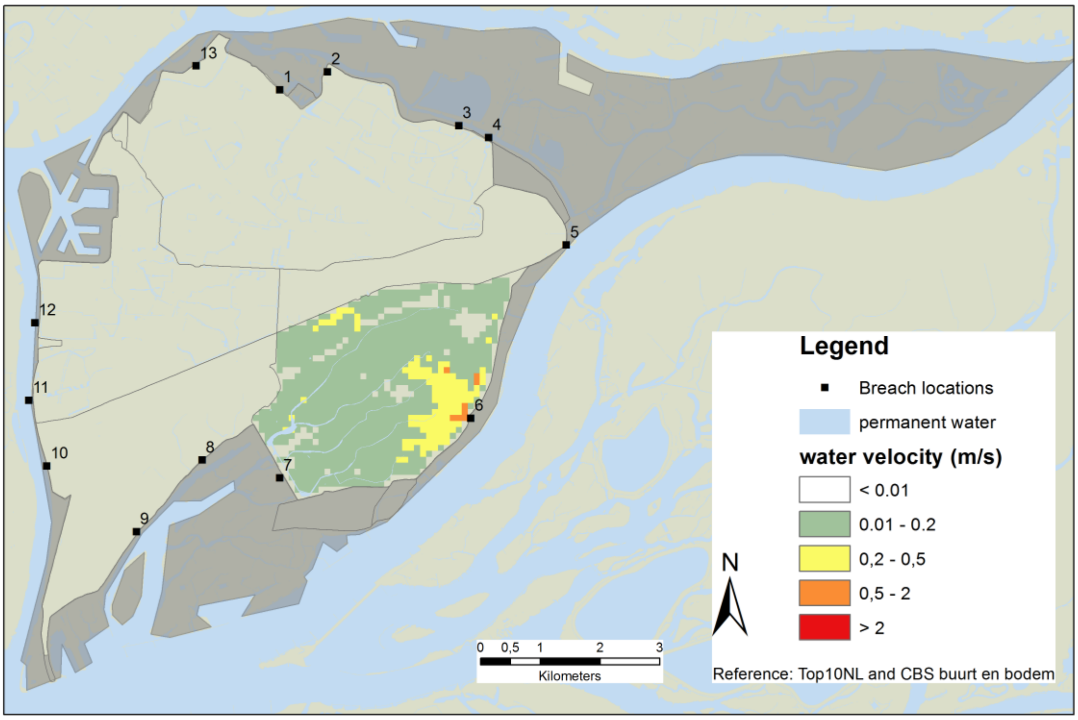
Maximum flow velocity breach 4



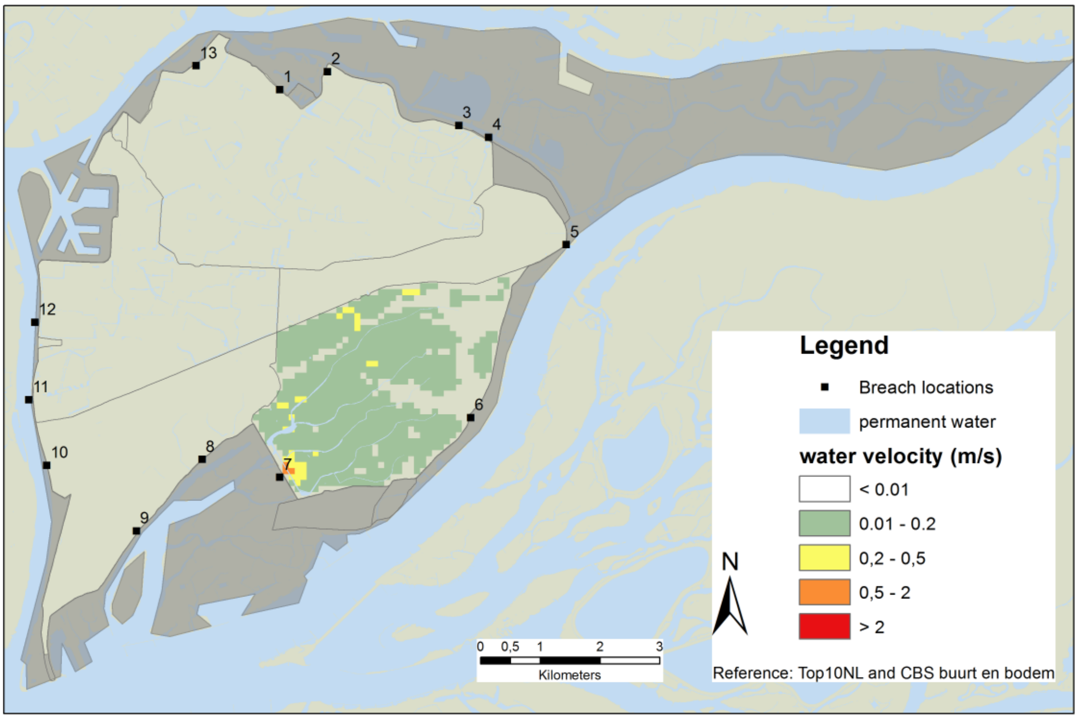
Maximum flow velocity breach 5



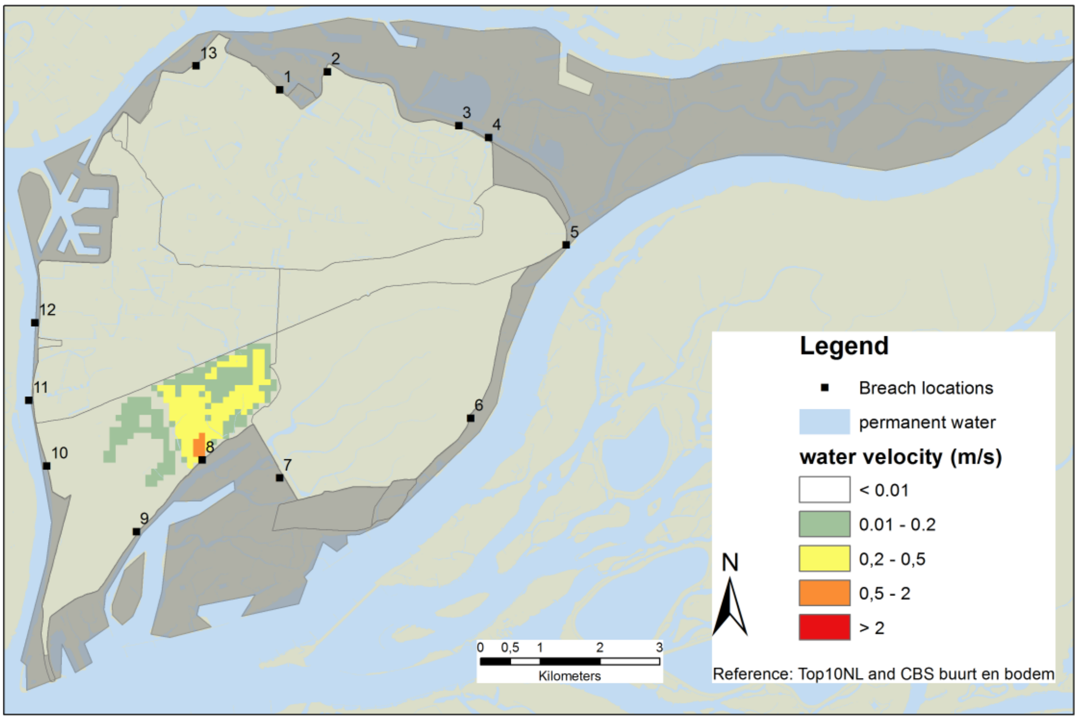
Maximum flow velocity breach 6



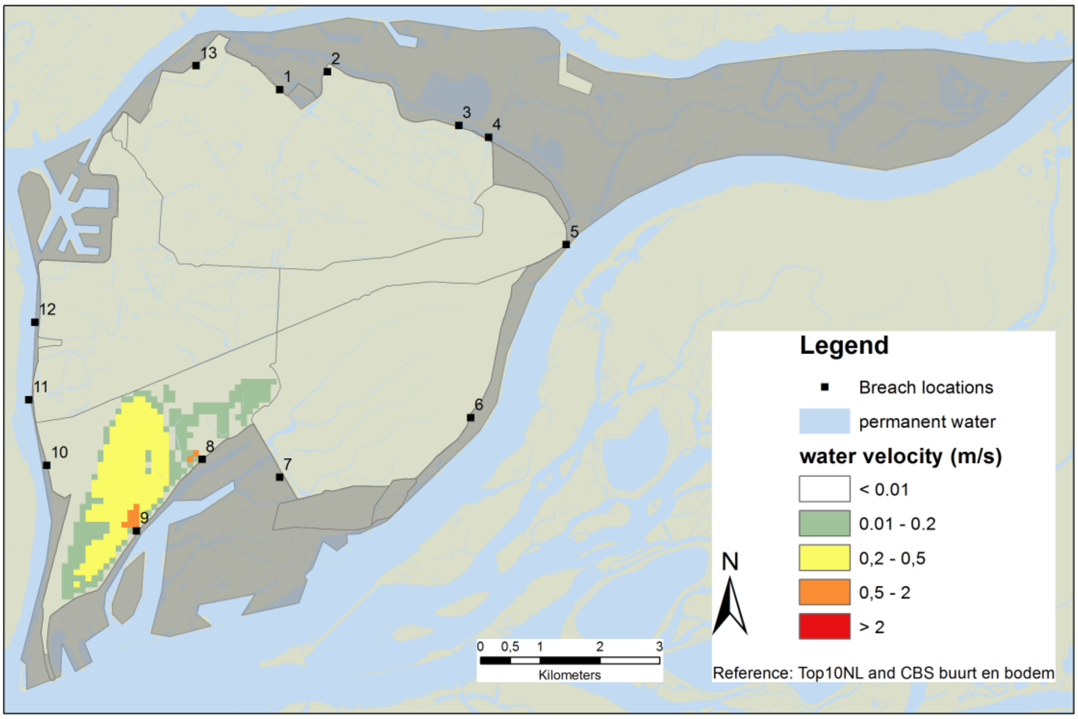
Maximum flow velocity breach 7



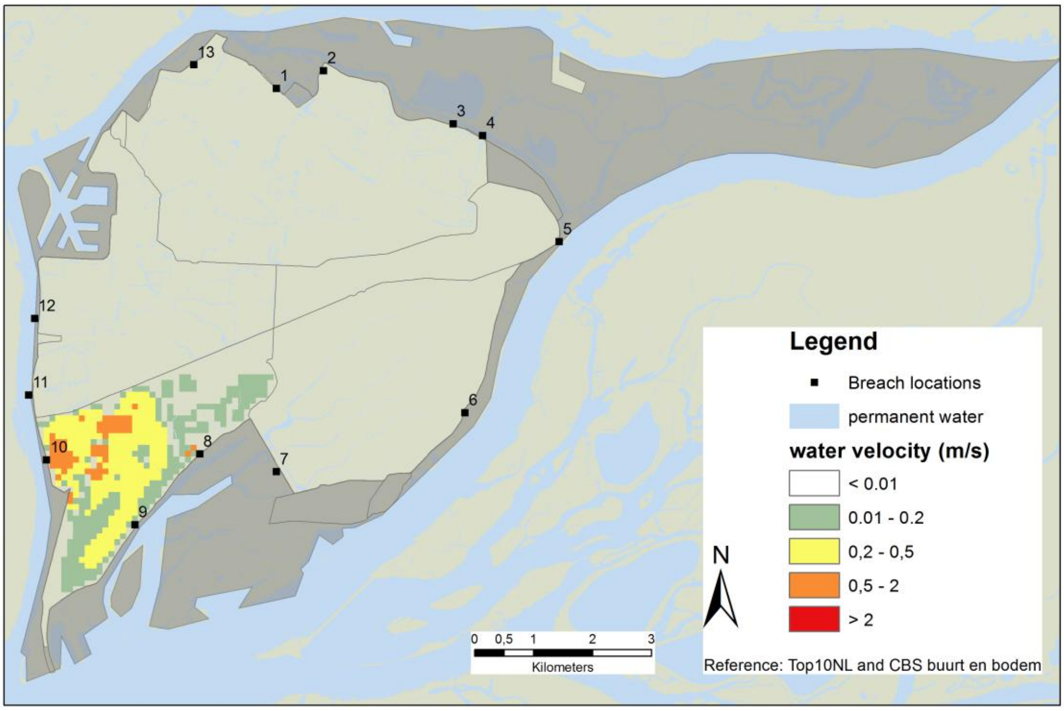
Maximum flow velocity breach 8



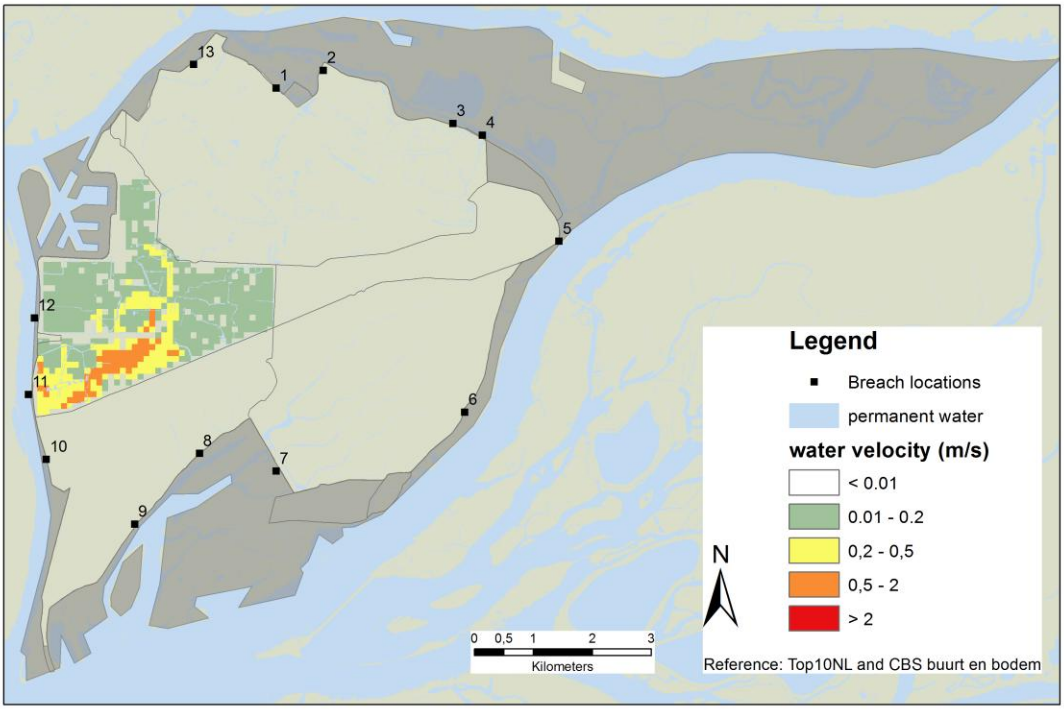
Maximum flow velocity breach 9



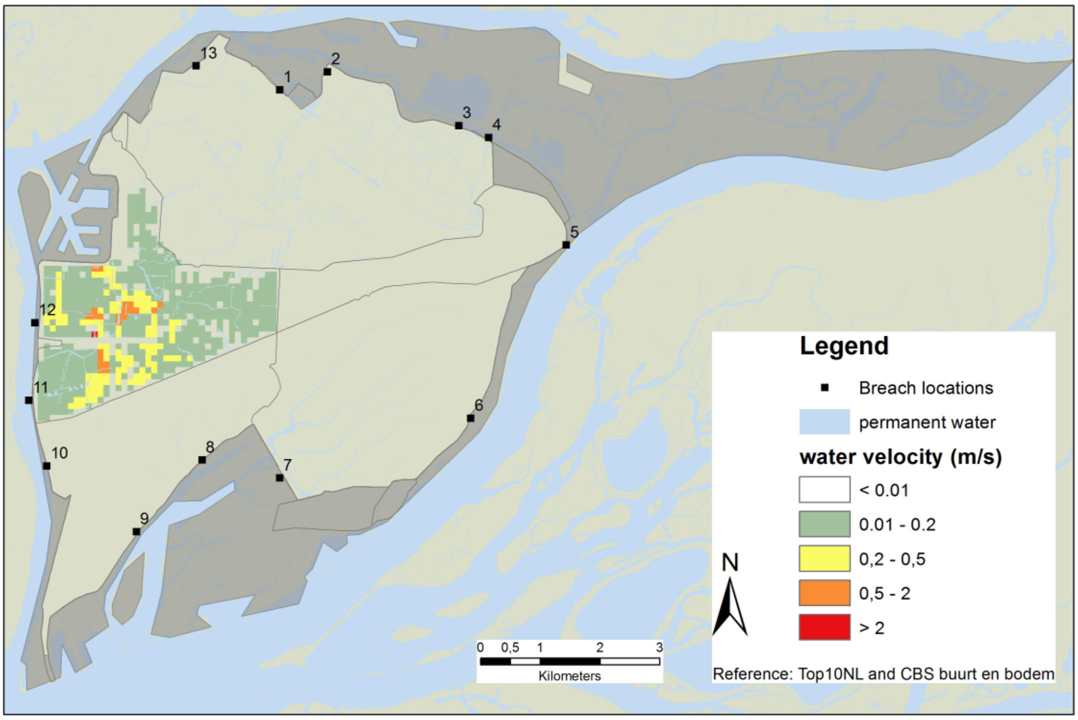
Maximum flow velocity breach 10



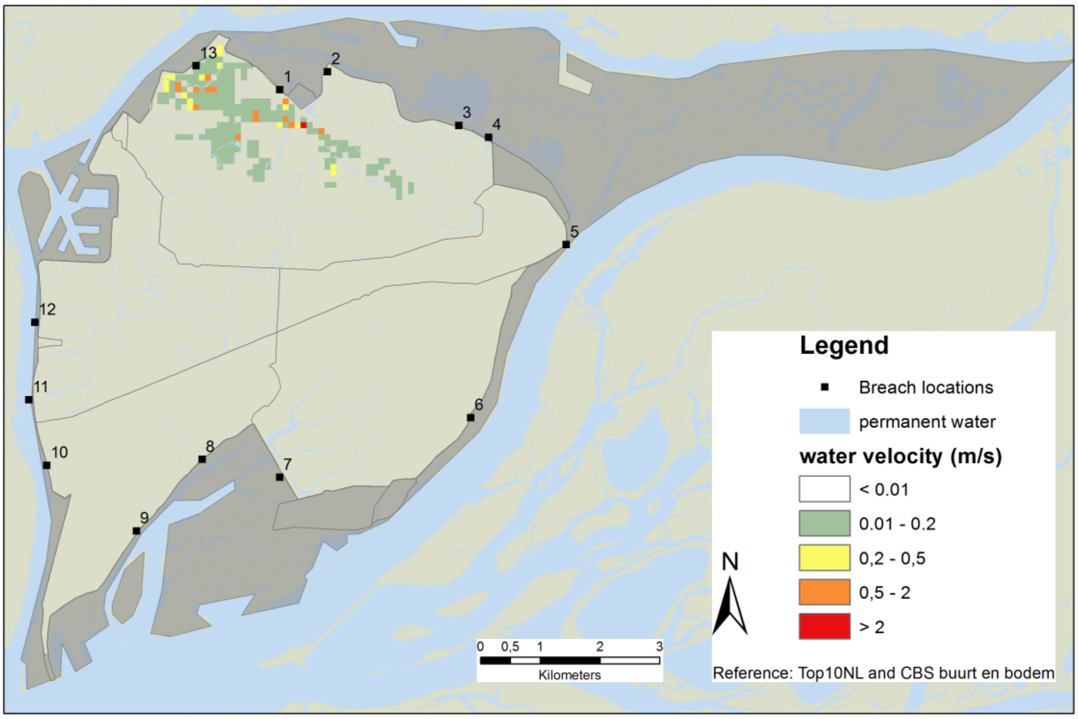
Maximum flow velocity breach 11



Maximum flow velocity breach 12



Maximum flow velocity breach 13



Appendix 3: Tables with measurements taken by the authorities

The tables showed in this appendix are in Dutch, because the actions are specific for the island of Dordrecht and also many terms are specific names used by the water board and cannot be translate to English.

Dijkbewakingsfase en criteria	Acties/taken voor dijkbewaking	Uitvoerende(n)
1 Voorwaarschuwing RWS voor Dordrecht > NAP + 1,80 m.	Peilbewaking buitenwaterstanden	Buitendienstmedewerkers beheer en onderhoud
	Waarschuwing WSHD aan coördinator Stadsbeheer Dordrecht	Calamiteitencoördinator
	Waterstanden en rivierafvoeren monitoren via MFPS, prognose geven van te bereiken waterstand in de komende 12 uur	Beleidsmedewerker beheer
