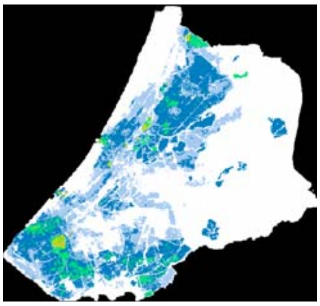
Compartmentalization of dike ring 14

An investigation into different compartmentalization strategies to reduce the systemic risk of flooding



Johan Oost

Master thesis

March 2007

University of Twente
Enschede - The Netherlands

twente WATER centre

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Preface

At the Elementary, I have written a little report about the Delta Works in the Netherlands. Since that time, I have been very excited about Civil Engineering. In 2000, I decided to start the study at the University of Twente, after finishing the Gymnasium in Zwolle. In 2004, I went to China for an internship at the Wuhan University. After that internship, I decided to do a Master at the Department for Water Engineering and Management, part of the Faculty of Engineering Technology. This graduation report forms the completion of my study at the University of Twente.

I am very grateful to the people who guided me during my graduation, prof. dr. ir. Arjen Hoekstra and dr. Jan Mulder, for their support and supervision. I would also like to thank dr. Wilfried ten Brinke for his role in the graduation committee. Also thanks to dr. Annika Hesselink for her help at the beginning of the study. I am grateful to Rene Buijsrogge (UT) for his help to get familiar with the models. Besides thanks to the people, who have gave me lots of useful advices and comments during the graduation period. I would also like to thank my colleagues of the 'Graduation Chamber' for sharing the good and bad times ("*In de uren van nood en ontbering, neem er nog één...*", V.O.F. de Kunst).

Furthermore, I would like to thank my parents for giving me the opportunity to study at the University of Twente. Also thanks to Digna for her dear support during my graduation period. I would like to thank my friends, with whom I have spent a great study time. The final thanks go to that crazy volleyball club Harambee . . .

Johan Oost
Enschede, March 2007

Summary

In Dutch water management, compartmentalization is seen as one of the promising risk reduction strategies. The current flood risk policy for dike ring 14 is based on the exceeding probability of 1/10,000 year^{-1}. The flood risk policy is thus based on controlling the probability of flooding and not on the potential effects of flooding. This contrasts to the existing policy in controlling so-called 'external risks', such as the risk of nuclear energy or pollution disasters. External risk policy aims at controlling large-scale disasters. External threats are quantified by group risk and the corresponding risk curve (probability - effect). Dutch policy for external risks aims to control the number of casualties. Other effects, like environmental and economic effects, are not included in the policy.

Flooding becomes more and more an external risk, because of the human interventions in the water system. For flood threat, the approach of systemic risk concentrates on the worst case scenario, which means that a system must be able to handle the worst possible attack. This worst case scenario is based on the potential damage and forms the 'tail' in the risk curve. Reduction of potential damage is the best solution to reduce systemic risk of flooding. Systemic risk has to do with the vulnerability of a whole society, which can be considered as a network of interlinked elements. In this study, the systemic risk is measured by taking the number of affected people, the number of casualties, the direct economic effects and the incoming water as indicators.

> ***The aim of this study is: Designing and analyzing different compartmentalization strategies for the reduction of the flood risk in dike ring 14 in the Netherlands, focusing on the reduction of systemic risk.***

The current situation of flooding risk of dike ring 14 in the Netherlands is that the flood probability is low, but the corresponding potential effects are very high. So, the systemic risk of flooding in dike ring 14 is considered as high. In this study, we show a worst possible attack that exists of five breaching locations, with flood water covering about half of the dike ring area. The corresponding effects are more than a million affected people, thousands of casualties and billions of euros of economic damage. The hydrodynamic model schematization in SOBEK has been used for measuring the flooding of dike ring 14 and the occurred effects have been calculated by HIS - SSM.

In this study, we analyze compartmentalization as a potential strategy for reducing the flood risk. Compartmentalization divides the dike ring area into subdivisions by using dikes. It aims to mitigate the effects and to create time for counteractions. In this study, three compartmentalization strategies, based on different spatial configurations have been worked out:

1) partition strategy, 2) secondary dike strategy and 3) value protection strategy. These strategies have been compared to the current (zero) situation, taking into account seven different flood scenarios based on single and multiple flood breaches.

In a theoretic model, the performance of the compartmentalization strategies have been compared by mainly looking at the benefits (gained risk reduction). The costs are qualitatively determined by the total length of the used compartmentalization dikes. This has been done for different cases, in which the distribution of value within the dike ring area has been varied. The main conclusion from the theoretic model is that the secondary dike strategy is the best if one is willing to invest a relative large amount of money (much compartmentalization dikes). Building less compartmentalization dikes, the partition and the value protection strategies are good strategies in respectively homogenous and heterogenous areas.

The analysis for dike ring 14 shows that compartmentalization has large influence on the overland water flow, especially within short distance from the breach location. The secondary dike strategy has the biggest influence, because it stops most of the overland water flow. However, the average dike heights have to be large.

The most attractive compartmentalization strategy in perspective of systemic risk reduction is the *secondary dike strategy*. The number of affected people and the economic damage will be reduced by about 15 - 50 % for all scenarios. In the worst case scenario, the secondary dike strategy reduces the number of affected people by 20 % and the economic damage by 26 %. The probability of failure of compartmentalization dikes has not been taken into account, so there is still a remaining risk behind the compartmentalization dikes. Flooding would have to occur in two stages: breaching of primary and then breaching of the secondary dike. The implementation of the secondary dike strategy suffers many strains, because the length of the compartmentalization dikes is large and the dikes are located across valuable areas. Besides, the strategy is not attractive for every inhabitant of the dike ring area, because the (relatively few) inhabitants between the primary and compartmentalization dikes have a higher risk.

The *partition strategy* is an attractive strategy from an incremental point of view, because less dikes are needed for the implementation, compared to the secondary dike and the value protection strategies. The strategy is however less effective for the reduction of the systemic risk in the dike ring area.

For the systemic risk reduction of dike ring 14, the *value protection strategy* is not attractive, because the implementation of the strategy costs about the same strains as the secondary dike strategy, but is not so effective as this strategy. Dike ring 14 is not an appropriate dike ring area for the implementation of the value protection strategy. The inhabitants and the capital value are not strongly concentrated at one place, but spread throughout the area.

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Chapter 1

Introduction

1.1 Background to the study

1.1.1 Flood threat

Man and their development are threatened by numerous kinds of disasters. These threats can be caused by nature, like windstorms, earthquakes, volcanos and meteorites. Other kinds of damage are created by mankind, like chemical or nuclear disasters. There are also disasters, which are related to water: drought or flooding. Flooding is mostly described as a natural threat. In this study flooding is considered as a threat for mankind and its development, see also Oost (2004).

Flooding is a threat for areas, situated below maximum levels of the surrounding water (sea, lakes and rivers). In the world, human development is often situated near rivers and seas. Large parts of the world is threatened by flooding (Hoozemans et al., 2004). A flood destroys human development and causes numerous of casualties. Flooding can even cause such huge effects that it can destroy whole human societies.

Nowadays, the flooding of New Orleans is often used as example for the societal impact of a flood. After hurricane Katrina, large parts of the city have been flooded. About 1100 people were killed and the total economic loss is estimated at US$ 125 billion (Kok et al., 2006). This event opened eyes of people, living on flood plains, that have to deal with the same problem: flood safety (MinBZK, 2006b).

1.1.2 Flood risk in the Netherlands

In history, the Netherlands have been confronted with several floods. The country is threatened by floods from two sides: rivers and sea, because three main European rivers, Rhine, Meuse and Scheldt, flow into the North Sea. Almost a quarter of the country is below sea level and about two thirds of the country has the potential to become flooded (Ten Brinke et al., 2007); Figure 1.1.

The Netherlands have been confronted by numerous floods in the past. The last serious flood was in 1953. The southwestern part was flooded by the sea, 1836 people died and the economical damage was about 680 million euros. More recent nearly floods occurred in 1993 and 1995 (MinV&W, 2000b). The floods have had an important impact in the flood protection of the Netherlands. For example, three important water management projects were implemented in the twentieth century (Van Steen and Pellenbarg, 2004):

1. Zuiderzee project (South Sea Project) with the Enclosure Barrier (decision was influenced by a storm in 1916)

2. Delta Project (decision taken after the storm of 1953)

3. Delta Project of the Large Rivers (this project has been taken after the nearly floods of 1993 and 1995)

Figure 1.1: The Dutch ground levels - plus or minus NAP (Dutch Ordinance Datum). Actual Height of the Netherlands (www.ahn.nl).

1.1.3 Dutch flood safety policy

The safety policy against flooding has changed after the flood disaster of 1953. Before 1953, the dikes were heightened to the highest water level plus a certain safety margin after a flood. As a result, the dikes became higher and higher during the centuries (Van Steen and Pellenbarg, 2004). After 1953, the *Delta Commission* was installed to advice the Dutch government about the safety policy against sea floods. In 1960, the Commission advised to heighten the dike levels to certain *design heights*. These design heights should provide an agreed protection level for coastal zone of the Netherlands.

The quantification of the design heights was based on (statistical) calculations of the water levels. The water levels were seen as the main reason to become flooded (MinV&W,

2000b). The Delta Commission concluded that the water levels at the storm of 1953 could have been much higher than the highest recorded level of 3.85 m +NAP at Hook of Holland. According to the Commission, a potential water level of 5 m +NAP (at Hook of Holland) could be reached in case of all unfavorable conditions. The probability of the case with such unfavorable conditions has been determined to be 1/10,000 per year. This probability has been chosen as the safety level (Ten Brinke et al., 2007).

Meanwhile, the Delta Commission has made an economic optimization calculation of dike ring 14 only to find an optimum between the benefits (value of property and the number of people) and the costs (the level of safety). The analysis resulted in an optimum protection level of 1/125,000 per year. After all, the advice of the Commission was to adopt the exceeding probability according to this flood probability was 1/10,000 per year, because the Commission assumed made that the dikes will not directly breach at the level of the probability of exceeding of 1/10,000 year. Moreover the calculated optimum has been based on the maximum potential damage, which was assumed to be overestimated. This resulted in a safety standard of 1/10,000 per year for dike ring 14 (RIVM, 2004).

The current Dutch safety policy against flooding is still based on the advice of the Delta Commission. After the determination of the safety standards for the coast by the Delta Commission, the safety standards for the other dike ring areas have been determined by other advisory commissions. The safety standards are formalized in the Flood Defence Act of 1996; Figure 1.2 (MinV&W, 2000b; RIVM, 2004).

1.1.4 Flood risk of the Netherlands

Safety against disasters is related to the presence or absence of risk. A risk is the combination of the probability of an event and the consequences of that event. A risk measurement is a mathematical function of the probability and consequences (Ale, 2003; Jonkman et al., 2003). The extent of damage is mostly given in casualties or economical damage, but also in other kinds of damage, like environmental or cultural-historic damage (Nieuwenhuizen et al., 2003; Jonkman et al., 2003; DWW, 2005b; MinV&W, 2005a).

Looking at the Dutch flood safety policy, this policy is only based on the probability of exceeding; Figure 1.2. This is just one of the failure mechanisms of the probability of *flooding*. Consequences of flooding are not taken into account at all (MinV&W, 2000b,a, 2001). Moreover, the current design levels are based on the situation from 1953. Since then, the water conditions have been changed. The potential damage also has grown since 1960, because of accumulation of inhabitants and property in the lower parts. Because of different changes in flood probabilities and consequences, the flood risks have been changed in the Netherlands. RIVM (2004) concluded that the aimed safety against flooding can not be guaranteed furthermore.

The latest results in this progress is the project *Veiligheid Nederland in Kaart (VNK)*, in English: *Flood Risks and Safety in the Netherlands (Floris) project.* This project is important for two reasons: First the actual conditions of the dikes and dams are determined, which leads to knowledge about the *flood probabilities* of some dike rings. Secondly, the Dutch got insight into *possible consequences* by flooding of dike ring areas. With these two sides of

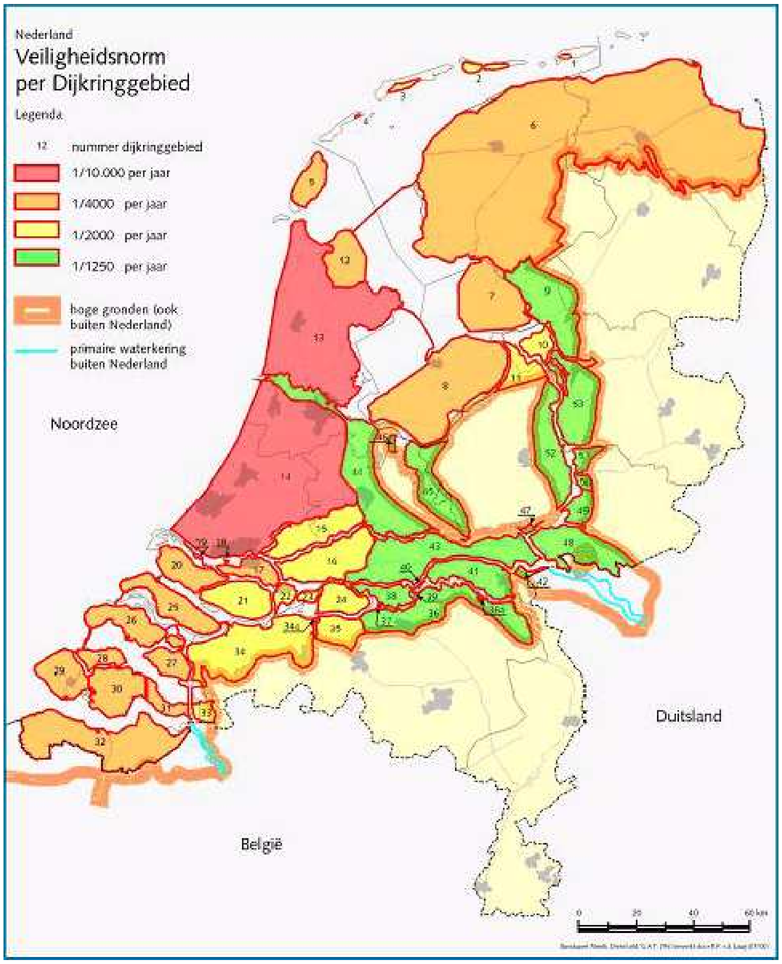


Figure 1.2: Overview of dike rings in the Netherlands and their safety standards (MinV&W, 2000b).

the risk, the actual *dike ring risk* is calculated instead of the probability of water exceeding. VNK showed that the Dutch dike rings can be characterized by relatively *high probability - low damage* or *low probability - high damage*.

Due to a report of the Commission Water Management in the 21^{st} century, the Dutch flood risk management implemented new approaches (Kabinet, 2000), that are more based on risks. The current policy of focusing on flood probability should not be the only tool for water management. The Dutch water policy should also be open to mitigate the possible consequences (MinV&W, 2001).

1.2 Problem definition

1.2.1 New safety approaches: *systemic risk*

In 2005, hurricane Katrina and the consequent floods destroyed New Orleans as society. Such flood disaster could also take place in the Netherlands. Especially flooding of dike ring 14 (Southern Holland) could be disastrous, looking at the size of the potential damage and importance of the dike ring area for the whole country (Kok et al., 2006). VNK does not say something about the worst case scenarios. The study of dike ring 14 handles ten scenarios, that are responsible for more than 99 % of the total flood probability of the dike ring. Cases worse than the worst case were determined by a certain *remaining risk* (MinV&W, 2006d). So, VNK does not show the Dutch risk on the worst case of flooding. The worst case is very important for determination of the possible maximum damage, the possible societal impact and a possible bankrupt of the economy of the entire country.

VNK mainly focuses on the average risk of casualties and economical damage. It does not say anything about the implications of a worst case disaster for the Netherlands as society. Average risk ($R = \sum_{i=1}^{n} P_i * E_i$, with P is probability of occurrence, E is consequences and i represents the various flood scenarios) to people and economy are very important, but risk to the society is more than just the integration of probabilities and corresponding effects. The societal impact, the resilience and the recovery of the country also depend on other factors than just the average risk of casualties and economical damage.

Systemic risk is a new type of risk, that is recently developed by OECD (2003). The term springs from the financial world and is used as the possibility of a total destruction of a (financial) system (Hoekstra, 2005). Systemic risks are used for determination of safety against different kinds of threats, like *flooding*, diseases, terrorism and also for different kind of systems (or potential damage object), like countries (areas), kind of species or functions (OECD, 2003; Renn and Klinke, 2004). In this study, systemic risk is used as concept to determine the social impact of flooding.

1.2.2 Compartmentalization

Since the risk situation has been studied by VNK, risk control strategies can be designed and analyzed, based on both reduction of probabilities and mitigation of damage. In flood risk management, there are several safety strategies that could be used for flood risk control. Oost (2006) has mentioned some of these strategies, like land elevation, moving to higher grounds, adaptation to water and creation of buffer zones. Compartmentalization is seen as one of the promising strategies for flood risk reduction of some dike ring areas in the Netherlands (RIVM, 2004). Besides, compartmentalization does not influence maintaining of the Basal Coastline of 1990 (MinV&W, 1990, 2000a).

Compartmentalization has to do with *subdivision* (Hesselink, 2006). The strategy implies that potential damage of an object should be reduced by subdivision of the whole damage object. Well-known examples of compartmentalization applications are in ships (reduction of *sinking risk*) and large rooms (reduction of *fire risk*). The main aims of compartmentalization for increasing the fire safety are the prevention of casualties and injuries by creating time to escape and the fire control in the building for mitigation of the direct and indirect damage (by holding the fire away from other subdivisions) (MinBZK, 1994). A ship is divided into compartments, which stops the incoming water of spreading to the whole ship. It also provides time for the people to escape or for the ship to reach a harbor and to save the whole ship. These examples show that compartmentalization has two important benefits. Firstly, the *total damage is reduced* by compartmentalization, so parts of the destructed objects can be recovered. Secondly, compartmentalization can provide *time to take counter actions* (people can escape, the damage can be mitigated and subdivisions can be saved and repaired) (Theunissen et al., 2006).

In case of flooding, a dike ring area can be divided up into different parts by *compartmentalization dikes*, which are dikes on land and are made behind the primary dikes. Compartmentalization is based on the philosophy that flooding can not be totally excluded in the future and that reducing flood probabilities is not the only answer of reducing the flood risk. The flood probability hardly changes due to compartmentalization. So, compartmentalization is mostly based on the mitigation of the potential damage (MinV&W, 2006e). Compartmentalization is an example of *fail-safe risk policy* (RIVM, 2004).

Insight into compartmentalization effects has been increased by some studies in the last years, for example: Hesselink et al. (2003); Alkema and Middelkoop (2005); MinV&W (2006d); De Bruine (2006); MinV&W (2006e); Theunissen et al. (2006). Hesselink et al. (2003); Alkema and Middelkoop (2005); MinV&W (2006d) have shown that historic and modern compartmentalization dikes or higher line elements influence the overland water flow, that determines the eventually effects. According to (Hesselink, 2006), compartmentalization has a steering role during the overland water flow. This will be more time to take counteractions, for example evacuation or mitigation of damage. (Alkema and Middelkoop, 2005) concluded that the water can be lead away from vulnerable and important areas. The main negative aspect of compartmentalization is the fastening of the water level rise on land. This leads to an increase of the amount of casualties in the flooded compartment. The total amount of casualties also can even be higher than in the area without the compartments (RIVM, 2004; MinV&W, 2006d).

In the studies of Alkema and Middelkoop (2005); De Bruine (2006); MinV&W (2006e); Theunissen et al. (2006), the effects of compartmentalization have been examined for different areas with fixed breach locations, but these studies have not been focused on comparison of *spatial configurations* of compartmentalization dikes. Configurations are patterns of compartmentalization dikes taking into account the whole dike ring area. This is also emphasized by Alkema and Middelkoop (2005): '*...restoration (of dikes on land) will not reduce flood damage, but that this must be achieved by a* strategic compartment plan'. According to Hesselink (2006), studies to compartmentalization should also be focused on the *lay out* of the compartmentalization dikes for different dike ring areas. Looking at compartmentalization strategies for the whole dike ring area, the configuration of the dikes there should be no negative effects due to system working and the compartmentalization effects of the whole dike ring becomes clear.

1.3 Study objective

The text above supposes that the effects of compartmentalization can be researched in two ways: Compartmentalization dikes for local fixed breaches and general compartmentalization strategies for whole dike ring area. In this study, compartmentalization is seen as the *central solution* for reduction of the flood risk. The effects of compartmentalization have been examined by focusing on certain configurations of compartmentalization dikes *or: compartmentalization strategies.*

Besides, RIVM (2004) pronounce that compartmentalization is an interesting strategy for reducing the risk in large flood plains. The study area is *dike ring 14* and this area is a large dike ring with a huge potential damage. Dike ring 14 is considered as the most important dike ring in the Netherlands. A flood in this dike ring area is disastrous for the dike ring area and the whole country. In this study, the flood risk is described in terms of *systemic risk*, which is a new type of risk definition. This concept could provide new insights for flood control in the Netherlands. "*Looking at systemic risks for the Netherlands, flooding of dike ring 14 is the highest kind of systemic risk*" (Hoekstra, 2005).

> ***Designing and analyzing different compartmentalization strategies for reduction of the flood risk in dike ring 14 in the Netherlands, focusing on the reduction of systemic risk.***

1.4 Method

This study combines different flood scenarios and some compartmentalization strategies for getting insight into the effects of the strategies. The study is focused on the reduction of the systemic flood risk of dike ring 14 in the Netherlands.

First, the different types of risk descriptions are explained and systemic risk is introduced and examined. Some indicators for quantification of systemic risk have been determined to give a proper quantification of the systemic risk for flooding. Dike ring 14 as the study area is described. The current risk situation is explained by considering the flood threat in the area and the possible effects. A worst case scenario has been determined by taking several dike breach locations at all sides of the dike ring area. Some other flood scenarios are also selected for comparison of the compartmentalization strategies. After all, the probabilities of occurrence for each scenario has been determined.

For getting insight into the working of compartmentalization strategies, a theoretic model is made in excel. The length of compartmentalization dikes are compared to the gained risk reduction. The value distribution of the area is also taken into account as parameter to describe the dike ring area.

For the determination of the effects of different compartmentalization strategies for dike ring 14, hydrodynamic model SOBEK is used, developed by WL | Delft Hydraulics. The outcomes of SOBEK are time and space independent inundation water depths and flow velocities (WL | Delft Hydraulics, 2004). The grid cell size is 100 m * 100 m. The time step of each computation is 5 minutes and the total simulation time is 240 hours. The schematization of dike ring 14, used by the project VNK (MinV&W, 2005a), is used during the study.

The compartmentalization dikes are implemented in the SOBEK schematization of dike ring 14 by increasing the ground level of the relevant grid cells by using ArcView (ESRI, 1996). The dikes have a width of 100 m, which is too broad for a compartmentalization dike, but this does not have much influence on the calculations by SOBEK. Adjustments to the roughness of the standard schematization of dike ring 14 is not necessary, because the water does not overtop the compartmentalization dikes.

With the output of SOBEK, different damage elements can be determined by the model HIS - SSM, made by DWW (2005a). The output of HIS - SSM are values for damage to people (affected people and casualties) and economy (direct material damage, direct damage to business outfall and indirect damage).

After all, the outcomes of the indictors of systemic risk are determined with HIS - SSM (for affected people, casualties and economic effects) and SOBEK (for incoming water). These outcomes of the compartmentalization strategies are put in some risk curves. The results of the different compartmentalization strategy are compared with the results of the zero situation. In the sensitivity analysis, the assumptions of this study and some uncertainties are handled. Finally, the main conclusions are drawn and discussed further.

Chapter 2

Systemic risk

2.1 Types of risk

There is a distinction between safety against disasters and the risk of a disaster. Safety is related to the probability of occurrence of a disaster, while risk also takes the corresponding effects into account. In risk management, a distinction is made between *natural* disasters and *human-made (or external)* disasters, as well as between *hazards* and *risks* (Joffe, 2003; RIVM, 2004).

> "*Natural disasters include earthquakes, hurricanes and floods. The 'human-made' disasters are those produced abundantly in contemporary Western society: nuclear and industrial accidents, acid rain and so on. 'Hazards' tend to be distinguished from 'risks' in that damage comes from an external source. The properties associated with the 'natural' disaster and 'hazard' categories overlap substantially. 'Hazards' are said to become 'risks' as soon as anything becomes known about how the danger might be averted; in other words, once human action can be taken in relation to it.*" (Joffe, 2003).

There are two types of risk identity in risk management: individual and group identity (Joffe, 2003). These two identities are also represented in Dutch society as two standards: the individual and the group risk standard. The individual risk handles the possibility of an individual death due to an accident, while group risk takes the number of casualties into account; Figure B.2. The individual risk is used for the natural risk and the group risk for the external (human-made) risks (Ale, 2003).

RIVM (2004) has considered flooding as external threat for comparing the Dutch flood risk to the threats in the external safety domain, Figure B.5. One of the main conclusions has been that the individual risk of flooding is relatively low, while the group risk of flooding relatively high (RIVM, 2004). In this research, RIVM (2004) postulates that flooding could be considered to become more an external event, because of the (technological) human interaction in the Dutch water system. The Dutch dikes become higher and steadier, which leads to a decrease of flood probability. Lower parts have become attractive for human development.

This resulted in an increase of potential damage: more capital and more inhabitants. So, the potential flood damage at one stroke is also increased by the human interaction.

2.1.1 Risk curve (Probability - Effect graph)

Risk situations have to do with the specific combination of the probabilities at one side and the effects at the other side. A risk with a *low probability - high effects* situation is different as a *high probability - low effects* risk situation (Hoekstra, 2005) p.68. For getting insight into the different situations, WBGU (1998) has made risk clusters representing different kinds of risk situations. These risk clusters have been put in a graph for getting more insight; see Figure C.4.

A risk measurement is a mathematical function of the two risk sides, probability and consequences. There are several risk measurements with their own field of application (Jonkman et al., 2003). One of the risk measurement is the **risk curve**; Figure 2.1. In the risk curve, the probability and corresponding damage are combined in a graph. Such risk curves give insight of the possible extent of the effects.

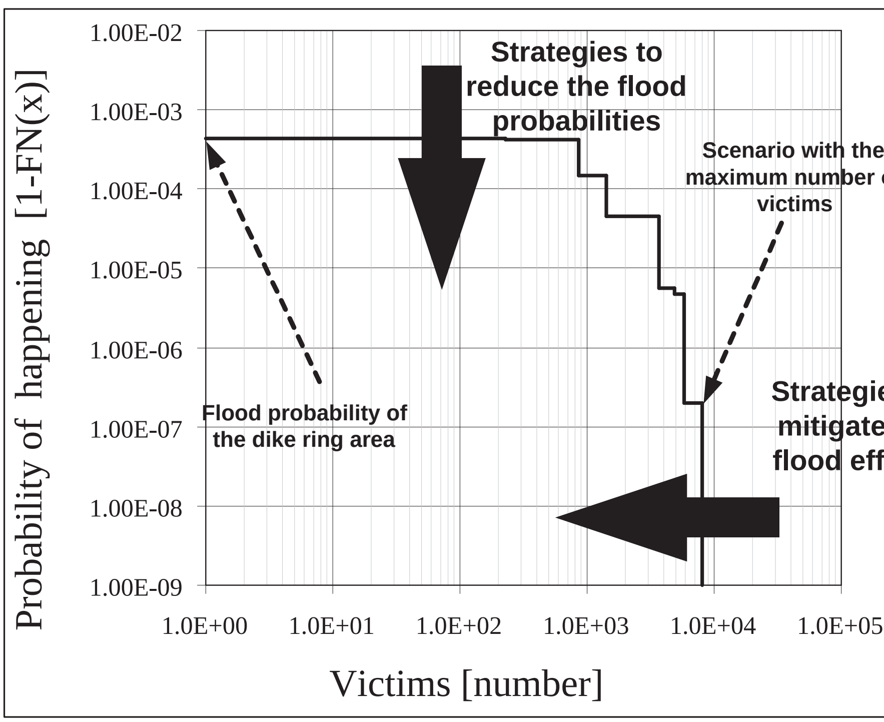


Figure 2.1: The working of the risk curve with some specific points on the graph (MinV&W, 2006a) p.41.

The group risk for casualties is presented by the F_N *curve*. The F_N curve gives the cumulative probability of exceeding of an event with N of more casualties. The F_N curve is made by two formula:

$$F_N(x) = P(N \leq x) = \int_0^x f_N(x)dx \tag{2.1}$$

$$1 - F_N(x) = P(N > x) \tag{2.2}$$

In Equation (2.1), $f_N(x)$ is probability density function of number of casualties (x) and in Equation (2.2), $F_N(x)$, probability distribution function of number of casualties (x). An example of the construction of the risk curve is given at Appendix B.4. The economic (group) risk, is called the F_G *curve* (Jonkman, 2001).

The risk limits for the Netherlands are given in a linear line in Figure B.3. This line of maximum casualties due to an external event, has a direction coefficient of '-2' in the double logarithmic graph (Ale, 2003), p.61. This means that the probability of larger numbers of casualties has a factor of hundred by an increase of casualties of ten times (RIVM, 2004), p.25. The graph does not have a fixed end, so there is not maximum value for the number of casualties in terms of group risk (Jonkman et al., 2003).

2.1.2 'Expected value of loss' and 'individual risk'

In case of individual risk, the consequences are concentrated on the individual person. The most simplified individual risk calculation is '*the probability of occurrence times the results (to one individual) of that occurrence*' (Jonkman et al., 2003). In general, the economic risk is quantified by the flood probability times the corresponding economic damage, like the VNK results in Figure B.4 (Hoekstra, 2005; MinV&W, 2005a).

Individual risks calculations are based on an integration of the probability of occurrence and the extent of damage; Equation (2.3). It shows an integration of all the individual risks of the whole population in the area (Jonkman et al., 2003). In Equation (2.3), IR stands for the individual risk. P_f is the probability of occurrence and $P_{d|f}$ is damage of that event. The outcomes are described in a value per year.

$$IR = P_f P_{d|f} \tag{2.3}$$

The expected value is the average (expected) damage per year. In general, this average value is high for *large probability / small effects* risk situations and low for *small probability / large effects* risk situations (Ale, 2003) p.46. The expected value for the number of casualties can be determined by taking:

$$E(N) = \int_0^\infty x.f_N(x)dx \tag{2.4}$$

In Equation (2.4), $E(N)$ stands for the expected value in number of casualties per year. x is the number of casualties and $f_N(x)$ is probability density function of number of casualties (x). The surface under the risk curve is equal to the expected value in number of casualties per year (Jonkman, 2001). The measurement of the expected value can be seen as a type of individual risk, because the outcomes are described in a value per year.

The individual risk is just one combination of probability and corresponding consequence, while group risk have numerous of these combinations. Group risk say more about the risk situation than individual risk level, because it contains more information. Another difference between individual risk and group risk is the risk situation with low probabilities and high consequences. At the level of group risk, the *low probability - high effects* situation can be seen in the risk curve (RIVM, 2004; Hoekstra, 2005; MinV&W, 2005a). At the type of individual risk this risk situation is more or less neglected, because of the dominance of the probability in the risk measurement. However, conclusions of the risk curve can made more difficult, because both probability and effects are taken into account (Ale, 2003) p.46.

The VNK results are given on the level of individual risk; Table B.4. Based on the results of the detailed study of VNK, MinV&W (2006a) have made the risk curve group risk of dike ring 14, Figure 2.2. The study of RIVM (2004) and the study of MinV&W (2006a) can be seen in this Figure. The risk curve of RIVM (2004) are given with the two boundaries. The scenarios of MinV&W (2006a) are given with and without breaches in line elements.

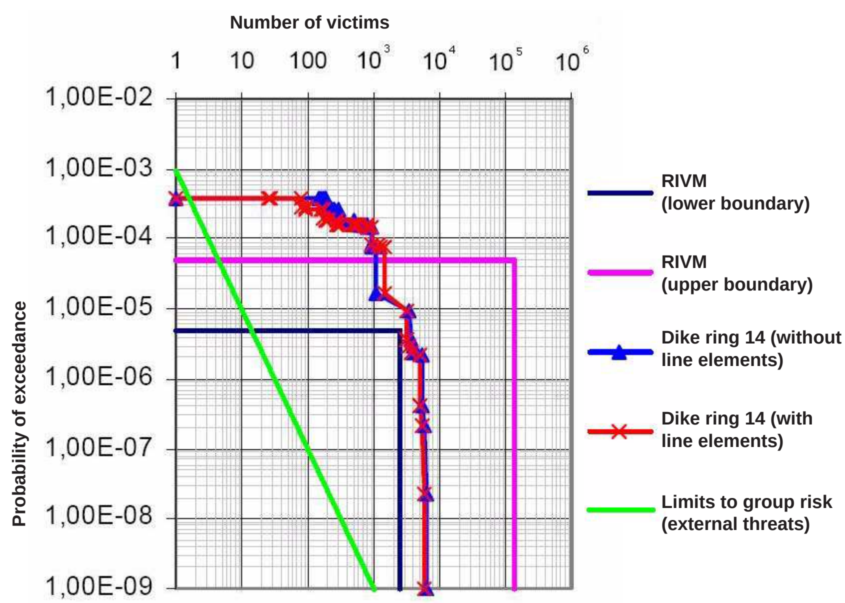


Figure 2.2: Group risk of flooding in dike ring 14, RIVM (2004); MinV&W (2006a), combined with the maximum acceptable values of group risk in the Netherlands (Ale, 2003; Jonkman et al., 2003).

2.1.3 A new risk concept: systemic risk

According to Hoekstra (2005), the further step in development of (flood) risk is thinking in systemic risk. *Systemic risk* is a new types of risk, that is recently developed by OECD (2003). The term springs from the financial world and is used as the possibility of a total destruction of a (financial) system (Hoekstra, 2005). Systemic risks are used for determination of safety against different kinds of threats, like *flooding*, diseases, terrorism and also for different kind of systems (or potential damage object), like countries (areas), kind of species or functions (OECD, 2003; Renn and Klinke, 2004).

Systemic risk considers the probabilities of a total destruction for a society as a whole and the 'survival probabilities' after that destruction. The resilience of an area also determines the 'probability of survival' of that area. Systemic risk provides more insight into the extent of effects than individual and group risk. Group risks give the number of casualties, while systemic risks concentrate on the continuity of the societies existence (OECD, 2003). This social existence has been interpret as certain relations (lines) between people; Figure 2.3. The society becomes a network of relations. A disaster does not affect only individual people, but it affects the existence of the whole society.

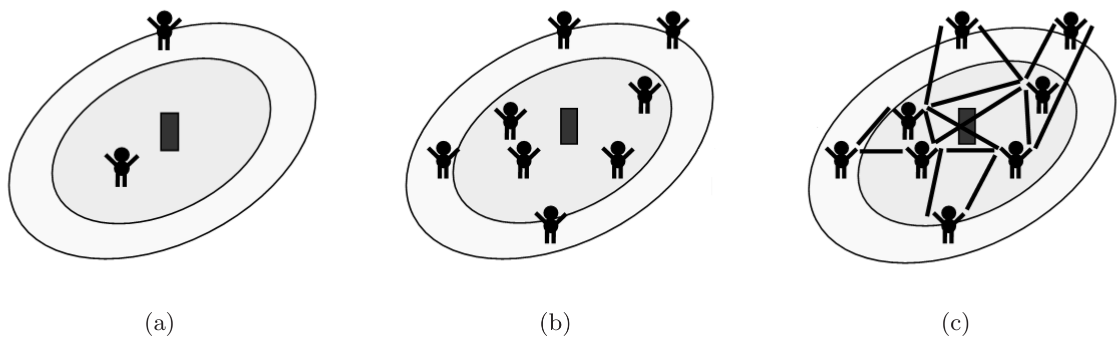


Figure 2.3: Schematization of different risk types: individual risk (a), group risk (b) and systemic risk (c), based on Figure B.2 of Stallen et al. (1996).

Figure 2.3 in short:
$IR_A = IR_B = IR_C$ (IR is individual risk)
$GR_A < GR_B, GR_B = GR_C$ (GR is group risk)
$SR_A < SR_B < SR_C$ (SR is systemic risk)

Beck (1997) described the current modern industrial society as a risk society, because technological development has brought a new order of risk definition, which can be considered as herald risk perception of systemic risk. Before the industrialization of the 19^{th} century, humanity could not destroy the living system (Earth). The technical development brought new threats (external disasters), which can cause a total destruction for the human society on Earth (Beck, 1997).

The worst potential scenario is very interesting for systemic risk. The total destruction of the society is determined by the worst potential scenario. This scenario is leading for the determination of the survival probability of a system and it shows the resilience after the worst attack. If the system can overcome the largest possible attack, it can also overcome little attacks against the system. **In this study, systemic risk is defined as the combination of the probability of the *worst possible attack* to the system and the consequences of that worst possible attack.**

Considering the worst case scenario, the probability of occurrence is not so interesting. In terms of Beck (1997), there is a gap between safety and *apparent* safety. The apparently safety stands for the risks, that are based on statistical measurements and do not exclude disasters. This strengthens that the probability of flooding is not leading in the systemic risk measurement. **In this study, the main focus is on the reduction of the *effects* of a possible disaster instead of the reduction of the probabilities of occurrence.**

According to OECD (2003), flooding is one of the possible systemic risks that can threaten a system. For the situation in the Netherlands, RIVM (2004) postulates that the risks of flooding have been transformed more and more from a natural disaster towards an external disaster due to technical development (human intervention) in the Dutch water system. In this study, flooding is also interpret as a new threat (Beck, 1997). The risk curve is used, because the **tail of the risk curve** gives a good insight into the effects in the worst case scenario; Figure 2.1.

2.2 Chosen indicators to quantify systemic risk

> *... in light of divergent principles, values and interests and few (if any) universally applicable moral guidelines, any general definition of risk remains* ***elusive*** *... (Renn and Klinke, 2004)*

This quote of Renn and Klinke (2004), strengthens the problem of quantification of systemic risk. There is no uniform measurement of systemic risk. Renn and Klinke (2004) have made a list with an overview of the whole extent concerning systemic risk.

- Extent of damage
- Probability of occurrence
- Incertitude (*overall indicator for uncertainty*)
- Ubiquity (*geographical dispersion of potential damage*)
- Persistency (*temporal effects of potential damage*)
- Reversibility (*possibility of restoring the damage*)
- Delay effects (*latency between the event and the damage*)
- Violation of equity (*difference between the prejudiced and the harmed*)
- Potential of mobilization (*social conflicts due to people who feel afflicted by the consequences*)

In Appendix C, an overview is given with the interpretation of systemic risk and some ideas about possible quantifications of it, which have been passed during this study. **In this study, it is chosen to quantify the systemic risk by taking indicators of systemic risk and to use the worst case of risk curve, taking only the effects into account.**

2.2.1 Numbers of affected people and casualties

Effects to people can be parted into direct and indirect effects to people. The direct effects can be described in number of a) killed and b) wounded people. The casualties have been caused by direct contact with water. The indirect effected people are still alive, but have been physically or emotionally damaged by the flood. These people do not have contact with water. For the quantification of effects to people mostly the number of casualties is used.

The used damage module (HIS - SSM) gives the number of *casualties*, but also the '*affected people*'; Chapter 4 (DWW, 2003). In this study, the term affected people has been used for people that live in the flooded area and are affected by the flood. The casualties are the people that are directly killed by the flood. The relation between the affected people and the casualties is called the mortality. The direct effects to people can be described as number of casualties and indirect effected people are described as the affected people. In this study, the risk curve of group risk is used for the determination of the systemic risk of affected people and casualties. The focus is on the tail of the risk curve.

2.2.2 Economic damage (three components)

There are several ways to define and quantify direct and indirect damage (Bockarjova et al., 2004). In this section, a little insight is given into the problems with the determination of the damage. Two main approaches are described: spatial criterion and stock-flow differential criterion (Bockarjova et al., 2007).

