Assessment of the Costs of Business Interruption caused by Large-scale Floods

A comparison of methods

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Colophon

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Preface

This report is the result of a graduation project of the master Hydraulic Engineering of the faculty of Civil Engineering and Geosciences at Delft University of Technology. In the summer of 2012 my search for a graduation topic started. During this search I realized that I would be working on a topic for at least six months and consequently a topic that is ’quite interesting’ to me would probably not cut it for this long period of time. This lead me to the conclusion that I would like to combine my healthy interest in economics with hydraulic engineering to come up with a topic for my thesis. After numerous conversations during my internship with employees of HKV CONSULTANTS about the choice of a topic the sentence I heard most was ’You should have a talk with Matthijs Kok’. This talk took place in August 2012 after which the topic was set. The study took place from the end of November 2012 to May 2013 at the offices of HKV CONSULTANTS in Delft and Lelystad.

Fortunately I had a lot of help in this period. I would like to thank Robin Nicolai for his daily supervision at HKV CONSULTANTS and help with a broad range of problems concerning the topic. Special thanks also go out to Matthijs Kok for the daily supervision at Delft University of Technology and coming up with the topic. Furthermore, gratitude goes to Bas Jonkman for leading the graduation committee and helping me with a large supply of information. I also thank Meine-Pieter van Dijk and Robert Verhaeghe for their thoughts on the economic topics considered in this thesis. One of the first things I was taught during the economics courses at Delft University of Technology is that it is not feasible to do experiments for most questions regarding economics, unlike most engineering disciplines. This curse (or blessing?) became clear to me during our discussions, for which I am grateful.

I also thank Sybe Schaap and Sicco Santema for their cooperation with the interviews.

I would like to thank Jakolien Leenders and Jan Huizinga for their help with HIS-SSM. Special thanks also go to the Dutch project *Veiligheid Nederland in Kaart* for making the hydrodynamic computations of the cases used in this thesis available. Moreover, I am grateful for Maarten-Jan Kallen’s help with editing the LaTeX template used by HKV CONSULTANTS . I thank Elco Koks for his comments on this report and our fruitful discussions, I am certain you could have learned me much more if we had met earlier during the project. My fellow graduate students at HKV CONSULTANTS are not forgotten, I thank Jeroen Winkelhorst and Remco Steenstra for their help and joyful moments. Special thanks go to all the other employees of HKV CONSULTANTS for my pleasant stay at the company.

Delft, May 2013

Summary

In the Netherlands one of the most important methods to determine the level of flood protection is a cost-benefit analysis. In this analysis the costs (investment and maintenance costs of dikes) are balanced with the benefits (a reduction of flood risk). Risk is defined as the product of probability and consequence. This approach requires a good estimate of the consequences of floods.

A large contributor to the total costs of a flood are the losses due to business interruption. This is defined as forgone value added that is not created due to the fact that firms have to stop production. The causes of the production stop considered in this thesis are material damage to the production facilities of the considered firms and both forward and backward effects in the supply chain. The latter effects include the interruption of firms which are not flooded themselves, unlike their suppliers or buyers.

In the Netherlands the software package HIS-SSM (*Hoogwater Informatie Systeem - Schade en Slachtoffer Module*) is used to determine the consequences of possible floods. This model uses a damage function approach to determine the losses due to business interruption, in which the duration of the business interruption depends on the water depth only. As a result of this assumption, the losses due to business interruption expressed as a share of the material damage range between 1.5 and 5%, independent of the scale of the flood according to HIS-SSM. The maximum duration of the business interruption is one year for industrial firms and two months for other firms in HIS-SSM.

An analysis of actual floods shows that these figures are between 30% and 125% for large-scale floods. The considered floods for these figures are hurricane Katrina in 2005, hurricane Sandy in 2012, the tsunami in Japan in 2011 and the river floods in Thailand in 2011. Therefore, the losses due to business interruption as calculated by HIS-SSM are expected to be an underestimation of the actual losses due to business interruption.

The losses due to business interruption are expected to increase non-linearly for larger amounts of material damage. The losses due to business interruption are the product of the amount of firms that stop production and the duration of the production stop. If the scale of the flood increase, the amount of firms that stop production increases. The duration increases as well, as the production capacity of the construction sector (which is responsible for most of the reconstruction works) decreases and the amount of required reconstruction works increases. The recovery period becomes longer. This leads to a non-linear increase of the losses due to business interruption. The outcome of HIS-SSM (in which the losses due to business interruption are a constant fraction of the material damage) goes against this expectation.

This gives reason to investigate the losses due to business interruption. Three cases in the Netherlands have been considered, in which a hypothetical dike breach caused a flood. The locations of the dike breaches are Lopik (between Rotterdam and Utrecht), Holwierde (in the north-eastern part of Groningen) and Arcen (in Limburg). The material damage and losses due to business interruption have been determined with HIS-SSM for these cases. The losses due to business interruption have also been determined with a different model, the ARIO (Adaptive Regional Input-Output) model. This model has been not been used yet by policy-makers, but it has been applied several times for academic purposes.

Regarding economics, the ARIO model is more sophisticated than the HIS-SSM model for losses due to business interruption. The ARIO model uses the material damage to determine a new production capacity and a new total demand of the economy, to determine the actual production after the flood. A part of this production is used to repair the material damage, such that

the remaining material damage decreases in time. The remaining material damage is used to determine the production capacity and the total demand at each considered time interval. The production in the aftermath of the flood is then compared to the production before the flood to determine the losses due to business interruption.

The results of the case studies show that the estimates of the losses due to business interruption as calculated by the ARIO model are more in line with figures from actual floods. As can be seen in figure 0-1, the losses due to business interruption are non-linear with respect to the material damage or scale of the flood according to the ARIO model. The losses due to business interruption increase linearly according to HIS-SSM.

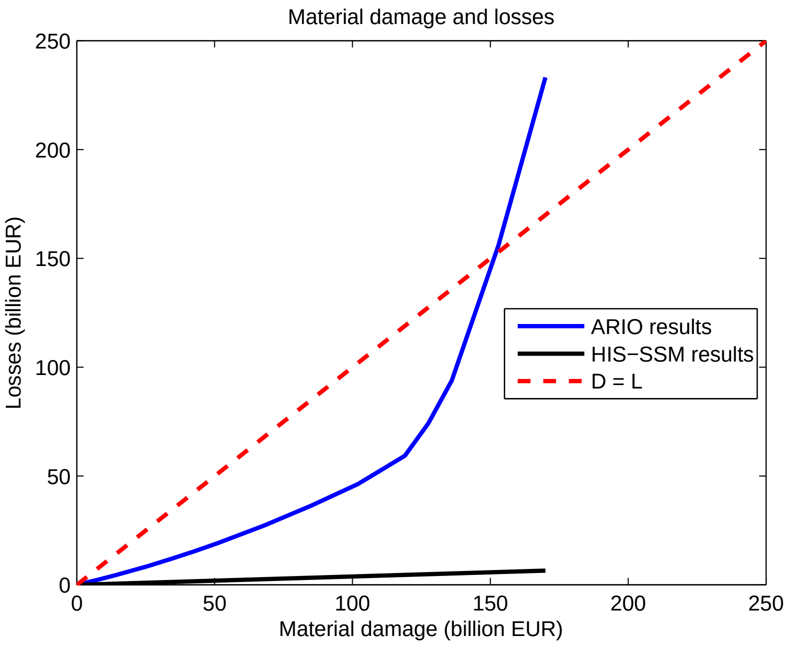

Figure 0-1: Relation between the material damage (D) and the losses (L) due to business interruption caused by the Lopik dike breach case. The material damage has been scaled (multiplied with a constant) to determine the losses due to business interruption for different scales of floods.

This gives reason to believe that the losses due to business interruption are indeed underestimated by HIS-SSM for large-scale floods and that alternative models are available. The results of the ARIO model depend strongly on the way the production capacity is determined however. Other parameters, like the parameters describing overproduction in the ARIO model also have a strong influence on the results according to a sensitivity analysis.

An important change has been made to determinate the production capacity in the ARIO model. In the original model, this was done using the capital intensity (the total capital stock divided by the yearly value added) of the considered sectors. This approach overestimates the production capacity in the aftermath of the flood however. In the new approach the production capacity of the considered sectors is determined using a GIS database of the amount of employees and the water depth as a result of the flood.

Both models do not take the interruption of a so called 'critical firm' well into account. The models use a sector approach, in which all considered firms are divided into sectors. Next the assumption is made that the value added per job is the same in a sector (HIS-SSM) or firms in the same sector can provide substitutes for each other (ARIO model). This may lead to an underestimation of the losses due to business interruption if a critical firm is flooded. Three criteria have to be met for a firm to be critical in this context. There are no substitute products or services available for the considered firm on a short notice, the effects of the interruption of the firm are geographically larger than the flooded area and the firm must be vulnerable to flooding. The geographical effects can be larger than the flooded area due to chain effects, if the flooded firm is an element of a chain and it fails, the whole chain fails. Examples of these firms are the gas fields in the north of the Netherlands, telecommunications centers and logistic centers like the port of Rotterdam. One of the recommendations is to take the losses due to business interruption caused by these firms into account individually.

Interviews have been conducted with a member of the Dutch parliament and an industrial design professor on the Dutch flood protection policy and possible chain effects after a flood. These interviews lead to the recommendation for policy makers to consider the cost efficiency of risk reduction in all fields when determining where to invest in safety. The permanent relocation of foreignly controlled firms, the use of the just-in-time principle and damage to the reputation of the Dutch water sector should also be considered.

The losses due to business interruption are a considerable part of the total costs of large-scale floods. Instead of focusing on the traditional measures against floods, which mostly aim to avoid floods or reduce the amount of material damage and fatalities, measures to reduce the duration of business interruption should also be considered. New possible measures include dike ring partitioning and making certain sectors (like the construction sector) more robust against floods. A cost-benefit analysis regarding these new measures should be made to see whether they are cost-efficient.

Contents

1 Introduction

Coastal areas have recently become more vulnerable to natural disasters due to climate change and socio-economic developments. The costs of natural hazards have been rising the last few decades. Besides the human suffering, the total economic costs of natural hazards in 2011 is estimated by Munich Re to be US$ 380 billion, surpassing the previous record of US$ 220 billion in 2005 [Munich Re (2012)]. Many different catastrophes in 2011 contributed to this astonishing number, including the earthquake/tsunami combination in Japan in March, the earthquake in Christchurch (New Zealand) and the river floods in Thailand throughout the second half of the year.

This chapter contains an introduction to flood protection in the Netherlands to explain why it is important to have good predictions of the consequences of floods in decision making. Next, the problems with the current method used to predict the costs of large scale floods in the Netherlands are explained. The goal of this study and the methodology used comes thereafter. The chapter ends with an outline of this report.

1.1 Flood protection in the Netherlands

The most recent large-scale natural disaster in the Netherlands occurred in 1953. A storm surge on the North Sea together with spring tide resulted in the inundation of 1365 square kilometers of land and the death of 1836 people. The event created a debate in the Netherlands on flood defense. One of the new methods proposed during the debate is a risk based approach to determine the height of the dikes. The *Deltacommissie* recommended in 2008 that this method should still be used to determine the economically optimum dike heights [Deltacommissie 2008 (2008)]. This approach seeks a balance between the risk of flooding and investments in flood protection. The costs of living in a flood prone area is made tangible by the risk, which is defined as the product of the probability of a flood and the consequences of the flood (expressed in monetary value). Risk can then be interpreted as the yearly expected cost of the flood. The investments in flood protection are also expressed in yearly costs. These costs consist of operational and maintenance cost of the flood protection system and interest payments on the initial investment.

Both the risk and the investments are depending on the dike height and strength. The higher the dikes, the smaller the risks (the probability of occurrence of a flood decreases quite rapidly, while the consequences increase less) and the higher the investment costs. At the economically optimal dike height the sum of these two costs is minimized. The procedure is graphically illustrated in figure 1-1. This figure is only an illustration to clarify the risk based approach. The investment costs are in reality not linearly related to the dike height.

The dashed line indicates the economically optimum dike height [Jonkman et al. (2004)]. When there are no dikes (dike height equals zero) the investment costs equal zero as well. The total costs are now dominated by the risk. In this scenario flooding takes place very regularly. When the dike height is very large (for example 5 meters) the risk becomes very small and most of the total costs are investment costs. In this case flooding almost never takes place, but the costs for the flood defense system are considerable. At the economically optimum dike height the investment of one extra euro in the flood defense system reduces the risk by less than one euro. The investment of one euro less increases the risk by more than one euro.

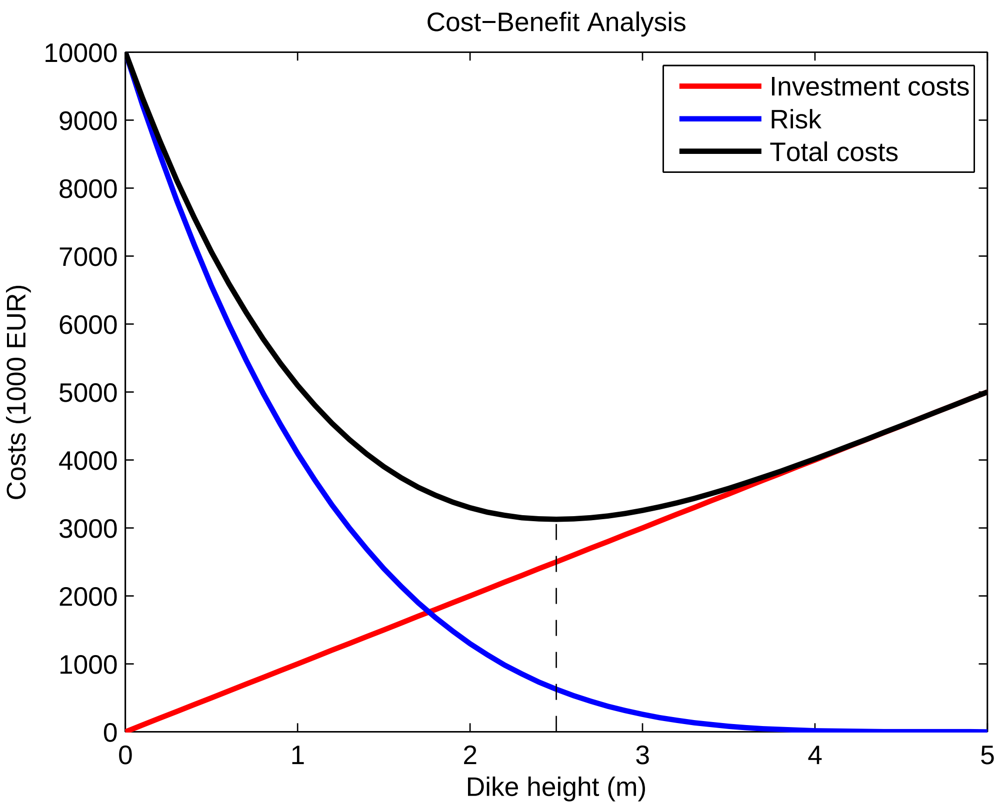

Figure 1-1: Example cost benefit analysis

The consequences of a flood are very important when determining the economically optimum dike height. These consequences should be assessed before flooding takes place to be able to use this strategy to determine the dike height. In the Netherlands the software HIS-SSM (*Hoogwater Informatie Systeem - Schade en Slachtoffer Module*) is used to determine the consequences of a flood. These consequences are combined with the probability of occurrence of a flood and the costs involved with the strengthening of the flood defense system to determine the economically optimum dike height. The results are published regularly in a report known as the *Maatschappelijk kosten-batenanalyse Waterveiligheid* [Deltares (2011)].

1.2 Problem definition

Recently a report has been published which assesses the method used in HIS-SSM and puts forth some critical notes about the method [RebelGroup Advisory (2009)]. Most of these notes are about the method used to forecast the costs due to business interruption by HIS-SSM. This gives reason to look into the methods used in HIS-SSM.

The main shortcomings in HIS-SSM are:

- The losses due to business interruption are probably underestimated
- The relative size of losses due to business interruption in the total costs of a flood are not dependent on the scale of the flood
- The losses due to business interruption are not dependent on the homogeneity of the shock[1]

[1] A homogeneous shock is a shock that reduces the production capacity of all sectors by the same percentage. The losses due to business interruption caused by heterogeneous shocks are expected to be larger due to effects in the supply chain.

- Lost housing services are not taken into account
- Failing of critical firms or infrastructure (for example the gas fields in Groningen or large power plants) is not taken into account adequately

Especially the shortcomings that the losses due to business interruption are underestimated and the inadequate treatment of critical firms and infrastructures can have an influence on the economically optimum dike height. If the risk of flooding is not determined accurately this can lead to an inefficient dike height according to a cost benefit analysis.

1.3 Goal

The objective of this thesis is to study the consequences of a flood and how these consequences can be predicted, in particular into the costs of business interruption. The following research questions will be answered:

- What are the potential effects of a flood? Does business interruption play a significant role in these effects?
- How do the economic losses due to business interruption computed by an input-output model differ from those computed by HIS-SSM in an actual case?
- Are the economic losses due to business interruption a constant fraction of the direct damage (to buildings and inventories)?
- Is the recovery time linearly related to the amount of direct damage?
- What measures could be taken to reduce the economic losses due to business interruption (both before and after the flood)?

1.4 Methodology

First the consequences of recent large-scale floods will be assessed to gain insight into the events that take place during a flood. Then these consequences will be classified to make clear what consequences are taken into account and which are neglected by certain methods to assess the consequences of a flood. An overview of available models and the types of consequences they predict will be made to get insight into the current state of research in the field.

After that business interruption will be looked into, including the main variables that determine the amount of losses due to business interruption. Several models to assess the losses due to business interruption will be evaluated which leads to a model that will be used in this thesis.

Both HIS-SSM and an alternative model will then be used on several cases. In these cases a large part of the Randstad area is flooded due to a dike breach near Lopik (next to the river Lek), the city of Delfzijl and parts of the city of Groningen are flooded due to a dike breach near Holwierde and the small town of Arcen in the province of Limburg is flooded by the river Meuse due to a dike breach. The results of these cases will be compared to actual figures from recent floods in foreign countries. The models are also used on the flooding of a single firm (a renewable diesel refinery) to see whether the models are useful for a small-scale flood as well. Furthermore, interviews on the importance of chain reactions in the aftermath of a flood and other important consequences of floods will be held with representatives of the academic world and governmental sector.

The results will be analyzed which will lead to conclusions, recommendations and answers to the research questions proposed in this introduction.

1.5 Outline

The report has been divided into four parts. The first part is an introduction in large-scale floods in general and comprises this chapter and chapter 2. In chapter 2 the analysis of recent floods can be found. The second part, consisting of chapter 3 and 4 is about the modeling of the consequences of large-scale floods. The classification, framework and available models to assess the consequences of floods in general can be found in chapter 3. The same can be found for losses due to business interruption in chapter 4. Part three is about the case study in which the province of South Holland is flooded. This part comprises chapter 5, 6, 7 and 8. A description of the Lopik dike breach case can be found in chapter 5. This is the only case that will be treated in detail in this study, the other two cases will be treated briefly. A detailed description of HIS-SSM and the results of the application of this model to the Lopik case can be found in chapter 6. A description of the alternative model (the Adaptive Regional Input-Output model) and the results of this model applied to the Lopik case can be found in chapter 7. An analysis of the results of both models and the figures from recent floods can be found in chapter 8. Finally the conclusions and recommendations can be found in chapter 9 which also forms the final part.

Appendix A contains several interesting news articles related to the recent flood in foreign countries. Information regarding the conducted interviews can be found in appendix B. In appendix C a complete description (equations, input and MATLAB script) of the ARIO model can be found. Appendix D contains information regarding the Lopik dike breach, including maps of the daily water depth of the flooded area and the raw results given by HIS-SSM. Information regarding the Holwierde dike breach case can be found in appendix E and about the Arcen dike breach case in appendix F. A description and the results of the renewable diesel refinery case can be found in appendix G.

2 Recent large-scale floods

In this section the consequences of recent floods are analyzed to be able to answer the first research question. The tsunami in Japan in 2011, the river floods in Thailand in 2011, the effects of hurricane Sandy in New York and New Jersey in 2012 and the flooding of New Orleans by hurricane Katrina in 2005 are described. In appendix A a small selection of news articles can be found to give an impression of the problems in the aftermath of a flood. The consequences of the events are compared to reveal similarities and differences.

2.1 Tsunami Japan 2011

On March 11th, 2011 an earthquake with the epicenter 70 km east of the coast of the Tohoku region in Japan took place. The earthquake with a magnitude of 9.0 caused a tsunami that hit the Japanese east coast with wave heights up to 20 meters. Large parts of the east coast were protected by anti-tsunami sea walls, huge concrete structures built to be able to withstand a tsunami. Some of these sea walls failed however, as the tsunami waves were higher than the sea walls leading to overtopping and collapsing of the structures. The duration of the flood was quite short due to the slope of the area.

Recent estimates of the amount of lethal victims are 16,273 and 3061 missing, making this one of the most deadly natural hazards of the previous five years [Vervaeck and Daniell (2011-2012)]. Most of these people were elderly [Kolen et al. (2012)]. The amount of buildings destroyed or severely damaged during the disaster is estimated to be 300,000. Among these buildings were houses, schools and hospitals. Between US$ 35 and 40 billion of the damage caused by the disaster were insured.

The devastation caused by the earthquake and tsunami was enormous. Several power plants were damaged or shut down as a precautionary measure (TEPCO's power supply capacity decreased from 40 GW to 30 GW), leading to rolling blackouts for the coming two months. A rolling blackout is an intentional stop in the supply of electricity to a specific region, to ensure that the remaining parts of the system still have power. This is generally considered a last resort to prevent a total blackout. The demand restriction target for households, large-volume and small-volume customers was set to 15% until September 2011 (6 months after the disaster) [Government of Japan (2012)]. Furthermore, several manufacturing firms agreed to help with solving these power related problems, either by using their own generators to supply power to the public or by producing on Saturday and Sunday instead of Thursday and Friday to lower peak demands.

The Fukushima nuclear power plant was automatically shut down after the disaster. After a shut down, the reactor needs to be cooled to remove decay heat to prevent a meltdown. This cooling is done by pumping water through the reactor. The conventional electricity supply was not working due to the earthquake and tsunami, but the power plant has backup diesel generators in case of an emergency. These backup generators were flooded however (the design wave height was much smaller than the actual wave height caused by the tsunami) and did not function properly. After several days the disaster team decided to use sea water for cooling the reactor, which meant that the reactor would be damaged beyond repairs. The radioactive cooling water leaked to the nearby sea, leading to possible negative environmental consequences.

The Fukushima accident caused a debate on the use of nuclear energy in Japan and the rest of the world. One year after the disaster, only two nuclear power plants in Japan were still operational. In September 2012 the Japanese government decided to phase out the use of nuclear power plants, such that in 2040 the Japanese power supply would be free of nuclear power. Instead of nuclear power, conventional power plants and renewable energy will be used. Similar reactions were seen in other parts of the world, such as Germany. Immediately after the disaster the seven oldest nuclear power plants in Germany were closed. The remaining nine power plants will be closed in the near future, with the most modern nuclear power plant closing in 2022.

Next to electricity, several other infrastructures were hit by the earthquake and tsunami. Telecommunication networks were disrupted, mainly in the areas near the epicenter of the earthquake. Several undersea cables (responsible for among others the world wide interconnectivity of the internet) were damaged, but sufficient capacity was available through other cables. The supply of water had halted to more than 1.4 million households the first week after the disaster [Tsimopoulou et al. (2012)]. This was a major concern for the emergency teams due to the threat of epidemics.

Transportation infrastructure was hit as well. Most of the industrial ports on the east coast of Japan were closed immediately after the disaster, reopening again two weeks later. The capacity of the ports was still very much reduced however, due to damaged cranes, quays, breakwaters and other port facilities. Many airports in the affected region were damaged and not accessible to air transport, hampering the emergency management efforts. The closest major airport to the epicenter of the earthquake (Sendai) was severely damaged, but the combined forces of the USA and Japan made it possible to clear the runway and make it operational again in only two weeks [Government of Japan (2012)].

Many roads in the affected area were damaged, including highways. Many sections (374 km out of 675 km) of the Tohoku Expressway, the main highway connecting Tokyo and northern Japan were damaged. This highway reopened two weeks after the earthquake to the public after emergency restorations [Government of Japan (2012)]. The Shinkansen highspeed-railway line through the affected area was reopened twenty days after the tsunami, but trains had a lower maximum speed due to the restoration works. The pre-disaster train schedule was reinstated in late September. Several local railway lines in Tokyo were affected by the rolling blackouts used to prevent a total blackout, some lines were operated less frequently, some only during rush hours and some were completely shut down. In the first week, many people living or working in Tokyo were not able to reach their work or home on a daily basis.

A detailed description of the damage to the capital stock can be found in table 2-1. Unfortunately the damage is split in only four categories. Buildings include all buildings (houses, offices, schools), lifeline utilities include infrastructures for water, gas, electricity and telecommunications. Social infrastructures consist of roads, ports, airports, rivers etc. and others includes the damage to remaining objects (like agriculture and forestry).

Sector	Damage	Share [%]
Buildings	10.4	61.5
Lifeline utilities	1.3	7.7
Social infrastructure	2.2	13.0
Others	3.0	17.8
Total	16.9	100

Table 2-1: Damage Tohoku earthquake and tsunami Japan. Damage in trillion JPY. The total damage estimate in USD equals 205 billion. [Government of Japan (2012)]

The destruction of homes caused many people to move to a new place. Instead of living near the coast, people moved further inland to higher ground. The accidents at the Fukushima nuclear reactor caused a high radiation level in the area nearby, making it unfit to live in.

After all these effects, it is not hard to imagine that the earthquake and tsunami impacted the Japanese economy as well. A week after the earthquake, the World Bank published a report on the Japanese economy. The World Bank expected the real GDP growth of Japan to slowdown through mid-2011, but due to reconstruction efforts (lasting up to five years) to increase in subsequent quarters. A small portion of the damage will be paid for by private insurers, leaving most of the costs to be paid to households and the Japanese government [World Bank (2011)]. The Government of Japan expects the maximum reduction of real GDP caused by the disaster (-6.8% on a quarterly basis) to be much smaller than after the Lehman shock (-14.8% on a quarterly basis) [Government of Japan (2012)]. The Lehman shock was caused by the bankruptcy of the American bank Lehman Brothers in 2008, which reduced confidence in the worldwide financial system.

If the assumption is made that there are no more losses in GDP in the second quarter after the flood, the reduction in GDP can be transformed to a figure representing the losses due to business interruption. The Japanese GDP in 2011 was 468 trillion JPY[1]. A reduction of 6.8% of this figure during one quarter leads to losses of business interruption equal to 8 trillion JPY, equal to half the material damage.

The impact on other Japanese and East-Asian firms can be significant. As inventors of the just-in-time principle, Japanese firms tend to attempt to reduce their inventories to save costs. With a sudden production loss of one of the firms in the production chain, it is possible that firms not directly hit by the earthquake or tsunami still have to reduce their production due to the absence of intermediate goods. Japan is a huge producer of components for the high-tech industry and automobile industry. The use of the just-in-time principle does not limit itself to Japan, many (international) firms in Asia utilise this strategy. Car exporters in Thailand have reported that their stock of parts produced by Japanese suppliers will last until the end of April 2011 (6 weeks from the disaster) [World Bank (2011)]. Furthermore, the prices of memory chips used by the high-tech industry have risen by 20% in merely two weeks. Japan accounts for 36% of this chip production, which are used by manufacturers commonly based in Korea.

Not only trade can affect the international economy, Japan is also a huge player in international finance. A significant share of the debt of developing countries in East-Asia is denominated in Japanese Yen. A reduction of exports, an increase of imports and quantitative easening by the Bank of Japan (which took place the first week after the disaster) might cause the value of the Yen to fall in international trade. This reduces the amount of interest other East-Asian countries have to pay in their local currency. Japan is a huge source of foreign direct investment for these developing countries, but a depreciation of the Yen or a shift of the focus to domestic reconstruction might lead to lower foreign direct investment [World Bank (2011)].

2.2 River flood Thailand 2011

The floods in Thailand in 2011 were of a completely different nature than the one in Japan. Due to excessive rainfall, high discharges and water levels on the Chao Praya river caused many dam failures. The heavy rainfall caused flooding in the north of Thailand by late July, which spread to the south gradually as dams increased their discharge capacity to remove the excessive water.

[1] Figure taken from the World Bank World Development Indicators at http://databank.worldbank.org

In mid-November, large parts of Bangkok were inundated marking the peak of the floods. It took until mid-January 2012 for all the water to clear the land.

The total number of deaths caused by the floods is estimated to be at least 680 [World Bank (2012)]. Many of these deaths were caused by the sudden breaking of dikes. The total number of people affected by the flood is estimated to be 13 million.

The World Bank used the DALA method [Economic Commission for Latin America and the Caribbean (2003)] to determine the damage and losses caused by the floods. The results can be found in table 2-2. Damage is damage to the capital stock, losses are forgone added value. The forgone added value is actually larger than the damage to the capital stock in this case, making this a very important category.

Sector	Damage	Share [%]	Losses	Share [%]
Water resources management	8,175	1.3	-	-
Transport	23,538	3.7	6,938	0.9
Telecommunication	1,290	0.2	2,558	0.3
Electricity	3,186	0.5	5,716	0.7
Water Supply and Sanitation	3,497	0.6	1,984	0.2
Agriculture	5,666	0.9	34,715	4.4
Manufacturing	513,881	81.5	493,258	62.0
Tourism	5,134	0.8	89,673	11.3
Finance and Banking	-	-	115,276	14.5
Health	1,684	0.3	2,133	0.3
Education	13,051	2.1	1,798	0.2
Housing	45,908	7.3	37,889	4.8
Cultural Heritage	4,429	0.7	3,076	0.4
Environment	375	0.1	176	0
Total	630,354	100	795,191	100

Table 2-2: Damage and losses Thai floods 2011. Damage and losses in million THB. The total damage and losses estimate in USD equal respectively 20.5 billion and 25.8 billion. [World Bank (2012)]

The losses due to business interruption are larger than the material damage caused by the flood. This is most likely a result of the long period the area was flooded. Some areas were flooded for months, and cleanup and reconstruction activities cannot start until all the water is gone.

More than 80% of the damage in Thailand is borne by the manufacturing sector, while it contributes 36% to the Thai GDP. When comparing table 2-2 to the Japanese figures, an interesting figure comes up. The share of damage to infrastructures is higher in Japan (20.7%) than it is in Thailand (6.3%), probably due to the more destructive impact of the tsunami than the slow flood in Thailand. There might also be more expensive infrastructures in Japan than in Thailand.

On average, 19% of the manufacturing firms in Thailand are involved in global production networks [Chongvilaivan (2012)]. In high-tech industries like computer and telecommunications equipment manufacturing this figure is even higher. Due to recent developments, like the increase of the share of parts (instead of complete cars) in the automotive exports, these global production networks are expected to intensify [Chongvilaivan (2012)].

Prices of hard disk drives around the globe nearly doubled due to production shortages. Many facilities of hard disk drive producer Western Digital were damaged by the flood, creating global shortages of the computer component. It took nearly a year for the supply to recover.

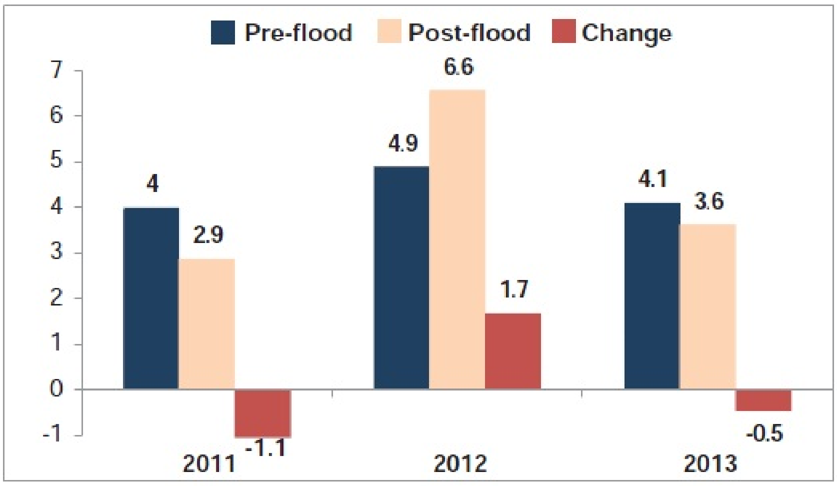

Figure 2-1: Real GDP growth Thailand estimates. These figures were published by the World Bank on January 1st, 2012. [World Bank (2012)]

The World Bank estimated the macro-economic effects of the flood. Real GDP growth is expected to decrease initially due to the flood, which can be found in figure 2-1. In 2012 real GDP growth is expected to increase due to reconstruction needs. The overall result of the flood is expected to be a very small increase in growth up to 2013, at the cost of a higher government deficit in 2011 and 2012 (due to reduced government income and reconstruction spending). In hindsight, real GDP growth in Thailand in 2011 was only 0.1%, much smaller than the World Bank estimate of 2.9%.

2.3 Hurricane Sandy

During late October 2012 Hurricane Sandy ravaged through the Caribbean and the United States of America, killing at least 253 people. The storm made landfall in the USA 8 kilometers south of Atlantic City, New Jersey. Most of the casualties and damage were located in the states of New York, New Jersey and to a lesser extent Connecticut.

The storm coincided with a spring tide in New York City and brought heavy precipitation, flooding several parts of the city including Manhattan and Queens. Many automobile bridges and tunnels were closed, the subway service was disrupted for days due to flooding as were the ferry services between the islands of the city. Blackouts occurred because of damage to the electrical infrastructure and critical communication infrastructure of Verizon Utilities was flooded as well. The New York Stock Exchange was closed for two consecutive days, preventing traders worldwide to exchange stocks listed on indexes like the S&P 500 and the Dow Jones.

The New York Governments Office collaborated with PricewaterhouseCoopers and the PFM Group to estimate the damage caused by the storm in the state of New York. Their results can be found in table 2-3.[2] This only comprises damage in the state of New York. About half of the total damage occurred in the city of New York. The New York Government Office expects to require 9.1 billion USD for prevention and mitigation works for the future in addition to the damage. The share of damage to infrastructures (30.2%) is of the same order of magnitude as in Japan.

[2] http://www.governor.ny.gov/assets/documents/sandyimpactsummary.pdf accessed 21/12/2012

Sector	Damage	Share [%]
Government response and repair	1,627	5.0
Individual assistance	913	2.8
Housing	9,672	29.5
Business impact	6,000	18.3
Health	3,081	9.4
Schools	342	1.0
Transit, roads and bridges	7,348	22.4
Parks and environment	793	2.4
Water, waste and sewer	1,060	3.2
Utilities	1,504	4.6
Government operation revenue	461	1.4
Total	32,804	100

Table 2-3: Damage Hurricane Sandy in the state of New York. Damage in million USD.

In New Jersey, Hurricane Sandy caused damage due to the storm and floods as well. New Jersey governor Chris Christie increased the preliminary estimate of damage to his state from 29.4 billion USD to 36.8 billion USD, including prevention and mitigation measures.

Total losses due to general business interruption are estimated to be between 10.8 and 15.5 billion USD, depending on the recovery period. Assuming the closing of the stock exchanges affected 30% of the United States finance sector, the indirect costs of the closure would approximate 9.8 billion USD [Muhr et al. (2012)].

The states of New York, New Jersey and Connecticut requested 82 billion USD in aid of the federal government, which is more than the aid package of 60.4 billion USD approved by the senate of the United States. 12 billion USD of the aid package will be used for repairing and strengthening the transportation system and 17 billion USD for community development like rebuilding houses, and hospitals and improving the power infrastructure.[3]

2.4 Hurricane Katrina

In August 2005 Hurricane Katrina made landfall near New Orleans in the state of Louisiana. Earlier that month it caused damage in nearby states, however at a much smaller scale than in New Orleans. The hurricane caused a storm surge near the city, eventually leading to the breaching of several levees. Consequently, more than 1100 people died, mostly due to the large flood depths and rise rate of the water level [Kok et al. (2006)].

The devastation caused by the disaster is enormous. A year after the hurricane, more than halve of the inhabitants have not returned to the city. Some of these have moved permanently to cities upstream of the Mississippi river to avoid future disasters by hurricanes.

A breakdown of the damage can be found in table 2-4. These figures do not include losses due to business interruption.

Business interruption played a major role in the aftermath of Hurricane Katrina. According to the Bureau of Labor Statistics the total amount of jobs in the private sector in Louisiana dropped from 1.57 million to 1.42 million in September 2005 (one month after the disaster). It took un-

[3] http://www.reuters.com/article/2012/12/29/us-congress-sandy-amendment-idUSBRE8BR0N120121229 accessed 2/1/2013

Sector	Damage	Share [%]
Houses	16.2	53.8
Firms and public buildings	2.9	9.6
Cars	1.4	4.7
Infrastructures	4.5	15.0
Cleanup costs	0.8	2.7
Evacuation and rescue operations	0.1	0.3
Flood defense repair	2.0	6.6
Temporary housing	2.2	7.3
Total	30.1	100

Table 2-4: Damage Hurricane Katrina in New Orleans. Damage in billion USD. [Kok et al. (2006)]

til October 2007 to restore back to 1.57 million. During the recovery time, the total amount of job-months[4] lost equals 1.6 million, assuming the amount of jobs would remain constant if the disaster did not occur. If the average weekly earnings are assumed to be 650 USD per job[5] the forgone wages due to business interruption are 4.5 billion USD (or 15% of the direct damage). The latter figure does not include other losses due to business interruption (like forgone profits and reduced dividends), it should be considered a bare minimum. The actual losses due to business interruption are probably more than twice as large if forgone profits and dividends are taken into account as well.

2.5 Comparison

In this section similarities and differences between the four catastrophic events will be discussed. The damage of all disasters as a share of GDP is of the same order of magnitude. For Japan this was 3.6%, Thailand 6.0%, New York and New Jersey 3.8% (based on the GDP of 2011)[6] and Louisiana 15.4%. For the American states the GDP is based on the GDP of the state, not the USA as a whole. The unavailability or rise in price of certain goods or services was common in most of these disasters, be it in different products (memory chips, hard disk drives and the stock exchange). This unavailability or rise in price were in all cases felt worldwide.

Power failure was also common in all disasters, either due to the destruction of the infrastructure to transport power (Sandy, Thailand) or because of the destruction of power plants (Japan). The latter seems to last longer, as repairing the infrastructure can be done quicker than building new power plants. Transport infrastructure failed as well in all catastrophes, however in Thailand it were usually roads that could not be used while in Japan and the USA it was the public transport (trains, the underground) that was out of operation. The share of damage to infrastructures in the United States and Japan (ranging from 15% to 22%) is larger than in Thailand (6%).

Losses due to business interruption play a significant role in the total costs of the considered floods. It is hard to determine these figures but a rough indication can be given. For Japan the losses due to business interruption are equal to approximately 50% of the material damage caused by the flood, only considering the GDP reduction in the first quarter after the flood. Dur-

[4]A job-month is similar to a man-hour; it is the product of the amount of jobs lost and the amount of months these jobs are lost.

[5]According to the Bureau of Labor Statistics the average weekly earnings were 700 USD in Louisiana in 2007, earlier data is not available.

[6]The fraction needs for prevention and mitigation of total damage in New Jersey is assumed to be equal to the figure in New York, because the figure is not given for New Jersey.

ing the floods in Thailand, the losses due to business interruption were equal to 125% of the material damage, making the losses due to business interruption the largest contributor to the total costs of these floods. The flooding of Bangkok and several industrial estates contributed to this large number, as did the fact that some areas were flooded for months. In Louisiana, the losses due to business interruption are equal to at least approximately 15% of the material damage, but this figure only took lost wages into account. If lost profits and dividends are also considered, the figure will probably double. For Hurricane Sandy the total losses due to business interruption (including the closing of the NYSE for two days) are approximately between 20.6 and 25.3 billion USD, or between 33% and 42% of the material damage.

A big difference can be found in the amount of fatalities. The figure in Japan is much larger than in the other three disasters, probably due to the short notice at which the disaster happened and the enormous impact of the floodwave in Japan. River flooding and hurricanes can often be seen in advance, making evacuation an effective strategy to avoid the loss of life. A warning system for tsunamis is operational in Japan, but the time span between the alarm and the occurrence of the tsunami is much smaller, usually less than one hour.

The duration of the floods was also quite different. The flood in Japan was relatively short, the floods in the USA slightly longer (several days to a few weeks) but the flood in Thailand took months in some provinces. This has a big influence on business interruption.

Another large difference can be found in the availability of information regarding the consequences caused by the disasters. In Japan a breakdown of material damage is available from the government in only four sectors, while in Thailand the World Bank published a much more detailed breakdown. Furthermore, the World Bank also published how much added value (in the time after and during the flood) was lost due to business interruption. In the USA, the damage caused by Hurricane Katrina was assessed by an interagency taskforce. The governor of New York published a detailed breakdown of the damage caused by Sandy, while the governor of New Jersey only published the total amount. This latter figure also contains the needs for prevention and mitigation works, but this is not actual damage caused by Sandy obviously. The amount and composition of the available information are very different.