	Hoofd WAC en ondersteuningsgroep inlichten	Beleidsmedewerker beheer of dienstdoende calamiteitencoördinator
2 Waarschuwing SVSD Verwachte waterstand Dordrecht> NAP +2,50 m	Beperkte dijkbewaking met eigen regiomedewerkers	Buitendienstmedewerkers beheer en onderhoud
	Hoofd WAC en ondersteuningsgroep inlichten	Beleidsmedewerker beheer of dienstdoende calamiteitencoördinator
	Regio-actiecentrum waarschuwen en opstarten	Hoofd WAC
	Dijkpostleiders inlichten over situatie en mogelijke opschaling	Hoofd WAC
	Dijkwachten informeren en zodoende overzicht verkrijgen over beschikbaarheid	Dijkpostleiders
	Informeren: directeur Beheer en Onderhoud hoofd afdeling Handhaving (senior) beleidsmedewerker waterkeringen	Beleidsmedewerker beheer of dienstdoende calamiteitencoördinator
	Waterstanden en rivierafvoeren monitoren via MFPS, prognose geven van te bereiken waterstand in de komende 12 uur	Beleidsmedewerker beheer
	Besluiten tot opschaling naar fase 3.	Hoofd WAC
3 Alarmering SVSD Verwachte waterstand Dordrecht > NAP +2,80 m.	Dijkposten bezetten met eigen medewerkers en uitgebreide dijkbewaking voorbereiden	Regiomedewerkers en overig aangewezen waterschaps-personeel
	WOT in kennis stellen	Hoofd WAC
	Dijkgraaf inlichten	Voorzitter van het WOT
	Dijkpostleiders oproepen	Regio-actiecentrum
	Dijkwachten waterschap oproepen en vrijwillige dijkwachten waarschuwen	Dijkpostleider
	Dijkposten inrichten	Dijkpostleider