'*According to the* spatial criterion *all losses attributable to the affected area are direct and losses incurred elsewhere are indirect. According to the* stock-flow differential criterion, *losses that refer to physical damage are considered as stock losses and are called direct losses; all losses associated with production curtailment - whether within or outside the affected area - then are referred as indirect losses, and measured as a flow.*'

In HIS-SSM, the economic damage is parted into three categories, which are added to get one value for the damage (DWW, 2003):

1. Direct damage - material
2. Direct damage - business interruption
3. Indirect damage

HIS - SSM uses the spatial criterion (Bockarjova et al., 2007). The direct material damage is defined as damage caused to capital by directly contact with water. Direct damage by business interruption (and corresponding loss of income) is presented in the flooded area. The indirect damage are economical effects for companies outside the affected area. Indirect damage includes the damage from companies who can not deliver or get goods from directly affected companies. Travel time losses are also part of the indirect damage, caused by the inoperative of transport axes in the affected area. (DWW, 2003). According to Bockarjova et al. (2007), the approach of HIS - SSM is not 'problem-free'. One of the problems is that the approach of HIS - SSM may lead to a double counting due to underestimation of distinction between stock and flow. The direct damage is subdivided into two damage categories, but the first one is a stock measure and the second one is a flow measure (Bockarjova et al., 2007).

The categories of HIS - SSM have been considered as fundamentally different in this study. The different categories are not added, but are presented as separated damage categories. The results of the different kinds of economical damage are put into an risk curve for getting a better indication of the societal impact of the flood to every part of economic damage. The direct material damage is taken as leading damage category.

2.2.3 Volume of incoming water

As said in section C.2, resilience time is the time to reach a new equilibrium after the flooding. The resilience time is dependent on some factors, like the amount of incoming water, the occurred damage, the relations between the damage and the recovery of the damage (time, money and energy).

The recovery of the damage can start after the drainage of the area. The drainage time is the time that the area needs to drain the incoming water. Some examples in history, like the Netherlands in 1953 and New Orleans in 2005, show that this drainage time takes some months to years. In this study only the water inflow is measured as parameter for the drainage time (as part of the resilience time). The more water inflow, the more water has to pump out the area. The start of rebuilding of the area is more delayed. The water inflow is given by SOBEK; Chapter 4.

Chapter 3

Study Area

3.1 Dike ring 14 in the Netherlands

The Dutch flood plains are divided into dike rings; Figure 1.2. A dike ring is an area, which is surrounded by a primary dike that protects the dike ring area from flooding by river, lake or sea. Dike ring 14 is the end of the Rhine - Meuse Delta, which catchment area lies in several European countries; Figure A.1. The surface of the dike ring area is about 223,000 ha and it lies within three Dutch provinces: North Holland, South Holland and Utrecht.

The area is characterized by a high density, because of several cities, like The Hague, Leiden, Haarlem and parts of Amsterdam and Rotterdam. The total population of the area is about 3.255 million people. Figure 3.1 shows the high - densely infrastructure network in the area. The area has an important industrial, commercial and governmental functions. Important places in the dike ring area are Schiphol Amsterdam (Haarlemmermeerpolder) and the seat of government (The Hague). The maximum possible damage is estimated at 290 billion euros (MinV&W, 2005a). There are numerous of cultural - historical and natural values; Figures A.11 and A.12. Dike ring 14 has the highest cost efficiency indicator of all dike rings in the Netherlands. The cost efficiency indicators is the possible damage in the protected area per kilometer primary dike; Figure A.2.

3.2 Water system

The western part of dike ring 14 is bordered by the coast of the North sea. The other borders are: Nieuwe Waterweg, Nieuwe Maas and Hollandse IJssel. The dike ring area is bordered in the northeast by the Amsterdam - Rijn Kanaal, the IJsselmeer and the Noordzeekanaal.

In past several lakes were reclaimed, like the Haarlemmermeer. Many polders results of this land reclamation, but it also implied that most parts of dike ring 14 are under sea level. The ground level of the Haarlemmerpolder, Alexanderpolder and Zuidplaspolder are more than six meter below sea level at some locations; Figure A.5. Due to the ground levels below sea level, there is a network of canals; Figure A.3(b). During precipitation, the canals collect the superfluous water and transports it to pumping systems; Figure A.9(b). The superfluous

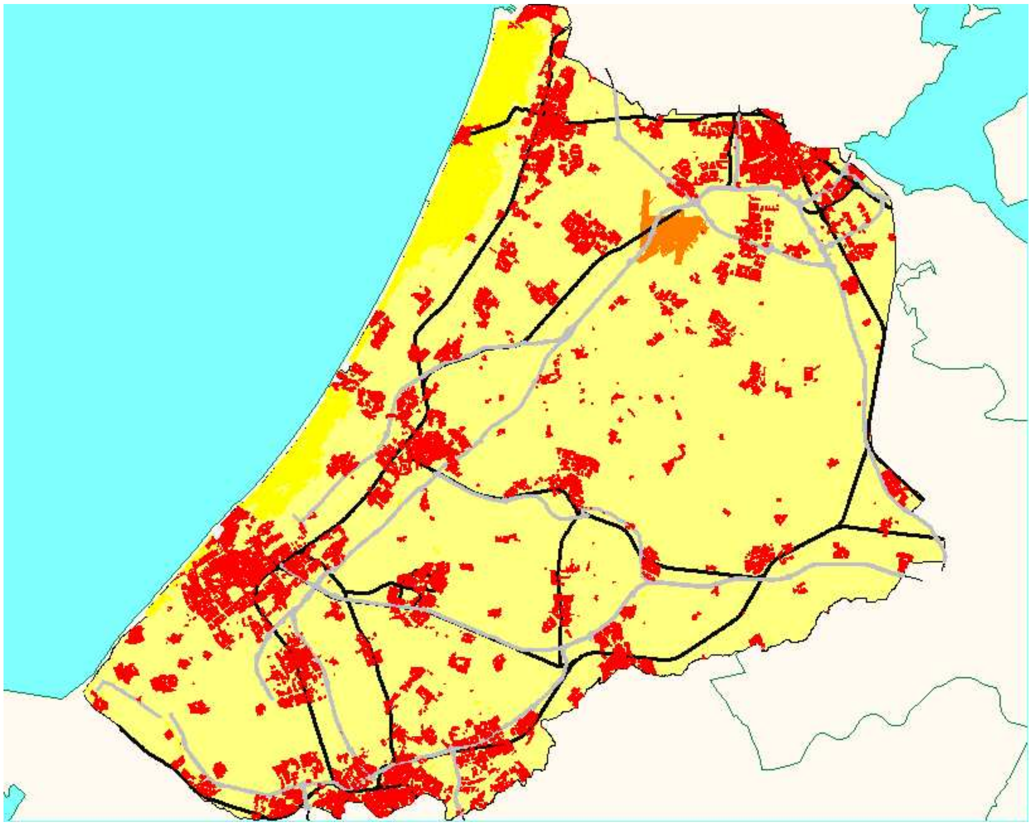


Figure 3.1: Current situation dike ring. The grey and black lines respectively represent the high ways and the railroads. The yellow surface are the dunes and the red surfaces are buildings (cities). Schiphol can be seen by the orange surface. (All information is from the SOBEK schematization by VNK).

water is drained off to the surrounding waters. The canals in the area have a higher level than the surrounding area. This also goes for the dikes of the Old Rhine, in the middle of the dike ring area.

3.3 Flood defence

The Flood Protection Act demands exceeding probability of 1/10,000 years^{-1} for dike ring 14. Primary dikes surround the dike ring area at all sides. The sea coast and the dikes between Hook of Holland and the Storm surge barrier Hollandsche IJssel are direct primary dikes. Clockwise from IJmuiden to the Storm surge barrier Hollandsche IJssel, the dikes are indirect primary dikes. The direct primary dikes (category a and b) should have the height which corresponds with the exceeding probability in the Flood Protection Act. The indirect primary dikes (category c) should have the same safety height as the day that the Flood Protection Act came into force (MinV&W, 2005b).

Besides the dikes and dunes, the dike ring is protected by three storm surge barriers: Storm surge barrier Nieuwe Waterweg, storm surge barrier Hartelkanaal and Storm surge barrier Hollandsche IJssel. There are also some sluices in the primary dikes of the area. One of it are the sluices at IJmuiden, which lies between the North Sea and the North Sea Channel. The sluices and storm surge barriers influence the water levels in the rivers and canals around the area (MinV&W, 2005b).

Land elevation has an important role during a possible flood. It guides the flow of water during the inundation of the polder. There are secondary dikes in the southern part of the dike ring area; Figure A.4(a). The Old Rhine Dike is also a secondary dike. High elevated line elements in the area, like (rail)roads and canals, also have a large influence on the inundation of the polder (Hesselink et al., 2003; Alkema and Middelkoop, 2005; MinV&W, 2006a).

The dams, dikes and dunes are controlled by five water boards; Figure A.4(b). These institutions are responsible for the maintenance of the dikes. The water boards have to report the provinces. The Flood Protection Act postulates that the provinces control the primary dams. The provincial level has to report the minister about the flood safety of dike ring 14 (MinV&W, 2006a). South Holland is leader on behalf of the provincial level.

3.4 Systemic risk of dike ring 14

3.4.1 Current risk situation

The combined failure probabilities of dike ring 14 is determined as 5.25E-04 year^{-1} or 1/1905 year^{-1} by VNK; Table 3.1 (MinV&W, 2005b). In this Table, the failure mechanisms at each dike section have been added to get the probability of failure of each mechanism for the whole dike ring. The failure mechanisms have been combined, for having one flood probability of the dike ring. The VNK results of the economic risk can be seen in Table 3.2. The economic risk of dike ring 14 is determined by taking the average risk of the Table: 2.3 million euros per year (MinV&W, 2005a). The expected annual casualties is dependent on the breach location and it varies between 0.012 and 2.44 a year (MinV&W, 2005a). The group risk of dike ring 14 is schematized in Figure 2.2 (MinV&W, 2006a).

3.4.2 Systemic risk situation

Dike ring 14 lies beneath sea level, so there exists a flood risk. The Dutch created an area with low risk of flooding. The area is threatened at all sides. Although the potential flood effects are very high. The technical measures bring along risks, which are of a higher kind of order.

> *The systemic risk situation for dike ring 14 is characteristic and maybe leading to the situation of The Netherlands. Dike ring 14 is such an important area with high density and with an important economical output. At the forehand can be said that the systemic risk of a flooded dike ring 14 is high for the Netherlands (Hoekstra, 2005).*

The Netherlands could also be chosen as system, but the country has several dike rings, that have a certain systemic risk of flooding. Taking one dike ring does not give the total systemic risk of flooding for the whole country. So, dike ring 14 is taken as study area, because it is strong defined system.

Table 3.1: Combined failure probabilities per failure mechanism of all dike sections in dike ring 14 (MinV&W, 2005b)

Parameters	Probability of failure
Dikes	
Overflow or wave overtopping	7.14E-06 yr^{-1}
Uplifting and piping	1.51E-04,yr^{-1}
Damage to the revetment and erosion of the dike body	1.41E-05 yr^{-1}
Sliding or heaving of the inner slope	1.12E-11 yr^{-1}
Dunes	
Dune erosion	1.76E-04 yr^{-1}
Dams	
Overflow or wave overtopping	4.20E-05 yr^{-1}
Not closing	1.07E-04 yr^{-1}
Structural failure	2.65E-05 yr^{-1}
Combined probability of failure for all failure mechanisms	**5.25E-04 yr^{-1}**

Table 3.2: Overview of the damage per flood scenario for the current situation in dike ring 14, Southern Holland (MinV&W, 2005a)

Scenario number	Breach location	Probability [$year^{-1}$]	Damage billion euros	Type	Number of breaches	Water level m +NAP
1	Kralingen	1/7300	6,8	River	1	1.95
2	Scheveningen Boulevard	1/8400	1.9	Coast	1	4.65
3	Scheveningen sluis	1/13,000	3.6	Coast	1	5.1
4	Katwijk	1/41,000	11.3	Coast	1	4.43
5	Hook of Holland	1/87,000	2.0	Coast	1	4.95
6	Katwijk and Scheveningen Boulevard	1/120,000	13.4	Coast	2	4.65
7	Scheveningen Boulevard and Ter Heide	1/140,000	22.8	Coast	2	5.67
8	Rotterdam West	1/200,000	2.5	River	1	3.79
9	Rotterdam Oost	1/127,000	5.7	River	1	3.73
10	Katwijk, Scheveningen Boulevard and Ter Heide	1/450,000	37.2	Coast	3	5.67

Chapter 4

Models and scenarios

4.1 Models

4.1.1 SOBEK

SOBEK is an integrated software package for river, urban or rural management developed by WL | Delft Hydraulics. In this study, the Overland Flow module of SOBEK Rural has been used to simulate the hydrodynamics of the flood scenarios. SOBEK combines the 1D channel flow with the 2D overland flow, Figure A.3(b). The 1D model simulates the water flow in drainage channels of the area (blue lines) and the breach scenarios of the dikes. The 2D grid determines the overland water flow during the flood. A standard grid used in SOBEK represents the height map of dike ring 14. It contains the heights and corresponding roughness at each grid cell. The grid cell is 100 m * 100 m. The grid is based on the 'Actueel Hoogtebestand Nederland' (actual height map).

During VNK project, SOBEK is used for modeling the flood scenarios in dike rings. A model schematization of dike ring 14 is made as implementation during the VNK research (MinV&W, 2005a, 2006d). SOBEK version 2.09.015 and the VNK schematization of dike ring 14 is used during this study.

Line elements as (rail)roads and compartmentalization dikes have influences on overland flow. These elements are included in the actual height map, which results in the standard SOBEK grid; Figure 3.1 (MinV&W, 2006d). This standard SOBEK grid is used in the zero situation.

During the project VNK, the situations with and without breaches in line elements has been researched, because some heights in the schematization are expected to fail by flooding. The differences between these two outcomes can be used in the research to compartmentalization. In most cases without breaching of line elements, the number of casualties decreases, because restriction of the flooded area. If this restriction leads to high values for the inundation depths and rising rate, the number of victims increase much (MinV&W, 2006a) p.28. The working of compartmentalization is also based on higher line elements. In some cases, compartmentalization will reduce the number of casualties, but it can also leads to increase in number of victims.

In this study, the schematization of the situation with breaches in line elements is taken as zero situation. Compartmentalization dikes are constructed in the area to hold the water. If current line elements are used as compartmentalization dikes, these dikes are assumed to be steady enough, which is not the case now (MinV&W, 2006a).

4.1.2 HIS - SSM

HIS - SSM (v2.2) is used for the determination of the affected people, casualties and economic damage. HIS - SSM (Hoogwater Informatie Systeem - Schade en Slachoffer Module) determines the damage to people and economy in a spatial extent. The outcomes of SOBEK are used as input for HIS - SSM. The inundation depth and velocity are given by SOBEK. Using the **water rise calculator of HIS - SSM**, the water rise can be determined per grid cell. Other parameters are the standard critical flow velocity of 8 m/s and high - rise block houses has been considered as safe (DWW, 2005b,a).

HIS - SSM calculates the economic damage, based on inundation depths of SOBEK. In HIS - SSM, the grid cells in standard grid of dike ring 14 contains information about the land function. For every land function, a damage factor has been determined. The damage factors are related to the inundation depths. The damage is determined by the following formula (DWW, 2005b):

$$S = \sum_{i}^{m} S_i \sum_{i}^{n} \alpha_{ij} n_{ij}$$

α_{ij} is the damage factor in damage category i on grid j
n_{ij} is number of units in damage category i on grid j
S_i is the maximum damage per unit in damage category i
n is the number of grid cells
m is the number of damage categories

For the determination in number of casualties, the total number of inhabitants are multiplied by a factor (*f(h)* [-]). This factor is based on the inundation depth (d [m]), flow velocity (v [m/s]) and rising rate (w [m/hr]). The following formulas have been based on these parameters (DWW, 2003, 2005b; MinV&W, 2006d).

In case of large flow velocities (mostly located near the breach):

$f(h) = 1$ (if $h \cdot v \geq$ and $v \geq 2$)

In case of casualties by large rising rate:

$f(h) = 1.45 \cdot 10^{-3} \cdot e^{1.39h}$ (if $w \geq 0.5$ and $1.5 \leq h \leq 4.7$)
$f(h) = 1$ (if $w \geq 0.5$ and $h > 4.7$)

In case of casualties in the other areas:

$$f(h) = 1.34 \cdot 10^{-3} \cdot e^{0.59h} \quad (\text{if } w < 0.5 \text{ and } h > 0)$$
$$f(h) = 1.34 \cdot 10^{-3} \cdot e^{0.59h} \quad (\text{if } w < 0.5 \text{ and } h < 1.5)$$

Using the **evacuation calculator** the preventive evacuation of dike ring 14 can be determined (MinV&W, 2006c). This only goes for evacuation before the flood occurs. Evacuation during the storm is not attractive, because of the storm in the area and the probability of becoming hit by flying objects in the area. The evacuation calculator is based on the current height map of dike ring 14. New compartmentalization strategies bring new heights in the area, which leads to new evacuation routes. The Determination of new evacuation routes is outside the scope of this study, so the evacuation calculator is not used. The evacuation factor in HIS - SSM is zero.

4.2 Flood scenarios

4.2.1 Flooding of dike ring 14

In this study is chosen for some flood scenarios, which are located around the whole dike ring. The flood scenarios have both a big probability/little damage and a little probability/big damage. Flood scenarios exist of:

- The locations of dike breaches, section 4.2.2 and section 4.2.3
- The hydraulic boundary conditions during the breaching of the dike, section 4.2.2
- The breaching scenario of the dike body, section 4.2.2
- The corresponding probability of occurrence of each scenario, described in section 4.2.2
- Overland flow of water; see Figure 4.2

4.2.2 Five dike breach locations

The primary dikes around the dike ring are parted into dike sections. These dike sections are parts of the dike, which have more or less the same characteristics. The dike sections can be divided into three types of flood defence: dikes, dunes and hydraulic structures (MinV&W, 2005a). In the study, several iteration steps have been taken for getting comparable effects with the VNK results; Table 7.7.

The following breach locations have been taken, because of the spread flood scenarios and location at all sides of the dike ring area.

- Scheveningen: This breach location (at the sea) has the name of ‘dune section 4102’ in Figure A.6 (MinV&W, 2005b). According to MinV&W (2005b); Appendix II, dune erosion is the main failure mechanism of this section.
- Kralingen: this location is also known in VNK as ‘Dike section Nijverheidstraat A (number 5002)’; Figure A.6. It is located west of the Storm surge barrier Hollandsche IJssel at the New Meuse near Kralingse Veer; Figure A.7 (Baan and Asselman, 2005;

MinV&W, 2005b). Piping is the main failure mechanism of this dike section, (MinV&W, 2005b), p.31.

- Katwijk: This seaside breach location has the name of 'dune section 5106'; Figure A.6 (MinV&W, 2005b). Dune erosion, not-closing and construction failure of sluices at Katwijk are the main failure mechanisms (MinV&W, 2005b), p.31.
- Ter Heijde: This breach location is located at the sea an it has the number of 4107; Figure A.6. The failure mechanism of Ter Heijde is dune erosion (Baan and Asselman, 2005; MinV&W, 2005b).
- Haarlem: The assumption has been made that the sluices of IJmuiden fail. The water flows into the North Sea Channel and it distributes to the dike ring 13 (northern boundary) and dike ring 14. The water flow is held by the Spaarndammer Dike, near Spaarndam, see photo tour at appendix A, located at the north east of Haarlem. The assumed failure mechanism of Haarlem is construction failure of the IJmuiden sluices and overtopping, compared with collapsing of the dikes near Spaarndam.

In the VNK reports, the hydraulic boundaries have been determined by using PC - Ring. In this model, the considered parameters are the discharges of Rhine (Lobith) and Meuse (Lith), the wind direction and the sea level (MinV&W, 2006d), p.30. It was outside the scope to determine the hydraulic boundaries by using PC - Ring. In this study, three water level patterns have been determined as boundary conditions, see Figure 4.1:

1. The breach locations at sea (Katwijk, Scheveningen and Ter Heijde) have the same hydraulic boundary condition, given by VNK. The condition is based on a average tide with a storm of 35 hours. The peak of the storm is at 4,5 hours after the top of the tide. The water level reaches a top of 5,67 m (MinV&W, 2006d), p.34. This maximum water level has a probability of occurrence of 1/10.000 per year (Baan and Asselman, 2005).

2. At Kralingen, the water level is determined by the sea water levels and the river discharges. The water levels show the same tide as the sea, only the levels are higher and have less amplitude. The Storm surge barrier Nieuwe Waterweg (Maeslantkering) must protect the hinterland against flooding, because the doors can be closed during high water levels at sea. In that situation, the water level is fully determined by the river discharges and does not show a tide. The river water can not flow into the sea, so the water level will rise and the rising rate is dependent on the river discharges. The closing and opening time of the Maeslantkering is about three hours (wikipedia.org). The barrier can be closed short before and after the critical sea water levels.

   There are two situations that can cause high water levels behind the Maeslantkering: 1) Very high water levels at sea and failure of the Maeslantkering (with a failure probability of 10^{-4} year^{-1}) and 2) High water levels at sea, closed Maeslantkering and high river discharges. For both situations holds: high water levels at sea are necessary to get high water levels behind the Maeslantkering. There is not much difference between the water levels in both situations at Kralingen. The sea dominates the water level at Kralingen and the Maeslantkering does not have much influence. (MinV&W, 2006d).

   In this study, the breach location at Kralingen has a hydraulic boundary condition with a top of 2.88 m. Comparing this value with the highest values in VNK, this value is overestimated in case of Kralingen. The results of VNK shows that Kralingen fails at a water level of about 1,90 m (MinV&W, 2006d).

3. The choice of hydraulic boundary condition of Haarlem is based on the boundary conditions of Ter Heijde. After the breach of the sluices of IJmuiden, the water flows into the Noordzeekanaal. The dikes are not high enough to hold a water level of 5,67 m. Assumed is that the water level at the breaching location of Haarlem is decreased to a value of about 4,5 m, because of the dispersal of water in the area.

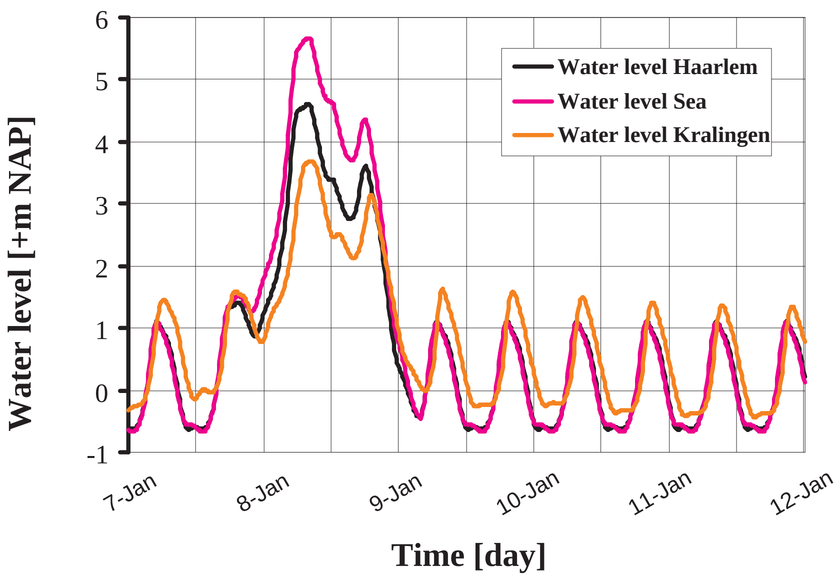


Figure 4.1: Water levels at breaching locations in the flood period. The flooding happens at 8^{th} January 1991.(in SOBEK)

The calculation of the breaching scenarios are a function in SOBEK (WL | Delft Hydraulics, 2004). The breaching scenarios exist of different parameters. In appendix D, the used model parameters of the breaching scenario are shown. In this study, two different breaching scenarios are used: clay dike and sand dike (dune).

In Figure D.1 and Table D.2, the begin time of the breach scenarios is given and the connection with the corresponding hydraulic boundary conditions is showed. The breach scenarios of Kralingen and Haarlem start at the time that the water level overtops the dike height. The start time of Ter Heijde, Katwijk and Scheveningen is given in the used schematization of VNK (MinV&W, 2006d).

It is assumed that the simulation time ends about ten days after the start of the dike breach scenarios. The assumption has been made that the breaches in the dike are not filled in these days. So, the water can flow freely in and out of the area during the simulation time.

4.2.3 Seven flood scenarios

The research to compartmentalization strategies for the whole dike ring needs flood scenarios that describe the corresponding overland flow that follows from the breaching scenarios. This study is focused on the worst case scenario. Dike ring 14 is surrounded by higher water levels at all sides, so the flooding threat comes from all sides. One breach location shall not cause a total flood in dike ring 14 (MinV&W, 2006d; De Bruine, 2006). So, the worst case scenario should exists of more dike breach locations; Figure 4.2. The following cases are taken as the flood scenarios. The cases are named after the breaching locations. The last flood scenario is considered as the worst case scenario.

Scenario A: **Scheveningen - Boulevard**

Scenario B: **Kralingen**

Scenario C: **Ter Heijde**

Scenario D: **Haarlem**

Scenario E: **Ter Heijde - Schevening - Katwijk**

Scenario F: **Ter Heijde - Kralingen**

Scenario G: **Ter Heijde - Scheveningen - Katwijk - Kralingen - Haarlem (Worst case)**

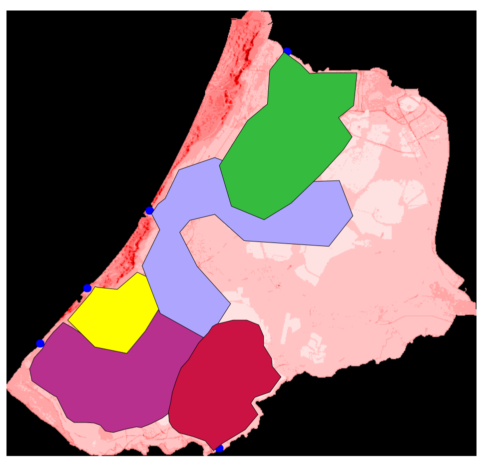


Figure 4.2: The five breaching locations in the worst case scenario and the corresponding overland flow during the worst case scenario.

The first four scenarios are selected, because of the locations at all sides of the dike ring. The choice of Kralingen, Ter Heijde and Scheveningen is based on VNK and Haarlem is based on the case of De Bruine (2006). Kralingen and Haarlem are located at rivers or canals and near deep polders, respectively Alexanderpolder and Haarlemmermeerpolder. Ter Heijde, Scheveningen and Katwijk is chosen as multiple breach scenario from sea. This scenario corresponds to the worst case scenario of VNK (MinV&W, 2005a). In the case of Ter Heijde and Kralingen the combination of high river discharge and high sea water level is examined. The worst case scenario is the possibility that all researched breaching locations are flooded. The water flows in the dike ring at all sides of the dike ring.

4.2.4 Probabilities of the flood scenarios

In terms of systemic risk, the flood probability has not the leading role. The focus of systemic risk are on the corresponding effects, Chapter 2. The conclusions of this study are based on the effects of the disasters. Although in this section a rough estimation has been made for the flood probability of each scenario. Some of the flood probabilities at each breach locations have been already calculated in preceding researches, but other have been estimated roughly. Besides, lack of time and information is the reason that the determination of probabilities is not very accurate.

The flood probabilities of dike sections can be related to each other and are between two extremes: *(completely dependent)* and *(completely independent)*. In the first case, the probabilities are added, while the probabilities are multiplied in the second case. In general, the calculated probabilities are between these two extremes.

In the research of VNK, the probability of flooding of a whole dike ring is dependent of the probabilities of flooding of its dike sections (MinV&W, 2005b). A failure of a dike section can be caused by several failure mechanisms, like overtopping, piping or dike breach. The flood probability of one dike section is based on the combined probability of each failure mechanism. The failure mechanism with the biggest probability is considered as leading for the flood probability of the dike section. In general, all failure probabilities of failure mechanisms are added. This goes for the different failure probabilities at each dike section and for all the dike sections together as one dike ring area (MinV&W, 2005b). VNK results contain also an uncertainty in the determination of the flood probability. Every dike section has a reliability index, by using betas. A small beta indicates a high reliability (MinV&W, 2005b).

In the following summation, the flood probabilities have been determined for each flood scenario, see also Table 4.1.

Scenario A: **Scheveningen** is the weakest link of dike ring 14, according to VNK. Scheveningen has a failure probability of 1/7300 year^{-1} (MinV&W, 2005b) p.30. In the VNK project, the maximum water level at the boundary condition was 1.02 m lower than in this study (MinV&W, 2005a), so the probability of occurrence of this case should be lower. Nevertheless, Scheveningen is assumed to have a probability of 1/7300 year^{-1} in this study.

Scenario B: **Kralingen** has a flood probability of 1/8500 a year (MinV&W, 2005b) p.31. According to Baan and Asselman (2005), the probability of flooding is 1/20,000 to 1/200,000 year^{-1} per year at this location. The closing of the Maeslant Barrier has not much influence on the water level at the start of the breaching of Kralingen: 1.86 +m NAP (closed state) and 1.95 +m NAP (open state) (MinV&W, 2006d) p.30.

In this study, the hydraulic boundary condition is higher than used during the VNK project (MinV&W, 2006d), so the probability is assumed to be lower. So, the assumption has been made that the scenario of Kralingen has a frequency of 1/20,000 year^{-1}.

Scenario C: **Ter Heijde** is considered as the weakest link in dike ring 14 with a returning period of about 1/3000 year in the research of Baan and Asselman (2005). VNK does not use Ter Heijde as single breach location, but it determines that also Scheveningen becomes flooded. VNK gives that scenario a probability of occurrence of about 1/140,000 year^{-1}, using the boundary condition of Figure 4.1 (MinV&W, 2005a) p.73.

In this study, Ter Heijde has just one breach, like in case of Baan and Asselman (2005). Using the probability of Baan and Asselman (2005) will cause some inconsistency in this study. The assumption has been made that Ter Heijde has a probability of occurrence of 1/50,000 year^{-1}. This value is roughly between the researches of MinV&W (2005b) and Baan and Asselman (2005).

Scenario D: **Haarlem** is a fictive scenario, based on the assumption that the dike ring can also become flooded in the northern part (De Bruine, 2006). The sluices of IJmuiden have to fail, before the water flows into the Noordzee Kanaal. A huge water front enters the area and overtops the dikes at the Noordzee Kanaal, which are about two to three meters above NAP. The Spaarndammer dike fails if the water front overtops the dike. The sluices have an average frequency of failure of 1/10.000 year^{-1}, according to the law. The sluices suffice to the standard, controlled by MinV&W (2006b). The calculation water level is mostly 10% lower than the testing water level at the time of failure (Personal conversation with K. Wouters at 22 August 2006, HKV, Lelystad). So, the sluices have been estimated to have a failure probability of 1/100,000 year^{-1}. The dikes at Spaarndam are about two meters high and will fail when the water front reaches the dike. The scenario of Haarlem is assumed to have a probability of occurrence of about 1/100,000 year^{-1}.

Scenario E: The scenario of **Ter Heijde, Scheveningen and Katwijk** has a probability of occurrence of 1/450,000 year^{-1} (MinV&W, 2005a,b). As said above, this scenario is assumed to happen by a water level of 5,67 m above NAP. The different probabilities of the single flood scenarios can be found in Table 4.1 (MinV&W, 2005a) p.73.

Scenario F: In the scenario of **Ter Heijde and Kralingen**, the Maeslantkering is between the breach locations. As already mentioned, the Maeslantkering has a slightly influence on the water level at Kralingen (MinV&W, 2006d).

The probability of occurrence is a multiplication of the probabilities, because it is assumed that the breaches have a partly influence on each other. Based on flood scenarios B and C, the probability of this scenario has a range of values between 1/50,000 and 1/1,000,000,000 year^{-1}. This reality is more likely to the situation of 1/50,000 year^{-1}, because of the scenarios' dependency by the Maeslantkering. The scenario is assumed to have a probability of occurrence from 1/2,000,000 year^{-1}, which is more likely to the value of scenario 14 of VNK. This scenario is also a combination of breach locations at the river and the sea and has a probability of occurrence of about 1/3,600,000 year^{-1} MinV&W (2006d) p.26. This has the same order of magnitude as the assumed probability of occurrence in this study.

Scenario G: The probability of occurrence of the **worst case scenario** is hard to determine. This scenario contains numerous of uncertainties. Assumed is that the probability of occurrence is about 1/10,000,000 year^{-1}. This is based on the fact that there are high water levels at sea and river and the sluices of IJmuiden and the storm surge barriers in the south fails.

The dike ring in this study has a different flood probability in comparison to the VNK research of dike ring 14, because other scenarios are used with other scenario probabilities. The flood scenarios lead to a flood probability for the whole dike ring of 1/4550 year. In comparison, VNK has determined a flood probability of 5.25E-04 year^{-1} or 1/1905 year^{-1}; Table 3.1 (MinV&W, 2005b).

Table 4.1: Flood probability of each flood scenario in this study

Flood scenario	Probability	Literature source
A Scheveningen	1/7,300 year^{-1}	MinV&W (2005a), p.30
B Kralingen	1/20,000 year^{-1}	partly based on MinV&W (2005a), p.31
C Ter Heijde	1/50,000 year^{-1}	based on Baan and Asselman (2005); MinV&W (2006a)
D Haarlem	1/100,000 year^{-1}	based on De Bruine (2006) and own interpretation
E Sea attack	1/450,000 year^{-1}	MinV&W (2005a), p.73
F Sea-river	1/2,000,000 year^{-1}	own interpretation
G Worst case	1/10,000,000 year^{-1}	own interpretation
# Katwijk	1/41,000 year^{-1}	MinV&W (2005a)

Chapter 5

Compartmentalization strategies: theoretic exercise

5.1 Compartmentalization strategy to reduce the systemic risk

In risk management are several safety strategies that reduce risk by lowering the probability of occurrence, mitigating the corresponding damage or a combination of both risk sides. WBGU (1998) has made six risk clusters, that exists of different risk combinations. These combinations contain different relations of probability at one side and consequences at the other side. Flooding belongs the to the *low probability - high effects* risk situation (Hoekstra, 2005) with corresponding risk clusters: *Damocles* and *cyclops*, see the risk curve of Figure C.4 (WBGU, 1998).

Some management strategies have been determined, which can be used for the different risk clusters, see Table C.1. The best approach for reducing the risk situation of low probability - high effects is to use the strategies of action that belongs to the scientific - based risk management; Table 5.1 (Renn and Klinke, 2004). Strategies and tools are presented in Table C.2 (WBGU, 1998). One of the strategies for action for reducing the (systemic) risk is the *decrease of the disaster potential*. Compartmentalization suits perfectly to this risk reduction strategy, because it divides (and reduces) the potential extent of effects. Compartmentalization aims to create time for counteractions, like evacuation. This is part of the *emergency management*. Based on Table 5.1, compartmentalization should be an useful strategy for systemic risk reduction in case of a low probability - high effects risk situation.

Table 5.1: Overview of science-based risk management strategies, part of Table C.1 (Renn and Klinke, 2004)

Management	Risk class	Extent of damage	Probability of occurrence	Strategies for action
Science-based	*Damocles*	high	low	• Reducing disaster potential
	Cyclops	high	uncertain	• Ascertaining probability
				• Increasing resilience
				• Preventing surprises
				• Emergency management

5.2 Compartmentalization in dimensions

In this section, the working of compartmentalization is explained by taking three dimensions. The dimensions are often combined, but it is useful to make distinction between them:

- Heights of compartmentalization dikes The first compartmentalization dimension is the *height of compartmentalization dikes* [in meters]. The dike height determines the potential maximum water depth during the first period of the flood. The final water level after the inundation is hardly influenced by compartmentalization (Alkema and Middelkoop, 2005). According to MinV&W (2006e), working of the compartment dike heights are based on two principles. These two principles can be adapted for every specific situation.:
  - *New dikes in the dike rings, which can turn the water out from vulnerable areas.*
  - *Low dikes, which can guide the water away from vulnerable areas.*
- Surface of the compartment The second dimension is the *size of compartment surfaces* [in square meters] and is determined by the length of the compartment dikes. This dimension is based on the assumption that the water stream does not pass the compartment dikes. The size of the compartments determines the amount of water, that the compartment can handle. The raising rate is dependent on the combination of surface and water inflow. In general leads a little surface to less damage, because less area is flooded. Although it is possible, that a higher raising rate leads to a larger damage, like in the case of Kralingen during the VNK measurements (MinV&W, 2006a).
- Compartment configuration (pattern of compartmentalization dikes) In this study a third principle dimension is emphasized: *the pattern of the compartmentalization dikes*. The configuration of the compartment determines has the steering role of the flowing water in the dike ring area. '*The dike can get a function as secondary dike behind the primary dike, but also used as dike perpendicular to the river*' (Hesselink, 2006). These two kinds of placing dikes in the area leads to two different configurations of compartment dikes and different water behavior in the area. The flooded area can be spread or be concentrated. The occurred damage shall be different for each of these configurations.

5.3 Compartmentalization strategies

Compartmentalization strategies are compartmentalization plans, that are based on combinations of the three principle dimensions. *In this study, the investigation into compartmentalization strategies for dike ring 14 is only based on different compartment configurations.* The assumption is that the compartmentalization dikes can stop the water flow, because the dikes are high and steady enough. The dimension of dike height is neglected. During the study, the surface plays indirectly a role, but this is not handled. The studied strategies are designed to cope with all possible flood scenarios in the area.

Looking at an area that is threatened by water at one side, there are roughly three different configurations of using dikes; Figure 5.1. The outer lines in the figure show the primary dikes, that protect the area against flooding. Figure 5.1(a) shows the situation of the dike ring without compartmentalization dikes, the zero situation. Figure 5.1(b), shows that the dikes are placed perpendicular to the primary dike. This causes an equal spread of the risk in the dike ring area. Looking at Figure 5.1(c), the dikes are parallel to the primary dike. Behind every compartmentalization dike, the risk of the area is more reduced. The last considered pattern is the placing of compartmentalization dikes around certain valuable areas. This strategy is based to reduce the risk within that specific area; Figure 5.1(d).

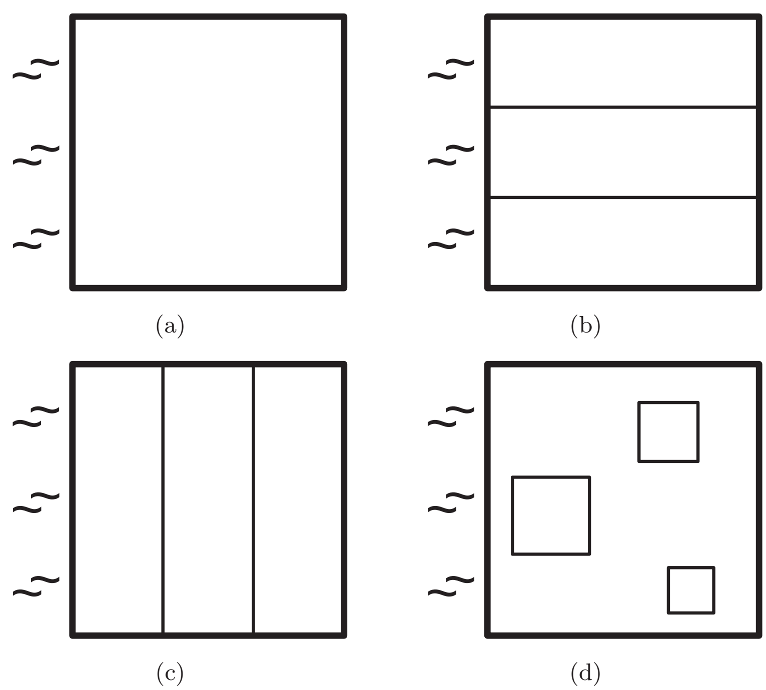


Figure 5.1: Schematization of different compartmentalization dikes patterns in a dike ring area: Zero situation (a), perpendicular dikes (b) parallel dikes (c) and dikes around an area (d). The water front is at the left side of the area.

The hydraulic boundary conditions are different for every dike ring, like the overland water flow and the inundation depths. The same goes for the total value and the value distribution for every dike ring. All such conditions influence the final effects (risk reduction) of the compartmentalization strategies. This leads to the underlaid hypothesis of this study. A dike ring area, threatened at one side and with one concentrated valuable part, needs a different kind of strategy then a dike ring area with an equal spread value and surrounded by water.

