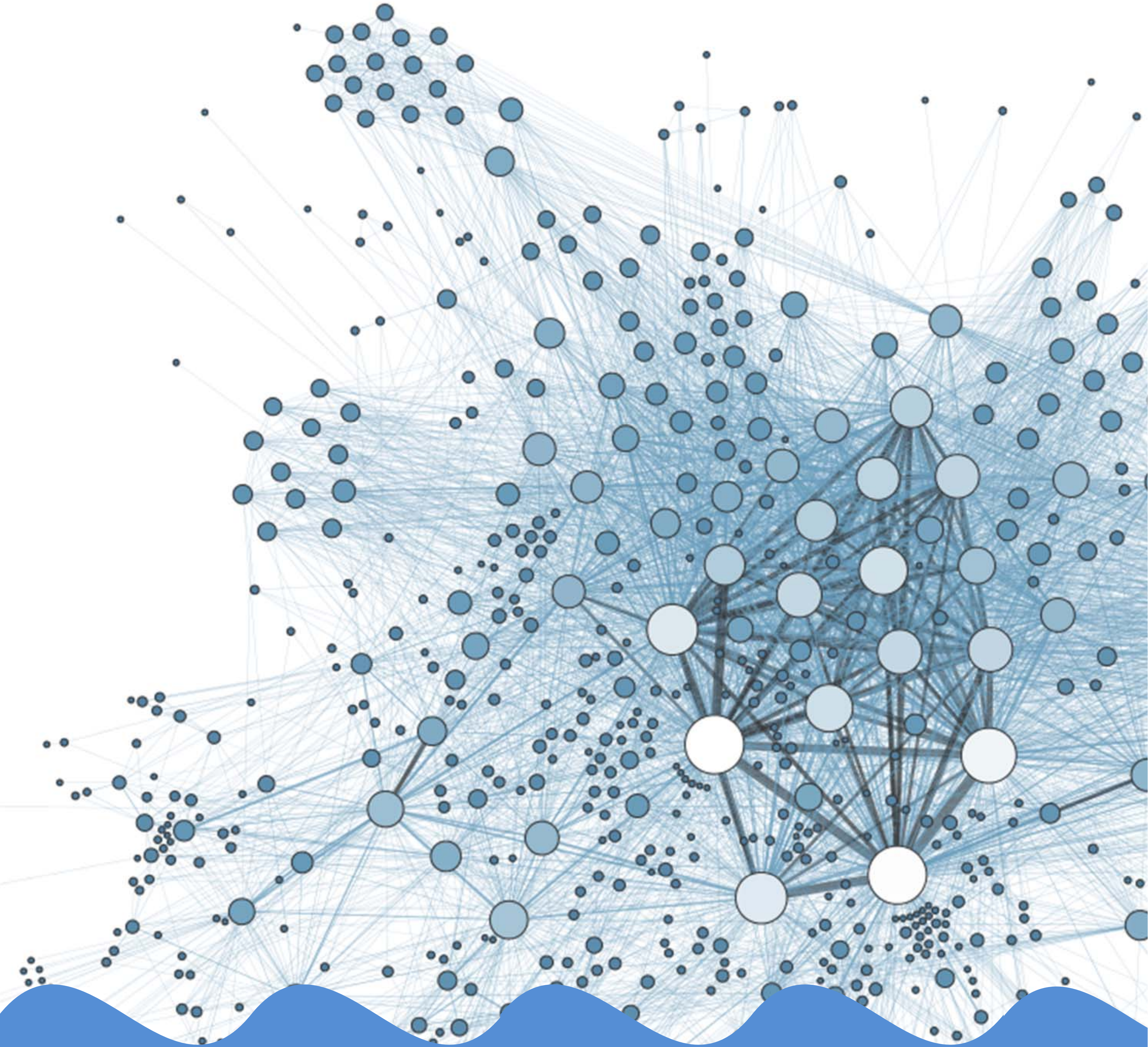
Mapping resilience

Developing a method to assess the resilience of critical infrastructure networks in flood prone urban areas.



Quirine van Wijngaarden

Master thesis

Figure on front page (Martingrandjean, 2013)

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‘Heere, geef ons heden ons dagelijks brood en af en toe een watersnood’

Preface

This report is the result of my thesis research conducted to complete the master program Construction Management and Engineering at the faculty of Civil Engineering and Geosciences at the Technical University of Delft. This report presents the effort to map the resilience of critical infrastructure networks in urban areas subject to flooding.

Attached to this report is the Atlas of Mapping Resilience, which includes the supporting documentation from the case analysis conducted in this research project. When printing this document, please bookbind the atlas as a separate document in order to make the most effective use of the atlas as support of this report.

The concept urban resilience has been the perfect opportunity to match my master program and my thesis research with my personal interest for urban development. This research has made it possible to dive into the concept of urban resilience and to get to the bottom of it, which has resulted in numerous insights.

Throughout this report photographs from the series Drowning World are presented, which are taken by photographer Gideon Mendel. These images draw a good picture of the reality that we do not encounter ourselves, while sitting behind our desks in our offices.

This thesis could not have been conducted without extensive help of a number of people whom I would like to thank.

First of all, I would like to thank the members of my graduation committee. Your input, knowledge and perspectives have been of great value to this research. Han, thank you for sharing your knowledge and experience, your critical and practical insights, and making me relate between theory and practice by removing me from my theoretical happy bubble. Fransje, your enthusiastic feedback has motivated me to deliver the best results possible, your practical insights and giving me the freedom to determine my own approach. Thank you for the right literature and getting to meet inspiring experts in the field of practice. Marian, your feedback has been sharp and your comments during our committee meetings were critical and on point. Thank you for restraining my unstrained enthusiasm with your positive support by handing me grips and the right focus. Pieter, your enthusiasm for the subject was contagious and your contributions during committee meetings have been helpful. Leon, thank you for your continuous support during our frequent meetings and your thoughts on all sorts of considerations. The process, with its responsibility and freedom, has been an educational and pleasant experience.

Secondly, I want to mention all experts that were willing to share their experiences. I enjoyed the interviews and was happily surprised by your eagerness to provide input for my research and motivation to further discover the possibilities of mapping resilience. Flood data was provided by the Steering Center of Flood Control Ho Chi Minh City.

Further, I would like to thank everyone at Witteveen+Bos who have contributed to the research by discussing the subject with me, helping with the GIS-work and sharing visions and ideas.

Concluding, I would like to thank my friends and family for their continuous support, reviewing and suggestions. And most of all, my parents and Laurens, thank you for your unlimited support and confidence.

Quirine van Wijngaarden
The Hague, November 2015

Summary

There is a growing need for resilient cities. Cities are resilient when they can endure the risks of flooding, even when being disrupted. Resilient cities can respond, recover and adapt quickly to the risks of the flooding event. A city can temporarily malfunction, for example because the electricity network is damaged, and recover. The question arises whether there is a relation between the resilience of a city and the spatial distribution of its critical infrastructure network assets. With knowledge of this relation, the urban planning of a city can increase its resilience.

The main problem addressed in this research is the gap of knowledge concerning the relation between the resilience of critical infrastructure networks and the spatial distribution of its assets. The main research question is: *How can the resilience of critical infrastructure networks of urbanized delta areas be related to the spatial distribution of its networks assets, with respect to the event of coastal and fluvial flooding?*

The result of this research is the conclusion that the resilience of critical infrastructure networks of flood prone urban areas can indeed be related to the spatial distribution of the networks assets, with the condition that this relation must be based on a qualitative assessment of the area and network.