Dijkbewakingsfase en criteria	Acties/taken voor dijkbewaking	Uitvoerende(n)
	Patrouillering starten op door WAC vastgesteld tijdstip	Dijkpostleider
	Waterkeringen laten inspecteren	Dijkpostleider
	Regelmatig rapportage stand van zaken aan hoofd WAC	Dijkpostleider
	Waterstanden monitoren	Calamiteitencoördinator
	Informeren OT over alle sluitingen	Hoofd WAC
	Rapportage stand van zaken door middel van actiecentrumrapport	Hoofd WAC m.b.v. de dijkpostleider(s)
	Aannemers inschakelen bij noodmaatregelen	Hoofd WAC
	Besluiten tot opschaling tot fase 4.	WOT

Dijkbewakingsfase en criteria	Acties/taken voor dijkbewaking	Uitvoerende(n)
4 Waterstand Dordrecht > NAP +2,80 m Of Sluiting Maeslant- en Hartelkering	Uitgebreide dijkbewaking	Dijkpostleider en dijkwachten
	Vrijwillige dijkwachten oproepen	Dijkpostleider
	Inpassen vloedschotten Dordrecht Dichtzetten afsluiters in gemalen primaire waterkeringen Preventieve sluiting van secundaire waterkeringen Hoogwaterbestrijding binnendijks	Hoofd WAC
	WOT in kennis stellen	Hoofd WAC
	Dijkgraaf inlichten	Voorzitter van het WOT
	Waterkeringen met uitgebreide bewaking laten inspecteren	Dijkpostleider
	Regelmatig rapportage stand van zaken aan hoofd WAC	Dijkpostleider
	Waterstanden monitoren	Calamiteitencoördinator
	Informeren WOT over alle acties	Hoofd WAC
	Rapportage stand van zaken door middel van actiecentrumrapport	Hoofd WAC m.b.v. de dijkpostleider(s)
	Aannemers inschakelen bij noodmaatregelen	Hoofd WAC
	Besluiten tot afschaling tot dijkbewaking	WOT

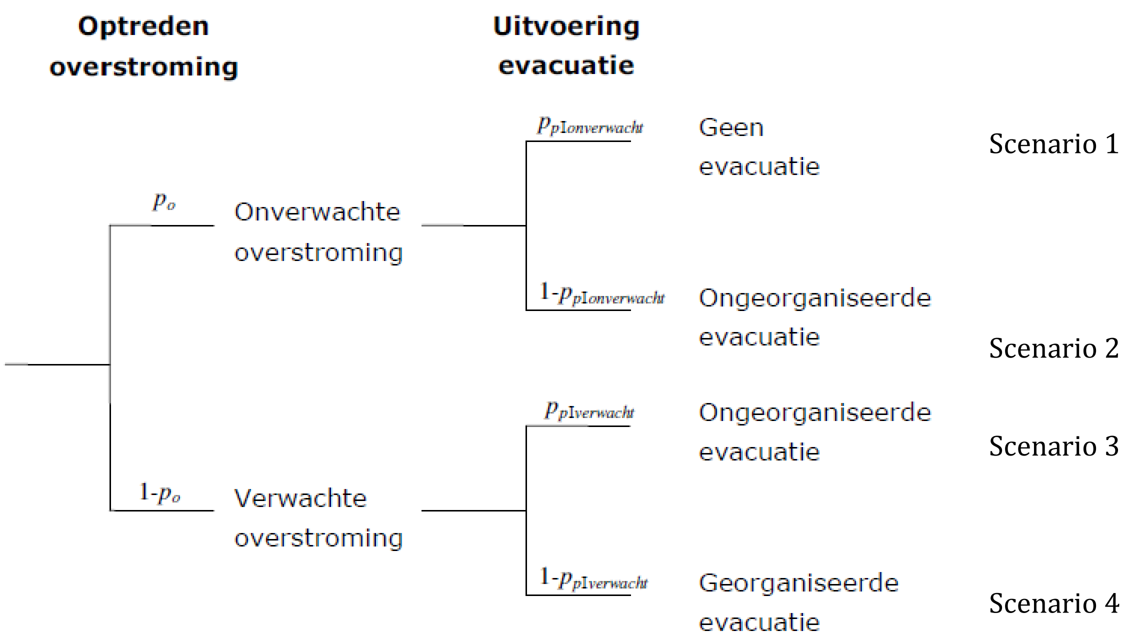
Dijkbewakingsfase en criteria	Acties/taken voor dijkbewaking	Uitvoerende(n)
Te verwachten waterstand > NAP +1,80 m te Dordrecht	Hoogwaterbestrijdingsorganisatie van de gemeente Dordrecht in beperkte schaal in bedrijf stellen	Stadsbeheer Dordrecht
	Bruggen laten openen	idem
	Afsluiten stroom en dichtzetten afsluiters in persleidingen	idem
	Voorbereiden en plaatsen van wegafzettingen in buitendijks gebied van het centrum van Dordrecht	idem
	Informeren van regionaal commandant dienst brandweer via de GMC over het plaatsen van wegafzettingen en het onderlopen van buitendijkse kades	idem
	Sector Stadswerken is direct inzetbaar voor plaatsen van vloedschotten of andere afsluitmiddelen	idem
	Voorbereiden en verstrekken van zandzakken in het buitendijks gebied van het centrum van Dordrecht.	idem

Dijkbewakingsfase en criteria	Acties/taken voor dijkbewaking	Uitvoerende(n)
Te verwachten waterstand > NAP +2,30 m te Dordrecht	Oproepen personeel van de sector Stadswerken tbv uitvoering van de bestrijdingsmaatregelen behorende bij Hoogwaterfase II	Stadsbeheer Dordrecht
	Verstrekken van opdrachten voor het plaatsen van wegafzettingen in het buitendijkse gebied van het centrum van Dordrecht	idem
	Laten waarschuwen van de bevolking in het buitendijkse gebied van het centrum van Dordrecht door de afdeling Communicatie van de gemeente Dordrecht	idem
	Informeren van Havenbedrijf Dordrecht	idem
	Plaatsen van wegafzettingen in het buitendijkse gebied van het centrum van Dordrecht na opdracht van directeur Stadswerken	idem
Te verwachten waterstand > NAP +2,80 m te Dordrecht	Inpassen vloedschotten Voorstraat	Stadsbeheer Dordrecht

Appendix 4: Evacuation scenarios and percentages

Representation of the evacuation models and table with conditions and percentages for the evacuation of the island of Dordrecht from Hoss et al. (2011).

Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Average
Conditional probability	0.40	0.44	0.12	0.04	
Evacuation factor	0.00	0.03	0.59	0.76	15%



Appendix 5: Assumptions used for the results of the storylines

This table shows the main important assumptions that are used to do the calculations on the end results of the storylines. The assumptions for critical infrastructure are based on the literature study on critical infrastructure and contacting the experts on these subjects. The percentages for the evacuation are taken from the evacuation calculator and from the report of Maaskant et al. (2009). The maximum distance for traveling on the island is determined with the use of ArcGIS. Finally, the water depths for driving vehicles is from Van de Pas et al. (2011).

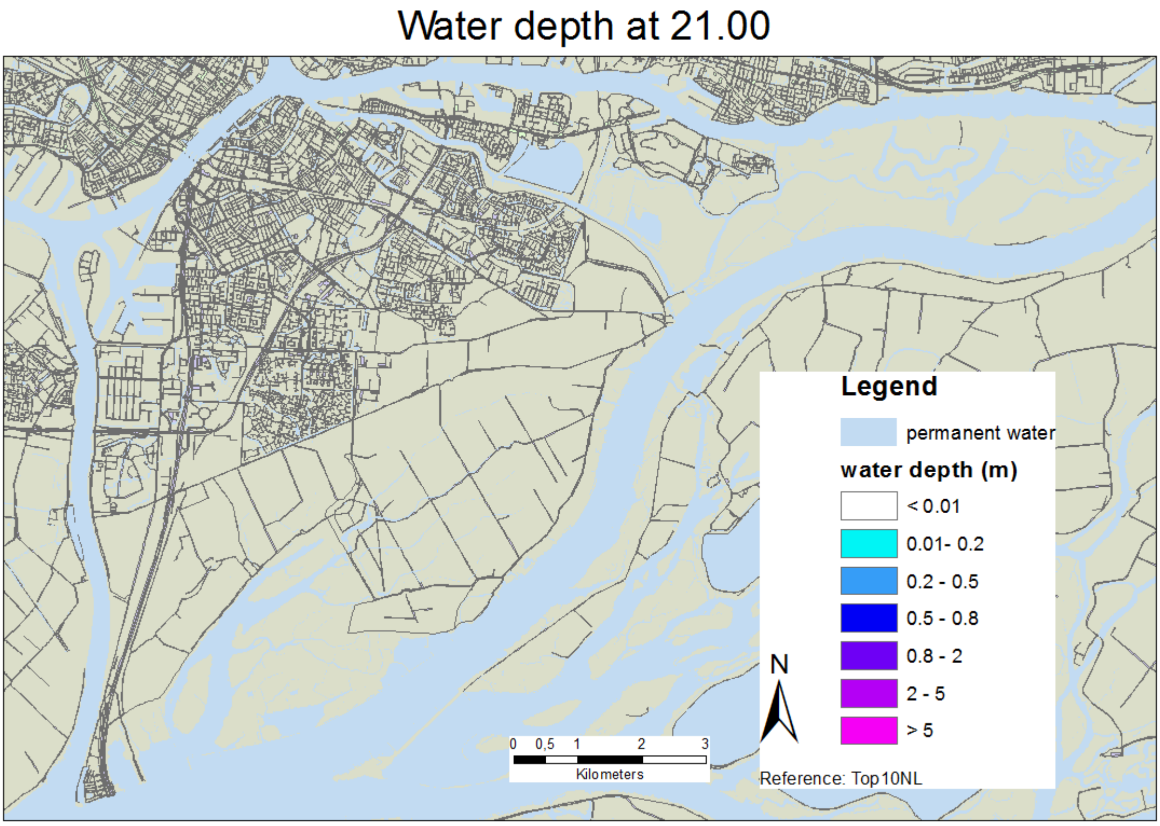
Category/event	Percentage, time, depth or velocity
Critical infrastructure fails:	**Water depth (m)**
Electricity network	0.3 (and is shut down as soon water enters an area to avoid electrocution)
Gas network	1.5 (in main distribution stations, and fails when electricity fails)
Communication network	0.3 (and fails when electricity fails)
Drink water network	20 m (main distribution center is self-sufficient for at least 10 days if other infrastructure fails)
Road network	0.2 m (in case of roads that border trenches etc., because no difference is seen between the road and the trench)
Percentage of non self reliant people:	
Age 0 – 64 years	0.01 %
Age > 64 years	0.1 %
Evacuation (speeds):	
By car	20 km/h with 2.26 person per car
By foot	4 km/h
Time between receiving warning and response of civilians	60 minutes
Maximum evacuation distance on the island	5 km
Ability of vehicles to drive through water:	Water depth (m)
Cars	< 0.5 (important for emergency rescues)
Emergency services/army vehicles	< 0.8 (important for emergency rescues)