3 Modelling the consequences of large-scale floods

This chapter considers the consequences of floods. First a classification is made to be able to group the different kinds of consequences. Next the variables that influence the size of the consequences are considered. The last section contains an overview of the available models to predict the consequences of floods.

3.1 Classification

From chapter 2 it becomes clear that the consequences of a flood can be very diverse. The loss of human life, destruction of houses and buildings, business interruption due to the lack of suppliers for firms outside the flooded area and psychological damage all have different characteristics. The following classification has been based on [Merz et al. (2010)], which has been expanded with a difference between damage and losses (based on time dependency). The consequences can be grouped on whether the consequence is:

- Tangible or intangible
- Damage (no time dependency) or losses (time dependent)
- Direct or indirect

Tangible consequences can be expressed in monetary values by market prices, whereas intangible consequences cannot (or proves to be very difficult). For example, if the flooding of a building causes the floor to be damaged, the tangible consequence of the flooding of the building is equal to the repair costs of the floor. Other consequences, like the loss of life, cannot be made tangible by market prices. Consequences that occur immediately after the flood and do not have a time dimension, like the flooded building in the previous example, are called damage. Consequences which are time dependent, like business interruption, are called losses. If the flooded building is an office which cannot be used after the repair of the floor, the forgone value added of the flood is dependent on how quick the floor can be repaired. The losses of the flood are thus dependent on when the floor is actually repaired, while the damage of the flood is not. An overview of the consequences of a flood is given in table 3-1.

Consequence	Damage	Losses (time dependent)
Tangible	Buildings Capital stock and inventories Vehicles Evacuation and rescue operations Infrastructures Clean up costs	Temporary housing Business interruption Adjustment of consumption patterns Adjustment of production patterns Traffic disruption
Intangible	Fatalities Injuries Inconveniences Historical and cultural damage	Utilities and communication Societal disruption Psychological traumas Less trust in public authorities Environmental losses

Table 3-1: Classification of the consequences of floods

The consequences can further be classified as direct or indirect. Direct consequences are those that arise in the flooded area, and indirect consequences arise outside of the flooded area. For some type of consequences the indirect consequences can be significant, like business interruption. Other types are usually only direct, like fatalities and injuries.

A brief example will be given to illustrate these classifications. An estuary floods the nearby farmlands during the growth season. The destruction of the crops, vehicles and clean up costs are all direct tangible damage. The consequences for the farmers are larger than this figure however, as the rest of the growth season they cannot produce. Furthermore, the flooding increased the salt concentrations in the soil for the next few years, reducing the growth of plants. These consequences are classified as direct tangible losses. The nearby food manufacturing firm (which is located outside of the flooded area) also reduces its production due to the reduction of available input goods for its production processes. The forgone production can be classified as indirect tangible losses. If the availability of sufficient food is compromised, societal disruption may rise, causing indirect intangible losses.

After a disaster, the reported (quantified) consequences are usually limited to the number of deaths and the direct tangible damage (to buildings, cars and infrastructure). Sometimes losses are estimated because in the direct aftermath of the disaster it is unknown when these losses will end (these losses continue after the physical disaster took place). Other categories, like societal disruption and a reduction of trust in public authorities, are hard to quantify.

3.2 Framework

Many different variables determine the consequences of a flood, ranging from hydrodynamic quantities to the culture of the people living the flooded area. There are four groups of variables that are particularly important:

- Hydrodynamic quantities
- Land use and objects
- Economic quantities
- Culture and flood experience

Hydrodynamic quantities like the flood depth and flow velocities are important to determine the direct tangible damage caused by the flood. Furthermore, flood duration plays a big role in the amount of business interruption and inconveniences (like the temporal unavailability of roads). The duration of a river flood is usually much longer than that of a coastal flood. The velocity with which the water rises is particularly important for the amount of fatalities and injuries [Jonkman et al. (2008)]. The geography of the area (whether there are polders or steep slopes) is also important.

Obviously the way the flooded land was used before the disaster determines the consequences as well, as does the amount of objects in the flooded area. The flooding of an empty car park will cause less damage than the flooding of a full car park, all other things equal. The same can be said for an empty school, so the amount of people evacuated is important too. The time between the start of the evacuation and the actual disaster is an important parameter, which is influenced by the time of day and evacuation training. The quality of governmental communication is important in this matter.

Economic quantities like the degree of economic integration, the unemployment rate and the availability of substitutes determine the amount of business interruption and the speed with which the region can recover after the flood [Messner et al. (2007)]. These quantities are mainly responsible regarding losses due to business interruption.

Whether a region has recent experience with floods is important mainly for the intangible consequences. The culture of the flooded area also determines some of the intangible consequences like societal disruption. In Japan people were waiting decently in line for food after the disaster in 2011, which can be explained by their disciplined culture. After other disasters, like the Hurricane Katrina in 2005, it has been said that people started looting shops in the aftermath.

3.3 Models

Several methods are available for assessing the different types of consequences of floods. An overview can be found in table 3-2. When neither direct nor indirect are stated, the method assesses both. All methods will be explained shortly. For some consequences no models are available, probably due to the complexity of the quantification of these consequences (societal disruption and less trust in public authorities). Other consequences are very complex to incorporate in a model (like the adjustment of production and consumption patterns and the disruption of utilities and communication networks).

Name	Type of consequence
Multivariate model	Tangible damage and losses
Damage function approach	Tangible damage, direct business interruption and fatalities
Zone-based damage estimation	Building damage
Input-output model	Business interruption
Computable general equilibrium model	Business interruption
Contingent valuation method	Intangible damage and losses
Hedonic pricing method	Direct intangible damage and losses

Table 3-2: Available methods [Lequeux and Ciavola (2012)]

In this section the general procedures used in the different types of methods is described. Some assumptions may be different in specific models in a certain category.

3.3.1 Multivariate model

The multivariate model uses historic events to estimate the tangible damage and losses of a flood. A multivariate regression analysis is used to determine the dependency of a variable (like damage to cars or business interruption) on independent variables (like population density, the price of houses and storm surge level). When the regression is complete, the dependency between the variables can be used to assess the consequences of a future flood. The independent variables can be expanded with storm or hurricane characteristics to take damage due to wind in to account. This method is applied to determine the possible costs of hurricanes in Lee County, Florida [Boswell et al. (1999)].

3.3.2 Damage function approach

The damage function approach is applied in software tools like the American HAZUS and Dutch HIS-SSM to determine tangible direct damage, business interruption and the number of deaths. A detailed map of the flooded area (preferably with characteristics like flood depth and flow velocities) is used in combination with damage functions to determine to what extent objects (cars, houses or land etc.) are damaged (from 0 to 100%) in a spatial grid. A damage function links the fraction of damage to conditions like the flood depth. An example can be found in figure 3-1. This fraction is multiplied with the amount of objects in that specific grid cell and the maximum damage per object. Next, all the damages are summed to find the damage for each category (like houses, vehicles and roads). The total direct damage caused by the flood can be found by summing up all the different categories.

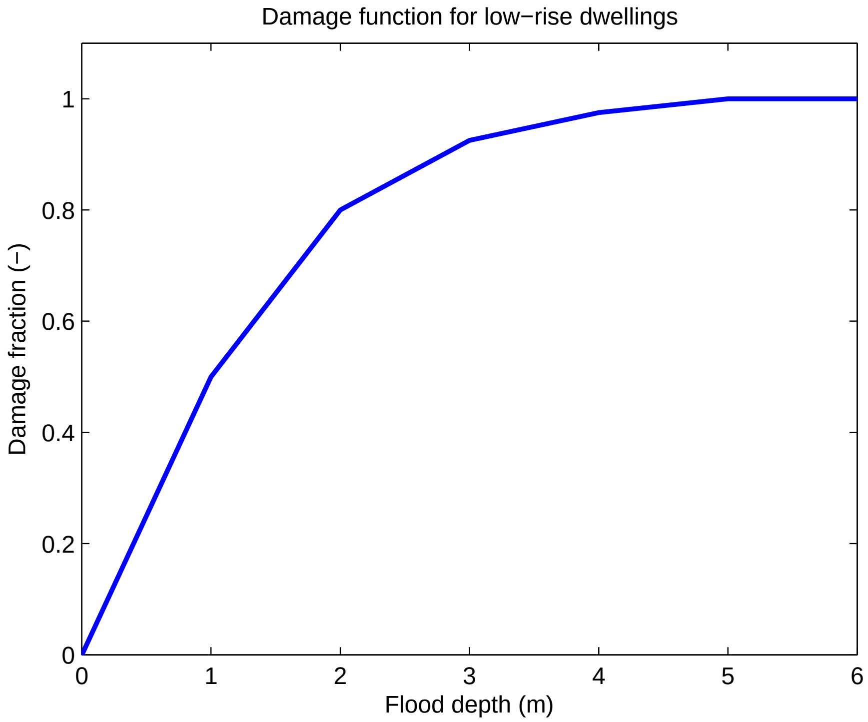

Figure 3-1: Example damage function [Kok et al. (2006)]

A similar procedure can be used to determine the direct business interruption, where the length of the interruption is dependent on the flood depth. A database with the spatial distribution of the amount of jobs in each sector is used to determine the amount of workplaces that are hit by the flood. Some models assume that the (in)direct losses due to business interruption are a constant fraction of the direct material damage, but this is only true for a small scale flood [Hallegatte (2008)].

3.3.3 Zone-based damage estimation

The zone-based damage estimation method divides the flooded area in three different parts depending on the distance to the shoreline. Moving inland, the zones are called zone of destruction, zone of structural damage and zone of flooding. Using historic flood events (of which the total damage is known), the average damage per structure in each zone is determined. These figures are used to determine the cost of a similar flood in the historic events, with the future city or town planning and coastal development. This method can be applied quickly to evaluate different town or city planning alternatives. The method has been applied to the North Carolina coast in [Hondula and Dolan (2010)], which included figure 3-2 for the geographic location of the different zones.

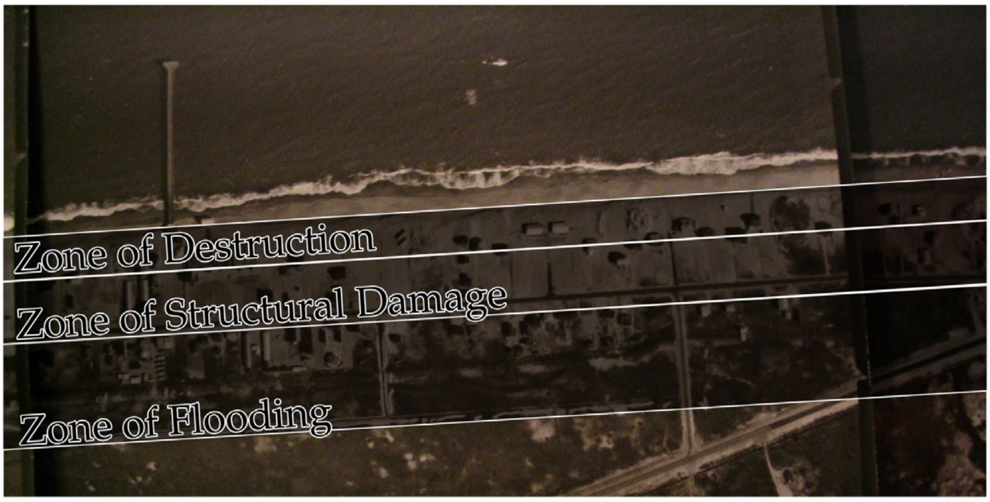

Figure 3-2: Example zone based damage estimation [Hondula and Dolan (2010)]

3.3.4 Input-output model

Input-output models are used to determine the direct and indirect tangible losses caused by a flood. These models use the interconnectedness of economic sectors (like agriculture, manufacturing and construction) to determine the amount of production loss after the flood. In the past the effects of a flood were modeled as a demand reduction (so the destruction of a coal power plant only led to a reduction of the electricity industry's production and a reduction of the coal mining industry's production, because the products of the latter are no longer required), but more recent models can put restrictions on other industries that use the products of the electricity industry. Even more sophisticated models determine the recovery of the economy to be able to come up with an estimate of the direct and indirect tangible losses. An example of these models can be found in [Bockarjova (2007)], in which a hypothetical flood in the Netherlands is treated.

3.3.5 Computable general equilibrium model

Computable general equilibrium models are an extension of input-output models, which are less rigid than input-output models but also more complex. These models are extended to take into account price and quantity effects to determine the tangible losses due to business interruption. This method has been applied to determine the effects of heavy rainfall and river flooding in Helsinki [Simola et al. (2011)].

3.3.6 Contingent valuation method

The contingent valuation method attempts to monetize the intangible direct damage and losses of a flood. The method uses questionnaires to determine the willingness to pay of individuals to prevent certain intangible effects, like injuries, inconveniences, environmental losses and the unavailability of communication networks. This method is often referred to as a stated preference method, as the outcomes are not based on actual choices but on what people state that they would choose. A different method that works similarly is a conjoint analysis, in which respondents can choose between two options a number of times to reveal their willingness to pay. This method has been applied in the United Kingdom by the Department on Environment, Food and Rural Affairs and the Environment Agency to determine the intangible effects on human health and well-being caused by a flood [Defra and Environment Agency (2004)].

3.3.7 Hedonic pricing method

The hedonic pricing method is also used to monetize intangible direct damage and losses, this method is based on revealed preference however instead of stated preference. In general, data based on revealed preference is assumed to be of better quality than data based on stated preference. This method assumes that the surrounding environment of a building has an influence on the price of this building. A large dataset is used to do a regression analysis that gives the price of house depending on local variables (like amount of rooms, quality of the neighborhood and environmental goods like a nearby forest). The value of an environmental good or service can then be determined using this function. For example, to determine the value of a forest the function is evaluated for all buildings in close vicinity of this forest, in cases with and without the presence of the forest. The difference in the sum of the house prices in the two cases is then assumed to be the value of the forest. This method has been applied on coastal areas in the USA in [Bin et al. (2008)].

3.3.8 Evaluation

The outcome of the more simpler multivariate analysis and zone-based damage estimation appear to be too inaccurate to be used in the discussion regarding flood prevention policy. They are useful directly after an actual disaster to get a preliminary estimate of the tangible consequences. Regarding direct tangible damage, the damage function approach seems to be the most appropriate method regarding accuracy [Messner et al. (2007)]. For direct and indirect losses due to business interruption, (sophisticated) input-output models give good results without requiring the tremendous effort a computable general equilibrium model requires [Lequeux and Ciavola (2012)]. Both the contingent valuation method and the hedonic pricing method can be used to attempt to monetize intangible consequences, but both have a disadvantage. The first method does not force respondents to show their preference, but merely state them (they do not have to put their money where their mouth is). The second method assumes that all of the environment is assumed to be incorporated in local real estate prices, implicitly assuming that all buyers and sellers of the real estate are aware of these environmental effects.

4 Business interruption

This chapter contains a description of the phenomenon business interruption and several models to predict the economic losses due to business interruption.

4.1 Definition

Losses due to business interruption are the forgone value added that is not created due to the flood. Added value is the difference between the turnover (which is the product of unit price and the amount of units sold) and the expenses on input products. The total value added is equal to the rewards for the factors of production, namely labor (wages), land (rent) and capital (interest, dividends and profits).

The standard of living in a certain country is often measured as the total of the value added per capita in a year, despite several shortcomings. Most of these shortcomings are due to intangible effects, like quality improvements. Computers currently manufactured are much faster than computers manufactured ten years ago, but the average price has dropped. It is likely that the added value of this sector has dropped as well, making it look like the computer manufacturing sector has not improved the last decade. Also environmental effects are not taken into account by using the added value as a performance indicator. Furthermore, leisure time is not taken account. For example, a certain country is able to produce the same added value per capita while inhabitants work only half as much hours per week than they did a year ago. The standard of living does not appear to have changed according to the value added per capita, while it has certainly improved.

Most firms create value added. Input products are bought at a certain price, then labor, capital and land are employed to increase the value of the input products and the final products are sold. When this production process cannot take place, for example due to damaged capital goods, there is no value added created. This makes the recovery period important when assessing the costs of a flood. If all the damaged capital goods are restored immediately after the flood, the cost of the flood (for the individual firm) is merely the material damage to the capital goods. If it takes two years before the capital goods are restored and production can continue again, the costs are equal to the material damage and two years worth of added value. The total costs are not equal to the material damage and two years worth of turnover, because the firm does not have to buy any input products. When business interruption occurs within the flooded area, these losses are called direct losses due to business interruption.

Business interruption can also occur because suppliers or clients (clients are assumed to be other firms in this case, not consumers) are not producing due to the flood. Firms can have losses due to the flood, while their firm is not located in the flooded area. These losses are called indirect losses due to business interruption. These losses can play a significant role depending on how heterogeneous the shock is. When the shock is completely homogeneous, the indirect losses are very small. This is illustrated in figure 4-1 using a simplified economy, in which all firms produce the same added value and hold the same capital stock.

This simple economy consists of three sectors. Farms produce wheat which is sold to the mills, the mills create flour from the wheat and sell this to the bakery. In the bakery the flour is used to make bread. This economy only produces bread to sell to consumers.

A homogeneous shock reduces the production capacity of all the sectors by a same percentage, as can be seen in figure 4-1. The firms marked with the red cross are out of operations because

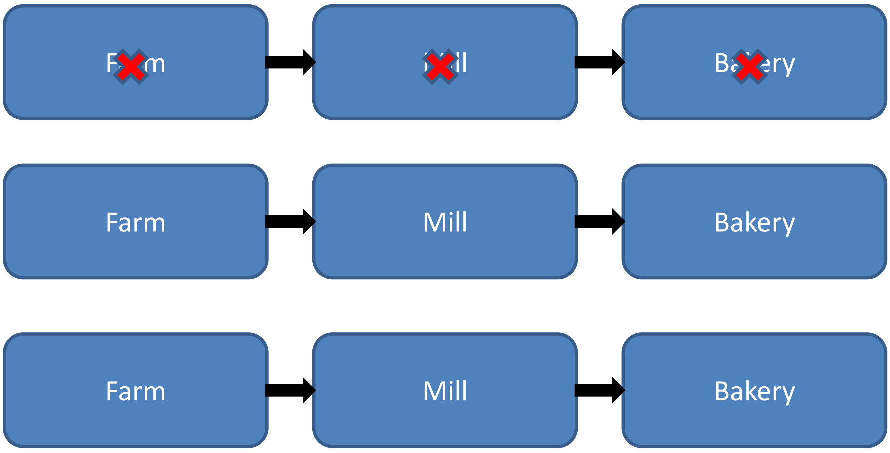

Figure 4-1: Example of a homogeneous shock

their capital stock is damaged by the flood water. In this case, a third of the total capital stock of the economy is damaged and the output of the economy is reduced by one third. There are no indirect losses (assuming the three damaged firms are repaired at the same time), as the firms outside of the flooded area can continue their production.

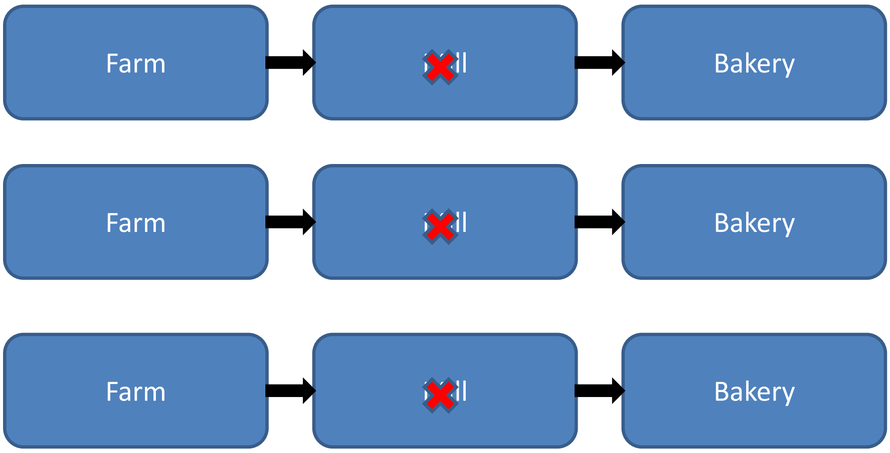

Figure 4-2: Example of a heterogeneous shock

The consequences of a heterogeneous shock can be much more devastating. In this case, the production capacity reduction caused by the flood is not the same for all sectors. An example can be found in figure 4-2. The farm and bakery sector are not directly hit by the flood, they bear no direct damage or direct losses due to business interruption. The mill sector bears all the direct damage, the production capacity is reduced to zero. The other sectors now suffer from indirect losses. The farms do not have any clients anymore, as the mills are not willing to buy wheat. The bakeries cannot produce bread, because the mills can no longer supply them with flour. When no substitution products can be found, the total production of this economy will be zero even though only one third of the capital stock is damaged. The indirect losses due to business interruption (two thirds of the value added) are in this case larger than the direct losses due to business interruption (one third of value added).

The losses due to business interruption are dependent on many different variables. The scale of the flood is important, because the construction sector can prove to be too small to repair all the damage at once. The degree of economic integration (a measure of how dependent firms are on each other) and the state of the economy contribute as well. The availability of substitutes can reduce the indirect economic losses.

Several different methods are available to predict the losses due to business interruption. Among these methods are the losses module of the 'Standaardmethode Schade en Slachtoffers' (S3) used in HIS-SSM, the 'Basic Equation' (BE) method by Bockarjova, 'the economic losses module of the HAZUS software' (HAZUS) used by the government of the United States and the 'Adaptive Regional Input-Output model' (ARIO) by Hallegatte. These methods are explained in detail in the next sections, after which a short evaluation of the methods is presented.

4.2 Standaardmethode Schade en Slachtoffers

The S3 method uses damage functions to approach the losses due to business interruption [Kok et al. (2005)]. This method makes a clear distinction between direct losses due to business interruption and indirect losses due to business interruption. To model the direct business interruption, the duration of interruption is assumed to depend on the water depth in the flooded area. For example, if in a certain grid cell the water depth due to the flood is one meter, then the business interruption is assumed to be two months. The total number of jobs (distributed over several sectors) in the specific grid cell is then multiplied with the length of the business interruption and the added value per month per job. The indirect business interruption is modeled in the same way, except that the added value per job is different. This figure is determined by looking at how other economic sectors depend on the 'flooded' job. This dependency is high for sectors like mining, utilities and industry because almost all other economic sectors use their products one way or the other. The dependency is low for health care and government, because firms in these sectors mostly serve the consumer market.

The current scale (100 by 100 meters) at which this method is applied can be found in figure 4-3. The area on the map is the Delftechpark business area in Delft.

There are three fundamental objections against the S3 method. First, the dependency of the duration of business interruption on water depth seems to exclude other important aspects like the scale of the disaster. If the flood is of large scale, the construction sector is not big enough to repair all the damage at once. The duration of business interruption is then not only dependent on the actual amount of damage to the individual firm (which is approximated using the flood depth), but also on the time between the flood and the start of reconstruction activities. This time can be quite long if the production capacity of the construction sector is not large enough to meet the demand for restoration activities. Second, the indirect losses module does not take into account the fact that other firms in the production chain are also damaged by the flood and reduce their demand if they are damaged. If a homogeneous shock takes place (all sectors decrease their production by the same percentage), there are no indirect losses assuming the firms that are not damaged switch to undamaged suppliers. To account for this, the indirect losses due to business interruption are multiplied with 0.25, but in reality this factor should depend on how homogeneous the shock is. Finally, the housing services lost are not taken into account, while these have the same characteristics as losses due to business interruption [RebelGroup Advisory (2009)].

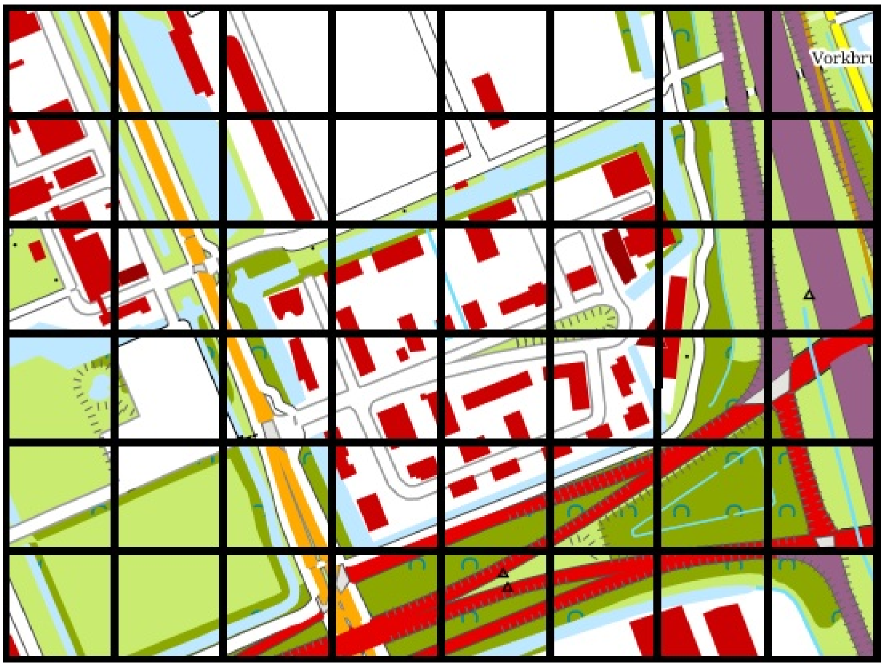

Figure 4-3: Grid example S3 method. ©TOP10NL

4.3 Introduction to the Leontief input-output model

The following three methods are based on the Leontief input-output model of the economy. A brief description of this model is given. In the 20th century, Leontief gave a static description of the economy using so called input-output tables [Leontief (1951)]. The basic structure of these tables can be found in table 4-1.

Sector	Agriculture	Industry	Services	Final Demand
Agriculture	0.2	0.12	0.05	100
Industry	0.35	0.3	0.14	200
Services	0.15	0.25	0.45	250

Table 4-1: Example basic Leontief input-output table

This table contains several elements. The agriculture, industry and services columns list the inputs required to create one unit of production for the specific sector. Usually the unit of production is expressed in monetary terms. For example, to create one unit of production in the industry sector, 0.12 units of production of the agriculture sector, 0.3 units of production of the industry sector and 0.25 units of production of the services sector are required. Thus the total input from other sectors to create one unit of production in the industry sector are 0.67 units of production. This total value cannot exceed one.

The final demand is the total amount of production that the economy would like to consume. The total amount of production should actually be bigger than the final demand to be able to meet this demand, as some of the production is used by the production processes itself. Let the coefficients be noted as the matrix A, the final demand as the vector y and the total production as the vector x, then the amount of production required as intermediate goods (goods used in the production process) can be calculated by the operation Ax. If the production would be equal to the final demand ($x = y$), the intermediate consumption would be 56.5 units of production of the agriculture sector, 130 units of production of the industry sector and 177.5 units of the services sector. The actual production available for consumption is thus much smaller than the final demand.

The production available for final demand is equal to $x - Ax$. When we want this difference to be equal to the final demand, the equation $x - Ax = y$ has to be solved, in which the actual production x is the unknown. Rewriting this equation leads to equation 4-1, in which I is the unit matrix.

$$x = (I - A)^{-1}\, y \tag{4-1}$$

Computing this equation gives a production x equal to 260 units of production of the agriculture sector, 573 units of production of the industry sector and 786 units of production of the services sector. When this amount of production is realized the production available for consumption equals the final demand.

The matrix $(I - A)^{-1}$ gives us important information, which has been evaluated in equation 4-2.

$$(I - A)^{-1} = \begin{bmatrix} 1.43 & 0.32 & 0.21 \\ 0.87 & 1.77 & 0.52 \\ 0.79 & 0.89 & 2.12 \end{bmatrix} \tag{4-2}$$

These coefficients or sensitivity parameters reveal how much the production has to be increased if the final demand changes. For example, if the final demand in the agricultural sector increases by 10 units of the production, the production of the agricultural sector has to increase by 14.3 units of production, the industry sector by 8.7 units of production and the services sector by 7.9 units of production.

The basic Leontief input-output model offers the possibility to follow the propagation of demand shocks through the economy. A demand shock is a sudden change in the final demand (for example increased government spending during a time of war). The model can be used to determine which sectors have to increase or decrease their production to be able to meet this demand and by how much the production should be changed. A supply shock is a sudden change in the supply or the cost price of a good (like a sudden increase of the oil price or a large-scale harvest failure due to drought. The basic Leontief input-output model cannot be used for supply shocks. The amount of sectors can be increased to give a good representation of a modern economy.

4.4 Basic Equation method

Bockarjova published her theory in 2007 [Bockarjova (2007)]. The input for this method are the amount of lost jobs in the flooded area, which can be computed by combining maps of the flood with the spatial distribution of jobs. The S3 method also utilizes this strategy. Her method identifies which part of the initial production is still possible after a flood. It does so by investigating what part of production is required by each sector. For example, the production of the agriculture sector leads to 50 units of production in the agricultural sector, 70 units of production in the industry sector and 60 units of production in the services sector. When this sector is damaged for 10% (so the production of this sector is reduced by 10%), the method determines which part of production survives and which part is lost. The final demand is also changed due to the flood. The indirect losses due to business interruption are determined after the flood, only as a percentage of production however.

The outcome of the method is a share of production lost immediately after the flood. There is no time dimension in the model, so this share of production lost cannot be written as a number in euros, which is a huge disadvantage. Furthermore, the consequences of the flood are modeled as a demand shock (as the final demand is adapted). In reality, the flood is primarily a supply shock (the maximum production is decreased). This can lead to strange outcomes. The example given in her publication [Bockarjova (2007)] starts with a pre-disaster production of 400 units and 1000 units in the two sectors of the economy. The flood destroys 40% of the production capacity of the first sector and 20% of the production capacity of the second sector. After applying the method, according to Bockarjova the leftover productions are respectively 290 and 750 units. Interestingly, if 40% of the initial production capacity of 400 units is destroyed a production capacity of 240 units would be leftover, which is significantly less than 290 units. Finally, lost housing services are not taken into account.

4.5 Economic losses module of HAZUS

HAZUS uses a description of the economy consisting of ten different sectors. The most important step of the module is illustrated in figure 4-4.

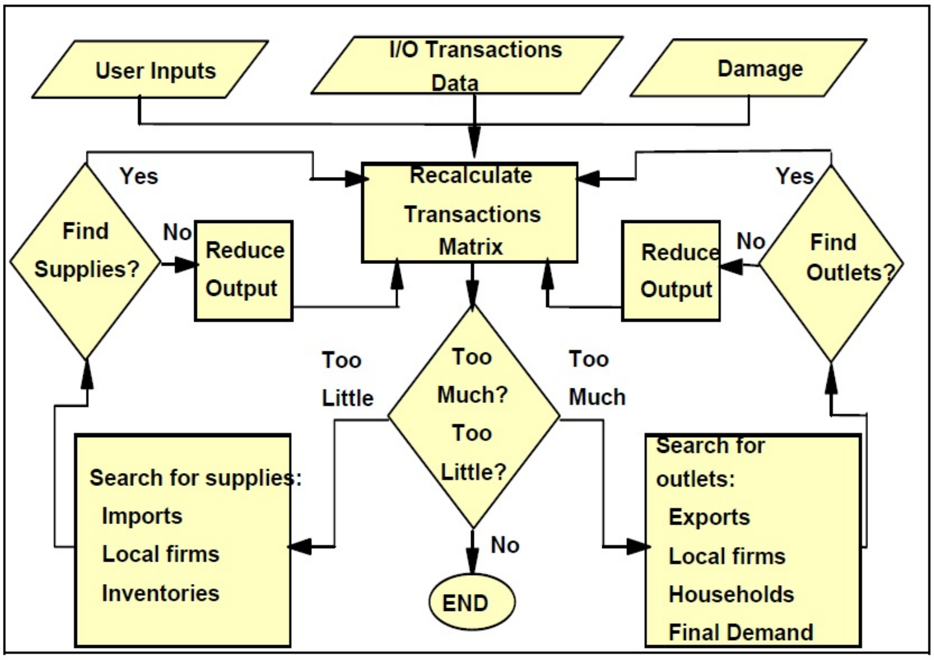

Figure 4-4: HAZUS scheme [Department of Homeland Security and Federal Emergency Management Agency]

The model calculates the production based on user input (like the unemployment rate before the flood), the input-output transaction table and the material damage. The algorithm makes several loops to include other supplies and outlets to find a set of productions in which the system is in equilibrium (or the coefficients in the initial input-output transaction table are satisfied). The damage has to be specified in all points of time as a percentage of production capacity decrease for each sector. The model is then evaluated in all the points in time to determine the income, employment and output of the region. The module includes the effect of borrowing for rebuilding and the effect on tax revenue.

A major disadvantage of the method is that the equations used are not written down, but embedded in the software. This makes it hard to determine to what extent several parameters are dependent on the input. Furthermore, the software can only be used with input-output tables of the private firm IMPLAN, which are not available freely. The amount of sectors (ten) is also quite small, while this cannot be changed.

4.6 Adaptive Regional Input-Output model

The ARIO model has been applied for the first time to assess the losses due to business interruption in the aftermath of Katrina [Hallegatte (2008)]. This method also uses the Leontief input-output model. The model starts by determining how much production capacity is left in each sector. This production capacity can be smaller due to direct damage by the flood (which is a reduction of the capital stock of a sector) or due to the unavailability of intermediate goods. After the actual production is determined, the production is distributed over the final demand. Other firms have a priority, they are served first (to avoid the loss of production capacity). Other components of the final demand, like local consumption, exports and household and firm damage are rationed proportionally. Household and firm damage are the actual direct damage caused by the flood, which increase demand in the construction sector (for repairing buildings) and manufacturing sector (for replacing building inventories).

Production that is used for reconstruction purposes for household and firm damage reduces the remaining amount of damage. The production capacity of each sector depends on the material damage in the sector, so the actual recovery of the economy is modeled. Furthermore, prices, profits and labor demand are calculated. These values are used to determine the adaptation of local consumption, exports and intermediate goods consumption. The model works with a time step, after which the remaining damage is updated to calculate new production capacities again until there is no damage left. The total losses can be found by comparing the value added after the disaster to the pre-disaster value added.

The method contains many explicit assumptions (like the priority of other firms when rationing) and equations to describe behavior of economic quantities (like prices and substitution). The fundamentals of the model appear to be correct however.

4.7 Evaluation

The damage function approach used by the S3 method to determine the losses due to business interruption is questionable. The amount of direct damage can be approximated quite well with this approach, but the water depth is not the only variable contributing to the length of the period that a business cannot produce value added. Other important contributors like the size of the production capacity still available and how homogeneous the shock is are not taken into account. The loss of housing services are not taken into account.

The BE method does not model the recovery period at all, it merely determines the indirect production losses based on the direct production losses. This gives an indication of the size of the indirect losses due to business interruption in terms of the direct losses due to business interruption. The outcome of the method cannot be used in the cost benefit analysis regarding flood safety, because it is not a monetary value. Furthermore, the shock is modeled as a demand shock even though a flood also causes a supply shock. This can make the outcome unrealistic. This method does not include the loss of housing services.

It is hard to assess the quality of the HAZUS method because not all the equations used in the model are published. Furthermore, the input data is not freely available but is sold by the private firm IMPLAN. This firm currently does not have data available for all the major economies in the world. Next to that, an ArcGIS license is required to be able to use the model.

The ARIO model seems to be quite complete but requires many input parameters. There are many assumptions in the model, but most of these only have a minor influence on the result.

The ARIO model is the most appropriate choice in this context. The underlying equations of the model are published and many of the important characteristics are taken into account.

5 Lopik dike breach case description

This chapter contains a description of the Lopik dike breach case. The other two cases are described very briefly in their respective appendices. The Lopik dike breach case is treated more extensively because the size of this flood is comparable to the recent large-scale floods treated in chapter 2.

In this case the hypothetical flooding of a part of the Randstad will be treated. To be able to get a good resemblance with the recent floods in chapter 2, the direct material damage caused by the flood should be at least a few percentage points of the Dutch GDP.

The Dutch project *Veiligheid Nederland in Kaart* (VNK2: Flood risk in the Netherlands) determines the flood risks in the Netherlands for each dike ring area. This done by considering a number of events that may lead to the flooding of a dike ring area, determining the probabilities of occurrence of these events and the consequences. The hydrodynamic properties (water depths, flow velocities etc.) are determined with the hydrodynamic model SOBEK and the consequences are assessed using HIS-SSM. The consequences of the following case are one of the largest of all the cases considered in the project *Veiligheid Nederland in Kaart*.

5.1 Flooding of the province of South-Holland

A dike breach near Lopik occurs, causing the river Lek to flood dike ring area 15. The discharge has a return period of 2000 years (the discharge of the river Rhine at Lobith is 16,500 $\frac{m^3}{s}$). The water level in the river is equal to 5.2 m + NAP [Rijkswaterstaat (2006)]. Dike ring area 14 is flooded as well, due to the cascade effect. Minor flooding occurs in dike ring area 44 through this effect.

A map containing the spatial distribution of dike rings in the Netherlands can be found in figure 5-1. This map also contains the design failure probabilities for each dike ring. The area indicated by the blue box is the area hit by the flood.

The flood is modeled up to 12 days. T is the time in hours with T = 0 at the moment of the breach. The situation before the breach can be found in figure 5-2. After 12 days a large part of the area is flooded as can be seen in figure 5-3. Figures containing the daily flood depth can be found in appendix D.

Most of the flooded area belongs to the *Groene Hart* region (Green Heart). This is a relatively thinly populated area in the otherwise densely populated area of the Randstad. The area is surrounded by Rotterdam, The Hague, Amsterdam and Utrecht. There are several smaller cities in the area however, such as Woerden, Gouda and Zoetermeer. Some of these cities are flooded due to the dike breach. Most of the land in the *Groene Hart* is used for recreational or agricultural purposes.

Several highways are flooded. The A12 (between Gouda and Utrecht) and N11 (between Gouda and Leiden) are flooded extensively (respectively 60 and 20 kilometers). Regional roads such as the N207 (from Bergambacht to Alphen aan de Rijn) and the N210 (from Rotterdam to Nieuwegein) are also flooded.

Railroads are flooded as well. Mainly the railroads between Woerden and Amsterdam, between Woerden and Alphen aan de Rijn and between Utrecht and Gouda. The latter connection is a vital link between the major cities in the Netherlands. The total amount of kilometers of railroads flooded exceeds 45 kilometers. In general, the water depth on roads and railroads is between one and two meters.

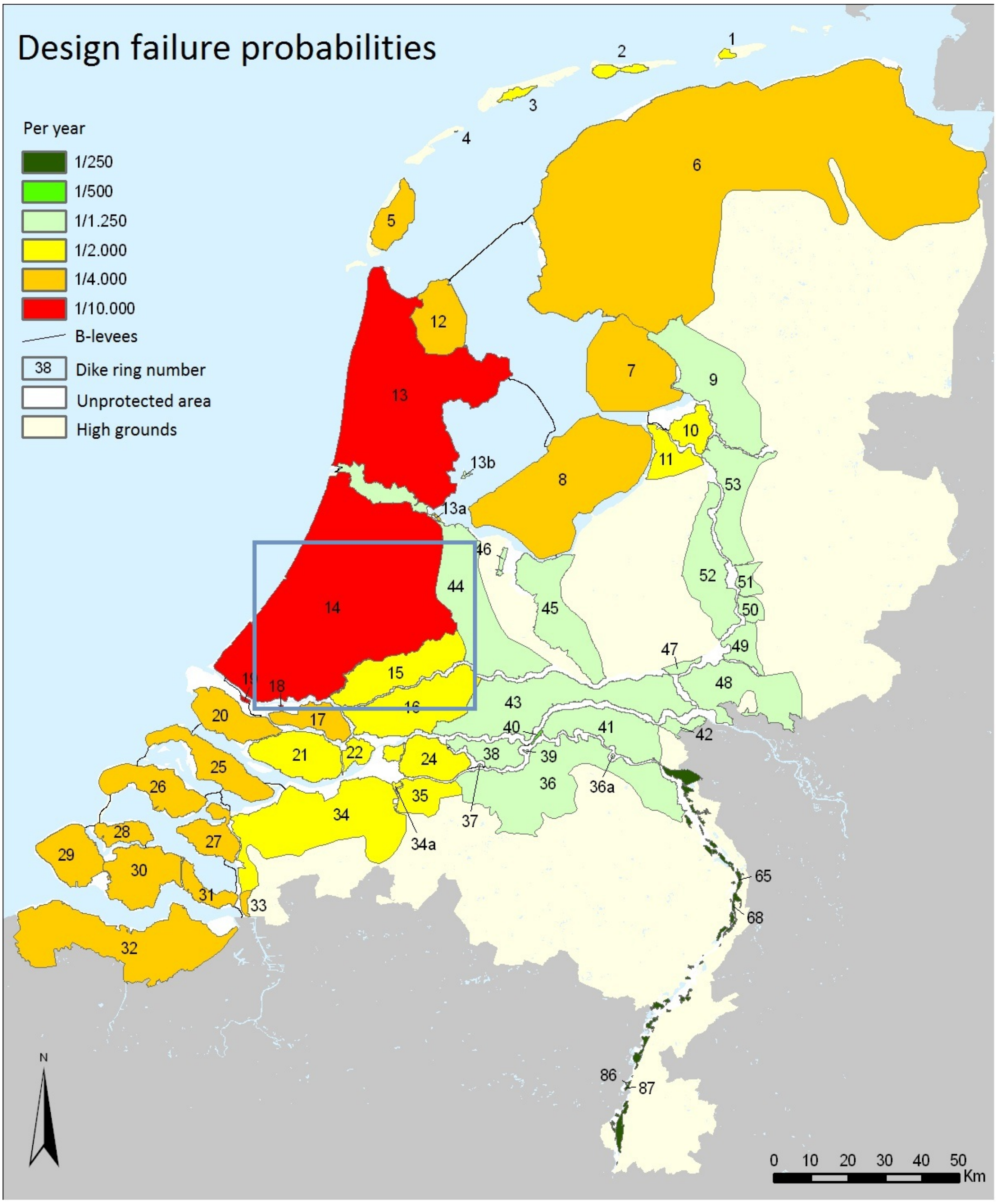

Figure 5-1: Dike ring areas in the Netherlands [Deltares (2011)]. The blue box indicates the area hit by the flood.