This research presents a resilience roadmap with which the reaction of a city to the disturbance by flooding can be quantified in terms of resilience indicators. On the basis of two cases, two networks and several alternatives to the spatial distribution of the network assets, this research outlines how these networks in the two cases respond to flooding. Based on this research it is possible to compare the values of the resilience indicators for the two networks and the two cases. The values can be supported by the spatial aspects of the case areas and the spatial distribution of the assets of the networks. The seven steps of the resilience roadmap are:

1. Build the case model;
2. Simulate the flood in the case model;
3. Map the effects of the flood on the network;
4. Calculate the damage to the network;
5. Map the recovery of the network capacity;
6. Visualise the values of the resilience indicators;
7. Conduct cost-benefit analysis.

The resilience roadmap has the following characteristics:

- The method is reproducible and widely applicable;
- The calculations of the resilience indicators are transparent;
- The resilience indicators form a basis for comparing the alternatives in area development;
- The resilience roadmap is a communication tool for stakeholders.

Resilience is defined as the ability of a system to maintain its capacity while being subject to disturbances. In this research four indicators are identified with which resilience is mapped:

- The damage caused by the flood to the network;
- The capacity of the network at the moment the flood start;
- The capacity of the network throughout the recovery process;
- The duration of the recovery process.

The critical infrastructure networks in flood prone urban areas are considered resilient by conformity to the following criteria:

- The damage caused by the flood to the network is small;
- The capacity of the network at the moment the flood start is high;

- The capacity of the network throughout the recovery process is high;
- The duration of the recovery process is short.

The research methodology has a designing and exploratory character, as it concerns the development of a structured approach of mapping the resilience of critical infrastructure networks as well as the use of this new method to answer the research questions. The performed activities include desk research, case studies, modeling, flood simulation and quantifying resilience. The data input concerns data of the cases, the networks, the alternatives and the inundation heights. The data output consists of the four resilience indicators.

Due to the explorative and designing nature of the methodology, it is not possible formulate hypotheses to give directions to this research on beforehand. Hypotheses are formulated on basis of the results. These hypotheses lead to recommendations for further research.

Two critical infrastructure networks are analysed; the electricity and the healthcare network. Failure of these networks can cause casualties and economic damage. Failure of the electricity network has major consequences, as the performance of societies and their economies are increasingly dependent on electricity. Failure of the healthcare network has serious consequences as the suffering of the human being has a large take in damage calculations.

In practice, the healthcare networks consist of several components like hospitals, aid posts, general practices, human resources, specific apparatus, medication and transportation. In this research, the healthcare network is described in a highly simplified representation of reality. The representation of the healthcare network is based on the locations of the general practices and hospitals within the case area. The capacity of this network is the number of patients that can be treated simultaneously.

In practice, the electricity networks consist of several components like the production system, the transport system (high voltage grid) and the distribution system (medium and low voltage grid). In this research, the electricity network is described in a highly simplified representation of reality. The representation of the network is based on the locations of its assets. The capacity of this network is the amount of households that are provided with electricity.

The two networks are analysed in two case areas. The case areas are areas in Ho Chi Minh City and Dordrecht; both the cases are subject to coastal and fluvial flooding. Respectively the probability of flooding in the two case areas is 1/100 and 1/2000.

The case area in Ho Chi Minh City Case 1 is District 4 in Ho Chi Minh City, in Vietnam. Ho Chi Minh City has been subject to flooding over the last few years. The city is confronted with flood events on a regular basis. Flood prevention has been one of the biggest preoccupations of Ho Chi Minh City authorities in recent years. Plans are being developed to create a water storage area in District 4. It is a water retention area to store excess rainwater and to block high tides from entering District 4 causing backflow in the sewer system. The reservoirs are expected to significantly reduce flooding, which has been a major problem for Ho Chi Minh City over the last few years.

Case 2 is an area on the isle of Dordrecht, in the Netherlands. The city does not longer only trusts on the strength of the dikes. In case of a flood Dordrecht wants to be self-sufficient and to minimize the impact of the flooding to as little as possible. Utilities like electricity, water, sewage systems should continue to function and roads should remain accessible. Local municipalities communicate invest in the competence development of the people. The people are made aware of the risks and strategies to reduce it. Dordrecht is progressive within the implementation of the repressive approach towards flood risk management.

On basis of this research Ho Chi Minh City can learn from Dordrecht with respect to the ratio between its spatial aspects like the average building height, ground space index and floor space. Dordrecht has a higher resilience resulting from the higher amount of average floors per building footprint. It can be concluded that of the area in Ho Chi Minh City is more surface is cultivated and there is less open space than in Dordrecht. However, the average amount of floors build per cultivated surface (the floor space index) is lower in Dordrecht. In Ho Chi Minh City the value for floor space index is smaller than the value for the ground space index.

On basis of this research Dordrecht can learn from Ho Chi Minh City with respect to the spatial distribution of the capacity. Ho Chi Minh City has a higher resilience in the current situation and the alternative with one centralized asset, due to majority of the networks capacity that remains available during the flood. Dordrecht can increase its resilience by evenly allocating its capacity over the case area, of which the majority will remain available during the flood depending on the elevation height of the surface.

In general, the resilience of a critical infrastructure network can increase with the optimisation of the four resilience indicators.

First, a critical infrastructure network that can maintain the majority of its capacity in the case of a flood can be established by the gradual distributing the total capacity over the case area, of which the majority of the capacitance is located on the section that does not become flooded.

Second, by increasing the density of the built floor area with respect to the cultivated ground area by increasing the ground space index, the number of households or services that are more likely to be affected by flooding is reduced. Herewith, the ratio of the affected number of households or services decreases with respect to the total number households or services.

On basis of the research five hypotheses are formulated:

- A spatially dispersed critical infrastructure network is more resilient than a concentrated network in the event of disturbance by coastal and fluvial flooding;
- When a concentrated critical infrastructure network can maintains the majority of its capacity in the event of disturbance, it is more resilient than a spatially dispersed network;
- A critical infrastructure network that can maintain the majority of its capacity in the event of disturbance can be established by the gradual distributing the total capacity over the case area, of which the majority of the capacitance is located on the section that does not flood;
- By increasing the density of the built floor area with respect to the cultivated ground area by increasing the ground space index, the number of households or services that are more likely to be affected by flooding is reduced. Herewith, the ratio of the affected number of households or services decreases with respect to the total number households or services;
- The damage caused by the indirect effects of flooding, in all alternatives considered in this research study, is greater than the damage caused by the direct effects of flooding.

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List of abbreviations

CBA	cost-benefit analysis
CEIS	cascade-effect impact scheme
CIN	critical infrastructure network
FSI	floor space index
GIS	geographical information systems
GSI	ground space index
MLS	multi-layer safety
SLR	sea level rise
UCF	urban climate framework

Ahmed
Khairpur Nathan Shah
Sindh
Pakistan
September 2010
Photo by Gideon Mendel

1 Introduction

This chapter describes the motivation for this research project. The need for resilience in urban development is outlined (§1.1). The problem statements are outlined (§1.2). The research objectives are outlined (§1.3). The sub-research questions and the main research question are outlined (§1.4).

1.1 The need for resilient cities

There is a growing need for resilient cities. The global development of growing attention to the threats posed by climate change towards cities has led to increasing awareness of the subsequent challenges: reducing the impacts of climate extremes by increasing urban resilience (Solecki, Leichenko, & O'Brien, 2011).