Dike ring 14 is surrounded by higher water, so there is a potential treat at all sides of the area. Based on this assumption, three compartmentalization strategies have been determined as fundamental different; Figure 5.2. The strategies in Figure 5.2 are based on the strategies in Figure 5.1. The only difference is that in Figure 5.2 the area is surrounded by water.

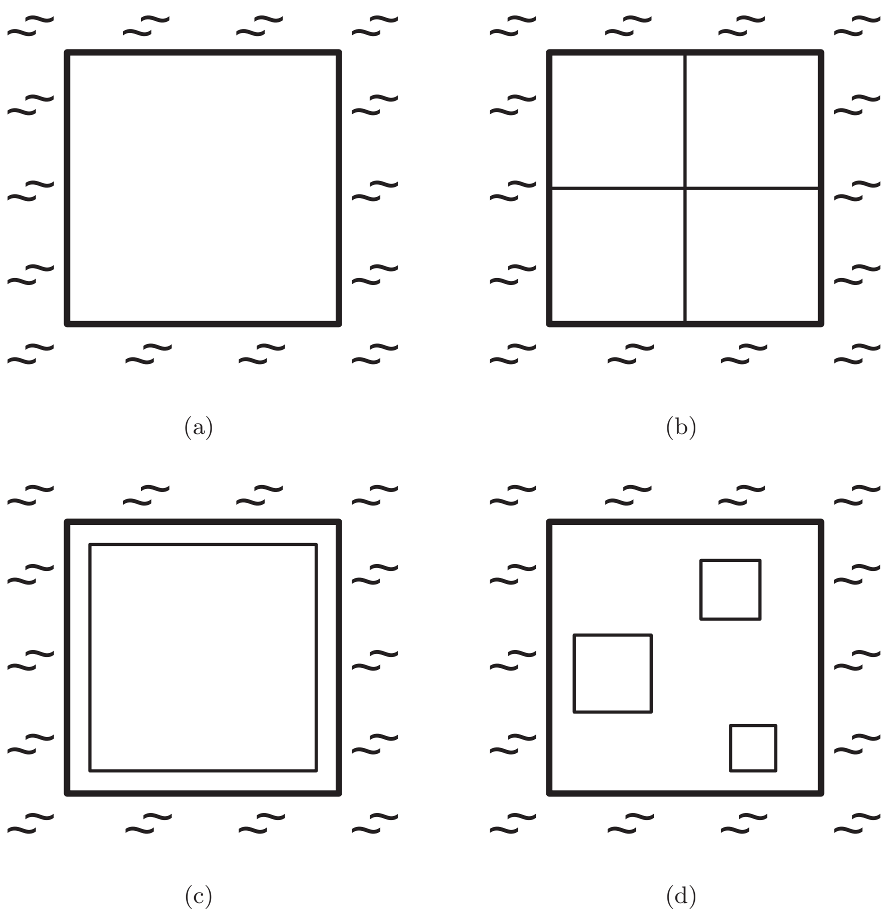


Figure 5.2: Schematization of different compartmentalization strategies for a dike ring area: Zero situation (a), Partition (or in case of many dikes: Chess board) (b) Secondary dike (c) and Value protection (d). The dike ring area is surrounded by water fronts.

5.3.1 Partition

Dikes used by the *partition strategy* divides the dike ring into equal compartments; Figure 5.2(b). Partition of the dike ring into equal parts leads to more or less equal flood risk in the compartments, assuming that the primary dikes have the same strengths and heights. The surfaces of each compartment are equal and each compartment has the same amount of primary dikes. In this report the term partition is only used when one or two compartmentalization dikes are placed and in case of two compartmentalization dikes, the dike have to be located crosswise in the area. Using more than three compartmentalization dikes, this partition strategy can also be called as, chess-board strategy. The chess-board strategy leads to compartments without primary dikes.

> *. . . The example of compartmentalization of in large buildings to reduce the fire risk is based on the partition strategy. The building is parted into subdivisions by fire resistent walls; Figure 5.3 . . .*

Figure 5.3: Compartmentalization in a building to reduce the fire risk.

Looking at an example of compartmentalization of an in area to reduce flood risk, the dikes of the Old Rhine is an interesting, because it divides dike ring 14 into two flood divisions. Recently dikes and sluices of the Old Rhine are recovered to become the function of compartmentalization dikes. This means that water can not pass the line between Katwijk and Bodegraven. This line lies in the middle of dike ring 14 from west to east (www.waterforum.net, 23 November 2006). This secondary dike is part of the partition strategy.

5.3.2 Secondary dike

The *secondary dike strategy* is called by placing compartmentalization dikes just behind the primary dike; Figure 5.2(c). The land behind the secondary dike is protected by two dikes. The secondary dike encloses a compartment, that is called *secondary dike ring*. The space between the primary and compartmentalization (or secondary) dike can be seen as a buffer zone landward. A flood only occurs by the breaching of both of the dikes. The flood risk in the secondary dike ring is lower than the flood risk in the buffer zone. It provides time for rescue of the people or the whole ship (as system) to enter a harbor and safe the ship. Such time for counteraction improves probabilities of survival of the ship becomes larger.

> *. . . In case of sinking reduction of a ship, ships have a double hulled sides. The risk of pollution by shipment is also reduced by double hulling of a ship. Two walls are constructed with a certain space between the walls; Figure 5.4. The double hulling of a ship can be compared with the secondary dike strategy . . .*

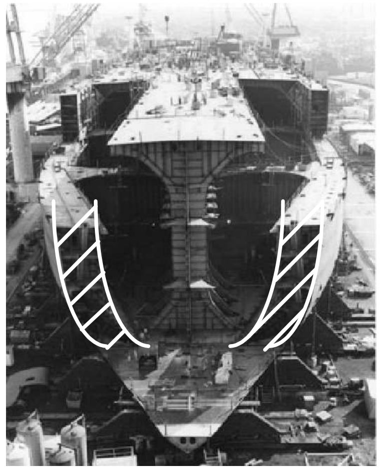


Figure 5.4: A double hulled ship as compartmentalization strategy to reduce the sinking risk of a ship.

5.3.3 Value protection

The strategy of protection of the valuable areas (*value protection strategy*) in the dike ring is based on protecting the most vulnerable or valuable places, which damage the area more than other parts; Figure 5.2(d). Compartmentalization dikes are build around the areas and form little secondary dike rings. For this strategy it is necessary to determine the weak or vulnerable links in terms of systemic risk. The value must exist in relative small areas, compared to the whole area. This strategy causes higher norms for vulnerable area than the other areas in the dike ring. This strategy is emphasized by MinV&W (2006e): '*Compartmentalization is most efficient in (vulnerable) areas with many inhabitants and a high potential damage. The same goes for vital transportation axes (railroads or highways)*'.

> *... The use of value protection can be compared with a bank safe. The most valuable part of the bank is the best protected place in the building. The value is a concentrated in a small location in the building; Figure 5.5. In case of burglary, the last obstacle that has to be taken by the thieves, is the bank safe. ...*

Figure 5.5: The safe in a bank building as example of the value protection strategy.

5.4 Theoretic exploration

Before the implementation of different strategies in the schematization of dike ring 14 (SOBEK), a rough theoretic model has been made in Excel.

5.4.1 Goal of theoretic approach

The purpose of this model is to get a rough insight into the working of compartmentalization strategies in an area and the corresponding risk reduction. The risk is measured by individual risk: probability times effects, but the systemic risk is also taken into account.

In the model, the area is described by a grid of 12 * 12 cells; Figure E.1. Each grid cell contains a value that can be varied. The value can be interpreted as potential loss (people, economic or environmental values) in an area. In this study, the value distribution is taken as parameter to describe the characteristic of the area. For example, the value (to people and economy) in a city is more concentrated than on the countryside. The characteristics of an area determines the potential effects due to a flood. The different compartmentalization strategies have their own influence on the spread of the overland water flow and the corresponding effects. (Nota bene, the value protection is based on heterogeneity in an area.)

In Appendix E, the working of the model is described. For each compartmentalization strategy, the generated risk reduction of have been given for different lengths of compartmentalization dikes. Furthermore, four cases have been schematized to describe areas with different value distribution. The value distribution is quantified by using the *Lorenz curve* and *Gini coefficient*.

Case 1: Completely homogenous area: All grids have value 1. Gini coefficient is 0 [-].

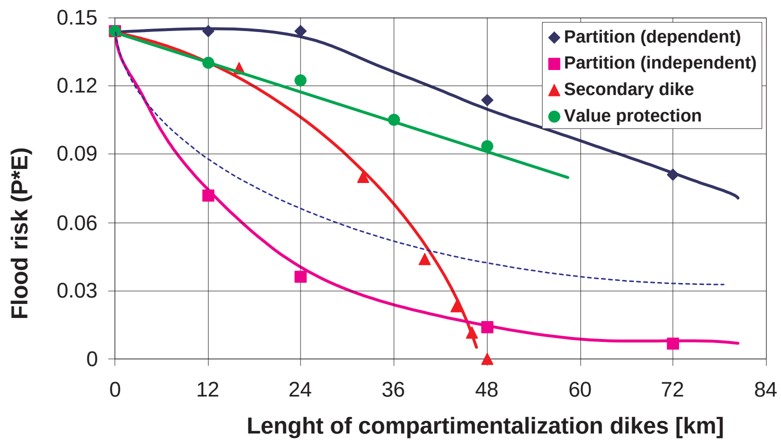
Case 2: Heterogenous and value is spread: 20% of surface has value of 10 and 40 % of surface has value 30. Gini coefficient is 0.40 [-].

Case 3: Heterogenous with valuable concentration: 20 % of surface has value of 10. Gini coefficient is 0.51 [-].

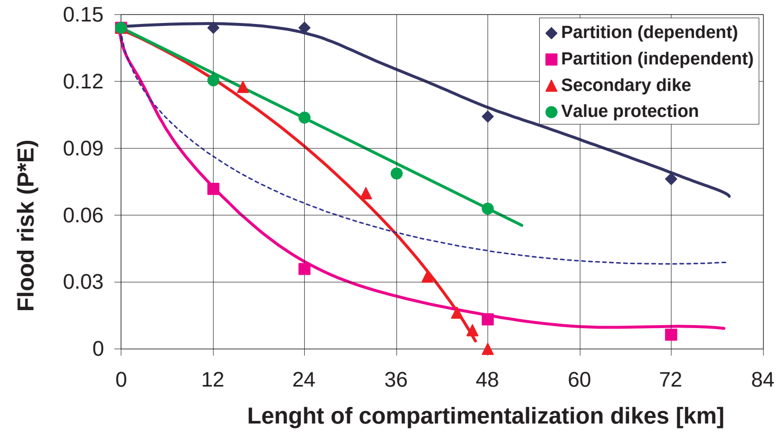
Case 4: Heterogenous with high valuable concentration: 5 % of surface has value of 50, Gini coefficient is 0.67 [-].

5.4.2 Results

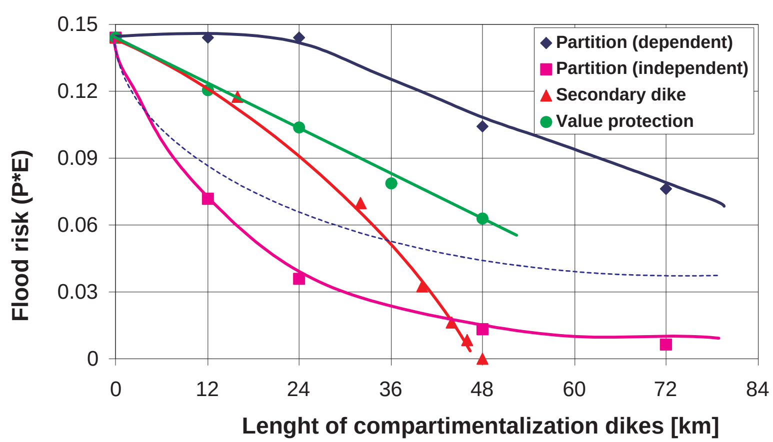
In Appendix E, the model has been worked out and the outcomes are represented in Figure 5.6. In the graphs, the risks (Y-axe) are given for each lengths of compartmentalization dikes (X-axe). The partition strategy is given by two lines. The ‘dependent line’ shows the effects of the partition strategy in situation of overtopping at all sides, while the ‘independent line’ gives the effects in case of one breach. There exists a band of outcomes for the partition strategy.



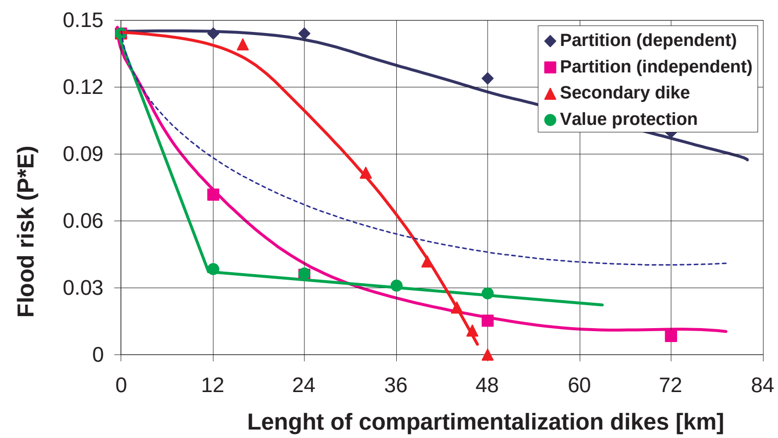
(a)



(b)



(c)



(d)

Figure 5.6: The results of the theoretic model presented in graphs. It shows the effects of different compartmentalization strategies by different lengths of the compartmentalization for different value distribution cases: Case 1 (a), Case 2 (b), Case 3 (c) and Case 4 (d). The blue dot line shows the average line for the partition strategy, considered by expert judgement of the author.

5.4.3 Conclusions

The conclusions of the theoretic model of compartmentalization strategies are given in Table 5.2, which is based on Figure 5.6. The length of compartmentalization dikes are given as a percentage of the length of the primary dikes.

Table 5.2: The best compartmentalization strategy as a function of the relative compartmentalization dike length per considered case. For the determination of the partition strategy, an fictive average line is chosen between the two boundaries.

	Relative length of compartmentalization dikes to the length of primary dikes 50 %	75 %	100 %
Case 1 *GINI coefficient* < 0 *(Completely homogenous)*	Partition	Partition	Secondary dike
Case 2 *GINI coefficient* > 0.40	Partition	Partition Secondary dike	Secondary dike
Case 3 *GINI coefficient* > 0.51	Partition	Partition, Secondary dike Value protection	Secondary dike
Case 4 *GINI coefficient* > 0.67	Value protection	Value protection	Secondary dike

- Compartmentalization as risk reduction strategy decreases the risk situation of the area, because all lines in the graph shows a reduction.
- **Partition**
  - Partition is only a good strategy in case of homogeneity. On the other hand, the value protection strategy only performs well in case of heterogeneity.
  - Partition shows the most risk reduction by placing less compartmentalization dikes in relation to the primary dikes.
  - The uncertainty of the partition strategy is high, because of the variability in outcomes of the risk situations. The breach location determines the inundated and the non-inundated area. In the secondary dike and value protection strategies, the non-inundated area is determined by the dikes, that forms a secondary dike ring.
- **Secondary dike**
  - The more willingness for placing dikes, the better the secondary dike strategy is. The direction coefficient of the line representing the secondary dike strategy is negative. Every increase of the lengths of the compartmentalization dikes results in a decrease of the risk.
  - The secondary dike strategy has only positive effects of risk reduction by placing much dikes in relation to the length of the primary dikes.

  - The distribution of the area has slight effects of the secondary dike strategy.

- **Value protection**
  - Value protection has the best performance in case of heterogenous distribution of the value.
  - The risk reduction is dependent on the amount of protected areas in the study area. The used length of compartmentalization dikes is based on the amount of these values.

Looking at the *systemic risk*, the worst possible attack exists of several breach locations around the dike ring area. Looking at the boundaries of the partition strategy, only the ‘dependent line’ should be taken into account. Based on this theoretic model, the conclusion can be made that partition is not an attractive strategy for reducing the systemic risks. The effects of the secondary dike strategy and value protection remain the same, focusing on systemic risk.

In Table 5.3, general conclusions have been made about the considered compartmentalization strategies. These conclusions are based on the data of Table 5.2. Many dikes stands for a high relative length compartmentalization dike length, while few dikes represents a small relative length of compartmentalization dikes. There is not an fixed boundary between homogeneity and heterogeneity in Table 5.3.

Table 5.3: Best compartmentalization strategy as a function of the value distribution within the dike ring area and the total compartmentalization dike length

	Few dikes	**Many dikes**
Homogeneity	Partition	Secondary dike
Heterogeneity	Value protection	Secondary dike

Dike ring 14 is a rich area, looking at values that represents people, economy, environment and cultural-history. The values are spread over the dike ring area. Most value concentrations are in the cities, but there are several cities and not just one or two. Dike ring 14 can be seen as an area with a relatively homogenous value distribution. Taking Table 5.3 into account, the secondary dike is the most promising for dike ring 14, only if the willingness of placing compartmentalization dikes is high.

Chapter 6

Compartmentalization strategies for dike ring 14

6.1 Implementation compartmentalization strategies in SOBEK

The compartmentalization dikes are implemented in the standard grid of dike ring 14 by using ArcView. The dikes have been drawn in the standard grid with a certain height. The length of the dikes have been calculated by ArcView. The grid with the dikes and the standard grid are merged together to a new grid, which is implemented in SOBEK. The following points give the assumptions, that have been made for the implementation of the dikes on the grid.

- Higher line elements are used as part of the compartmentalization dikes as much as possible. The implementation is not worked out in the field, so the placement of dike is based on rough estimations.
- The dikes are assumed to be high and steady enough to hold the water. (The necessary height of the dikes can be determined after the flood simulations)
- Compartmentalization dikes cannot be build in lakes.
- Dikes through the cores of the cities should be avoided as much as possible.
- The compartmentalization dikes through the cities have been placed by rough estimations in the map of Arcview. The implementation is not worked out in the field.
- The water cannot flow through the dikes. This includes some cuts in 1D model (SOBEK), because the 1D model does not take the height of the grid into account. Without cutting the 1D model, water flows into the area behind the compartmentalization dikes.
- The modeled breaches in line elements of the SOBEK schematization have been removed, because compartmentalization dikes do not have breaches.
- Groundwater effects and meteorological influences are assumed to be neglected by implementing the different strategies.

A major problem exists when vulnerable areas (cities) are directly located at the primary dike. There is no space for construction of a compartmentalization dike behind the primary dike. Two choices can be made: 1) a small part of the vulnerable area between the primary and the compartmentalization dike is used as buffer zone. 2) The compartmentalization dike is build before the current primary dike. The current primary dike becomes part of the compartmentalization dike. This problem occurs in the secondary dike and value protection strategies.

6.2 Partition strategy

The implementation of the partition strategy in dike ring 14 is shown in Figure 6.1. The line from east to west is based on the flow of the Old Rhine. These dikes are already planned to become compartmentalization dike *(www.waterforum.net, 23 November 2006)*. Most of the compartmentalization dikes have been placed outside the cities. Since the location of some cities directly near the Old Rhine, parts of the placed dikes are in the cities. The line element from north to south is built on the location of high ways in the north and new dikes are build in the south. The high way A4 is used as higher elements and it goes through the Schiphol area, see the highway at photo in Figure A.9(a). The length of the compartmentalization dike is about 120 km, Table 6.1.

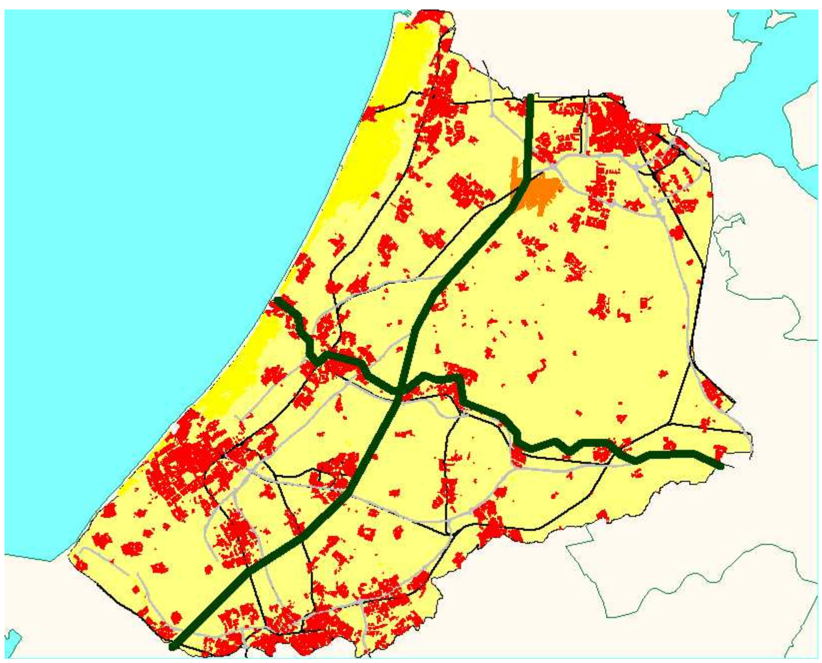


Figure 6.1: Input for SOBEK: Dike ring 14 of Figure 3.1 with implementation of partition strategy

6.3 Secondary dike strategy

The secondary dike strategy is based on a second dike just behind the primary dike. Some parts of the compartmentalization dikes are constructed in city areas, that are located directly behind the primary dike. The dikes in cities (Amsterdam, Rotterdam and The Hague) are build on places without buildings. In case of Amsterdam, the secondary dike is build before the primary dike, however this has no influence on the results. The implementation of this strategy in dike ring 14 can be seen in Figure 5.2(c). During the implementation, the line elements directly behind the primary dike are used as compartmentalization dike. The distances between primary dike and secondary dike differ at each point in the dike ring area. The length of the compartmentalization dike is about 194 km. It may be possible to build the compartmentalization dikes in the dunes near Haarlem and The Hague. The length of the dunes that can be used for the secondary dike strategy is about 10 km (The Hague) and 11 km (Haarlem).

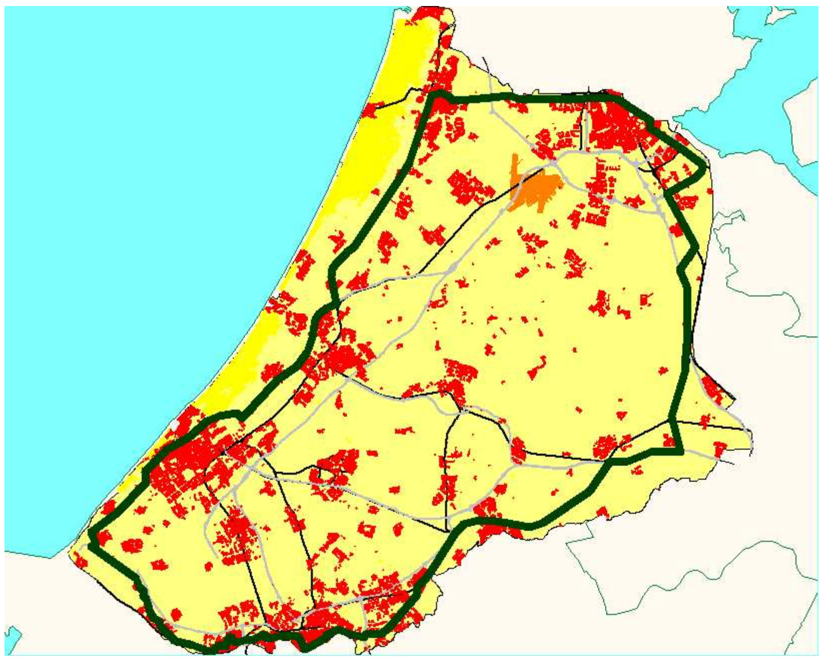


Figure 6.2: Input for SOBEK: Dike ring 14 of Figure 3.1 with implementation of secondary dike strategy

6.4 Value protection strategy

The main aim of value - protection strategy is to reduce the risk by protecting valuable or vulnerable places; see Chapter 5. The compartmentalization dikes form 'secondary dike rings' within the primary dike ring area. At all sides, there is space between the primary dikes and compartmentalization dike. Parts of Amsterdam, Rotterdam and The Hague can be flooded, because these cities are directly located at the primary dike; Figure 5.2(d). The compartmentalization dikes are built around an area with a high concentration of people and/or economic value.

In this study, the political decision has been taken that every city with about 100,000 or more inhabitants will have a secondary dike ring. Amsterdam, Rotterdam, The Hague, Haarlem, Leiden, Zoetermeer and Delft will have a secondary dike. Congregations with more than 100,000 inhabitants, which are spread around the area, do not have a secondary dike ring, like Haarlemmermeer and Westland. Schiphol Airport will also have a secondary dike ring, because of the importance for the economy. The total length of the compartmentalization dike is about 247 km.

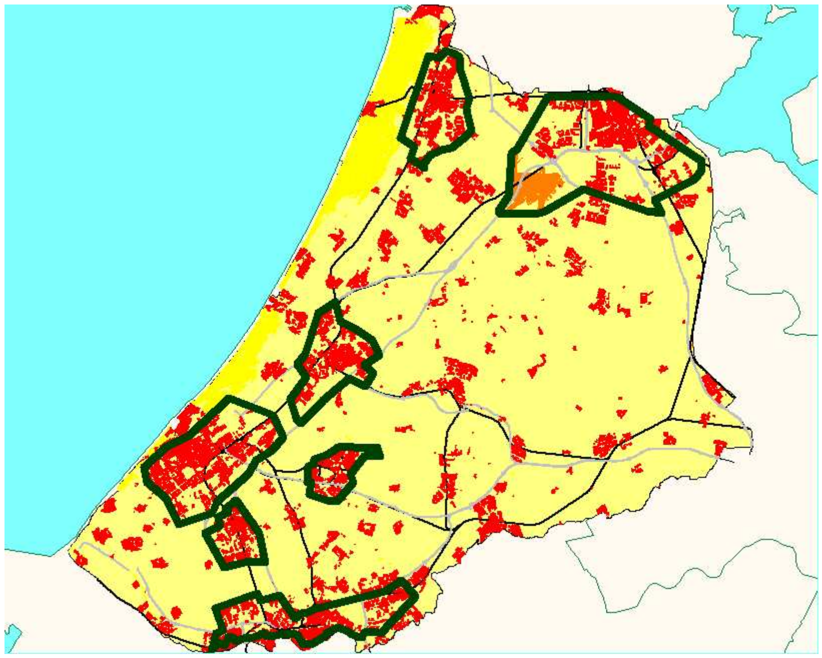


Figure 6.3: Input for SOBEK: Dike ring 14 of Figure 3.1 with implementation of value protection strategy

6.5 Comparison

6.5.1 Dike heights per strategy

The overland water flows to the lowest point. In Figure 7.1, the final inundation depths are given. The average heights of the compartmentalization dikes can be determined by the inundation depths at the compartmentalization dikes. The dikes have to be at least as high as the maximum inundation depths determines, otherwise the dikes are overtopped. The dike heights in the partition and value protection strategies can compared with each other, because the colors of the inundation depths are equal more or less. Some parts of the secondary dike have to be constructed to a height of more than six meters (red parts).

The average height of the compartmentalization dikes is dependent on the distance to the breach location. The heights near the breach locations have to be higher. The height differences can be noticed well in the value protection strategy. The dikes directly behind the primary dikes have to be constructed higher than the dikes that have to protect the city of overland flow. Looking at all strategies, the compartmentalization dikes in the secondary dike strategy have to be significantly higher.

6.5.2 Dike lengths per strategy

The total length of the compartmentalization dikes, implemented in the schematization of dike ring 14, are shown in Table 6.1. The dikes through cities are the dike parts that are placed in cities. These dikes need further examination, for detailed implementation in the cities. Table 6.1 gives also the lengths of the higher line elements that have been used by the implementation of the strategies. The line elements have been parted into the categories: highways, railroads, dunes and current compartmentalization dikes. These line elements need to transform into a compartmentalization dike. The category new dikes give the lengths of dikes that has to be build at areas without line elements.

Table 6.1: The layout of dikes in the different strategies, implemented in the SOBEK schematization. The values are given in lengths [km] and rough percentage [%] of total length, calculated by using ArcView

Part of dike	**Partition**	**Secondary dike**	**Value protection**
Total Dike Length	120.4	194.0	246.6
Dikes through cities	18.5 (15.4 %)	41.8 (20 %)	30.3 (12.3 %)
Highways	18.7 (15.5 %)	35.4 (18 %)	66.7 (27.1 %)
Railroads	0 (0 %)	40.2 (20 %)	9.1 (3.7 %)
Dunes	0 (0 %)	1.4 (0.7 %)	19.6 (4.3 %)
Current compartmentalization dikes	0 (0 %)	28.1 (14.5 %)	14.3 (5.8 %)
Adjusted elevated heights	18.7 (15.5 %)	105.0 (54.2 %)	100.9 (40.9 %)
New dikes	101.7 (84.5 %)	88.9 (45.8 %)	145.7 (59.1 %)

6.5.3 Synthesis

The only conclusion is that the implementation of the partition strategy in dike ring 14 is considerably lower than the secondary dike and value protection strategies. The length of dikes and the average height of these dikes is not high compared to the other strategies. Just 15 percent of the dike lengths is located in through cities and it may possible to construct the dikes around cities.

In this study, the location of the compartmentalization dikes through Amsterdam, Rotterdam and The Hague are equal in the secondary dike and value protection strategy. Although the value protection strategy has more total lengths of dikes (194 km versus 247 km), the secondary dike strategy needs more dikes through the cities (42 km versus 30 km). The implementation of such dikes are more expensive than the costs of the dikes in other categories. Further research to detailed implementation of each strategy is necessary. The implementation costs of the secondary dike and the value protection will be equal more or less, compared to the implementation of the partition strategy.

Chapter 7

Results

7.1 Simulation results

During this study, there have been analyzed three compartmentalization strategies and the zero situation (without compartmentalization dikes) against the background of seven flood scenarios. This results in a number of 28 cases. Visible illustrations of the inundation depths that occur during the flood scenarios of the 28 cases are given in Appendix F. The darker the blue parts in these figures, the larger the inundation depths. In the next paragraphs, the results of the cases have been describe for the systemic risk indicators (affected people, casualties, direct economic effects and incoming water). At the end of this Chapter, the results of this study have been compared with the VNK results.

In Table 7.1, four indicators of the hydraulic behavior are presented. This information is based on grid (ASC.files) given as output from SOBEK. The *maximum inundation* is the largest inundation depth [m] that occur in the area. The *flooded area* is the total surface [ha] which is flooded. The flooded surface is also divided into *classes of maximum inundation depths*. The classes are based on certain body heights: 0 - 0.1 m (ankle), 0 - 0.4 m (knee), 0.4 - 0.8 m (hip), 0.8 - 1.6 m (head) and higher than head. This combination provides information about the survival probabilities of the affected people in the area. For example, a large flood surface with a height to the knees does not lead to a large number of casualties. Information about the *overland water flow* is given by the size of the surface [ha], divided into time classes on which the grid reaches the maximum velocity. If the overland water flow is streaming over the area, new grids reach the maximum velocity at the end of the simulation. So, it gives information about the control of the overland water flow.

Table 7.1: Hydraulic effects of the simulations during the zero situation and the partition strategy.

Compartmentalization strategy					**Zero situation**							**Partition strategy**			
Flood scenario		A	B	C	D	E	F	G	A	B	C	D	E	F	G
Flooded area	[ha]	13,932	14,461	37,916	27,891	81,129	42,561	92,513	14,308	14,404	28,296	21,434	42,627	36,568	64,495
Flooded area	[%]	6.2	6.5	16.9	12.5	36.3	19.0	41.3	6.4	6.4	12.6	9.6	19.0	16.3	28.8
Flooded surface with the period in which the maximum velocity has been reached:															
0 - 0.1 m	[ha]	2,484	1,544	2,406	3,445	5,698	2,489	5,934	2,693	1,442	2,353	3,060	2,644	2,503	4,472
0.1 - 0.4 m	[ha]	3,277	1,892	4,203	4,318	12,651	4,856	12,627	3,088	1,867	3,849	3,742	5,002	5,069	9,039
0.4 - 0,8 m	[ha]	2,138	1,596	5,492	5,540	15,720	5,528	15,545	2,550	1,548	3,437	2,838	5,991	5,293	10,156
0.8 - 1.6 m	[ha]	5,534	7,679	16,704	10,733	31,451	17,890	35,950	5,301	7,761	10,929	9,255	16,130	14,149	23,577
1.6 - 2.5 m	[ha]	211	1,248	7,665	3,095	13,488	9,936	19,120	388	1,273	5,114	1,291	9,436	6,448	12,231
2.5 < m	[ha]	288	502	1,446	760	2,121	1,862	3,337	288	513	2,614	1,248	3,424	3,106	5,020
Maximum inundation depth	[m]	5.2	3.7	5.9	3.7	5.9	5.9	6.0	5.2	3.7	5.9	4.7	6.0	6.0	6.0
Flooded surface with the period in which the maximum velocity has been reached:															
0 - 12 hours after breach	[ha]	5,748	5,243	9,843	3,698	15,680	9,350	16,207	5,549	5,176	10,323	5,318	16,200	10,562	16,688
12 - 24 hours after breach	[ha]	1,742	1,106	11,703	5,089	21,141	13,348	31,580	1,813	1,139	10,611	5,154	15,045	12,481	22,447
24 - 48 hours after breach	[ha]	1,550	1,168	3,666	5,999	11,740	5,632	18,053	1,815	1,161	1,912	2,702	4,429	3,255	8,842
48 - 120 hours after breach	[ha]	810	2,551	4,809	6,985	11,513	6,776	13,163	1,034	2,455	800	2,008	1,565	3,463	6,382
120 - 240 hours after breach	[ha]	477	926	3,925	2,255	6,843	3,092	6,986	767	962	909	1,674	1,818	2,404	4,275

Compartmentalization strategy					**Secondary dike strategy**							**Value protection strategy**			
Flood scenario		A	B	C	D	E	F	G	A	B	C	D	E	F	G
Flooded area	[ha]	7,905	9,643	10,442	9,634	18,391	12,617	22,799	7,786	13,515	33,058	17,335	58,479	36,857	68,126
Flooded area	[%]	3.5	4.3	4.7	4.3	8.2	5.6	10.2	3.5	6.0	14.8	7.7	26.1	16.5	30.4
Flooded surface with a maximum inundation depth of:															
0 - 0.1 m	[ha]	1,535	1,518	1,557	1,538	2,083	1,563	1,707	1,504	1,570	1,543	1,865	3,292	1,606	3,202
0.1 - 0.4 m	[ha]	941	897	979	949	903	986	1,369	891	1,699	2,806	2,372	6,945	2,924	7,077
0.4 - 0,8 m	[ha]	216	196	359	270	1,340	386	968	173	1,286	3,083	2,276	7,594	3,550	7,895
0.8 - 1.6 m	[ha]	4,734	4,781	5,417	5,389	6,756	5,638	8,221	4,748	7,271	14,162	8,905	23,510	14,935	27,845
1.6 - 2.5 m	[ha]	192	1,180	1,274	497	4,958	2,329	6,406	183	1,250	8,369	795	13,424	10,393	17,116
2.5 < m	[ha]	287	1,071	856	991	2,351	1,715	4,128	287	439	3,095	1,122	3,714	3,449	4,991
Maximum inundation depth	[m]	5.4	6.5	5.3	4.1	5.4	6.5	6.3	5.4	5.6	4.9	4.7	5.4	5.6	5.5
Flooded surface after what period the maximum velocity has been reached:															
0 - 12 hours after breach	[ha]	4,685	5,082	6,728	5,165	11,621	6,822	12,043	4,554	4,864	7,774	5,056	11,697	8,572	13,142
12 - 24 hours after breach	[ha]	75	950	559	1,308	3,367	2,144	6,633	92	1,199	9,420	3,602	17,683	10,624	22,597
24 - 48 hours after breach	[ha]	60	355	63	80	251	377	762	56	1,314	3,195	850	10,693	4,186	12,504
48 - 120 hours after breach	[ha]	38	90	45	34	91	107	167	40	1,289	3,941	514	7,958	4,799	9,149
120 - 240 hours after breach	[ha]	10	109	10	10	23	113	137	12	992	4,233	2,033	5,290	3,934	5,271

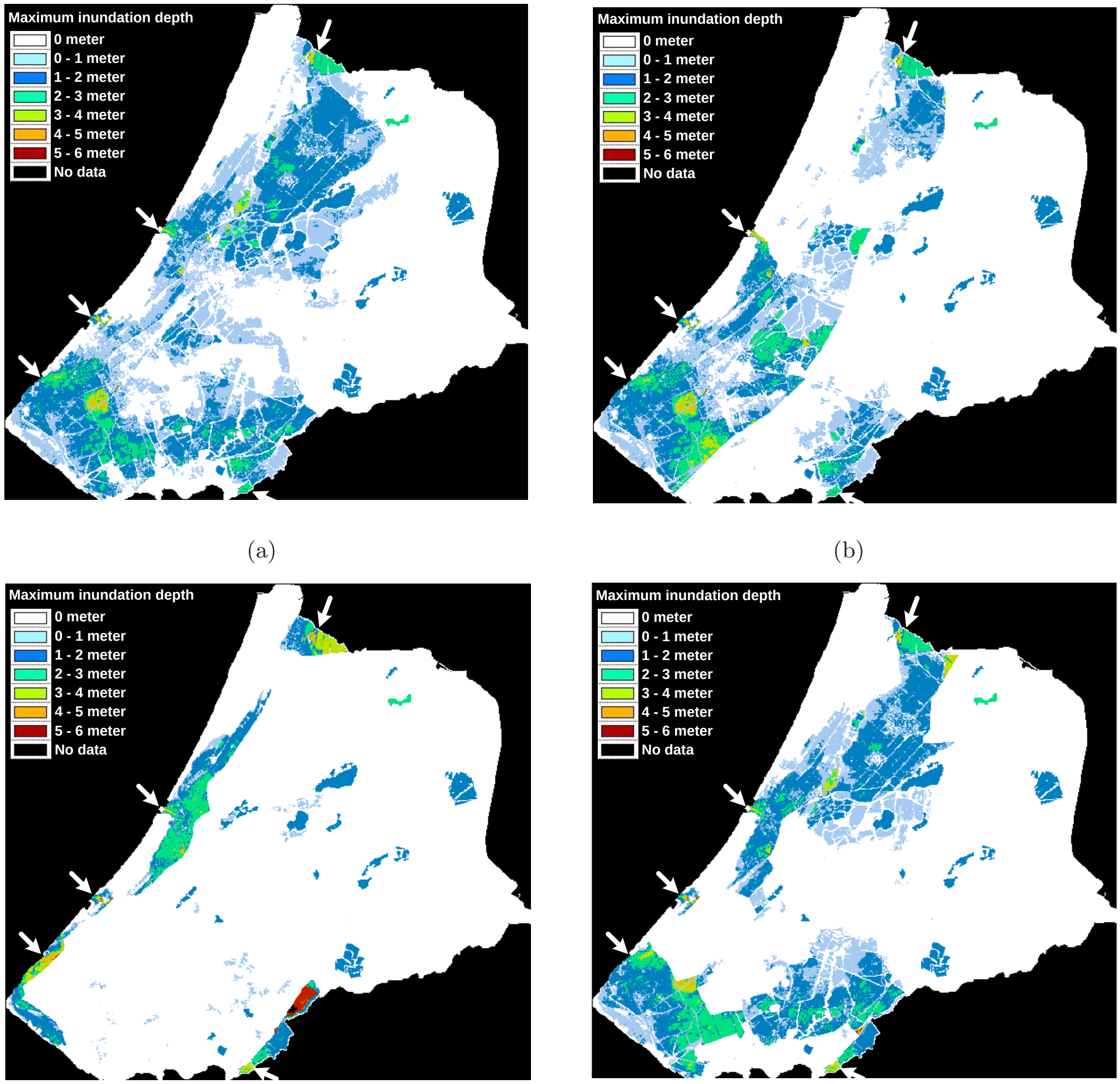
Looking at the *flooded surface* of each case, all compartmentalization strategies cause an decrease of the flooded surface during the flood scenarios with multiple breach locations (scenarios E, F and G). In the single breach scenarios, only the secondary dike strategy shows an obvious decrease of the flooded area for all scenarios. In the partition and value protection strategy the water still spreads through the area. The secondary dike holds the water near the breach location, which leads to a less flooded surface.