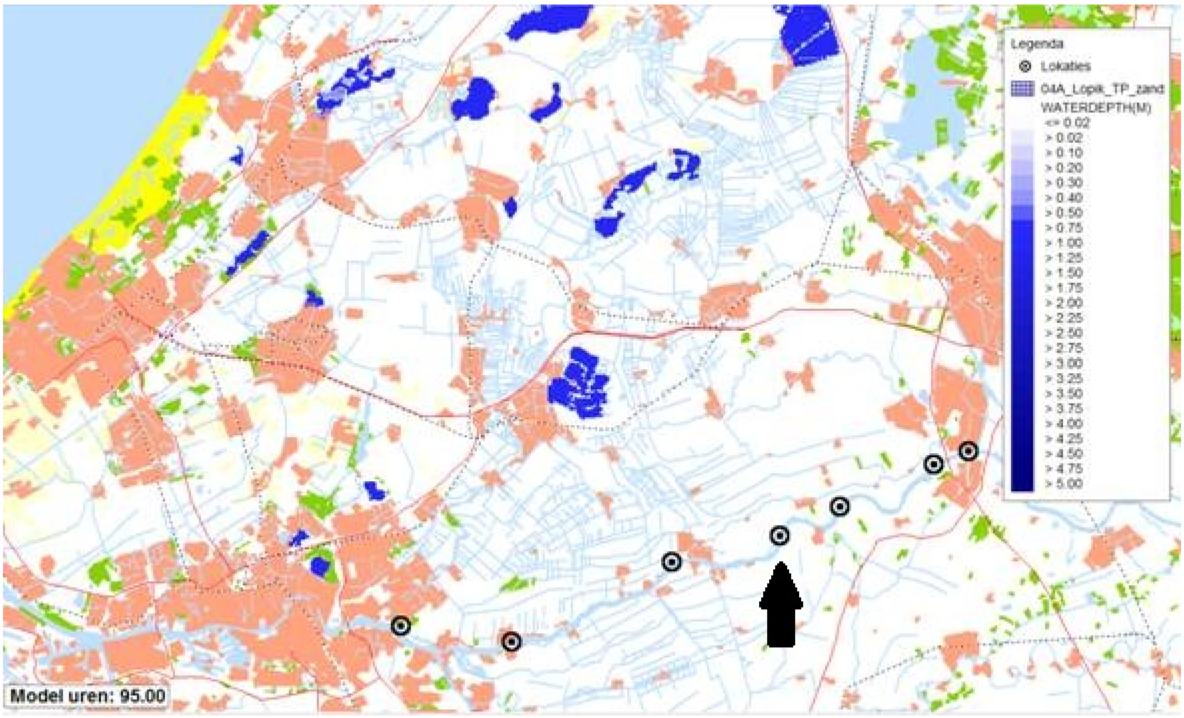

Figure 5-2: Flooding at T = 0. The arrow indicates the breach location.

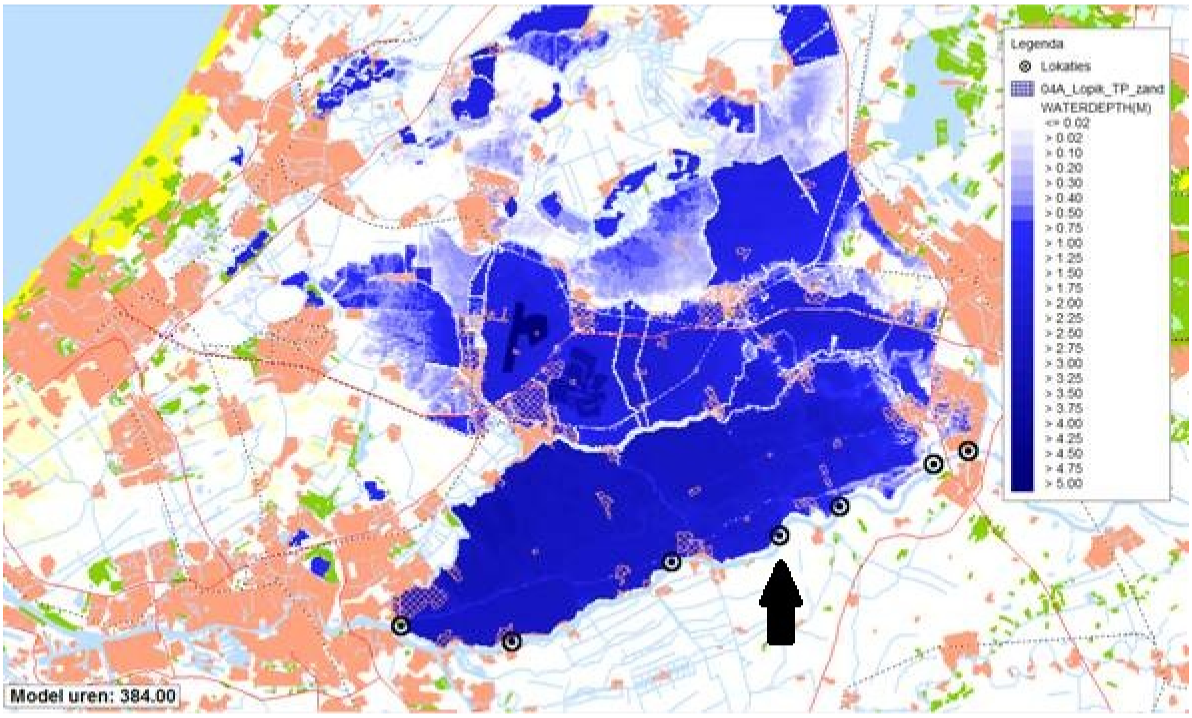

Figure 5-3: Flooding at T = 288. The arrow indicates the breach location.

6 HIS-SSM

In this chapter HIS-SSM will be used to predict the consequences of the floods in the considered cases. Only the results of the Lopik dike breach case will be analyzed in detail, the results of the other cases can be found in their respective appendices. First the working of the method will be explained in more detail. The module to determine the loss of life will not be treated.

6.1 The HIS-SSM method in details

HIS-SSM considers direct material damage (to cars and buildings for example) and losses due to business interruption (both direct and indirect). The method combines GIS data with flood parameters to be able to calculate the expected costs.

The direct material damage is calculated with equation 6-1, in which D is the total damage in the considered cell, α_i is the damage factor for category i, n_i the number of units in category i and S_i the maximum damage per unit in category i.

$$D = \sum_{i=1}^{n} \alpha_i n_i S_i \tag{6-1}$$

The damage factor α_i is based on the water depth. This factor is calculated using damage functions. An example of a damage function can be found in figure 6-1. According to this damage function, a flood depth of five meters or more indicates that the building is completely damaged. If the water depth is one meter, fifty percent of the building is damaged.

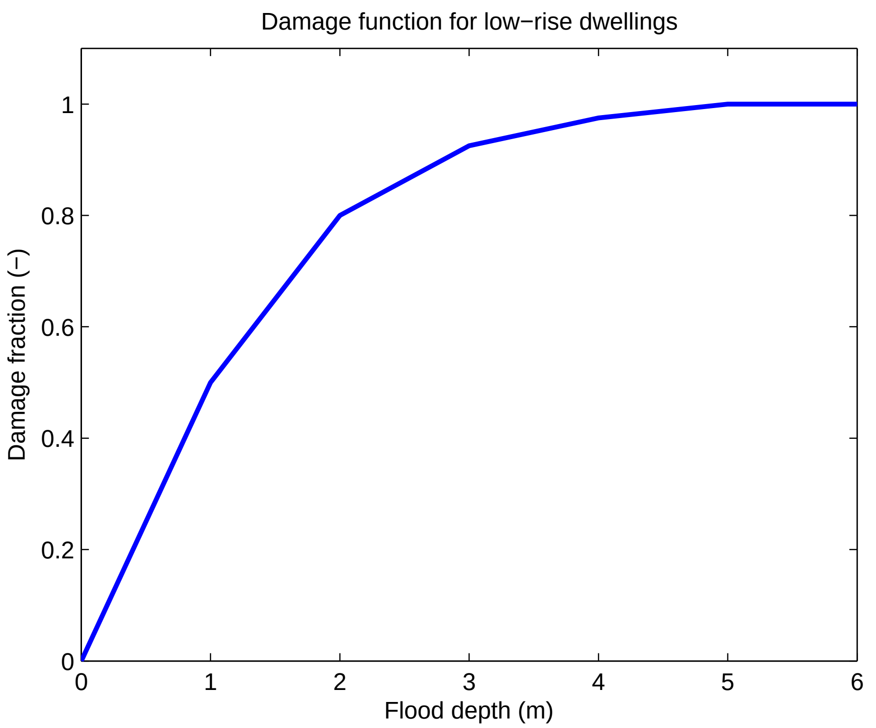

Figure 6-1: Example damage function [Kok et al. (2006)]

The number of units n_i is based on a GIS database. The flooded area is divided into cells (size 100 meters by 100 meters), as can be seen in figure 6-2 in which the grid in Woerden is shown at the actual scale. The amount of objects in all categories is counted for each grid cell, which is stored as n_i. For example, $n_{low-rise\ dwellings}$ equals five in cell C6 and zero in cell B6.

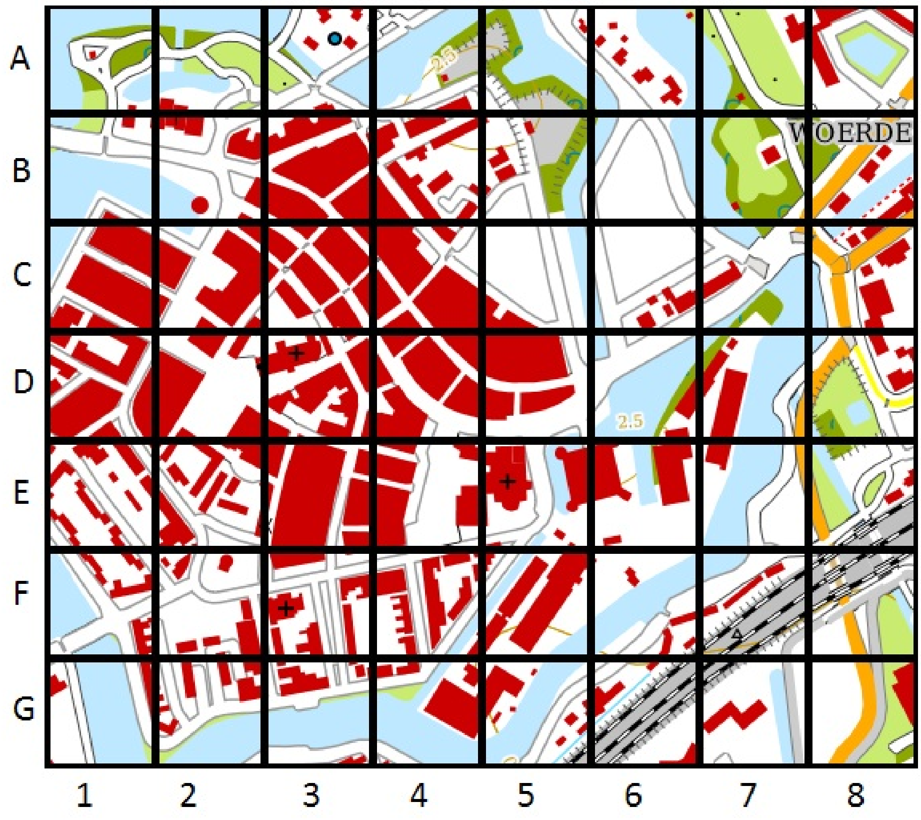

Figure 6-2: Example grid (size 100 by 100 meters). ©TOP10NL

The maximum damage per unit is constant in all the cells. For low-rise dwellings this is 215,000 EUR.[1] When the assumption is made that the water depth in cell C6 is equal to one meter, the damage to low-rise dwellings in this cell can be calculated. The damage factor α is equal to 0.5, the number of units n is equal to five and the maximum damage per unit S is equal to 215,000 EUR. The multiplication of these numbers gives 537,500 EUR damage to low-rise dwellings in this grid cell.

This procedure is repeated for all categories, after which the numbers are summed to get the value of D in the cell. After this has been done for all the grid cells, the total direct damage can be calculated by summing the values of D of all the cells.

The direct losses due to business interruption are determined in a similar fashion. The number of units n_i is expressed as the amount of jobs in the grid cell (distributed over several sectors). The maximum damage per unit S_i is based on the value added per job and the maximum time the business is interrupted by the flood. For services sectors this maximum time equals two months, for all other sectors one year [RebelGroup Advisory (2009)]. The actual damage factor α_i is again determined by a damage function which depends on the water depth.

The indirect losses are calculated by multiplying the direct losses due to business interruption and a factor which is based on the Dutch input-output tables [RebelGroup Advisory (2009)]. Afterwards, the losses per cell are multiplied with 0.25. This is done to take into account that

[1] This figure is transformed from the price level in 2000 to the price level in 2011 using the actual inflation (CPI)

some of the firms that are interrupted due to indirect effects are already interrupted by direct effects and because substitution takes place.

6.2 Results

In this section the results of the application of HIS-SSM to the Lopik dike breach case are presented. The raw, ungrouped data can be found in appendix D.

The figures are transformed to 2011 from the reference year 2000, using the actual inflation (CPI) in the Netherlands. An overview is given in the following tables, in which all numbers are in million EUR unless stated otherwise. The types of consequences considered in HIS-SSM are direct damage, direct losses due to business interruption and indirect losses due to business interruption. The sum of all these consequences equals 17.8 billion EUR. A breakdown can be found in table 6-1. All these categories will be elaborated on.

Category	Costs	Share of costs [%]
Direct damage	17,128	96.3
Direct business interruption	344	1.9
Indirect business interruption	308	1.7
Total	17,779	100

Table 6-1: Costs due to a dike breach near Lopik according to HIS-SSM. Costs in million EUR.

6.2.1 Direct damage

Direct damage consists of damage due to land use, firms, households and infrastructures. Damage to farms is considered damage to firms, though these buildings also fulfill a housing function. An overview can be found in table 6-2.

Category	Damage	Share of damage [%]
Land use	3,438.8	20.1
Firms	2,108.4	12.3
Households	10,681.7	62.4
Infrastructures	899.0	5.2
Total	17,127.8	100

Table 6-2: Breakdown of direct damage. Damage in million EUR. This table only contains the material damage, the losses due to business interruption are not considered in this table.

The share of damage to infrastructures is relatively small. This might be due to the fact that only airports, roads, railroads and water treatment plants are considered in this category. Damage to the electricity grid and the networks to distribute natural gas and water are considered in the land use category.

Land use has a substantial contribution to the damage caused by the flood. As expected, most of the damaged land (in square meters) is used for agricultural purposes. Most of the damage is found in the urban sector however, as the damage per square meter is much higher for this sector. An overview of the damage to land use can be found in table 6-3.

Household damage consists of damage to cars and houses, with the latter category contributing most (92.8%) to household damage.

Category	Damage	Share of damage [%]	Damaged area [million m^2]	Share of damaged area [%]
Agriculture	926.0	26.9	688.3	88.1
Greenhouses	245.4	7.1	10.1	1.3
Urban	2,067.3	60.1	53.9	6.9
Recreation	199.9	5.8	28.7	3.7
Total	3,438.6	100	781.0	100

Table 6-3: Breakdown of direct damage to land use. Damage in million EUR.

The breakdown of damage to firms by category is given in table 6-4. Damage to the agriculture sector does not include damage to land use, only damage to farms (which is measured by the amount of farms instead of the amount of jobs). Most of the direct damage is borne by the agricultural, financial, transport and communication and industry sector.

Category	Damage	Share of damage [%]	Affected jobs [#]	Share of affected jobs [%]
Agriculture	498.8	23.7	-	-
Mining	0.8	0	2	0
Construction	7.8	0.4	5,467	3.7
Retail and food services	143.8	6.8	54,850	36.9
Transport and communication	381.4	18.1	7,598	5.1
Financial services	464.1	22.0	41,420	27.9
Government	167.2	7.9	20,151	13.6
Industry	409.0	19.4	13,076	8.8
Utilities	20.0	0.9	310	0.2
Healthcare and others	15.4	0.7	5,760	3.9
Total	2,108.4	100	148,634	100

Table 6-4: Breakdown of direct damage to firms. Damage in million EUR.

Comparing the share of the damage and the share of affected jobs gives some interesting figures. The construction, retail and food services and healthcare and other services sectors bear relatively little damage compared to the amount of jobs affected. The damage per job is small compared to sectors like transport and communication, industry and utilities. The maximum amount of damage per job can be found in table 6-5, in which the agriculture sector is not present because this damage is not based on the amount of jobs. The capital intensity is calculated by dividing the amount of capital stock used in a sector by the amount of people working in that sector.[2] Sectors with a high capital intensity show a high maximum damage and bear relatively high damage in the case of flooding.

The actual damage per job is also dependent on the local flood depth. The damage function for firms is illustrated in figure 6-3. The damage function reaches the value of one when the flood depth exceeds five meters. This flood depth is not reached in this case, which explains why the average damage per job is much smaller than the maximum damage.

[2] Both figures are available at Statistics Netherlands

Category	Maximum damage	Capital intensity
Mining	2,275	4,702
Construction	13	40
Retail and food services	25	36
Transport and communication	94	150
Financial services	113	118
Government	75	310
Industry	349	155
Utilities	775	1,300
Healthcare and others	25	42

Table 6-5: Maximum damage and capital intensity per job. All figures in EUR thousands. See text for an explanation on the capital intensity. [Geodan and Royal Haskoning (2007)]

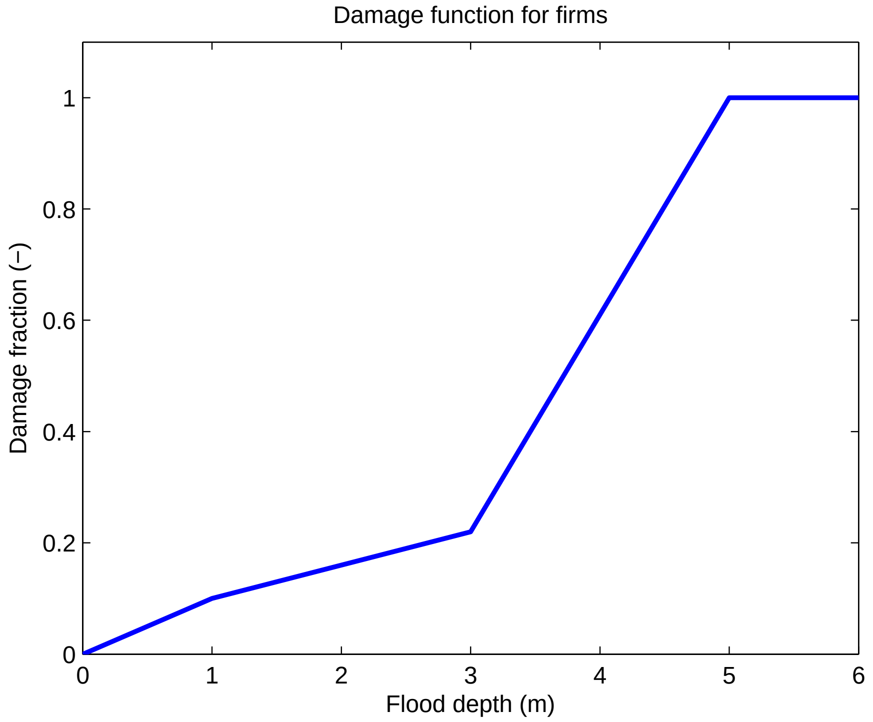

Figure 6-3: Damage function for firms [Geodan and Royal Haskoning (2007)]

6.2.2 Losses

The losses due to business interruption (totaling 651.5 million EUR) are much smaller than the direct material damage. This figure includes both direct and indirect losses due to business interruption. Total losses due to business interruption equal 3.8% of total direct damage.

An overview of the total cost per sector (the sum of direct damage, direct losses due to business interruption and indirect losses due to business interruption), the direct losses due to business interruption and indirect losses due to business interruption is given in table 6-6. The losses due to direct business interruption in the agriculture sector are not assessed. The direct damage to the agriculture sector includes only farms, damage to agricultural land is not included.

The indirect losses due to business interruption in the agriculture sector are relatively large. More than 80% of the total indirect losses due to business interruption are caused by the agri-

Sector	Damage	Direct losses	Direct losses/sum [%]	Indirect losses	Indirect losses/sum [%]
Agriculture	498.8	-	-	256.1	33.9*
Mining	0.8	0.05	5.9	0	0
Construction	7.8	20.3	55.0	8.8	23.8
Retail and food services	143.8	53.9	26.4	6.3	3.1
Transport and communication	381.4	58.8	13.3	1.7	0.4
Financial services	464.1	72.2	13.2	9.0	1.7
Government	167.2	25.6	13.2	1.5	0.8
Industry	409.0	102.6	19.2	22.7	4.2
Utilities	20.0	5.3	20.2	0.9	3.4
Healthcare and others	15.4	4.8	23.0	0.7	3.3
Total	2,108.4	343.6	12.5*	307.7	11.1*

Table 6-6: Breakdown of losses to firms. All figures in million EUR or %. The sum is the total of the material damage, the direct losses due to business interruption and the indirect losses due to business interruption (for each sector). (*) These figures are influenced by the absence of a figure for direct losses in the agriculture sector.

cultural sector. It is interesting to see that the construction sector is the only sector in which the losses are larger than the damage. Both the direct and the indirect losses due to business interruption are relatively large in the construction sector.

The maximum losses per job can be found in table 6-7. The added value per job is calculated by dividing the yearly added value of the sector by the amount of people working in the sector.[3] Some of the direct losses appear to be very small. For example, the mining industry bears a maximum loss of 145,000 EUR per job. This figure is equal to three weeks worth of added value in this sector. The direct and indirect losses use the same damage function as the material damage bore by firms (see figure 6-3), so these maximum losses only occur when the flood depth is at least five meters. Another example, if the water depth for a financial firm is three meters, the losses per job are 3,600 EUR (the damage function returns a value 0.2 for this depth). This is approximately equal to one week worth of value added for this sector.

This offers an explanation why the losses due to business interruption as a share of total costs are very small. The business interruption caused by the flood is assumed to be very short. The longest business interruption can be found in the industry sector (which is just over a year for a flood depth larger than five meters). Furthermore, the length of the business interruption is not dependent on the scale of the flood. Business interruption caused by a large scale flood will probably be longer than business interruption by a small scale flood, due to the limited capacity of the construction (and industry) sector to repair the damage that is causing the business interruption. Also lost housing services are not taken into account.

[3] Both figures are available at Statistics Netherlands

Category	Direct losses	Indirect losses	Added value
Mining	145	105	2,464
Construction	33	56	59
Retail and food services	9	4	42
Transport and communication	14	8	72
Financial services	18	9	156
Government	12	3	62
Industry	88	78	82
Utilities	140	204	320
Healthcare and others	8	4	37

Table 6-7: Maximum losses per job. All figures in EUR thousands. These figures do not include the 0.25 scale factor for indirect losses. See text for an explanation on added value [Geodan and Royal Haskoning (2007)].

7 Adaptive regional input-output model

This chapter contains the methodology and the results of the Adaptive Regional Input-Output (ARIO) model to determine the losses due to business interruption, as an alternative to the method used in HIS-SSM. A detailed description of the model can be found in [Hallegatte (2008)]. The following topics are treated in this chapter.

- A basic explanation of the model
- A detailed explanation of the model
- Required input
- Shortcomings and assumptions
- The results of the Lopik dike breach case
- A sensitivity analysis

7.1 Introduction

The goal of the ARIO model is to determine the amount of created value added after a flood at a monthly interval. This value added can be compared to the value added that would have been created if the area was not flooded to determine the losses due to business interruption as a result of a flood. The no-flood value added is assumed to be equal to the value added before the flood.

A simple schematic of the model can be found in figure 7-1. The losses due to business interruption are a result of the material damage caused by the flood. The material damage has two consequences, namely a reduction of the production capacity of the economy and an increase in the total demand to the economy.

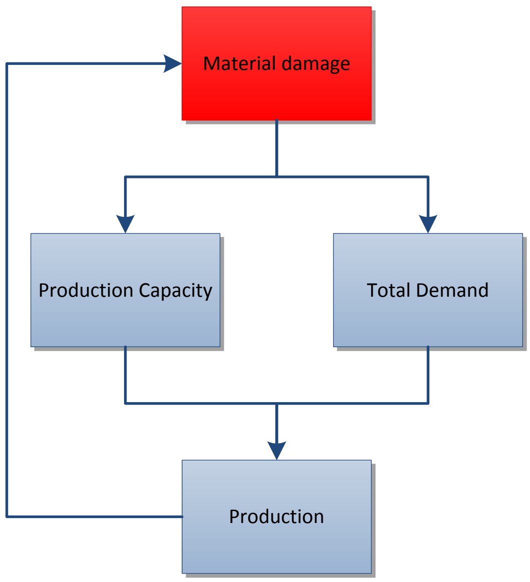

Figure 7-1: Basic flow chart of the ARIO model.

The presence of material damage means that some production facilities (like buildings, machines and computers) are broken and cannot be used. This reduces the production capacities of firms. The broken production facilities have to be repaired though. This increases the total demand (which comprises everything that the local consumers, other firms and foreign countries wish to use), because it leads to more work for the firms offering repair services.

The total demand and the production capacity together determine the actual amount of production. The total demand basically holds what the economy wants to be produced by firms and the production capacity determines how much production is actually possible. When the actual amount of production is determined, a part of this production will be used to repair the broken production facilities and damage to households.

In the following month, a part of the material damage has been repaired (as a result of the production in the previous month). This reduces the remaining material damage, which has an influence on the production capacity and the total demand. Compared to the previous month, the production capacity will be higher and the total demand smaller. This leads to a new actual production, of which a part will be used for repairing the remaining material damage as well. This goes on until all the material damage caused by the flood has been repaired.

The added value can be determined by subtracting the production with the value of the intermediate goods used for the production. Intermediate goods are goods used in the production processes to create the final product. The amount of intermediate goods used is also determined in the model. The total losses due to business interruption can be determined by comparing the added value in the aftermath of the flood with the added value before the flood.

The following section contains a more in-depth description of the model.

7.2 The ARIO model in details

The ARIO model is not able to predict the direct material damage of a flood. This damage is actually the input to be able to compute the direct and indirect losses due to business interruption.

A flow chart containing a detailed schematic of the model can be found in figure 7-2. The numbers after concepts refer to the boxes in this figure. The red arrows indicate the main components of the model. All the steps will be explained in detail. The full equations, MATLAB script and input data can be found in appendix C.

The most important box in the model is the production (6) box. To be able to determine the production (6), two economic variables are important. The first one is that of total final demand (4), which basically is what society wants to consume and what is to be exported. The second variable is the production capacity (8), which contains information on how much each sector can possibly produce in a given time, assuming there are no constraints.

The total final demand (4) is the vector y introduced in section 4.3. The total final demand (4) is the sum of local final demand (3) (goods and services used by local consumers), exports (2) (goods and services exported outside of the considered area) and material damage (1) (as this leads to reconstruction demand). Damage (1) is the direct material damage caused by the flood. This damage (1) is assumed to increase the demand for products made by the construction sector (rebuilding houses, firms and infrastructure) and industry sector (replacing inventories).

The total demand (5) is the sum of the total final demand (4) and the intermediate consumption (7). This intermediate consumption (7) consists of goods and services used by firms in their production processes. The amount of intermediate consumption (7) depends on the amount of production (6), explaining the small loop in the flow chart between total demand (5), production (6) and intermediate goods (7).

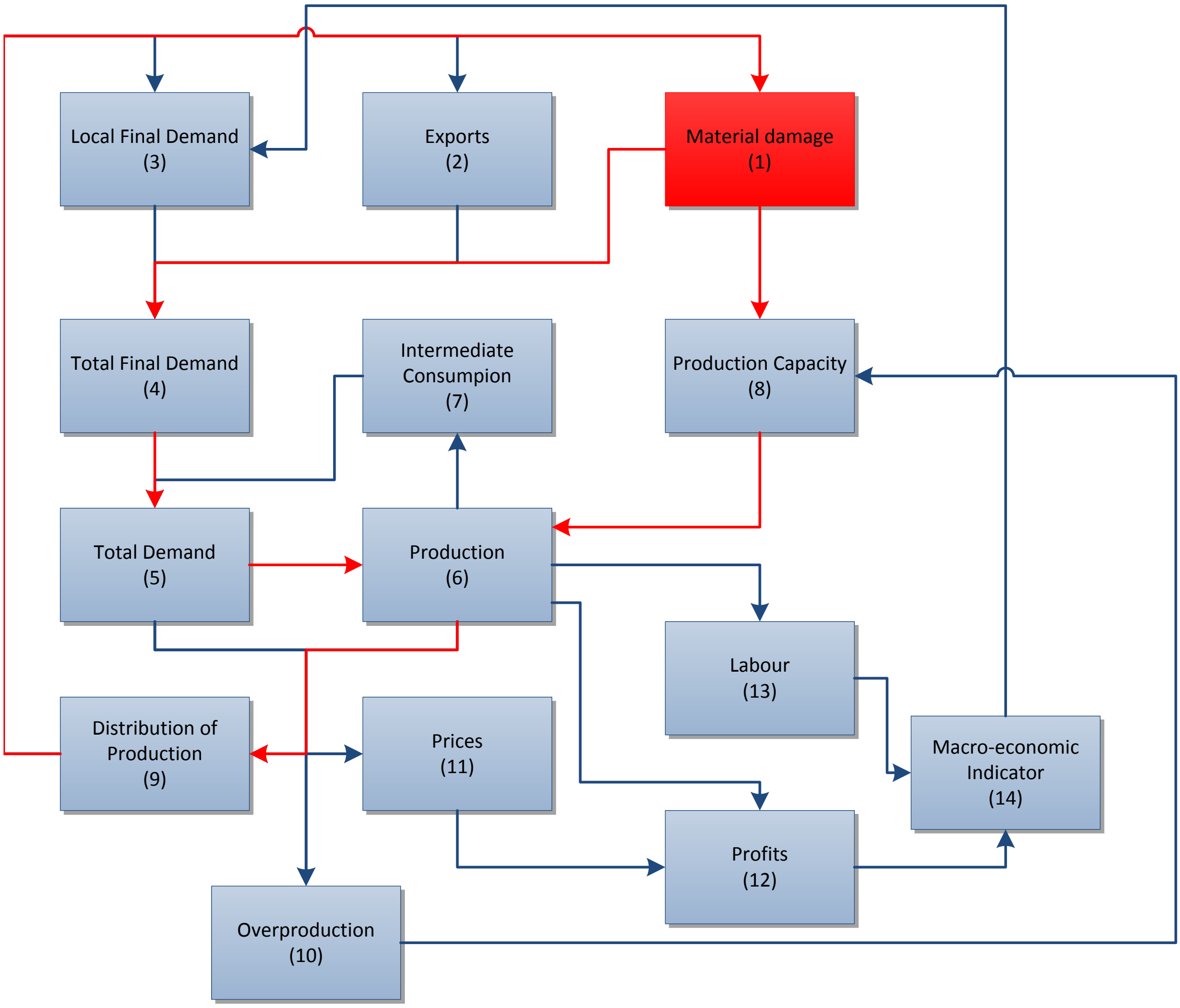

Figure 7-2: Flow chart of the ARIO model. The red lines indicate the fundamentals of the model. The red box contains the shock to the economic system.

The production capacity (8) also depends on the damage (1). The more direct damage an industry suffered, the less it can produce. The production capacity (8) is assumed to be linear with damage (1). For example, if a certain sector bears 10 million EUR of damage, the production capacity is 90% of the pre-disaster production capacity. When after a few months the damage has been reduced to 5 million EUR by reconstruction works, the production capacity is 95% of the pre-disaster production capacity.

The basic Leontief input-output table is used to determine the total production required to be able to meet the total final demand (4). This production will most likely be higher than the production capacities (8). After all, the required production has increased due to the extra demand by the damage (1) and the production capacities (8) have been reduced by the damage (1). Imports are assumed to be unconstrained. The next estimate of the production is the minimum of the production capacity (8) and the total production required to meet the final demand. With this estimate, the intermediate consumption (7) (which are goods and services used in the production of other goods and services) can be estimated.

The rationing scheme adopted is a combination of a priority and a proportional system. Intermediate consumption (7) is prioritized, firms first supply each other before they serve consumers (3), exports (2) and damage (1) demands. This is not uncommon in the aftermath of a disaster because this strategy reduces indirect losses. If the intermediate consumption (7) is smaller than the production estimate then the production does not have to be reduced, the production estimate is in this case equal to the actual production (6).

If the intermediate consumption (7) is larger than the production for one or more sectors, the production of all other sectors has to be reduced. This has to continue until the intermediate consumption (7) demand to the bottleneck sector is equal to the production of this sector. The productions of the other sectors are reduced proportionally. For example, if the intermediate consumption (7) demand to the construction sector is 101 EUR (so other firms need 101 EUR worth of production of the construction sector to be able to produce themselves) but the production capacity (8) for the construction sector is 100 EUR, all the other firms will have to reduce their production by a little over 1%. The bottleneck sector does not reduce its production, as this would only increase the problems. The reduced production leads to a smaller intermediate goods consumption (7), such that the intermediate good consumption (7) is smaller than the production (6) for each sector.

Next the production (6) is distributed (9). The intermediate consumption (7) can always be satisfied, as this consumption is reduced until it is smaller than the production (6) for each sector. The components of the total final demand (4) are rationed proportionally. For example, if the actual production (6) available for the total final demand (4) is half of the total final demand (4), then all components only get half of what they wanted.

The production distribution (9) leads to the consumption of a certain proportion of the production by damage (1). This part of production is used for reconstruction works. The result is that the amount of remaining material damage (1) to households and firms is reduced. The amount of production that is used for the repairs leads a reduction of the remaining material damage by the same amount. This results in a decrease of the total final demand (4) and an increase in the production capacity (8) in the next time step.

This rationing has all kinds of consequences in the model. First, the local final demand (3) and export (2) demands will be reduced in the future as these economic agents will seek other sources (like imports) to fulfill their needs. Substitution takes place, but not for all sectors though. The products of some sectors (like construction and transport) cannot be imported, so for these sectors no substitution takes place. When substitution takes place, a part of the local final demand (3) and exports (2) will be supplied for by firms located outside of the considered area. Also overproduction (10) and prices (11) will increase. All these factors are a function of the difference between total demand (5) (which is the sum of total final demand and intermediate consumption) and production (6). The larger the difference between these two, the stronger the substitution effect. Overproduction (10) and prices (11) will also increase more if the difference between total demand (5) and production (6) is larger. An important assumption is that there are no permanent substitution effects. When a sector has recovered such that it can supply sufficient again, the local final demand (3) and exports (2) will return to their pre-disaster values again. Prices (11) and overproduction (10) also return to their pre-disaster value in the long term.

Overproduction (11) may increase the production capacity (8) of a sector. Firms will notice the difference between the initial total demand (5) and the production (6). This gives them an incentive to attempt to increase their production capacities (8) in other ways, like working more hours. The amount of capital goods cannot be increased rapidly due to the flood, but is taken into account with the reduction of the remaining material damage (1). This overproduction (10) is quite limited however. There is no economic growth in the model, the outcome returns to the pre-disaster situation.

The production (6) and prices (11) are used to determine the profits (12) of firms. Wages (13) are assumed to remain constant in the aftermath of the flood, such that the total amount of wages (13) earned is dependent only on the amount of production (6). The sum of profits (12) and wages (13) gives an indication of the consumer confidence in the affected area. If this is high, consumers are optimistic about the future and increase their spending. This indicator (14) therefore only has an influence on the local final demand, not on the demands by export.

The most important outcome of the model is the production (6) each time step. Together with the intermediate consumption (7) and imports the added value can be calculated. If this added value is compared to the pre-disaster value added, the total losses due to business interruption can be determined.

7.3 Input data

The model requires a lot of input data. All the input can be found in appendix C. The Dutch pre-disaster productions and input-output table are available at Statistics Netherlands [Centraal Bureau voor de Statistiek (2012)]. This input-output table should include the local final demand, export demand, labor input and imports. This information should be available for each sector.

The direct damage to each sector and households should be available. This information is hard to come by for actual floods but the direct damage computed by HIS-SSM is very useful in this case. The input-output table in the national accounts is more detailed (21 sectors) than the direct damage given by HIS-SSM (10 sectors). The direct damage calculated by HIS-SSM is therefore distributed over the corresponding sectors in the ARIO model, where damage is assigned proportional to sector size (based on the yearly added value of the sector). The material damage to households equals 10,682 million EUR and the material damage to firms equals 6,447 million EUR in the Lopik dike breach case.

The model also contains several behavioral parameters that determine how strong certain effects like overproduction, substitution and price changes are. The model should be calibrated with these parameters, but this is not possible in this study due to the hypothetical flooding. Therefore, the parameters are assumed to be the same as in [Hallegatte (2008)], in which the model was applied to determine the losses due to business interruption caused by hurricane Katrina.

7.4 Assumptions and shortcomings

The model has several assumptions and shortcomings which will be discussed. Some of these come with the model itself, others with the use of the direct damage output of HIS-SSM as input to the ARIO model. The following assumptions and shortcomings are explained.

- Full substitution in sectors
- Considered area
- The simple modeling of reconstruction demands
- Stock and flow summation in the total final demand
- The absence of inventories
- The transformation of material damage to production capacity

The transformation of material damage to production capacity is explained in detail due to the large influence this assumption has on the results of the model and because there are a number of possibilities for this transformation.

7.4.1 General assumptions and shortcomings

The first shortcoming has to do with the input-output tables used. An implicit assumption of these tables is that all firms in the same sector provide substitutes for each other's products. Often the tables consist of only a few sectors (like 20). This can lead to unrealistic situations. Usually, agriculture is only one sector comprising every firm from wheat farm to dairy farm and tobacco farm. The consequence is that if an area with a relatively high density of dairy farms is flooded, the tobacco farms in an area that is not flooded are assumed to be able to meet the demand for agricultural products (including milk). This is not realistic. Even in larger input-output tables, the sectors usually comprise different firms. In the 180-sector version of the Thai input-output table education is a single sector. This implies that the local elementary school can provide a substitute for the services offered by a flooded university. The only remedy is to use more detailed input-output models, but this increases the efforts to use the model significantly. The direct damage caused by the flood should be available per sector after all. Also the consequences of failure by a one-of-a-kind utility or firm (like the strategic petroleum reserves and natural gas distribution nodes) is not considered in detail, as other firms in the respective sector are assumed to be able to provide substitutes.

The next shortcoming has to do with the considered area of the input-output table. The considered region should be equal to the region in which firms can provide substitutes for each other. This differs between sectors however. For primary education the considered area should be quite small (municipality to province level), while for other sectors like industry it can be quite large (probably European to global level). A compromise has to be made between the sectors, leading to the choice of the national level. The most important sector in the reconstruction phase (the construction sector) operates on this level in the Netherlands.

The reconstruction demands are modeled quite simply. A large part (75%) of the damage is assumed to be repaired by the construction sector, the remaining part (25%) by the manufacturing sector. In reality, this distribution is different for all sectors however. Retail trade, the construction sector and the industry sector will probably have more damage to inventories than structural damage. Sectors like real estate will probably have more structural damage.

The total final demand consists of local final demand, exports and damage. The first two components are a flow, while the latter is essentially a stock. The local final demand and exports can be expressed as needs in a certain period of time, for example two loaves of bread per week. Damage on the other hand, is a stock and has no time dimension. To be able to sum these three, the damage should be transformed to a flow. This is done by assuming that society wants all the damage repaired in a single year. This is important for the distribution of the production. If society wants the reconstruction period to be much smaller, a larger proportion of the final production is used for reconstruction instead of exports or local final demand.

The model does not take inventories into account. Inventories can reduce direct and indirect losses due to business interruption. The direct losses due to business interruption may be reduced because the restoration process goes faster, time may be saved because products are already available in the aftermath of the flood. The indirect losses due to business interruption will also be smaller because outside of the flooded area firms can (temporarily) continue producing using their inventories. Taking inventories into account would give useful insight in the effects of the just-in-time principle in disaster aftermaths. The use of this principle will probably lead to higher losses due to business interruption caused by floods, but the current model does not take this into account.