Climate extremes are expressed as increased temperatures, sea level rise, more intense rainstorms, droughts, heat waves and secondary effects (Jabareen, 2013; Döpp, Hooimeijer, & Maas, 2011). Consequences of these extremes pose particular threats to urban infrastructure like transport disturbances, higher peak electricity load and voltage fluctuations, increased strain on material and equipment, and increased need for emergency management (Wardekker, de Jong, Knoop, & van der Sluis, 2010; Jabareen, 2013). Hence, there is a need to make cities resilient to climate extremes (Wardekker, de Jong, Knoop, & van der Sluis, 2010).

Cities are continuously threatened by a variety of risks. The probability and impact of each risk differs due to differences in the type of risk, geographic location, urban structure and its infrastructure networks. Due to these differences in risks, each city needs city specific risk management. In order to estimate the impacts of the risks, the city as a whole needs to be quantified (Pennings, 2013).

Cities are resilient when they can tolerate risks, climate extremes, through components and measures that limit the impact, by reducing or counteracting the damage of disturbance, and allow the system to respond, recover and adapt quickly to the risks (Wardekker, de Jong, Knoop, & van der Sluis, 2010). Resilience is determined by relationships within a system and the ability of these systems to absorb changes of state variables, driving variables, and parameters (Holling, 1973; De Bruijn, 2004). Cities are resilient to flooding when they can endure, even when being disrupted, and respond, recover and adapt quickly to the risks of the flooding event. A city can temporarily malfunction, for example because the electricity network is damaged, and recover.

The question arises whether there is a relation between the resilience of a city and the spatial distribution of its critical infrastructure network assets in the event of natural disasters like coastal and fluvial flooding. With knowledge of this relation, the spatial planning can increase the networks and cities resilience. A city can, with the proper distribution of its assets, increase its resilience in the event of (natural) disasters.

This research attempts to relate the extent of resilience of critical infrastructure networks to the spatial distribution of the critical networks infrastructure assets in the event of coastal and fluvial flooding. The aim is to determine whether there is a relation between the resilience of a critical infrastructure and the spatial distribution of the networks assets.

Two critical infrastructure networks are analysed, the electricity network and the healthcare network. Failure of these networks can cause casualties and economic damage. Failure of the electricity network has major consequences, as the performance of societies and their economies are increasingly dependent on electricity. Failure of the healthcare network has serious consequences as the suffering of the human being has a large take in damage calculations.

These networks are analysed in two cases; Ho Chi Minh City and Dordrecht; both cases are subject to coastal and fluvial flooding. Worldwide, floods affect cities located in the delta, where land and water meet. The location of a city in a delta is economically strategic, but also makes it highly vulnerable to flooding events (Wamsler, Brink, & Rivera, 2013).

Ho Chi Minh City, in Vietnam, has been subject to flooding over the last few years. The city is confronted with flood events on a regular basis. Floods are caused by high tides in the South China Sea, high intense rainfall on the city, high river discharge due to spilling from the reservoirs after prolonged periods of high rainfall and diverted flood waters from the Mekong river (Unknown, 2013; Dahm, Diermanse, & Phi, 2013). Flood prevention has been one of the biggest preoccupations of Ho Chi Minh City authorities in recent years. The city is a good example of flood risk management joint with urban development, because plans are being developed to create a water storage area in district 4. It is a water retention area to store excess rainwater and to block high tides from entering district 4 causing backflow in the sewer system. The reservoirs are expected to significantly reduce flooding (Davies, 2015).

Dordrecht, in the Netherlands, is a good example of the repressive approach to flood risk. The city does not longer only trusts on the strength of the dikes. In case of a flood Dordrecht wants to be independent in terms rescue operations and emergency equipment. Utilities like electricity, water, sewage systems should continue to function and roads should remain accessible (Heilemann, 2013). Local municipalities invest in the empowerment of its inhabitants. The awareness of people towards risk and adaptive strategies is raised. (Gemeente Dordrecht, 2009). Dordrecht is progressive with the implementation of the repressive approach towards flood risk management.

The necessity for more knowledge about climate effects on critical infrastructure networks was confirmed in June 2015 by the report published by Deltares (2013), presenting the results of the monitor of the Dutch Delta Decision Spatial adaptation (DBRA). In the report critical infrastructure networks are referred to as vital and vulnerable functions. The national, vital and vulnerable functions are one of the five themes of the DBRA-evaluation, besides water flogging, droughts- or water shortages, flooding and heat stress. The DBRA states that the Dutch government ensures that the national critical infrastructures are more resistant to floods by 2050. In the DBRA the Dutch government, provinces, municipalities and water boards agree to integrate flood- and climate resilience in spatial planning. The aim is that in 2020 climate-proof and water-robust development is an integral part of their policies and actions, so that ultimately the Netherlands will be climate proof in 2050 (van der Brugge, R.; Ellen, G. J.; Eshuis, J., 2013). This confirms that on a national level there is awareness for the necessity increasing the resilience of critical infrastructure networks.

The monitor points out that knowledge regarding climate impacts on critical infrastructure networks, along with knowledge about heat stress, has the lowest score of the five themes. Therefore, the monitor confirms the knowledge gap in the field of critical infrastructure networks subject to climate effects and that more research needs to be done on this matter.

1.2 Problem statements

The main problem addressed in this research is the gap of knowledge concerning the relation between the resilience of critical infrastructure networks and the spatial distribution of its assets.

The second problem that is addressed is the absence of a clear methodology with which the damage calculation of a flooding event can be visualised. Research from multiple perspectives is conducted on the resilience of critical infrastructure networks. To increase the reliability of this research it is outlined and visualized how the damage calculations are made, to assess the resilience of the analysed critical infrastructure networks.

1.3 Research objectives

The main objective is to determine whether it is possible to relate the resilience of critical infrastructure networks and the spatial distribution of its assets.

The second objective is to develop a method to map the resilience of critical infrastructure networks subject to disturbances. This is necessary to achieve the main objective.

The third objective is to subsequently assess measures with which the resilience of the networks can be increased.

1.4 Research questions

On basis of the research objectives the main research question and sub-research questions are formulated.

Main research question	*How can the resilience of critical infrastructure networks of urbanized delta areas be related to the spatial distribution of its networks assets, with respect to the event of coastal and fluvial flooding?*

To answer the main research question, three sub-research questions are formulated. The answers of these sub-research questions are used to substantiate the answer to the main research question.

Sub-research question 1	*How can the resilience of a critical infrastructure network be measured?*

Sub-research question 2	*Which (combination of) features are needed to measure the resilience of critical infrastructure networks?*

Sub-research question 3	*Is there a measurable difference in the extent of resilience of critical infrastructure networks between the different spatial distributions of the networks assets?*

The methodological approach to answer these questions has an explorative and designing character. Due to the nature of the approach, it is not possible formulate hypotheses to give directions to this research on beforehand.

However, it is possible to formulate hypotheses on basis of the research results. These hypotheses will be leading to recommendations for future research. The methodology that leads to the hypothesis is outlined in Chapter 3. The resulting hypotheses are outlined in Paragraph 9.1.

Jeff and Tracey Waters
Staines-upon-Thames
Surrey
UK
February 2014
Photo by Gideon Mendel

2 Theoretical framework

Literature research was conducted on five main topics that build the theoretical framework. This framework enables to understand the context and existing knowledge on the key concepts. This theoretical framework is used to formulate the positions and perspective of this research within and towards the existing knowledge and literature.