The secondary dike strategy has the highest *inundation depths* compared to the zero situation. In the other strategies the maximum inundation depths do not have increased much. The point with the largest inundation depth in the worst case scenario is protected in the value protection strategy, because of the increase of the maximum inundation depth. Figure 7.1 shows the maximum inundation depths of the worst case of the zero strategy and the three compartmentalization strategies. In Figure 7.1, the compartmentalization patterns can be seen clearly. In the zero situation (Figure 7.1(a)), the water spreads in the whole area, but the average inundation depths remains low. Looking at the secondary dike strategy in Figure 7.1(c), the water is not spread over the area, but the average inundation depths are about four to six meters. In Figure 7.1(b), the water flow, from sea to the deep polders, is stopped by the compartmentalization dike (from north to south). This causes an increase of inundation depths, directly in front of the compartmentalization dikes. In Figure 7.1(d), the water is spread through the area, but locally the inundation depths are increased by the compartmentalization dikes. It becomes obvious that the protected cities (Rotterdam, Leiden, The Hague and Delft) remain dry in this strategy. Alkema and Middelkoop (2005) have concluded that the water can be lead away from vulnerable and important area, which is strengthened in this study.

This study strengthens that compartmentalization dikes have large influence on the overland water flow. Compartmentalization stops the spread of water in the dike ring, but this leads to an increase of inundation depths in front of the dikes. The dikes near the breach location have to be significantly higher than the dikes more landward. Concluded, the less water can spread through the area, the higher the occurred inundation depths.

The flow of the overland water can be roughly determined by the time on which the maximum velocity occurs. In general, the spread of the overland water flow has been reduced by compartmentalization. The only strategy with a significant reduction of the spread of water is the secondary dike strategy. After about twelve hours, the surface on which the maximum flow velocity occurs, has been reduced enormously. This means that the secondary dike stops the water flow in about half a day. In the other compartmentalization strategies, the propagation goes on after ten days and is not stopped.

Looking at the flood simulations in Appendix F, the monumental cities of Amsterdam, Rotterdam, The Hague, Leiden, Delft and Haarlem remain dry or have small inundation depths. The concentrated value in the larger cities of dike ring 14 is mostly at higher elevated grounds than in the surrounding area. So, the monumental cities are quite well protected by the current elevations.



(a) (b) (c) (d)

Figure 7.1: Maximum inundation depths in the worst cases of the different compartmentalization strategies during the simulation time: Zero situation (a), Partition strategy (b) Secondary dike strategy (c) and Value protection strategy (d).

7.2 Affected people

In Table 7.2, the number of the affected people are given for all scenarios. Compartmentalization strategies have large influence on holding the water back from the houses. Compared to the zero situation, the number of affected people is almost lower in every case. The largest reduction is caused in the cases E, F and G. These scenarios are based multiple breach locations. For every scenario, the secondary dike has the largest reduction in number of affected people. **In the worst case scenario, the secondary dike strategy has the largest reduction of the affected people (80 %)**, followed by the value protection strategy (59 %).

The partition strategy slightly reduces the number of affected people (15 %), compared to the other strategies.

Table 7.2: The number of affected people for all 28 cases and the corresponding percentage of the zero situation.

Flood Scenario	Zero situation	Partition	Secondary dike	Value protection
A Scheveningen	206,574 (100 %)	207,877 (101 %)	32,960 (16 %)	33,280 (16 %)
B Kralingen	172,725 (100 %)	171,746 (99 %)	62,233 (36 %)	120,811 (70 %)
C Ter Heijde	664,095 (100 %)	497,519 (75 %)	43,499 (7 %)	250,969 (38 %)
D Haarlem	128,905 (100 %)	129,720 (101 %)	69,694 (54 %)	71,048 (55 %)
E Sea attack	1,130,151 (100 %)	872,370 (77 %)	168,214 (15 %)	480,927 (43 %)
F Sea-river	790,925 (100 %)	681,871 (86 %)	93,493 (12 %)	311,258 (39 %)
G Worst case	1,372,497 (100 %)	1,171,311 (85 %)	275,718 (20 %)	565,342 (41 %)

The data of Tables 4.1 and 7.2 have been used for making the risk curves in Figure 7.2. The line of the secondary dike strategy attracts attention, because the number of affected people has been decreased for all scenarios. The value protection also shows a reduction of the affected people, but this reduction is lower than the reduction of the secondary dike strategy. The the partition strategy has the least reduction in number of affected people.

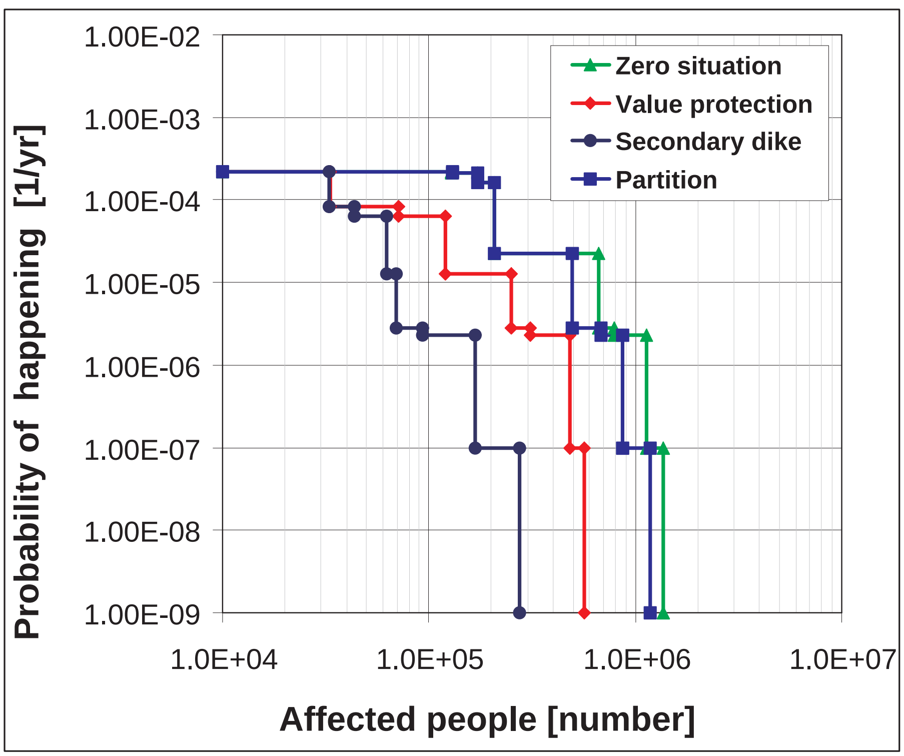


Figure 7.2: The risk curve with the numbers of affected people per compartmentalization strategy.

7.3 Casualties

The number of casualties of every case are presented in Table 7.3, which data are combined with the data of Table 4.1 for making the risk curve for the numbers of casualties; Figure 7.3. Looking at the worst case scenarios, all compartmentalization strategies show a reduction of the amount of casualties. The reduction of the value protection shows is the largest with 23 %.

Looking at all scenarios, the reduction in number of casualties shows a different view, compared to the reduction in number of affected people. The lines in the risk curve are mixed up. No general conclusion about the reduction in number of casualties by compartmentalization can be drawn. The compartmentalization strategies shows different outcomes for all cases. The changes of casualties are dependent on the breach location. In case of deep polders directly behind breach (Kralingen), the more water on a small area with high dikes, the larger increase of casualties. In this case, compartmentalization increase the amount of casualties. These conclusions are also drawn in other studies: MinV&W (2006d); Theunissen et al. (2006).

Table 7.3: The number of casualties for all 28 cases and the corresponding percentage of the zero situation.

Flood Scenario	Zero situation	Partition	Secondary dike	Value protection
A Scheveningen	862 (100 %)	973 (113 %)	658 (76 %)	659 (76 %)
B Kralingen	1.403 (100 %)	1.488 (106 %)	2.689 (192 %)	2.736 (195 %)
C Ter Heijde	3.701 (100 %)	3.440 (93 %)	2.102 (57 %)	1.213 (33 %)
D Haarlem	227 (100 %)	223 (98 %)	194 (85 %)	157 (69 %)
E Sea attack	5.867 (100 %)	6.082 (104 %)	4,012 (68 %)	3.702 (63 %)
F Sea-river	4.914 (100 %)	5.002 (102 %)	4.745 (97 %)	3.734 (76 %)
G Worst case	8.130 (100 %)	7.783 (96 %)	6.957 (86 %)	6.230 (77 %)

In Figure 7.3, the line representing the zero situation is above the line of the external threats. The group risk of flooding is higher than the maximum advised values for the group risk (the dot line) (Ale, 2003). This has also been concluded by RIVM (2004). The different compartmentalization strategies do not reduce the group risk of flooding to values that are under the line of accepted risks of external threats. This conclusion is made with reservations, because the evacuation is not included in this study.

The **expected value** of annual casualties (E(N)) can be determined from the probability density function of amount of direct economic damage ($f_N(x)$). The expected value is equal to the surface under the F(N) curve (Jonkman, 2001). The expected values of annual casualties (E(N)) under a particular compartmentalization strategy can be determined by taking the surface under the graph in Figure 7.3:

- Zero situation: E(N) = 0.445 casualties/year
- Partition: E(N) = 0.469 casualties/year
- Secondary dike: E(N) = 0.490 casualties/year
- Value protection: E(N) = 0.595 casualties/year

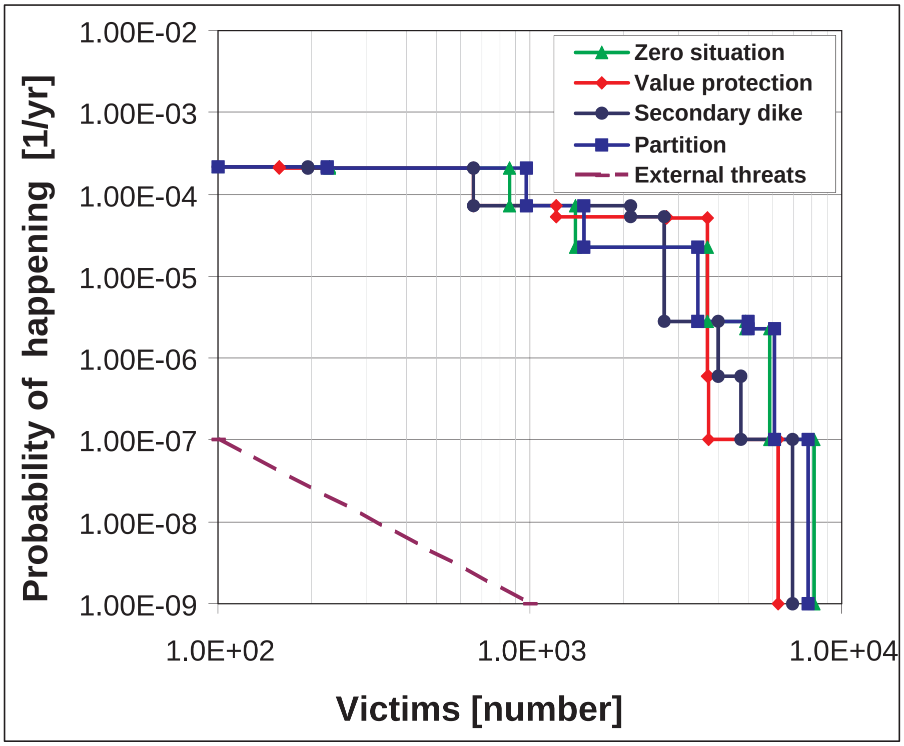


Figure 7.3: The risk curve with the numbers of casualties per compartmentalization strategy. The line of 'External threats' gives the maximum acceptable values of the external risks in the Netherlands (Ale, 2003)

The expected values of annual casualties are relatively low. In traffic, the annual expected number of casualties is about 1000 casualties/year. This point strengthens the discussion that the risk management of flooding should be based on group risk instead of individual risk.

The expected values of the annual casualties show a different picture of the results, that have been concluded by the risk curve. The different compartmentalization strategies cause a worsening of the expected annual casualties in comparison to the zero situation. The value protection has the largest increase of the expected value, while this strategy is considered as the best performing strategy in the risk curve. This is caused by the large number of casualties, caused by scenario of Kralingen (B).

The **mortality** (casualties/affected people) gives the probability of drowning in the threatened area (MinV&W, 2006a). It connects the affected people and casualties to get better insight into the risk situation for people. The mortality of the flooded area shows different outcomes by using different compartmentalization strategies; Table 7.4. The water flows to other parts of the area and the rise rate of the water level is also different. The higher the mortality, the higher the probability of starvation in the flooded area of an individual person. A high mortality can be seen as a negative effect of the concerning strategy (MinV&W, 2006a).

The mortality of the flood scenarios for every compartmentalization strategy is shown in Table 7.4. Scenario B (Kralingen) is the leading scenario for the mortality for the zero situation, the partition and the value protection strategies. The maximum mortality of the secondary dike strategy is scenario F. The partition strategy has hardly changed the mortality of the area, while the value protection and the secondary dike strategies shows an increase of it. Dikes near the breach locations cause an increase of the water level and the water level rise in the area, which results in an increase of the casualties. Besides, the number of affected people significantly reduces by these strategies.

Table 7.4: Mortality in each flood scenario.

Flood Scenario	Zero situation	Partition	Secondary dike	Value protection
A (Scheveningen)	0.0042	0.0047	0.0120	0.0198
B (Kralingen)	0.0081	0.0087	0.0432	0.0432
C (Ter Heijde)	0.0056	0.0069	0.0483	0.0048
D (Haarlem)	0.0018	0.0017	0.0028	0.0022
E (Sea attack)	0.0052	0.0070	0.0239	0.0077
F (Sea-river)	0.0062	0.0073	0.0508	0.0120
G (Worst case)	0.0059	0.0066	0.0252	0.0120
Minimum	0.0018	0.0017	0.0028	0.0022
Maximum	0.0081	0.0087	0.0508	0.0432

Concluded, the different strategies have different effects to people. The number of affected people reduces by the compartmentalization strategies. The reductions in number of the casualties vary in the flood scenarios. There is a relative small effect in reduction of casualties, which can be seen in the mortality: The affected people reduces, while the mortality increases. Besides, compartmentalization does not reduce the number of casualties in all cases. This conclusion can also be drawn by looking at the increase of the expected annual casualties due to compartmentalization.

The number of affected people reduces, because less houses are flooded due to compartmentalization. The number of casualties is dependent of more parameters, the inundation depth, water velocity and rising rate. Compartmentalization causes higher values for these parameters, so the advance of the size reduction of the flooded surface is neutralized. Compartmentalization mostly reduces damage which main damage factor is to become flooded or not. **Compartmentalization reduces the risk of affected people, while it is not much effective for the reduction of number of casualties.**

Looking at the different strategies, the secondary dike strategy has the largest reduction of the affected people, while the value protection strategy shows the best results in case of casualties (in case of the risk curve). Because of the lack of a good insight into evacuation, the conclusions about the number of casualties are made with reservations. Maybe compartmentalization is not a good risk reduction strategy for casualties and should the situation become better by making evacuation plans or other strategies.

7.4 Direct economic effects (material)

In Figure 7.4, the damage of HIS - SSM in the worst cases of each compartmentalization strategies is shown. Although HIS - SSM gives damage as the addition of direct material damage, business outfall and indirect damage, it gives a good insight into the spread of the economic damage and the threatened valuable areas.

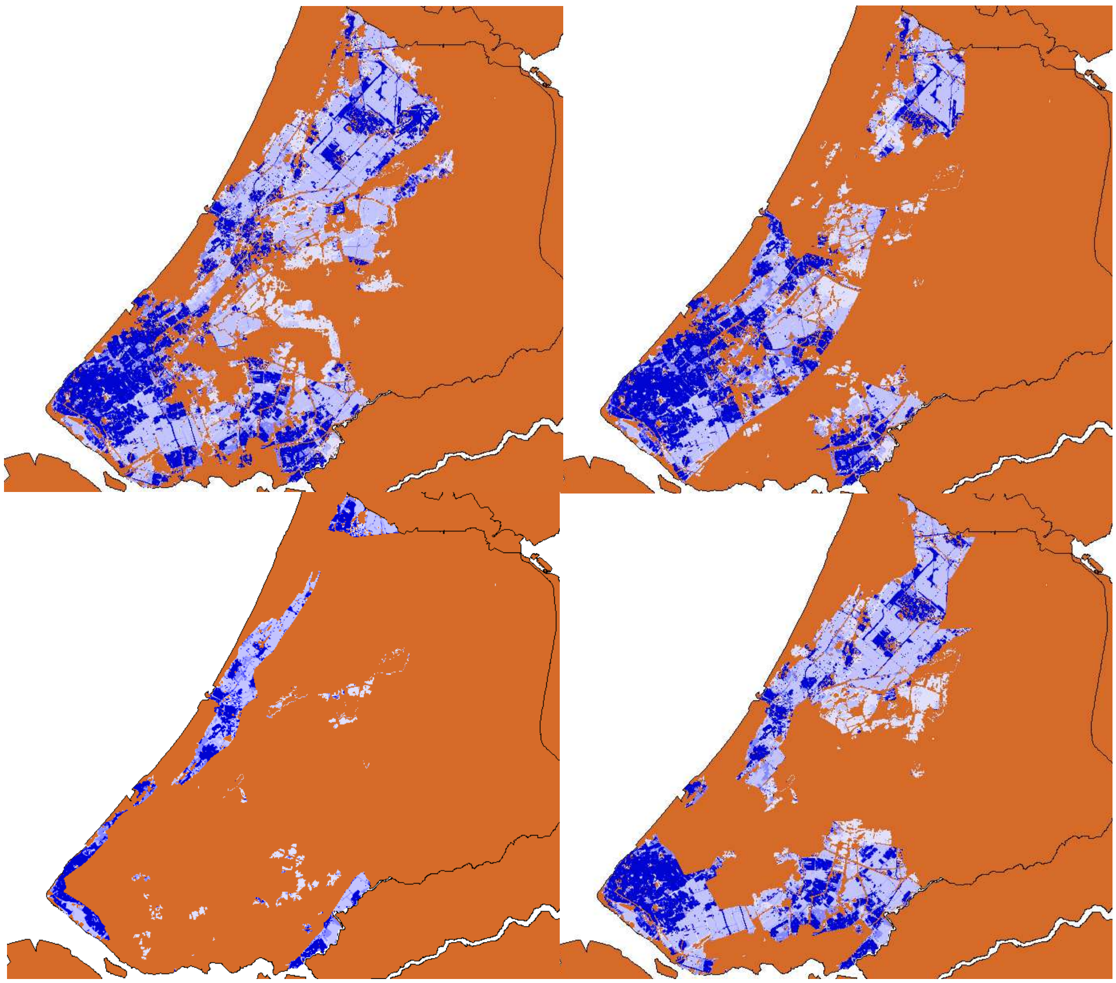


Figure 7.4: The economic damage [euros] in the worst case scenarios in the different compartmentalization strategies. The darker the blue color, the higher the damage at the grid.

In Table 7.5 the direct economic effects (of material damage) are given for all scenarios. The F(G) curve of the direct economic effects to material losses are given in Figure 7.5, which data is based on Tables 4.1 and 7.5. In Figures G.1 and G.2, the results of effects caused by respectively business outfall and indirect economic effects are shown. The values of these effects are negligible in comparison to the direct economic effects.

Compartmentalization strategies have large influence on the economic damage. The economic effects reduce in almost every case compared to the zero situation. The largest reduction is caused in the cases E, F and G, that are based multiple breach locations. Looking at Figure 7.5, the effects are reduced in the tail of the graph. Every compartmentalization leads to reduction of direct economical effects in the worst case scenarios. Looking at the worst case scenarios, the partition strategy reduce the effects with 17 %, while the value protection reduce the damage with 52 %. **The secondary dike results in the highest decrease of damage: 74 %**.

Table 7.5: The direct economic damage (material) in billion euros for all 28 cases and the corresponding percentage of the zero situation.

Flood Scenario	Zero situation	Partition	Secondary dike	Value protection
A Scheveningen	5.4 (100 %)	5.3 (99 %)	0.9 (17 %)	0.9 (18 %)
B Kralingen	5.7 (100 %)	5.7 (101 %)	2.6 (47 %)	3.6 (64 %)
C Ter Heijde	18.5 (100 %)	14.4 (78 %)	1.8 (10 %)	9.8 (53 %)
D Haarlem	5.3 (100 %)	2.8 (52 %)	2.0 (38 %)	2.0 (38 %)
E Sea attack	35.4 (100 %)	27.5 (78 %)	6.9 (20 %)	16.8 (47 %)
F Sea-river	23.6 (100 %)	20.7 (88 %)	4.3 (18 %)	12.6 (53 %)
G Worst case	44.1 (100 %)	36.4 (83 %)	11.5 (26 %)	21.0 (48 %)

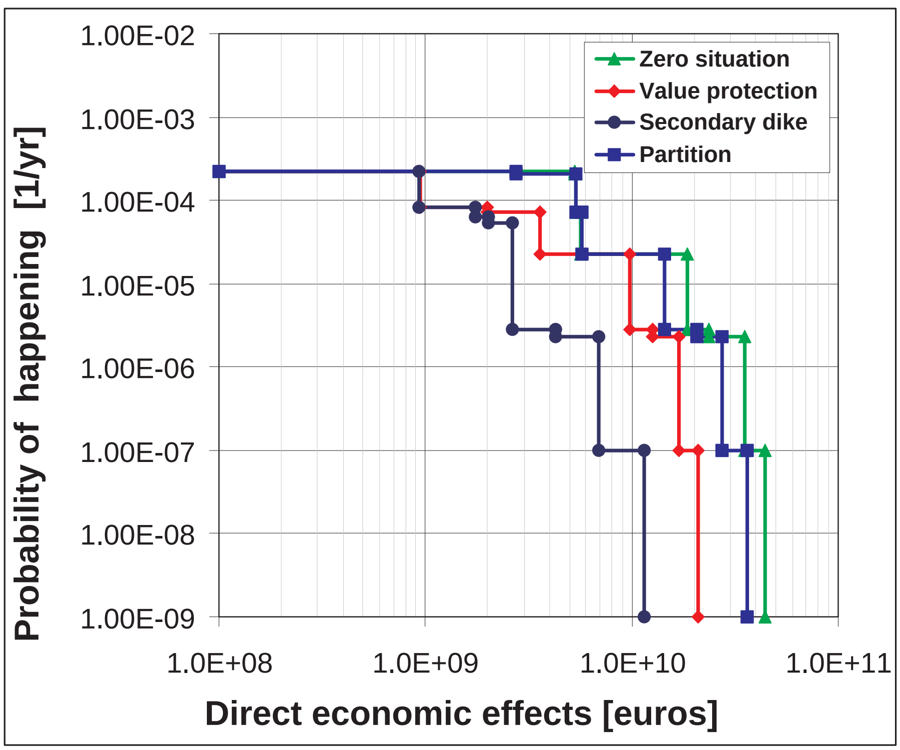


Figure 7.5: The risk curve with the direct economic damage [euros] per compartmentalization strategy.

The **expected value** of annual direct economic damage (E(G)) can be determined from the probability density function of amount of direct economic damage ($f_G(x)$). The expected value is equal to the surface under the F(G) curve (Jonkman, 2001).

The expected value of direct economic effects under a particular compartmentalization strategy can be determined by taking the surface under the graph in Figure 7.5:

- Zero situation: E(G) = 3,286,000 euro/year
- Partition: E(G) = 2,598,000 euro/year (benefit of 688,000 euro/year)
- Secondary dike: E(G) = 648,000 euro/year (benefit of 2,638,000 euro/year)
- Value protection: E(G) = 936,000 euro/year (benefit of 2,350,000 euro/year)

The expected annual loss by the detailed study of VNK is about 2.3 million euros per year, which is in the same order of magnitude as the results in this study (MinV&W, 2005a) p.B-18. The secondary dike strategy shows the largest reduction of the expected annual damage. The value protection strategy shows more or less the similar reduction of the annual direct economic damage, while the reduction of the partition strategy is the least reduction.

> The annual benefits of the secondary dike is roughly about 2.5 million euros per year, by taking the costs for a green dikes: 200 km compartmentalization dikes multiply the costs of 3,000 euros per meter[1] = 600 million euros. The roughly amount is assumed by taking into account that the dikes are green dikes with a height of 5 meters (RoyalHaskoning, 2005) p.21. The final costs will be a multiplication of this rough measurement (for example the extra costs of implementation of the dikes and the multiplication of costs due to dikes through cities). This measurement shows that the cost-benefit analysis may not be an appropriate tool for compartmentalization dikes in this study.

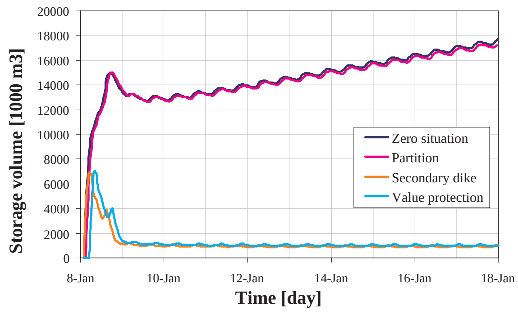
Compartmentalization reduces the direct economic effects after flooding of dike ring 14. This is shown in the risk curve and in the corresponding expected annual effects as well. Compartmentalization leads to reduction of direct economic effects, because of the occurred changes in flooded surfaces. The reduction of the direct economic effects is roughly similar to the reduction of the affected people.

7.5 Incoming water

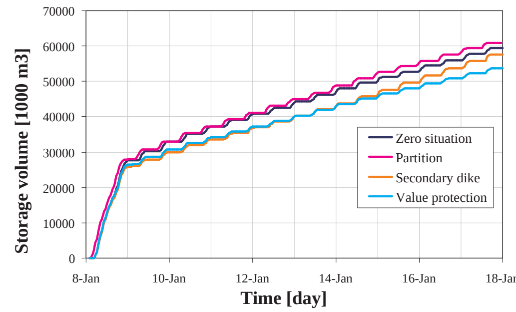
As said in Chapter 2, the amount of incoming water can be used as a parameter for the resilience time. The more incoming water, the more water has to be pumped out the system. This leads to an increase of the resilience time, because the recovery can be started earlier.

In Figure 7.6, the graphs of the incoming water are given for the flood scenarios. One of the assumptions in this study is that the breach is not closed during the simulations. This leads to an increase of incoming water during the whole flood scenario; Figures 7.6(b), 7.6(d) for example. The influence of the tide can be seen in these Figures.

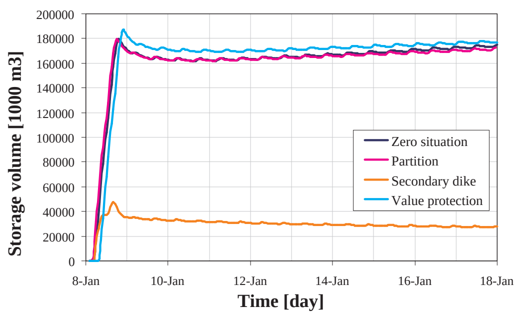
The strategies of partition and value protection shows more or less the same line as the zero situation line. Except of Figure 7.6(b), the secondary dike strategy causes an decrease of the amount of incoming water. The scenario of Kralingen is a flooding of a deep polder directly behind the breach. The water can flow in the polder and the polder is deep enough to storage the water during the flood scenario. This is the exception of the conclusion of the decreasing incoming water by the secondary dike strategy.



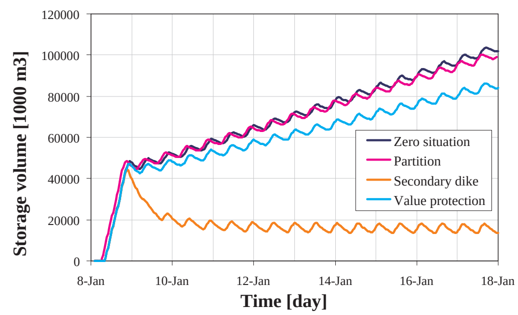
(a)



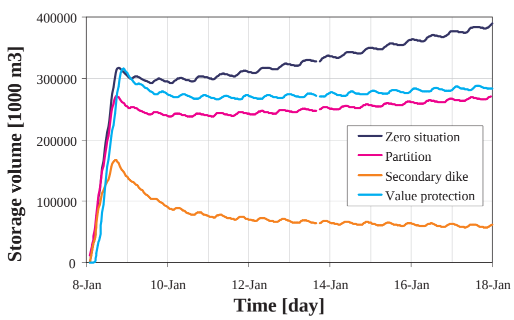
(b)



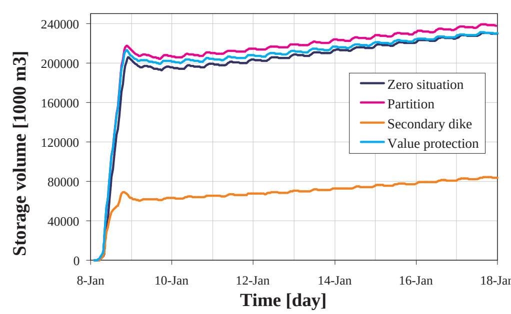
(c)



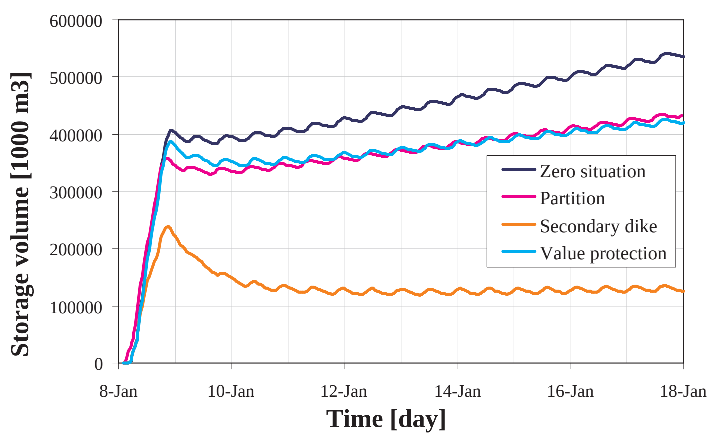
(d)



(e)



(f)



(g)

Figure 7.6: Incoming water per volume of $1000\,m^3$ of the considered scenarios after ten days: Scheveningen (a), Kralingen (b), Ter Heijde (c), Haarlem (d), Ter Heijde, Scheveningen and Katwijk (e), Kralingen and Ter Heijde (f) and Worst Case (g).

It is not easy to determine the drainage time, because much information is missing. Besides, it takes a long time to run the drainage time in SOBEK. In this part a rough estimation has been made about the drainage time.

> One of the water boards in dike ring 14, Hoogheemraadschap van Rijnland have done some research to the draining capacity of the area. Looking at Figure A.4(b), the area of this water board is about half of the dike ring area. Main drainage stations in the dike ring are located in this water board, like Katwijk, IJmuiden and Gouda. The current pumping capacity in this area is 13 millions of cubic meters water per day (Rijnland, 2000), p.11. Taking the assumption that the water board of Rijnland is only responsible for the pumping of the water, the time of drainage is 41.3 days. The drainage times in the worst case scenarios of the partition, the secondary dike and the value protection strategies are respectively 33.2 days, 9.7 days and 32.3 days.
>
> This outcomes have been based on very rough estimations, because most of the water is in deep polders, which are hard to drainage. In this situation, only the incoming water is taken into account, while also precipitation occurs during the storm influences the days of drainage. There are more drainage stations in dike ring 14, besides the ones of the Hoogheemraadschap van Rijnland. Besides, the necessary time, to filled up the breaches (ten days) and to stop the water inflow, has not been taken into account.

Looking at the results in Table 7.6, **the compartmentalization strategies have influence on the incoming water in some cases.** Especially, in the situations in which the water is hold near the breach location, the compartmentalization strategies have many influences, for example the secondary dike strategy and the value protection strategy in case of Scheveningen. In the worst case scenario, the secondary dike strategy reduces the incoming water to 24% of the zero situation, while the other strategies show a reduction of about 80%. Taking a drainage capacity into account, this means that the resilience of the area can begin about 23 days earlier, because of the drainage time.

Table 7.6: The amount of incoming water after ten days (per millions of cubic meters) for all 28 cases and the corresponding percentage of the zero situation.

Flood Scenario	Zero situation	Partition	Secondary dike	Value protection
A Scheveningen	17.7 (100 %)	17.2 (97 %)	1.0 (6 %)	1.0 (6 %)
B Kralingen	59.4 (100 %)	60.9 (103 %)	57.7 (97 %)	53.6 (90 %)
C Ter Heijde	175.3 (100 %)	172.5 (98 %)	27.9 (16 %)	176.6 (101 %)
D Haarlem	101.9 (100 %)	99.1 (97 %)	13.5 (13 %)	83.9 (82 %)
E Sea attack	389.1 (100 %)	270.8 (70 %)	61.6 (16 %)	283.3 (73 %)
F Sea-river	229.7 (100 %)	238.0 (104 %)	83.8 (37 %)	230.3 (100 %)
G Worst case	536.3 (100 %)	431.7 (81 %)	126.0 (24 %)	419.6 (78 %)

7.6 Study results in comparison with VNK

During this study, the choice have been made to have comparable flood scenarios and corresponding damage values with the results of some flood scenarios of the VNK project; Table 7.7. In the zero situation, several iteration steps have been made by taking different breach depths and breach widths in SOBEK. Two breach scenarios are chosen: 1) breaches in river dikes and 2) breaches at the coast.

For getting comparable results, the indicator of affected people and economic damage have been used, because these indicators are dependent on the flooded surface and the inundation depths. These parameters can be changed by different iterations steps in the breach scenarios. In Table 7.7, the three components of HIS - SSM are added. The determination of casualties in HIS - SSM is dependent to the evacuation factor. During this study, the evacuation factor is outside the scope of the study. So, the number of casualties is not taken into account during the iteration steps.

The results of the cases (A) Scheveningen, (B) Kralingen, Katwijk and (E) Ter Heijde-Scheveningen-Katwijk (the worst case of VNK) are given in the Table. The cases of (B) Kralingen and (E) Ter Heijde - Scheveningen - Katwijk fits more or less with the results of VNK. In case of (A) Scheveningen and Katwijk, the results of the study are significantly larger. This results from the higher water level boundaries.

Table 7.7: The results of the study in comparison with the VNK results for: affected people (MinV&W, 2006a) and economic damage (MinV&W, 2005b).

Case number	Case name	Results this study	VNK results
		Affected people	
A	*Scheveningen*	206,574 people	111,513 people
B	*Kralingen*	172,725 people	180,202 people
#	*Katwijk*	316,66 people	204,103 people
E	*Ter Heijde - Scheveningen - Katwijk*	1,130,151 people	1,014,960
		Economic damage	
A	*Scheveningen*	5.6 billion euros	1.9 billion euros
B	*Kralingen*	5.9 billion euros	6.8 billion euros
#	*Katwijk*	10.9 billion euros	11.3 billion euros
E	*Ter Heijde - Scheveningen - Katwijk*	37.1 billion euros	37.2 billion euros

Chapter 8

Sensitivity analysis

During the study, numerous of parameters came across. The most important parameters will be described in this sensitivity analysis.

- Choice of systemic risk indicators
- Compartmentalization as central risk reduction strategy
- Choice of flood scenarios
- Determination of probabilities
- Breaching scenarios
- Implementation of compartmentalization strategies
- Incoming water
- Economic values
- Evacuation of people

Choice of systemic risk indicators
In this study, just the effects of the worst possible attack have been assumed to be leading for systemic risk. A proper quantification of systemic risk does not exist. One single measurement can not be reached, in terms of Renn and Klinke (2004): '*remains elusive*'. So the choice of examine some of the indicators give enough insight of the systemic risk.

Four systemic risk indicators (affected people, have been researched and quantified, while systemic risk exists of more elements, like environment and cultural-historic losses. A proper presumption can be made that the quantified systemic risk indicators give a good insight into the size of the disasters impact to the society. The comparison of the strategy's performance in terms of systemic risk is also not impede of this choice of the indicators.

Compartmentalization as central risk reduction strategy
The central assumption in this study has been that compartmentalization is considered as the central flood risk reduction strategy. There are several other kinds of risk reduction strategies

with their advantages and disadvantages (Oost, 2006). Based on the insights and the results of this study, it is difficult to compare the compartmentalization strategy with other strategies.

Choice of flood scenarios

For the examination of the best performing compartmentalization strategy for the whole dike ring area, it is useful to have breach locations at all sides of the area. Each strategy should perform the same *at all sides of the dike ring*. In this study, the chosen flood scenarios have been selected by taking locations at all sides of the dike ring area. The occurring overland water flow covers a large part of the whole dike ring. Instead of this study, VNK has taken 13 dike sections between the Sluices of IJmuiden, Hook of Holland and the Storm surge barrier in the Hollandse IJssel without taken into account the other part. In this study, the north eastern part of dike ring 14 is only not flooded in the worst case. The influence of this part on the results is that the results will be higher with a certain factor. The choice of the worst case with five breach locations can be considered as leading for dike ring 14.

Although, it is imaginable that there are cases worse then the worst case scenario. More dike breaches leads to more incoming water and corresponding effects. More incoming water only leads to larger dikes, because of the larger inundation depths. This is relative to the results of this study. It does not give more insight into the working of compartmentalization strategies.

Determination of probabilities

A main assumption in this study was that the effects of a possible disaster are more interesting in terms of systemic risk. This has been caused that the determination of probabilities are very questionable. Besides, the uncertainty of the effects determination is lower than the probability of occurrence. (Personal conversation with K. Wouters at 22 August 2006, HKV, Lelystad).

The influence on the determination in calculation of the *expected values* is very large. These results should be taken very carefully. This assumption does not have much influence for the results (and the comparison) of the maximum effects.

Breaching scenarios

The actual size of a breach in a clay dike and also the growth of the breach as a function of time are very difficult to compute (Hesselink et al., 2003). In Figure 8.1, the different sizes of dike breaches can be seen. It is difficult to predict the incoming amount of water through a breach, because of the large differences in the breach sizes.
During this study numerous of iteration steps are made to get results that are comparable to the results of VNK. The initial breach width and the lowest crest level of this study are put into Table D.2 an Table D.1, just like the other used parameters. In this study, the influence of the breach depths and breach widths to the effects are put respectively in Table 8.1 and Figure 8.2.

In Figure 8.2 can be seen that the results of HIS - SSM are sensitive to the breach sizes. The outcomes can reach large values for the damage, so the sensitivity is very high. This point is emphasized by Alkema and Middelkoop (2005):'*The damage and hazard associated with a catastrophic dike breach are significantly higher than in case of a spill-over construction*'.

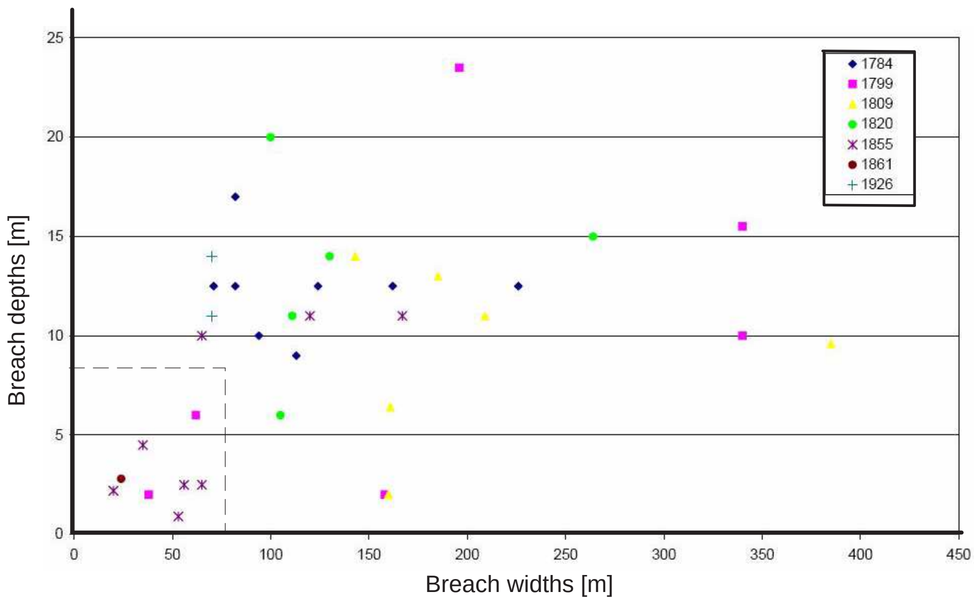


Figure 8.1: Historical well-documented breaches with forming of wheels in the Netherlands (selection of M. ten Voorde, 2004) This Table was given by Wilfried ten Brinke). The breach sizes of this study is showed in the area with the dot lines.