7.4.2 Determination of the production capacity

The way damage is transformed to production capacity is also questionable. This is done using a damage-to-production-capacity-ratio (DPCR). In the original model, a parameter is used in this transformation which is the same for each sector. The total amount of damage in a sector is combined with the capital intensity of a sector (measured by the total amount of capital employed divided by the yearly value added) to be able to determine the production capacity still available. The weakness of this method is illustrated for a single firm using figure 7-3.

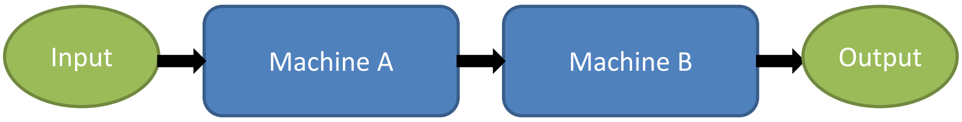

Figure 7-3: Example production process

This firm utilizes two machines in its production process. The inputs are first processed by machine A and then by machine B to produce the output of the firm. Imagine both machines are worth ten million EUR each and the annual added value of the firm is two million EUR. The capital intensity of this firm thus equals ten (twenty million EUR over two million EUR). Unfortunately the firm is flooded and machine A is completely destroyed, while machine B could be saved and is not damaged at all. The remaining capital stock of the firm is ten million EUR (the value of the remaining machine). By simply using the capital intensity, the remaining yearly added value should be equal to one million EUR (not taking into account the possible unavailability of suppliers or clients).

This is not realistic however. The firm cannot produce anything until machine A is repaired, as machine B can only work when the input has been processed by machine A. The yearly added value of the firm is actually zero. This method underestimates the production loss. Some capital goods (like software licenses and ships) will probably not be damaged by a flood. If all the capital goods but software licenses in a single sector are destroyed by a flood, the production capacity of this sector is not equal to zero according to the model.

A different way to determine the DPCR is using HIS-SSM. HIS-SSM gives the amount of flooded jobs. This amount can be compared to the actual amount of jobs in the sector (which can be found in [Centraal Bureau voor de Statistiek (2012)]) to determine the production capacity losses. For example, a certain sector consists of one hundred jobs. The annual value added of the sector is ten million EUR. A flood takes place and ten jobs are flooded, while the direct damage (estimated using HIS-SSM) is equal to one million EUR. Now the production capacity available is reduced by 10% (because the amount of jobs is reduced by 10%), so the annual added value remaining is nine million EUR. This figure can be used to determine the DPCR. In this example, one million EUR worth of damage reduces the annual added value by one million EUR, so the ratio equals one. This method provides an overestimate of the production capacity loss, because using this methodology the amount of lost jobs is determined by the question whether the firm is flooded or not, the actual water depth does not play a role.

This method tends to overestimate the production losses, as the amount of affected jobs is not necessarily equal to jobs that are lost. The water depth in some flooded areas is very small, leading to very small ratios (the direct damage is then small, but the production capacity loss is not based on the water depth). This leads to an overestimation of the production loss.

The amount of jobs lost can be dependent on the water depth using a damage function, but the current damage function in HIS-SSM for firms (figure 6-3) is not appropriate to be used in this context. The current damage function leads to a very few amounts of lost jobs. The result is that the ratios are very large, much larger than the ratios computed with the capital intensity method. The resulting production capacity reductions are thus too small. The damage function for firms in HIS-SSM implicitly contains a time dimension which is not present in the DPCR, making it unfit to solve this problem. For this reason a new damage function has been implemented in HIS-SSM to determine a weighed amount of lost jobs. This linear damage function can be found in figure 7-4.

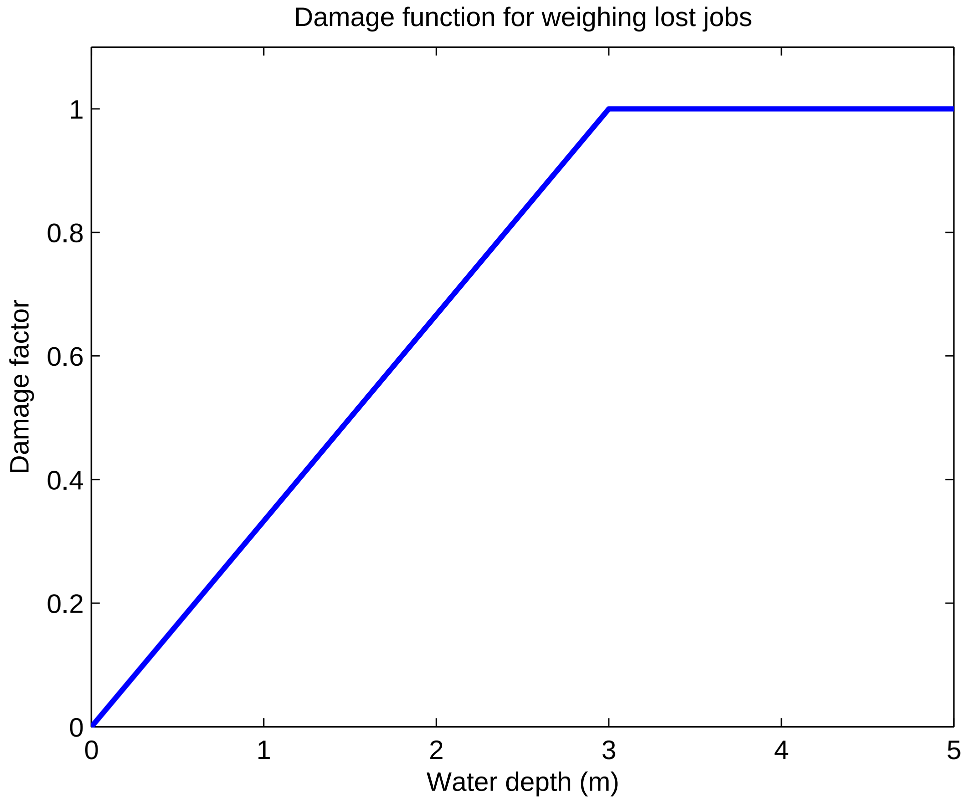

Figure 7-4: Damage function for weighing lost jobs. This damage function assumes a job is completely lost when the water depth is larger than three meters.

The damage function works as a regular damage function. For example, if the water depth in a flooded firm with ten employees is equal to 1.5 meters, the amount of lost jobs in this firm is five. When the water depth is larger than three meters all the jobs are assumed to be lost. The amount of lost jobs can then be used to determine the lost production capacity immediately after the flood. When the lost production capacity and the material damage is known the DPCR can be calculated.

7.5 Results

The ARIO model has been applied to all three cases, but only the results of the Lopik dike breach case (see chapter 5) will be analyzed in detail. Information regarding the other two cases can be found in appendix E and appendix F. The results are presented using different values for the DPCR, which is a factor that determines how much production capacity is lost as a result of the material damage. The following ways to determine the DPCR are considered.

- Capital intensity

- Amount of lost jobs
- Weighed amount of lost jobs

7.5.1 Capital intensity

First the DPCR is determined using the total amount of capital invested divided by the yearly value added. The production capacity reductions are underestimated using this method. The resulting total value added in time can be found in figure 7-5 and the evolution of the direct damage in time can be found in figure 7-6.

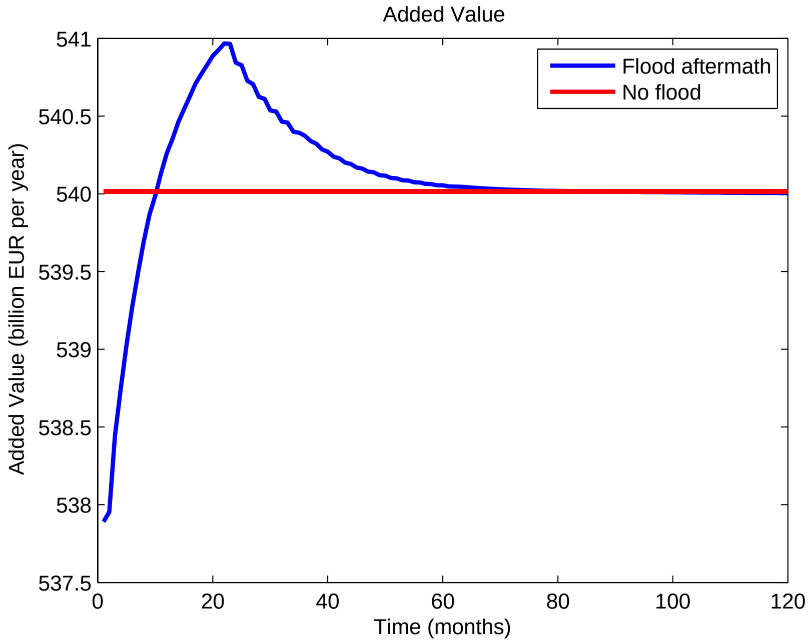

Figure 7-5: Added value after the flood resulting from the dike breach near Lopik. The DPCR is based on the capital intensity. The red line indicates the pre-flood added value.

The added value in time can be used to determine the total losses due to business interruption. This is done by integrating the added value over time in the flood aftermath and comparing this to the situation in which the area was not flooded. The total losses due to business interruption are -832 million EUR in this case, which can be found by numerically integrating the difference between the two lines in figure 7-5. The losses for firms are actually negative (so they create more added value in the aftermath of the flood than they would have done without the flood).

The added value is reduced by the flood to a little less than 538 billion EUR per year in the direct aftermath of the flood. This causes losses due to business interruption. Without the flood, the added value would have been 540 billion EUR per year. About twelve months later, the added value in the aftermath of the flood is equal to the pre-disaster added value again. The added value in the aftermath of the flood keeps rising however, due to the extra demand by the material damage. This is known as a demand surge. A large contributor to the demand surge is the reconstruction and repairs of damage to households. This damage does not reduce the production capacity of the economy, but it does increase the total final demand. When the damage to households becomes smaller, the losses due to business interruption increase.

This outcome does in no way state that the flooding is beneficial for the country. Indeed, there are gains due to the flood according to the model, but there are important costs as well. The 17,000 million EUR direct damage has to be paid for, probably by insurance companies and the

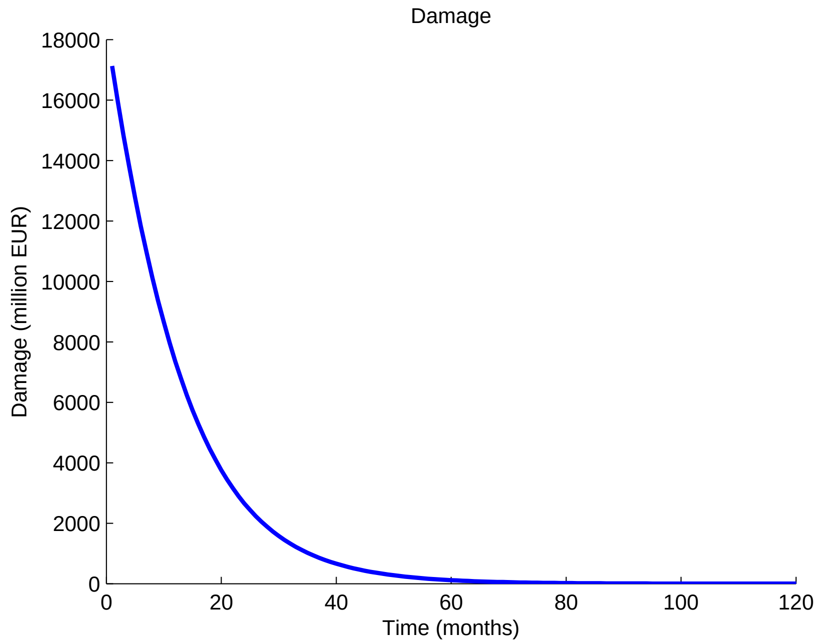

Figure 7-6: Evolution of the remaining direct damage after the flood resulting from the dike breach near Lopik. The DPCR is based on the capital intensity.

government (or taxpayers). It would be much better to able to choose how to spend this 17,000 million EUR in a different way, for example by upgrading the flood defense system in the whole country. The gains for private firms are probably the same (or even bigger), but the country as a whole can also enjoy a better protection against flood. Stating that the flood is good for the Dutch economy is incorrect and known as a parable of the broken window.

The reduction of the direct damage in time does not indicate that the flood becomes less costly in the future. It merely states the remaining direct damage caused by the flood. For example, after twenty months about 3,000 million EUR of direct damage is still left. This means that 14,000 million EUR has been spent on reconstruction and repair works.

The added value reduction in the immediate aftermath of the flood is quite small. The 6,447 million EUR direct damage to firms only reduces the added value by 2,100 million EUR per year the month after the flood.

7.5.2 Amount of lost jobs

When the DPCR is based on the amount of flooded jobs the losses due to business interruption increase. The added value for this situation can be found in figure 7-7. The production capacity reduction is overestimated using this method.

The total losses due to business interruption are 18,761 million EUR using this method. This is an enormous increase of the previous -832 million EUR. The initial material damage is the same in both methods, only the ratio between material damage and production capacity is different. This has huge consequences. The added value in the immediate aftermath of the disaster is reduced by almost 18 billion EUR per year. This enormous decrease of production capacity fully suppresses the demand surge. This can be seen in figure 7-7, the blue line remains under the red line for all considered time steps. The accumulated added value of the construction sector is larger than the pre-flood added value of this sector, but for other sectors this is definitely not the case.

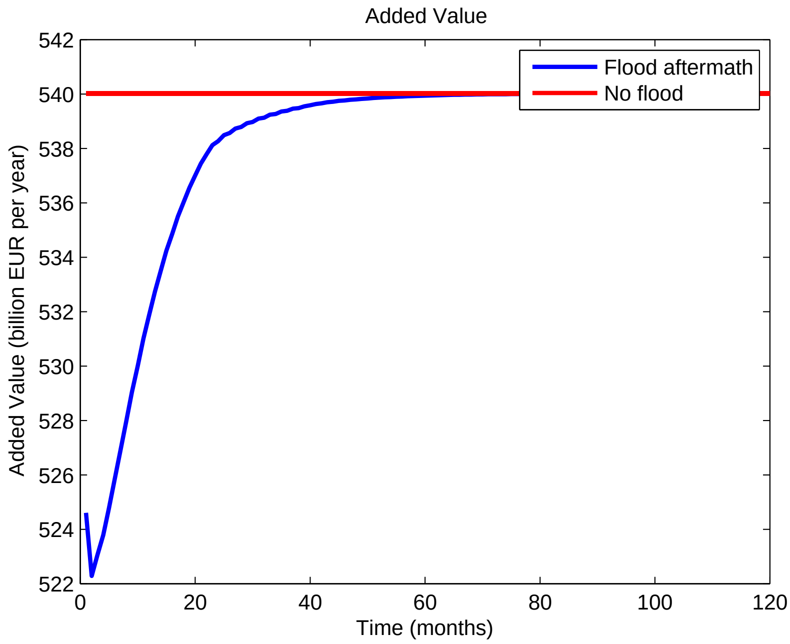

Figure 7-7: Added value after the flood resulting from the dike breach near Lopik. The DPCR is based on the amount of jobs. The red line indicates the pre-flood added value.

The direct damage reduction in time is quite similar to the one with the DPCR based on the capital intensity. This is because the production capacity reduction in the construction sector is not so different between the methods, and only a small part of the production is actually used for reconstruction. The difference for the industry sector is quite large (the production capacity differs by 3,700 million EUR in the month immediately after the flood), but these goods may be imported so it is not that big a deal for the reconstruction of material damage.

7.5.3 Weighed amount of lost jobs

Several damage functions have been used to determine the weighed amount of lost jobs. The shape of these functions is the same as the (linear) shape of the damage function in figure 7-4, but the point of the slope discontinuity is different however. The point of slope discontinuity can be interpreted as the minimum water depth required to reduce the production capacity of the flooded firm to zero in the immediate aftermath of the flood. In figure 7-4 the slope discontinuity is at three meters, for which all the jobs are assumed to be lost. The point of slope discontinuity has been set from one meter to five meter with 0.5 meters intervals. A plot of some of these damage functions can be found in figure 7-8.

The DPCR have been calculated with all these damage functions, after which the losses due to business interruption have been determined with the ARIO model. The results are collected in table 7-1.

The losses due to business interruption decrease for increasing values of points of slope discontinuity. The larger the point of slope discontinuity, the fewer production capacity is lost (because jobs are only assumed to be completely lost for higher water depths). This leads to smaller losses due to business interruption. The differences in the amount of losses due to business interruption are quite large, so the choice of what damage function is used to determine the amount of lost jobs is important.

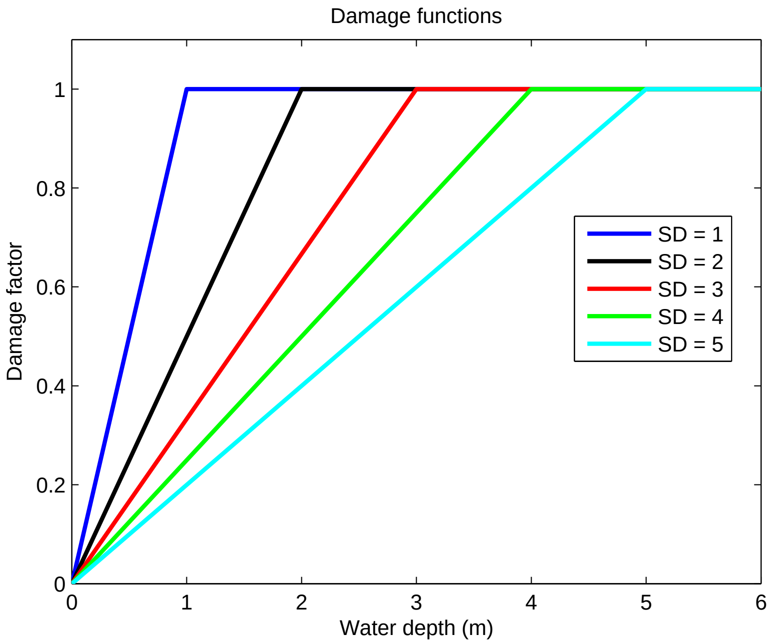

Figure 7-8: Example of damage functions for different slope discontinuities (SD).

Slope discontinuity (m)	Average DPCR	Losses due to business interruption (million EUR)
1.0	1.42	11,300
1.5	1.63	8,946
2.0	1.95	6,701
2.5	2.35	4,968
3.0	2.74	3,646
3.5	3.17	2,613
4.0	3.62	1,838
4.5	4.07	1,246
5.0	4.55	778

Table 7-1: Losses due to business interruption for different DPCRs based on damage functions to determine the weighed amount of lost jobs.

Only the results with the slope discontinuity at 2.5 meters water depth will be analyzed. When the water depth in a firm is 2.5 meters or more, the ground floor is most likely completely flooded. Many facilities (like electricity) will not function properly in this case. The assumption that the production capacity of the firm is reduced to zero at this water depth is plausible.

The added value of the total economy can be found in figure 7-9. The total losses due to business interruption are equal to 4,968 million EUR (which has been found by numerically integrating the difference between the two lines in figure 7-9). The demand surge caused by the flood is very small.

The remaining direct damage in time can be found in figure 7-10. The development of the remaining damage in time is not that different in the other simulations in which the DPCR is determined in a different way. This is because only a small part of the production of the construction sector is actually used for reconstruction and repair, and the DPCR for the construction sector is

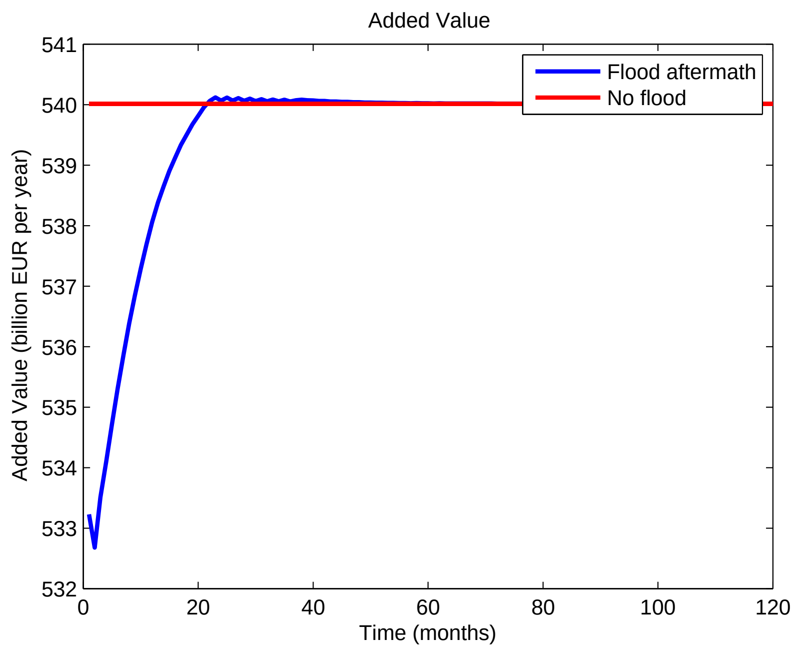

Figure 7-9: Added value after the flood resulting from the dike breach near Lopik. The DPCR is based on the weighed amount of lost jobs. The red line indicates the pre-flood added value.

not that different. The repair demands to the industry sector can be fulfilled by imports so this sector does not prove to be an important bottleneck for the reconstruction works after the flood.

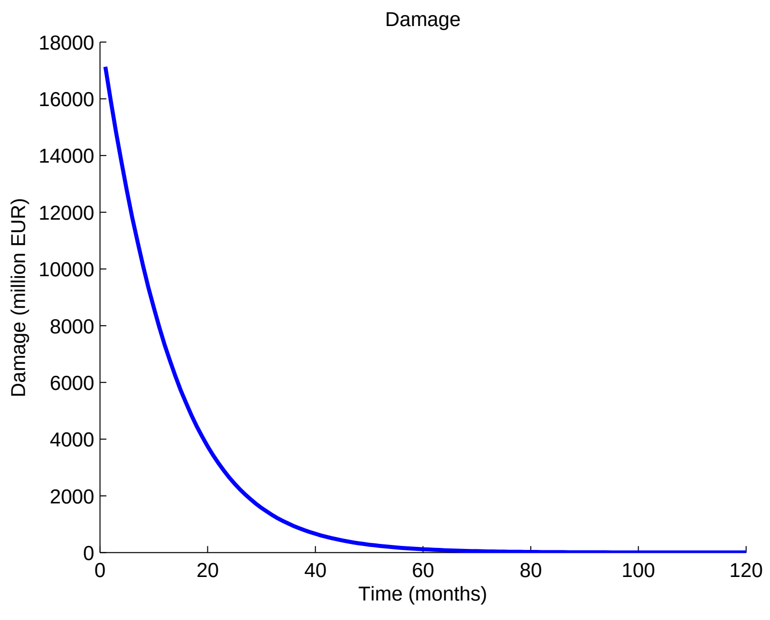

Figure 7-10: Remaining material damage after the flood resulting from the dike breach near Lopik. The DPCR is based on the weighed amount of lost jobs.

The added value per sector has also been determined. This can be found in figure 7-11. The sector names, annual production and annual added value can be found in table 7-2.

The agricultural sector is hit hardest (-8%) by the flood. This makes sense as most of the flooded area is used for agricultural purposes. The financial sector is also hit quite hard, probably due to the flooding of the cities of Woerden and Gouda. The added value of the construction

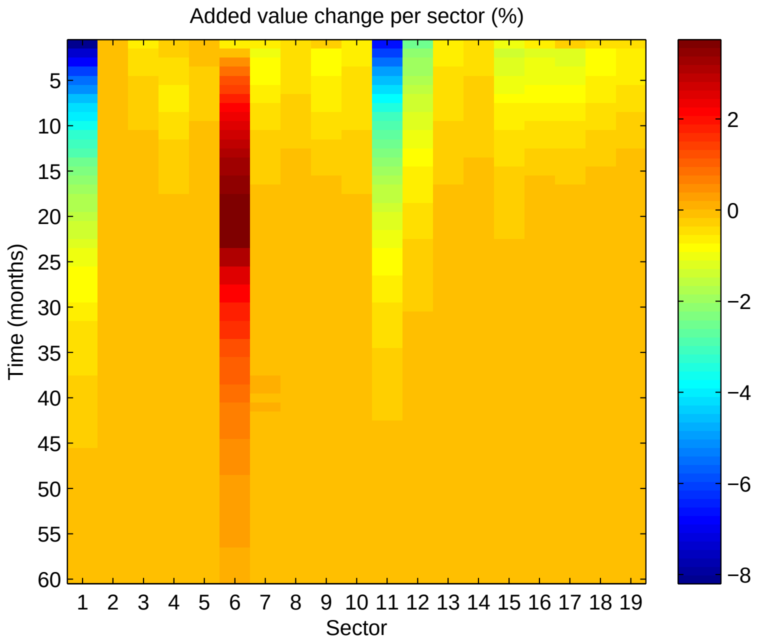

Figure 7-11: Added value changes (%) after the flood resulting from the dike breach near Lopik, based on the pre-flood added value. The DPCR is based on the weighed amount of lost jobs. The list of sectors can be found in table 7-2.

	Sector	Added value	Production
1	Agriculture	8663	27213
2	Mining	19708	25498
3	Industry	69626	304294
4	Power supply	11104	37468
5	Water and waste management	4595	12920
6	Construction	28727	78971
7	Retail	68689	122780
8	Transport and storage	23042	53232
9	Food services	9470	18631
10	Information and communication	25351	51787
11	Financial services	42534	80605
12	Real estate	34975	61158
13	Specialist business services	30771	62960
14	Other business services	29114	47636
15	Governmental services	38937	68851
16	Education	27158	35220
17	Health care	53282	72654
18	Culture, sports and recreation	4879	11445
19	Other services	6356	10592

Table 7-2: Sectors used in the ARIO model. All figures in million EUR. These are pre-disaster values [Centraal Bureau voor de Statistiek (2012)].

sector increases by almost 4%, after a small initial reduction due to the material damage by the flood. The added value of this sector is larger than the pre-flood added value for a long time, while the recovering of other sectors takes less time. Despite the extra demand (by the damage) to the industry sector, the added value of this sector does not increase. This is because the goods made by this sector may be imported, while for the construction sector this is not possible.

The price level in the construction sector increase by 1.2% in the first month after the flood. The price level gradually decreases in the months after to go to back to pre-flood price level. The sum of profits and wages (the macro-economic indicator) is reduced by little over 1% in the immediate aftermath of the flood. It is restored to the pre-disaster value after twenty months (as is the annual added value).

The housing services lost are also calculated with the model. The monetary value of housing services under normal circumstances are assumed to be 4% of the value of the house each year. If this figure is multiplied with the remaining damage in the household sector the housing services lost can be approximated. The lost housing services add up to 463 million EUR.

7.6 Sensitivity analysis

Due to the uncertainty in the input parameters of the model a sensitivity analysis has been performed. The following parameters were taken into account in the sensitivity analysis.

- Price level parameters
- The macro-economic indicator
- Substitution timescale parameters
- Overproduction parameters

The large influence of the DPCR on the outcome of the ARIO model has been shown already in section 7.5. All the results in this section have been determined with the DPCR based on the weighed amount of lost jobs, using a linear damage function which assumes a job has been completely lost if the water depth is larger than 2.5 meters (as was done in the previous section). The influence of the parameters has been analyzed separately, no combination of parameter-changes has been considered.

7.6.1 Price parameters

The model contains two price parameters. The parameter γ_p models the response of prices to the amount of underproduction (the difference between production and total demand), so this parameter is used to model producer behavior. The parameter ξ models the response of demand to the price changes, which is the consumer behavior.

The results can be found in figure 7-12, in which the blue line lies almost completely under the black line. The cyan colored line indicates the added value after the flood when the parameter γ_p is doubled (from 0.07% per month to 0.14% per month), so prices respond twice as strongly on underproduction. The black line indicates the added value when the local final demand and exports demand react twice as strong on price changes (the parameter ξ is changed from 0.9 to 1.8). The total losses due to business interruption does not change much due to the price parameters (from 4,968 million EUR to 4,753 million EUR and 5,033 million EUR respectively).

It is interesting to see that the losses due to business interruption become smaller when firms change their prices more. Most of the price changes occur in the construction sector, because of the large underproduction in that sector after the flood. When the price level increases in this sector, the export demand and local final demand to this sector go down (the higher the prices, the fewer consumers wish to use). The reconstruction demands are assumed not to dependent on prices. This leads to a situation in which the reconstruction demand become a larger propor-

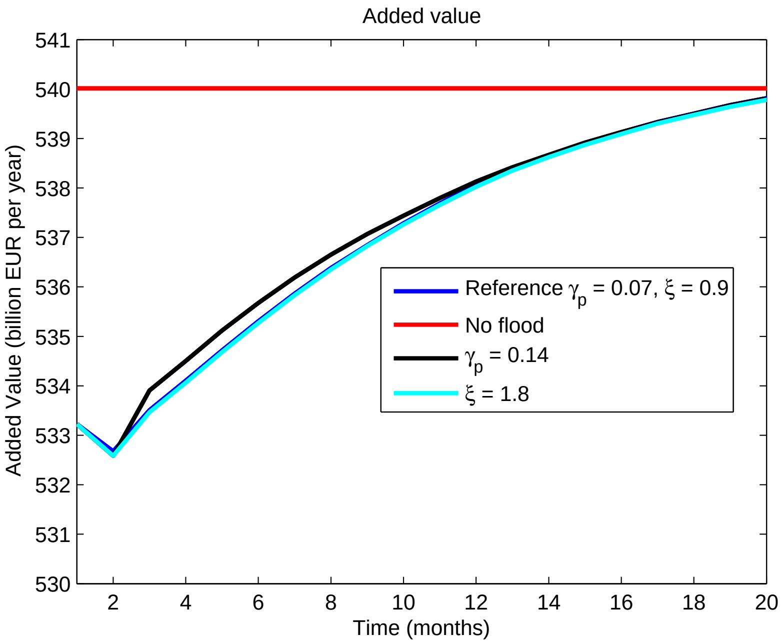

Figure 7-12: Sensitivity analysis for the price parameters. The DPCR is based on the weighed amount of lost jobs. The values for γ_p and ξ have been doubled to test their influence on the solution.

tion of the total final demand to the construction sector, so the production used for reconstruction demand also increases. This leads to a shorter reconstruction duration and therefore decreases the losses due to business interruption.

7.6.2 Macro-economic indicator

The macro-economic indicator has also been changed to assess its effects. This indicator is calculated by dividing the sum of the actual wages and profits by the sum of the wages and profits before the flood. It is an important parameter in determining the local final demand.

The results can be found in figure 7-13. The macro-economic indicator has been kept constant at the value one in the sensitivity analysis. This basically means that the local final demand is not dependent on the total income of the local area. The influence of this parameter on the outcome is significant. The losses due to business interruption change from 4,968 million EUR to 3,847 million EUR if the macro-economic conditions are not taken into account. This influence is large because it works through all the sectors of the economy. Prices on the other hand are determined per sector (so a price increase in the construction sector does not influence the demand for the industry sector).

The reduction of the added value in the second month after the disaster mainly seems to be the result of the macro-economic indicator.

7.6.3 Substitution timescale

The model contains a certain timescale to model the substitution of goods and services. These parameters (simplified to a single parameter τ in this case) contain information on how long it takes to find a substitute for a certain product.

The results can be found in figure 7-14. The parameter has been changed from six months to three and twelve months to determine its influence. The influence on the losses due to business

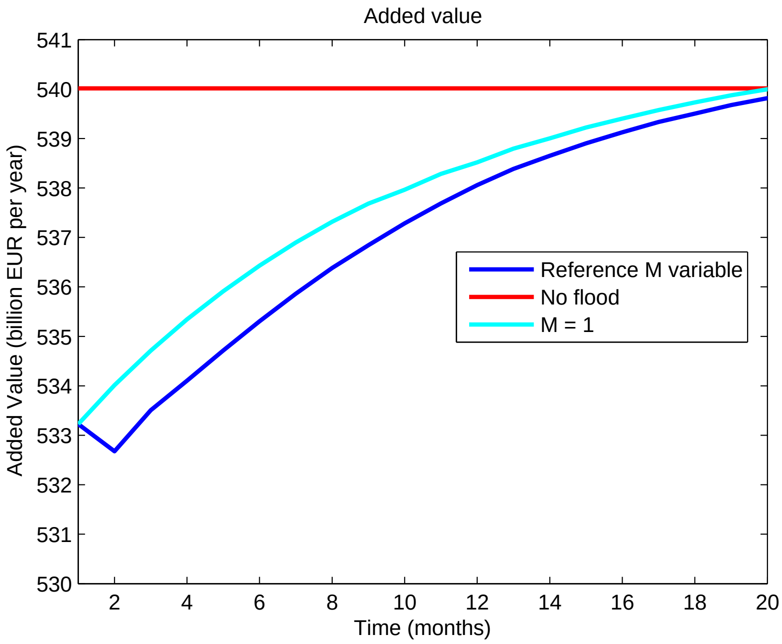

Figure 7-13: Sensitivity analysis for the macro-economic indicator. The DPCR is based on the weighed amount of lost jobs. The value for the indicator has been kept constant at one to determine its influence.

interruption is quite small, similar to the influence of the price parameters. The losses due to business interruption change to 4,675 million EUR for τ = 12 months and 5,098 million EUR for τ = 3 months.

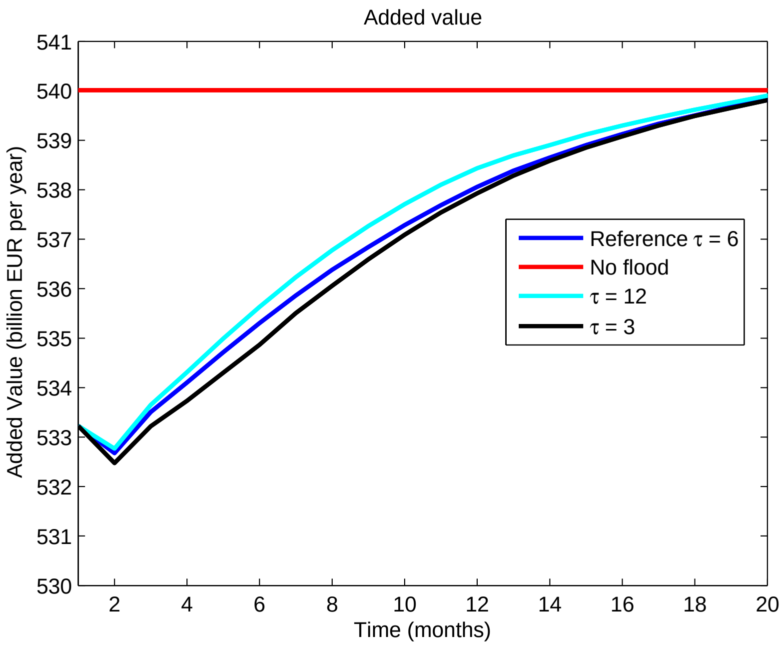

Figure 7-14: Sensitivity analysis for the substitution timescale. The DPCR is based on the weighed amount of lost jobs. The value for the parameter has been halved and doubled in the sensitivity analysis.

The faster substitution takes place, the larger the losses due to business interruption. This makes sense, because if substitution is fast the total final demand to the local economy will become smaller. This gives firm owners less incentive to increase the output of their firms (and take overproduction measures) as quickly as possible because there is less demand to be fulfilled.

7.6.4 Overproduction parameters

The sensitivity of the model to two overproduction parameters has been analyzed. These parameters are the maximum overproduction α_{max} and the overproduction timescale τ_α. The maximum overproduction indicates how much the production may increase and the overproduction timescale indicates how quickly this level of production may be reached.

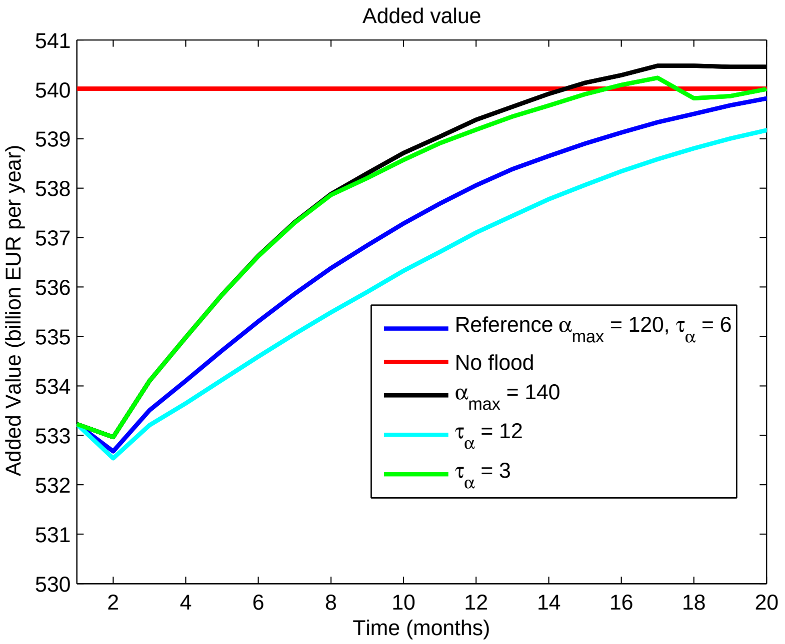

Figure 7-15: Sensitivity analysis for the overproduction parameters. The DPCR is based on the weighed amount of lost jobs. The value for the parameters has been halved or/and doubled in the sensitivity analysis.

The results can be found in figure 7-15. The influence of these parameters on the losses due to business interruption is large. When the maximum overproduction is doubled from 20% of the pre-flood production to 40% of the pre-flood production, the losses due to business interruption decrease from 4,968 million EUR to 2,873 million EUR. This large influence makes sense, as the losses due to business interruption are basically caused by a reduction of the production capacity. Overproduction directly counters this problem. The timescale of the overproduction has been changed from six months to three months and twelve months. The losses due to business interruption are in those cases 3,721 million EUR and 6,258 million EUR respectively.

7.6.5 Conclusion

The results depend most on the overproduction parameters. Both the maximum overproduction and the timescale for reaching this overproduction have a strong influence on the outcome of the model. The macro-economic indicator has a significant influence on the results as well. The parameters regarding substitution do not influence the solution a lot, just like the parameters regarding prices.

8 Analysis

In this chapter the results of the case studies will be analyzed. The outcome of the two methods (HIS-SSM and the ARIO model) will be compared and some drawbacks of the ARIO model are considered. The influence of approaching the economy by dividing all firms into sectors will also be investigated. The relation between the amount of material damage and the amount of losses due to business interruption is also investigated, as is the influence of the amount of material damage on the duration of the recovery period after the flood. Finally, the possible influence of the permanent leaving of firms will be considered. For all the results in this chapter the DPCR is based on the weighed amount of lost jobs (with the point of slope discontinuity at 2.5 meters).

8.1 Comparison

The outcomes of HIS-SSM and the ARIO model applied to the three dike breach cases will be analyzed in this section. The most important results of HIS-SSM in the Lopik dike breach case are repeated in table 8-1.

Category	Costs	Share of costs [%]
Direct damage	17,128	96.3
Direct business interruption	344	1.9
Indirect business interruption	308	1.7
Total	17,779	100

Table 8-1: Costs due to a dike breach near Lopik according to HIS-SSM. Costs in million EUR.

The material damage caused by the Lopik dike breach flood is equal to 3.1% of the Dutch GDP in 2011. This makes the size of the flood comparable to the floods considered in chapter 2. The total losses due to business interruption as a share of the direct material damage is very low compared to figures from actual floods. In the Lopik case this is only 3.8%, while for the floods considered in chapter 2 the numbers vary from 15% to more than 100%. This gives reason to expect that the losses due to business interruption are severely underestimated using HIS-SSM in large-scale floods.

Furthermore, the share of losses due to business interruption in the total costs of the flood will most likely not increase significantly if the scale of the flood increases. This is a result of one of the assumptions in the model, namely that the duration of the business interruption is only dependent on the water depth.

The outcome of the ARIO model is more in line with the data from recent floods. The losses due to business interruption as a share of the material damage of the flood is 29% according to this model. The outcome of this model depends very strongly on the damage-to-production-capacity-ratio however, which determines the production capacity still available in the presence of material damage. Interestingly, there are no indirect losses due to business interruption according to the model. This is a result of the assumption that firms first supply other firms before they sell their products to consumers or foreigners and that the shock is not very heterogeneous.

The results of the two different models and some characteristics of recent floods have been collected in table 8-2. This table also contains the results of the Holwierde and Arcen dike breach cases which can be found in appendix E and F.