The main topics are:

- The definition of flood risk management (§2.1). The theoretical framework on flood risk management contains on the definitions of risk, the perspectives towards risks and the assessment of risk. The framework is used to identify an attitude within risk management and to identify how risk relates to resilience;
- The definition of spatial distribution of network assets (§2.2) includes the existing knowledge on the measurement of resilience in spatial distribution of network assets in urban areas;
- The definition of critical infrastructure networks (§2.3) is formulated using the work of six authors that are concerned with the (mal) functioning of urbanized areas in case of a flooding event;
- The definition and assessment of complexity (§2.4). The definition of complexity is given. Different approaches to complexity are outlined. The objective of this paragraph is to identify the frameworks are used to grasp complexity;
- The definition and assessment of resilience (§2.5). Theory about this matter provides the necessary knowledge on the genesis and developments of resilience. The methods for the quantification of resilience are important to create knowledge on how to measure resilience.

2.1 Flood risk management

The risk of an event is determined by the product of its probability of occurrence and the impact of its occurrence. Within flood risk management, risk is determined by the product of the flood probability and flood impact.

$$risk = \frac{probability \times impact}{discount\ factor}$$

De Bruijn (2005, pp. 24,25) defines risk as a function of flood probabilities and flood impacts. The risk can be quantified as the excepted annual damage (EAD). This formula can be used to identify possible directions towards a reduction of risks: either by lowering the probability and/or reducing the impact (Klijn, van Buuren, & van Rooij, 2004).

De Bruijn (2005, p. 24) defines flood risk management as all activities that aim at maintain or improving the capability of a region to cope with flood waves. The type of risk to which an urbanized delta area is exposed is the event of flooding as a consequence of sea level rise and excessive river discharge, in technical terms coastal and fluvial flooding.

According to De Bruin (2005, p. 25) flood risk management comprises of flood abatement, flood control and flood alleviation. Flood abatement aims at the prevention of the occurrence of peak flows. Flood control comprehends all activities that aim at preventing inundations. Flood alleviation comprehends all activities that aim at flood impact reduction.

Preventive versus repressive flood risk management

When making a distinction in types of behaviour towards potential risk of flooding, a suitable metaphor would be the boat with two types of engineers on it:

The “preventive” engineers are sitting on the left side of the boat (van Gelder, 2015). These engineers concern about preventing the occurrence of risk. The traditional Dutch water management is sitting on this side of the boat. Hydraulic engineers design flood protection constructions on basis of a given risk, as a product of probability and impact. The design of the construction meets the safety standard and will therefore exclude the risk by minimizing the probability component.

The “repressive” engineers are sitting on the right side of the boat (van Gelder, 2015). These passengers concern about dealing with the occurrence of a risk. This group explores what will exactly happen when a risk occurs. The impact of a risk is identified and with this knowledge the possible methods for mitigation are examined.

The theory of Van Gelder (2015) is that, in order to keep the boat in balance and buoyant, both types of engineers are required on the boat. This implies that the right of existence of the engineers is interdependent, without the other type of engineer one cannot survive. The prevailing thought, in accordance with the traditional water management, is that the preventive engineers can survive without the other, and that the repressive engineer needs the preventive engineer. This research demonstrates the importance of the repressive engineer. Conclusive, flood risk management can be accomplished with the acknowledgement of the interdependence of the two types of engineers.

Traditional versus resilient water management

Wardekker *et al.* (Wardekker, de Jong, Knoop, & van der Sluis, 2010) distinguish two types of water management: the traditional ‘Dutch’ water management and the resilient approach.

According to Wardekker *et al.* (2010) the traditional ‘Dutch’ water management focuses on predictive approaches, by reducing the probability of occurrence of flood events, by designing for a desired safety level. It is referred to as the ‘predict-and-prevent’-approach. One of the downsides of this approach is the risk of over-investment; by dimensioning to the maximum likely scenario by means of predictive modelling one can exclude scenario uncertainty.

Wardekker *et al.* (2010) consider the ‘resilience approach’ a ‘bottom-up’ way of thinking to enable a systems capability of coping with disturbances caused by flood events. Wardekker *et al.* (2010) have assessed flood events, defined characteristics to make a system resilient, and used these to explore options and to specify and categorize how the options can contribute to the systems resilience. This ‘bottom-up’ way of thinking was intended to support the ‘resilience-thinking’.

The theory of Van Gelder and Wardekker *et al.* correspond in the sense that the “preventive” engineers apply the traditional “predict-and-prevent” approach. It cannot be stated that the “repressive” engineers apply the “resilience-approach”, therefore more substantiation is needed.

De Bruijn (2005) provides a proper substantiation. De Bruijn (2005) distinguishes two main types of measures in flood risk management: structural and non-structural measures. Structural measures aim at modifying the flood pattern. Non-structural measures aim at reduction of the flood impacts.

Hereby, the theory of Van Gelder and Wardekker et al. is confirmed by De Bruijn when describing the difference between the two strategies for flood management. The traditional flood risk management of lowland rivers focuses on flood prevention and can be considered resistance strategies. In contrast, the resilient strategies focus more on living with the risk of floods instead of preventing them. Resilient strategies rely on a flexible response to floods and a rapid recovery.

Multi-layer safety

The multi-layer safety (MLS) concept was introduced in 2008 in the Dutch National Water Plan (Ministerie Verkeer en Waterstaat, 2008). The multi-layer safety concept is designed to limit the consequences of flooding by a more effective spatial organization and disaster management. The multi-layer safety concept identifies three different layers in which risks can be appointed. The three layers are prevention, impact reduction and disaster mitigation (Ministry of Infrastructure and Environment, 2012). Hence, the multi-layer safety concept explicitly calls for the consideration of measures to reduce adverse consequences and to implement these measures (van Herk, Zevenbergen, Gersonius, Waals, & Kelder, 2014)

In Figure 1 the three layers of the multi-layer safety concept are depicted. Per layer the risk component is given:

- Layer 1 (the bottom layer), '*prevention*', addresses the probability component;
- Layer 2 (the middle layer), '*impact reduction*', addresses the impact component;
- Layer 3 (the top layer), *'disaster mitigation'*, addresses the impact component.

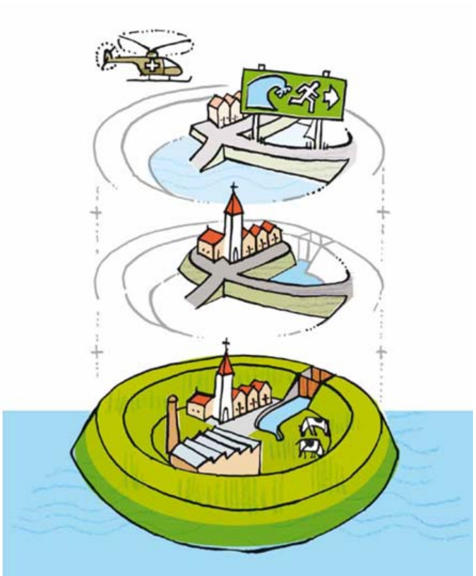


Figure 1 - The multi-layer safety concept (Ministry of Infrastructure and Environment, 2012)

By linking the multi-layer safety concept to the engineer's metaphor of Van Gelder, it can be stated that layer 1 addresses the preventive behaviour and layer 2 and 3 address the repressive behaviour. Preventive action refers to the minimization of the probability. Repressive action indicates the minimization of the impact.