Appendix 6: Figures representing storyline 1, 2 and 3

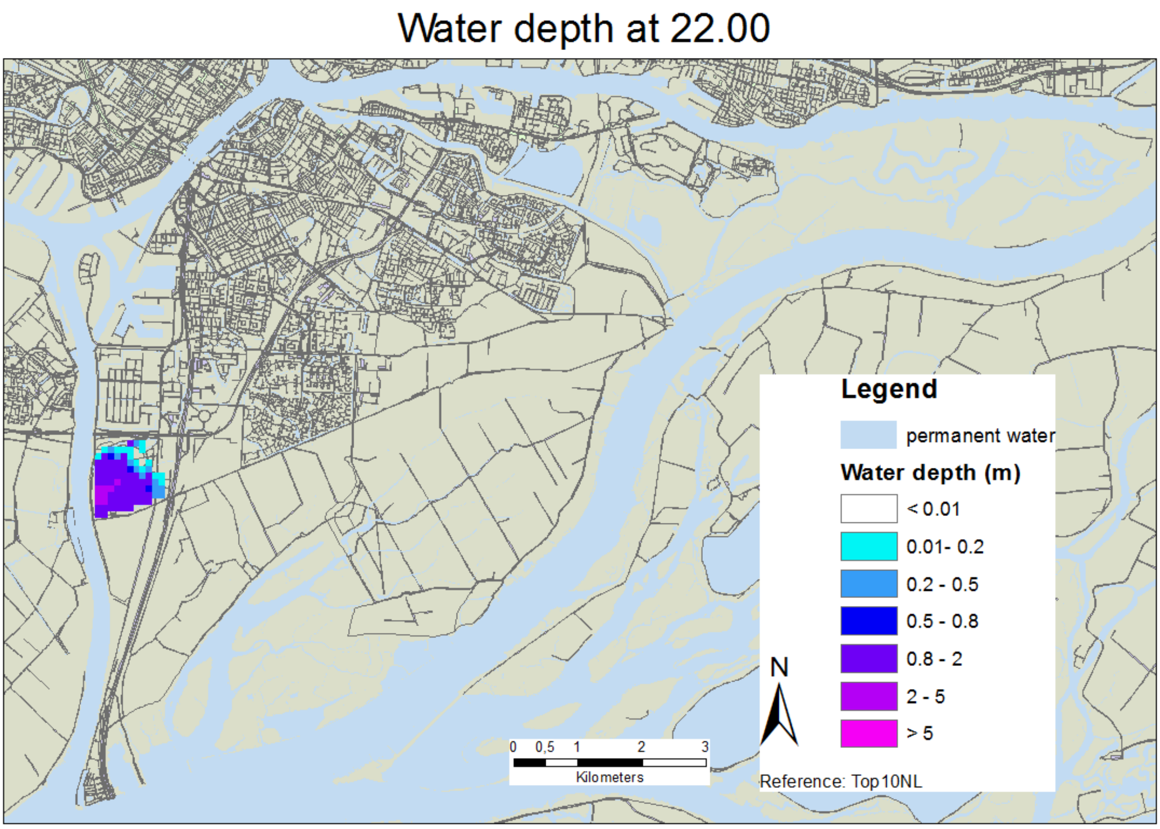
The figures that were produced by "De Urbanisten" are fitted on an A0 format, otherwise the representation is too small to read if printed. However this size is too large to fit and print within this report, therefore this appendix is included on the CD on the back cover of this document.

Appendix 7: Inundation through the breach along the "Kildijk"

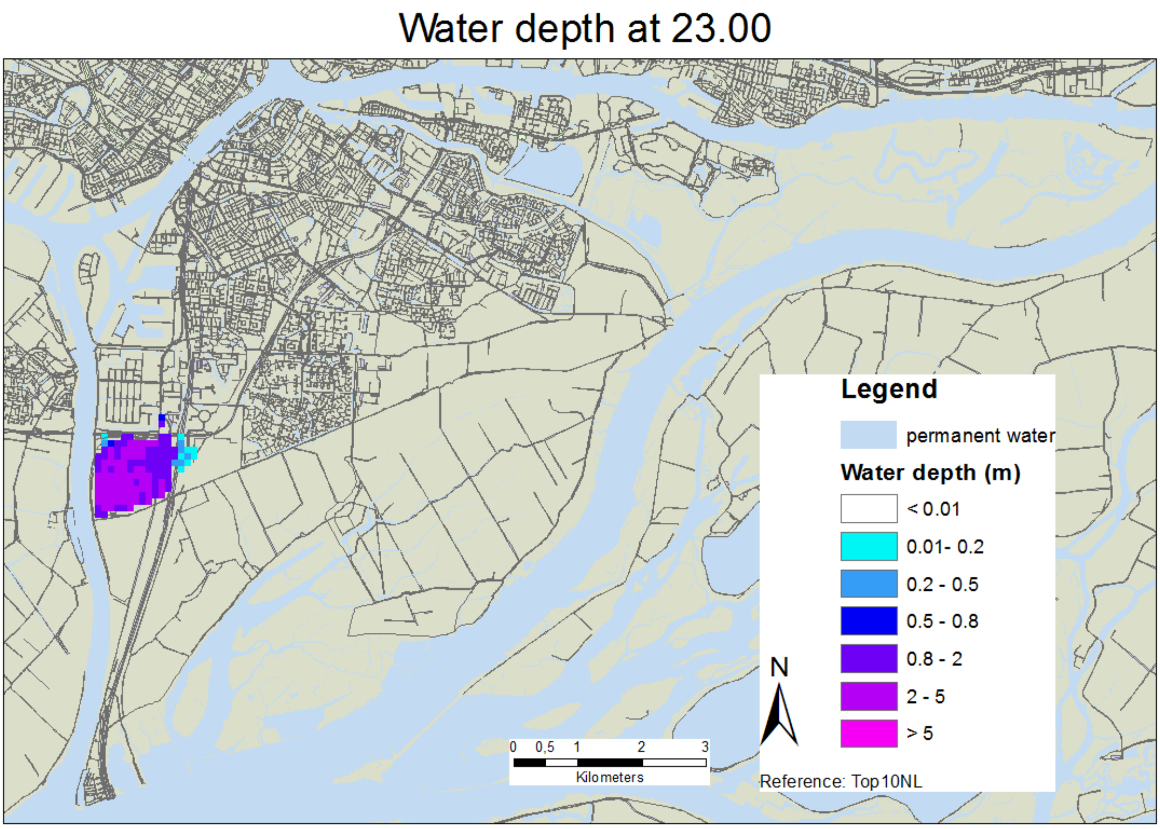
Breach occurs at January the 8th at 20.50