Table 8.1: The sensitivity analysis of the breach width and depth, looking at the number of casualties and economic damage in the scenario of Kralingen. The economic damage is the quantification of the total damage according to HIS-SSM (DWW, 2005b).

Initial breach width [m]	Depth breach [+m NAP]	Number of casualties [people]	Economic damage [billion Euros]
10	0	711	4.9
30	0	1,403	5.9
75	0	6,425	8.3
100	0	12,166	9.6
150	0	24,114	11.4
250	0	33,867	12.8
400	0	37,600	13.5
600	0	39,126	13.9
30	0	1,403	5.9
30	-1	5,621	9.5
30	-3	19572	12.7
30	-12	36783	15.6

Water that overtops the dike does not result in large effects, instead of a dike breach.

In this study, relatively little values have been taken for the breach width and depth. The results in absolute terms should be taken very carefully. The parameters are sensitive, so the influence of the breach sizes is very high. The same conclusions about the uncertainty can be made for the outcomes of VNK.

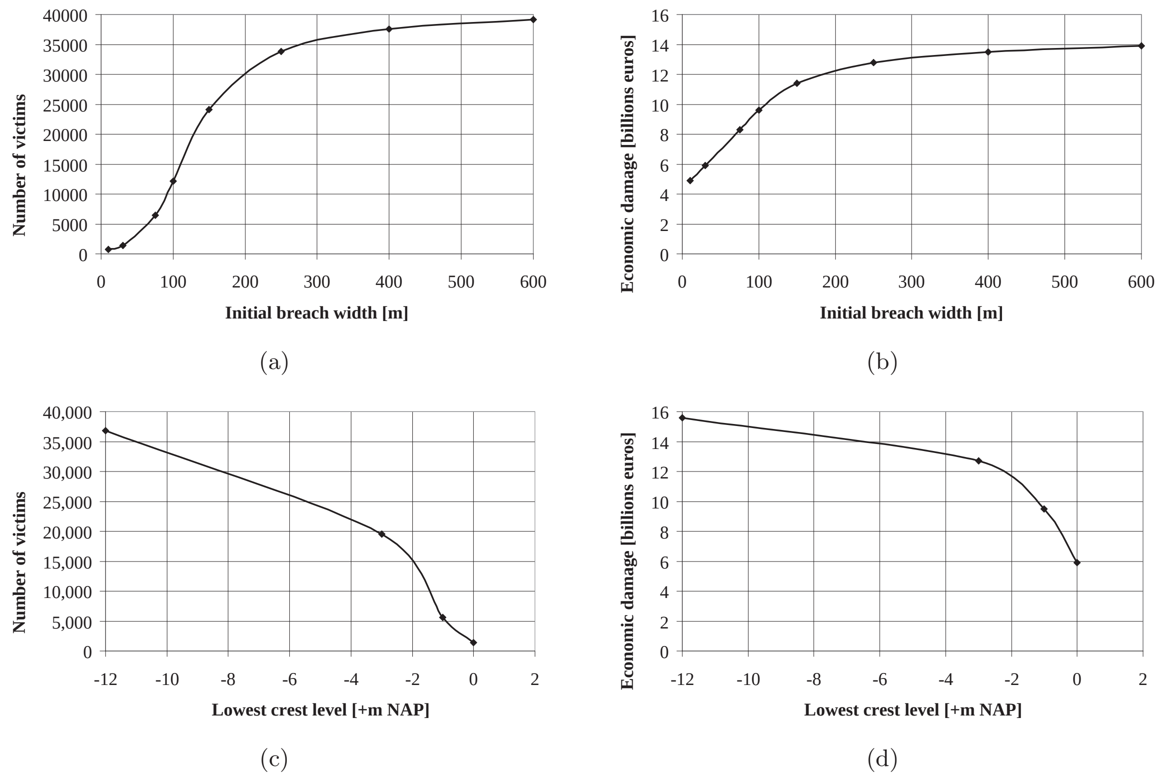


Figure 8.2: The sensitivity of the (initial) breach width to the number of casualties (a) and the economic damage (b) and the sensitivity of the breach depth (lowest crest level) to the number of casualties (c) and the economic damage (d). The economic damage is the quantification of the total damage according to HIS - SSM (DWW, 2005b). The used flood scenario is Kralingen at the zero situation.

Behind the primary dikes at the breach location, deep *scour-holes* can be formed with depths of several meters (personal conversation with Annika Hesselink). In this study, several iteration steps have been made to have comparable results with VNK. Scour-holes of several meters leads to higher effects, so scour-holes has not been taken into account.

Implementation of compartmentalization strategies

The implementation of the compartmentalization strategies is based on higher line elements. The location of the dikes is based on rough data, while the final implementation is very detailed. The possibility of dike construction through cities as The Hague, Amsterdam and Rotterdam needs more investigation. Other ideas can be used as possible alternatives, like a seaward dike in front of The Hague.

The use of higher line elements as compartmentalization dikes is questionable. The possibility of transforming these elements to compartmentalization dikes should be researched, because of the uncertainties and the lack of knowledge.

The assumption has been made that the dike must hold the water. This means that the heights of the compartmentalization dikes should be high enough. Compartmentalization dikes near the breach location must be as high as the maximum water levels at the breach, because the water can not spread in the area for reducing the height.

Further research is necessary, to get proper relations between compartmentalization shapes, dike heights and compartment sizes. For example, the distance between primary and compartmentalization dike is important in the secondary dike strategy. The heights of the compartmentalization dikes are not part of the study, but this dimension could also reduce effects.

Incoming water

The section of the incoming water shows that the ground level behind the primary dike has a large influence on the volume of incoming water. In the zero situation, the volume of incoming water at Ter Heijde is about a factor ten larger than in the Scheveningen scenario. Though the breach sizes of Ter Heijde and Scheveningen are equal. The amount of incoming water is very sensitive to ground level behind the breach location.

Economic values

The determination of the economic values in the area and the damage have been based on the given by the locations of the potential damage and the damage functions in HIS - SSM. The damage functions only take into account the inundation depths. The flow velocity is also important, especially in the zone near the dike breach. Looking at the secondary dike strategy, the effects occurs near the primary dikes.

Evacuation of people

The outcomes of the evacuation calculator of HIS - SSM, shows that the influence of evacuation is large. The evacuation curves shows an large reduction in number of evacuated people, if there is enough time for preventive evacuation (MinV&W, 2006c) p.31.

During this study the evacuation factor is zero, because the implementation of new dikes in the area changes the evacuation routes. For getting better insights in number of casualties, further investigation into evacuation is important. It should be possible to reach a good equilibrium between the distance to a compartmentalization dike (as possible evacuation height in the area) and the rising rate of the water, which should reduce the number of casualties and the expected annual casualties.

Chapter 9

Discussion

The safety of dike ring 14 has been investigated for the systemic risk indicators: affected people, casualties and economic damage. Systemic risk focuses on the probability of survival of an area due to the worst possible attack. The worst case scenario of the zero situation for dike ring 14 has five breach locations, spread along all sides of the dike ring. The probability of the worst case scenario is very low and uncertain. The costs are very roughly qualitatively estimated by lengths of compartmentalization dikes. So, this study only focuses on the effects of the flood, because for systemic risk, the effects are more important than the probabilities of occurrence.

In this study, compartmentalization is assumed to be the central strategy to reduce the systemic risk of dike ring 14. Considering compartmentalization as the central solution, it is necessary to assume that dikes constructed on land are the only solution to reduce flood risk. The compartmentalization dikes represent certain compartment configurations. Three compartmentalization strategies are implemented in dike ring 14, based on three fundamentally different compartment configurations: 1) partition strategy, 2) secondary dike strategy and 3) value protection strategy, Figure 5.2. The dike heights are assumed to be high and steady enough to hold the overland water flow.

The most attractive compartmentalization strategy in perspective of systemic risk reduction is the *secondary dike strategy*. The number of affected people and the economic damage have been reduced with a percentage of about 15 - 50 % for all scenarios. In the worst case scenario, the secondary dike strategy has reduced the number of affected people by 20 % and the economic damage by 26 %. In the worst case scenario, the secondary dike strategy show the largest reduction of the incoming water (76 %). In case of the secondary dike strategy, the results of the different scenarios show that the reductions in number of casualties vary, because it shows an increase in the Kralingen scenario. In this study, there is no evacuation assumed, because the implementation of the dikes lead to different evacuation routes. The secondary dike strategy could have a larger positive effect if it is also designed to improve the evacuation routes. The probability of failure of compartmentalization dikes has not been taken into account, so some potential damage still exists in the area. The only difference is that the flooding has two stages: breaching of the primary dikes and breaching of the secondary dike. The implementation costs of the secondary dike strategy suffers is qualitatively estimated to be high, because of the large length of the compartmentalization dikes. The compartmentalization dikes are also located across valuable areas, that are difficult to split by dikes (like old cities). This strategy is not attractive for all inhabitants in the dike ring area, because the inhabitants between the primary and compartmentalization dike have a higher mortality.

The *partition strategy* is an attractive strategy, looking at the relatively low (qualitatively) costs for implementation of the strategy in dike ring 14. However, The partition strategy is less effective for the reduction of the systemic risk in the dike ring area.

For the systemic risk reduction of dike ring 14, the *value protection strategy* is not attractive. The qualitatively costs to implement the strategy is comparable with the secondary dike strategy, but it is less effective as the secondary dike strategy. Dike ring 14 is not an appropriate dike ring area for the implementation of the value protection strategy. The dike ring area has a relatively homogenous value distribution, because the area is strongly urbanized.

Looking at the Dutch policy to risk management, risks are always quantified in terms of probability of *casualties* by an event. Only in case of flood risk, the probability of occurrence is taken into account (in terms of probability of exceeding a specific water level). As mentioned, compartmentalization does slightly reduce the number of casualties, taking compartmentalization strategies without evacuation plans into account. Adaptive evacuation measurements are necessary for the reduction of casualties. Considering more *systemic risk indicators* for flooding than casualties only, some compartmentalization strategies can be effective for the reduction of the systemic risk.

This study shows that different compartmentalization strategies have their own characteristics and benefits in terms of reduction of systemic risk. At the moment, the dikes along the Old Rhine are reconstructed to become a compartmentalization dike in dike ring 14. The configuration of the reconstructed dikes is part of the partition strategy. However, this study shows that a secondary dike is more effective for dike ring 14 than the partition strategy. Policy makers should make a decision about the configuration of the compartments and the willingness to invest, before implementing dikes in the dike ring area. The political decision of compartmentalization has been made without considering of the best compartmentalization strategy for dike ring 14. The planned reconstruction of the dikes of the Old Rhine only, can become useless in the future. Besides, it is not necessary to implement the compartmentalization strategies in one time. The secondary dike strategy can be implemented on a gradual way; Figure 9.1.

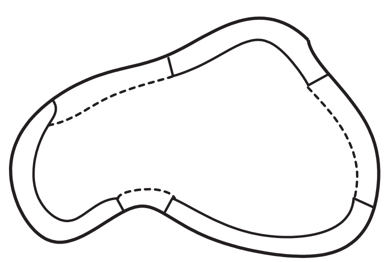


Figure 9.1: A possible gradual implementation of the secondary dike strategy in dike ring 14.

Bibliography

Ale, B. J. M. (2003). *Risico's en Veiligheid - Een historische schets*. TU Delft.

Alkema, D. and Middelkoop, H. (2005). The Influence of Floodplain Compartmentalization on Flood Risk within the Rhine - Meuse Delta. *Natural Hazards*, (36):125–145.

Baan, P. J. A. and Asselman, N. E. M. (2005). Hoe groot is het risico van overstromingen? H_2O, 12:25–32.

Beck, U. (1997). *De wereld als risicomaatschappij - essays over de ecologische crisis en de politiek van de vooruitgang*. De Balie, second (2001) edition. Composition and introduction: M. Hajer and M. Schwarz.

Bockarjova, M., Steenge, A. E., and Hoekstra, A. Y. (2007). Management of catastrophes: A paradigm shift in thinking about flood risk (chapter 3). In *WB Book: Water Problems and policies in the Netherlands*. Folmer, H. and Reinhard, S., RFF Press, Washington, D.C.

Bockarjova, M., Steenge, A. E., and Van der Veen, A. (2004). Dijkdoorbraak bij Capelle treft gehele Nederlandse economie. *Land + Water*, (5):28–29.

De Bruine, E. P. (2006). *The influence of compartmentalisation on flooding in Central Holland*. TU Delft. Master thesis.

DWW (2003). *Schade na een grootschalige overstroming*. Number DWW-2003-056. Dienst Weg- en Waterbouwkunde (part of Ministry of Transport, Public Works and Water Management), The Hague.

DWW (2005a). *HIS - Schade en Slachtoffer Module - Versie 2.2 (Gebruikershandleiding)*. Number DWW-2005-005. Dienst Weg- en Waterbouwkunde (part of Ministry of Transport, Public Works and Water Management), The Hague.

DWW (2005b). *Standaardmethode2004 Schade en Slachtoffers als gevolg van overstromingen*. Number DWW-2005-005. Dienst Weg- en Waterbouwkunde (part of Ministry of Transport, Public Works and Water Management), The Hague.

ESRI (1996). *ArcView GIS - The Geographic Information System for Everyone*. Environmental Systems Reserach Institute, Inc.

Hesselink, A. W. (2006). *WINN compartimentering - Projectplan*. Lelystad. Internal report RWS RIZA and RWS RIKZ, Concept 1.0.

Hesselink, A. W., Stelling, G. S., Kwadijk, J. C. J., and Middelkoop, H. (2003). Inundation of a Dutch river polder, sensitivity analysis of a physically based inundation model using historic data. *Water Resources Research*, 39(9):229 – 248.

Hoekstra, A. Y. (2005). *Generalisme als specialisme - Waterbeheer in de context van duurzame ontwikkeling, globalisering, onzekerheden en risico's*. Twente University. Oration on 11th of November 2005.

Hoozemans, F. J. M., Klein, R. J. T., Kroon, A., Verhagen, H. J., and van der Wegen, M. (2004). The coast in conflict - an interdisciplinary introduction to coastal zone management (chapter 1). In *UNESCO - IHE lecture note*.

Joffe, H. (2003). Risk: From perception to social representation. *British Journal of Social Psychology*, (42):55–73.

Jonkman, S. N. (2001). *Overstromingsrisico's: Een onderzoek naar de toepasbaarheid van risicomaten*. TU Delft. Master thesis.

Jonkman, S. N., Van Gelder, P. H. A. J. M., and Vrijling, J. K. (2003). An overview of quantitative risk measures for loss of life and economic damage. *Journal of Hazardous Materials*, A99:1–30.

Kabinet (2000). Anders omgaan met water - waterbeleid in de 21^e eeuw (kabinetsstandpunt).

Kok, M., Theunissen, R. P. G. J., Jonkman, S. N., and Vrijling, J. K. (2006). *Schade door overstroming: Ervaringen uit New Orleans*. $\text{HKV}_{LIJNINWATER}$ and TU Delft, Lelystad.

MinBZK (1994). *Brandbeveiligingsconcept. Beheersbaarheid van brand. Onderzoeksrapportage (1.0.0)*. Nibra: Dutch Institute for Physical Security, The Hague. (werkenvoorveiligheid.nl, January 2007).

MinBZK (2006a). *Katrina - 100 days after the crisis*. Ministry of the Interior and Kingdom Relations, The Hague. background information on behalf of the work conference New Orleans.

MinBZK (2006b). *Lessons learned New Orleans*. Ministry of the Interior and Kingdom Relations, The Hague. "Als het toch gebeurt...", Conference 31th of May 2006.

MinV&W (1990). *Kustverdediging na 1990 - 1^e kustnota*. Ministry of Transport, Public Works and Water Management, The Hague.

MinV&W (2000a). *3e kustnota - Traditie, trends en toekomst*. Ministry of Transport, Public Works and Water Management, The Hague.

MinV&W (2000b). *Anders omgaan met water - Waterbeleid in de 21e eeuw*. Ministry of Transport, Public Works and Water Management, The Hague.

MinV&W (2001). *Omgaan met veiligheid in de toekomst - Verkenning Deltawateren*. Ministry of Transport, Public Works and Water Management, The Hague.

MinV&W (2005a). *Hoofdrapport onderzoek overstromingsrisico's - Veiligheid Nederland in Kaart*. Ministry of Transport, Public Works and Water Management, The Hague.

MinV&W (2005b). *Overstromingsrisico dijkring 14 Zuid-Holland - Veiligheid Nederland in Kaart.* Ministry of Transport, Public Works and Water Management. (with Grontmij and Witteveen + Bos).

MinV&W (2006a). *Inschatting van het aantal slachtoffers ten gevolge van overstroming (Dijkringen 7, 14 en 36) - Veiligheid Nederland in Kaart.* Ministry of Transport, Public Works and Water Management, The Hague.

MinV&W (2006b). *Landelijke Rapportage Toetsing 2006 - Achtergrondrapport, deel 2: Verbindende Waterkeringen.* Ministry of Transport, Public Works and Water Management, The Hague.

MinV&W (2006c). *Modellering en analyse van evacuatie (Dijkringen 7, 14 en 36) - Veiligheid Nederland in Kaart.* Ministry of Transport, Public Works and Water Management, The Hague.

MinV&W (2006d). *Risicocase dijkring 14 Zuid - Holland - Berekening van het overstromingsrisico - Veiligheid Nederland in Kaart.* Ministry of Transport, Public Works and Water Management.

MinV&W (2006e). *Synthese rapport Onderzoeksprogramma - Rampenbeheersingsstrategie Overstromingen Rijn en Maas.* Ministry of Transport, Public Works and Water Management (together with Ministry of the Interior and Kingdom Relations).

Nieuwenhuizen, W., Wolfert, H. P., Higler, L. W. G., Dijkman, M., Huizinga, H. J., Kopinga, J., Makaske, A., Nijhof, B. S. J., Olsthoorn, A. F. M., and Wösten, J. H. M. (2003). *Standaardmethode Schade an LNC-waarden als gevolg van overstromingen - Methode voor het bepalen van de gevolgen van overstromingen voor de aspecten opgaande begroeiing, vegetatie, aquatische ecosystemen en historische bouwkunde.* Alterra, Research Instituut voor de Groene Ruimte.

OECD (2003). *Emerging risks in the 21st Century - An OECD International Futures Project.* Organisation for Economic Co-operation and Development, Paris. (A summary of 'Emerging Risks in the 21^{st} Century - An Agenda for Action').

Oost, J. (2004). Sustainable Development on flood control - Flood control in China and the role of the Three Gorges Project. Report as result of an internship at Wuhan University in China.

Oost, J. (2006). Strategie in Veiligheid - Consequenties van verschillende veiligheidsstrategieën tegen overstromingen. Report as result of an internship at Grontmij (De Bilt) and Twente University.

Projectbureau-Belvedère (2003). Project Compartimentering van het Land van Maas en Waal, www.belvedere.nu.

Renn, O. and Klinke, A. (2004). Systemic risks: a new challenge for risk management. *European Molecular Biology Organization*, 5:41 – 46.

Rijnland (2000). *Waterhuishouding 21^{ste} eeuw - Beheersgebied van Rijnland.* Hoogheemraadschap van Rijnland, Leiden.

RIVM (2004). *Risico's in bedijkte termen - een evaluatie van het beleid inzake de veiligheid tegen overstromingen*. National Institute for Public Health and the environment, Bilthoven.

RoyalHaskoning (2005). *Compartimenteringsdijken - Kostenraming voor zeven tracé's*. Ministry of Transport, Public Works and Water Management (together with Ministry of the Interior and Kingdom Relations), The Hague.

Stallen, P. J. M., Geerts, R., and Vrijling, J. K. (1996). Three conceptions of quantified societal risk. *Risk Analysis*, 16(5):635–644.

Ten Brinke, W. B. M., Bannink, B. A., and Ligtvoet, W. (2007). Changes and challenges: the evaluation of flood risk policy in the Netherlands. *Journal on Watermanagement (submitted)*.

Theunissen, R. P. G. J., Kok, M., and Vrijling, J. K. (2006). Compartimentering van dijkringen: niet altijd dé oplossing. H_2O, 21:29–31.

Van Steen, P. J. M. and Pellenbarg, P. H. (2004). Water Management Challenges in the Netherlands - The Netherlands in maps. *Tijdschrift voor Economische en Sociale Geografie*, 39(9):590 – 599.

WBGU (1998). *World in Transition - Strategies for Managing Global Environmental Risks*. German Advisory Council on Global Change (WBGU), Berlin. Executive Summary.

WL | Delft Hydraulics (2004). *SOBEK rural - Managing your flow*. WL | Delft Hydraulics, Delft. Version 2.09.015.

Glossary

Affected people	People who lives in the dike ring and are directly affected by the flood.
Breaching scenario	The supposed of breaching of the dike, that leads to a flood.
Compartmentalization	Division into smaller subdivisions. In this study: dividing a dike ring area into compartments
Configuration	spatial pattern of compartmentalization dikes, taking into account the whole dike ring area
Dam Failure	The failure of the dams primary function: the protection of land against the incoming water
Dike ring (area)	Enclosed area, which is lower than the surrounded water and is protected by primary dikes or higher ground
Dune	Sand body on the separation of land and sea, which protects the land from the incoming water.
Economic risk	The probability of economic damage in an area due to flooding
Evacuation	Removal of threatened people, following after warning
Exceeding probability	The probability that the water level is higher than the height of the dams
Fail-safe risk policy	Policy based on counteractions by failure of the standard policy (RIVM, 2004)
Failure mechanism	The succession of events that leads to the failure of a dam
Flood probability	The probability that water flows into an area

Flood scenario	Supposed flooding of an area, determined by several parameters
Group risk	The risk of a large amount of casualties or big economic damage at one stroke
Hydraulic boundary conditions	Reference water levels, wave and wind conditions (Ten Brinke et al., 2007)
Indirect casualties	People who have been damages after a flood, but did not have contact with the water, but have been physical
Individual risk	The probability that a person is killed at a certain location as a result of an event.
Line elements	Heights in an area influencing the overland water flow
NAP	Dutch Ordinance Datum (*Dutch: Normaal Amsterdams Peil*)
Polder	Area lower than the surrounding water, protected by primary or secondary dikes (De Bruine, 2006)
Primary dike	Dikes that protects the dike ring area against floods.
Resilience time	The time to reach a new equilibrium after a disaster
Risk	The combination of the probability of an event and the consequences of that event (Ale, 2003).
Risk curve	A risk measurement that combines the probability and the effects into a graph.
Risk measurement	A mathematical function to quantify the risk (Jonkman et al., 2003)
Risk situation	The specific combination of the probabilities at one side and the effects at the other side.
Sea level rise	The rising of the average sea level
Secondary dike	All dikes that are not primary dikes.
Spatial pattern	The placing of dikes in an area, based on a strategic plan
Societal risk	Same as group risk
Structural measures	Measures which changes the physical characteristics of floods
Systemic risk	The risk that a society becomes instable after a flood for a long period.
Zero-situation	The outcomes of the model for the current situation

Appendix A

Dike ring 14

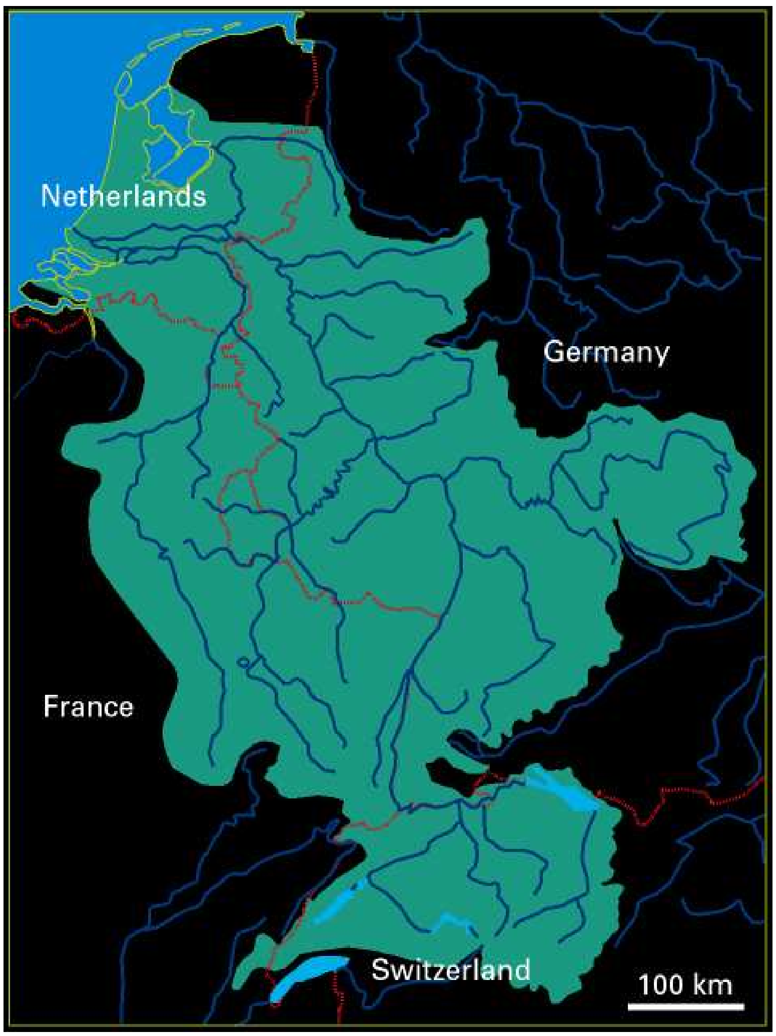


Figure A.1: Rhine - Meuse catchment area in West Europe (www.natuurdichtbij.nl).

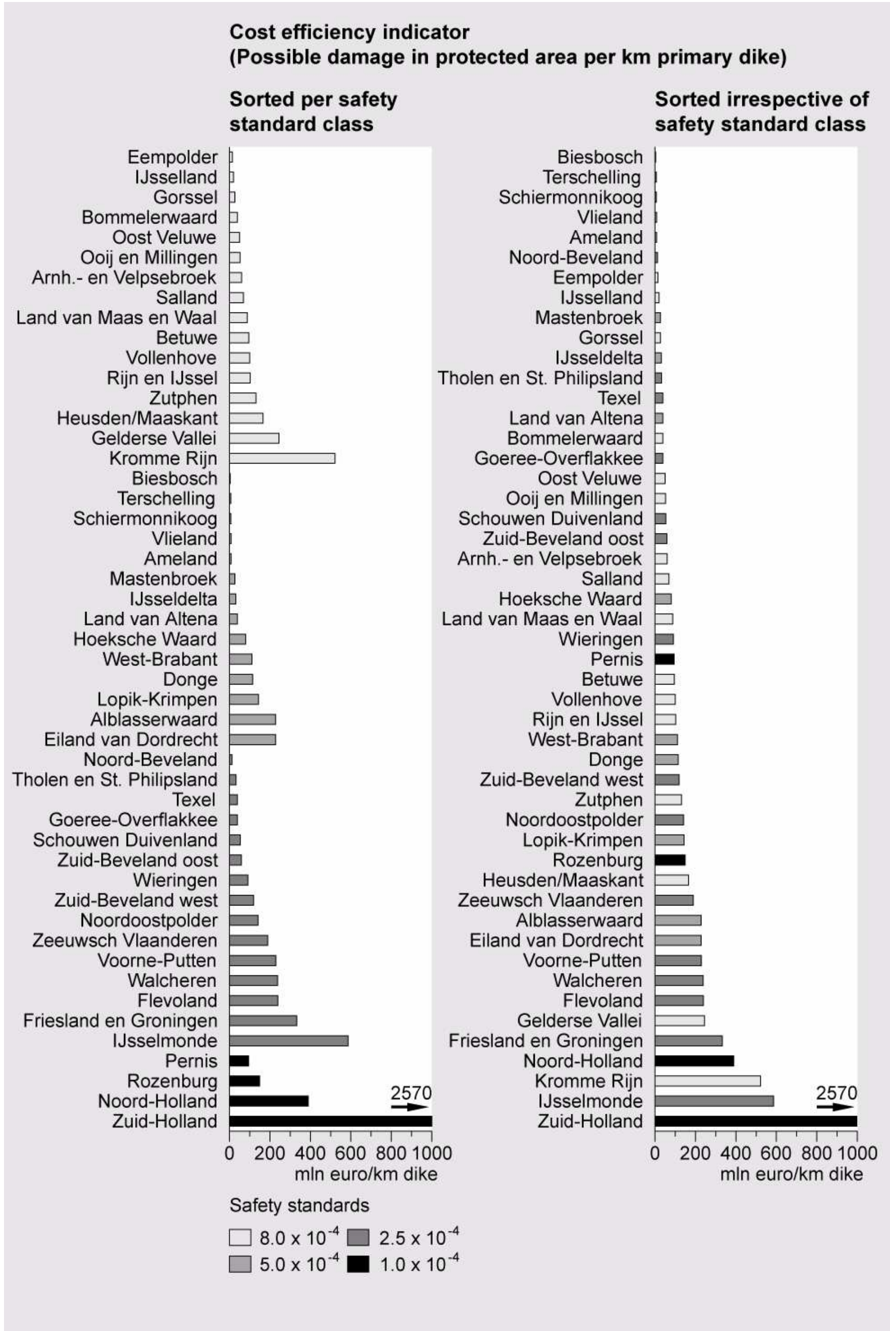
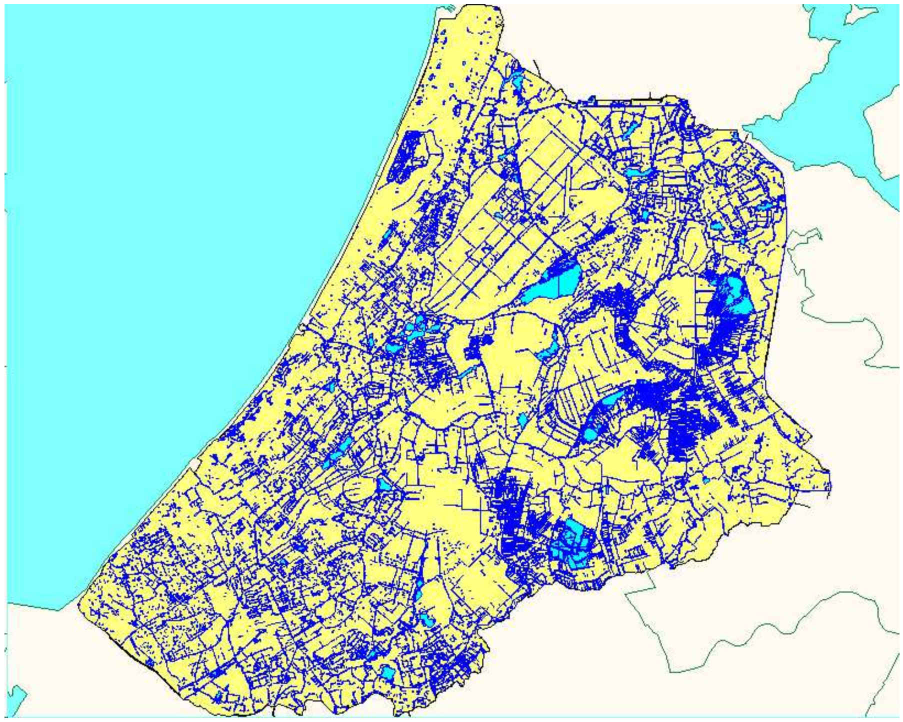
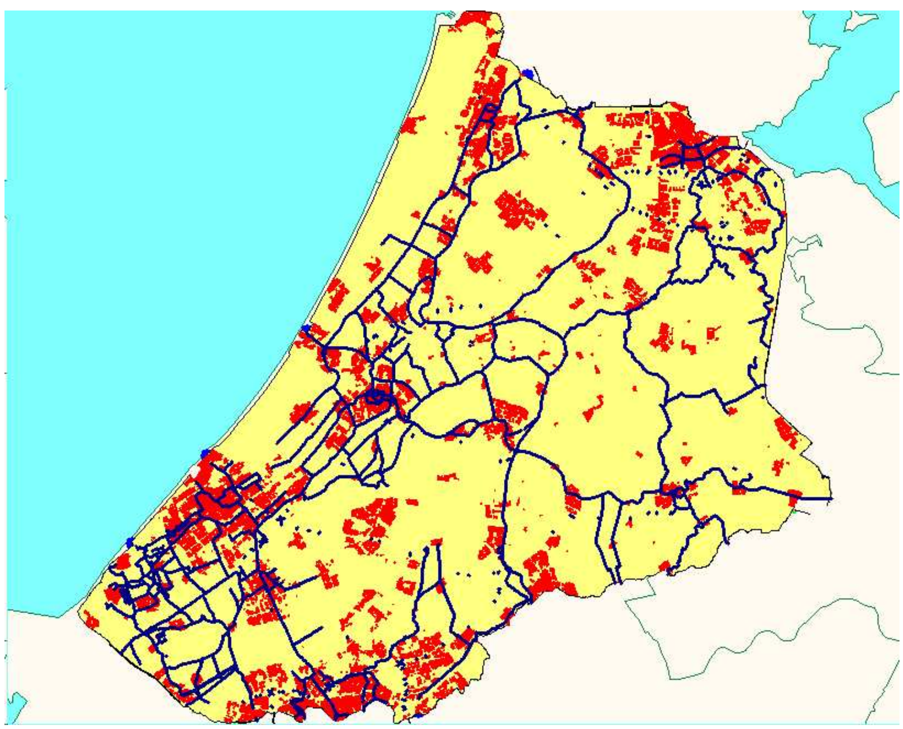


Figure A.2: The cost efficiency indicator for the comparison of the dike rings in the Netherlands (RIVM, 2004).

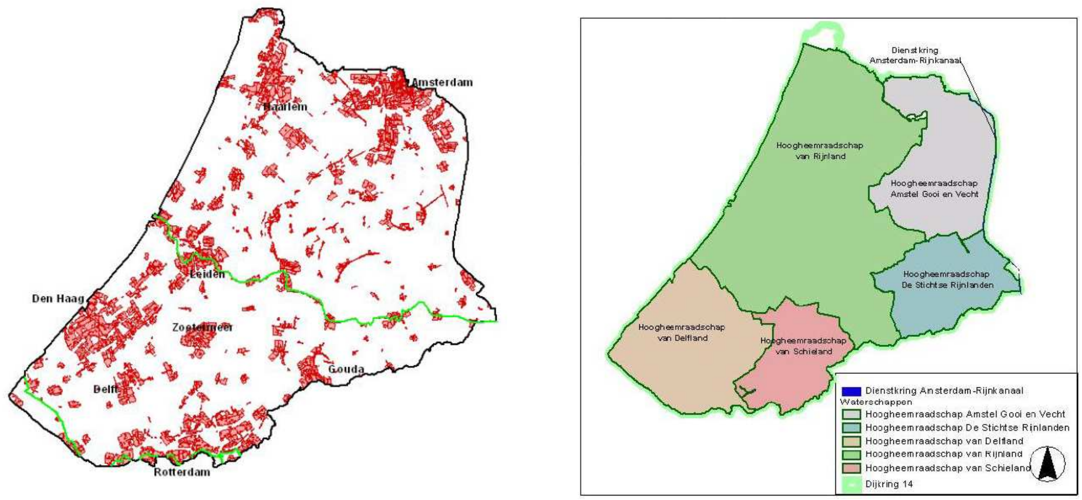


(a)



(b)

Figure A.3: Current situation dike ring: all surface waters in dike ring 14 (a) and the main water drainage system implemented in the SOBEK schematization of dike ring 14 (MinV&W, 2006d) (b).



(a) (b)

Figure A.4: Location of secondary dikes in the research area (MinV&W, 2005b) (a) and water boards (b)(MinV&W, 2005b).

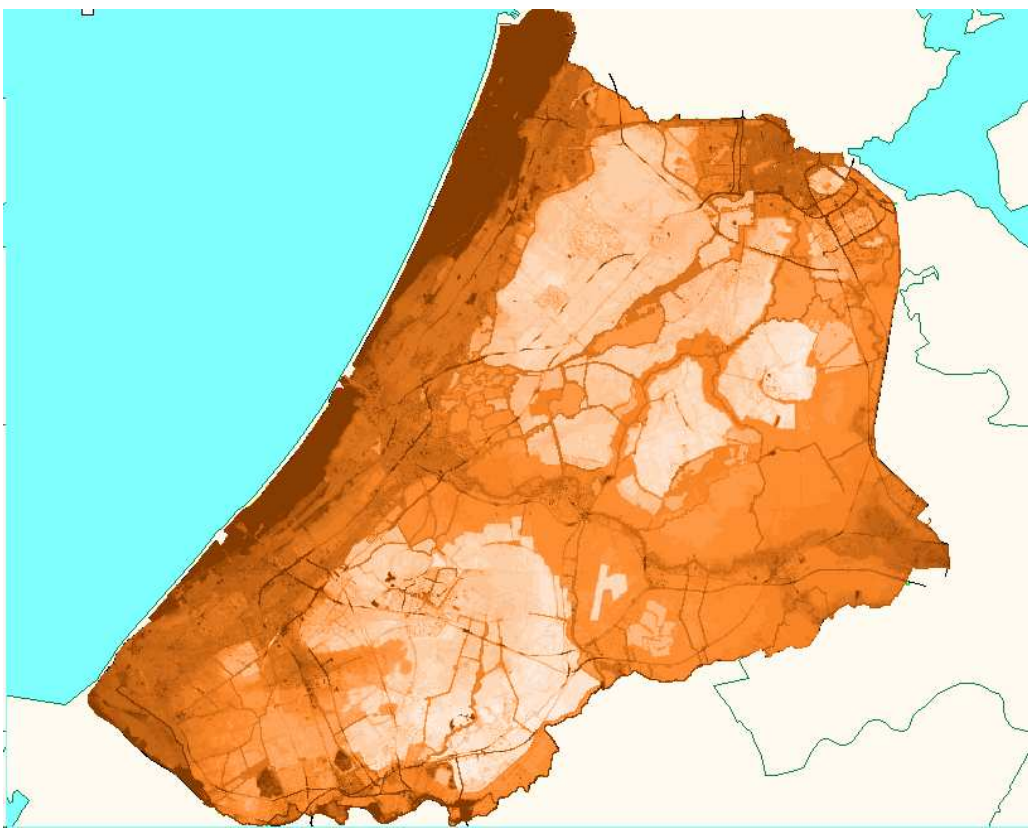


Figure A.5: Height map of dike ring 14 (ArcView). (The higher the ground level, the darker the red color.)

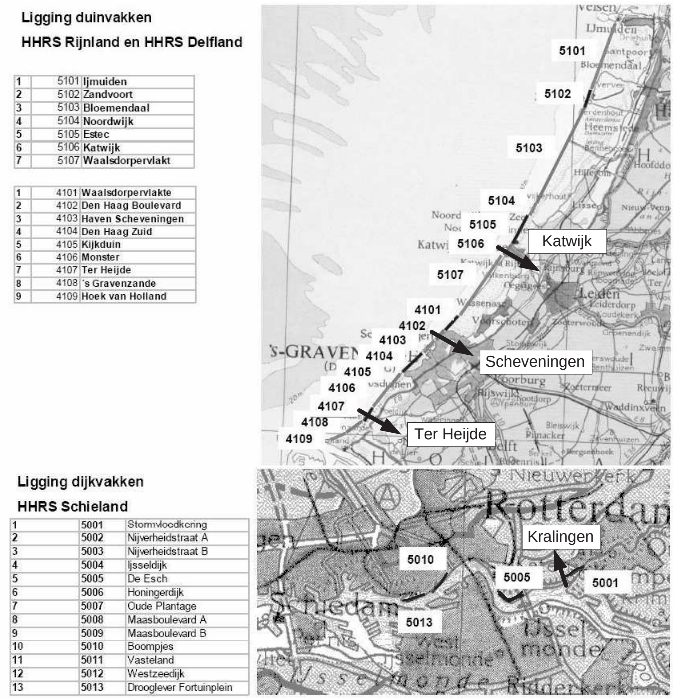


Figure A.6: Some of the dike sections of dike ring 14, with four of the five breaching locations (MinV&W, 2005b)

(a) (b)

Figure A.7: Location of breach at Kralingen: overview with breach location as arrow and the Storm surge barrier Hollandsche IJssel in the circle (Google Earth) (a) and Storm surge barrier Hollandsche IJssel (www.neeltjejans.nl) (b)

(a)

(b)

Figure A.8: Overview of the photo tour in dike ring 14 with the location of the photos, represented by an arrow. The arrow also shows the direction of the picture (a) and the overview of Spaarndam (b) (Google Earth).