Actual floods

Event	Material damage/GDP [%]	Losses/material damage [%]
Japan 2011	3.6	50.0
Thailand 2011	6.0	125.0
Hurricane Sandy	3.7	37.5
Hurricane Katrina	15.4	30.0

Lopik dike breach

Model	Material damage/GDP [%]	Losses/material damage [%]
HIS-SSM	3.1	**3.8**
ARIO	3.1	**29.0**

Holwierde dike breach

Model	Material damage/GDP [%]	Losses/material damage [%]
HIS-SSM	0.3	**4.0**
ARIO	0.3	**3.1**

Arcen dike breach

Model	Material damage/GDP [%]	Losses/material damage [%]
HIS-SSM	0.01	**1.8**
ARIO	0.01	**5.8**

Table 8-2: Comparison of recent events with model outcomes. The material damage is expressed as a share of the GDP in the year of the flood. The losses due to business interruption are expressed as a share of the material damage.

Only the Lopik dike breach is comparable to the actual floods due to the relative size of this flood. The Holwierde and Arcen dike breach (which are much smaller than the Lopik case) show that the relative size of the losses due to business interruption do not depend on the scale of the flood according to HIS-SSM, as this share is of similar size in the three considered cases. The results of the ARIO model differ strongly with the size of the flood. For small floods (like the Holwierde and Arcen dike breach cases) the losses due to business interruption are less than 6% of the material damage caused by the flood. If the scale of the flood increases, the losses due to business interruption play a larger part in the total costs of the flood (comparable to the figures found for actual floods).

The share of losses due to business interruption in the total costs of a flood cannot be compared to actual cases for the Holwierde and Arcen dike breach to determine whether the results of HIS-SSM and the ARIO model are of the correct order of magnitude. This is due to the absence of detailed information regarding the losses due to business interruption in actual floods of this size.

8.2 Drawbacks of the ARIO model

The ARIO model contains several drawbacks and assumptions due to the complexity of the model. It is hard to quantify the influence of these drawbacks and assumptions due to a lack of data. The following drawbacks should be kept in mind when applying the ARIO model, in addition to the more detailed shortcomings in section 7.4.

- No technological development

- Simplified substitution
- No new equilibrium

The ARIO model does not contain technological development. The input-output table used in the model does change, but these changes are very small and are based on substituting intermediate goods for imported goods due to a lack of supplies. Changes to the input-output table based on new products or production processes are not taken into account, neither are permanent changes due to the flood. The latter can be for example an increase in the demand to the construction sector by all other firms, because the other firms want their buildings to be able to withstand floods better.

Substitution is also modeled quite simply. Firms in the same sector are assumed to be able to substitute for each other, but between sectors there is no substitution at all. Both these assumptions are not in line with reality. Substitution in the final demand is also not taken into account.

A flood will probably lead to a new permanent equilibrium state of the economy. Some firms will leave the Netherlands, other firms will go out of business permanently and the worsened reputation of the water sector may lead to fewer orders from abroad. Especially for open economies firms may choose to relocate to a different country after a severe flood. The investments in flood defense may increase perhaps due to the increased acknowledgment of the severe consequences of floods. All these effects are not taken into account however. A rough estimate based on the conducted interviews on the importance of this assumption can be found in section 8.6.

8.3 Sector approach

Both methods use a sector approach, in which individual firms are assigned to a certain sector. In the ARIO model and HIS-SSM the firms in a sector are assumed to be of the same kind. For example, the maximum damage per job in HIS-SSM and the corresponding damage functions are the same for firms in the same sector. In the ARIO model firms in the same sector are assumed to be able to substitute for each other. This has large consequences for the costs of a flood if a unique or very large firm is flooded. In appendix G the costs of the flooding of a diesel refinery at the Maasvlakte area in the port of Rotterdam is assessed using different methods. The diesel refinery (owned by Neste Oil Nederland BV) can be considered a very large and important firm in the Netherlands.

The implications of the sector approach are illustrated in figure 8-1. The production capacity reduction in the diesel production sector is 12.3% due to the flooding of the Neste Oil diesel refinery, but in the models this is aggregated to a 0.1% production capacity reduction of the whole industry sector. The consequences of these two events are probably quite different, but HIS-SSM and the ARIO model consider them to be the same.

The potential losses due to business interruption are probably underestimated by both HIS-SSM and the ARIO model, as the reduction of the availability of diesel in the Netherlands is not taken into account. The ARIO model works on the industry level, so all other firms in the industry sector (including the electronics industry and metal industry) are assumed to be able to produce diesel. This assumption is clearly not in line with reality, underestimating the costs of a flood in which such a firm is damaged. The costs of the (indirect) business interruption should be assessed on the individual firm level for these specific firms. Examples of these kind of firms are large (petro-)chemical plants, large power plants, telecommunication centers and the gas fields in the north of the Netherlands. The losses due to business interruption caused by the flood-

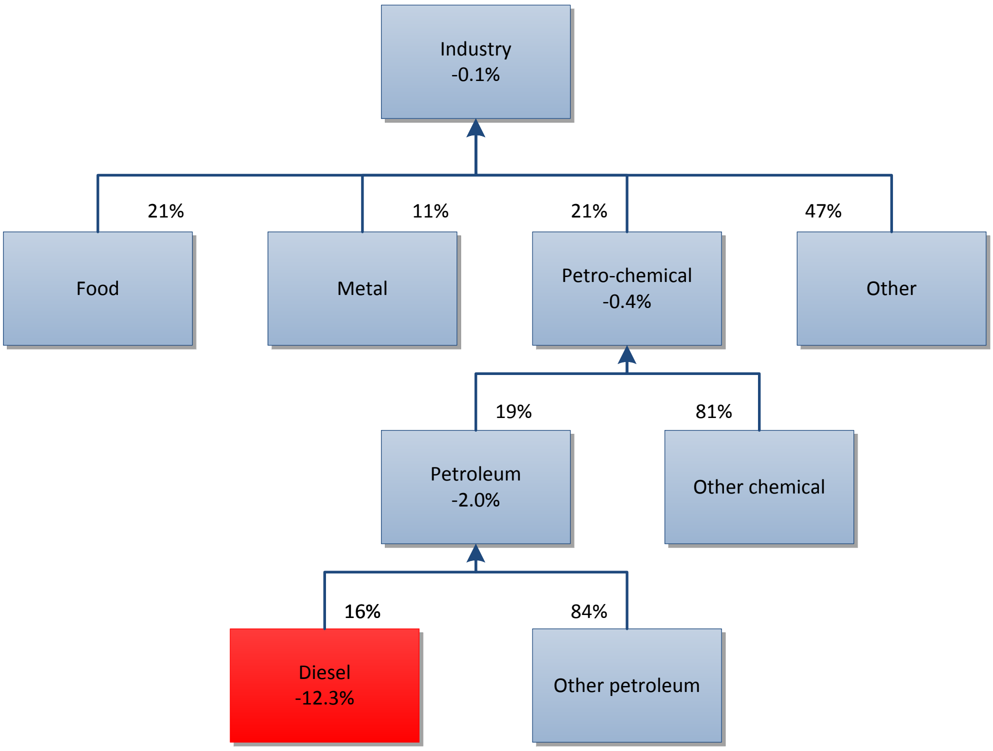

Figure 8-1: Industry sector tree. The figures in the boxes give the production capacity reduction of the box. The figures near the lines indicate the size of the box relative to the size of the box above. Figures based on [Centraal Bureau voor de Statistiek (2012)].

ing of these firms should be considered in more detail than the level offered by HIS-SSM or the ARIO model.

The following three conditions make it necessary to assess the losses due to business interruption of a certain firm on an individual basis. First, the firm can be interrupted by a flood. This can be a result of material damage, power failure and many other reasons. If the firm is built in such a way that it can withstand floods without being interrupted it is not necessary to make a detailed assessment of the potential losses due to business interruption. Second, the firm must provide goods or services that cannot be substituted for at short notice. For example, other refineries in Europe are probably able to increase their production (temporarily) to meet the demand for diesel in the Netherlands if the Neste refinery stops its production, avoiding large negative consequences. Third, the interruption of the firm should have an influence on a geographic area larger than the flooded area,so the indirect effects actually increase the magnitude of the disaster.

8.4 Material damage and business interruption

Whether the losses due to business interruption are a constant fraction of the material damage of a flood is an interesting question. If this is the case, these losses can be determined much more easily than how it is done today. The analysis of recent floods in chapter 2 showed that the fraction is not constant for different floods though.

Figure 8-2 confirms that there is no constant fraction between the two according to the ARIO model.

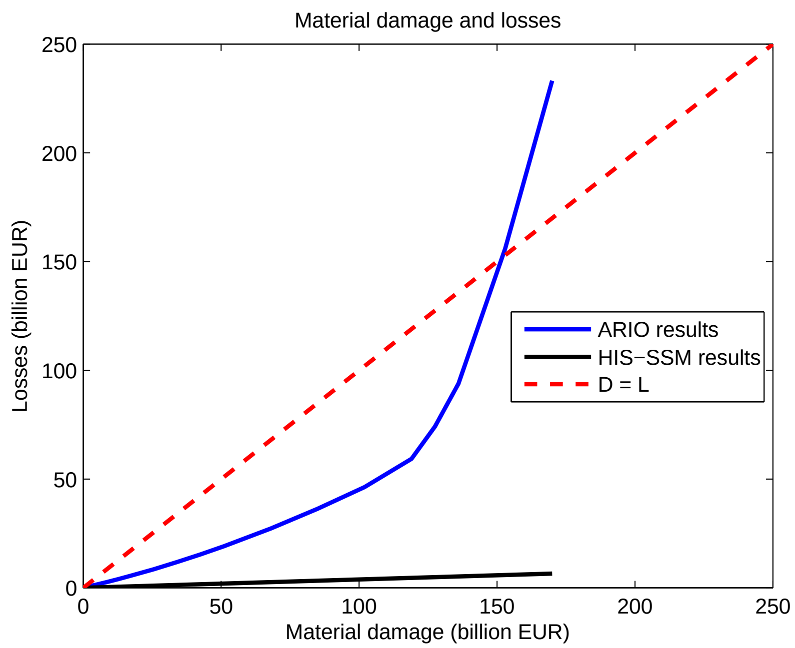

Figure 8-2: Relation between the material damage and the losses due to business interruption caused by the Lopik dike breach case. See text for an explanation.

The vertical axis contains the losses due to business interruption, the horizontal axis the material damage. The blue line has been determined by multiplying the material damage in the Lopik dike breach case by several different factors and using this damage in the ARIO model to determine the losses due to business interruption. The relative breakdown of the material damage does not change, only the size. This is done to determine the losses due to business interruption by the flooding of an area similar to but smaller or larger than the flooded area in the Lopik dike breach case. The black line indicates the losses if an area similar to but larger than the flooded area in the Lopik dike breach case is flooded according to HIS-SSM. The losses due to business interruption also increase, but the slope is constant. The red line indicates whether material damage or losses due to business interruption constitute the largest part of the total costs of the flood. If the blue line is below the red line, the material damage is larger than the losses due to business interruption. If the blue line is over the red line, the losses due to business interruption are larger than the material damage caused by the flood. The black line is always below the red line, so the losses due to business interruption are smaller than the material damage for these scaled cases according to HIS-SSM.

For relatively small amounts of material damage the blue line is below the red line. The material damage is larger than the losses due to business interruption in this area, but the losses due to business interruption still play a significant role. At a certain point, the losses due to business interruption start rising a lot faster than the material damage. For a material damage of 150 billion EUR (about nine times the material damage in the actual Lopik dike breach case) the losses due to business interruption are 150 billion EUR as well. This is a very severe flood however and fortunately unlikely to happen.

The black line indicates that the losses due to business interruption are a constant fraction of the material damage according to HIS-SSM. As can be seen in figure 8-2, the difference in results in the ARIO model and HIS-SSM increases especially for very large scale floods. Together with the data on actual large-scale floods, this gives reason to believe that the losses due to business interruption are underestimated for large-scale floods in HIS-SSM.

The non-linear behavior makes it important to take the losses due to business interruption into account, especially for large-scale floods.

8.5 Recovery period duration

The amount of direct material damage also has an influence on the duration of the recovery period. If the amount of material damage is larger, the reconstruction period will take longer. Figure 8-3 confirms this. This figure contains the amount of material damage on the horizontal axis and the duration of the recovery period on the vertical axis.

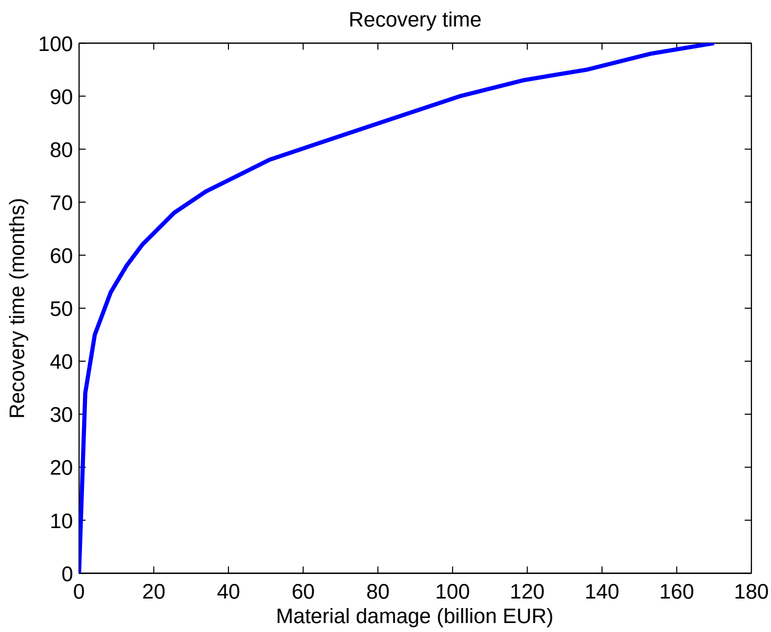

Figure 8-3: Relation between the material damage and recovery period duration. See text for an explanation.

The remaining material damage is reduced asymptotically to zero, so a certain value has to be chosen to determine when the recovery period has ended. This number is set to 100 million EUR material damage (which is less than 1% of the initial material damage in the Lopik dike breach case). The material damage has been changed in the same way as was done to determine the relation between the material damage and the losses due to business interruption.

There are two forces at work that influence the recovery period duration. The first is that the amount of material damage determines how much production is used to repair the damage (instead of being used for local final demand or exports). An increased amount of material damage increases the share of production spent on repairs. The second is that more material damage reduces the production capacity of the economy even further. In other words, an increase in the amount of material damage increases the share of the economic pie used for repairs, but reduces the total size of the economic pie.

The recovery time increases, but the increase becomes less for larger amounts of material damage. This is a result of the rationing scheme and the production capacity reduction. As the material damage increases, so does the share of production that is used to repair the material damage. For this reason the amount of remaining material damage decreases very fast in the first few months after the flood (as can be seen in figure 7-10), but the reduction slows down later on. The effect of the rationing scheme is larger than the effect of the production capacity reduction. This relation can intuitively be felt when looking at figure 7-10, because the reduction of the remaining material damage per month is much larger when the amount of remaining material damage is larger.

8.6 Permanent leaving of firms

Both the ARIO model and HIS-SSM assume that in the end the situation will return to the pre-disaster state. This is a convenient assumption, as it is not necessary to determine how many firms leave the flooded area permanently. In actual floods such as the flooding of New Orleans by hurricane Katrina this assumption does not hold, as many of the pre-disaster inhabitants and firms did not return at all. This makes it interesting to see how large this effect potentially is.

Using several assumptions the costs due to the permanent leaving of firms in the Lopik dike breach case will be compared to the losses due to temporary business interruption. An important question in this matter is where the firms are being relocated to. If they stay in the Netherlands, the effects are not different from a temporary business interruption from the viewpoint of the Dutch society in total. For this reason, it is assumed that only firms of which the final control is situated outside of the Netherlands will possibly leave the Netherlands. In other words, Dutch firms will remain in the Netherlands, but foreign firms might choose to relocate to a foreign country.

	Sector	Dutch control	Foreign control	Potential leavers [%]
2	Mining	7,800	1,944	20.0
3	Industry	33,754	23,839	41.1
4	Power supply	4,483	2,465	35.5
5	Water and waste management	3,055	326	9.6
6	Construction	24,942	1,551	5.9
7	Retail	47,491	20,028	29.7
8	Transport and storage	17,801	7,311	29.1
9	Food services	5,979	1,409	19.1
10	Information and communication	16,066	8,585	34.8
12	Real estate	12,165	289	2.3
13	Specialist business services	30,858	4,286	12.2
14	Other business services	16,899	4,411	20.7

Table 8-3: Firm ownership in 2010. The Dutch control and foreign control columns give the yearly value added per sector of all the firms that are under respectively Dutch or foreign control. The potential leavers are calculated by the relative share of foreignly controlled yearly value added divided over the total yearly value added.

Statistics Netherlands collects data on firm ownership. Relevant data is collected in table 8-3.[1] Unfortunately data of 2011 is not available yet. Firm ownership is only available for a limited amount of sectors. For the remaining sectors, the assumption is made that foreign ownership is equal to the average of the listed sectors (25.7%). The sectors governmental services, education, health care and culture, sports and recreation are assumed to be completely Dutch owned.

[1] Available at http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=81358NED&D1=1,4,10&D2=1-2,27,29,34,47,72,83,93,104,106,114,l&D3=1-2&D4=l&HDR=T&STB=G1,G2,G3&VW=T accessed 10-4-2013

The production capacity reductions immediately after the flood according to the ARIO model are collected in table 8-4. This table also contains the fraction foreignly controlled firms as determined in table 8-3 and the permanent, potential economic losses if all the flooded foreignly controlled firms leave the Netherlands.

	Sector	VA reduction	Foreign ownership [%]	Potential losses
1	Agriculture	701.1	25.7	180.2
2	Mining	4.9	20.0	1.0
3	Industry	426.1	41.1	175.1
4	Power supply	34.3	35.5	12.2
5	Water and waste management	3.5	9.6	0.3
6	Construction	161.3	5.9	9.5
7	Retail	425.6	29.7	126.4
8	Transport and storage	99.7	29.1	29.0
9	Food services	33.8	19.1	6.5
10	Information and communication	162.6	34.8	56.6
11	Financial services	2,796.8	25.7	718.8
12	Real estate	856.6	2.3	19.7
13	Specialist business services	206.0	12.2	25.1
14	Other business services	132.7	20.7	27.5
15	Governmental services	434.1	0	0
16	Education	152.7	0	0
17	Health care	102.9	0	0
18	Culture, sports and recreation	25.5	0	0
19	Other services	26.6	25.6	6.8
	Sum	6,786.8	-	1394.7

Table 8-4: Potential permanent losses due to firms leaving the Netherlands as a result of the Lopik dike breach. Value added (VA) reduction immediately after the flood and potential permanent losses in million EUR per year.

If all the foreignly controlled flooded firms leave the Netherlands the value added by the Dutch economy will be reduced by almost 1.4 billion EUR per year. More than half of this is the result of a permanent relocation of firms belonging to the financial services sector. The agricultural, industrial and retail sector are responsible for most of the remaining reduction.

To compare the permanent and temporary losses, this perpetuity should be expressed as a monetary value in the year 2011 by using the discounting rule in equation 8-1. The discount rate (i) is set to 5.5% in accordance with guidelines from the Dutch national government[2] and the *Maatschappelijke kosten-batenanalyse Waterveiligheid* [Deltares (2011)].

$$PV = \sum_{t=1}^{\infty} \frac{FV}{(1+i)^t} = \frac{FV}{i} \tag{8-1}$$

The future value (FV) equals 1.4 billion EUR per year, leading to a present value (PV) of 25.4 billion EUR. Compared to a material damage of 17.1 billion EUR and losses due to temporary business interruption of 5.0 billion EUR the possible losses due to permanent relocation appear to be very large.

[2] https://zoek.officielebekendmakingen.nl/kst-29352-5.html accessed 12-4-2013

These permanent losses will only occur if all the flooded foreignly controlled firms leave the Netherlands. According to Sicco Santema (who was interviewed in appendix B) the amount of firms that will relocate permanently after a flood will be very small. Some of those firms will move to other locations in the Netherlands, not leading to permanent losses to the Netherlands as a whole. If the amount of firms that move to foreign countries equals 2%, the permanent losses due to firm relocation are about 0.5 billion EUR, making them equal to 10% of the losses due to temporary business interruption. This can be a considerable contribution to the total costs of a flood.

The preceding cost estimate does not take into account that the permanent relocation of firms to foreign countries can have a large influence on the supply chains of these firms. Suppliers of the relocated firm will probably move as well, increasing the losses due to firm relocation.

8.7 Implications

The underestimation of the costs of large-scale floods by HIS-SSM can have large implications. The economically optimum dike height is an important variable in the discussion on flood protection. If the total costs of a flood increase, the economically optimum dike height will also increase. Large possible consequences justify the spending of large amounts of money on the prevention of these consequences, in an economic sense.

The dike height in the Netherlands is not only based on the economically optimum dike height however, but also on ethical considerations regarding the loss of life and injuries caused by a flood. The economically optimum dike height is merely one of the arguments in this discussion and can be found in the *Maatschappelijke kosten-batenanalyse Waterveiligheid* [Deltares (2011)].

Instead of merely focusing on prevention, other measures to reduce the risk of floods can also be considered. Next to spatial solutions and crisis management measures (the other two strategies in the multilayered safety approach), measures to reduce the duration of business interruption caused by floods could also be cost-efficient. For example, the partitioning of large dike ring areas (to avoid large-scale floods in which the losses due to business interruption have a relatively large contribution to the total costs) and to make certain sectors more robust to floods (for example by using a dual-sourcing supplier strategy instead of a single-sourcing strategy, see appendix B). A cost-benefit analysis should be performed on each measure to test the cost-efficiency.

9 Conclusion

This chapter contains the conclusions and recommendations based on the current study.

9.1 Conclusions

The conclusions are summarized in the following list:

- Four historical floods show that the losses due to business interruption play a significant role in the costs of large-scale floods (contribution 23% to 56% to the total costs)
- Large differences exist in the methodology and results of HIS-SSM and economic input-output models
- HIS-SSM probably underestimates the losses due to business interruption as a result of large-scale floods
- The outcome of the ARIO model depends strongly on the damage-to-production-capacity-ratio and to a lesser extent on the overproduction parameters
- Both HIS-SSM and the ARIO model underestimate the potential losses due to business interruption if a critical firm or infrastructure is flooded
- The losses due to business interruption are not a constant fraction of the material damage caused by a large-scale flood
- The recovery time increases if the amount of material damage is larger, but the increase becomes smaller for large amounts of material damage
- Losses due to permanent firm relocation may constitute a considerable contribution to the total costs of a flood

Each conclusion is explained in more detail below.

The losses due to business interruption play a significant role in the costs of floods, as can be seen in table 8-2. In the Thai floods of 2011 the losses due to business interruption were actually larger than the material damage caused by the flood. The relative size of the losses due to business interruption as determined by HIS-SSM are much smaller than the figures found in actual cases. The results of the ARIO model are more in line with the data from recent floods in foreign countries.

The methodology and results of HIS-SSM and input-output models are very different. Input-output models are capable of taking the heterogeneity of an economic shock (like a large-scale flood) into account while HIS-SSM cannot. Input-output models can also take the scale of the flood into account. A major disadvantage of input-output models is the data requirement, which is quite large compared to HIS-SSM.

The losses due to business interruption are most likely underestimated in HIS-SSM. In the Lopik dike breach case the losses due to business interruption are equal to only 3.8% of the material damage caused by flood, while this figure ranges from 30% to 125% for the actual recent floods.

The losses due to business interruption as determined with the ARIO model dependent very strongly on the damage-to-production-capacity-ratio (DPCR), which basically contains how much material damage is required to reduce the production capacity with one euro worth of added value. This ratio can be determined in a number of ways. Both a maximum and a minimum value can be determined, but the range between these two extremes is quite large. The influence of the overproduction parameters is also quite strong compared to the remaining parameters in the model.

HIS-SSM and the ARIO model both use a sector approach to determine the amount of losses due to business interruption. The consequence of this methodology is that each firm is assigned to a certain sector, and in that sector firms are assumed to be able to substitute each others products and services. This leads to an underestimation of the losses due to business interruption if a critical firm or infrastructure (like the considered renewable diesel refinery) is flooded.

The losses due to business interruption become relative larger if the scale of the flood becomes larger, as can be seen in figure 8-2. At a certain point, the losses due to business interruption become larger than the material damage caused by the flood. This is expected, as one of the most important variables regarding the losses due to business is the production capacity of the construction sector. If the scale of the flood is larger, the production capacity of this sector is reduced more so the recovery takes more time. If the recovery takes more time, the duration of business interruption increases and so do the losses.

According to the ARIO model, the recovery time increases if the material damage increases, but this increase becomes smaller if the material damage is larger. This has to do with the rationing scheme in the model. If the amount of material damage is larger, the (monthly) amount of production used to repair the damage becomes relatively larger. This results in a large amount of repair works in the first few months after the flood.

A preliminary estimate of the losses due to permanent firm relocation indicate that these losses form a small but considerable contribution to the total costs of a flood, even if only a very small (2%) part of the foreignly controlled flooded firms decide to leave the Netherlands. The effect of permanent relocation on supply chains is not taken into account, while this might have a considerable contribution to the losses related to permanent relocation.

9.2 Recommendations

The recommendations are summarized in the following list:

- Consider the duration of the flood
- Take critical firms and infrastructures individually into account
- Validate and update the HIS-SSM business interruption module
- Perform more research on the relation between material damage and production capacity
- Study the effects and causes of permanent firm relocation in the aftermath of a flood
- Consider measures for reducing the duration of the recovery period

The duration of a flood has a large influence on the losses due to business interruption. The cleanup and reconstruction activities cannot start before all the water is gone. This probably had a large contribution to the losses due to business interruption in Thailand in 2011, but it is currently not taken into account in HIS-SSM or the ARIO model.

The losses due to business interruption caused by the failure of a critical firm or infrastructure should be taken into account more thoroughly. The effects of these failures are not taken into account adequately by HIS-SSM and the ARIO model because these models use an aggregated approach in which firms are assigned to a certain sector of the economy. Even during large-scale floods the effects of such a failure are present and thus should be predicted to determine the costs of a flood. A good approach would be to identify these firms and predict the effects of the individual failure to determine whether the costs contribute significantly to the total costs of a flood. If this is the case the costs of the flood and the costs of the individual failure should be combined.

Using HIS-SSM the losses due to business interruption are probably underestimated in the Lopik dike breach case and the scale of the flood does not influence the relative amount of losses due to business interruption. These two characteristics are quite important and have a large influence on the total costs of a flood. Increasing the accuracy of the cost predictions of a flood leads to a more accurate economically optimum dike height. There should be more research on the validity of the business interruption module of HIS-SSM, preferably by applying HIS-SSM to recent floods in foreign countries to validate its results. If the accuracy of the module proves to be insufficient in these cases a more sophisticated model should be implemented to predict the losses due to business interruption.

The ARIO model strongly depends on the relation between material damage and production capacity. This relation is actually important in all other models to assess the losses due to business interruption as well in one way or the other. For example, the damage functions in HIS-SSM incorporate this relation. More research should be performed on this topic to be able to model this relation in a good way.

A preliminary estimate indicated that permanent firm relocation as a result of floods may contribute significantly to the total costs of a flood. Much is unknown about this subject however. The causes and effects of this phenomenon should be studied more thoroughly to be able to take these costs into account.

The overproduction parameters have a strong influence on the losses due to business interruption as calculated by the ARIO model. In the multilayered safety approach flood protection policies are focused on three pillars, namely prevention, spatial solutions and crisis management [Hoss (2010)]. Prevention is the traditional flood defense strategy of building dikes and storm surge barriers to avoid land from being inundated. Spatial solutions consists of using spatial planning and the adaptation of buildings to reduce the consequences of a flood. Crisis management focuses on disaster plans, early warning systems and evacuation. The losses due to business interruption play a significant role in the total costs of a flood, but these losses take place in the aftermath of a flood. If the duration of the recovery period after a flood can be shortened, these losses due to business interruption decrease. This makes flood resilience perhaps a fourth layer in the multilayered safety approach. Measures in this layer would be aimed at reducing the duration of the recovery period. This comprises many different measures, like stimulating the construction sector to become more flexible to be able to increase the production capacity quickly if needed. Ensuring that sufficient construction materials are available or can be imported on short notice is also a possible measure. To determine whether these measures should be taken or not, a cost-benefit analysis as proposed in the introduction of this report should be made on each individual measure.

Many more measures can be considered, like the prevention of large-scale floods by the partitioning of large dike ring areas in the Netherlands. The ARIO model results show that the losses due to business interruption become very large if the scale of the flood increases. By partitioning the dike ring areas these large-scale floods are less likely to happen.

Another measure would be to increase the DPCR (so the same amount of material damage leads to a smaller reduction of the production capacity). This can be done by flood-proofing machinery or placing the machinery in such a way that some of the assembly lines are completely safe from flooding. This makes sure that a flood cannot damage the vital components of many different assembly lines leading to the complete interruption of the firm.

As the interviews pointed out, it may also be beneficial to switch to dual-sourcing instead of single-sourcing in supply chains. With a single-sourcing supply strategy a firm is dependent on one firm to supply certain components, which is good for establishing strong relationships between firms to reduce production costs. In the case of a flood however, if one firm is interrupted the others will be interrupted as well much quicker, leading to larger losses due to business interruption. A second (or back-up) source of components can reduce these losses.

It may also prove to be worthwhile to make certain sectors more robust against floods. Especially the construction sector would be eligible for this, as this sector has a large influence on the recovery duration in the aftermath of a flood. Measures could be for example to temporarily park vehicles used by the construction sector on higher grounds during high water. If a flood occurs, then the vehicles will be saved and can be used in the reconstruction phase.

Protecting critical firms or infrastructures individually could also be an efficient measure. If the consequences of flooding of a certain firm are very large (the gas mining facilities in Groningen for example), protecting these facilities with spatial solutions (like increasing the ground level or adapting buildings) is an option. A cost-benefit analysis should be performed to determine whether such measures are actually efficient.

Literature

O. Bin, J. Kruse, and C. Landry. Flood Hazards, Insurance Rates, and Amenities: Evidence from the Coastal Housing Market. *Journal of Risk and Insurance*, 75, 2008.

M. Bockarjova. *Major Disasters in Modern Economies: An Input-Output Based Approach at Modelling Imbalances and Disproportions*. PhD thesis, University of Twente, 2007.

M. Boswell, R. Deyle, R. Smith, and E. Baker. A Quantitative Method for Estimating Probable Public Costs of Hurricanes. *Environmental Management*, 23, 1999.

Centraal Bureau voor de Statistiek. Nationale Rekeningen 2011, 2012.

A. Chongvilaivan. Thailand 2011 flooding: Its impact on direct exports and global supply chains, 2012.

Defra and Environment Agency. The Appraisal of Human related Intangible Impacts of Flooding. Technical report, Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme, 2004.

Deltacommissie 2008. Samen werken met water, 2008.

Deltares. Maatschappelijke kosten-batenanalyse Waterveiligheid 21e eeuw. Technical report, Deltares, 2011.

Department of Homeland Security and Federal Emergency Management Agency. HAZUS MR3 Technical Manual.

Economic Commission for Latin America and the Caribbean. Handbook for Estimating the Socioeconomic and Environmental Effects of Disasters, 2003.

Geodan and Royal Haskoning. HIS-Schade en Slachtoffers Module Gebruikershandleiding, 2007.

Government of Japan. Road to recovery, 2012.

S. Hallegatte. An Adaptive Regional Input-Output Model and its Application to the Assessment of the Economic Cost of Katrina. *Risk Analysis*, 28, 2008.

D. Hondula and R. Dolan. Predicting severe winter coastal storm damage. *Environmental Research Letters*, 5, 2010.

F. Hoss. A comprehensive assessment of Multilayered Safety in flood risk management. Master's thesis, Delft University of Technology, 2010.

S. Jonkman, M. Brinkhuis-Jak, and M. Kok. Cost benefit analysis and flood damage mitigation in the Netherlands. *Heron*, 49, 2004.

S. Jonkman, M. Bockarjova, M. Kok, and P. Bernardini. Integrated hydrodynamic and economic modelling of flood damage in the Netherlands. *Ecological Economics*, 66, 2008.

M. Kok, H. Huizinga, A. Vrouwenvelder, and A. Barendregt. Standaardmethode2004 Schade en Slachtoffers als gevolg van overstromingen. Technical report, Rijkswaterstaat, 2005.

M. Kok, R. Theunissen, S. Jonkman, and H. Vrijling. *Schade door overstroming: Ervaringen uit New Orleans*. 2006.

B. Kolen, S. Jonkman, and L. Bouwer. Case study Anderhalf jaar na de Tohoku tsunami in Japan. *Water Governance*, 4, 2012.

W. Leontief. Input-output economics. *Scientific American*, 1951.

Q. Lequeux and P. Ciavola. Methods for estimating the costs of coastal hazards. Technical report, CONHAZ, 2012.

B. Merz, H. Kreibich, R. Schwarze, and A. Thieken. Assessment of economic flood damage. *Natural Hazards and Earth System Sciences*, 10:1697–1724, 2010.

F. Messner, E. Penning-Rowsell, C. Green, V. Meyer, S. Tunstall, and A. Van Der Veen. Evaluating flood damages: guidance and recommendations on principles and methods. Technical report, FLOODsite, 2007.

B. Muhr, M. Kunz, T. Kunz-Plapp, J. Daniell, B. Khazai, M. Vannieuwenhuyse, T. Comes, F. Elmer, K. Schroter, A. Leyser, C. Lucas, J. Fohringer, T. Munzberg, W. Trieselmann, and J. Zschau. CEDIM FDA-Report on Hurricane Sandy 22-30 October 2012. Technical report, Center for Disaster Management and Risk Reduction Technology, 2012.

Munich Re. Natural Catastrophes 2011. Technical report, Munich Re, 2012.

Neste Oil. Neste Oil Corporation Financial Statements for 2012, 2013.

R. Ohm. Duurzaam geproduceerde biodiesel heeft de toekomst. *Transport & Logistiek*, 6, 2012.

RebelGroup Advisory. Schade ten gevolge van productie-uitval bij overstromingen. Technical report, RebelGroup Advisory, 2009.

Rijkswaterstaat. Hydraulische Randvoorwaarden 2006. Technical report, Ministerie van Verkeer en Waterstaat, 2006.

A. Simola, A. Perrels, and H. J. Extreme weather events in Finland - a dynamic CGE-analysis of economic effects. Global Economic Analysis Conference, 2011.

V. Tsimopoulou, S. Jonkman, B. Kolen, J. Van Alphen, R. Stroeks, and F. Van De Ven. *The Great Eastern Japan earthquake and tsunami: Facts and implications for flood risk management*. 2012.

A. Vervaeck and J. Daniell. Tohoku Earthquake Articles on earthquake-report.com. 2011-2012.

World Bank. East Asia and Pacific Economic Update. Technical report, World Bank, 2011.

World Bank. Thai Flood 2011 Rapid Assessment for Resilient Recovery and Reconstruction Planning. Technical report, World Bank, 2012.

Appendices

A Selection of interesting news articles

This appendix contains several articles on recent floods to illustrate the consequences of the floods. The first two articles are on the consequences of Hurricane Sandy in the USA in 2012. The third article is on the availability of hard disk drives after the flood in Thailand in 2011. One of these articles is in Dutch.

A.1 New York vooral ontwricht door kettingreactie na orkaan Sandy

This article appeared on waterforum.net on February 27th, 2013.

New York vooral ontwricht door kettingreactie na orkaan Sandy

Het was vooral de onvoorspelbare kettingreactie, na het overtrekken van orkaan Sandy, die New York en omgeving hebben ontwricht. Dat vertelde Rob Pirani van de Regional Planning Association van New York op een congres in Amsterdam. De storm van vorig jaar oktober had de Amerikaanse metropool grotendeels overvallen, zo blijkt uit Pirani's verhaal. Ondanks de grote verschillen met New York zijn er voor Amsterdam wel lessen te leren uit de gebeurtenissen, zo bleek op het congres. Beide metropolen kunnen van elkaar leren in hoogwaterbescherming en klimaatadaptie.

Die conclusie werd getrokken tijdens het op 7 februari gehouden congres over de metropoolregio Amsterdam. In het filmmuseum EYE werd onder de titel 'EYE on the future' gedebatteerd over de ambities van Metropoolregio Amsterdam met deelnemers, experts en bestuurders uit binnen- en buitenland. Daarbij werd ook ingegaan op de waterveiligheid in relatie tot de toekomstige ontwikkeling van de Amsterdamse regio. Voor dit onderdeel was Rob Pirani uitgenodigd, vice-president van de 'regional planning association' in New York.

Pirani verhaalde over de gevolgen van orkaan Sandy die de New Yorkse regio trof op 29 oktober vorig jaar en meer dan honderd dodelijk slachtoffers maakte en een schade veroorzaakte van bijna 100 miljard dollar. Naast de directe herstelwerkzaamheden wil New York een langetermijn-strategie ontwikkelen om de gevolgen van toekomstige superstormen in te perken.

Vergelijking met Amsterdam

De geografische situatie van New York en Amsterdam zijn niet geheel vergelijkbaar, maar het verhaal van Pirani gaf wel een beeld welke gevolgen een overstroming van een stad als Amsterdam en de omliggende regio met veel polders onder zeeniveau kan hebben. Volgens Pirani was vooral de kettingreactie verrassend die de orkaan in het gebied teweegbracht. Na het overtrekken van Sandy was het gebied rond New York zeker nog twee weken volkomen ontwricht.

Problemen met benzinetekort en vervuiling

Er traden grote benzinetekorten op, er waren problemen met de aanvoer van brandstof en de elektriciteitsvoorziening lag op veel plaatsen plat. De bevolking in de getroffen buitenwijken van de Amerikaanse metropool waren lange tijd geïsoleerd en mensen konden ook niet aan brandstof voor generatoren komen. Brandstoftanks in kelders van woningen kwamen door het water los van de grond waardoor diesel vrijkwam en zich met het water vermengde. Die verontreiniging is ook een groot probleem bij het wegpompen van het water. Bovendien waren ook raffinaderijen en distributiestations onder water komen te staan, net als verscheidene chemische complexen. Ook hier is voor Amsterdam een les uit te trekken, bijvoorbeeld met zijn grote benzineopslag in het westelijk havengebied en de industrie langs het Noordzeekanaal.

Omvang Sandy pas vlak tevoren duidelijk

Pirani vertelde hoe vlak voor de komst van Sandy pas duidelijk was hoe zwaar de impact zou zijn en dat die het gebied veel harder zou treffen dan de bestaande scenario's (1:100 jaar). Wel hebben instanties in de stad nog op het laatste moment voorzorgsmaatregelen getroffen. Kwetsbare installaties van de metro konden nog op tijd worden veiliggesteld of afgeschermd, met als gevolg dat twee weken later, na het wegpompen van het water, 80% van de metro's weer aan het rijden was.

Zelfredzaamheid in zeer kritische situatie

Terwijl in de stad de gevolgen van het natuurgeweld nog enigszins konden worden beperkt, was de schade en ontreddering in de wijken langs de kust enorm, vertelt Pirani. 'Huizen waren weggevaagd. De federale hulpverlening kwam laat op gang en kon de omvang van de gevolgen niet altijd behappen. De bewoners waren aanvankelijk helemaal op elkaar aangewezen. Wat dat betreft hebben wij veel geleerd van (het belang van) de menselijke veerkracht in de eerste dagen na de ramp. Iedereen, rijk en arm, hielp elkaar en de eerste aandacht richtte zich bijvoorbeeld op het redden van zieke en oudere mensen van wie men de woonadressen kende. Het was een zeer kritische situatie die voornamelijk dankzij de vrijwilligers minder rampzalig is verlopen', aldus Pirani.

Problemen met schadeloosstelling en verzekering

Onzekerheid over financiële steun van de federale overheid maakte de situatie in de getroffen gebieden volgens Pirani alleen maar erger. 'Tot op de dag van vandaag is de bevolking nog zeer nerveus door de gebeurtenissen en de vraag of en in hoeverre zij schadeloos gesteld worden.' Pirani vertelt dat juist enkele maanden voor de storm belangrijke wijzigingen waren doorgevoerd in de zogenaamde 'flood insurance maps' die gebaseerd zijn op de kans van 1:100 en gelden voor 2/3 van het metropool gebied. 'Sinds juni vorig jaar wordt de overstromingsverzekering niet meer gesubsidieerd en betalen huiseigenaren een vier keer zo hoge premie. Daar komt bij dat in 1983 de voorwaarden van de overstromingsverzekering waren aangepast, waardoor bewoners van de woningen die voor die tijd zijn gebouwd, veel minder uitgekeerd krijgen dan zij hadden verwacht. En dan te bedenken dat het 95% van alle woningen betreft die zware schade hebben opgelopen. Woningen van na 1983 die wel aan de nieuwe voorwaarden van de overstromingsverzekering voldeden hebben relatief weinig schade opgelopen', aldus Pirani.

Het is volgens hem afwachten hoe de overstromingsverzekeraars met de ervaringen van deze ramp omgaan in hun polis. 'Overstromingskaarten zullen ontegenzeggelijk worden aangepast en premieverhoging zal onvermijdelijk zijn', denkt Pirani.