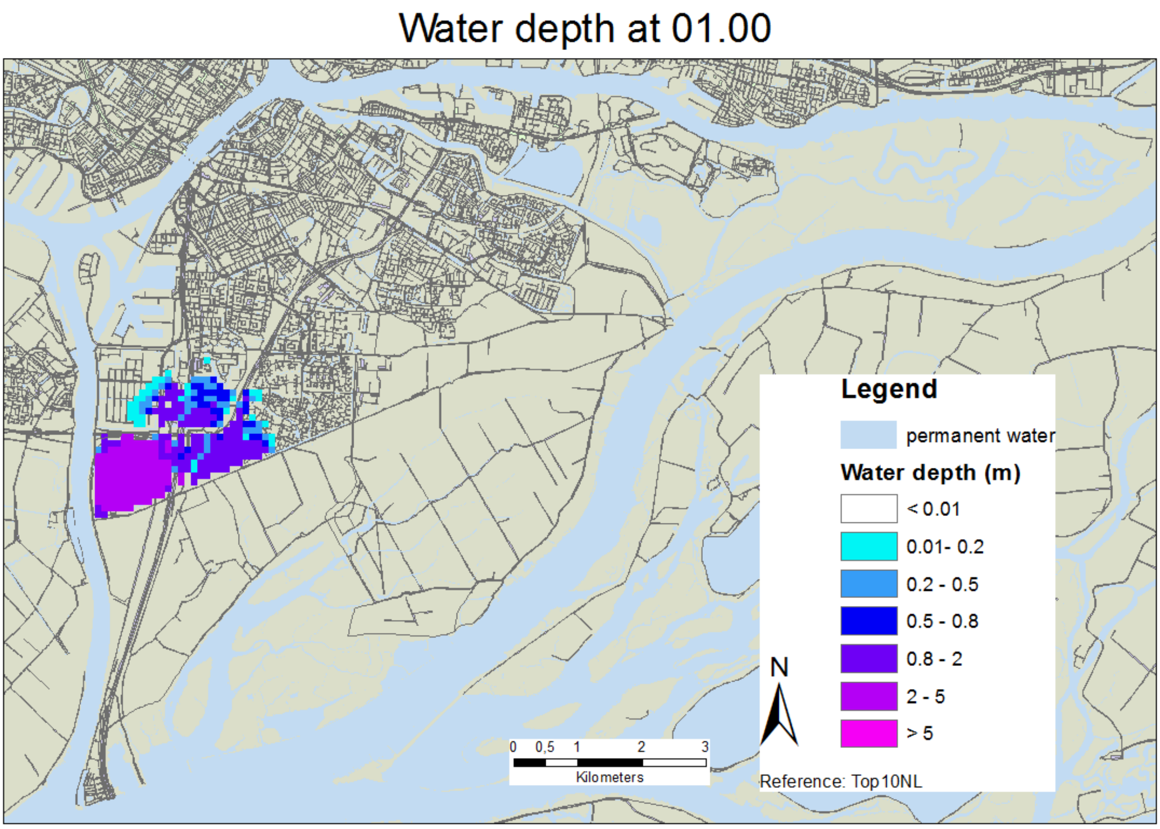
0 hours after the breach



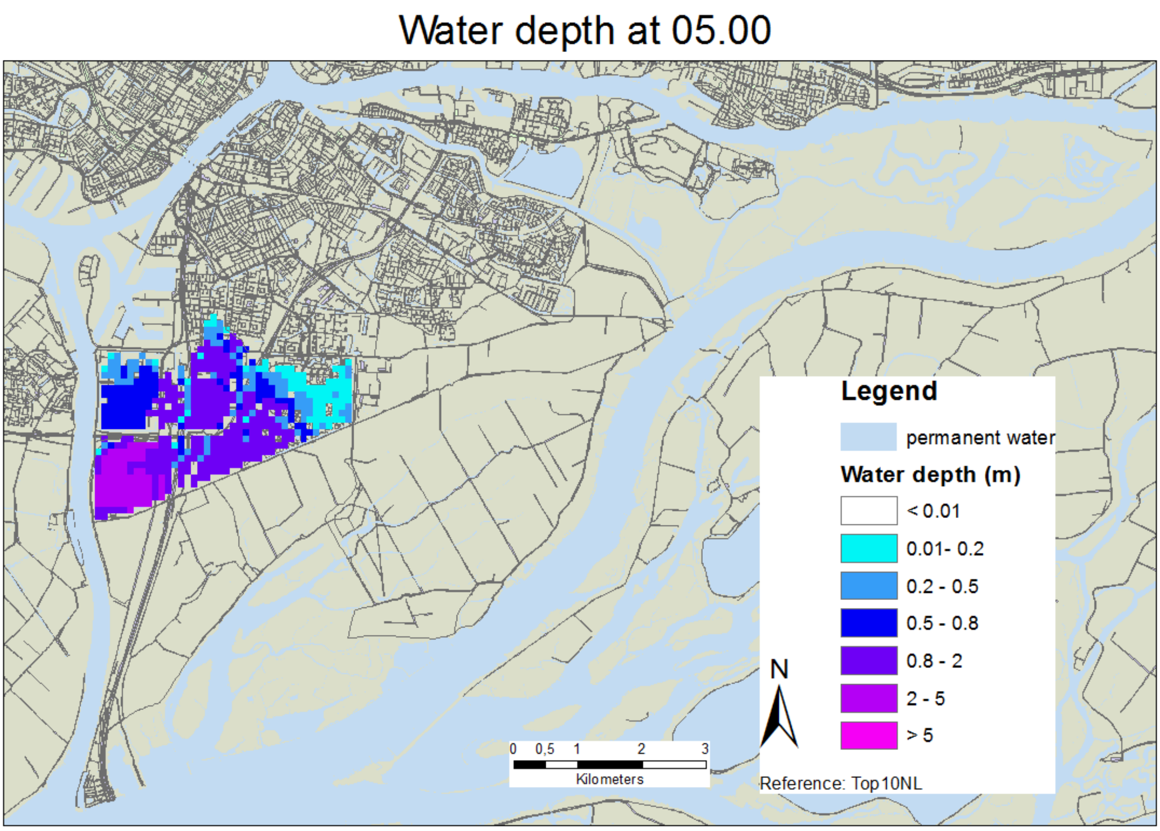
1 hours after the breach



2 hours after the breach

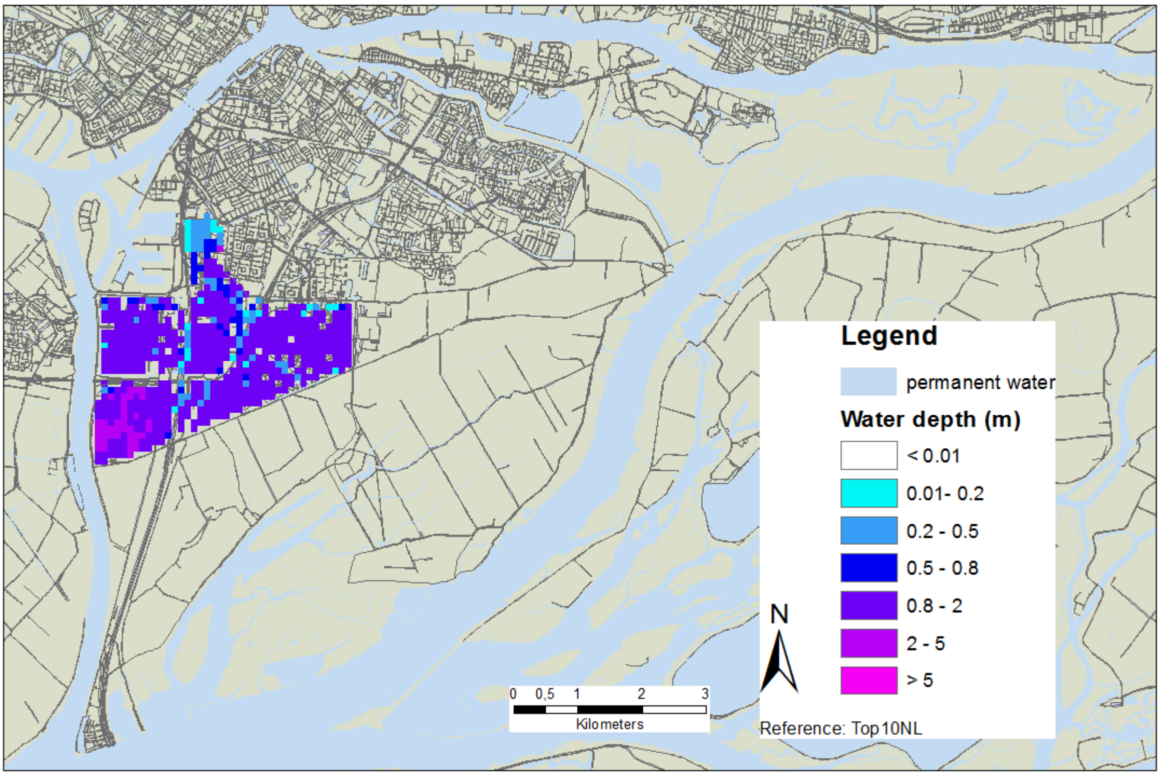


4 hours after the breach



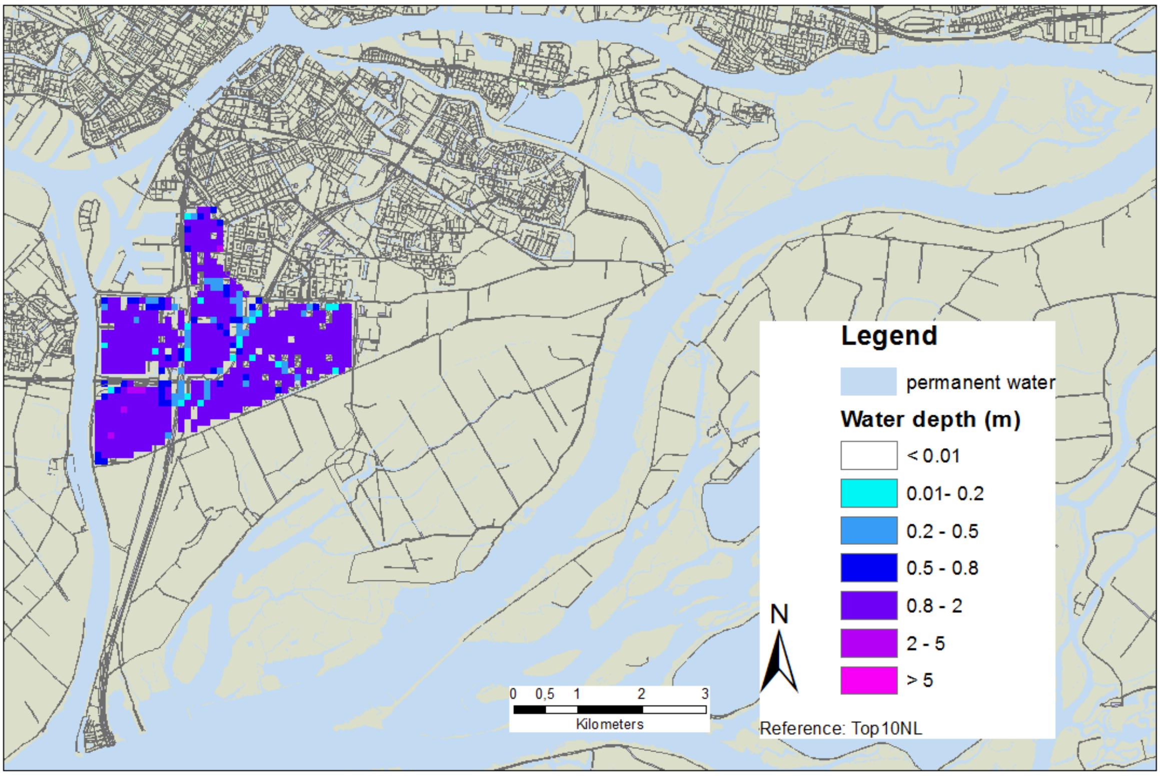
8 hours after the breach

Water depth at 13.00

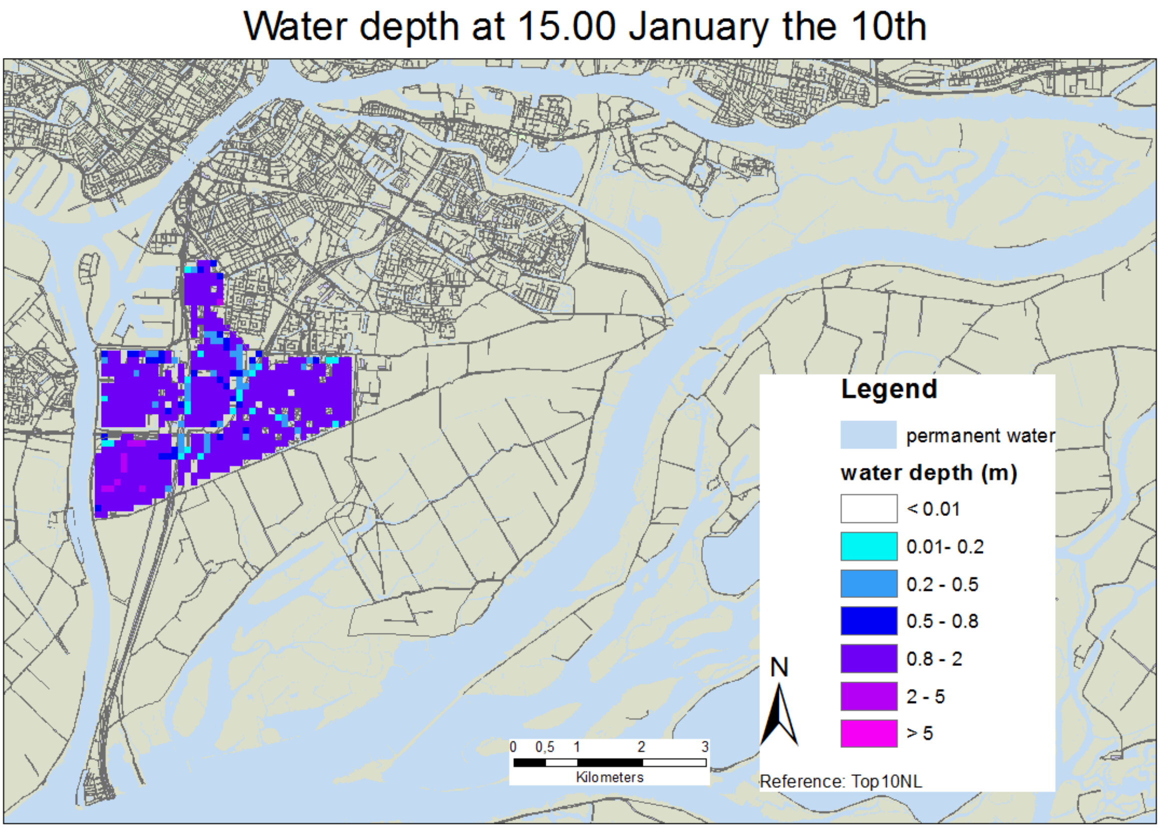


16 hours after the breach

Water depth at 5.00 January the 10th



32 hours after the breach



42 hours after the breach

Appendix 8: Calculations on draining the island for the two storylines

For the calculations on the drainage of the island 2 different numbers for the pumping capacity are used, as the precise capacity is not known. The first number is based on the pumping capacity found in the Memo of Karin Stone (2012). The second one is based on the advice of Hans Waals of the Water Board. Furthermore, calculations are made for both including and excluding the emerengy pumps of RWS, as it is not exactly know if the total capacity of these pumps is available.