(a) (b)

(c) (d)

Figure A.9: Photos of the photo tour in Figure A.8(a): photo 1 shows a highway (junction A4 with N201) that has to become a compartmentalization dike (a), photo 2 shows the steam pumping station of Cruquius, on the edge of the Haarlemmermeer (b), photo 3 is the 'Ringvaart van de Haarlemmermeerpolder', which will be closed by sluices (part of the compartmentalization dikes) (c) and photo 4 shows the city of Haarlem. The railroad in front shall be reconstructed to becomes a compartmentalization dike in secondary dike strategy (d).

(a)

(b)

(c)

Figure A.10: Photos of the photo tour near Spaarndam; Figure A.8(b): photo 5 shows the inner bank of the Spaarndammerdijk (a), photo 6 is the inner bank of the Spaarndammerdijk at Spaarndam (b) and photo 7 shows the little sluices in Spaarndam, which have an open connection to the Noordzeekanaal (c).

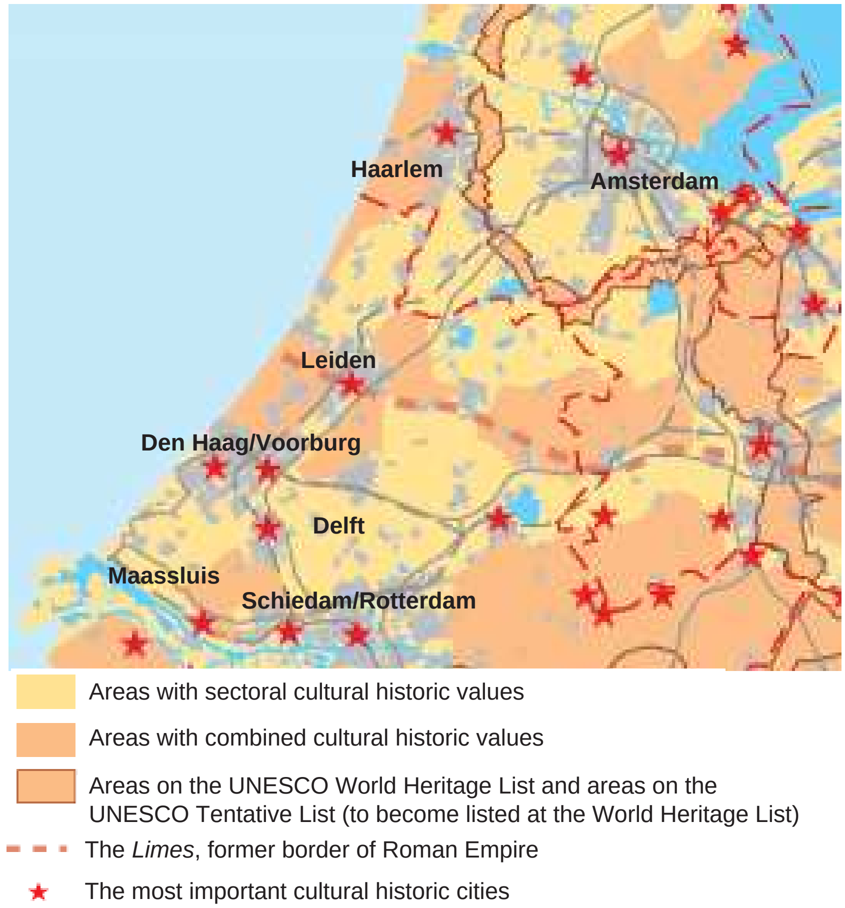


Figure A.11: Overview of dike ring 14 with the important cultural-historic places and the monuments cities (Projectbureau-Belvedère, 2003)

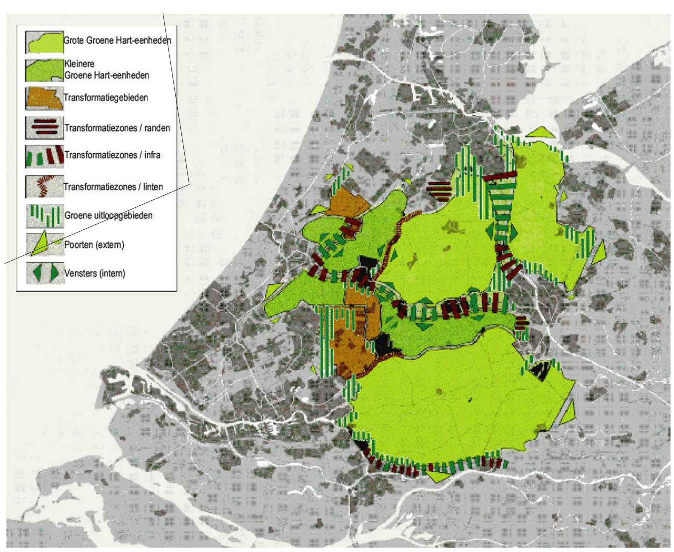


Figure A.12: The Green Heart, most important natural resource of dike ring 14 (www.vrom.nl)

General data

	Amount	Unit	Source
The Netherlands			
Surface	4,152,803	ha	site CBS
Population	16,356,914 (December 2006)	people	site CBS
(nominal) GDP (estimation of 2006)	629,391	million $	nl.wikipedia.org - IMF
Density	392,8	inhabitants/km2	nl.wikipedia.org
GDP/capita	38,320	$/year	nl.wikipedia.org - IMF
Dike ring 14			
Surface	223,000	ha	(MinV&W, 2005a)
Population	3,255,000	people	(MinV&W, 2005a)
Potential Damage	290 billion	euros	(MinV&W, 2005a)
Dike ring 14 relative to the Netherlands			
Surface	5.4	%	
Population	20.0	%	

Table A.1: General data of the Netherlands and dike ring 14

Appendix B

Risk analysis

B.1 Definition of safety against disasters

Safety against disasters is normally described as a certain risk. A risk is defined as a mathematical function of the probability of an event and the consequences of that event (Jonkman et al., 2003). Mentioned consequences of disasters are mostly negative damage on short term, which causes a negative sense of risk. On long term, a disaster also provides probabilities for the affected area and people (Bockarjova et al., 2007).

Damage is mostly given in number of casualties or economic damage, but damage can also be a loss of environmental aspects, or *LNC-values*, for example (Nieuwenhuizen et al., 2003; Jonkman et al., 2003; DWW, 2005b). More definitions for quantification of risk measurements are used in practise. No uniform measurement exists that can be used for all kinds of threats. Mentioned risk measurements have its own field of applications, for example nuclear disaster versus flood disaster. Besides this, countries use also different risk measurements for the same field of applications. Hong Kong uses other risk measurements than the Netherlands. This causes a big spectrum of risk measurements and quantification of it. Jonkman et al. (2003) gives an summarization of twenty five different risk measurements.

Each risk has its own limits for acceptability. Figure B.1 shows three zones for the acceptability of risks. The first zone deals with such huge risks that are unacceptable for society. Negligible risk are placed in zone three. The second zone are risks that are acceptable, but need further consideration. These risks should go to zone three (Ale, 2003). Risks are pronounced by risk types. A risk type gives the relation of probability and damage. Jonkman (2001) summarizes risk measurements into four risk types: 1) individual risk, 2) societal risk, 3) economic risk and 4) potential damage. Hoekstra (2005) parted risk measurements into three risk types, which can be used for *flooding*: 1) individual (or economical) risk, 2) group risk and 3) systemic risk. The list is similar to the risk types of Jonkman (2001). The individual and economic risks are interpret as the same type.

The first two risk types are already used in Dutch policy (Ale, 2003). The last risk approach is a new concept, developed by OECD (2003). This chapter explains the three above

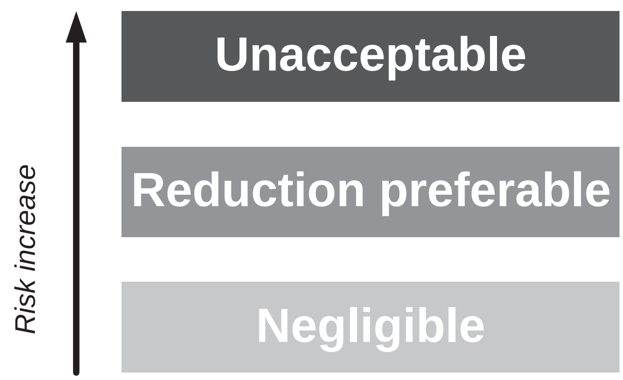


Figure B.1: Three Zone Model for risk (Ale, 2003).

risk types and goes further into the development of systemic risk.

B.2 Risk types in Dutch policy

The Dutch safety policy is roughly based on two different kinds of threat: natural (or normal) and external threats. The main difference in the Dutch policy between natural and external threats is that external threats are introduced by human activities. The RIVM (National Institute for Public Health and the Environment) examines the risk management of external threats in the Netherlands.

The type of *individual risk* is often used for safety of normal or natural threats by the Dutch government. The term *group risk* is used for the determination of the safety from external events, like nuclear power stations, air planes and transport of dangerous matters . The limits in the Dutch law is higher for external threats than for normal threats (Jonkman et al., 2003; Ale, 2003; RIVM, 2004).

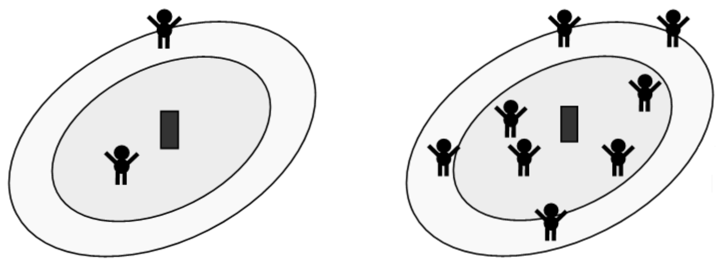
Individual risk
At the type of individual risk, consequences are concentrated on the individual person . The most simplified individual risk calculation is '*the probability of occurrence times the results (to one individual) of that occurrence*' (Jonkman et al., 2003).

Individual risks calculations are based on an integration of the probability of occurrence and the extent of damage (MinV&W, 2005a). It is an integration of all the individual risks of the whole population in the area ($\mathrm{IR} = P_f P_{d|f}$) (Jonkman et al., 2003). The outcomes are described in certain value [*damage/year*]. This is also called the aggregated individual risk [*number of casualties*] and aggregated economic risk [*euros*]. The risk shows one aggregated value for probability of occurrence and extend of damage, which has to represent the whole area.

Economic risk is quantified by flood probability times the economic damage. The damage is split by direct and indirect damage, which will be handled in chapter (Hoekstra, 2005). In general, economic consequences are given at the type of individual risk.

Group risk

Risk measurement in terms of group risk is a different type of individual risk according to Hoekstra (2005). In group risk also the amount of the casualties is taken into account, which is not represented at the type of individual risk (RIVM, 2004). The difference between individual risk and group risk is schematized by Figure B.2. The risk source is the black rectangle inside the circles. The circles are areas with a certain risk, for example 10^{-2} and 10^{-3} a year. The individual risk is equal in both areas, but the amount of affected people is bigger in the second picture (Stallen et al., 1996).



(a) (b)

Figure B.2: Schematization of different risk types: individual risk (a) and group risk (b) (Stallen et al., 1996)

The quantification of the risk curve is given in the main text; Chapter 2. The determination of the acceptable values of group risk got stick in Dutch policy. Based on individual risk, Dutch limits of group risk is determined and can be seen in Figure B.3. The Figure takes into account the Three Zone Model of Figure B.1. The surface under the dot line is zone three and the surface above the straight line is zone one.

Individual risk versus Group risk

Group risk can be seen as an aggregation of all the possible individual risks of the researched flood scenarios. The individual risk is just one combination of probability of occurrence and corresponding consequence, while group risk have numerous of these combinations. The individual risk is just an integration of the group risk. Group risk say more about the risk situation than individual risk type, because it contains more information.

Another important difference between individual risk and group risk is the risk situation with low probabilities and high consequences. This situation is more or less neglected at individual risk type, because of the integration. At the type of group risk, the *low probability - high consequences* situation can be seen in the risk curve (RIVM, 2004; Hoekstra, 2005; MinV&W, 2006d).

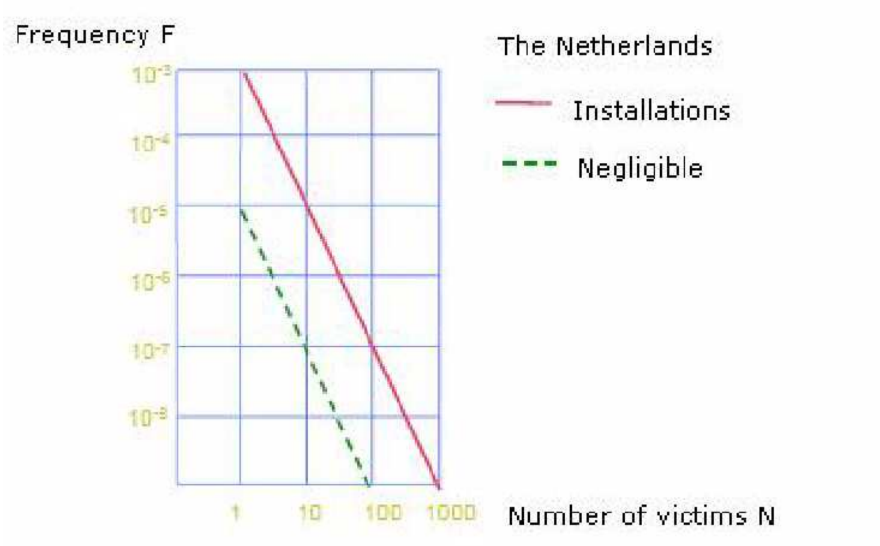


Figure B.3: Limits to group risk in the Netherlands (Ale, 2003).

B.3 Implementation into flood risk

Research to Dutch flood risk

An important current research to flood risk of The Netherlands is made by project Veiligheid Nederland in Kaart (VNK). The outcomes of the flood probability per dike ring are given at the individual risk type MinV&W (2005a). The results of most of the researched dike rings are just a global risk measurement by taking the littlest probability of occurrence and the highest possible damage per dike ring, see Table B.4.

Dike ring	Economic risk: flooding probability multiplied by the economic damage [million €/year]	Consequence: maximum economic damage* [miljoen €]	Annual probability of flooding
Noordoostpolder	10 **	9,000	1/900
Zuid-Holland	116**	290,000	1/2500
Land van Heusden / De Maaskant	180**	18,000	>1/100
Terschelling	0.1	160	1/1500
Mastenbroek	12	1,200	> 1/100
Noord-Holland	116	58,000	1/500
Lopiker- en Krimpenerwaard	100	10,000	>1/100
Alblasserwaard	48	19,000	1/400
Goeree-Overflakkee	3	3,700	1/1200
Zeeuws Vlaanderen	140	14,000	>1/100
Bommelerwaard	10	2,600	1/250
Land van Maas en Waal	64	6,400	>1/100
Ooij en Millingen	0.7	1,000	1/1.400
Betuwe, Tieler- en Culemborgerwaarden	180	18,000	>1/100
Rijn en IJssel	34	6,800	1/200
Oost-Veluwe	31	3,100	>1/100

* The damage is the maximum damage which would occur if the entire dike ring area were to be flooded. This is overestimated for major dike ring areas and dike ring areas with compartments. The number of victims cannot be determined with the global method.

** The damage calculated using the detailed method appears to be much less than the damage calculated with the global method.

Figure B.4: Results from VNK; determination of flood probabilities of Dutch dike rings (MinV&W, 2005a)

In the same research more accurate results are determined for three of the dike rings by taking more flood scenarios. It concludes that the results of the global method are highly overestimated, in comparison with the more detailed method. MinV&W (2005a). One of the detailed researched dike rings is dike ring 14. Ten flood scenarios are taken for the calculation of the average flood risk of dike ring 14. These ten scenarios covered 99 % of the flood probability of the whole dike ring, which is assumed to accurate enough (MinV&W, 2005a).

(RIVM, 2004) has tried to compared flood risk with the external safety. The external safety is presented by all the external safety domains, which are already examined of the RIVM; Figure B.5. The group risk of flooding is presented range of a lower and an upper boundary of flood probability per dike ring and the corresponding numbers of casualties. MinV&W (2006a) has made a more detailed group risk of dike ring 14 in case of flooding, Figure 2.2.

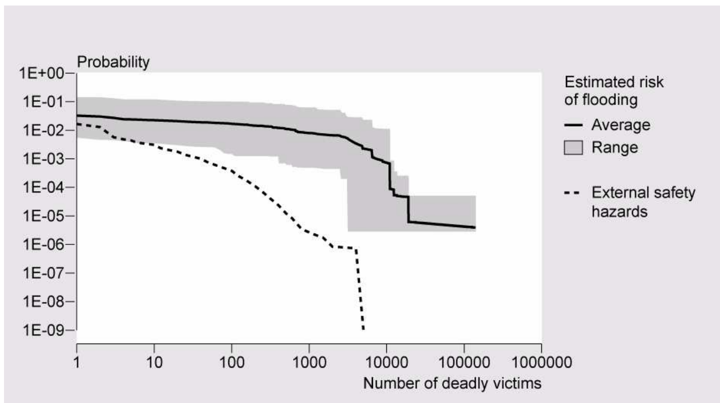


Figure B.5: Dutch Group risk of flooding and a summation of all external risks (RIVM, 2004)

B.4 Construction of risk curve

In this section, the construction of the risk curve is explained for the number of victims at the zero situation. The results of the study are presented in Table B.1. The three next graphs presents the following steps, that have been taken for the construction of the risk curve, (Jonkman, 2001). The used formulas are given in the main text: Chapter 2.

Table B.1: The number of affected people for all 28 cases and the corresponding percentage of the zero situation.

Flood Scenario	Probability density function ($p_N(x)$)	Casualties (N)
A Scheveningen	1.37E-04	862
B Kralingen	5.00E-05	1,403
C Ter Heijde	2.00E-05	3,701
D Haarlem	1.00E-05	227
E Sea attack	2.22E-06	5,867
F Sea-river	5.00E-07	4,914
G Worst case	1.00E-07	8,130

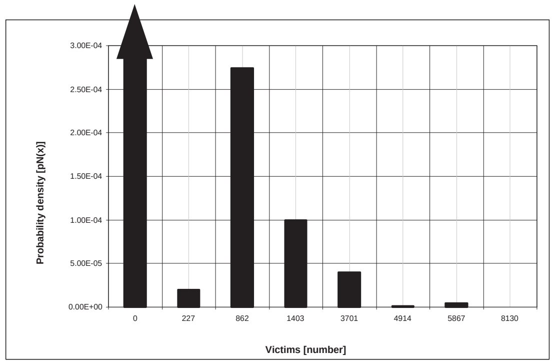


Figure B.6: The probability density function in number of casualties for the zero situation of the study. The probability density of zero casualties is not showed, because of this is the situation with the higher probability density. The sum of the 7 scenarios is 4.40E-04 [-]. The value of the situation without casualties is 0.99956 [-]. (MinV&W, 2000b).

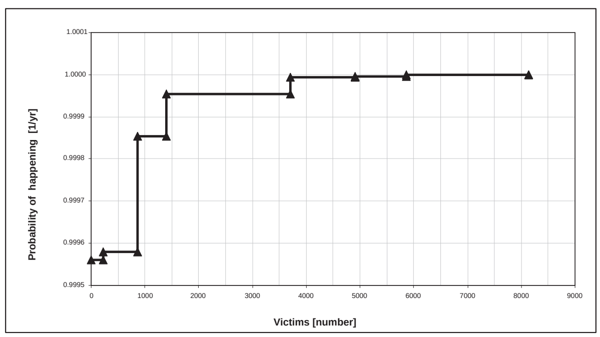


Figure B.7: The probability distribution function in number of casualties.

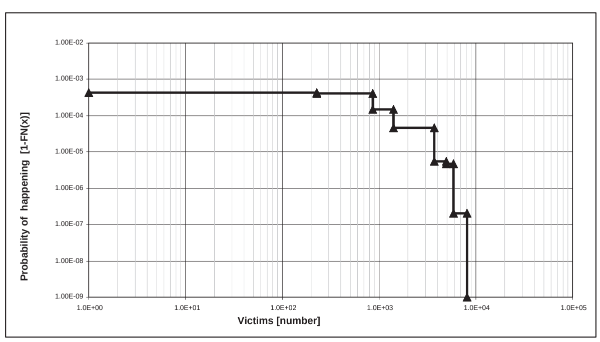


Figure B.8: Probability of exceeding in number of casualties. This is the constructed F_N curve (or risk curve) on a double logarithmical axes.

Appendix C

Behind systemic risk

During this study, some systemic risk elements have been researched. No detailed conclusions have been taken, because shortage of time. So the results of the understanding of systemic risk is not showed in the main text, but in this appendix.

C.1 Systemic risk: new risk type

OECD (2003) has developed a new concept of risk management, called *systemic risk*. The name springs from the financial world and is used as the possibility of a total destruction of a (financial) system. Hoekstra (2005) considers systemic risk as a higher development than individual and group risk.

Risk society

Systemic risk is a continuation of the *risk society*, created by Ulrich Beck, a German sociologist. Beck described the current modern industrial society as a risk society, because technological development has brought a new order of risk definition. Before the industrialization of the 19th century, humanity could not destroy the living system (Earth). The technical development brought new threats, which can cause a total destruction for the human society on Earth. Human mankind create threats (especially chemical and nuclear threats), which can destroy the basic of the society, called the *Earth*. Beck considers that the industrialization is the first period in the human world, in which it is possible to destroy the world by human interaction (Beck, 1997).

Since the industrialization, scientists use statistical risk calculations to describe the world safety. Beck concludes that these risks are based on statistical measurements and do not exclude disasters. This also goes for potential big-scaled problems, which can destroy the Earth. Beck pronounce that there is a big gap between safety and *apparently* safety. The possibility of a big-scaled disaster still exists, which can cause an enormous damage. Besides the magnitude of the disaster, also the risk uncertainty plays a role. It is hard to know the consequences of a big-scaled disaster, because it can not be tested in laboratories. The world has become a laboratory itself. The magnitude and the uncertainty of the corresponding consequences caused by such a disaster is of a new risk type (Beck, 1997).

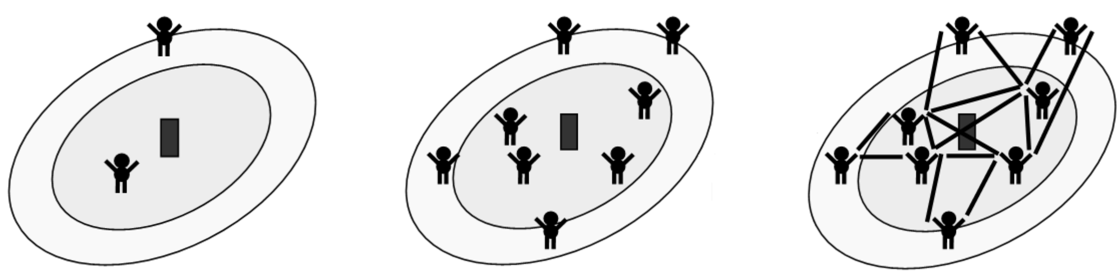
Definition of systemic risk

The last development in risk perception is to determine safety into systemic risk. This type of risk is recently developed by the OECD (2003). The systemic risk is the risk that a defined system becomes instable (OECD, 2003). The term systemic risks springs from the financial world, where it contains the risks that the whole financial market is destructed in stead of some participants Hoekstra (2005). The term is used for different threats, like flooding, diseases, terrorism and also for different kind of systems (or potential damage object), like countries (areas), kind of species or functions (OECD, 2003; Renn and Klinke, 2004).

Systemic risk shows the probability that a society becomes instable or bankrupt after an external event and several negative consequences occur (OECD, 2003). The purpose of the group risk is to give an indication to the societal impact of a disaster (RIVM, 2004), but systemic risk goes further than just looking at casualties. Systemic risk considers the defined society (system) as a whole. Considering the risk types of Jonkman (2001), systemic risk is situated between the types of *group risk* and *potential damage*. The importance of the size of damage is also shown by the following quote

> *... with a flood, everyone in an affected region files a claim simultaneously (called systemic risk) ...*
> (The Washington Post, 21 September 2005, www.env-econ.net/2005/09/washington_post.html)

Differences between the risk types for casualties are schematized in Figure C.1. The difference between Figure C.1(a) and Figure C.1(b) is the amount of damage, because the impact of the external event is bigger in Figure C.1(b). The individual risk of every doll is the same, but more dolls are affected in Figure C.1(b) (Stallen et al., 1996). When people form a society, they become more independent of each other. The systemic risk can be presented by drawing lines between the people; see Figure C.1(c). The thought behind this schematization is that more people are hit by a catastrophe, because their society (system) is hit. The directly damaged people tow other people in the system into the damage indirectly.



(a) (b) (c)

Figure C.1: Schematization of different risk types: individual (or economical) risk (a), group risk (b) and systemic risk (c), based on Stallen et al. (1996)

Figure C.1 in short:
$IR_A = IR_B = IR_C$ (IR is individual risk)
$GR_A < GR_B, GR_B = GR_C$ (GR is group risk)
$SR_A < SR_B < SR_C$ (SR is systemic risk)

A society with strong relations is hit harder by a disaster, than a society with less relations. A chain reaction follows after the disaster, which affects people indirectly. The consequences are spread through the system and are felt by a large amount of people. In general: *The more relations, the more negative effects and the more problems the system has to recover.*

Systemic risk: absolute or relative?
The defined system is the central issue in the systemic risk. The conclusions about the systemic risk are fully dependent on the choice of the system. Systemic risk is a *relative* object, because it is always related to the defined system. Hurricane Katrina in New Orleans in 2005 shows a good example of the relativity of a disaster for a system: "*In relative terms, effects evidently were of a much higher order at the Louisiana state level than at the federal level* (Bockarjova et al., 2007)." The highest level of the system in the world is the world on its own. Only in this case, the results can be presented in absolute terms.

In this study, dike ring 14 is taken as study area instead of the Netherlands. (West-)Europe as system is also a possible option, because the countries become closer and closer since the foundation of the European Union. The same problem occurs like taking the Netherlands as system, but (West-)Europe gives a good insight into the relativity of systemic risk. A flood in dike ring 14 has also an impact for the EU. Looking at the situation in New Orleans and Louisiana after the floods, caused by hurricane Katrina, the damage on the long term is very located. Especially New Orleans and the state of Louisiana have been confronted by the impact, while the United States just goes through. For the government and senate of the United States is Katrina a passed station MinBZK (2006a). The states of the USA are closer than the countries of Europe. Looking at the scale of dike ring 14 in Europe, the influence of dike ring 14 is small.If dike ring 14 has confronted by a flood, the Dutch society should recover it on her self. This is the reason to take dike ring 14 as study area.

Flooding as systemic risk
Beck labels chemical and nuclear disasters, as the main threats to human mankind. Renn and Klinke (2004) combine systemic risk to threats, like people's food chain, diseases, global warming and genetically modified organisms. Systemic risk approach can be used for threats, that deals with human interaction. OECD (2003) pronounce explicitly that *flooding* belongs to the area of systemic risk. Flooding was one of the research fields, besides nuclear accidents, infectious diseases, food safety and terrorism. As said in 1, flooding is a threat for human. If a flood occur, the affected society has to recover their development. The damage affects a whole human society or *system*.

> *The expected annual loss of life by flooding is ten times higher than in case of cumulation of all external risks* (in the Netherlands)*; see Figure B.5 (RIVM, 2004)*

Structural measurements for flood control cause a change in the water household. This change has influence on the risk situation of the area. An increase of safety by reducing the probability of occurrence leads to an increase of Becks *apparently safety* of the system. This apparently safety causes an vicious circle of developing the system Hoekstra (2005). In this case, a disaster brings more damage to the system, because the size of impact grows. Concluded, if the apparently safety increases, the systemic risk also increases. In this situation, society can only be affected by a big-scaled flood, which lead to a higher corresponding extent of damage.

Looking at the systemic risk clusters of WBGU (1998), flooding belongs to the clusters named *Cyclops* and *Damocles*. These clusters focus on *low probability - high effects*, only the probability of Cyclops is uncertain. The more a flood plain is controlled by structural measurements, the more the risk situation is going to risk cluster Damocles. The worst case scenario becomes more and more a leading role and belongs to Damocles.

C.2 Resilience of the system

This section represents my own interpretation of systemic risk. For me, the situation of New Orleans after Katrina represents the systemic risk of flooding. Years after the floods, the city of New Orleans is still not recovered. Can the city recover or are the effects to high to recover the 'Old New Orleans'? So, the (Ir)reversibility *and* recovery *of the city are important elements for systemic risk. Systemic risk has to do with the probability of a society to continue her existence after a disaster. My interpretation: the systemic flood risk of New Orleans was too large, see quote at the backpage.*

An important phrase for improving probabilities to continue society after a disastrous event, is ***resilience***. The strong relations of Figure C.1(c) shows that such societies have difficulties with the resilience to cope with an event. There is a shortage of space, time and energy for mitigating the impact of a disaster. *Directly damaged people tow other people in the system into the damage indirectly.* A disaster spreads through the system and causes damage to the systems functions. The size of damage and the resilience of the system determine the possibility of recovery of the system.

> *A system with strong relations and less resilience is comparable to a car with less crumple zone.*

The worst case is the most interesting situation for systemic risk management, because a system has to survive and recover from that case. (*The system has to overcome the hardest attack.*) So the potential damage of a system is important for the determination of the damage (Jonkman, 2001). Besides the hardest attack, the safety of the system is dependent on other attacks, which cause less damage. These kinds of risk combinations are more presented on the type of group risk.

After a situation with numerous negative and irreversible effects, the system is changed. It is just not possible to come to the old situation. After the recovery a *new equilibrium* will be reached. This does not mean that disasters only cause damage. On short term, the disaster causes mostly negative effects, which is damage in terms of casualties and economical damage, for example. Positive effects occur on the long term, like better houses and infrastructure, product substitutions and adjustment on the production and consumption markets for example (Bockarjova et al., 2007).

The term *recovery time* should be seen as *resilience time* towards a new equilibrium (Bockarjova et al., 2007). Renn and Klinke (2004) also considered recovery time as a part of the systemic risk. They speak of *persistency*, which contains the temporal extension of potential damages.

The ability of resilience will be improved, when the system can cope with *(human) errors in the system* (Renn and Klinke, 2004). Human being plays an important role in risk situations that can lead to systemic risk, section C.1.

The system is able to provide sufficient time for *counteractions* (Renn and Klinke, 2004). This implies that the possibility exists to make counteractions during the whole chain of safety, especially during and after the event. After all, these counteractions should result in reduction of damage.

A system can be interpret as *healthy* if it has *resilience to recover from the disaster*. The probability of system to survive a disaster becomes higher, which leads to a reduction of systemic risk. The improvement of a systems resilience roughly contains:

- Reduction of negative effects to different kinds of damage
- Less resilience time to overcome the event
- Forgiving (and bear in mind) human errors
- Sufficiency to overcome the hardest attack
- Create sufficient time for counteractions

C.3 Quantification of systemic risk

There is not a general definition of systemic risks, which can be put into measurements, like individual and group risk. This also means that there is not a quantification of systemic risks in one singular measurement.

> *... in light of divergent principles, values and interests and few (if any) universally applicable moral guidelines, any general definition of risk remains* ***elusive*** *...*
> *(Renn and Klinke, 2004)*

Because of lack of definition, some quotes are made during the research. It express a feeling of the main extent of systemic risks. Each of the quote can be answered, but describes systemic risk just partly:

"*After certain damage, society becomes instable.*" There is a certain amount of damage (a point), which leads to instability. What is that point and how can we measure it?

"*Systemic risk is the extent in which the system characteristics are perished (temporal or definitive)*" What is the threat that a society can not rebuild their culture? The characteristics of the society are the main issue in this approach.

"*The vitality of a society to recover from a disaster towards a new equilibrium*" This approach looks into the irreversibility of the damage and the attitude of a society to rebuild their land. The ability of a society to adapt to the changing situation is also taken into account.

Elements for systemic risk measurement
Till now, systemic risks are described by elements of systemic risk. Renn and Klinke (2004) have made a selection of several risk criteria was made and put into a list. This list gives an overview of the whole extent concerning systemic risk:

- Extent of damage
- Probability of occurrence
- Incertitude (*overall indicator for uncertainty*)
- Ubiquity (*geographical dispersion of potential damage*)
- Persistency (*temporal effects of potential damage*)
- Reversibility (*possibility of restoring the damage*)
- Delay effects (*latency between the event and the damage*)
- Violation of equity (*difference between the prejudiced and the harmed*)
- Potential of mobilization (*social conflicts due to people who feel afflicted by the consequences*)

In the main text, four systemic risk indicators have been determined to quantify in this study. During this study, more indicators have been studied, but no conclusions have been made.

Effects to important links
Important links is a phrase for places or buildings which are more important for the system than the link on its own. Important link are elements, which are necessary for the well-functioning of a system. The destruction of an important link will affect the whole system, because the system can not functioning anymore. The risk of destruction is part of the systemic risk, because it contains a higher risk than a normal link (places). So, systemic risk becomes higher due to important links.

The system is depending on system functions, which makes the area habitable and economic useable. The destruction of important links makes the area inhabitable and economy dysfunctional. There are lot kinds of places which can be considered as important link, like:

- Infrastructure for transportation (rail roads, high ways, airports or harbors)
- Infrastructure for internet (Internet Exchange (Amsterdam))
- Water supply
- Electricity supply
- Organization of society (Political institutions, Administration of justice and police)
- Junction for economy (Stock Exchange, companies)

- *'Weak objects'* (Buildings with large numbers of people or building with vulnerable people, like elderly, sick, children and prisoners.)

Irreversible effects
Important links are resilient after a period, *irreversible links* is not resilient. The damage have such a destructive effect that the places or buildings can not rebuild to its original state. Irreversible damage has to do with places that are more worthy than others, because of its history, scarce or importance for the society. Destruction of irreversible links have more impact on the society than other kind of buildings and will lead to social unrest and demolition of the identity of the researched area, like cultural - historic places or natural places.

Cultural-historic places are irreversible links, because it is hard to rebuild. The effects of flooding on monuments are more dramatic than other buildings, because of old construction material. The walls and (wooden) constructions match badly with saturation of water, saline water and the effects of wave movement. A general assumption can be made that the monumental value is lost if recovery is necessary (Nieuwenhuizen et al., 2003).

The places are certain important buildings, unique sights or areas with archaeological meaning (Projectbureau-Belvedère, 2003). Dike ring 14 has a lot of unique cultural-historic places, because it is an important historic area for the Netherlands. The former province Holland was the center at the time of the Dutch Golden Century and the foundation of the Netherlands as country.

The Dutch State Monument List (*Rijksmonumentenlijst*) is a list with all the monuments that are considered as important for the Dutch society. The monuments on this list are older than fifty years and are of common interest, because of their beauty, cultural-historic value or importance of science. Archaeological areas with monuments can also be part of this list. The monuments have a protected state, which is determined in the Monument Law (*Monumentenwet*) of 1988.

It is hard to examine all the monumental places, because of the amount of places on the list. A good separation is to look at the density of monuments in an area (so called *monument cities*) and the archaeological value of the *limes*; Appendix A. There are about 50 cities in The Netherlands with more than 200 state monuments, monument cities. Dike ring 14 has ten of such places (Projectbureau-Belvedère, 2003).

- Haarlem
- Amsterdam
- Leiden
- The Hague / Voorburg
- Delft
- Gouda
- Maassluis

- Schiedam / Rotterdam

Irreversible natural effects can be occur if important natural resources are flooded by saline sea water or polluted river water. The Green Heart is the most important natural resource in Dike ring 14. It is a closed area in the eastern part of the dike ring, see Figure A.12.

C.4 The management of systemic risk

In this part, the research of WBGU (1998); Renn and Klinke (2004) will be shortly handled. I have used these researches for getting better insight into the matter of (systemic) risk and the risk management to control and reduce the systemic risk.

For getting a better insight into the whole safety of a dike ring, an *Effect-Probability graph* is very useful, because all the possible scenarios are taken into account. Besides the most probable scenarios, also the worst case scenario is presented in the E - P graph. It shows also the relation between the probability of occurrence and extent of damage better and at least the societal impact of a disaster is shown (RIVM, 2004). The researches of WBGU (1998); Renn and Klinke (2004) gives insight into the different relation of effects and probabilities in the risk measurement. Some risk cluster have been made, to represent a risk situation with more or less the same characteristics, looking at the combination of probability of occurrence and extent of effects. This resulted into a E - P graph with risk clusters; Figure C.4.

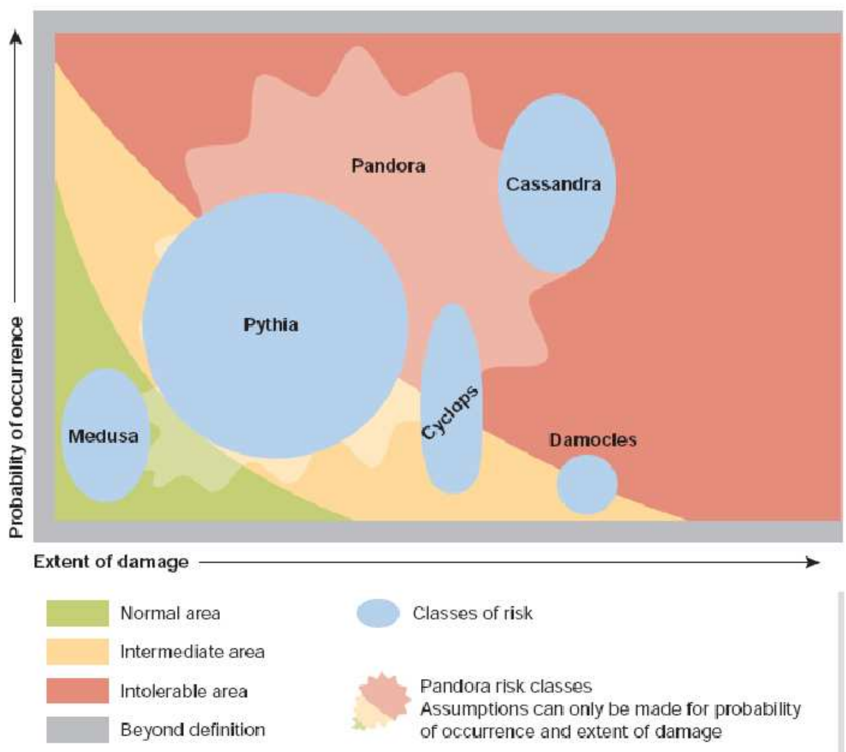


Figure C.2: Risk clusters defined by WBGU (1998)

Based on the risk clusters, some management strategies have been determined by WBGU (1998). The risk reduction management is based on the relation of probability of occurrence at the one hand and the extent of damage at the other hand; Figure C.4. In Table C.1, the whole risk management based on systemic risk, is showed. Based on an E - P graph, MinV&W (2006a) also gives insight into risk management actions for reducing (group) risk; see Figure 2.1. In case of high probability - low damage, the probability of occurrence should be reduced and in case of low probability - high damage, the damage should be reduced.