Concluding on flood risk management

The attitude within flood risk management is characterized by the focus on the impact-component, which is visualized by the blue rectangle in the formula.

$$risk = \frac{probability \times impact}{discount\ factor}$$

This attitude is substantiated by the flood alleviation and resilient measures mentioned by De Bruijn (2005), the repressive behaviour mentioned by Van Gelder (2015), the resilient approach of Wardekker *et al.* (2010) and the layers 2 and 3 of the multi-layer safety concept.

2.2 Spatial structures of networks in urbanized areas

The spatial structures of networks in an urbanized areas concern the distribution of a critical and essential services for living in an urban area. The consistency of the assets with which this service can be provided is referred to as a network.

A distinction is made between two types of spatial structures of networks in urbanized areas: the mono-centre spatial structure displayed in Figure 2 and the decentralized spatial structure displayed in Figure 3. The figures represent the spatial structure of a network in which the shaded circles represent the services, the circles with no filling represent the users, the lines between the circles represent the dependencies and distribution directions (UrbanNebula, 2011).

The mono-centre spatial structure, in Figure 2, represents one centred core of services that distributes to the users. The users are dependent on this one core. In the event of failure of the operating of the core, the whole system is subject to this failure.

The decentralized spatial structure, in Figure 3, represents a network of services that distribute to the users. The users are not dependent on one core, but on multiple services. In the event of failure of the operating of one service, the users can switch to the other services.

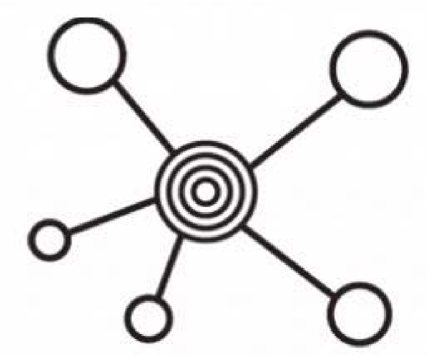


Figure 2 - Example of mono-centre spatial structure (UrbanNebula, 2011)

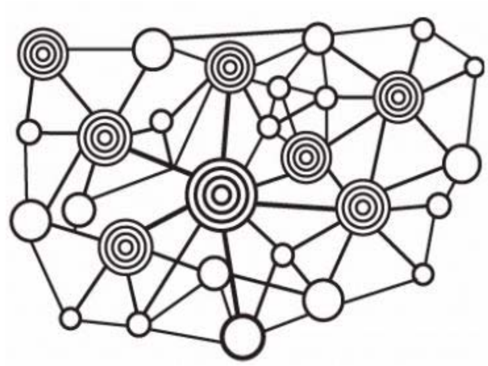


Figure 3 - Example of multi-nuclei spatial structure (UrbanNebula, 2011)

Allenby (2005) enumerates multiple advantages of the physical dispersion of assets. The physical dispersion of assets makes them less subject to local disasters. A decentralized network is more resilient against a number of disturbances, for example diseases. A dispersed workforce enhances resiliency in more subtle ways in addition to the obvious reduction in direct impact. Concerning data, Allenby prescribes that data that is duplicated in multiple locations and not located in one area, is affected in a lesser extent by the same local event, and therefore the dispersion helps to protect against catastrophic loss.

The spatial distribution of the services of a network influences the accessibility and travel time to the services. The following two subparagraphs give an illustration of the possible spatial structures of health services and their (dis)advantages.

Concerning the mono-centric healthcare network: in a centrally organized structure one hospital serves all people of the area, similar to Figure 2. An advantage of this structure is its low cost. The cost of building and maintaining of a single hospital are relatively low. A disadvantage of this structure is the travel time. The travel time to the hospital vary from very short to very long, depending on the distance to the hospital. In case of a flooding, there is a great disadvantage to this structure. When the hospital is hit by a flood, the vulnerability of the health services for the whole environment is concentrated on one point. Therefore it is highly vulnerable. With the loss of the function of the hospital, there are no more health services on which the people in the area can depend.

Concerning the decentralized healthcare network: in a diffuse structure numerous health services serve all people of the area, similar to Figure 3. An advantage of this structure is the short travel time, due to the access to multiple services. A disadvantage of this structure is the high costs, because multiple services need to be built and maintained. In case of a flooding, there is a great advantage to this structure. When a service is hit by a flood, the vulnerability of healthcare for the whole area is spread over multiple points. It is therefore vulnerable in a small extent. With the loss of the function of one service, there are several health services which can count the people of the area.

The concentration of assets of critical infrastructure networks

The concentration of assets of the critical infrastructure networks is measured in two manners. The first is to measure the amount of critical infrastructure network assets over the total surface of the area. The second is to measure the capacity of the critical infrastructure network over the surface.

The two concentrations are related to the ground space index and the floor space index. The calculation of the ground space index is to divide the surface area of the footprint of the buildings by the area that has not been built on (Oostdijk & Zenger, 2008); this is depicted in Figure 4. The calculation of the floor space index is to divide the surface of all the built floor area, including the ground floor, by the total surface area (footprint plus non-built-up) (Oostdijk & Zenger, 2008). This is depicted in Figure 5.

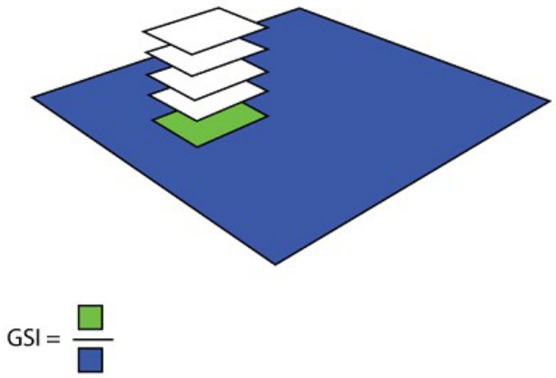


Figure 4 - Calculation of ground space index (Oostdijk & Zenger, 2008)

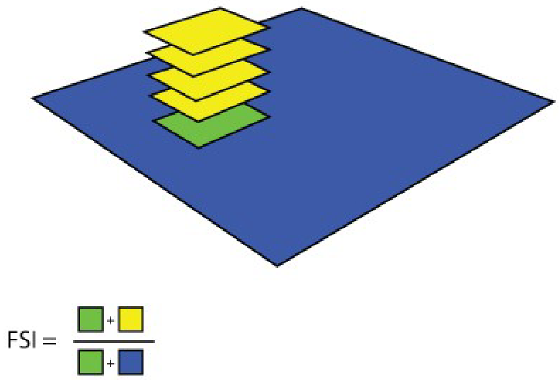


Figure 5 - Calculation of floor space index (Oostdijk & Zenger, 2008)

Concluding on spatial structures of networks in urbanized areas

The spatial distribution of assets are analysed by comparing the concentration of assets, the capacity of the critical infrastructure network, the population density, the ground space index (GSI) and the floor space index (FSI).

2.3 Critical infrastructure networks

According to research performed within FloodProBe there is neither a standard list on critical infrastructures nor a definition that is internationally agreed upon (Lhomme, Nie, Balmand, Heileman, & Bruijn, 2013; FloodProBe, 2011). FloodProBe is a European research project with the objective of providing feasible solutions for flood risk reduction in urban areas (FloodProBe, 2011). The following part will address six authors that have contributed to the definition of critical infrastructures concerning the (mal) functioning of urbanized areas in case of a flooding event.