Lessen voor Amsterdam en New York

De toehoorders beseften dat - ondanks grote verschillen in situatie en aanpak met New York - ook in de Amsterdamse regio zulke taferelen zich kunnen voordoen. Een orkaan van de omvang van Sandy is in Nederland bijna uitgesloten en de kust is veel beter bestand tegen overstromingen. Amsterdam loopt vooral gevaar vanuit het zuiden, als de dijken van de Lek bij Utrecht zouden doorbreken. Zo'n scenario zou zich kunnen voordoen als de rivieren door klimaatverandering veel meer zullen gaan voeren. Het Deltaprogramma schenkt extra aandacht aan de versterking van deze dijken.

Ook binnen de agglomeratie zelf kan water in de toekomst grote problemen gaan veroorzaken, bijvoorbeeld na zeer zware regenbuien. In Nederland is er daarom veel aandacht voor meerlaagsveiligheid die de gevolgen van overstromingen of wateroverlast moet beperken. Van deze aanpak en de herstructureringsaanpak die New York in het getroffen gebied gaat opzetten, kunnen beide partijen veel van elkaar leren, zo werd tenslotte geconcludeerd. Pirani zelf was er in ieder geval van overtuigd dat zijn stad enorm veel kan leren van de preventieve aanpak van de Nederlanders. Hij reageerde daarmee op de opmerking van de Noord-Hollandse gedeputeerde Joke Geldhof dat de miljarden die nu aan schade en herstel in de regio New York moet worden uitgegeven toch veel beter in de preventie had kunnen worden gestoken?

This article is mainly interesting due to the large amounts of effects the hurricane caused. In the aftermath of the disaster the main problem is not the water but the lack of electrical power and gasoline. The information regarding the flood insurance is also quite interesting, as there is a debate going on in the Netherlands between home owners and insurance companies about a (compulsory) flood insurance.

A.2 Hurricane Sandy Alters Utilities' Calculus on Upgrades

This article was published in the New York Times on 28 December 2012. The authors are D. Cardwell, M.L. Wald and C. Drew.

Hurricane Sandy Alters Utilities' Calculus on Upgrades

After Hurricane Sandy wreaked havoc with power systems in the Northeast, many consumers and public officials complained that the electric utilities had done far too little to protect their equipment from violent storms, which forecasters have warned could strike with increasing frequency.

But from a utility's perspective, the cold hard math is this: it is typically far cheaper for the company, and its customers, to skip the prevention measures and just clean up the mess afterward.

Consolidated Edison, for example, expects to spend as much as $450 million to repair damages to its electric grid in and around New York City. Since utilities are generally allowed to recover their costs through electric rates, customer bills in the region, which typically run about $90 a month for residential customers, would have to rise by almost 3 percent for three years to cover those expenses alone.

Fully stormproofing the system - sinking power lines, elevating substations and otherwise hardening equipment against damage from torrential winds and widespread flooding - could easily cost 100 times as much. For Con Ed, carrying out just one measure - putting all of its electric lines underground - would cost around $40 billion, the company estimates. To recover those costs, electric rates would probably have to triple for a decade or more, according to Kevin Burke, Con Ed's chief executive.

Avoiding such large investments is also appealing for another reason: the federal government has sometimes helped bail out utilities after catastrophes, like the Sept. 11 terror attacks and Hurricane Katrina. It may do so again this time in response to pleas from the governors of New York and New Jersey.

Still, there are signs that the devastation caused by Hurricane Sandy is upending the traditional cost-benefit calculations.

The Northeast has been hit by three big storms in just over a year, and forecasters say that so-called 100-year storms are likely to occur more frequently.

Utilities and policy makers can see that ocean surge poses a previously unexpected threat to the power grid.

And there is growing recognition that the true cost of disruptions, in terms of gasoline lines, lost workdays and business sales, and shivering homeowners, is far higher than the simple dollars and cents spent to protect the power system. A recent report from the National Academy of Sciences about the vast 2003 blackout in the Eastern United States determined that the economic cost of that disruption was about 50 times higher than the price of the actual electricity lost, and that didn't take into account deaths or other human consequences.

'We need to think now of not just restoring the grid, but how to make it more survivable,' said Philip B. Jones, president of the National Association of Regulatory Utility Commissioners, a trade association of state officials. 'I think most commissioners are coming around to that.'

After Gov. Chris Christie of New Jersey and Gov. Andrew M. Cuomo of New York traveled to Washington to lobby for aid, the Obama administration proposed a broad $60 billion recovery package, including several billion dollars that could be used to protect the utility infrastructure from storms.

'The governor decides if the utilities are deserving and eligible for getting some of that assistance,' said Kevin Lanahan, director of governmental relations at Con Ed. 'But we've never had discussions on this scale, at least in the Northeast. So we're not certain how that might go.'

Political leaders, who have traditionally pressed to keep consumer rates low, are also talking in New York, New Jersey, Connecticut and other states about raising rates - perhaps gradually over many years - to pay for improvements.

This year, after Maryland was hit by several storms, the state's governor, Martin O'Malley, even took the unusual step of asking regulators to raise electric rates by a dollar or two a month to allow utilities to do more preventive work. Abigail R. Hopper, his chief energy adviser, compared the process to losing weight. 'It might take you a while to get to your goal, but you start feeling better and better,' she said.

Ralph A. LaRossa, president and chief operating officer of the Public Service Electric & Gas Company, New Jersey's largest utility with 2.2 million customers, said during hearings in Trenton that what the governor, legislators, utility regulators and the utilities 'need to do is price out what the optimum solution would cost and do a cost-risk analysis - how much are we willing to pay for minimum risk, how much risk are we willing to live with? - and then come up with the best solution for the customers.'

He said that the utility's costs for restoring service after Hurricane Sandy could run to $300 million. But utilities in the state are now considering whether to move some 32 electrical substations - critical relay points where power voltages are reduced for distribution to many homes and businesses - that sit in 100-year flood zones.

Mr. LaRossa estimated that it would cost $10 million to $15 million to build each new substation and $120 million to build each new switching station, where power is routed to different areas.

Another solution, he said, could be to build greater redundancy into the network. For example, P.S.E.& G. has bought land inland from Newark, where most residents lost power from storm surges during the hurricane, to build a new station that could continue to serve the city if older substations flooded.

Such public discussions of more prevention reflect a major change in thinking. Traditionally, utilities have focused largely on tree-trimming and sandbags to ease storm damage, and politicians and regulatory commissions have discouraged spending to protect against what seemed to be the long odds for catastrophic storms.

'It was pretty widely understood that things like subway tunnels and underground facilities, including substations and junction boxes, were all very vulnerable,' said M. Granger Morgan, director of the Center for Climate and Energy Decision Making at Carnegie Mellon University in Pittsburgh. 'The difficulty is it's a low-probability event, and they're operating with pretty limited budgets.'

After a series of storms, including Hurricane Irene, hit New Jersey in 2011, public anger and regulatory oversight in that state focused mainly on poor communication by the utilities and their sluggish efforts to restore power.

Even if many consumers now agree that more prevention is needed, they will undoubtedly differ over how much they can afford to pay for it, and state rate commissions plan to hold hearings to weigh their views.

Paula M. Carmody, the Maryland state official who represents consumers before the public service commission, said the high costs of preventive measures raised fairness questions that until now have been mostly unexamined.

If the electric system's reliability is judged to be 'a societal issue,' she said, then the political system should consider using tax dollars. High-income people might be happy to pay extra on their bills to reduce the chance of blackouts, or might buy backyard generators, but poorer people may not be able to afford higher bills, she said; if the improvements are paid for through income taxes, the poor are not so burdened and universal access to electricity is maintained.

Under President Obama's proposal to Congress, $2 billion would specifically be devoted to utility projects, while the governors in New Jersey, New York and Connecticut would also be able to apportion parts of more than $15 billion in other grants for that task.

Referring to that aid, which Congress must still approve, Jeanne M. Fox, a Democrat on the New Jersey Board of Public Utilities, said, 'We'll work with what we've got.'

'The more we can get from the federal government, the less our ratepayers will have to pay,' she said.

This article shows the importance of governance after a flood. The electrical utility companies (which are privately owned in the USA) do not flood-proof their distribution networks to avoid a large price increase for their customers. Initially the US government did not want to contribute to the flood-proofing of the system. When a flood happens, the firms expect the government to pay for the damages, so the costs of the flood for the electrical utility sector are shared by all the American citizens instead of just the people served by the firm in the flooded area. After the flood, after the US government was confronted with the large amount of damage they are willing to contribute to the flood-proofing of the system.

A.3 Floodwaters Are Gone, but Supply Chain Issues Linger

This article was published in the New York Times on 20 January 2012 (three months after the flooding of the HDD industries in Thailand). The author is T. Fuller.

Floodwaters Are Gone, but Supply Chain Issues Linger

KHLONG LUANG, Thailand - The floodwaters receded weeks ago from this sprawling industrial zone, but the streets are littered with detritus, the phones do not work and rusted machinery has been dumped outside warehouses that once buzzed with efficiency.

Before Thailand's great flood of 2011, companies like Panasonic, JVC and Hitachi produced electronics and computer components that were exported around the world. Now of the 227 factories operating in the zone, only 15 percent have restarted production, according to Nipit Arunvongse Na Ayudhya, the managing director of the company that manages the Nava Nakorn industrial zone, one of the largest in Thailand and located just north of Bangkok.

'The recovery has not been that easy,' Mr. Nipit said in an interview Friday on the sidelines of a meeting where he sought to soothe anxious foreign factory managers.

The slow recovery here is having global consequences. Before the floods, Thailand produced about 40 percent to 45 percent of the world's hard disk drives, the invaluable and ubiquitous storage devices of the digital age. It is now becoming clear that it will be months - significantly longer than initially expected - before production of hard drives returns to antediluvian levels.

The upshot for consumers worldwide is that they may face a prolonged period of higher prices for hard drives. In the United States, certain models are currently 40 percent to 50 percent more expensive than before the floods, levels that may remain for several months, analysts say.

'By the end of the year, HDD price could come back to preflood level for certain drives,' said Fang Zhang, an analyst at IHS iSuppli, a market forecasting company based in the United States. He used the acronym for hard disk drives.

John Coyne, the president and chief executive of Western Digital, which makes about one-third of the world's hard drives, said this past week that production in the company's factories in Thailand would not return to preflood levels until September. About 60 other companies that produce hard drives and components were flooded, he said.

The challenges facing all flood-affected companies in Thailand are apparent during a drive through the Nava Nakorn industrial zone. Rotting furniture and rusted file cabinets are strewn outside a Panasonic factory. Workers brought in from Cambodia are cleaning up - dredging filthy drainage ditches and cleaning up trash in front of a JVC facility. But more than a month after the last puddles of floodwater dried in the tropical sun, parts of Nava Nakorn, which means 'new city,' still resemble a municipal dump. Large piles of garbage bags sit beside roads fissured and potholed by the floods.

Many buildings bear the telltale scar of the floodwaters - a high water mark about two meters above street level.

For most factories, the hopes of recovering machinery seems to have been dashed by the prolonged exposure to corrosive, polluted water - in some cases two months.

One manager at a factory that produces components for television sets described his machinery as '100 percent killed in action.' Mr. Nipit estimates that about 60 percent of machinery will be thrown away.

As they rebuild, many foreign investors seem anxious and uncertain whether the Thai government is taking enough measures to prevent another round of flooding during future monsoons.

On Friday, factory managers attended a presentation about future flood prevention measures. By August, the Nava Nakorn industrial zone is to resemble a fortress, with a giant flood wall around the perimeter and sealable aluminum flood barriers across entrance points.

But the audience at the presentation peppered the managers of the industrial zone with skeptical questions about the timetable of rehabilitation and the reliability of future flood forecasting.

Mr. Coyne, the Western Digital president, also delivered a relatively frank message to the Thai government at a separate meeting earlier in the week. Thailand needs 'a credible plan, well executed with measurable milestones along the way,' he said. 'And we need to define those milestone quickly.' He urged the government to speed up flood prevention measures. 'We have to ensure that we have no self-inflicted wounds in 2012,' he said. The monsoon season begins in May.

Before the floods last year, the concentration of hard-drive manufacturing in Thailand kept prices down because of economies of scale and the proximity of suppliers to one another. But the floods showed how risky this arrangement was.

Mr. Coyne said Thailand's reputation was on the line. The No. 1 expectation of customers was that hard drives are available when they need them, he said.

'We need to work together to restore that guarantee of uninterrupted, predictable supply so that our customers will continue to believe in us - and believe in Thailand,' he said.

On Friday, the Thai prime minister, Yingluck Shinawatra, presented a plan to mitigate future flooding that includes reforestation, better coordination of the release of water from hydroelectric dams and a streamlining of decision-making when the risk of flooding arises.

'We will see how we can manage effectively to drain the water to the ocean and the canals as soon as possible,' she said.

Ms. Yingluck's government, which came to power last August just as the flooding was intensifying, has been widely criticized for disseminating inconsistent and inaccurate reports during the floods.

'The information that we obtained from the government was useless,' Mr. Nipit said. 'It was all misinformation.'

As reconstruction grinds on, Mr. Nipit and his colleagues are beseeching foreign factory managers for patience.

Prajak Visuttakul, another manager of the Nava Nakorn industrial zone, told the representatives of dozens of companies that water supplies would not be fully restored until May.

A former major general in the Thai Army, Mr. Prajak bowed to the audience made up of largely Japanese managers.

'We are sorry for this inconvenience,' he said. 'This is the fastest we can do.'

This is an interesting article as the predictions of the hard disk drives prices were quite good. It also shows the impact of business interruption, three months after the flood most industrial firms were still not recovered at all from the flood.

B Interviews

This appendix contains two interviews on flood risks in the Netherlands. The goal of these interviews is to identify the important aspects of floods and consequently to determine the limitations of the models. The two persons that were interviewed are Sybe Schaap (a member of the Dutch Parliament) and Sicco Santema (a professor in industrial design at Delft University of Technology). The following two sections contain a short description of the interviewees and the results of the interviews.

B.1 Sybe Schaap

Sybe Schaap (1946) is a member of the Dutch Senate (which is a part of the Dutch Parliament) and chairman of the Netherlands Water Partnership. He also is a professor of water policy and governance at Delft University of Technology and Wageningen University and Research centre. Previously he was the chairman of the regional water authorities (*waterschappen*) of the Noordoostpolder and Groot Salland. A regional water authority is responsible for the prevention of floods (together with the national government), water quantity and water quality in a certain area. He chaired the umbrella organization of the regional water boards, the *Unie van Waterschappen* (the association of regional water authorities), for three years.

The interview took place at Monday the 8th of April 2013 in Delft. Matthijs Kok was also present during the interview.

One of the most important aspects of risk management policy is to compare different risks with each other to reduce the total amount of risks in society. Money should be spent on risk reduction in areas in which this is most effective. For example, spending large amounts of money on improving the safety of tunnels with complex systems is probably less effective than using the same money to increase the awareness of the public of possible accidents at home.[1] Flood prevention policy should also be considered in this view on risk management.

An interesting anecdote about this occurred in Amsterdam. Due to new safety guidelines, the trams in Amsterdam were considered unsafe according to the fire brigade. The fire brigade thus advised the government officials to close the tram until they are considered safe again. The government official did not close the tram however, because if the trams would be shut down all the potential passengers would probably use a bicycle to move around in the city. This would lead to a large increase in accidents and harm. The government official compared the two risks in this case, the risk of accidents related to the use of trams and the risk of accidents related to the use of bicycles to transport large amounts of people.

Several important consequences of floods and characteristics of the flooded area are currently not taken into account in models to assess flood consequences. These are:

- A new equilibrium
- Reputational damage
- Unavailability of transport infrastructure
- Just-in-time principle

These items will be elaborated on shortly.

[1] In 2011 the amount of fatalities as a result of accidents at home is four times as large as the amount of fatalities caused by traffic according to http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=37683&D1=0-3,20,42,67,81,104-105&D2=0&D3=0&D4=l&VW=T

One of the possible consequences of floods is that inhabitants and firms will permanently leave the flooded area, leading to a new equilibrium of the flooded area. A good example of this effect can be seen in New Orleans, almost eight years after Katrina the amount of inhabitants is still significantly lower than it used to be. An important parameter in this seems to be whether the flooded area is ’booming’ or not. Areas that are growing quickly can cope with a flood, while regions that were already in decline (such as New Orleans and many areas hit by the tsunami in Japan in 2011) do not fully recover. The kind of firms that are flooded also has an influence on whether a new equilibrium will come into play. Many services firms are very flexible and are able to leave the flooded area, while other firms are more bound to a certain location (think of the agricultural and mining sector). The (governmental and legal) complexity of the flooded society also has a large influence on this. The more complex a society is, the longer it will take for everything to recover. This may explain why rebuilding takes much longer in the USA and Japan than in rural areas of Indonesia (Atjeh) for example. These effects are currently not taken into account by the considered models.

Reputational damage also plays a large role, especially in the Netherlands. The Dutch are considered experts on flood protection policy, so a large-scale flood in the Netherlands can lead to a lot of damage to this image. This does not merely affect the water sector, but it can effect the attraction of all kinds of foreign firms to the Netherlands. After the floods in Thailand, some Japanese firms announced that they would withdraw from Thailand if the government did not invest seriously in flood protection policy. Sybe came across an anecdote about the Dutch water policy reputation in the south-east of Germany. The number one item on the news on the radio was that a small quay in Groningen in the Netherlands was flooded (with only a few centimeters of water). This shows that very small incidents lead to an increased awareness on the Dutch expertise on flood protection policy.

The unavailability of transport infrastructure may also lead to large costs in the aftermath of a flood. Flooding of the *Vallei en Eem* area (near Amersfoort) will probably not lead to a lot of material damage, but many important road and rail connections run through this area. The unavailability of these connections for several months can lead to large economic costs for the Netherlands.

The just-in-time principle can also lead to large costs. If the system is running as it should, the benefits of using this principle are large. The harms of the principle can be very large though in case a certain element of the system does not function properly anymore, for example due to a flood. The spreading of the interruption of firms goes much faster when the just-in-time principle is used, especially in combination with the unavailability of physical infrastructure.

The amount of fatalities in the Netherlands during a flood will probably be much lower than in 1953 for a similar flood. A better building quality (most buildings can withstand a flood nowadays) and better communication services will increase the awareness of a possible flood.

A common misconception in the Netherlands is that the Dutch should not be very afraid of extremely high discharges in the river Rhine. The argument for this statement is that the dikes in Germany are not as high or strong as the dikes in the Netherlands. Therefore, if the Rhine has a very high river discharge the dikes in Germany will fail first, acting like a storage basin for the Netherlands. Consequently, it is unlikely that the river dikes in the Netherlands will fail. The consequences of a flood in Germany will be felt in the Netherlands as well though. If the industrial area of the Ruhr area is flooded, many suppliers in the Netherlands will see a large decline in the demand for their services and products. The material damage will occur in Germany indeed, but the indirect effects will certainly be felt in the Netherlands.

B.2 Sicco Santema

Sicco Santema (1960) is a professor at the faculty of industrial engineering at Delft University of Technology. He specialized in business to business marketing and supply chain management. He is also one of the owners of the management consulting firm Scenter in the Netherlands.

The interview took place at Friday the 12th of April 2013 by phone.

In the aftermath of the river floods in Thailand in 2011 the availability of hard disk drives was limited and prices increased tremendously. Two effects were responsible for this phenomenon. First, the hard disk drives are used in the supply chain of many other products like computers, servers and television recorders. The demand for hard disk drives thus remained high, even after a price increase. Second, the supply of hard disks is largely concentrated in Thailand in a number of industrial areas. This caused a sharp decline in the production capacity of this product when one of these industrial areas was flooded. The price increase is the result of the simple price mechanism, the supply of hard disk drives was reduced significantly while the demand remained high leading to a higher price.

An interesting solution to this problem would be to apply (back-up) dual sourcing. In dual sourcing, supply chains make use of two manufacturers to provide the same components to the production process. If the production at one of the sources is interrupted, the other firm should be able to increase its production at short notice to avoid disruption of the whole supply chain.

Another interesting example of supply chain problems was the unavailability of a certain component used by Océ (the printer manufacturer) in the aftermath of the tsunami in Japan. Océ used a single sourcing strategy with a firm that was closed for several months after the flood.

There are some firms in the Netherlands that might have similar effects. The port of Rotterdam and the airport Schiphol can have large effects like these in case one of them is flooded. Other firms, like chip machine manufacturer ASML, can probably restart quite quickly and will not lead to worldwide problems.

The losses due to business interruption in the aftermath of a flood will increase if the just-in-time principle is used. The just-in-time principle is usually combined with single sourcing to be able to establish strong relationships between firms. In the Netherlands, the cost reduction realized by using this principle during normal operations is probably larger than the extra costs that arise in the aftermath of a flood. When the decision is made to apply the just-in-time principle in the Netherlands the probability of a flood is usually not taken into account, because very few floods occur in the Netherlands. Even in other countries (like Thailand) it is usually not taken into account, otherwise firms would have been built on elevated ground.

A large-scale flood can have huge consequences for the reputation of the Dutch water sector internationally. A good example of damage to the reputation of a sector is the nuclear disaster in Fukushima after the tsunami in Japan. Many governments and private firms will think twice before making plans for a new nuclear power plant and think thrice before letting a Japanese firm design it. It is very hard to quantify this reputation damage.

Not many international firms will leave the Netherlands if an incidental flood takes place. When floods start to occur more frequently, they might be inclined to leave however. There are many reasons why international firms come to the Netherlands. When they do choose to move, it is important to determine where they are going. If they move to less flood-prone areas in the Netherlands, the economic losses for the Netherlands are small. If they choose to move to a different country, the economic losses may be large. Many firms will choose to stay where they are however, because a geographical relocation requires a relocation of the supply chain as well. The latter can be very costly.

C Adaptive regional input-output model

This appendix contains a full description of the ARIO model, the MATLAB script used to evaluate the equations and all the necessary input.

C.1 Detailed description of the ARIO model

All the necessary variables are collected in tables in the sections, which also contains in which equations the variables are used. It is important to realize that most of these variables are vectors or matrices, providing information per sector. First the production part is described, then the prices, profits and labor demand. Substitution and overproduction come next.

All the equations are evaluated each time step. The model is run until all the material damage has been reduced to zero.

C.1.1 Production

Variable	Description	Equation
Y_{max}	Production capacity	C-1, C-4
Y_B	Pre-disaster production	C-1
D	Damage per sector	C-1, C-2, C-15
K	Capital intensity	C-1
VA	Pre-disaster value added	C-1
α	Actual overproduction	C-1
TFD	Total final demand	C-2, C-3, C-8
LFD	Local final demand	C-2, C-10
E	Export demand	C-2
HD	Household damage	C-2, C-14
TD_0	First guess total demand	C-3, C-4
Y_0	First guess production	C-3, C-10, C-11, C-12, C-13
A	Input-output table	C-3, C-5, C-9
Y_1	Second guess production	C-4, C-5, C-6, C-7
O_1	First guess orders	C-5, C-6
RF	Reduction factor	C-6, C-7
Y_2	Third guess production	C-7
TD_1	Second guess total demand	C-8
O_∞	Final orders	C-9, C-10, C-11, C-12, C-13
Y_∞	Final production	C-9, C-10, C-11, C-12, C-13
LFD_∞	Final local final demand	C-10
E_∞	Final exports demand	C-11
ΔHD	Household repairs	C-12, C-14
ΔD	Firm repairs	C-13, C-15

Table C-1: Variables used in the ARIO model (production part)

The production capacity is given by equation C-1.

$$Y_{max} = Y_B \left(1 - \frac{D}{K\ VA}\right) \alpha \tag{C-1}$$

The production capacity is based on the pre-disaster production, the amount of damage and the actual overproduction. To be able to transform damage to production decreases, the damage-to-production-capacity-ratio (DPCR) is required. In the original model this DPCR is equal to the capital intensity (K) of the sector, but other ratios may be used. The model assumes that the production capacity is proportional to the amount of capital goods utilized by a sector. If half of the capital goods are damaged, the maximum production is also halved. The capital intensity K describes how much capital goods are required to create one euro worth of value added in a year. In the original model, this factor was assumed to be four for all sectors. In reality, this factor is not equal for all sectors. The governmental, water supply and real estate sectors have higher values. The business services, construction and retail sectors have lower values. The average value for the Dutch economy is close to four however. The overproduction variable may increase the production capacity, which is determined in equation C-29.

The first guess production is based on the basic Leontief input-output table. The total final demand is given by equation C-2 and the production required to meet this demand can be found in equation C-3.

$$TFD = LFD + E + HD + D \tag{C-2}$$

The household damage is part of the total final demand, because the damage to households (HD) increases the demand in the construction and industry sector. The same holds for the damage to firms (D). The household damage does not influence the production capacities of the producing sectors of the economy.

$$TD_0 = Y_0 = (I - A)^{-1} TFD \tag{C-3}$$

The production required to meet the total final demand (Y_0) is the first guess of the total demand (TD_0). This is most likely greater than the production capacity. This leads to the second guess of the production, Y_1. Production capacities are taken into account in the second guess of the production.

$$Y_1 = MIN(Y_{max}, TD_0) \tag{C-4}$$

Next the rationing scheme is implemented. An important question is whether the production capacity is sufficient for all sectors to supply other sectors. If this is not the case, the production is also constrained by the supplies of other firms. The first guess orders (O_1) between sectors of the economy is determined with equation C-5.

$$O_1 = AY_1 \tag{C-5}$$

There are two possibilities. Either the orders are smaller than the production ($O_1 \leq Y_1$), or the orders are larger than the production ($O_1 > Y_1$). In the first case, the production is not constrained by the intermediate goods consumption and the second guess production is the actual production. In the second case, firms have to be rationed as well. First the most critical sector has to be determined, which sector is the source of the rationing. The maximum reduction factor is determined using equation C-6.

$$RF = MIN\left(\frac{Y_1}{O_1}\right) \tag{C-6}$$

All other sectors now have to reduce their production. It does not make sense to reduce the production of the most critical sector as well, because this reduces the total output of the economy even more. This leads to the third guess production, which can be found in equation C-7.

$$Y_2 = RF \times Y_1 \tag{C-7}$$

With this third guess production the orders are still larger than the production however, as the production of the most critical sector is not reduced while this sector orders from itself. For this reason, the second guess total demands are determined (TD_1) using equation C-8.

$$TD_1 = TFD + AY_2 \tag{C-8}$$

This second guess total demand is used in equation C-4 to C-8 to create a new guess of the productions. This continues until the difference between the orders and productions can be neglected.

The final values for the production, total demand and orders are referred to as Y_∞, TD_∞ and O_∞. The production is distributed by a mixed priority and proportional system. The orders are prioritized according to equation C-9. The production is always sufficient to meet these orders, as the production of other firms is reduced to achieve this.

$$O_\infty = AY_\infty \tag{C-9}$$

The components of the total final demand are rationed proportionally. The share of production available for the local final demand is determined using equation C-10.

$$LFD_\infty = LFD\frac{Y_\infty - O_\infty}{Y_0 - O_0} \tag{C-10}$$

The share of production available for exports is determined by equation C-11.

$$E_\infty = E\frac{Y_\infty - O_\infty}{Y_0 - O_0} \tag{C-11}$$

The share of production available for household repairs is determined by equation C-12.

$$\Delta HD = HD\frac{Y_\infty - O_\infty}{Y_0 - O_0} \tag{C-12}$$

The share of production available for firm repairs is determined by equation C-13.

$$\Delta D = D\frac{Y_\infty - O_\infty}{Y_0 - O_0} \tag{C-13}$$

The household and firm damage may now be updated. A part of the production is used to repair these damages, so the actual damage should be reduced. This is done according to equations C-14 and C-15.

$$HD - \Delta HD \mapsto HD \tag{C-14}$$

$$D - \Delta D \mapsto D \tag{C-15}$$

This ensures that the damage is reduced such that the economy may recover.

C.1.2 Prices, profits and labor demand

Prices (p) increase when the total demand is larger than the production for a sector. This is described by equation C-16. The prices are normalized before the disaster (so $p_0 = 1$) and γ_p is the price elasticity parameter, indicating how much prices change due to underproduction.

$$p = p_0\left(1 + \gamma_p\left(\frac{TD_\infty - Y_\infty}{Y_\infty}\right)\right) \tag{C-16}$$

Variable	Description	Equation
p	Normalized price level	C-16, C-17
p_0	Normalized pre-disaster price level	C-16
γ_p	Price elasticity parameter	C-16
Π	Profits	C-17, C-19
A_p	Price adjusted input-output table	C-17
L	Wages as share of production	C-17, C-18
Y_∞	Final production	C-16, C-17, C-18
TD_∞	Final total demand	C-16
I	Imports as share of production	C-17
W	Wages	C-18, C-19
Π_b	Pre-disaster profits	C-19
W_b	Pre-disaster wages	C-19

Table C-2: Variables used in the ARIO model (prices, profits and labor demand part)

Profits and wages are used to determine the macroeconomic state. Profits are determined using equation C-17.

$$\Pi = pY_\infty - A_pY_\infty - LY_\infty - IY_\infty \tag{C-17}$$

Profits are calculated by the turnover of a sector, minus the inputs used, minus the wages paid and minus the imports used. The input-output table (A_p) is updated to take into account the price changes of inputs. The price of labor and imports are assumed to remain constant.

The total wages per sector are determined using equation C-18.

$$W = LY_\infty \tag{C-18}$$

The macroeconomic indicator is defined in equation C-19. The indicator compares the current sum of wages and profits to the situation before the disaster.

$$M = \frac{\sum(\Pi + W)}{\sum(\Pi_b + W_b)} \tag{C-19}$$

C.1.3 Substitution

The local final demand, exports demand and intermediate consumption demand will decrease if the total demand is larger than the production. The economic agents will search for other sources to fulfill their needs and desires. The result is that these agents substitute imported products for locally produced products. This is only possible if the products are transportable. The vector σ takes the value one if substitution is possible and zero if it is not.

The local final demand adapts according to equation C-20.

$$\overline{LFD} - \sigma\frac{TD_\infty - Y_\infty}{TD_\infty}\overline{LFD}\frac{\Delta t}{\tau^{\downarrow}_{LFD}} \mapsto \overline{LFD} \tag{C-20}$$

Exports adapt according to equation C-21.

$$\overline{E} - \sigma\frac{TD_\infty - Y_\infty}{TD_\infty}\overline{E}\frac{\Delta t}{\tau^{\downarrow}_{E}} \mapsto \overline{E} \tag{C-21}$$

When the production is equal to the total demand, the substitution is reversed. The local final demand adapts then according to equation C-22. The parameter ε is used to make sure that the

Variable	Description	Equation
$\overline{LFD}$	Adjusted local final demand	C-20, C-22, C-24
σ	Substitution integer	C-20, C-21, C-22, C-23, C-26, C-27
Y_∞	Final production	C-20, C-21, C-26
TD_∞	Final total demand	C-20, C-21, C-26
Δt	Time step	C-20, C-21, C-22, C-23, C-26, C-27
$\tau^{\downarrow}_{LFD}$	LFD substitution parameter	C-20
$\overline{E}$	Adjusted exports demand	C-21, C-23, C-25
$\tau^{\downarrow}_{E}$	Exports substitution parameter	C-21
ε	General parameter	C-22, C-23, C-27
LFD_b	LFD before the disaster	C-22
$\tau^{\uparrow}_{LFD}$	LFD substitution parameter	C-22
E_b	Exports before the disaster	C-23
$\tau^{\uparrow}_{E}$	Exports substitution parameter	C-23
LFD	Local final demand	C-24
M	Macroeconomic indicator	C-24
ξ	Elasticity of demand	C-24, C-25
p	Prices	C-24, C-25
E	Export demand	C-25
A	Input-output table	C-26, C-27, C-28
$\tau^{\downarrow}_{A}$	IO substitution parameter	C-26
A_b	Pre-disaster input-output table	C-27, C-28
$\tau^{\uparrow}_{A}$	IO substitution parameter	C-27
I	Share of production spent on imports	C-28
I_b	Pre-disaster import quote	C-28

Table C-3: Variables used in the ARIO model (substitution part)

local final demand eventually returns to its pre-disaster value. The actual value of ε does not influence the solution. The variable LFD_b is the local final demand before the disaster.

$$\overline{LFD} + \sigma\left(\varepsilon + \frac{\overline{LFD}}{LFD_b}\right)\left(LFD_b - \overline{LFD}\right)\frac{\Delta t}{\tau^{\uparrow}_{LFD}} \mapsto \overline{LFD} \tag{C-22}$$

The exports demand adapts according to equation C-23. The variable E_b is the export demand before the disaster.

$$\overline{E} + \sigma\left(\varepsilon + \frac{\overline{E}}{E_b}\right)\left(E_b - \overline{E}\right)\frac{\Delta t}{\tau^{\uparrow}_{E}} \mapsto \overline{E} \tag{C-23}$$

The actual local final demand and export demand depend on the prices and macroeconomic indicator as well. The local final demand is described in equation C-24. The parameter ξ indicates how strong the demand depends on prices.

$$LFD = M \times \overline{LFD} \times (1 - \xi(p-1)) \tag{C-24}$$

The actual export demand is given by equation C-25. The export demand does not depend on the macroeconomic indicator.

$$E = \overline{E} \times (1 - \xi(p-1)) \tag{C-25}$$

The intermediate consumption can also be substituted. This is described in equation C-26.

$$A - \sigma\frac{TD_\infty - Y_\infty}{TD_\infty}A\frac{\Delta t}{\tau^{\downarrow}_{A}} \mapsto A \tag{C-26}$$

When the production is equal to the total demand the substitution is reversed. This is done according to equation C-27. The variable A_b is the input-output table before the disaster.

$$A+\sigma\left(\varepsilon+\frac{A}{A_b}\right)(A_b-A)\frac{\Delta t}{\tau_A^{\uparrow}}\mapsto A \tag{C-27}$$

The sum of the inputs used in the input-output table and the imports must remain constant. The share of production spent on inputs is bound by technology. Therefore, if the local inputs are substituted, the import quote of a sector should increase. This is done with equation C-28.

$$I=I_b+\sum(A_b^T-A^T) \tag{C-28}$$

C.1.4 Overproduction

Variable	Description	Equation
α	Actual overproduction	C-29, C-30
α_{max}	Maximum overproduction	C-29
Y_∞	Final production	C-29
TD_∞	Final total demand	C-29
Δt	Time step	C-29, C-30
τ_α	Overproduction parameter	C-29, C-30
α_b	Pre-disaster overproduction	C-30

Table C-4: Variables used in the ARIO model (overproduction part)

The overproduction depends on the difference between the total demand and production and is given by equation C-29.

$$\alpha+(\alpha_{max}-\alpha)\frac{TD_\infty-Y_\infty}{TD_\infty}\frac{\Delta t}{\tau_\alpha}\mapsto\alpha \tag{C-29}$$

When the total demand equals the production, the overproduction is reduced again according to equation C-30.

$$\alpha+(\alpha_b-\alpha)\frac{\Delta t}{\tau_\alpha}\mapsto\alpha \tag{C-30}$$

C.2 Input data

This appendix covers all the input data used in the ARIO model. First the model parameters are considered, then the general input data and the material damage.

C.2.1 Model parameters

The parameters for substitution, overproduction and prices are collected in table C-5. These values are taken from [Hallegatte (2008)].

C.2.2 General input data

All the sectors of the economy used in the ARIO model and their size is collected in table C-6.

Information regarding the sectors is given in table C-7. The expenses on imports and labor are given as share of production. Regarding the material damage, 75% is assumed to be repaired by the construction sector and 25% is replaced by the manufacturing sector. The households

Parameter	value
τ	6 months
ξ	0.9
γ_p	0.07% per month
α_b	100%
α_{max}	120%
τ_α	6 months

Table C-5: Parameter values

	Sector	Added value	Production
1	Agriculture	8663	27213
2	Mining	19708	25498
3	Industry	69626	304294
4	Power supply	11104	37468
5	Water and waste management	4595	12920
6	Construction	28727	78971
7	Retail	68689	122780
8	Transport and storage	23042	53232
9	Food services	9470	18631
10	Information and communication	25351	51787
11	Financial services	42534	80605
12	Real estate	34975	61158
13	Specialist business services	30771	62960
14	Other business services	29114	47636
15	Governmental services	38937	68851
16	Education	27158	35220
17	Health care	53282	72654
18	Culture, sports and recreation	4879	11445
19	Other services	6356	10592
20	Households with personnel	2394	2394
21	Other goods and services	0	1320

Table C-6: Sectors used in the ARIO model. All figures in million EUR. These are pre-disaster values. [Centraal Bureau voor de Statistiek (2012)]

Sector	Imports	Labor	LFD	Exports	Substitutable	Capital intensity
1	0.15	0.11	2094	10467	Yes	5.63
2	0.11	0.03	484	14930	Yes	1.91
3	0.44	0.13	40275	168347	Yes	1.90
4	0.16	0.05	9297	1848	Yes	3.81
5	0.14	0.17	2706	595	No	7.29
6	0.17	0.23	42059	2032	No	0.67
7	0.14	0.33	98688	11777	No	0.79
8	0.22	0.30	19746	21663	No	3.81
9	0.17	0.28	10843	1896	No	0.78
10	0.12	0.27	17670	8014	Yes	1.22
11	0.19	0.24	21372	17557	Yes	0.76
12	0.04	0.05	45501	1129	Yes	28.93
13	0.11	0.40	11612	14158	Yes	0.40
14	0.10	0.44	7779	2023	Yes	0.67
15	0.10	0.40	61811	782	Yes	7.40
16	0.05	0.65	31194	1336	Yes	1.70
17	0.10	0.55	68872	281	Yes	1.13
18	0.12	0.30	6640	1251	Yes	2.43
19	0.10	0.41	7451	327	Yes	3.66
20	0	0.02	0	52	Yes	3.66
21	0.61	0	0	0	Yes	3.66

Table C-7: Sector characteristics. Imports and labor are given as fractions of the production. Local final demand and exports are given in EUR millions per year. Capital intensity is given in years. [Centraal Bureau voor de Statistiek (2012)]

with personnel and other goods and services sectors are assumed not to be damaged. The capital intensity is defined as total capital stock over yearly added value and thus carries the dimension of years. The figure can be interpreted as how much capital has to be invested to increase the yearly added value by one. This figure can be used to determine the damage-to-production-capacity-ratio.

The input-output table is given in table C-8 and C-9.

C.2.3 Damage

The material damage is an input to the ARIO model, but unlike the previous input this is case-specific in this study. Therefore, the methodology used to determine this input is explained. The actual figures can be found in the respective appendix of the case.

The material damage estimated with HIS-SSM cannot be used directly in the ARIO model. The categories considered in HIS-SSM are not the same as those considered in the ARIO model. Therefore the direct damage of HIS-SSM has to be distributed over households and producing sectors of the economy. It is assumed that all the damage in all categories will be repaired.

The direct damage to firms has been redistributed using table C-10. The distribution is based on the sector size (measured by yearly added value). The coefficient determines what part of the damage is considered in the ARIO sector.