Drainage pumps	**Memo Karin Stone (m3/s)**	**Water board (m3/s)**
Noordbovenpolder	0.2167	-
Stadspolders	3	2
Weeskinderendijk	4	-
Staring	0.8333	-
Loudon	1.6667	1.6
Noordendam	-	-
Johannes Vis	-	2
Extra pumps water board	-	1.5
Total	**9.7**	**7.1**
RWS emergency pumps	22	

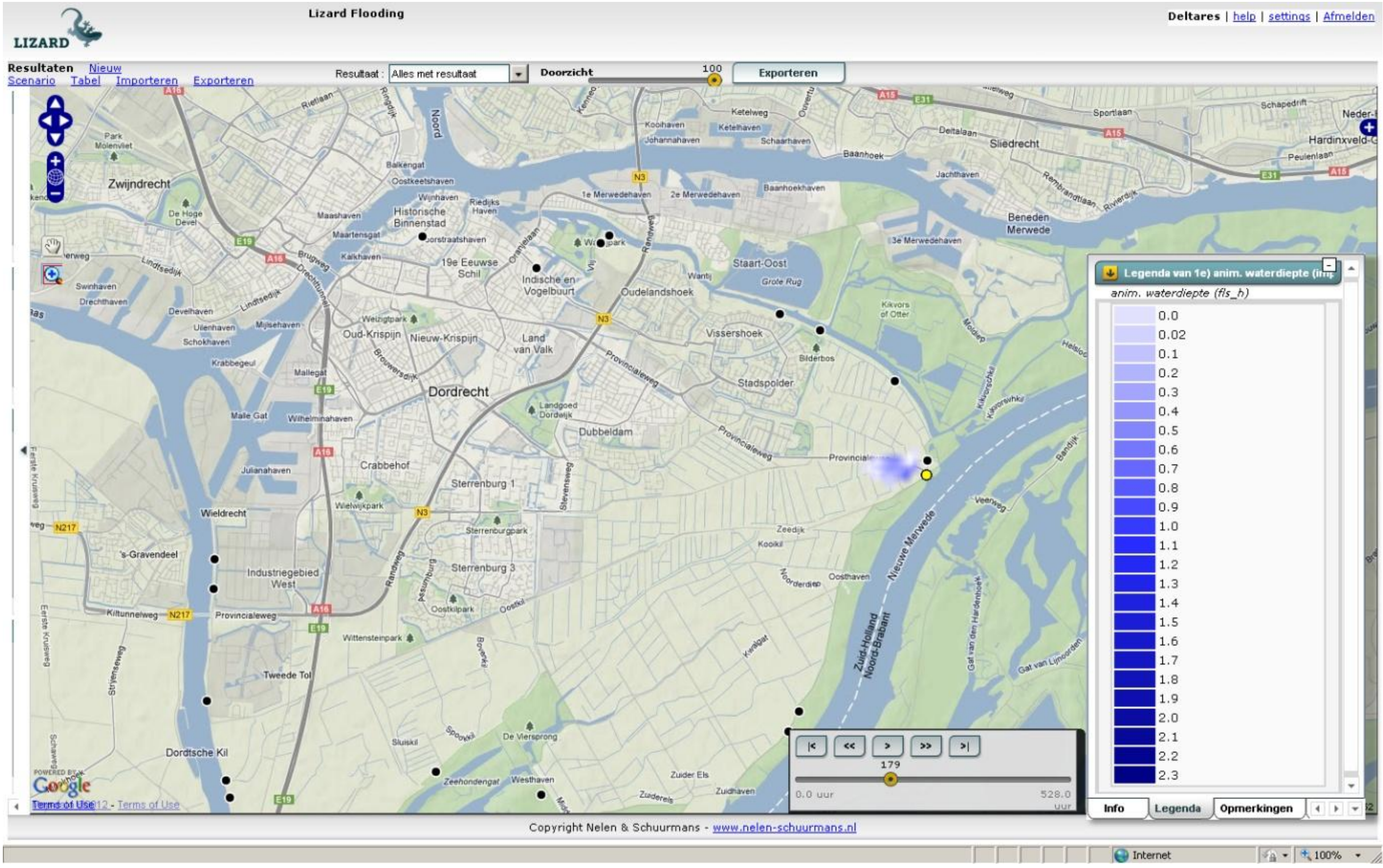
Total volume inundation	**m3**
Breach "Kop van 't land"	60260000
Breach "Kildijk"	9870000

Draining time (days)	**Memo Karin Stone**		**Water Board**	
	including RWS pumps	excluding RWS pumps	including RWS pumps	excluding RWS pumps
Breach "Kop van 't land"	22	71.8	24	98.2
Breach "Kildijk"	3.6	11.8	3.9	16.1

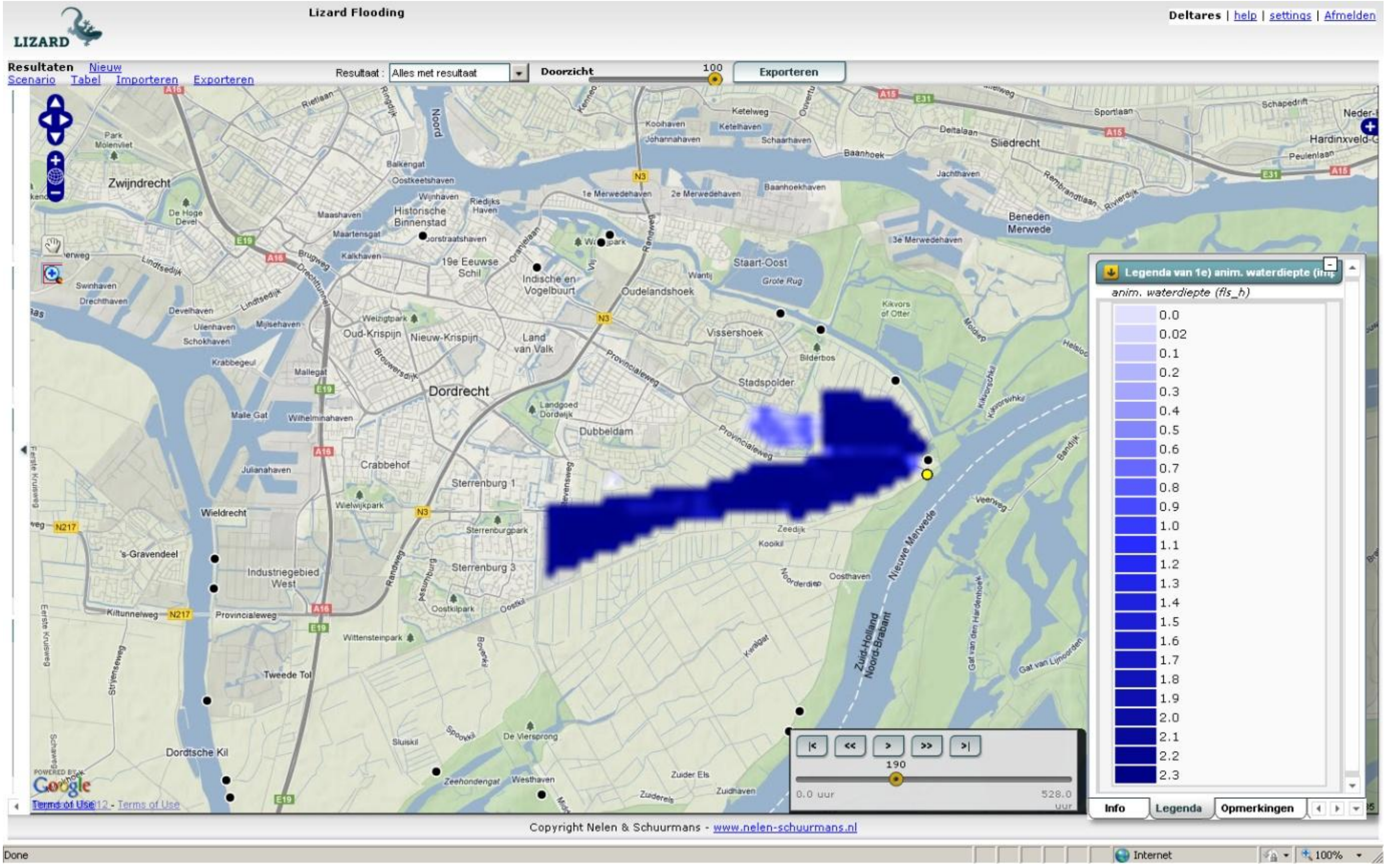
Appendix 9: The inundation of the island through the breach near the “Kop van ‘t land”

As no flood model run was executed for the breach near the “Kop van ‘t land” the Lizard tool of Nelen en Schuurmans was used to represent the inundation pattern during time for this breach.