The conditions for critical infrastructure networks

Luijf, Burger and Klaver (2003) have conducted a quick-scan into the critical infrastructure of the Netherlands, on behalf of the independent research institute TNO. The authors have determined what products and services are vital to the nation and which are 'just' very important. This is not exact science, as political sensitivities play a certain role as well. The report outlines the extent of criticality of products and services and the underlying interdependent processes. The research makes a distinction between direct criticality and indirect criticality. In this distinction subsequently electricity, water quantity, drinking water supply, maintaining public safety, food supply and healthcare are amongst the most direct critical products/services. This research was commissioned by the Dutch government and was part of the interdepartmental project Protection Critical Infrastructure (den Ouden & Souwer, 2013).

DHV (2011) considers critical infrastructures as products and services that are essential for the functioning of all other products and services. The list subsequently consists of: electricity, natural gas, drinking water supply, fixed/mobile communication and ICT, water quantity, road traffic (DHV, 2011). The report about protection of the critical infrastructure of preparation to crises and disasters was commissioned by the Ministry of Infrastructure and Environment (den Ouden & Souwer, 2013).

Heileman (2013) argues that critical infrastructure includes all networks and buildings that are essential for the functioning of society during and for the recovery from the flood event. Critical infrastructure is considered 'critical' because an outage of the infrastructure has a serious effect on many people over a long period. The functioning of critical infrastructure is crucial for the functioning of an area because (temporary) failure can cause social disturbance (victims / economic damage / repair or disability). The vital infrastructure must be repaired before they can recover other functions.

The extent of criticality

According to McBain *et al.* (2010) criticality can be used to quantify the resilience. The criticality can be expressed by;

- The severity of the effect (number of fatalities/wounded or monetary damage);
- The extent of the area or the number of people affected;
- The rate of recovery from the outage.

Jolly (2013) appoints the snowball effects that the disturbance of critical infrastructure can bring in motion. Failures among other sectors with probably extensive damages and losses can be consequences of the disturbance of critical networks. These critical infrastructure networks are complex, interconnected and highly interdependent.

The vulnerability of a critical infrastructure

The visualization of MUST Urbanists and Witteveen+Bos (2013) gives a comprehensive visualization of the effects of disturbance of critical networks on the vulnerable functions and the interdependencies of the networks. This visualization is given in Figure 6. This visualization shows the direct effects but also the indirect effects of multiple orders. However, this visualization misses information on the type, the extent and the exact order of the effect. The diagram can be diverted into multiple dimensions of the cascade-effects in order to become more comprehensive.

Currently, De Bruijn *et al.* (in press) analyse the vulnerability of the critical infrastructure networks by means of an assessment of the networks, the network elements, the effects of element failure on the network, the effects of failure of the network to other networks and the effect of outage of the networks on society.

This particular research of De Bruijn is considered as a useful representation of the current developments in research on mapping the vulnerability of critical infrastructure networks. The research of De Bruijn confirms and justifies the sense of urgency of this study and the related knowledge.

Dependencies of critical infrastructures

The Rathenau Institute (Steetskamp & Van Wijk, 1994) has published a report in which the social consequences of failure of the electricity network are mapped according to network dependencies.

The Rathenau Institute describes the societal vulnerability as a result of the dependencies of the other infrastructure networks to the electricity network. In the event of a failure of the electricity supply basically all other infrastructures can become disrupted, because of the dependency of infrastructure to electricity, such as drinking water supply, water management, telecommunications and transport.

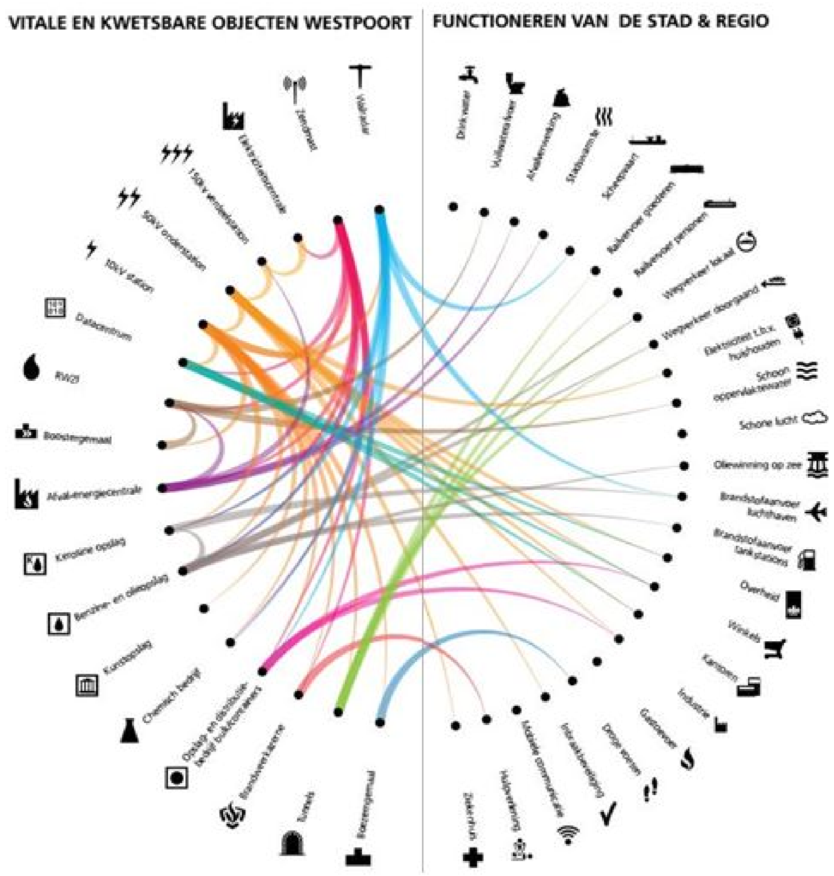


Figure 6 - The assets of the vulnerable networks in Westpoort Amsterdam
(MUST Stedenbouw; Witteveen+Bos, 2013)

Concluding on critical infrastructure networks

Critical infrastructure networks are referred to as all networks that are essential for the general health of the residents that are serviced by the network. Also networks are critical as the residents are dependent on the functioning of the network during the flood event and the recovery from the flood event. Hence the functioning of a critical infrastructure is crucial for the functioning of an area as failure can cause disturbance.

The snowball effect as a consequence of disturbance of a critical network is referred to as the cascade-effects.

2.3 Approaching the complexity of networks

In order to grasp the complexity of the critical infrastructure networks, several network approaches are elaborated. The use of a network approach enables to define the essential elements and functions of the urban network that are subject to climate change (Gunderson & Holling, 2001; Döpp, Hooimeijer, & Maas, 2011).

By identifying the networks and their and the assets dependencies, a bottom-up network analysis can be conducted.

An example by Batty (2010, p. 109) to indicate the extent of complexity is to measure the average distance between the assets of each network separately and to compare this with the total average path length of the whole network. The overall network connectivity increases with the increase of connections between the sub-network assets, caused by a decrease of the distance between the sub-networks assets.

In Figure 6 a comprehensive example is given of the network approach, showing all critical and vulnerable assets and their dependencies of an urbanized delta area Westpoort in Amsterdam.

The layers approach

The layers approach was developed by De Hoog, Sijmons, and Verschuuren (1998a) as a conceptual framework to guide the future Dutch spatial development. There was a demand for integral planning concerning climate change, water management, the economic position of the Netherlands in international networks and urban dynamics. The three layers are:

1. Occupation
2. Network
3. Substratum

The three layers are characterised by the dynamics of time. The approach provides a distinction in spatial layout as a result of the rate of developments in time. The main assumption is that layer 1 changes slower than layer 2, which changes slower than layer 3. This assumption has led to the idea that the layers from the lowest layer to the highest layer set priorities and conditions to the spatial planning tasks on the other layers (de Hoog, Sijmons, & Verschuuren, 1998a; de Hoog, Sijmons, & Verschuuren, 1998b; Schaik & Klaasen, 2011; Döpp, Hooimeijer, & Maas, 2011). But the difference in rate of change works both ways. The substrate can limit the occupation layer, but the pressure in the occupation layer increases as such that the substrate layer must be addressed.