Direct damage in other categories has been distributed over the sectors in the ARIO model as well, as can be seen in table C-11. The ARIO sector households with personnel and households

	1	2	3	4	5	6	7	8	9	10	11
1	0.154	0.000	0.030	0.009	0.004	0.001	0.000	0.000	0.005	0.000	0.000
2	0.000	0.012	0.012	0.156	0.001	0.004	0.000	0.000	0.000	0.000	0.000
3	0.205	0.014	0.179	0.025	0.065	0.126	0.049	0.086	0.095	0.035	0.009
4	0.061	0.056	0.014	0.268	0.042	0.002	0.019	0.011	0.042	0.006	0.004
5	0.017	0.001	0.004	0.003	0.196	0.005	0.002	0.004	0.002	0.001	0.000
6	0.005	0.002	0.002	0.007	0.033	0.222	0.003	0.012	0.006	0.010	0.004
7	0.007	0.002	0.007	0.003	0.019	0.008	0.029	0.024	0.004	0.010	0.005
8	0.009	0.009	0.004	0.001	0.013	0.003	0.015	0.052	0.004	0.009	0.006
9	0.000	0.001	0.002	0.001	0.004	0.001	0.007	0.012	0.012	0.005	0.005
10	0.003	0.002	0.009	0.006	0.011	0.006	0.032	0.013	0.011	0.126	0.037
11	0.021	0.008	0.009	0.009	0.017	0.013	0.022	0.015	0.022	0.022	0.146
12	0.003	0.001	0.004	0.002	0.009	0.013	0.036	0.017	0.033	0.011	0.006
13	0.032	0.004	0.017	0.032	0.018	0.028	0.039	0.028	0.023	0.045	0.018
14	0.014	0.008	0.028	0.014	0.058	0.027	0.034	0.063	0.037	0.069	0.030
15	0.002	0.001	0.001	0.002	0.006	0.002	0.004	0.005	0.005	0.003	0.008
16	0.001	0.000	0.002	0.001	0.002	0.000	0.004	0.001	0.001	0.003	0.000
17	0.000	0.000	0.001	0.000	0.001	0.001	0.002	0.002	0.000	0.001	0.002
18	0.000	0.000	0.000	0.000	0.001	0.000	0.002	0.001	0.007	0.026	0.000
19	0.002	0.000	0.001	0.001	0.002	0.003	0.002	0.000	0.009	0.002	0.001
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.001	0.001	0.000	0.001	0.004	0.001	0.002	0.001	0.000

Table C-8: Input-output table (part one of two) [Centraal Bureau voor de Statistiek (2012)]

	12	13	14	15	16	17	18	19	20	21
1	0.000	0.001	0.004	0.003	0.000	0.001	0.002	0.001	0.000	0.064
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.013	0.022	0.032	0.025	0.011	0.021	0.049	0.032	0.000	0.277
4	0.001	0.013	0.003	0.013	0.012	0.012	0.033	0.024	0.000	0.000
5	0.001	0.001	0.001	0.054	0.001	0.004	0.005	0.002	0.000	0.000
6	0.107	0.025	0.001	0.061	0.016	0.008	0.021	0.008	0.000	0.000
7	0.002	0.009	0.037	0.004	0.003	0.002	0.008	0.007	0.000	0.004
8	0.003	0.008	0.035	0.011	0.005	0.008	0.005	0.009	0.000	0.002
9	0.001	0.006	0.017	0.008	0.003	0.007	0.012	0.011	0.000	0.000
10	0.005	0.037	0.020	0.024	0.020	0.012	0.080	0.020	0.000	0.034
11	0.198	0.027	0.028	0.045	0.006	0.009	0.023	0.044	0.000	0.000
12	0.040	0.009	0.008	0.005	0.002	0.011	0.011	0.026	0.000	0.000
13	0.007	0.181	0.023	0.029	0.013	0.007	0.043	0.046	0.000	0.006
14	0.008	0.039	0.068	0.019	0.031	0.022	0.064	0.031	0.000	0.000
15	0.001	0.007	0.004	0.018	0.046	0.003	0.005	0.003	0.000	0.000
16	0.000	0.005	0.003	0.005	0.003	0.001	0.010	0.001	0.000	0.002
17	0.000	0.003	0.001	0.004	0.005	0.026	0.001	0.000	0.000	0.000
18	0.000	0.004	0.005	0.001	0.002	0.001	0.077	0.003	0.000	0.000
19	0.001	0.003	0.002	0.002	0.001	0.008	0.007	0.029	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.002	0.001	0.001	0.000	0.000	0.001	0.001	0.005	0.000	0.000

Table C-9: Input-output table (part two of two) [Centraal Bureau voor de Statistiek (2012)]

HIS-SSM category	ARIO sector	Coefficient
Farms	Agriculture	1
Mining	Mining	1
Industry	Industry	1
Utilities	Power supply	0.707
	Water and waste management	0.293
Construction	Construction	1
Retail and food	Retail	0.383
	Food services	0.053
	Specialist business services	0.172
	Other business services	0.162
	Real estate	0.195
	Other services	0.035
Transport and communication	Transport and storage	0.476
	Information and communication	0.524
Financial services	Financial services	1
Health care and others	Health care	1
Government	Governmental services	0.549
	Education	0.383
	Culture, sport and recreation	0.069

Table C-10: Firm damage distribution

are two different sectors. The general sector households does not produce anything, only housing services (shelter from rain, cold and wind).

HIS-SSM category	ARIO sector
Agriculture area	Agriculture
Greenhouses	Agriculture
Urban area (15%)	Water and waste management
Urban area (35%)	Power supply
Urban area (50%)	Governmental services
Extensive recreation	Governmental services
Intensive recreation	Governmental services
Airports	Governmental services
Primary roads	Governmental services
Secondary roads	Governmental services
Other roads	Governmental services
Railroads	Governmental services
Water pumping stations	Governmental services
Water purification plants	Water and waste management
Vehicles	Households
Single family homes	Households
Low-rise dwellings	Households
Medium-rise dwellings	Households
High-rise dwellings	Households

Table C-11: Other damage distribution

C.3 MATLAB script

The Matlab script can be found in listing C.1. The equation numbers in the comments correspond to the equations in the beginning of this appendix.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Adaptive Regional Input Output model %
%%%%%% Based on Hallegatte (2008) %%%%%%
%%%%%%%%%%%%%% Jos Vilier %%%%%%%%%%%%%%
%%%%%%%%%%%%%% 12-12-2012 %%%%%%%%%%%%%%
%%%%%%%%%% josvilier@gmail.com %%%%%%%%%

%% Input parameters (constants)
GammaP = 0.07; % Price elasticity parameter [%/month]
Xi = 0.9; % Elasticity of local final demand
TauLFDDown = 6; % Characteristic time for substitution of local final demand by
    imports [month]
TauLFDUp = 6; % Characteristic time for substituion of local final demand by
    local production [month]
TauExportsDown = 6; % Characteristic time for substitution of exports by imports
    [month]
TauExportsUp = 6; % Characteristic time for substitution of exports by local
    production [month]
TauIGDown = 6; % Characteristic time for substitution of intermediate goods by
    imports [month]
```

```
TauIGUp = 6; % Characteristic time for substitution of intermediate goods by
    local production [month]
AlfaMax = 120; % Maximum overproduction [%]
AlfaB = 100; % Overproduction capacity before the disaster [%]
TauAlfa = 6; % Characteristic time for realizing overproduction [month]
P0 = 1; % Normalized prices before disaster
DeltaT = 1; % Time step [month]
Tmax = 120; % Amount of time steps
Epsilon = 0.01; % Parameter to ensure LFD and E return to their initial values (
    does not influence solution)

%% Data input
load('NationalAccounts2011Fixed.mat') %Input data example
% The following data is required, these should be in the current workspace:
% LFD(21,1) Local Final Demand for each sector
% E(21,1) Export demand for each sector
% HD(2,1) Construction and industry reconstruction requirements for the housing
    sector
% D(21,2) Construction and industry reconstruction requirements for each sector
% IO(21,21) Input-output table coefficients
% AV(21,1) Added value per sector before disaster
% L(21,1) Share of production that results in wages
% I(21,1) Share of production that is spent on imports
% YB(21,1) production before disaster
% Sigma(21,1) Parameter for allowing substitution [0 = no substitution]
% DPCR (21,1) Amount of material damage that reduces the added value of the
    sector by one

%% Initializing
LFD(:,2:Tmax) = 0;
E(:,2:Tmax) = 0;
HD(:,2:Tmax) = 0;
D(:,:,2:Tmax) = 0;
Ymax(1:21,1:Tmax) = 0;
Y(1:21,2:Tmax) = 0;
Alfa(1:21,1:Tmax) = 1;
TFD(1:21,1:Tmax) = 0;
LFDInf(1:21,1:Tmax) = 0;
EInf(1:21,1:Tmax) = 0;
DeltaHD(1:2,1:Tmax) = 0;
DeltaD(1:21,1:2,1:Tmax) = 0;
P(1:21,1:Tmax) = 1;
Profits(1:21,1:Tmax) = 0;
Wages(1:21,1:Tmax) = 0;
M(1:Tmax) = 0;
LFDOverbar(1:21,1:Tmax) = 0;
EOverbar(1:21,1:Tmax) = 0;
I(1:21,2:Tmax) = 0;
Rationing(1:Tmax) = 0;
```

```
%% Before disaster
OB = IO*YB; % Orders before disaster
ProfitsB = sum(P(:,1).*YB − P(:,1).*(sum(IO)'.*YB) − L.*YB − I(:,1).*YB); % Total
    profits before disaster
WagesB = L'*YB; % Total wages before disaster
LFDOverbar(:,1) = LFD(:,1); % Adapted local final demand equals local final
    demand for the first time step
EOverbar(:,1) = E(:,1); % Adapted exports equal exports for the first time step
LFDB = LFD(:,1); % Local final demand before disaster
EB = E(:,1); % Exports before disaster
IOB = IO; % Input−output table before disaster
TWB = YB − sum(IOB.*repmat(YB',21,1))' − I(:,1).*YB; % Added value before the
    disaster

%% Compute reconstruction phase
for i = 1:Tmax

    %% Production Capacity
    Ymax(:,i) = YB(:).*(1−sum(D(:,:,i)')'./(CapitalIntensity.*AV(:,1))).*Alfa(:,i
        ); % maximum production (C.1)

    %% Total final demand
    TFD(:,i) = LFD(:,i) + E(:,i); % No reconstruction demands (C.2)
    TFD(3,i) = TFD(3,i) + HD(2,i) + sum(D(:,2,i)); % HD and D increased industry
        TFD (C.2)
    TFD(6,i) = TFD(6,i) + HD(1,i) + sum(D(:,1,i)); % HD and D increased
        construction TFD (C.2)

    %% Production
    LI = (eye(21)−IO)^−1; % Leontief Inverse
    Y0 = LI*TFD(:,i); % First guess production (C.3)
    O0 = IO*Y0; % First guess intermediate outputs
    TD0 = Y0; % First guess total demands equal first guess production
    Y1 = min(TD0, Ymax(:,i)); % Production is equal to the minimum of total
        demand and the production capacity) (C.4)
    O1 = IO*Y1; % Initial orders between sectors (C.5)
    factoropslag(:,i) = Y1./O1;
    if (min(Y1./O1) < 1) % Rationing if orders are larger than production
        for k = 1:100
            O1 = IO*Y1; % Determine amount of orders (C.5)
            factor = Y1./O1; % Determine how much rationing takes place
            MinReductionFactor = min(factor(1:19)); % Determine maximum rationing
                (C.6)
            MinRFLoc = find(factor == MinReductionFactor);
            ReductionFactor(1:21) = MinReductionFactor; % All other sectors have
                to reduce their output
            ReductionFactor(MinRFLoc) = 1; % The bottleneck sector does not
                reduce its production
```

```
            Y1 = ReductionFactor'.*Y1; % Determine new productions (C.7)
        end
    else
        Rationing(i) = 100;
    end
    YInf = Y1; % Determine production
    TDInf = IO*Y1 + TFD(:,i); % Determine total demand (C.8)
    OInf = IO*Y1; % Determine orders (C.9)

    %% Production sold to/used by
    LFDInf(:,i) = LFD(:,i).*(YInf-OInf)./(Y0-O0); % Production sold to consumers (C.10)
    EInf(:,i) = E(:,i).*(YInf-OInf)./(Y0-O0); % Production exported (C.11)
    DeltaHD(1,i) = HD(1,i)*(YInf(6)-OInf(6))/(Y0(6)-O0(6)); % Construction production spent on household repairs (C.12)
    DeltaHD(2,i) = HD(2,i)*(YInf(3)-OInf(3))/(Y0(3)-O0(3)); % Industry production spend on household repairs (C.12)
    DeltaD(:,1,i) = D(:,1,i)*(YInf(6)-OInf(6))/(Y0(6)-O0(6)); % Construction production spent on sector repairs (C.13)
    DeltaD(:,2,i) = D(:,2,i)*(YInf(3)-OInf(3))/(Y0(3)-O0(3)); % Industry production spend on sector repairs (C.13)

    %% Remaining damage
    HD(:,i+1) = HD(:,i) - DeltaHD(:,i)*DeltaT/12; % New household damage equals old household damage minus repairs (months) (C.14)
    D(:,:,i+1) = D(:,:,i) - DeltaD(:,:,i)*DeltaT/12; % New sector damage equals old sector damage minus repairs (months) (C.15)

    %% Prices, profits, wages and macroeconomic indicator
    P(:,i+1) = P(:,1).*(1+GammaP.*((TDInf-YInf)./YInf)); % New prices (C.16)
    Profits(:,i) = P(:,i).*YInf - (sum(repmat(P(:,i),1,21).*IO)'.*YInf) - L.*YInf - I(:,i).*YInf; % Profits (C.17)
    Wages(:,i) = L.*YInf; % Total wages (C.18)
    M(i) = (sum(Profits(:,i)+Wages(:,i)))/(ProfitsB + WagesB); % Macroeconomic indicator (C.19)

    %% Final demand adaptation
    IncreaseImports = TDInf - YInf > 0; % Determine whether imports have to be increased
    DecreaseImports = TDInf - YInf < 0; % Determine whether imports have to be decreased

    LFDOverbar(:,i+1) = LFDOverbar(:,i) - IncreaseImports.*Sigma.*(TDInf - YInf)./(TDInf).*LFDOverbar(:,i)*DeltaT/TauLFDDown; % LFD decrease (C.20)
    EOverbar(:,i+1) = EOverbar(:,i) - IncreaseImports.*Sigma.*(TDInf - YInf)./(TDInf).*EOverbar(:,i)*DeltaT/TauExportsDown; % Exports decrease (C.21)
    LFDOverbar(:,i+1) = LFDOverbar(:,i+1) + DecreaseImports.*Sigma.*(Epsilon + LFDOverbar(:,i+1)./LFDB).*(LFDB - LFDOverbar(:,i+1))*DeltaT/TauLFDUp; % LFD increase (C.22)
```

```
    EOverbar(:,i+1) = EOverbar(:,i+1) + DecreaseImports.*Sigma.*(Epsilon + EOverbar(:,i+1)./EB).*(EB - EOverbar(:,i+1))*DeltaT/TauExportsUp; % Exports increase (C.23)

    LFD(:,i+1) = M(i)*LFDOverbar(:,i+1).*(1-Xi*(P(:,i+1)-1)); % New LFD due to prices, macroeconomic situation and substitution (C.24)
    E(:,i+1) = EOverbar(:,i+1).*(1-Xi*(P(:,i+1)-1)); % New exports due to prices and substitution (C.25)

    %% Intermediate consumption adaptation
    for l = 1:21
    IO(l,:) = IO(l,:) - IncreaseImports(l)*Sigma(l)*(TDInf(l)-YInf(l))/TDInf(l)*IO(l,:)*DeltaT/TauIGDown; % Reduce IG if total demand is higher than production (C.26)
    IO(l,:) = IO(l,:) + DecreaseImports(l)*Sigma(l)*(Epsilon + IO(l,:)./IOB(l,:)).*(IOB(l,:)-IO(l,:))*DeltaT/TauIGDown; % Increase IG if total demand is smaller than production (C.27)
    end
    IO(isnan(IO)) = 0; % Replace all not-a-number entries with 0's
    I(:,i+1) = I(:,1) + sum(IOB-IO)'; % Increase or decrease imports due to substitution (C.28)

    %% Production adaption
    IncreaseProduction = TDInf - YInf > 0; % Determine whether production has to be increased
    DecreaseProduction = TDInf - YInf < 0; % Determine whether production has to be decreased

    Alfa(:,i+1) = Alfa(:,i) + IncreaseProduction.*(AlfaMax - AlfaB)/100.*(TDInf-YInf)./TDInf*DeltaT/TauAlfa; % Increase production (C.29)
    Alfa(:,i+1) = Alfa(:,i+1) + DecreaseProduction.*(AlfaB/100 - Alfa(:,i+1))*DeltaT/TauAlfa; % Decrease production (C.30)

    %% Save results
    Y(:,i) = YInf;
    TW(:,i) = YInf - sum(IO.*repmat(YInf',21,1))' - I(:,i).*YInf;
end

%% Process the results
Firmlosses = sum((sum(TW)-sum(TWB)))/12;
Householdlosses = -sum(sum(HD))*0.04/12;
Totallosses = Firmlosses + Householdlosses;