As mentioned, systemic risk for flooding is based on the Damocles risk cluster. The main problem of this cluster is the high disaster potential. Strategies and tools for the Damocles risk class are given in Table C.2 (WBGU, 1998). The studies of WBGU (1998); Renn and Klinke (2004) give insight into the useful management strategies which can be taken for reduction of the systemic risk for flooding.

Table C.1: Overview of the risk management strategies, combined with the risk clusters of Figure C.4 (Renn and Klinke, 2004)

Management	Risk class	Extent of damage	Probability of occurrence	Strategies for action
Science - based	*Damocles*	high	low	• Reducing disaster potential
	Cyclops	high	uncertain	• Ascertaining probability
				• Increasing resilience
				• Preventing surprises
				• Emergency management
Precautionary	*Pythia*	uncertain	uncertain	• Implementing precautionary principle
	Pandora	uncertain	uncertain	• Developing substitutes
				• Improving knowledge
				• Reduction and containment
				• Emergency management
Discursive	*Cassandra*	high	high	• Consciousness-building
	Medusa	low	low	• Confidence-building
				• Public participation
				• Risk communication
				• Contingency management

Table C.2: Strategies and tools for the Damocles risk cluster. The main problem of this cluster is the high disaster potential. (WBGU, 1998)

Strategies	Tools
1. Reducing disaster potentials	• Research aimed at developing substitutes and **reducing the disaster potential**
	• **Technological measures for reducing the disaster potential**
	• Stringent liability regimes
	• International safety standards authority
	• Subsidization of alternatives that have equal utility
	• **Containment (minimizing the spread of damage)**
	• International coordination (e.g. to mitigate meteorite hazards)
2. Strengthening resilience	• Human-resource and institutional capacity building (licensing produces, monitoring, training etc.)
	• International liability commitments
	• Expansion of technological procedures by which to improve resilience (redundancy, diversity etc.)
	• Blueprint for resilient organizations
	• Model role: Licensing procedures
	• International controls (IAEA)
3. Emergency management	• Human-resource and institutional capacity building (emergency prevention, preparedness and response)
	• Education, training, empowerment
	• Technological protective measures, including containment strategies
	• International emergency groups (e.g. fire services, radiation protection etc.)

Appendix D

Model input

SOBEK calculates the breach scenario by using the method of Vermeil-Vedanta(2002) (WL | Delft Hydraulics, 2004). Two different kinds of breaching scenarios are used: river (clay) and sea (sand). The parameters are put into Table 4.1.

Table D.1: Parameters for breaching scenarios of dunes (at the sea) or dikes (at the river)

Parameter	**River (clay)**	**Sea (dune)**	**Source**
Factor 1 (alpha)	1.3 [-]	0.5 [-]	(MinV&W, 2006a)
Factor 2 (Beta)	0.04 [-]	0.04 [-]	(MinV&W, 2006a)
Initial breach width (B_0)	30 m	50 m	own interpretation
Initial crest level	height at location	height at location	see SOBEK
Lowest crest level (Z_{min})	-1 m	-3 m	own interpretation
Critical flow velocity (U_c)	0,5 m/s	0,1 m/s	MinV&W (2006a)
Discharge coefficient (C_e)	1 [-]	1 [-]	MinV&W (2006a)

In Figure D.1 and Table D.2, the connection of the breach scenarios and the corresponding hydraulic boundary conditions is showed. The breach scenarios of Kralingen and Haarlem start at the time that the water level overtops the dike height. The start time of Ter Heijde Katwijk and Scheveningen is determined by VNK (MinV&W, 2006d).

Table D.2: The determination of the breaching scenarios for every breach location.

Breaching location	**Breaching type**	**Dike type**	**Start breaching**	**Corresponding water height**	**Breaching time**
Kralingen	River	Clay	4:30 h	1.95 m	10 min
Ter Heijde	Sea	Dune	7:30 h	5.67 m	30 min
Scheveningen	Sea	Dune	4:50 h	4.65 m	30 min
Katwijk	Sea	Dune	4:30 h	4,43 m	30 min
Haarlem	Sea and river	Clay	8:00 h	2.8 m	10 min

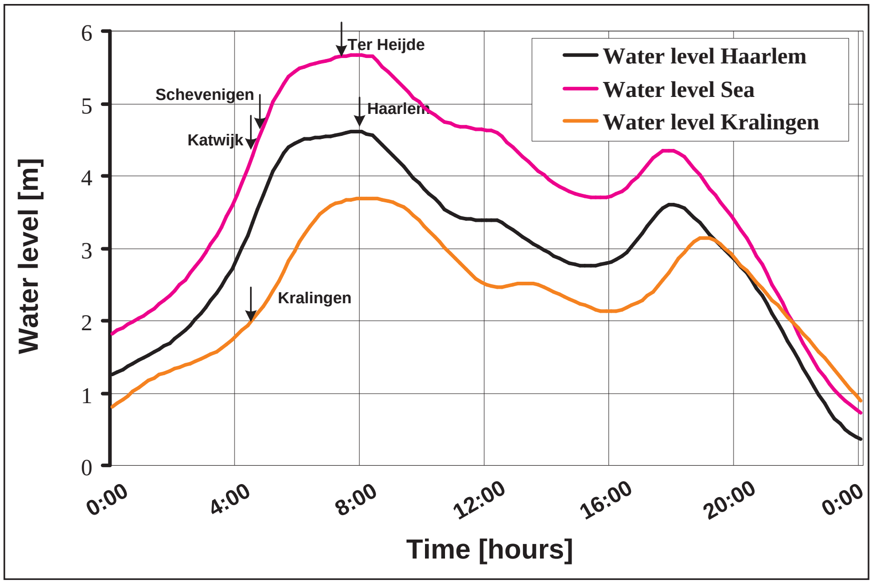


Figure D.1: The water level at the start of dike breach scenario

Appendix E

Theoretic model for compartmentalization strategies

E.1 Basic assumptions of the theoretic model

The model is explained in chapter 5. For this examination some assumptions have been made in the model:

- The area is described by a grid of $12 \times 12\,\mathrm{km}^2$, protected by a primary of 48 km. The area is parted into 48 dike sections of 1 km; Figure E.1.
- There are no height differences in the grid, so there are no different inundation depths.
- Each grid contains a certain value that can be flooded or not.
- During the flood, the value of the grid is lost.
- In this study, the water level is supposed to be equal at all sides of the dike ring. A breach of a dike section can be caused by two kinds of failure mechanisms: 1) *external* (failure by water level) or 2) *internal* (dike failure). The external failure mechanism is overtopping, which leads to incoming water at all sides of the area. The internal failure mechanisms have to do with the strength of the dike. The water flows into the dike ring though one dike breach location. In reality, the internal and external failure mechanism are taken together, like VNK (MinV&W, 2005a).
- The flood probability is determined for the whole dike ring.
  - If the external failure mechanism is leading, the probability of flooding of each dike section is *completely dependent* on each other. There are no distinctions between the dike sections. All dike sections will be overtopped and water flows into the dike rings at all sides.
  - If an internal dike failure causes the flood, the probability of flooding becomes *completely independent*. The water flows into the dike ring though one dike breach location.

The compartmentalization strategies can be compared better, because flooding can be caused at one breach location or by overtopping the whole dike ring area (considered as worst case).

- In case of partition strategy, the difference of external and internal failure mechanisms cause a band of risk situations. The partition strategy, parts the primary dikes, which cause a change in the flood probability of the whole dike ring.
- The risk measurement is scaled on the y axe of the model. The risks of the zero situation is the same for every case.
- The flood probabilities can be varied in the model. This goes for both primary and compartmentalization dikes. The flood probability of the whole dike ring is considered to be as 1/1000 year^{-1}. The assumption has been made that the compartmentalization dikes have no failure probability.
- In the model, each dike section has a flood probability parted by length of primary dike surrounding the compartment. The probabilities of the compartmentalization dikes have been parted by the lengths of the compartmentalization dikes. The summation of these parts brings the total flood probability of the dikes.

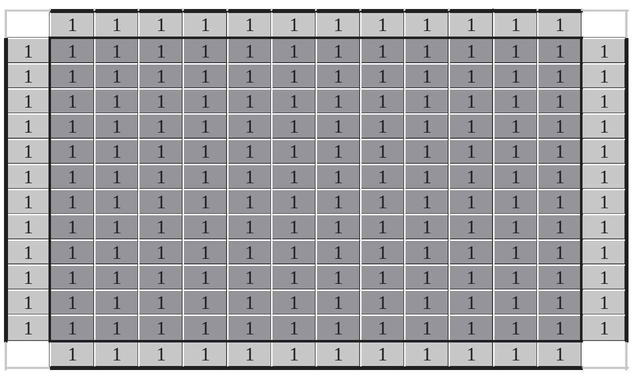


Figure E.1: The study area in the theoretic model. The dark areas have a value of 1. The light areas are primary dikes of 1 km. This represents the completely homogenous value distribution (case 1)

E.2 Implementation of strategies

Every step one dike is implemented for the **partition** strategy; Figure E.2. These compartmentalization dikes divide the area into equal surfaces and the length of each compartmentalization dike is 12 km. In the partition strategy, the probability of flooding changes, because the lengths of the primary dikes bordering the compartment change. In Table E.1 can be seen that after step 2, secondary dike rings are formed. These areas won't be flooded in case of overtopping the dikes at all sides.

The starting point of **secondary dike** is a central secondary dike ring of 16 km^2 with compartmentalization dike length of 16 km. The area between the compartmentalization dikes is growing in every step; Figure E.3. The steps leads to a relation of area between the primary

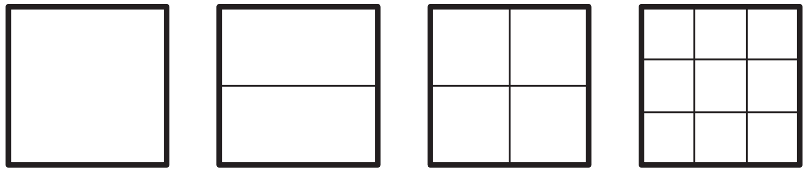


Figure E.2: The first three model steps of risk reduction of partition strategy by different lengths of the compartmentalization dikes.

Table E.1: Parameters in model for partition strategy

Step	Surface per compartment [km]	Total surface of compartments without primary dikes [km^2]	Compartmentalization dike length [km]
0	144	0	0
1	72	0	12
2	36	0	24
3	16	16	48
4	9	64	96

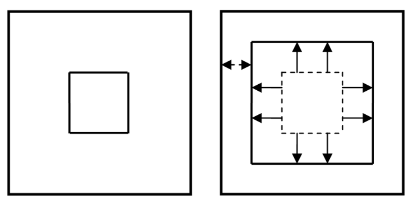


Figure E.3: The growth of the secondary dike ring surface in the model. The risk reduction of partition strategy can be measured for the different lengths of the compartmentalization dikes.

Step	Flooded surface [km^2]	Non flooded surface [km^2]	Compartmentalization dike length [km]
0	9	0	0
1	8	1	16
2	5	4	32
4	2.75	6.25	40
8	1.44	7.56	44
16	0.73	8.27	46
Infinity	0	9	48

Table E.2: The distribution of the flooded and non-flooded area for secondary dike strategy. The numbers have been based on a grid of nine compartments and have to be multiplied by 16 km^2 to get the surface of the study area.

dike and compartmentalization dike and the secondary dike ring. The relation of the flooded and non-flooded surfaces have been determined in Table E.2.
The **value protection** strategy is schematized a growth of protected area in steps of one secondary dike ring around the determined valuable area; Figure E.4. One secondary dike ring

protects a surface of 7 grids, that contains 5 % of the total area. The compartmentalization dikes forming a secondary dike ring have a length of 12 km.

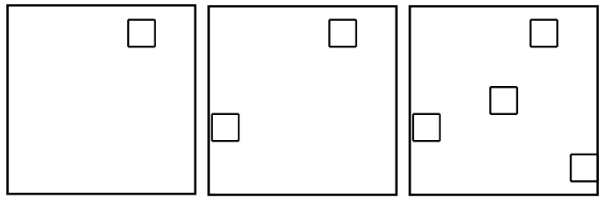


Figure E.4: Some model steps of the value protection strategy. Every step gives one dike ring around an valuable area extra.

E.3 Quantification of value distribution

"*The **Lorenz-curve** is used in economics and ecology to describe inequality in wealth or size. The Lorenz curve is a function of the cumulative proportion of ordered individuals mapped onto the corresponding cumulative proportion of their size. If all individuals are the same size, the Lorenz curve is a straight diagonal line, called the line of equality. If there is any inequality in size, then the Lorenz curve falls below the line of equality. **The Gini coefficient** (or Gini ratio) $\mathcal{G}$ is a summary statistic of the Lorenz curve and a measure of inequality in a population. The Gini coefficient ranges from a minimum value of zero, when all individuals are equal, to a theoretical maximum of one in an infinite population in which every individual except one has a size of zero.*" (mathworld.wolfram.com/GiniCoefficient.html)

In Figure E.5, the Lorenz curves of all considered scenarios are given. The Lorenz curve of case 1 is on the line of total equality. Of all cases in this study, Case 4 is mostly comparable line of total inequality. The Gini coefficients and the total value of each case is given in Table E.3.

Case	**Total value**	**Gini coefficient**
1	144	0
2	637	0.40
3	405	0.51
4	487	0.67

Table E.3: Total value and Gini coefficient for the different cases

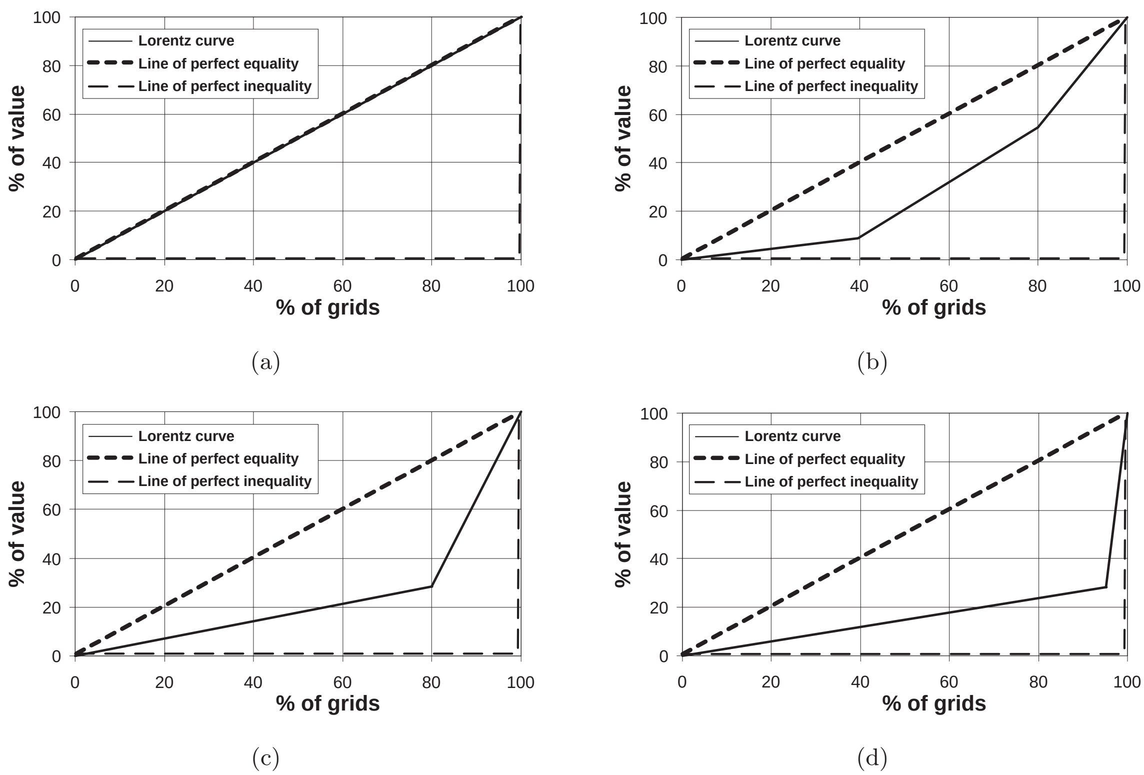


Figure E.5: Lorenz curves of Case 1 (a), Case 2 (b) Case 3 (c) and Case 4 (d)

Appendix F

Inundation depths per scenario per strategy

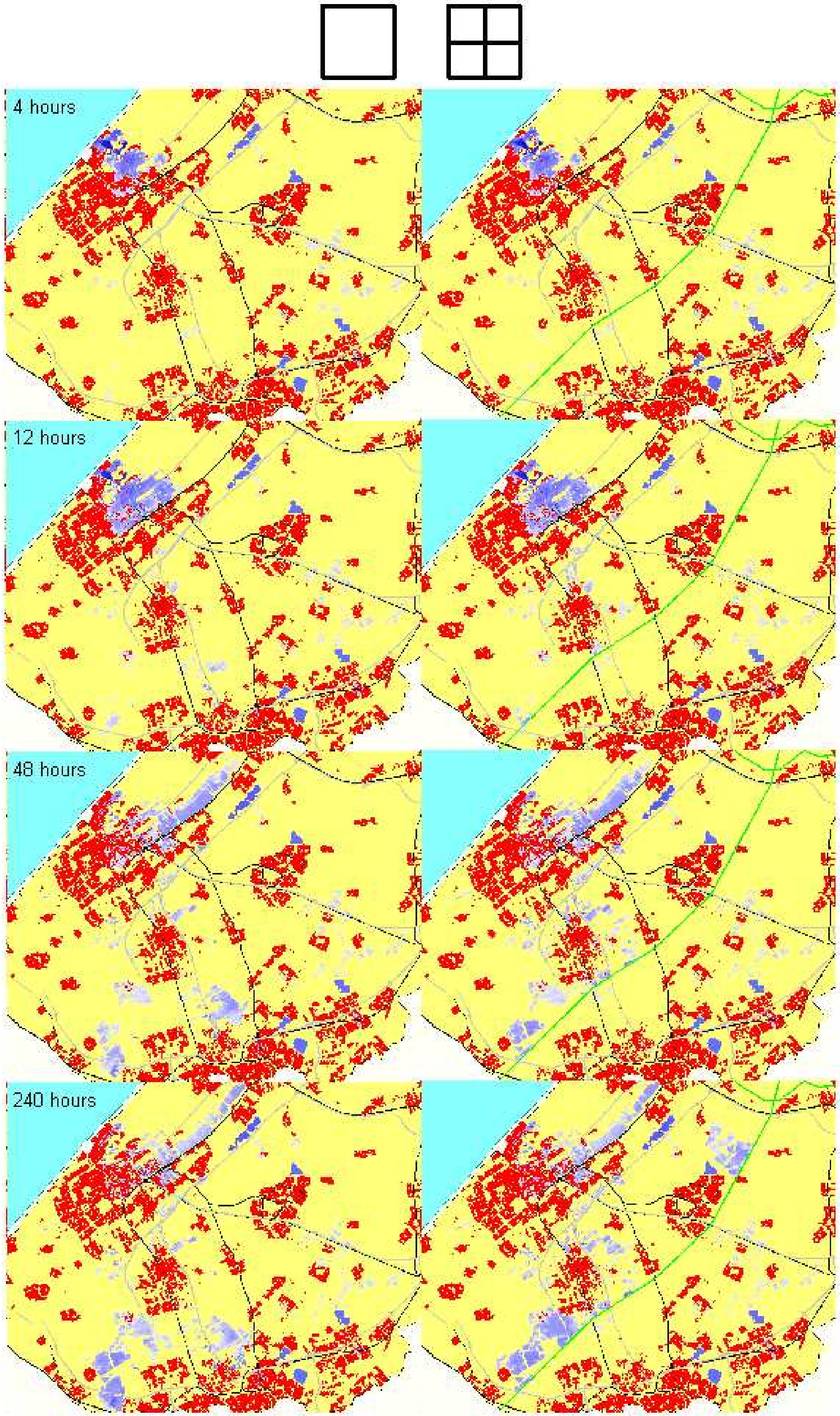


Figure F.1: Flood scenarios Scheveningen for zero situation (left) and partition strategy (right)

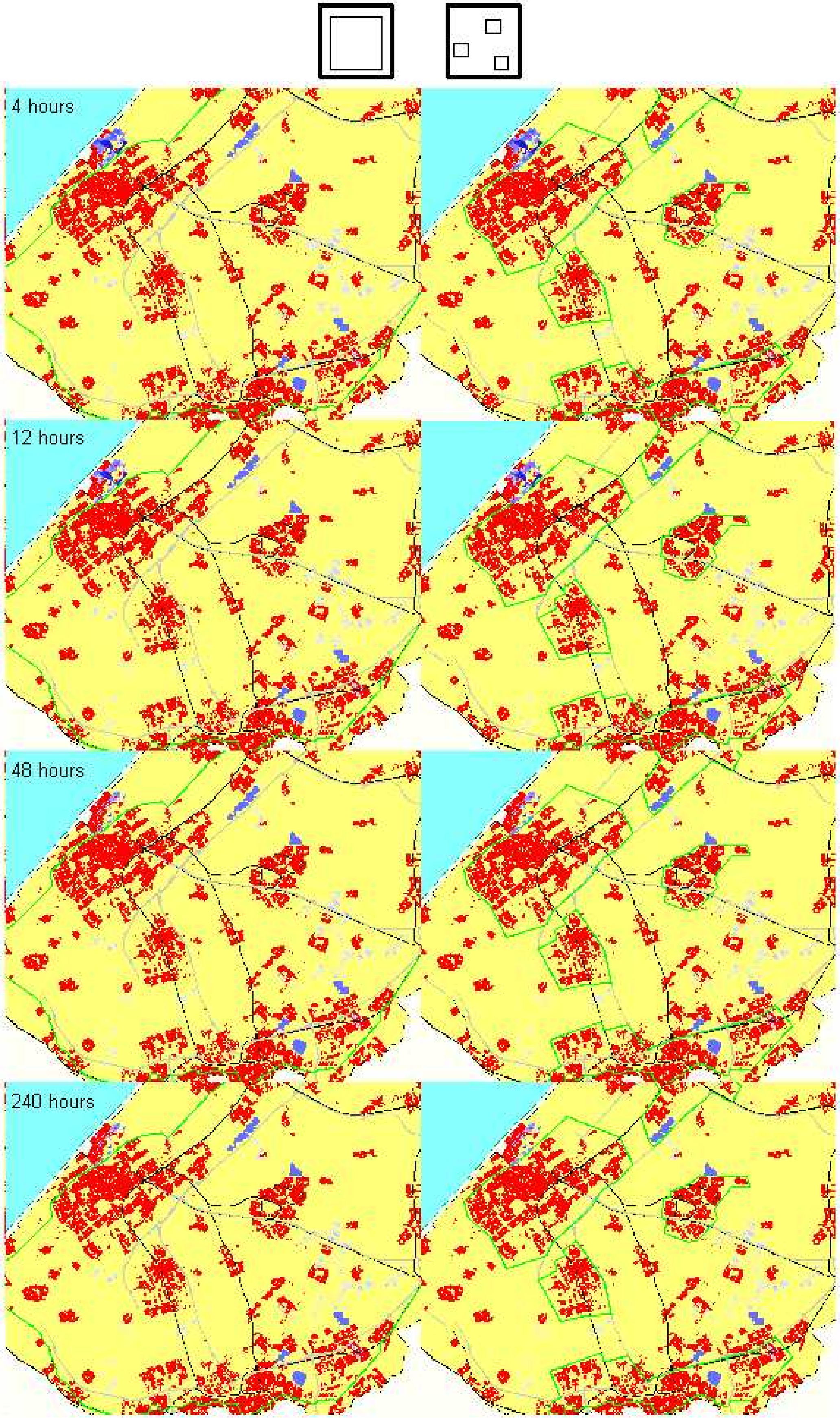


Figure F.2: Flood scenarios Scheveningen for secondary dike strategy (left) and value protection strategy (right)

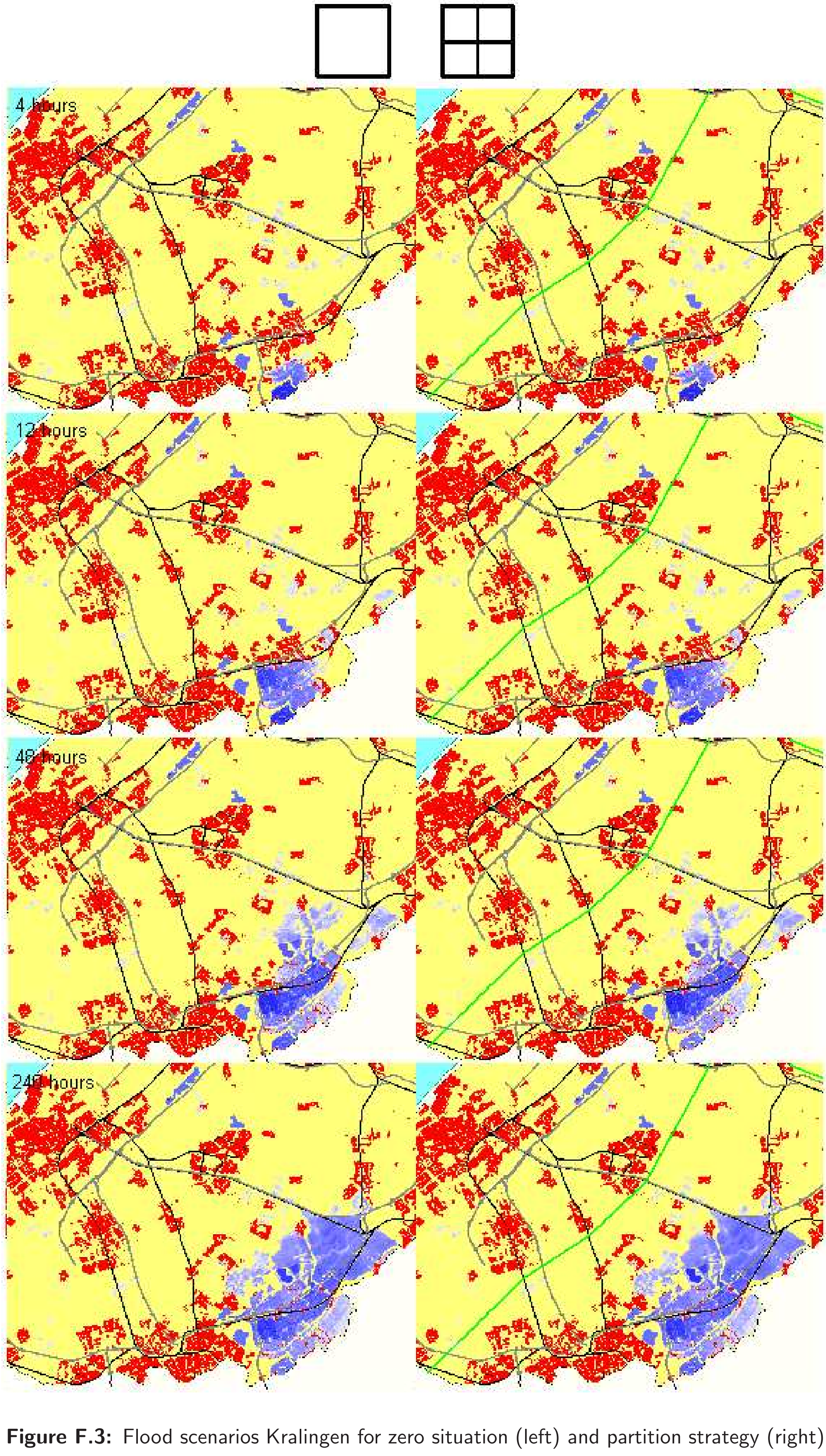


Figure F.3: Flood scenarios Kralingen for zero situation (left) and partition strategy (right)

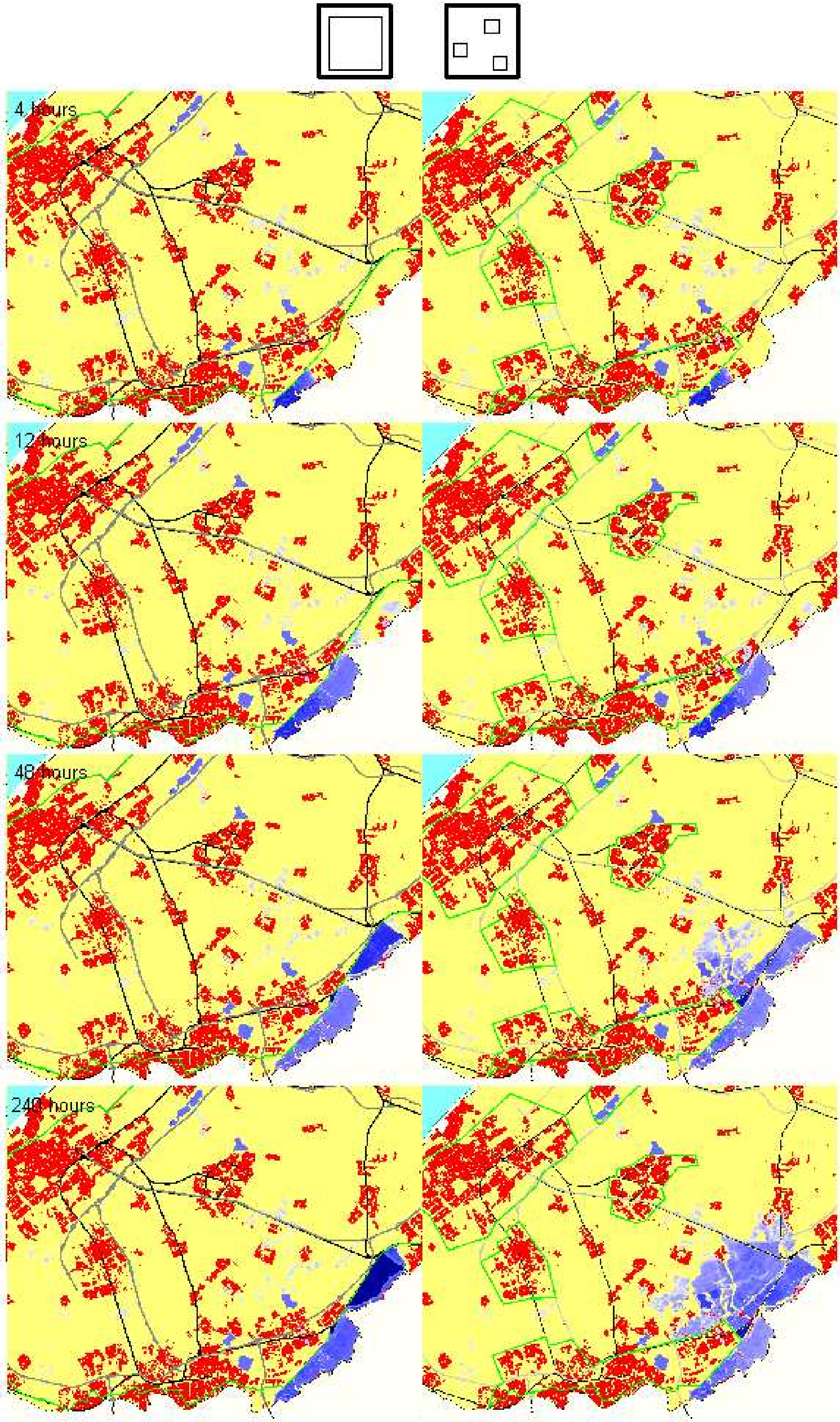


Figure F.4: Flood scenarios Kralingen for secondary dike strategy (left) and value protection strategy (right)

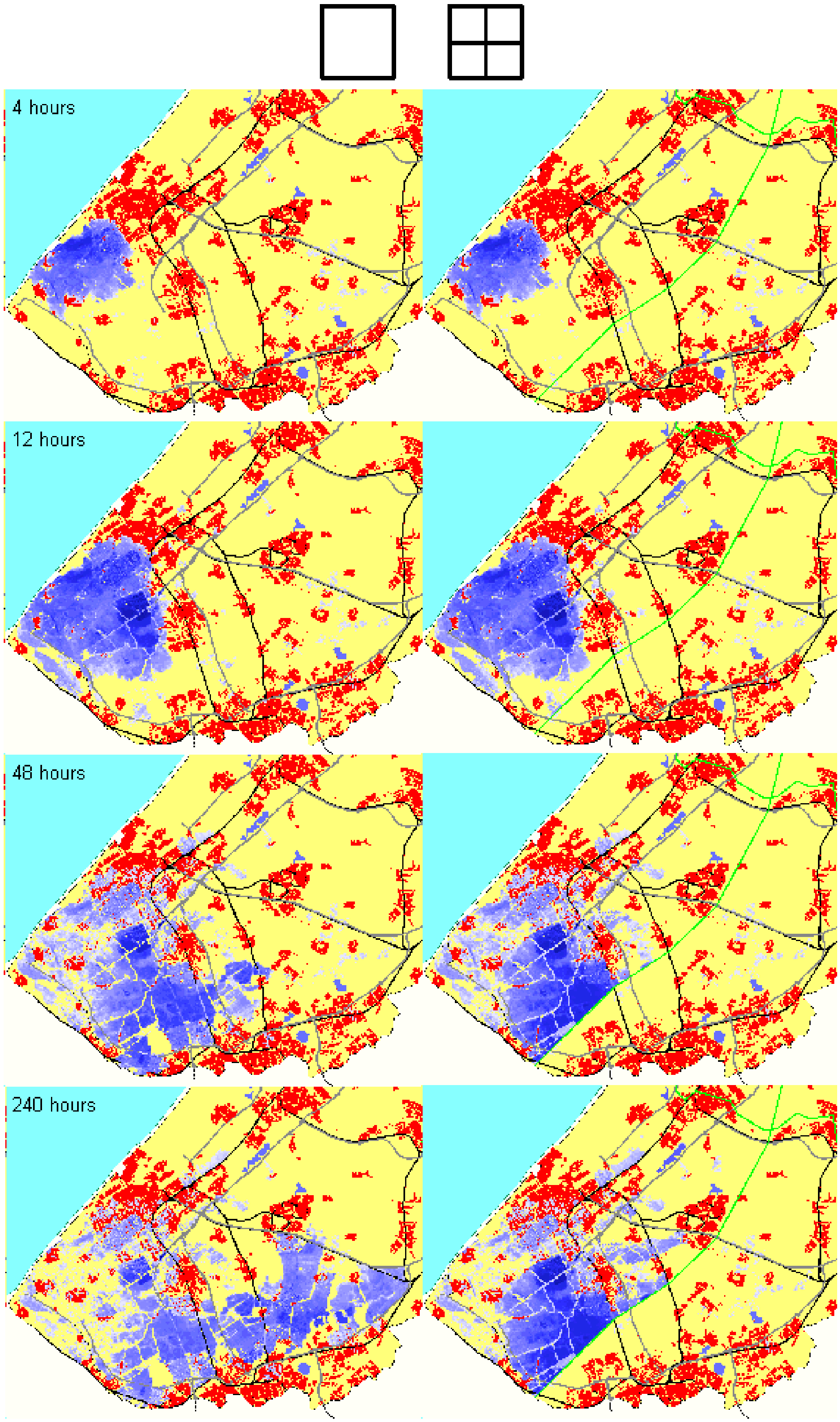


Figure F.5: Flood scenarios Ter Heijde for zero situation (left) and partition strategy (right)

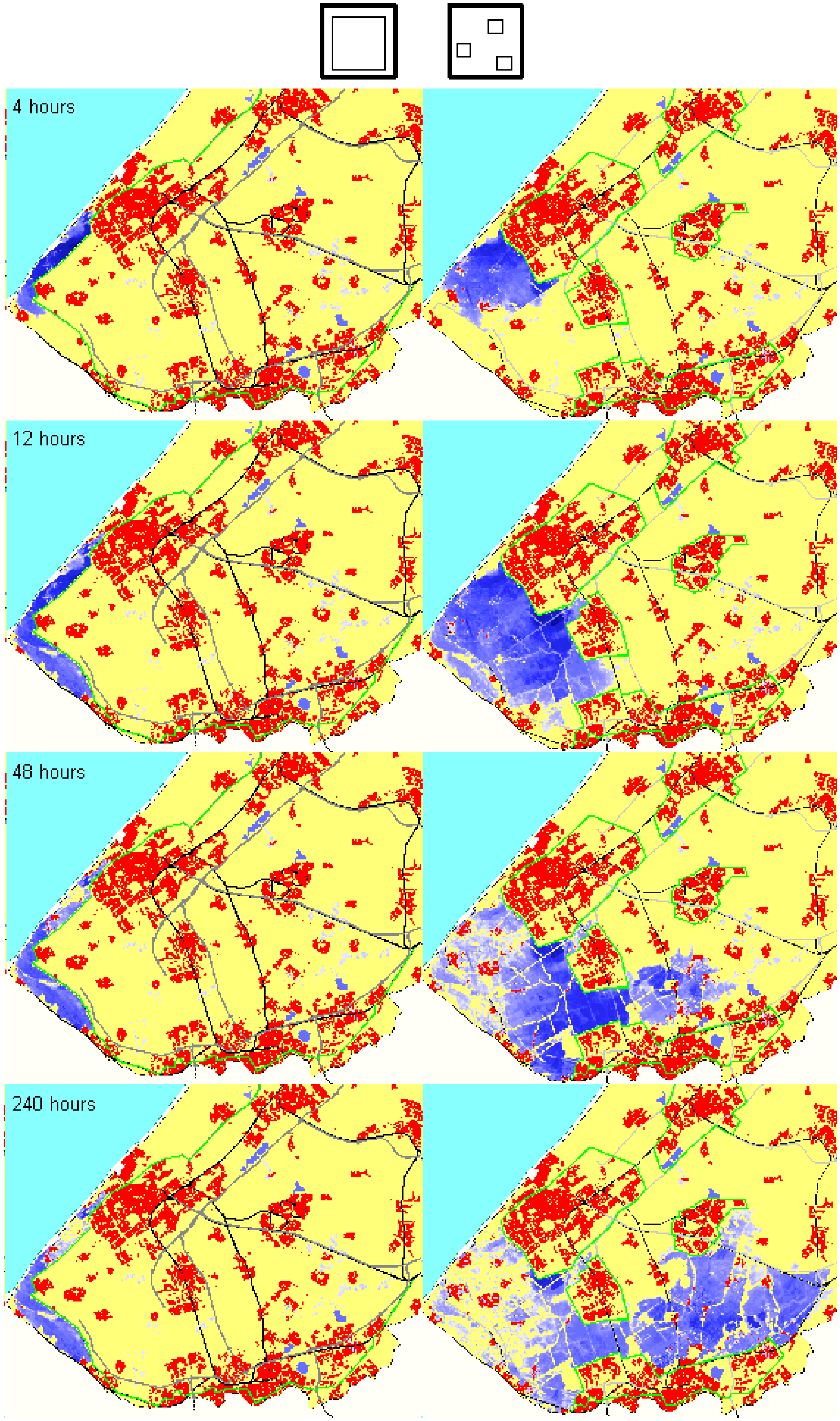


Figure F.6: Flood scenarios Ter Heijde for secondary dike strategy (left) and value protection strategy (right)