The layers approach elaborates the strict subsidiarity in the duties and responsibilities of the various levels of government. It clarifies what the planning tasks on a national level, and the primary planning tasks of local governments, citizens and their organizations. The model distinguishes three layers and this distinction is explicitly hierarchical intended. It makes choices and set priorities. It helps to guide policy-making and expressing priorities for citizens, politicians and planners (Sijmonds, Feddes, & al., 2002).

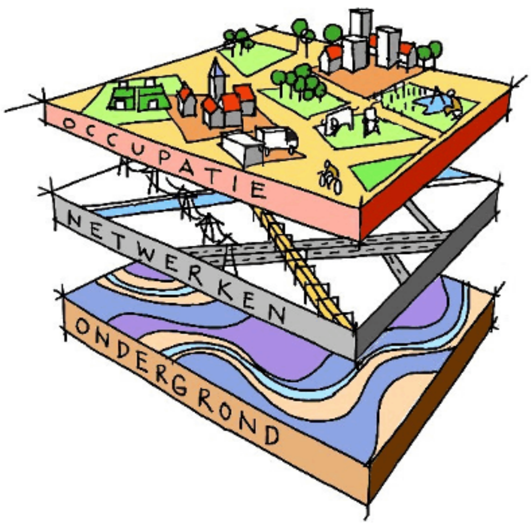


Figure 7 - The layers approach (Sijmonds, Feddes, & al., 2002)

The UCF approach

The urban climate framework (UCF) developed by Döpp, Hooimeijer, & Maas (2011), functions as a brokerage tool wherein all components of the network are brought together in a comprehensive way. The urban climate framework enables to organize different types of information, it enables to visualize and compare possible mechanisms, and it offers a location-based integrated assessment of mitigation and adaptation measures. The most important goal of the urban climate framework is to mainstream climate tasks with day to day city development (Döpp, Hooimeijer, & Maas, 2011).

On basis of the layers approach, developed by De Hoog, Sijmons and Verschuuren (1998b), containing of the three layers (occupation, infrastructure and substratum) additions were made. Three six layers of the UCF classification are:

1. Users
2. Metabolism
3. Buildings
4. Public space
5. Infrastructure
6. Subsurface

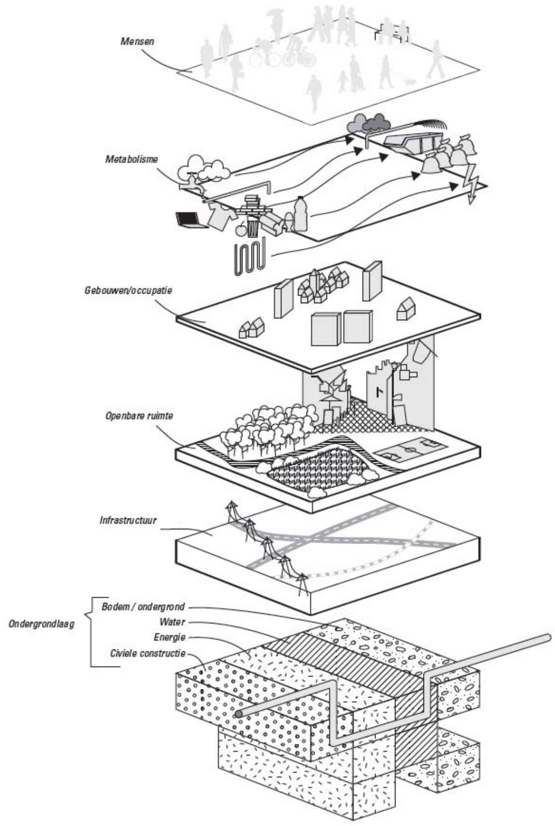


Figure 8 - The six layers of the UCF approach (Hooimeijer)

In Figure 8 the six layers of the UCF classification are visualised.

- The users-layer represents humans in the form of people and users.
- The metabolism-layer represents all assets that are produced and consumed by the users-layer. These assets concern drinking water, food, medicine, fuel, energy, air, water for domestic and industrial use and waste.
- The buildings-layer is all built up space. The buildings are homes, offices, shops, industry, culture, religion, agriculture and recreation.
- The public space-layer represents non-build, open spaces in the urban area.
- The infrastructure layer represents roads, networks, and hydrological structures.

The subsurface-layer represents soil, water, energy and civil constructions (Döpp, Hooimeijer, & Maas, 2011).

In the UCF a network is analysed by means of the specific local conditions of its stock, state and flow (European Environment Agency, 1994).

- The stock is described as the capital domain of the network in a certain situation before or after an event. The identification of the stocks provides insight into the direct effects of

climate change. The difference in the stock, after an event or after a change of its state, influences the flow.
- The flow describes the relationship between different stocks. The identification of the flows between the stocks provides insight into the indirect effects of climate change.
- The state describes the state of the stock. The difference in state is caused by an event. The difference in state has effect on the stock or the flow between stocks.

The development of the UCF is related to the DPSIR framework (European Environment Agency, 1994), which can be used to identify a chain of causal links between components of the different layers and their system. The DPSIR framework enables understanding of the complex relationships between urban system and its environment, including driving forces, pressure and state of the stock, the impacts of climate change and the responses to deal with these impacts. In Figure 9 the relations within the DPSIR model is visualised.

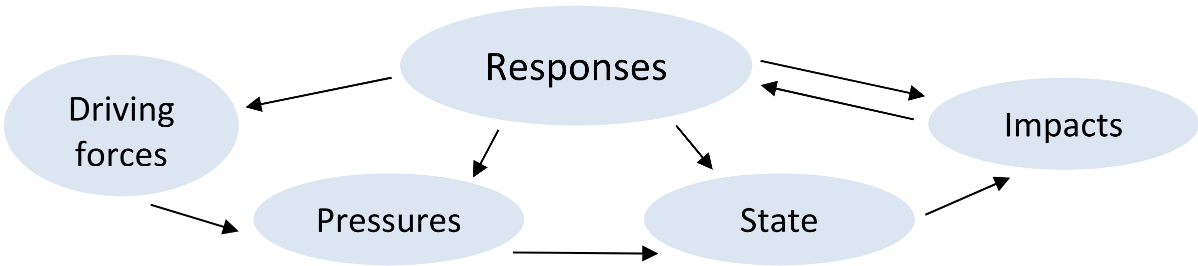


Figure 9 - The DPSIR Model (European Environment Agency, 1994)

In the UCF the different dynamics are distinguished between the layers, concerning the speed and costs with which adjustments can be made. The slowest and most expensive layer is represented by the subsurface layer that consists of longstanding structures that are difficult to change. The middle layer, the infrastructure, represents structures that can be changed but still at a low rate and often involving high costs. The upper and fastest layer, the users- and metabolism-layers, can change with a relatively high rate. In Table 1 the relation between the layers and their dynamics is summarized.