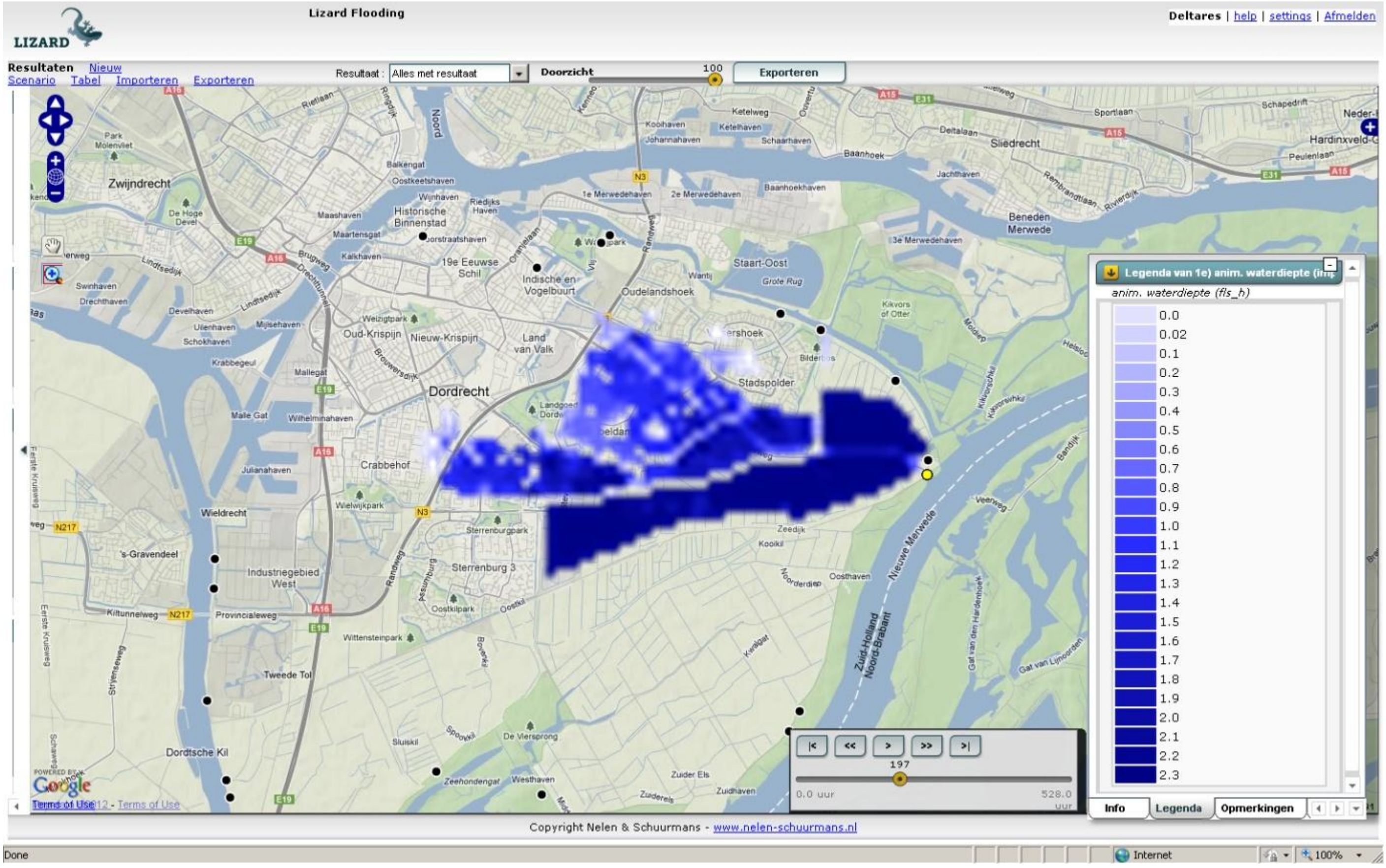
0 hours after the breach



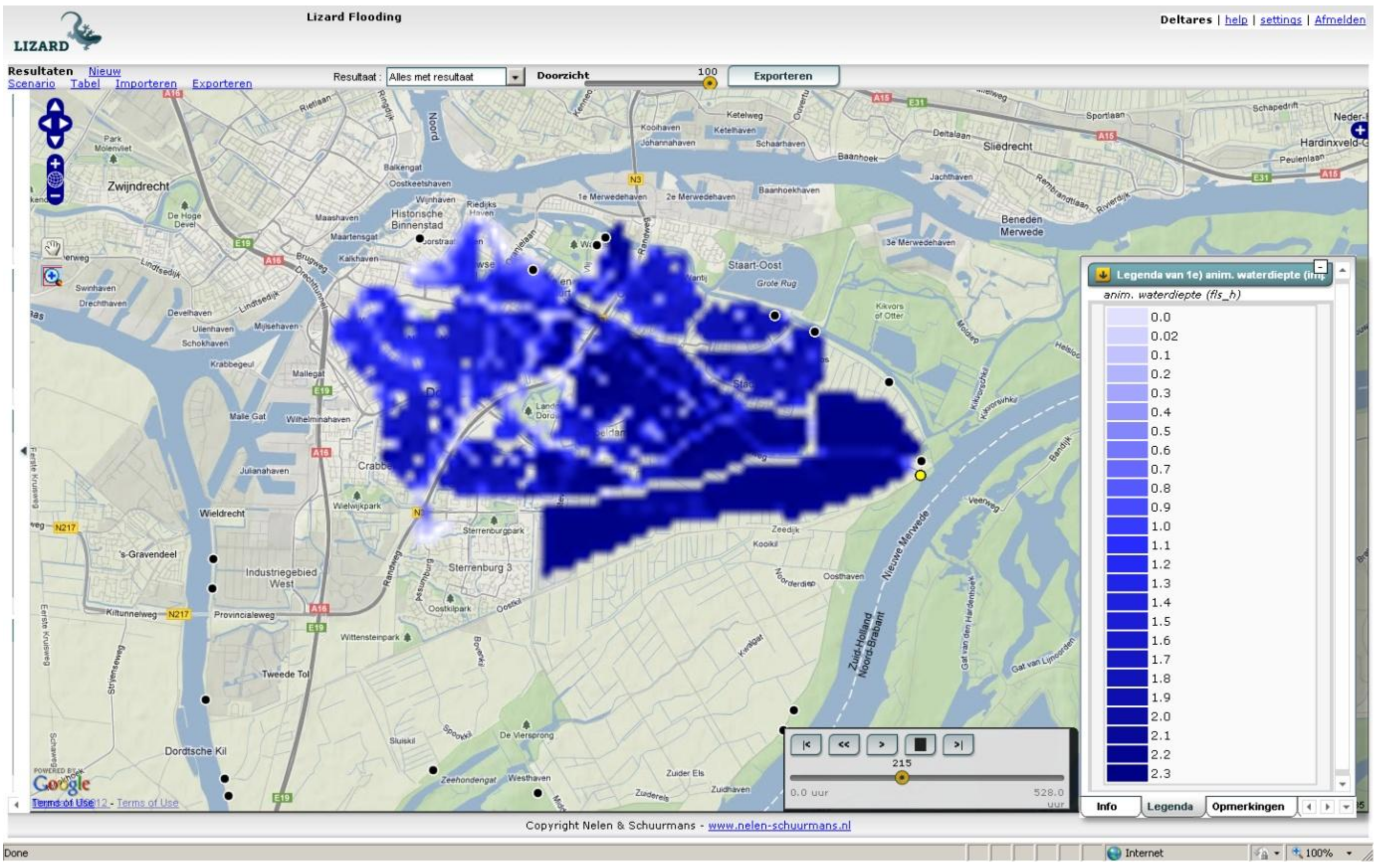
11 hours after the breach



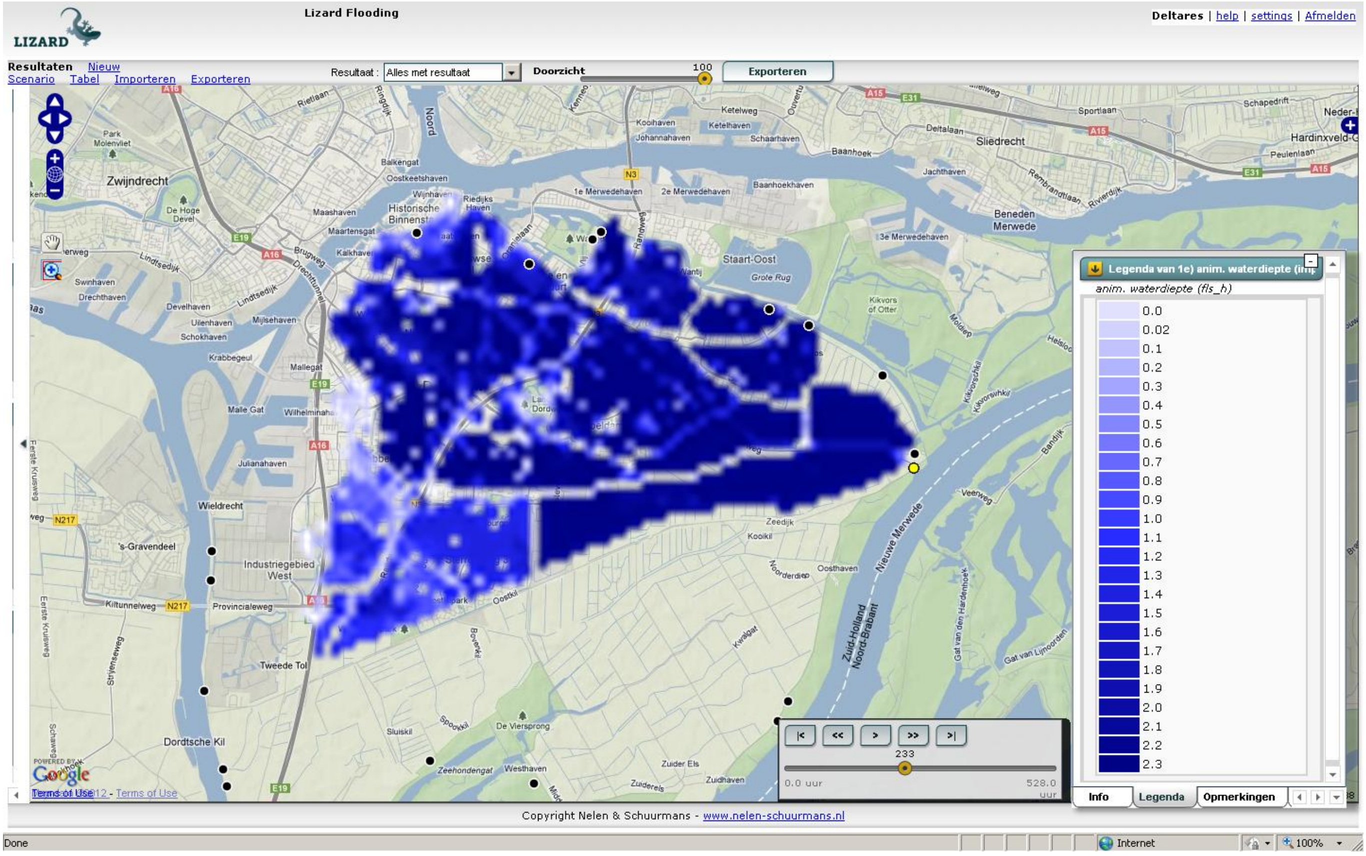
18 hours after the breach



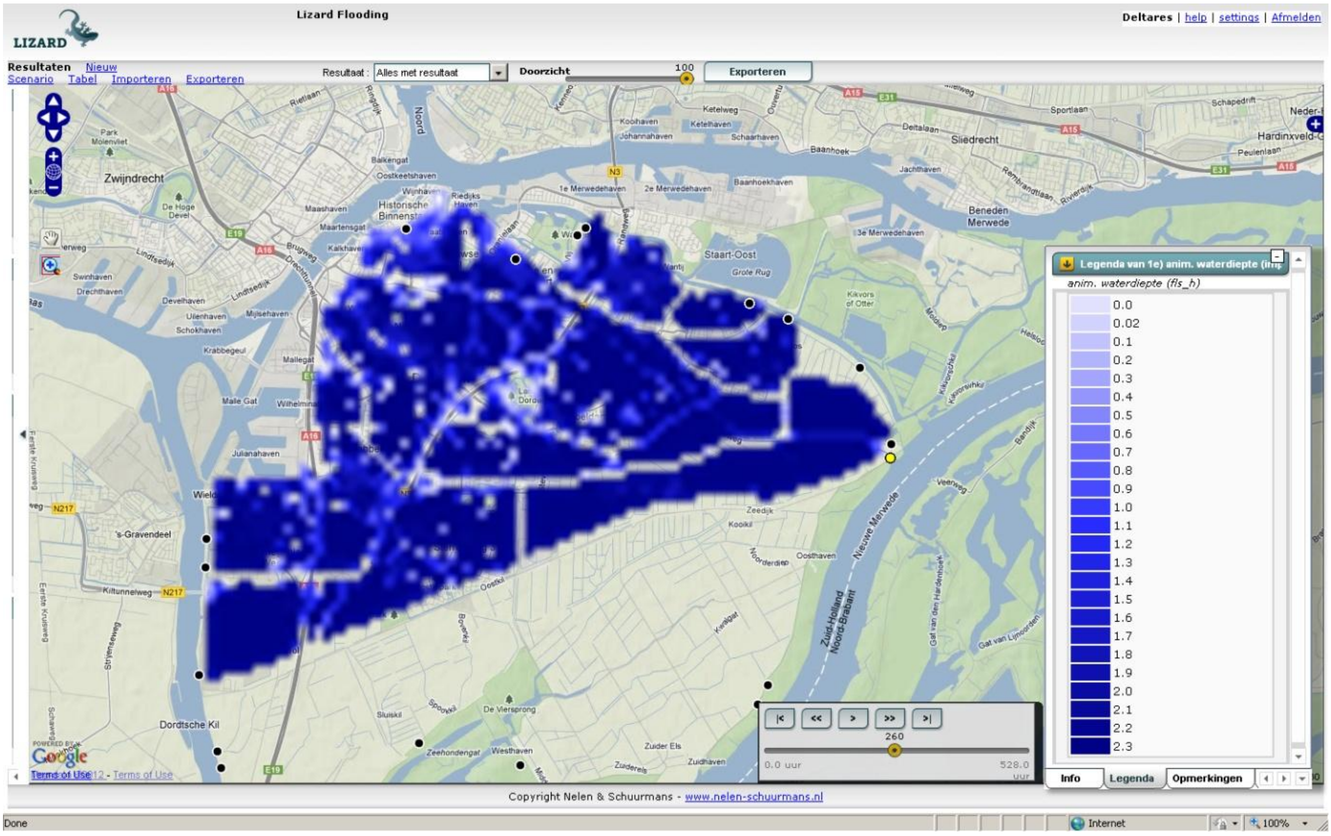
36 hours after the breach



54 hours after the breach



81 hours after the breach



Appendix 10: HIS-SSM report for the breach along the "Kildijk"