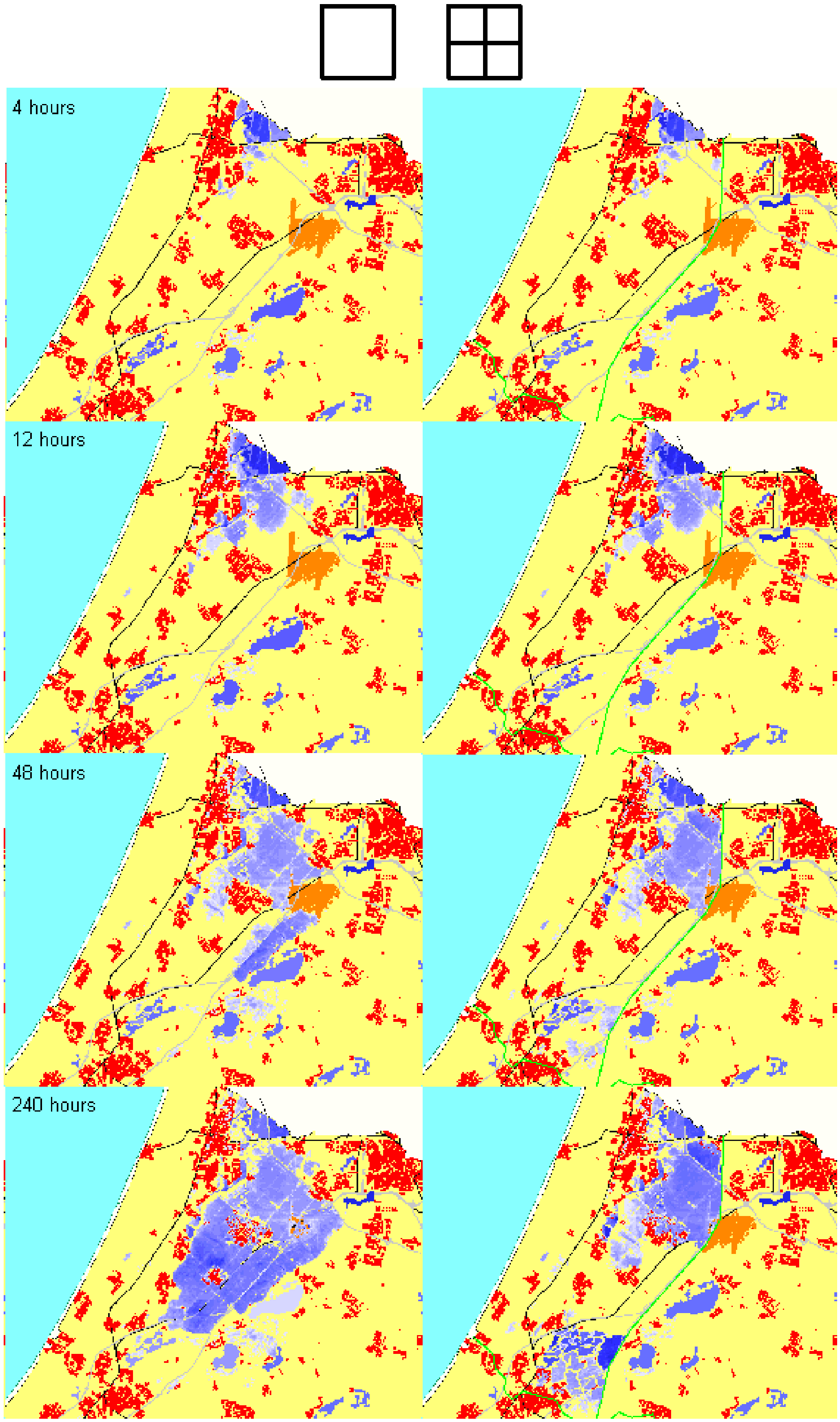


Figure F.7: Flood scenarios Haarlem for zero situation (left) and partition strategy (right)

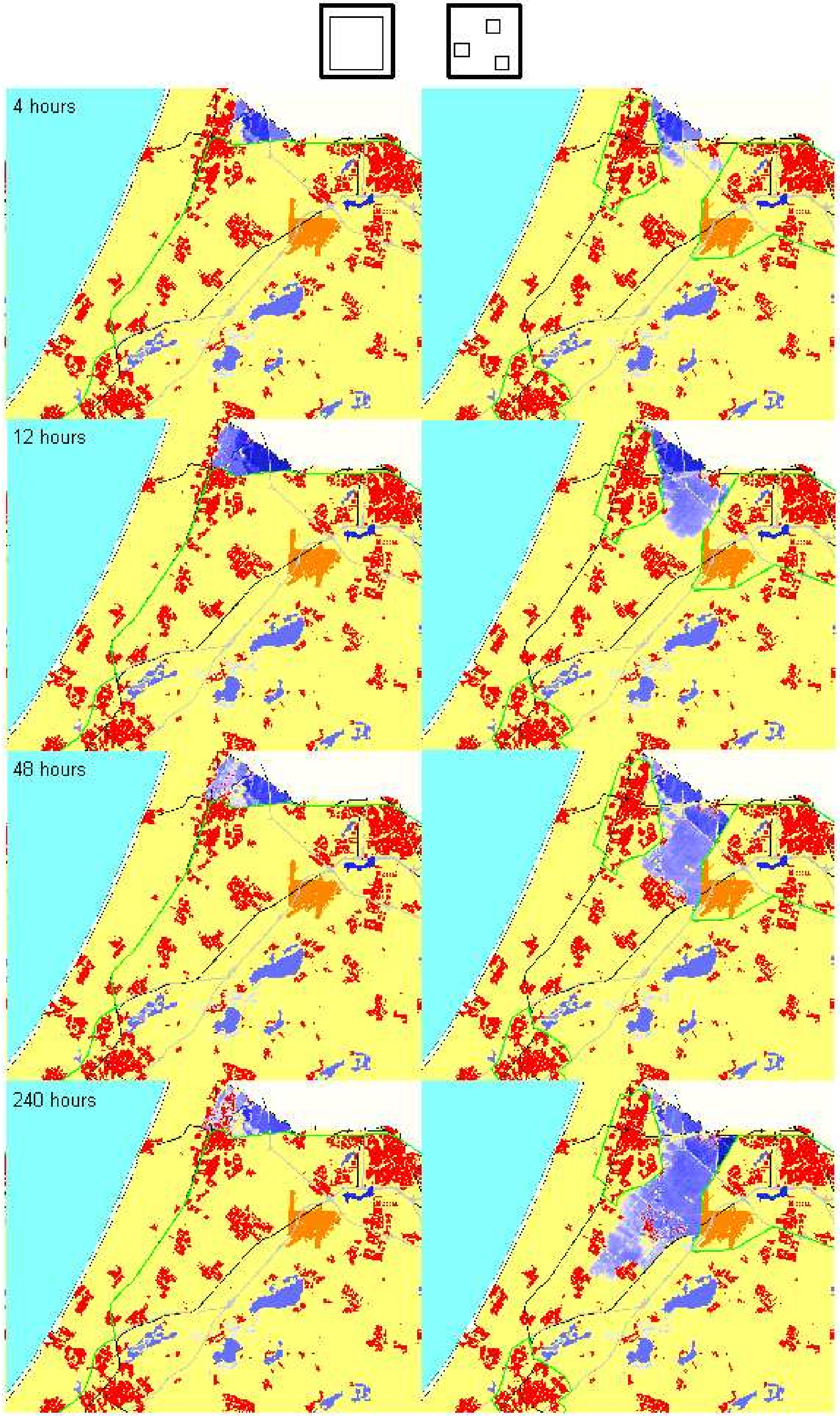


Figure F.8: Flood scenarios Haarlem for secondary dike strategy (left) and value protection strategy (right)

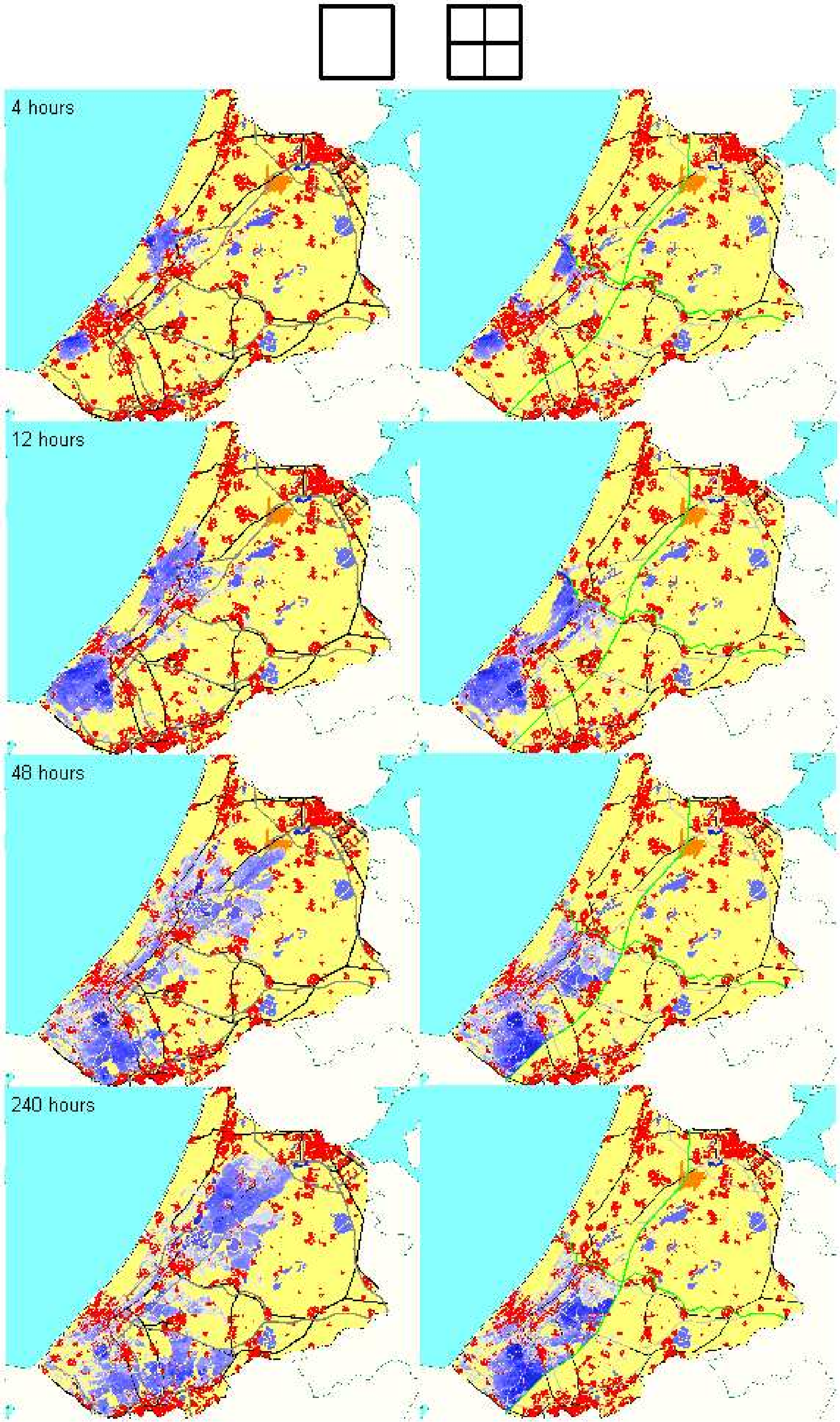


Figure F.9: Flood scenarios Ter Heijde, Scheveningen and Katwijk for zero situation (left) and partition strategy (right)

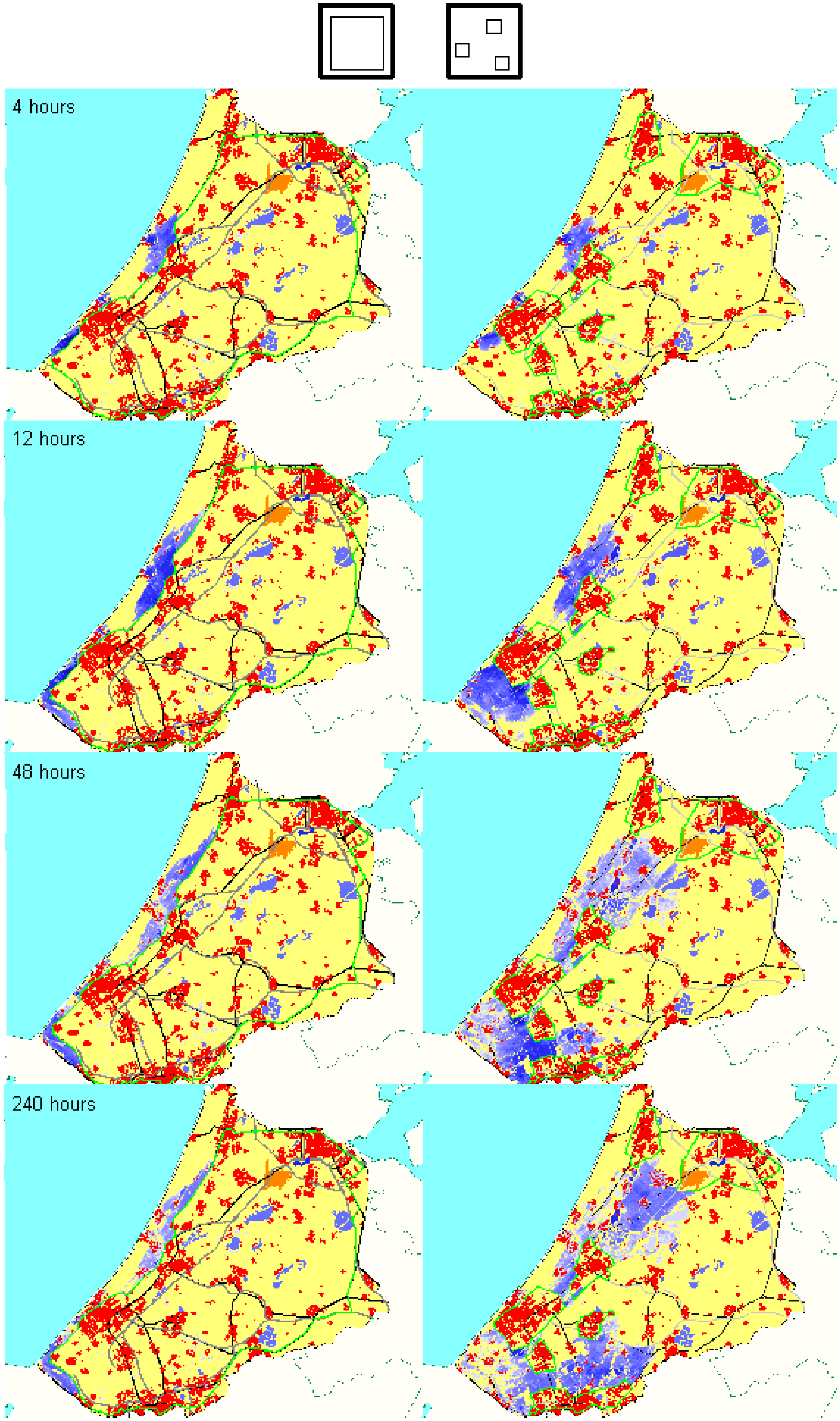


Figure F.10: Flood scenarios Ter Heijde, Scheveningen and Katwijk for secondary dike strategy (left) and value protection strategy (right)

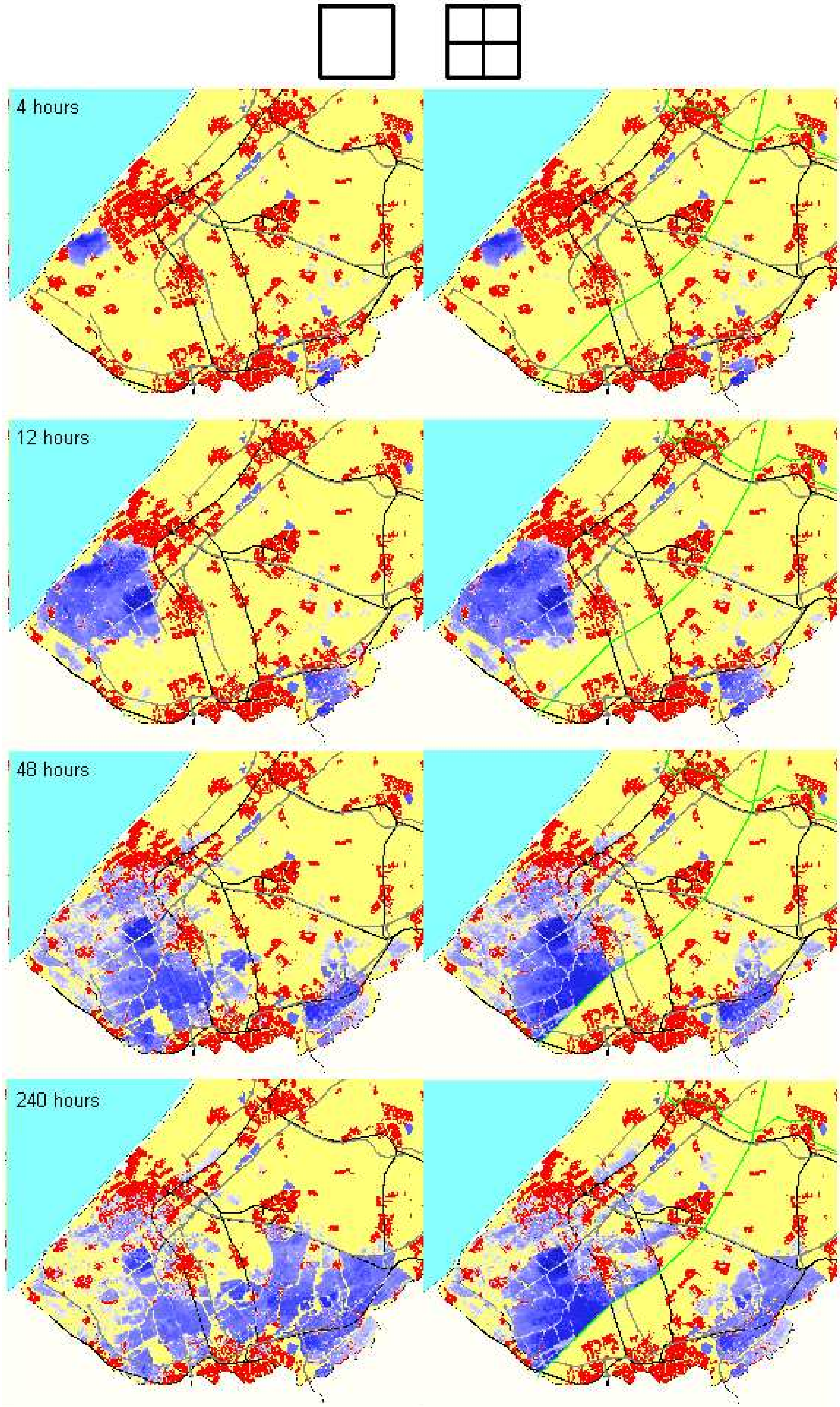


Figure F.11: Scenario of Kralingen and Ter Heijde for zero situation (left) and partition strategy (right)

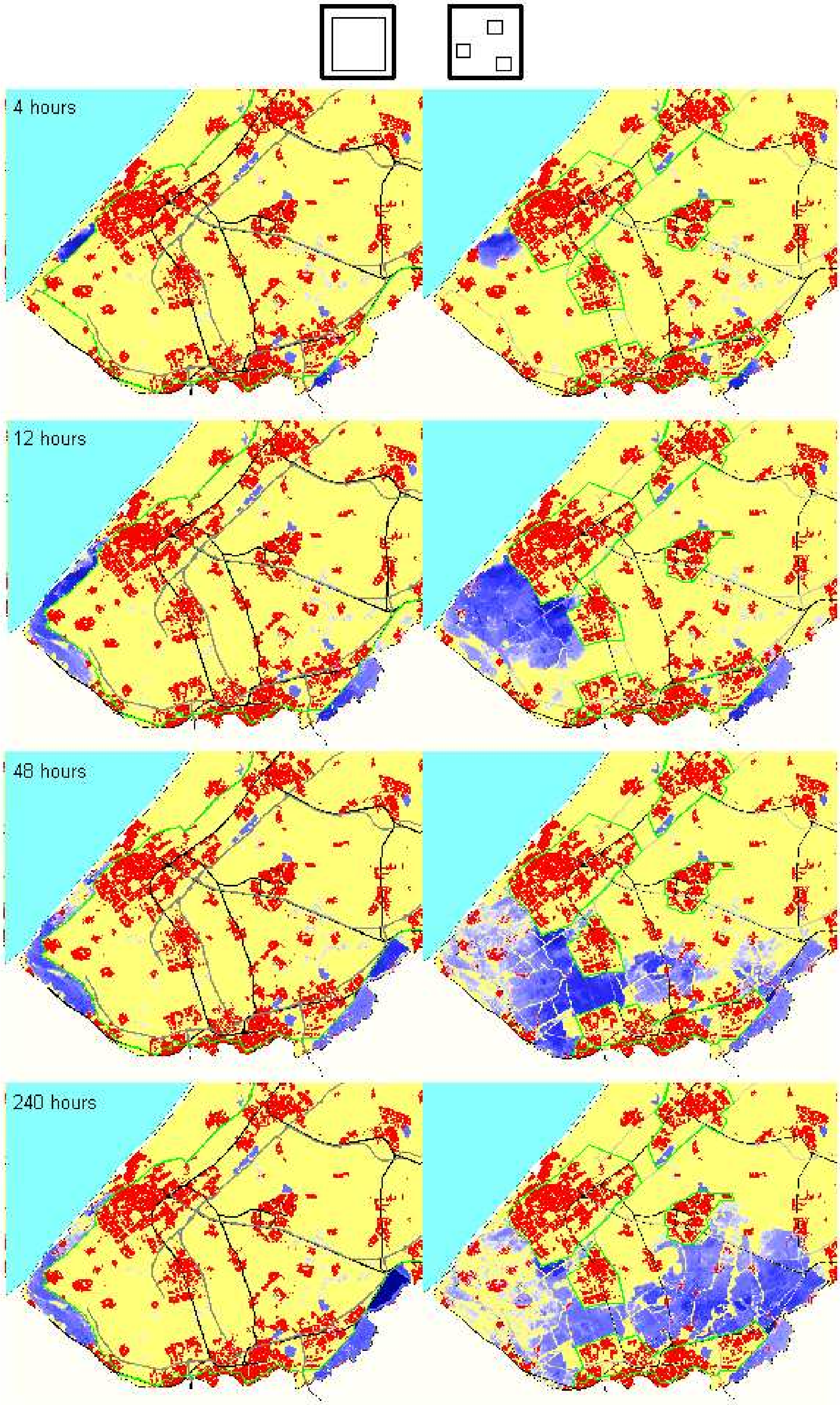


Figure F.12: Scenario of Kralingen and Ter Heijde for secondary dike strategy (left) and value protection strategy (right)

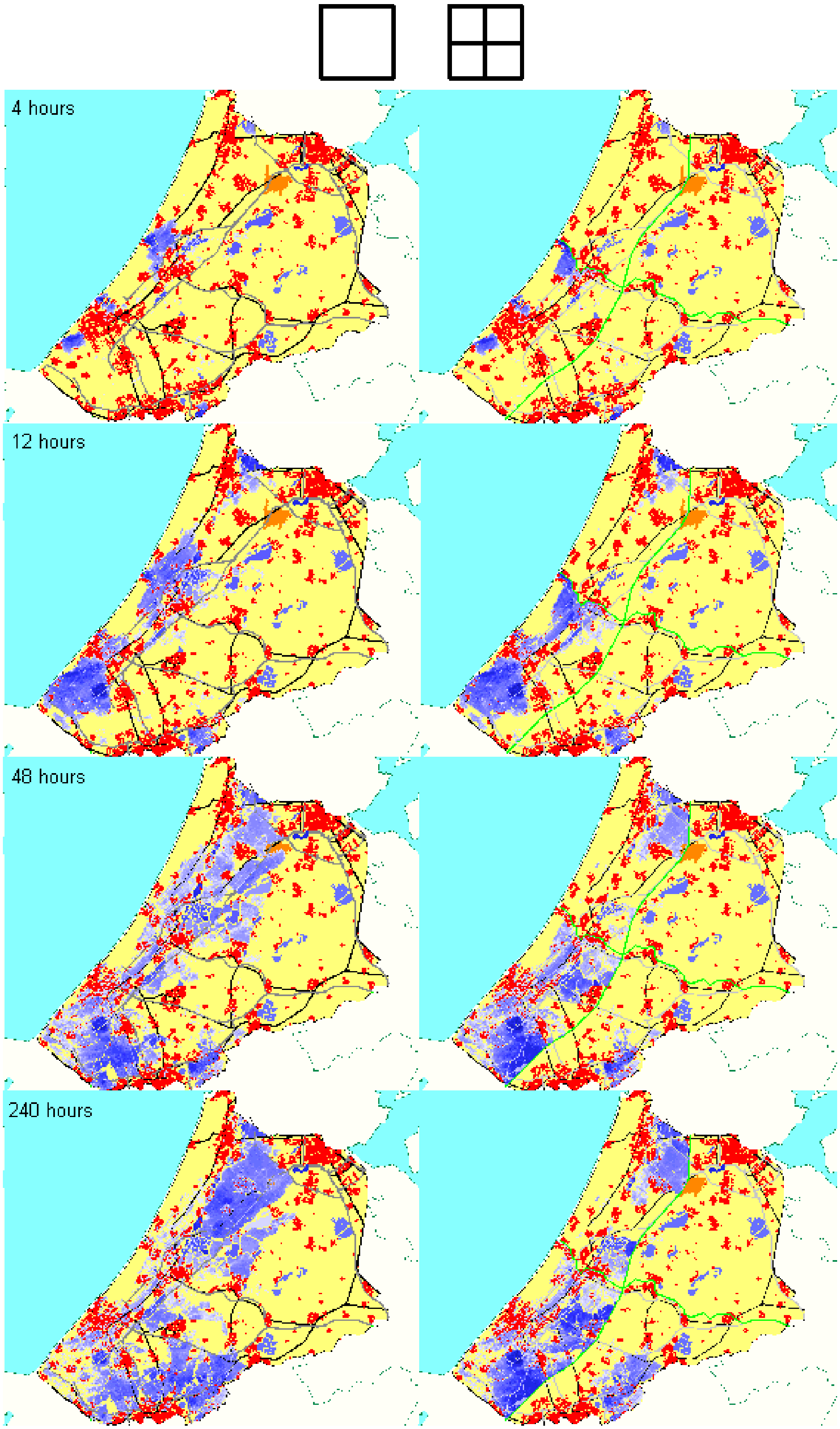


Figure F.13: Worst case scenario for zero situation (left) and partition strategy (right)

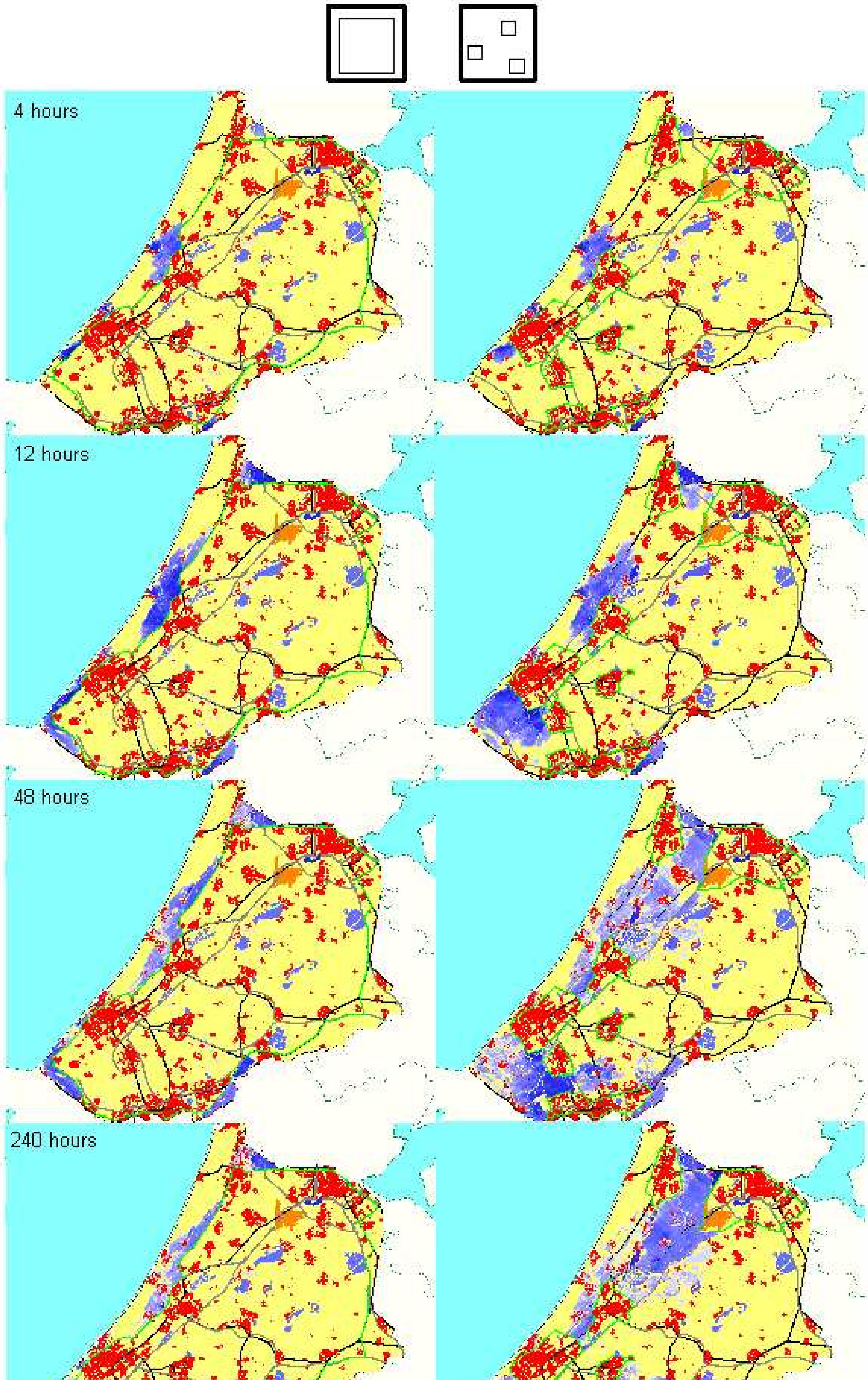


Figure F.14: Worst case scenario for secondary dike strategy (left) and value protection strategy (right)

Appendix G

Extra outcomes

In this Appendix, the outcomes of HIS - SSM about the business interruption and the indirect damage are shown. These risk curves are not given in the main text, because the values are significantly lower than the direct economic damage due to material losses. These risk curves also show the roughly same patterns.

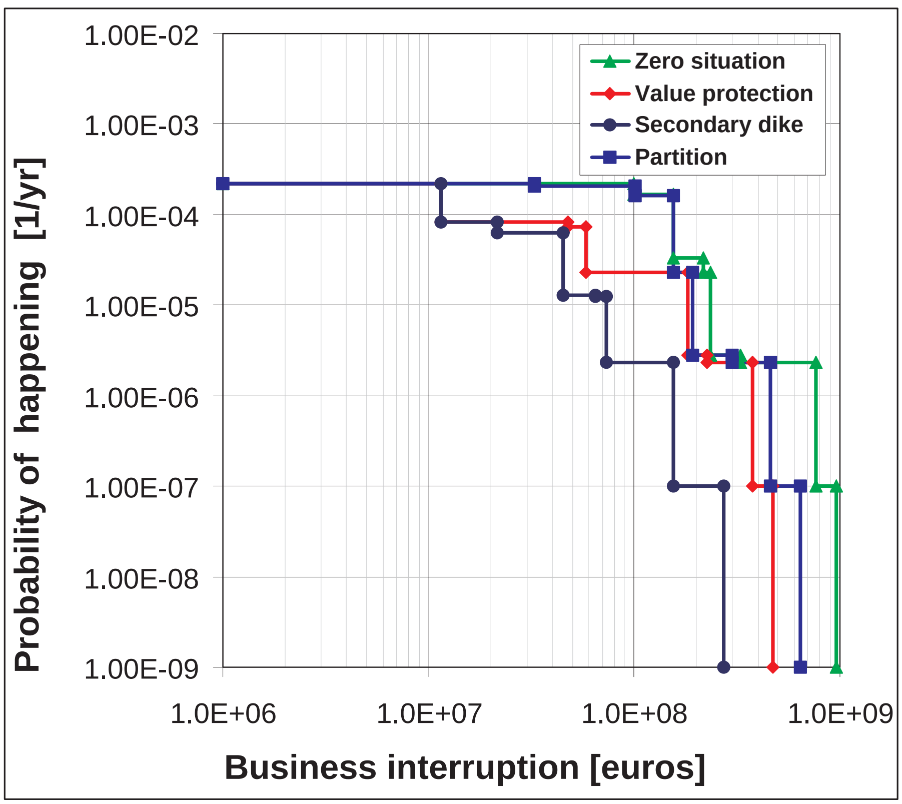


Figure G.1: The risk curve with the direct economic damage due to business interruption [euros] of HIS - SSM per compartmentalization strategy.

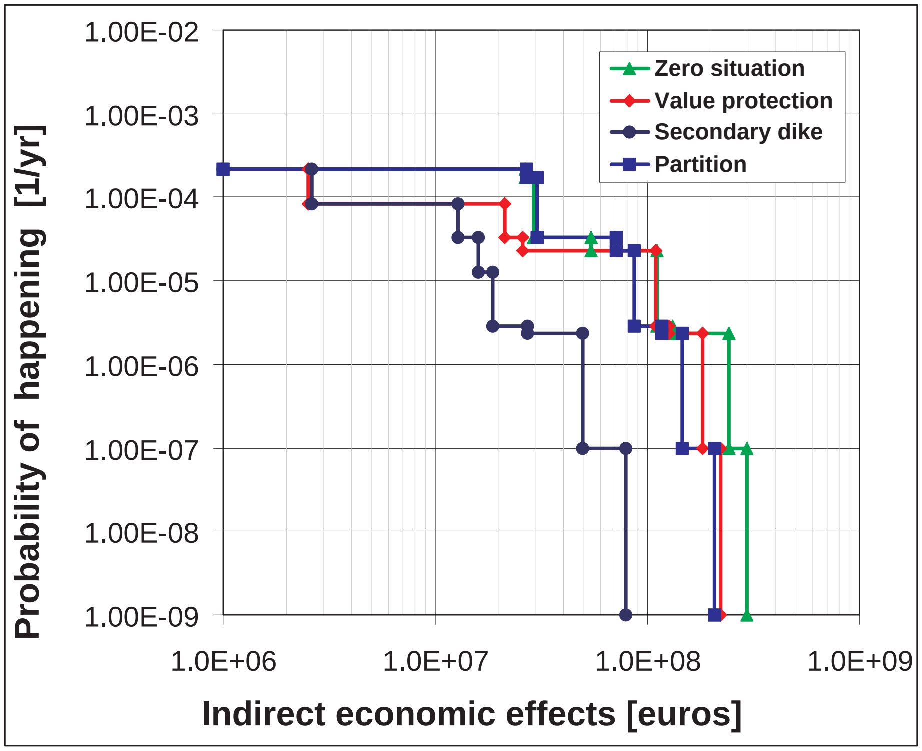


Figure G.2: The risk curve with the indirect economic damage [euros] of HIS - SSM per compartmentalization strategy.

Appendix H

One dike around Delft

Delft wants to protect itself against flooding and builds a dike around the city.

This extra study is outside the scope of the main study. Ter Heijde is taken as breach location for this extra study. It has a probability of failure of 1/50,000 year^{-1}. Table 4.1. The height of the compartmentalization dikes is 4 m and the total length of it is about 20 km. A rough estimation of the costs of a 4 m high green compartmentalization dike is about 3,000 euros / m^1 (RoyalHaskoning, 2005). A dike of 20 km is about 60 million euros.

	Normal case	**One dike Delft**	**Difference**
Affected people	664,095 people	609,822 people	54,273 people
casualties	3701 people	3659 people	42 people
Direct economic damage - material	18,470,408,680 euros	17,825,062,431 euros	645,346,249 euros
Direct economic damage - material	235,300,742 euros	240,442,006 euros	-514,1264 euros
Indirect economical damage	110,890,681 euros	111,835,465 euros	-944,784 euros

Table H.1: The effects of the normal flood scenario of Ter Heijde and the effects of the case 'One dike around Delft'.

- One compartmentalization dike around Delft causes less affected people, while the amount of casualties slightly reduces.
- Delft has about 95,000 inhabitants, which means that other people are affected. The affected people are shifted to other parts of the dike ring area.
- The direct material damage reduces about 650 million euros. The other two kinds of damage increase slightly.

Looking at a rough cost - benefit analysis, the costs of a dike is about 60 million euros, while the benefits are about 650 million euros. The reduction of the direct economical risk (material) is: 650 million euros * 1/50,000 yr = 13,000 euros / yr. This is the annual profit of building a dike around Delft. The earning back time of the dike investment (without discount rate) is: 60 million euros / 13,000 euros / yr = 4615 yr. After 4615 years, the construction of compartmentalization dikes is a better option than the zero situation.

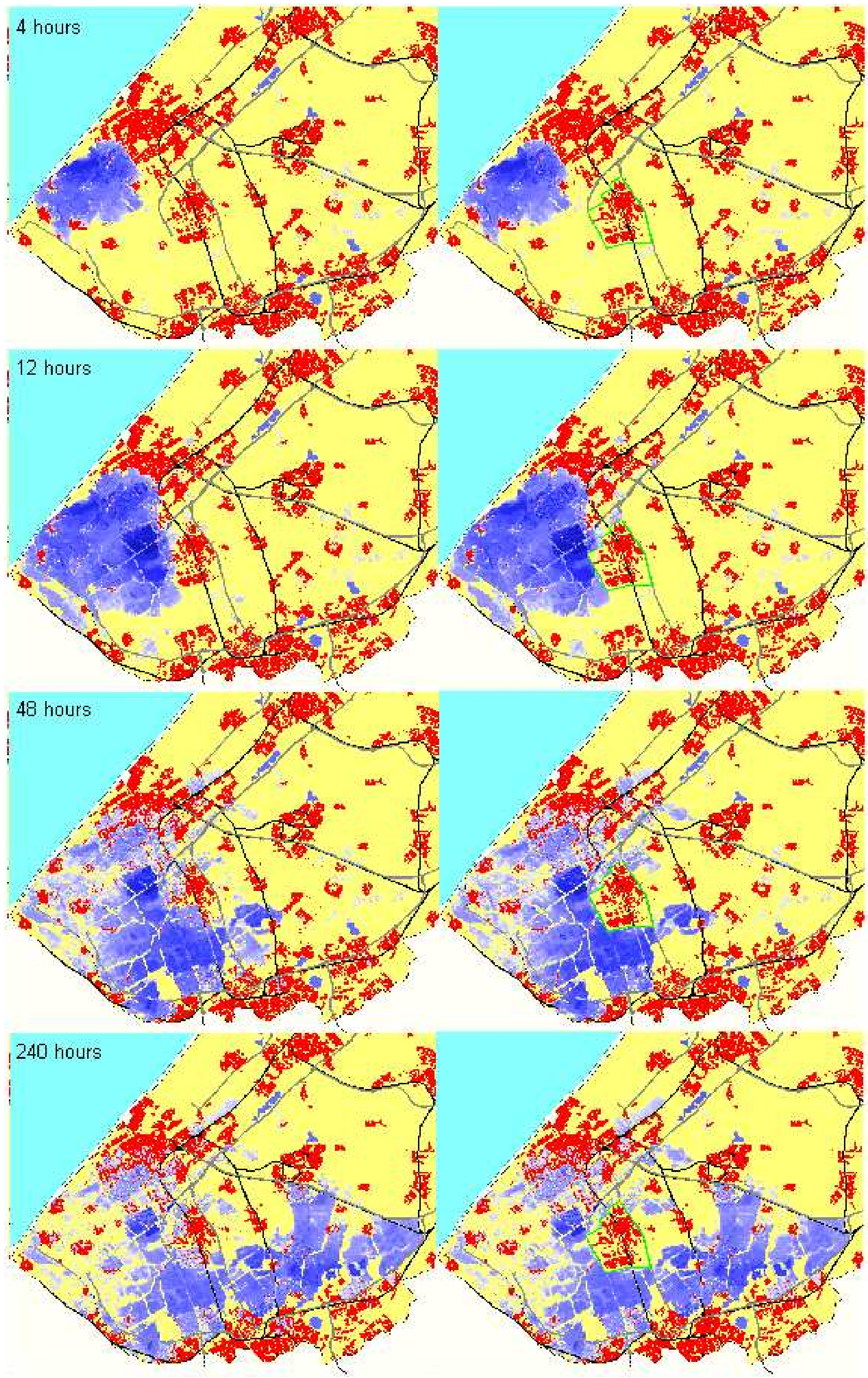
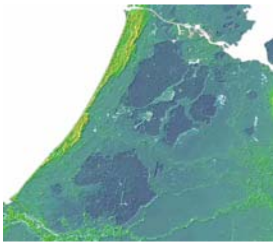


Figure H.1: The flood scenarios of Ter Heijde, without and with '*One dike around Delft*'






“New Orleans, New Orleans, New Orleans, you will come back. But will you be my New Orleans...? I doubt it. Katrina and the politicians have made you a different New Orleans forever.”

(National Geographic, Augustus 2006)