for z = 1:121
    Dleft(z) = sum(sum(D(:,:,z)));
end
Damageleft = Dleft+sum(HD);
```

Listing C.1: ARIO Matlab script

D Lopik case

This appendix provides information regarding the Lopik dike breach case. It contains maps of the flood, the HIS-SSM output and the ARIO model input that is specific for this case.

D.1 Flood maps

The images show the water depth at daily intervals. The time T is indicated in hours.

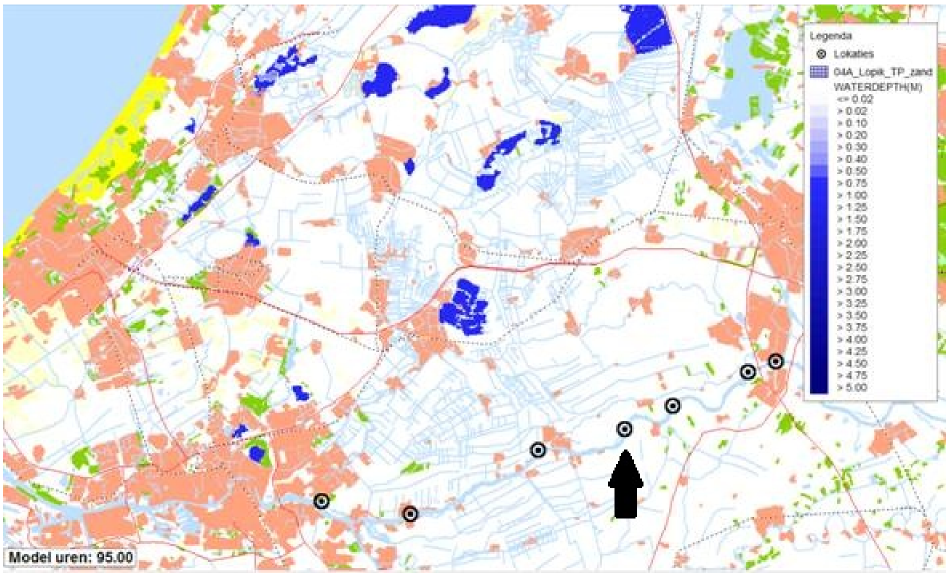

Figure D-1: Flooding at T = 0. The arrow indicates the breach location

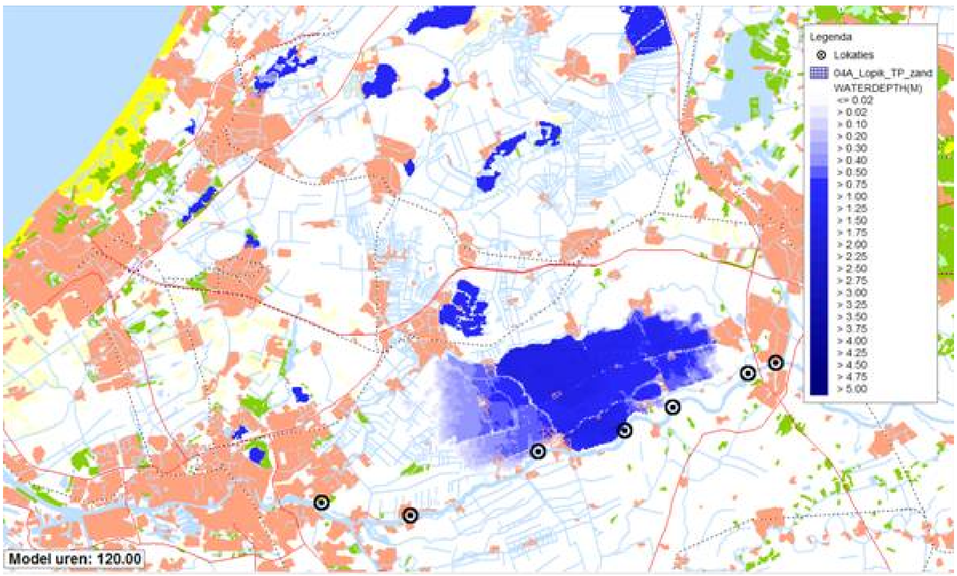

Figure D-2: Flooding at T = 24

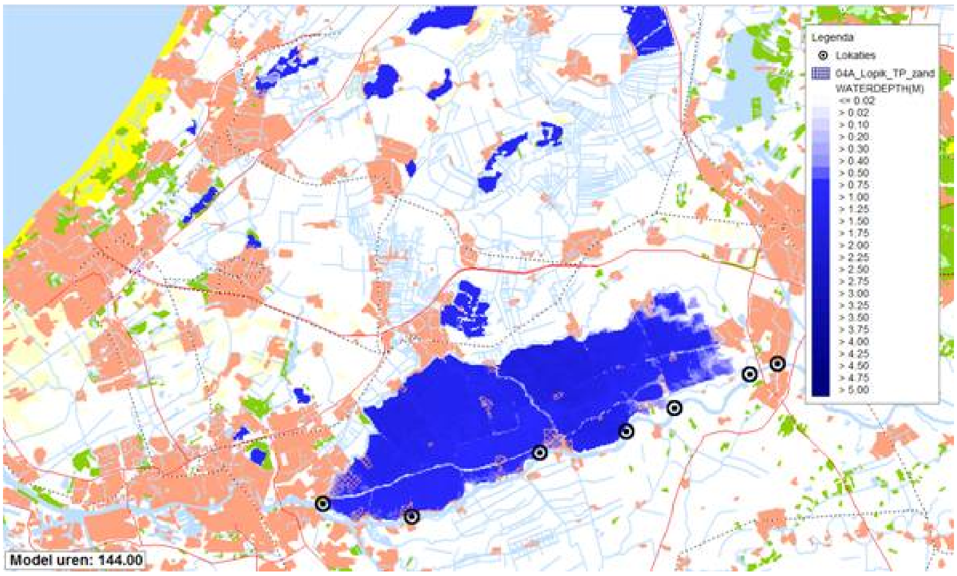

Figure D-3: Flooding at T = 48

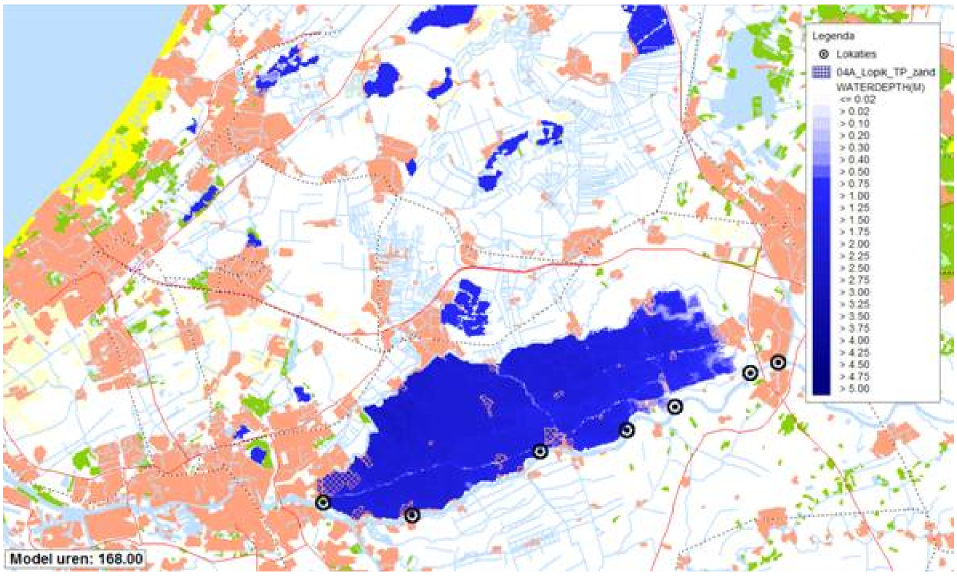

Figure D-4: Flooding at T = 72

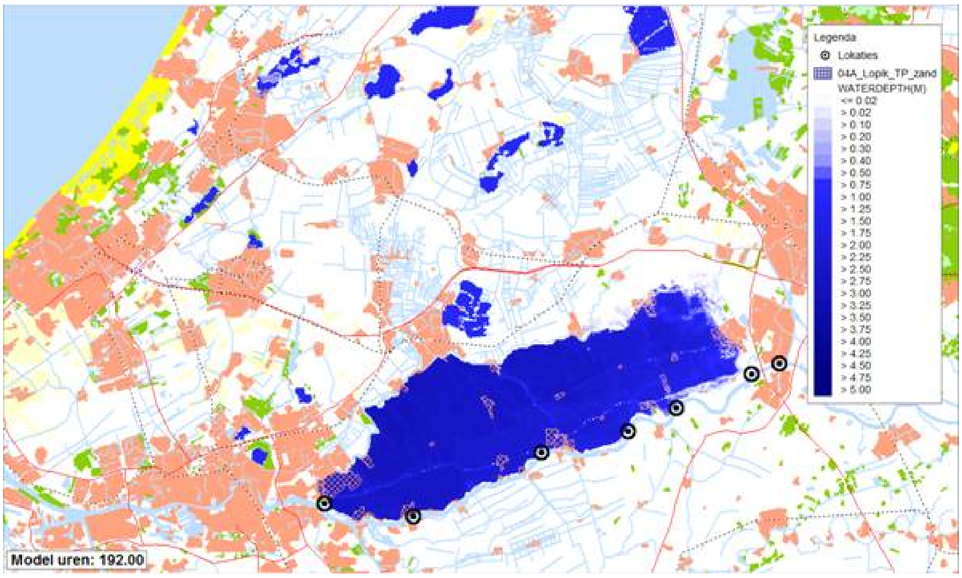

Figure D-5: Flooding at T = 96

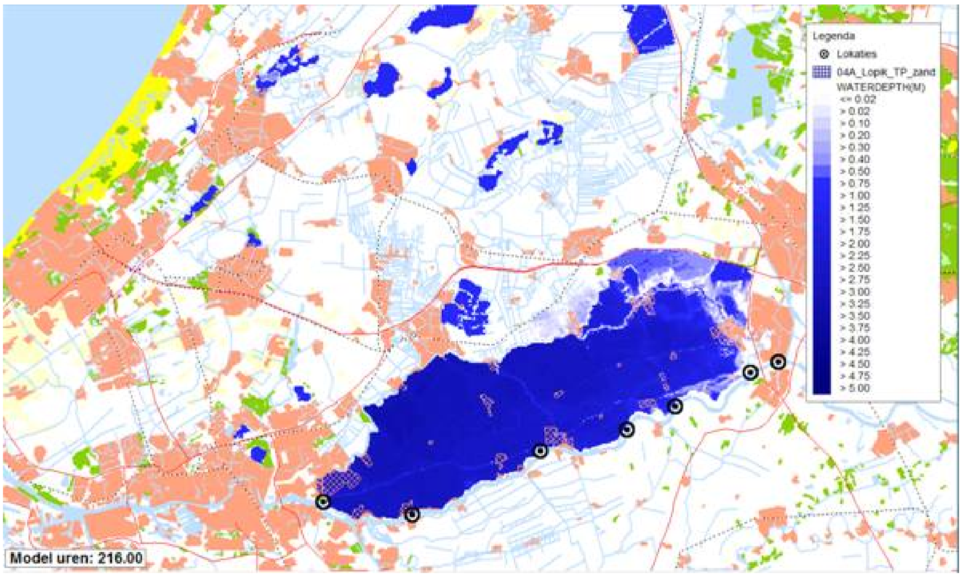

Figure D-6: Flooding at T = 120

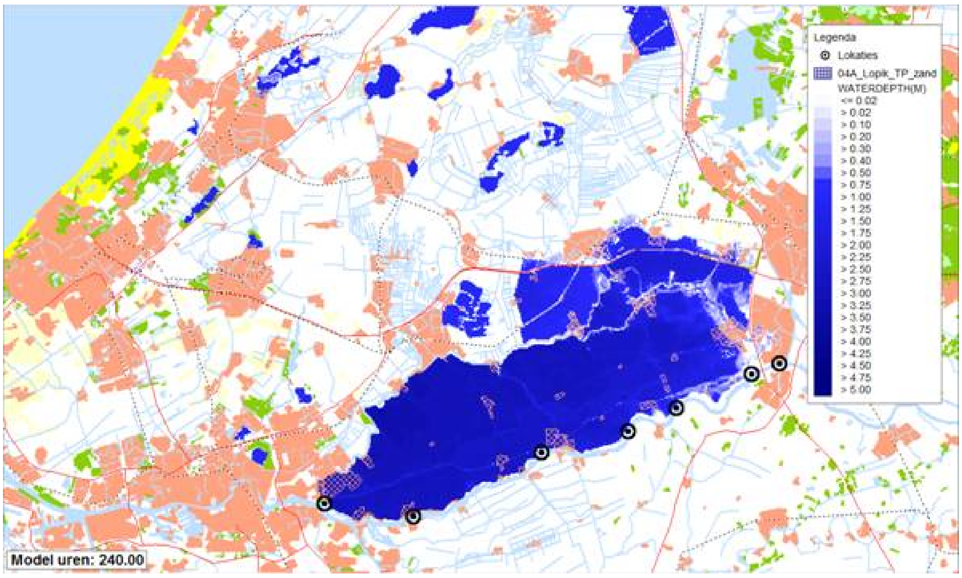

Figure D-7: Flooding at T = 144

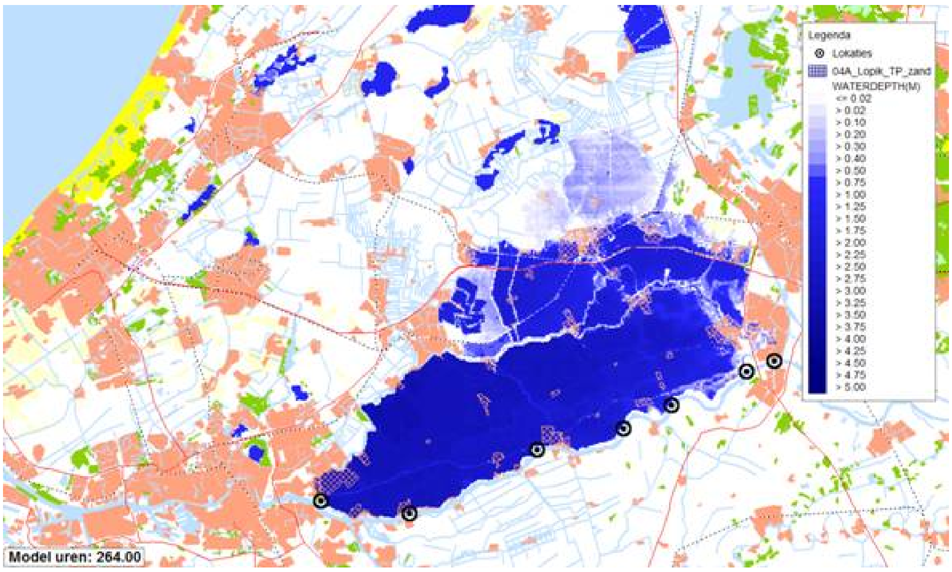

Figure D-8: Flooding at T = 168

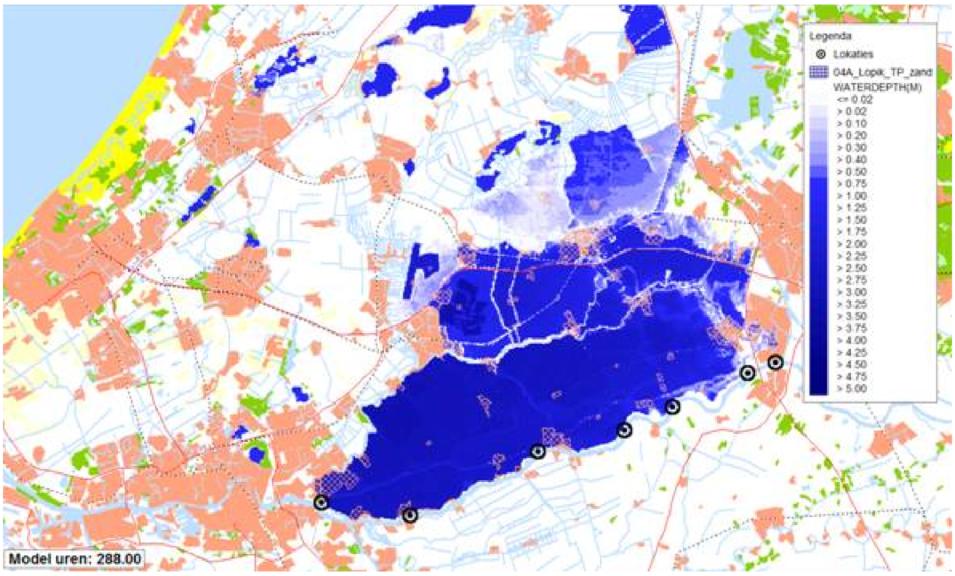

Figure D-9: Flooding at T = 192

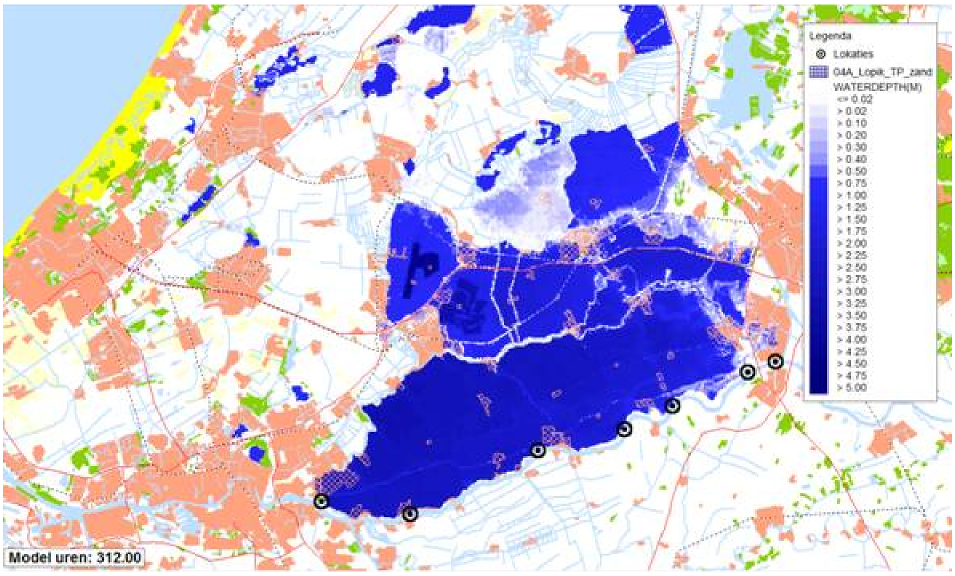

Figure D-10: Flooding at T = 216

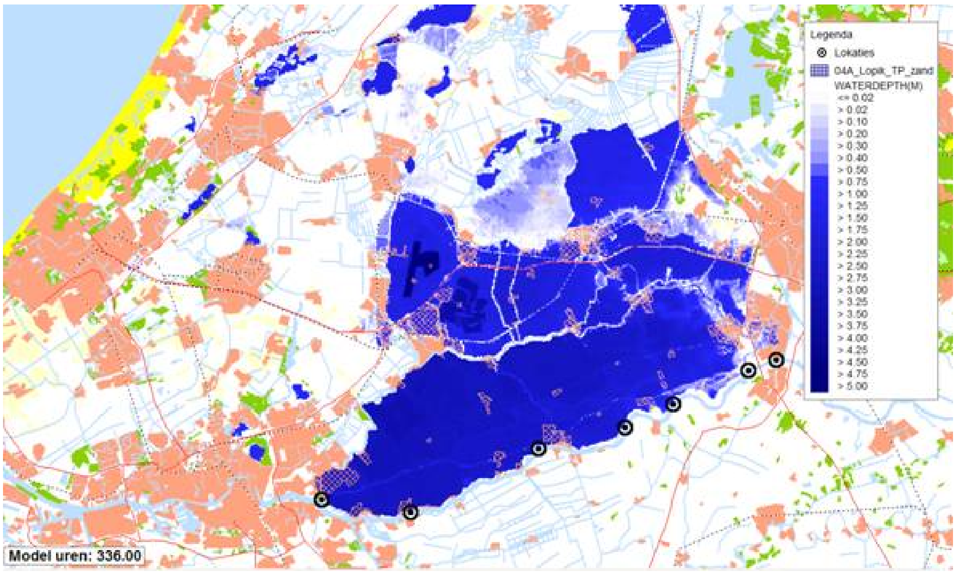

Figure D-11: Flooding at T = 240

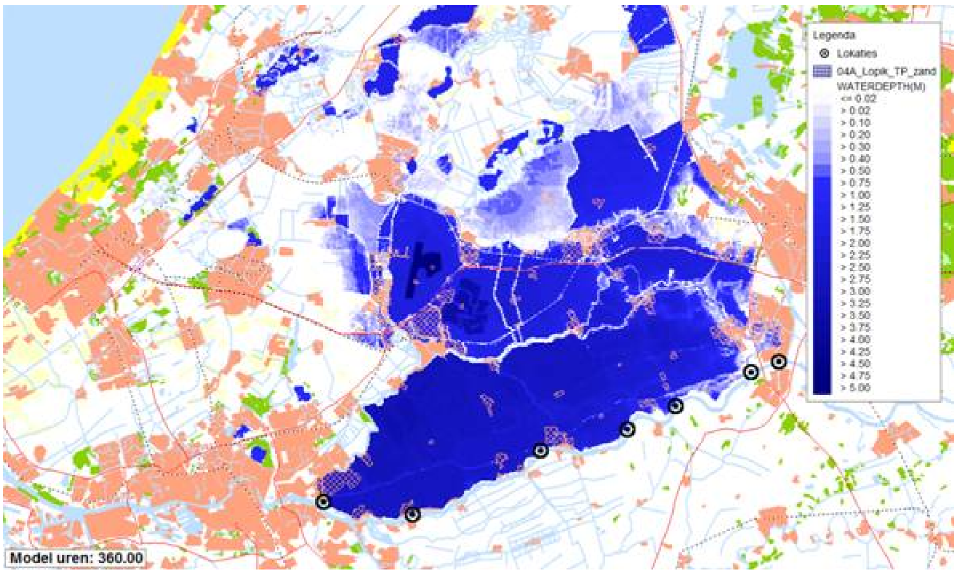

Figure D-12: Flooding at T = 264

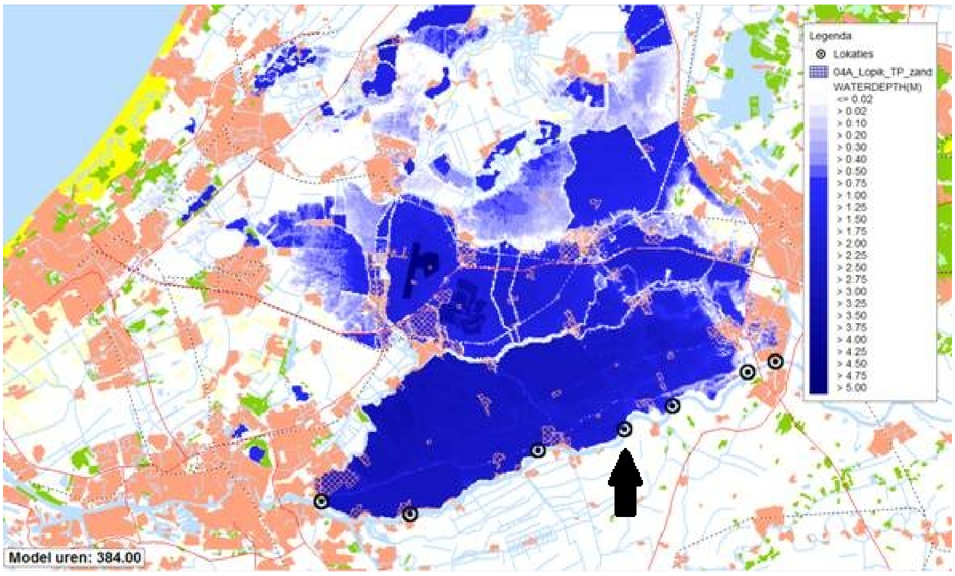

Figure D-13: Flooding at T = 288. The arrow indicates the breach location

D.2 HIS-SSM

This appendix contains the raw results of HIS-SSM after applying it to the Lopik dike breach case. All figures are transformed to 2011 from the base year 2000 using the actual inflation. The natural units and natural amounts gives damage in its non-monetary value (like 20 houses or $100m^2$ of land). The figures for direct material damage can be found in table D-1, direct losses due to business interruption in table D-2 and indirect losses due to business interruption in table D-3.

Category	Damage	Natural units	Natural amounts
Agriculture area	926.0	m^2	688,329,527
Greenhouses	245.4	m^2	10,078,309
Urban area	2,067.3	m^2	53,895,647
Extensive recreation	134.8	m^2	21,532,488
Intensive recreation	65.1	m^2	7,163,325
Airports	0	m^2	0
Primary roads	36.2	m	87,753
Secondary roads	107.1	m	256,896
Other roads	252.3	m	2,312,029
Railroads	308.9	m	46,130
Water pumping stations	43.3	amount	95
Water purification plants	151.2	amount	23
Vehicles	295.9	amount	171,697
Single family homes	8,369.6	amount	126,968
Low-rise dwellings	663.7	amount	5,777
Medium-rise dwellings	931.6	amount	12,164
High-rise dwellings	420.9	amount	8,165
Farms	498.8	amount	4,145
Mining	0.8	jobs	2
Construction	7.8	jobs	5,467
Retail and food services	143.8	jobs	54,850
Transport and communication	381.4	jobs	7,598
Financial services	464.1	jobs	41,420
Government	167.2	jobs	20,151
Industry	409.1	jobs	13,076
Utilities	20.1	jobs	310
Healthcare and others	15.4	jobs	5,760

Table D-1: Breakdown of direct damage. Damage in million EUR. Primary roads are indicated by single or double digits (like A4 or N11) and secondary roads by triple digits (like N272).

Category	Losses	Natural units	Natural amounts
Airports	0	m^2	0
Railroads	1.9	m	46,130
Mining	0.1	jobs	2
Construction	20.3	jobs	5,467
Retail and food services	53.9	jobs	54,850
Transport and communication	57.0	jobs	7,598
Financial services	72.2	jobs	41,420
Government	25.6	jobs	20,151
Industry	102.6	jobs	13,076
Utilities	5.3	jobs	310
Healthcare and others	4.8	jobs	5,760

Table D-2: Breakdown of direct losses due to business interruption. Losses in million EUR.

Category	Losses	Natural units	Natural amounts
Agriculture	250.0	m^2	688,329,527
Greenhouses	6.1	m^2	10,078,309
Mining	0	jobs	2
Construction	8.8	jobs	5,467
Retail and food services	6.3	jobs	54,850
Transport and communication	1.7	jobs	7,598
Financial services	9.0	jobs	41,420
Government	1.5	jobs	20,151
Industry	22.7	jobs	13,076
Utilities	0.9	jobs	310
Healthcare and others	0.7	jobs	5,760

Table D-3: Breakdown of indirect losses due to business interruption. Losses in million EUR.

D.3 ARIO model input

The material damage is the only case-specific input to the ARIO model in this study. This can be found in table D-4.

	Sector	Material Damage
1	Agriculture	1,670.2
2	Mining	0.8
3	Industry	409.1
4	Power supply	737.8
5	Water and waste management	467.2
6	Construction	7.8
7	Retail	55.1
8	Transport and storage	181.6
9	Food services	7.6
10	Information and communication	99.9
11	Financial services	464.1
12	Real estate	28.0
13	Specialist business services	24.7
14	Other business services	23.3
15	Governmental services	2,073.1
16	Education	64.0
17	Health care	15.4
18	Culture, sports and recreation	11.5
19	Other services	5.9
20	Households with personnel	0
21	Other goods and services	0
	Households	10,682.0

Table D-4: Material damage used in the ARIO model for the Lopik dike breach case. All figures in million EUR.

The results of the model are explained in detail in chapter 7.

E Holwierde case

This appendix contains the results of both HIS-SSM and the ARIO model of the flood in Groningen due to a dike breach at Holwierde. The return period of the water level during the flood is 4000 years (which is the design dike height of the considered area). The material damage has been determined with HIS-SSM only, while the losses due to business interruption are determined with both HIS-SSM and the ARIO model.

E.1 HIS-SSM

The material damage according to HIS-SSM can be found in table E-1, the direct losses due to business interruption in table E-2 and the indirect losses due to business interruption in table E-3. The total costs of this flood are 1.57 billion EUR, of which 1.51 billion EUR is material damage. The losses due to business interruption are equal to 4% of the material damage.

Category	Damage	Natural units	Natural amounts
Agriculture area	206.0	m^2	228,247,126
Greenhouses	0	m^2	1,268
Urban area	290.7	m^2	11,000,755
Extensive recreation	39.7	m^2	6,770,409
Intensive recreation	10.9	m^2	1,209,807
Airports	0	m^2	0
Primary roads	9.5	m	33,697
Secondary roads	10.2	m	48,672
Other roads	34.7	m	577,834
Railroads	38.4	m	11,051
Water pumping stations	12.0	amount	32
Water purification plants	6.0	amount	1
Vehicles	11.2	amount	22,266
Single family homes	647.0	amount	18,316
Low-rise dwellings	43.7	amount	769
Medium-rise dwellings	59.8	amount	1,946
High-rise dwellings	11.1	amount	340
Farms	44.3	amount	721
Mining	0	jobs	0
Construction	0.1	jobs	139
Retail and food services	2.8	jobs	2,079
Transport and communication	7.3	jobs	229
Financial services	3.9	jobs	525
Government	1.8	jobs	951
Industry	13.9	jobs	554
Utilities	0.4	jobs	7
Healthcare and others	1.2	jobs	560

Table E-1: Breakdown of direct damage for the Holwierde dike breach case. Damage in million EUR. Primary roads are indicated by single or double digits (like A4 or N11) and secondary roads by triple digits (like N272).

Category	Losses	Natural units	Natural amounts
Airports	0	m^2	0
Railroads	0.2	m	11,051
Mining	0	jobs	0
Construction	0.3	jobs	169
Retail and food services	1.0	jobs	2,079
Transport and communication	1.1	jobs	229
Financial services	0.6	jobs	525
Government	0.3	jobs	951
Industry	3.5	jobs	554
Utilities	0.1	jobs	7
Healthcare and others	0.4	jobs	560

Table E-2: Breakdown of direct losses due to business interruption for the Holwierde dike breach case. Losses in million EUR.

Category	Losses	Natural units	Natural amounts
Agriculture	55.6	m^2	228,247,126
Greenhouses	0	m^2	1,268
Mining	0	jobs	0
Construction	0.1	jobs	169
Retail and food services	0.1	jobs	2,079
Transport and communication	0	jobs	229
Financial services	0.1	jobs	525
Government	0	jobs	951
Industry	0.8	jobs	554
Utilities	0	jobs	7
Healthcare and others	0.1	jobs	560

Table E-3: Breakdown of indirect losses due to business interruption for the Holwierde dike breach case. Losses in million EUR.

E.2 ARIO model

The input for the ARIO model can be found in table E-4. All the other parameters can be found in appendix C. The DPCR is equal to the DPCR used in the Lopik dike breach case by weighing the amount of lost jobs with a damage function (slope discontinuity at 2.5m).

The total losses due to business interruption are 46.5 million EUR. This makes the losses due to business interruption equal to 3.1% of the material damage. The value added created by the Dutch economy after the flood can be found in figure E-1. This graph shows that the reduction of the value added immediately after the flood is relatively small, 250 million EUR per year (about 0.05% compared to the pre-flood situation). A large demand surge is visible after the flood.

The remaining material damage can be found in figure E-2 and the value added per sector in figure E-3. This last figure shows that mainly the agricultural and governmental sector are hit hardest by the flood. The value added created by the construction sector actually increases compared to the pre-flood value added, as is expected.

	Sector	Material damage
1	Agriculture	250.3
2	Mining	0
3	Industry	13.9
4	Power supply	102.0
5	Water and waste management	49.7
6	Construction	0.1
7	Retail	1.1
8	Transport and storage	3.5
9	Food services	0.1
10	Information and communication	3.8
11	Financial services	3.9
12	Real estate	0.5
13	Specialist business services	0.5
14	Other business services	0.5
15	Governmental services	301.8
16	Education	0.7
17	Health care	1.2
18	Culture, sports and recreation	0.1
19	Other services	0.1
20	Households with personnel	0
21	Other goods and services	0
	Households	772.8

Table E-4: Material damage used in the ARIO model for the Holwierde dike breach case. All figures in million EUR.

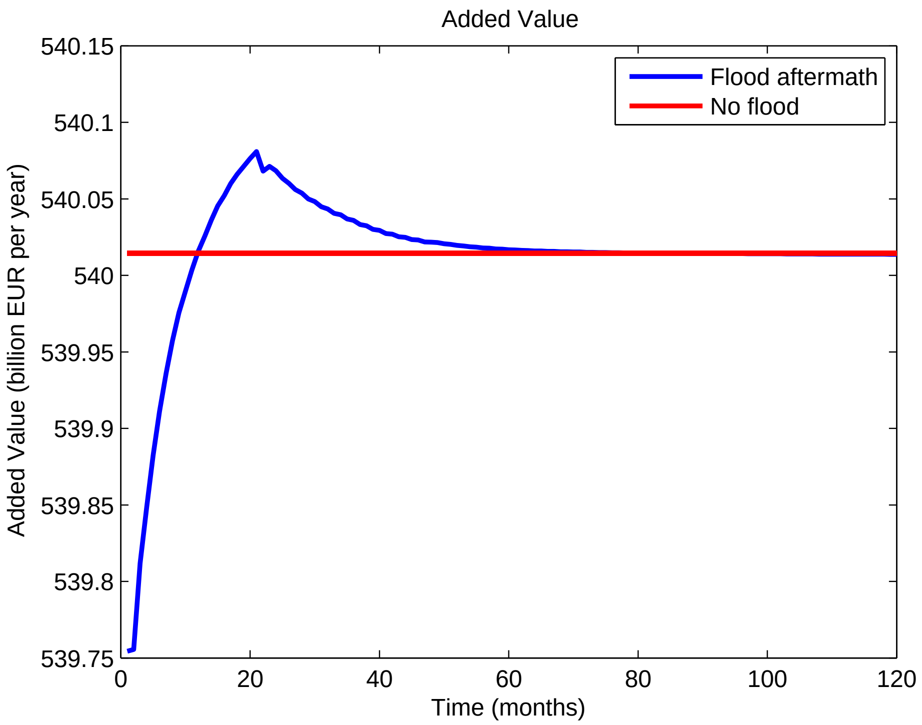

Figure E-1: Added value after the dike breach in Holwierde.

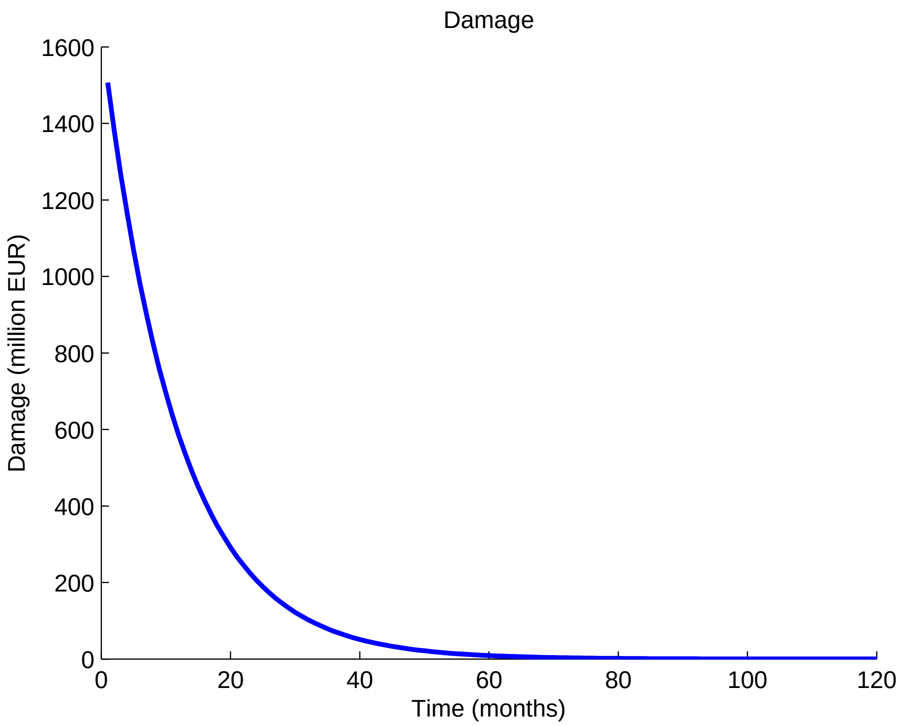

Figure E-2: Remaining material damage after the dike breach in Holwierde.

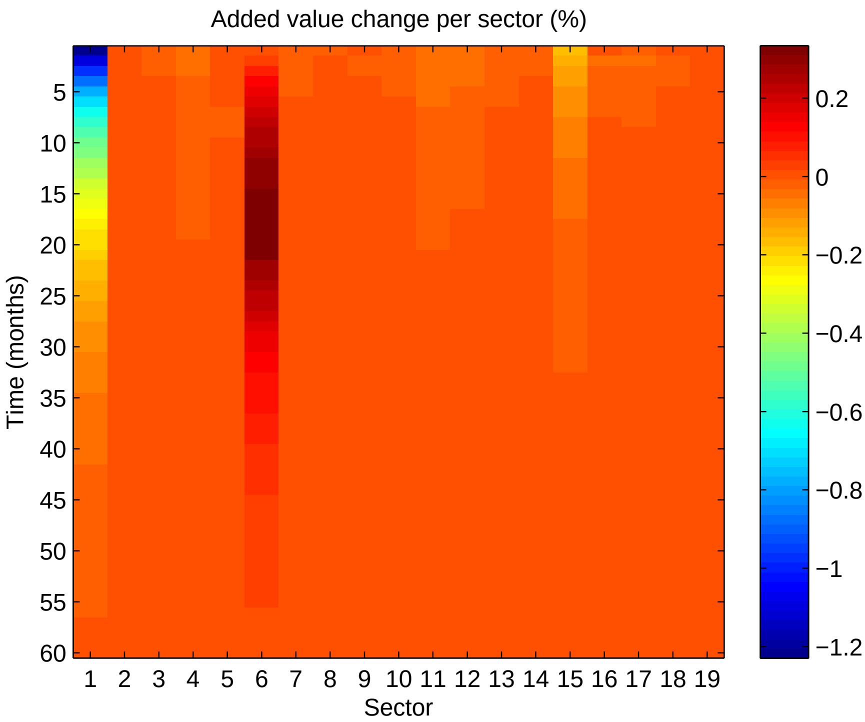

Figure E-3: Added value change (%) per sector after the dike breach in Holwierde. A description of the sectors can be found in table E-4.

F Arcen case

This appendix contains the results of both HIS-SSM and the ARIO model of the flood in Limburg due to a dike breach at Arcen. The return period of the water level in the river Meuse during the flood is 250 years (which is the design dike height of the considered area). The material damage has been determined with HIS-SSM only, while the losses due to business interruption are determined with both HIS-SSM and the ARIO model.

F.1 HIS-SSM

The material damage according to HIS-SSM can be found in table F-1, the direct losses due to business interruption in table F-2 and the indirect losses due to business interruption in table F-3. The total costs of this flood are 71.8 million EUR, of which 70.5 million EUR is material damage. The losses due to business interruption are equal to 1.8% of the material damage.

Category	Damage	Natural units	Natural amounts
Agriculture area	2.4	m^2	1,782,712
Greenhouses	1.0	m^2	25,277
Urban area	14.6	m^2	409,085
Extensive recreation	6.6	m^2	969,753
Intensive recreation	0	m^2	0
Airports	0	m^2	0
Primary roads	0	m	0
Secondary roads	0.9	m	3,360
Other roads	2.2	m	21,868
Railroads	0	m	0
Water pumping stations	0	amount	0
Water purification plants	0	amount	0
Vehicles	1.0	amount	787
Single family homes	38.9	amount	712
Low-rise dwellings	0	amount	0
Medium-rise dwellings	0	amount	0
High-rise dwellings	0	amount	0
Farms	2.0	amount	26
Mining	0	jobs	0
Construction	0	jobs	5
Retail and food services	0.4	jobs	166
Transport and communication	0.1	jobs	2
Financial services	0.1	jobs	9
Government	0.1	jobs	12
Industry	1.4	jobs	24
Utilities	0	jobs	0
Healthcare and others	0	jobs	0

Table F-1: Breakdown of direct damage for the Arcen dike breach case. Damage in million EUR. Primary roads are indicated by single or double digits (like A4 or N11) and secondary roads by triple digits (like N272).

Category	Losses	Natural units	Natural amounts
Airports	0	m^2	0
Railroads	0	m	0
Mining	0	jobs	0
Construction	0	jobs	5
Retail and food services	0.2	jobs	166
Transport and communication	0	jobs	2
Financial services	0	jobs	9
Government	0	jobs	12
Industry	0.4	jobs	24
Utilities	0	jobs	0
Healthcare and others	0	jobs	0

Table F-2: Breakdown of direct losses due to business interruption for the Arcen dike breach case. Losses in million EUR.

Category	Losses	Natural units	Natural amounts
Agriculture	0.6	m^2	1,782,712
Greenhouses	0	m^2	25,227
Mining	0	jobs	0
Construction	0	jobs	5
Retail and food services	0	jobs	166
Transport and communication	0	jobs	2
Financial services	0	jobs	9
Government	0	jobs	12
Industry	0.1	jobs	24
Utilities	0	jobs	0
Healthcare and others	0.1	jobs	0

Table F-3: Breakdown of indirect losses due to business interruption for the Holwierde dike breach case. Losses in million EUR.

F.2 ARIO model

The input for the ARIO model can be found in table F-4. All the other parameters can be found in appendix C. The DPCR is equal to the DPCR used in the Lopik dike breach case by weighing the amount of lost jobs with a damage function (slope discontinuity at 2.5m).

The total losses due to business interruption are 4.1 million EUR according to the ARIO. This makes the losses due to business interruption equal to 5.8% of the material damage. The value added created by the Dutch economy after the flood can be found in figure F-1. This graph shows that the reduction of the value added immediately after the flood is very small, 14 million EUR per year (about 0.003% compared to the pre-flood situation). A large demand surge is visible after the flood.

The remaining material damage can be found in figure F-2 and the value added per sector in figure F-3. This last figure shows that mainly the agricultural, real estate and governmental sector are hit hardest by the flood. The value added created by the construction sector actually increases compared to the pre-flood value added, as is expected.

	Sector	Material damage
1	Agriculture	5.4
2	Mining	0
3	Industry	1.4
4	Power supply	5.1
5	Water and waste management	2.2
6	Construction	0
7	Retail	0.2
8	Transport and storage	0.1
9	Food services	0
10	Information and communication	0.1
11	Financial services	0.1
12	Real estate	0.1
13	Specialist business services	0.1
14	Other business services	0
15	Governmental services	17.1
16	Education	0
17	Health care	0
18	Culture, sports and recreation	0
19	Other services	0
20	Households with personnel	0
21	Other goods and services	0
	Households	39.9

Table F-4: Material damage used in the ARIO model for the Arcen dike breach case. All figures in million EUR.

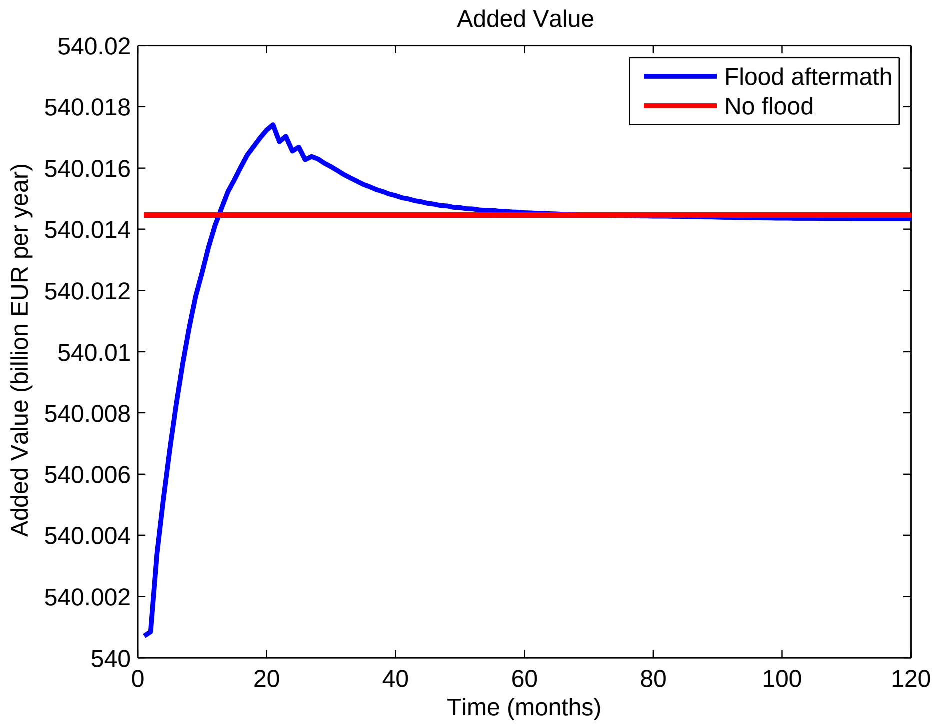

Figure F-1: Added value after the dike breach in Arcen.

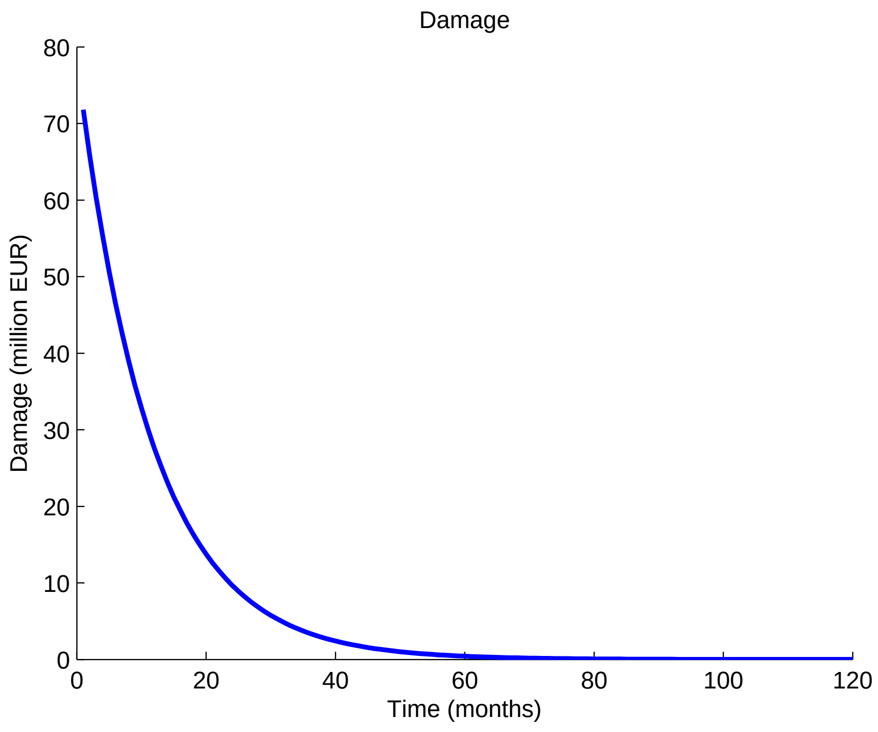

Figure F-2: Remaining material damage after the dike breach in Arcen.

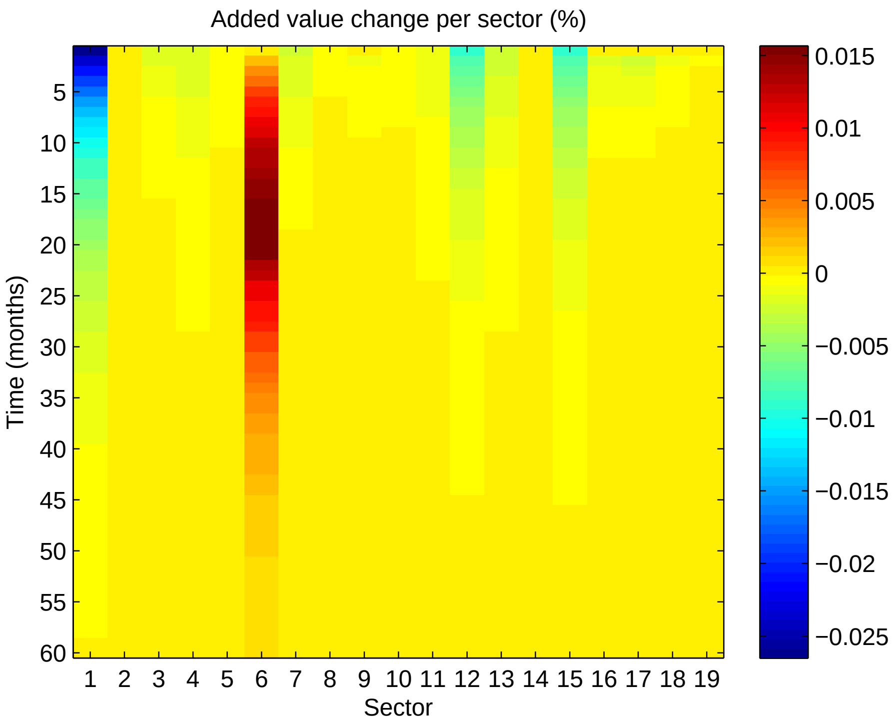

Figure F-3: Added value change (%) per sector after the dike breach in Arcen. A description of the sectors can be found in table F-4.

G Flooding of a renewable diesel refinery

This appendix contains a case about the flooding of the renewable diesel refinery of Neste Oil Nederland BV at the Maasvlakte in the port of Rotterdam. Neste Oil Nederland BV is owned by Neste Oil, a Finnish petrochemical firm. This case has been chosen to illustrate the consequences of using sectors of the economy to approach the costs of a flood. The refinery was completed in 2011, after a building period of two years. The total building costs were almost 700 million EUR. The total output of the refinery is 800,000 tonnes of diesel annually [Ohm (2012)]. About 150 people are working at the refinery.[1]

The renewable diesel refinery processes palm oil into diesel. This diesel is mainly used as fuel by road vehicles. The firm belongs to the industry sector in both HIS-SSM and the ARIO model.

A digital elevation map of the Maasvlakte can be found in figure G-1. The area is not protected by a dike.

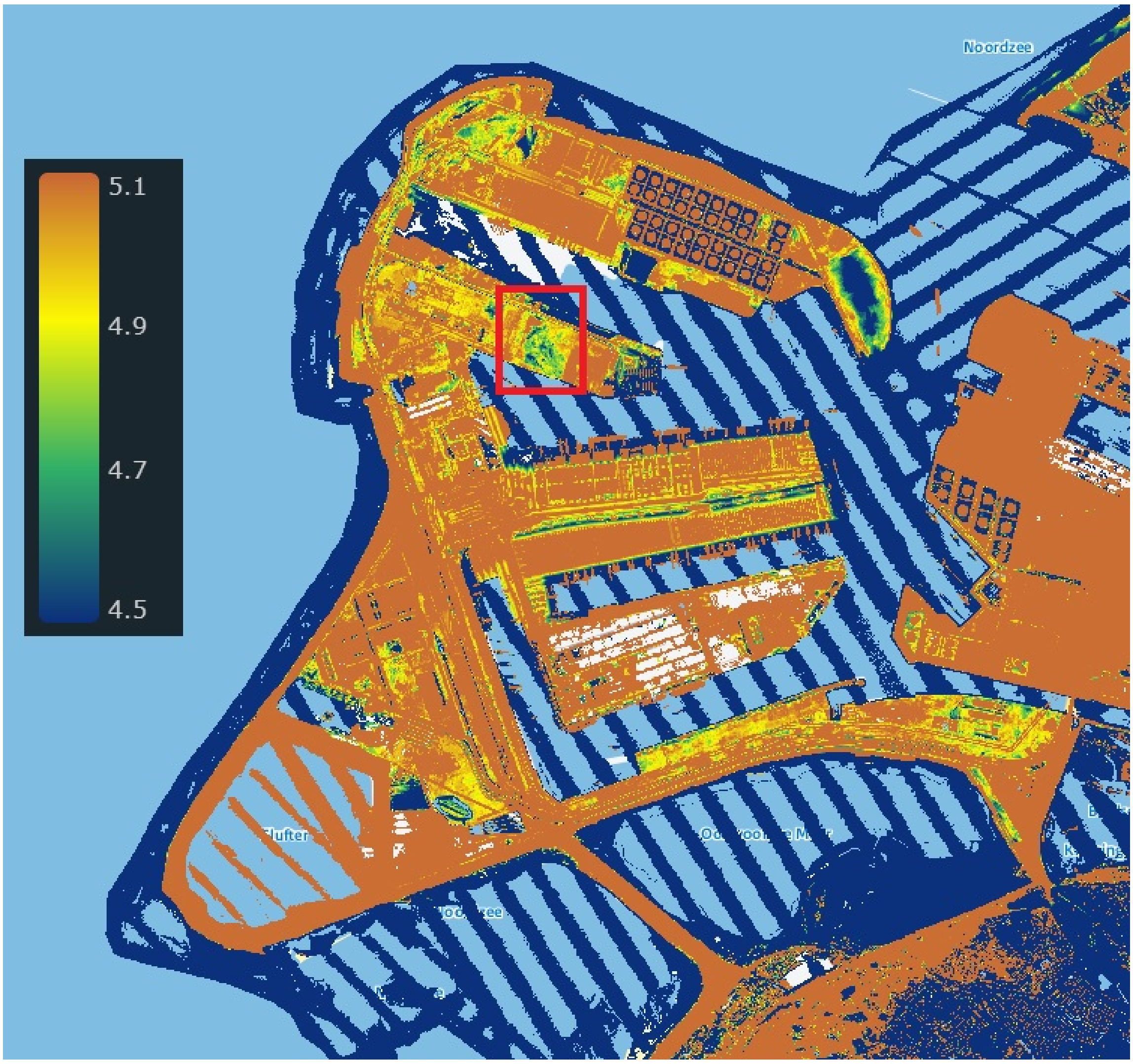

Figure G-1: Digital elevation map of the Maasvlakte. The boxed area is owned by Neste Oil Nederland BV. The legend indicates the ground level compared to NAP in meters. © ahn.nl

[1] http://www.nesteoil.com/default.asp?path=1,17765,17766,17790,17791 accessed 7-3-2013

The ground level at the refinery is slightly lower than the ground level of nearby areas. The water level with a return period of 10,000 years at the entrance of the port is 5.1 meters +NAP [Rijkswaterstaat (2006)]. The assumption is made that the water level in the Maasvlakte port area is equal to the water level at the entrance of the port. The orange colored areas in the figure are above this 5.1 meters +NAP level and will not be flooded. Other areas may be flooded if they are not surrounded by elevated ('orange') areas.

A digital elevation map of the area owned by Neste Oil Nederland BV at the Maasvlakte can be found in figure G-2.

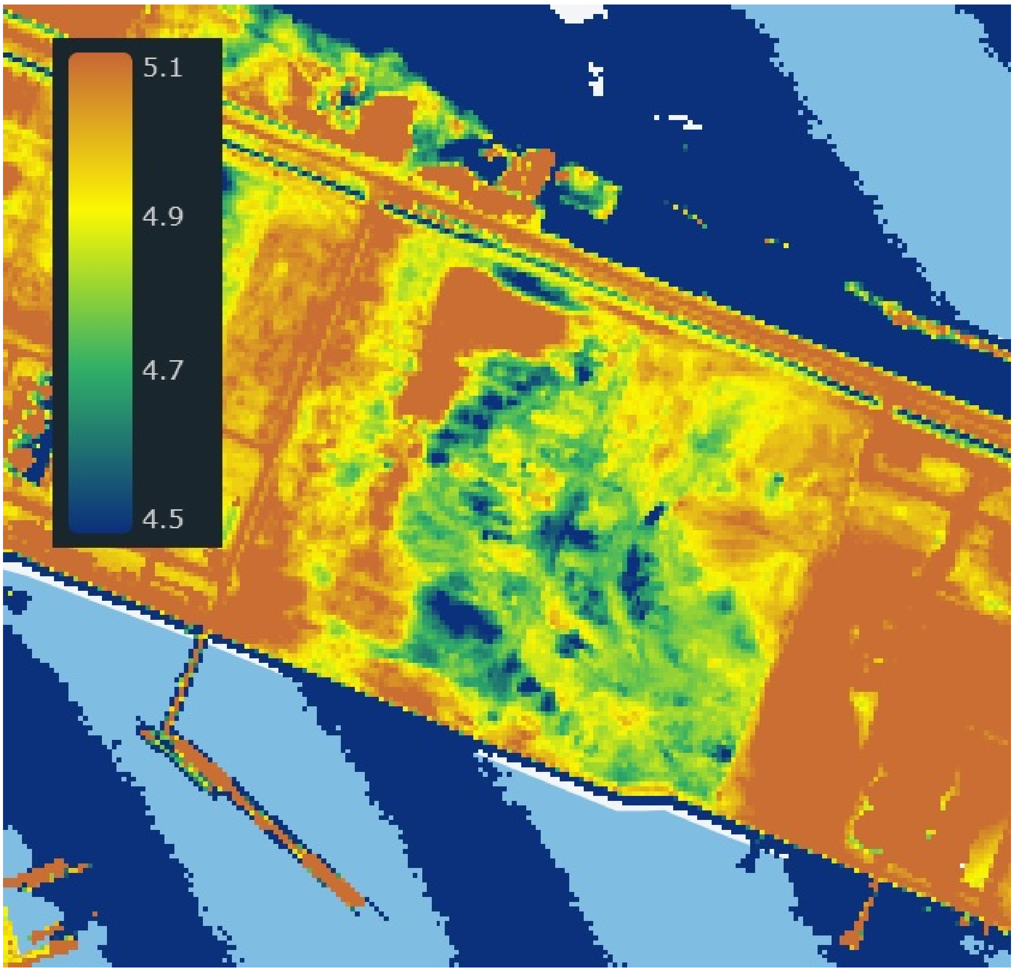

Figure G-2: Digital elevation map of the area owned by Neste Oil Nederland BV. The legend indicates the ground level compared to NAP in meters. © ahn.nl

The lowest parts of the area will have an inundation depth of about 0.6 meters if the water level in the port rises to 5.1 meters +NAP.

G.1 Costs

Both HIS-SSM and the ARIO model will be used to determine the costs if this area is flooded. These models are not intended to assess the costs of the flooding of an individual firm but the application still gives useful insight. The financial statement of the firm and common sense are also used to estimate the costs of the flood.

To determine the costs according to HIS-SSM, equation G-1 should be evaluated.

$$D = \sum_{i=1}^{n} \alpha_i n_i S_i \tag{G-1}$$

Only three categories of consequences have to be considered, namely the direct material damage to firms, the direct losses due to business interruption and the indirect losses due to business interruption. The variable α_i is the value returned by the damage function used for firms (which can be found in figure 6-3), n_i is the amount of jobs and S_i is the maximum damage or losses per job. The damage function returns a value of 0.06 for this inundation depth and the amount of jobs is 150. The firms belongs to the industry sector, so the maximum material damage per job is 349,000 EUR (see table 6-5), the maximum direct losses due to business interruption are 88,000 EUR per job and the maximum indirect losses due to business interruption are 19,500 EUR per job (see table 6-7).

A simple multiplication of these numbers give the results of HIS-SSM in this case. The results can be found in table G-1. The total costs are just over four million EUR.

Category	Costs	Share of costs [%]
Material damage	3,141.0	76.5
Direct losses	792.0	19.2
Indirect losses	175.5	4.3
Total	4,108.5	100

Table G-1: Costs of the Neste Oil diesel refinery flood according to HIS-SSM. All costs in thousands EUR.

The total losses due to business interruption are 20 million EUR according to the ARIO model. Together with the material damage determined by HIS-SSM this brings the total costs to 23 million EUR according to this model.

The fact that only one firm is flooded in this case makes it possible to look into the individual effects of the flood. Two critical parts of the infrastructure used in the refinery may be broken by the flood. The electricity infrastructure may be broken down due to the contact with seawater during the flood. The refinery obviously cannot work without power. The second infrastructure that may be damage are the pipelines and storage tanks. Especially when the storage tanks and pipelines are empty they might start floating during the flood and break down consequently. When either of the two infrastructures is broken the production at the refinery will stop.

The costs of the direct business interruption can also be approximated using the financial statements of the firm. The value added created by this firm is equal to the (pre-tax) sum of the wages, interest and profits paid to respectively the employees and the investors. Assuming the average yearly wage costs are 60,000 EUR per employee, the total wage costs are 9 million EUR per year for the refinery in Rotterdam. The return on capital employed (pre-tax) was 6.5% for Neste Oil (the international firm) in 2012 [Neste Oil (2013)]. If the total amount of invested capital in the refinery in Rotterdam is equal to the building costs (700 million EUR) and the return on capital employed is equal to the 6.5% for the whole firm, the total capital costs are 46 million EUR annually. The direct losses due to business interruption are thus approximately 55 million EUR per year for this firm if it is out of operation.

The duration of the business interruption has a strong influence on the actual amount of losses. If the firm is 3 months, 6 months or 12 months out of operation after the flood the direct losses due to business interruption are respectively 14, 28 and 55 million EUR. These numbers are far greater than the costs determined with HIS-SSM, the ARIO model is in the correct range however. This merely shows that these models are not fit to be used to assess the costs of floods for individual firms, because they are based on averaging the costs of a flood over many different buildings, firms and other objects.

The indirect losses due to business interruption can be far larger than the direct losses due to business interruption however. The output of the refinery in Rotterdam is 800,000 tonnes of diesel annually. The diesel consumption of all road transport in the Netherlands in 2011 was 6,513,000 tonnes of diesel.[2] The Neste Oil refinery in Rotterdam thus produces about 12.3% of the diesel used in the Netherlands. A sudden stop of production of this refinery may lead to price increases or even shortages of diesel in the Netherlands, depending on the amount of diesel that can be imported.

A shortage of diesel can have wide consequences in the Netherlands. Considering the economic consequences, people may have problems reaching their work. Furthermore, almost all trucks in the Netherlands use diesel as a fuel. The road transport sector contributed eleven billion EUR to the Dutch GDP in 2011 [Centraal Bureau voor de Statistiek (2012)]. This is equal to 212 million EUR per week. A shortage of diesel can have large consequences in this sector, but the indirect losses due to business interruption caused by a shortage of road transport are enormous. Almost all other sectors will be hit by a shortage of road transport.

This effect is not taken into account in both HIS-SSM and the ARIO model. This has to do with the sector approach in both models. The refinery belongs to the industry sector in both models, which comprises all kinds of industry from metal and electronics to petrochemical industry. The industry sector is quite large, so a small reduction in the production capacity of this sector does not lead to large losses in the ARIO model. The same goes for HIS-SSM. The consequences of these kind of floods are underestimated in both models. The flooding of critical infrastructure or firms which are unique and critical in the production processes of other firms is not taken into account very well in these models. A graphical illustration of the problem can be found in figure G-3.

The production capacity reduction takes place in the diesel refinery sector. For this sector in isolation, the production capacity reduction is 12.3% as mentioned before. If the whole petroleum industry is considered however, the production capacity reduction reduces to 2%. For the petrochemical industry the production capacity reduction is only 0.4% and for the whole industry sector just 0.1%. HIS-SSM and the ARIO model consider the effects of the flood on the industry level and thus take a reduction of the availability of a specific important commodity (diesel in this case) not into account. The costs of a homogeneous 0.1% production capacity reduction in the industry sector (which is calculated by HIS-SSM and the ARIO model) are much smaller than a 12% production capacity reduction in the diesel production sector (what actually happens in this flood scenario).

The problem is that these effects can also occur in large-scale floods, for which the models are intended to be used. For large-scale floods the production capacity reduction in the industry sector will probably be larger, but the effects of the unavailability of a specific commodity can still take place. Not taking these effects into account may lead to an underestimation of the costs of a large-scale flood. The flooding of these critical infrastructures and firms should therefore be assessed not only with HIS-SSM or the ARIO model (or a similar model), but also on an individual firm level by an expert in the field. Examples of these critical infrastructures are large (petro-)chemical plants, large power plants, telecommunication centers and the gas fields in the north of the Netherlands.

[2]http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=80101NED&D1=8&D2=a&D3=257&VW=T accessed 7-3-13

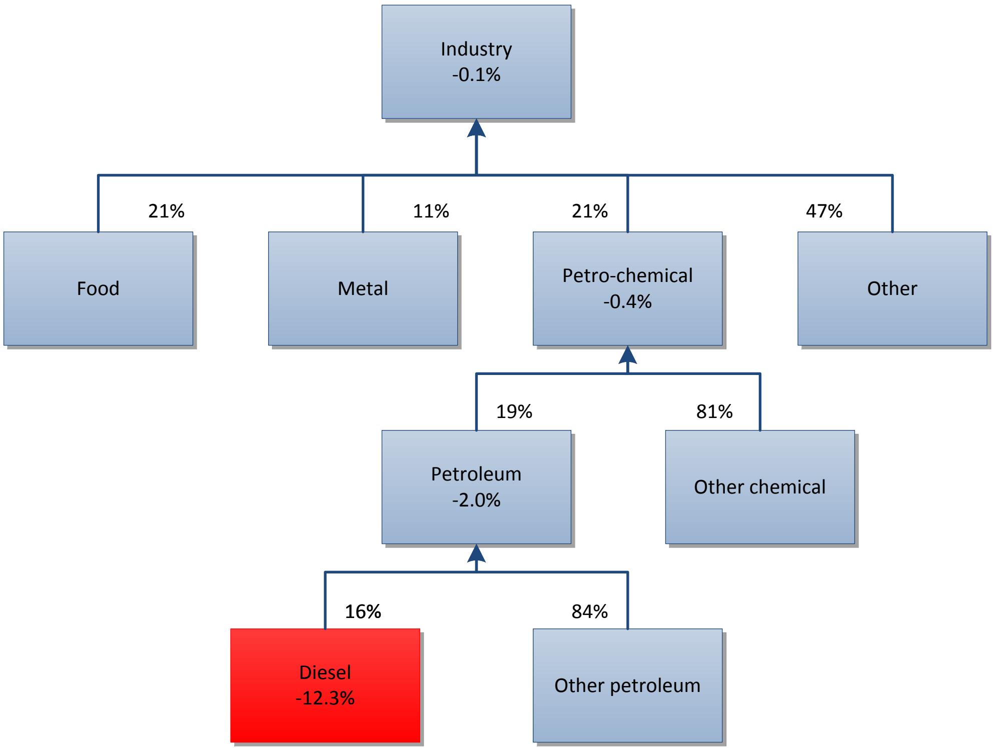

Figure G-3: Industry sector tree. The figures in the boxes give the production capacity reduction of the box. The figures near the lines indicate the size of the box relative to the size of the box above. Figures based on [Centraal Bureau voor de Statistiek (2012)].

If a firm or infrastructure meets the following three criteria a more detailed assessment of the interruption of that firm or infrastructure should be made. First, it should be vulnerable to floods. If all the systems are flood-proof then it is not necessary to make a detailed assessment. Next, the firm or infrastructure must provide goods or services which cannot be substituted for at short notice so shortages will occur. Finally, the effects of the unavailability should be geographically larger than the flooded area. If the effects of the shortages only occur in the flooded area the consequences are usually not that large, as there are more pressing matters present in the flooded area.