This is the output of the HIS-SSM calculation. The tool is in Dutch, so is the report.

```
Berekening                      :
Standaardmethode2008_SSM100NL2006_Bres11_2000_hbaan
Omschrijving                    : Bres11_2000_hbaan
Datum                           : 7/10/2012 2:43:10 PM
Model                           : Standaardmethode2008
Dataset                         : SSM100NL2006
Scenario                        : Bres11_2000_hbaan
Wegingset                       : standaard

Details van scenario
Locatie op schijf               : D:\Data en Model\Backup_03-02-
12\DR_22.lit\8\
Waterdiepte [m]                 : dm1maxd0.asc
Stijgsnelheid [m/uur]           : stijgsnelheid_DH.asc
Stroomsnelheid [m/s]            : dm1maxc0.asc
Hoogbouw veilig                 : J
Evacuatiefactor [-]             : 0
Initieel prijspeil [jaartal]    : 2000
Gehanteerd prijspeil [jaartal]: 2000
Gehanteerd inflatiecijfer [%] : 2% per jaar

Resultaat Schade
     Schade                                                   :
741,829,338   Euro

Totaal aantal slachtoffers                                    :
67   Pers

Inwoners in beschouwd gebied
     Aantal inwoners in beschouwd gebied                      :
20,415   Pers
     Aantal inwoners in laagbouw in beschouwd gebied          :
18,946   Pers
     Aantal inwoners in hoogbouw in beschouwd gebied          :
1,469   Pers
     Aantal evacuees uit beschouwd gebied                     :
0   Pers
Inwoners in overstroomd gebied (getroffenen)
     Aantal inwoners in overstroomd gebied                    :
20,415   Pers
     Aantal inwoners in laagbouw in overstroomd gebied        :
18,946   Pers
     Aantal inwoners in hoogbouw in overstroomd gebied        :
1,469   Pers

Oorzaak slachtoffers
     Aantal slachtoffers in breszone                          :
0   Pers
```

Aantal slachtoffers in stijgsnelheidzone : 0 Pers
Aantal slachtoffers in overgangszone : 0 Pers
Aantal slachtoffers door overige oorzaken : 67 Pers

==

totaal

Schaderelatie	Soort	Schade(prijspeil 2000)	Aantal "nat" Eenh.	Wegingsfactor
Landbouw	direct	1,848,724 Euro	1,498,527 m2	1.00
Glastuinbouw	direct	0 Euro	0 m2	1.00
Stedelijk Gebied	direct	94,018,072 Euro	2,715,943 m2	1.00
Recreatie Extensief	direct	4,797,177 Euro	865,227 m2	1.00
Recreatie Intensief	direct	615,543 Euro	81,181 m2	1.00
Vliegvelden	direct	0 Euro	0 m2	1.00
Rijkswegen	direct	1,881,263 Euro	7,129 m	1.00
Autowegen	direct	480,317 Euro	1,331 m	1.00
Overige wegen	direct	7,739,197 Euro	84,524 m	1.00
Spoorwegen	direct	8,908,027 Euro	1,820 m	1.00
Vervoermiddelen	direct	9,857,404 Euro	8,574 stuk	1.00
Gemalen	direct	917,741 Euro	2 stuk	1.00
Zuiveringsinstallaties	direct	0 Euro	0 stuk	1.00
Eengezinswoningen	direct	293,366,161 Euro	6,266 stuk	1.00
Laagbouwwoningen	direct	42,680,235 Euro	387 stuk	1.00
Hoogbouwwoningen	direct	29,700,351 Euro	698 stuk	1.00
Middenbouwwoningen	direct	73,008,220 Euro	1,216 stuk	1.00
Boerderijen	direct	345,993 Euro	4 stuk	1.00
Delfstoffen	direct	0 Euro	0 abp	1.00
Bouw	direct	310,097 Euro	298 abp	1.00

Handel/Horeca	direct	8,091,867 Euro	3,191	abp	1.00
Transport/Communicatie	direct	30,544,769 Euro	562	abp	1.00
Banken/Verzekeringen	direct	28,373,183 Euro	2,640	abp	1.00
Overheid	direct	8,002,952 Euro	1,097	abp	1.00
Industrie	direct	52,496,298 Euro	1,668	abp	1.00
Nutsbedrijven	direct	1,296,482 Euro	10	abp	1.00
Zorg/Overige	direct	7,372,129 Euro	3,428	abp	1.00
Landbouw	indirect	499,155 Euro	1,498,527	m2	0.25
Glastuinbouw	indirect	0 Euro	0	m2	0.25
Delfstoffen	indirect	0 Euro	0	abp	0.25
Bouw	indirect	348,859 Euro	298	abp	0.25
Handel/Horeca	indirect	354,019 Euro	3,191	abp	0.25
Transport/Communicatie	indirect	131,268 Euro	562	abp	0.25
Banken/Verzekeringen	indirect	551,701 Euro	2,640	abp	0.25
Overheid	indirect	73,360 Euro	1,097	abp	0.25
Industrie	indirect	2,916,461 Euro	1,668	abp	0.25
Nutsbedrijven	indirect	58,551 Euro	10	abp	0.25
Zorg/Overige	indirect	313,316 Euro	3,428	abp	0.25
Vliegvelden	b.u.	0 Euro	0	m2	1.00
Spoorwegen	b.u.	53,484 Euro	1,820	m	1.00
Delfstoffen	b.u.	0 Euro	0	abp	1.00
Bouw	b.u.	806,252 Euro	298	abp	1.00
Handel/Horeca	b.u.	3,034,450 Euro	3,191	abp	1.00
Transport/Communicatie	b.u.	4,561,352 Euro	562	abp	1.00
Banken/Verzekeringen	b.u.	4,413,606 Euro	2,640	abp	1.00
Overheid	b.u.	1,227,119 Euro	1,097	abp	1.00
Industrie	b.u.	13,171,114 Euro	1,668	abp	1.00
Nutsbedrijven	b.u.	340,849 Euro	10	abp	1.00

```
Zorg/Overige              b.u.           2,322,221 Euro
3,428 abp    1.00
--------------------------------------------------------------
---------------------------------

==============================================================
=================================
kwalitatieve resultaten
--------------------------------------------------------------
---------------------------------
Schaderelatie : Rijkswegen <indirect>
                     WEGNUMMER   aantal nat [m]
                           003            2,584
                           016            4,546
Schaderelatie : Autowegen <indirect>
                     WEGNUMMER   aantal nat [m]
                          N217            1,331
Schaderelatie : Spoorwegen <indirect>
                          NAAM   aantal nat [m]
      LAGE ZWALUWE - DORDRECHT            1,820
==============================================================
=================================
```

Appendix 11: HIS-SSM report for the breach near the "Kop van 't land"

This is the output of the HIS-SSM calculation. The tool is in Dutch, so is the report.

Berekening	lizard_flooding	
Omschrijving	lizard_flooding	
Datum	1-12-2010 17:35	
Model	Standaardmethode2008	
Dataset	SSM100NL2006	
Scenario	nens	
Wegingset	standaard	
Details van scenario		
Locatie op schijf	..\demo\scenario1	
Waterdiepte [m]	dm1maxd0.asc	
Stijgsnelheid [m/uur]	grid_dh.asc	
Stroomsnelheid [m/s]	dm1maxc0.asc	
Hoogbouw veilig	N	
Evacuatiefactor [-]	0	
Initieel prijspeil [jaartal]	2000	
Gehanteerd prijspeil [jaartal]	2000	
Gehanteerd inflatiecijfer [%]	2% per jaar	
Resultaat Schade		
Schade	4,780,549,343	Euro
Totaal aantal slachtoffers	714	Pers
Inwoners in beschouwd gebied		
Aantal inwoners in beschouwd gebied	2,741,086	Pers
Aantal inwoners in laagbouw in beschouwd gebied	2,541,346	Pers
Aantal inwoners in hoogbouw in beschouwd gebied	199,740	Pers
Aantal evacuees uit beschouwd gebied	0	Pers
Inwoners in overstroomd gebied (getroffenen)		
Aantal inwoners in overstroomd gebied	95,167	Pers
Aantal inwoners in laagbouw in overstroomd gebied	89,365	Pers
Aantal inwoners in hoogbouw in overstroomd gebied	5,802	Pers

Oorzaak slachtoffers					
Aantal slachtoffers in breszone	0	Pers			
Aantal slachtoffers in stijgsnelheidzone	0	Pers			
Aantal slachtoffers in overgangszone	94	Pers			
Aantal slachtoffers door overige oorzaken totaal	621	Pers			
Schaderelatie	Soort	Schade(prijspeil 2000)		Aantal "nat"	Eenh.
Landbouw	direct	8,804,083	Euro	6,370,227	m2
Glastuinbouw	direct	7,702,102	Euro	205,355	m2
StedelijkGebied	direct	470,465,862	Euro	########	m2
RecreatieExtensief	direct	21,042,597	Euro	2,934,165	m2
RecreatieIntensief	direct	3,145,369	Euro	336,029	m2
Vliegvelden	direct	0	Euro	0	m2
Rijkswegen	direct	8,442,640	Euro	18,012	m
Autowegen	direct	732,552	Euro	2,177	m
Overigewegen	direct	45,398,797	Euro	333,419	m
Spoorwegen	direct	75,039,519	Euro	7,461	m
Vervoermiddelen	direct	96,950,598	Euro	39,970	stuk
Gemalen	direct	5,231,255	Euro	8	stuk
Zuiveringsinstallaties	direct	0	Euro	0	stuk
Eengezinswoningen	direct	2,352,938,265	Euro	29,667	stuk
Laagbouwwoningen	direct	331,328,675	Euro	2,556	stuk
Hoogbouwwoningen	direct	220,988,840	Euro	3,049	stuk
Middenbouwwoningen	direct	646,600,913	Euro	6,838	stuk
Boerderijen	direct	6,619,911	Euro	50	stuk
Delfstoffen	direct	0	Euro	0	abp
Bouw	direct	933,528	Euro	512	abp
Handel/Horeca	direct	32,341,871	Euro	8,979	abp
Transport/Communicatie	direct	76,154,215	Euro	1,133	abp
Banken/Verzekeringen	direct	98,107,999	Euro	6,042	abp
Overheid	direct	50,439,612	Euro	5,036	abp
Industrie	direct	107,059,544	Euro	2,111	abp
Nutsbedrijven	direct	4,663,196	Euro	30	abp
Zorg/Overige	direct	13,277,976	Euro	3,607	abp
Landbouw	indirect	2,377,103	Euro	6,370,227	m2
Glastuinbouw	indirect	192,072	Euro	205,355	m2
Delfstoffen	indirect	0	Euro	0	abp
Bouw	indirect	1,050,219	Euro	512	abp
Handel/Horeca	indirect	1,414,957	Euro	8,979	abp
Transport/Communicatie	indirect	369,453	Euro	1,133	abp
Banken/Verzekeringen	indirect	1,907,656	Euro	6,042	abp
Overheid	indirect	462,363	Euro	5,036	abp
Industrie	indirect	5,947,752	Euro	2,111	abp

Nutsbedrijven	indirect	210,596	Euro	30	abp
Zorg/Overige	indirect	564,314	Euro	3,607	abp
Vliegvelden	b.u.	0	Euro	0	m2
Spoorwegen	b.u.	450,535	Euro	7,461	m
Delfstoffen	b.u.	0	Euro	0	abp
Bouw	b.u.	2,427,172	Euro	512	abp
Handel/Horeca	b.u.	12,128,202	Euro	8,979	abp
Transport/Communicatie	b.u.	11,372,363	Euro	1,133	abp
Banken/Verzekeringen	b.u.	15,261,244	Euro	6,042	abp
Overheid	b.u.	7,734,074	Euro	5,036	abp
Industrie	b.u.	26,860,818	Euro	2,111	abp
Nutsbedrijven	b.u.	1,225,969	Euro	30	abp
Zorg/Overige	b.u.	4,182,562	Euro	3,607	abp

kwalitatieve resultaten

Schaderelatie	Rijkswegen <indirect>
WEGNUMMER	aantal nat [m]
3	11,817
16	6,195

Schaderelatie	Autowegen <indirect>
WEGNUMMER	aantal nat [m]
N217	2,177

Schaderelatie	Spoorwegen <indirect>
NAAM	aantal nat [m]
DORDRECHT	1,098
Dordrecht Zeehaventerrein 1	11
GELDERMALSEN - DORDRECHT	2,071
LAGE ZWALUWE - DORDRECHT	4,281