Table 1 - The layer approach of the UCF with corresponding dynamics (Döpp, Hooimeijer, & Maas, 2011)

Physical layer	Dynamics
Users	Very high
Metabolism of the city	Very high
Occupation/buildings	High
Public space	Moderate
Infrastructure	Low
Underground	Very low

The UCF is a great approach to identify which costs result from making adaptations within a built environment. Between the six layers of the UCF there is a definite difference of costs required to make adjustments. It is assumed that the implementations of adjustments in the surface layer are significantly more expensive than adjustments in the buildings- or people-layer.

Concluding on approaching the complexity of networks

The network approach is relevant, as it enables to distinguish and identify different networks within urbanized areas. It enables to order and visualize the complexity of an urbanized delta area. The bottom-up approach enables to identify the assets and the networks and their dependencies.

The layers approach is relevant, as it enables to explore the layers and networks and subsequently the dependencies between the layers and networks. The modification of the six layers in the UCF is used as a descriptive and structuring framework.

The UCF is used to provide a clear view of the context of the case and insight into the spatial complexity. It is used as a database that presents a moment in time for a specific situation and to find a balance between measures for a certain goal or to explore the results of a specific scenario.

On basis of the knowledge and structure gathered with the UCF a distinction can be made between people, production-consumption and objects (Ruijgrok, 2015). Object can be subdivided into residential, services and production. This classification is referred to as the PPO classification (people, production-consumption, objects). The following classification arises:

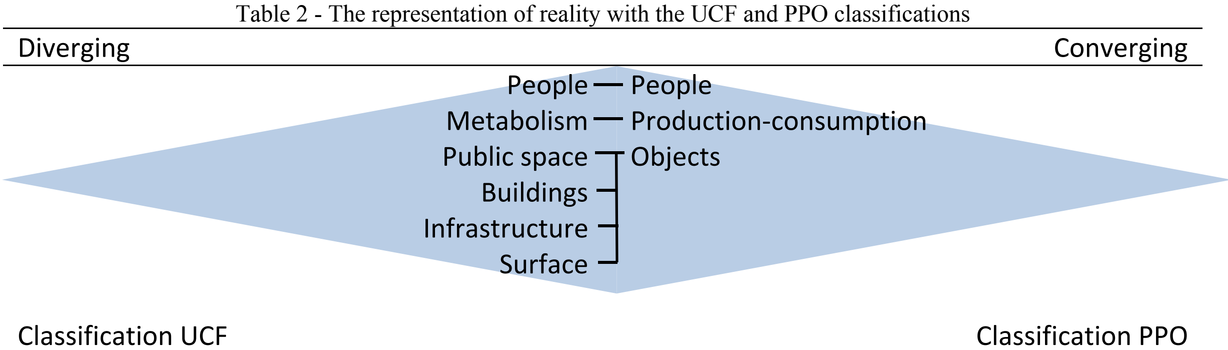
- People
- Production-consumption
- Objects (residential/services/production)

The two classifications of the UCF and PPO complement one another when it comes to the theoretical reproduction of the complex reality. The layout of the UCF is appropriate to give a precise and realistic view of reality. The layout of PPO is suitable to structure the representation of reality. Also, there are clear parallels between the classification of the UCF and the classification of PPO.

- People (UCF) is similar to people (PPO)
- Metabolism (UCF) corresponds to production-consumption (PPO)
- Public space, buildings, infrastructure and subsurface (UCF) correspond to objects (PPO)

An overview in which the two classifications complement one another is visible in Table 2.

Table 2 - The representation of reality with the UCF and PPO classifications



In Table 2 the diverging and converging is represented by the blue diamond. In Table 2 the diverging activities are represented by the left part of the table, for which the classification of the UCF was used. The converging activities are represented by the right part of the table, for which the classification into PPO was used.

2.4 Resilience

The definition of resilience

The ecologist Holling introduced the concept of resilient systems in the 1970's, when the systems approach was popular in the ecology. Holling (1973) states that the most essential feature of ecosystems is the ability to recover from risks. With this recovery the principal components of the system are restored, but do not to return the exact same situation. Resilience is the persistence of relationships within a system and the ability of these systems to absorb changes of state variables, driving variables, and parameters (Holling, 1973; De Bruijn, 2004).

Resilient cities are cities regarded as systems that can tolerate risks, climate extremes, through components and measures that limit the impact, by reducing or counteracting the damage of disturbance, and allow the system to respond, recover and adapt quickly to the risks. (Wardekker, de Jong, Knoop, & van der Sluis, 2010).

The definition or resilience by Gersonius (2009) is taken from Norris *et al.* (2008) as the ability of process that links a set of system capacities to the preservation or enhancement of system functioning. This concept recognizes implicitly that resilience emerges from a set of system capacities that provide a strategy to ensure dynamic stability.

The Rathenau Institute (Steetskamp & Van Wijk, 1994) acknowledges a strong relationship between the vulnerability and resilience of a system. The Rathenau Institute states that the extent in which a system is able to address the effects of a disturbance will determine the vulnerability to a large extent. The societal resilience is described as the reduction in demand patterns in emergency situations and possibilities to restore the normal situation. The Rathenau Institute further states that the societal vulnerability is not static, given the significant extent in which it can be influenced by societal resilience.

Types of resilience

On basis of theory of Wardekker *et al.* (2010) en De Bruijn (2005), two types of resilience are defined supplemented by the method of measuring. The types are referred to as "Elasticity" and "Transition".

"Elasticity" is the ability of a system to return to an earlier equilibrium or pattern after a disturbance (De Bruijn, 2004). It indicates the amount of change that a system can undergo and retain the same control on function and structure (Wardekker, de Jong, Knoop, & van der Sluis, 2010). Resilience as elasticity is measured as the return time of a system. Both the time needed to return to equilibrium and the movement of the system after a disturbance should be measured (De Bruijn, 2004).

"Transition" is the degree to co-evolve, to which the system is capable of self-(re)organisation to accommodate external changes (Wardekker, de Jong, Knoop, & van der Sluis, 2010). Resilience as transition is measured by the magnitude of disturbance that the system can absorb before redefining its structure (De Bruijn, 2004).

Wardekker *et al.* (2010) define resilience as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks". This definition is consistent with the two types of resilience mentioned above. A system is elastic as it is can continue with functioning, after being disrupted. A system reorganizes when it transits while undergoing change, co-evolving, and retain its functioning.

Here appears to arise a conflict in between the theory of De Bruijn and Wardekker *et al.* De Bruijn defines resilience as the ability of a system to maintain its most important processes and components when subjected to disturbances. Therefore, De Bruijn assumes that the system maintains its main characteristics after being recovered from a disruption. Wardekker *et al.* define resilience as the ability to adapt to disruption. Hence, Wardekker *et al.* assume that the system can adapt to a new form, in which it is not excluded that the main characteristic remain unchanged.

According to De Graaf *et al.* (2009) the vulnerability of a system and the ability to deal with climate change can be determined by a combination of four types of capacities:

1. Threshold/resistance capacity is the capacity to build up a threshold to prevent the risk even;
2. Coping capacity is the capacity to reduce the effects in case a risk event exceeds the threshold;
3. Recovery capacity is the capacity to recover quickly and effectively from the (negative) effects of a risk event above the threshold;
4. Adaptive capacity is the capacity to adjust adaptively to future change.

In theory, a flood-proof city has the perfect balance of these four capacities and is therefore less vulnerable to the effects of flooding (Döpp, Hooimeijer, & Maas, 2011).

The system capacities, developed by De Graaf *et al.* (2009), and the multi-layer safety concept have different backgrounds. The multi-layer safety has been developed in an environment grafted on practical implementation, stimulated by the Dutch government. The theory of De Graaf *et al.* was developed in a theoretical environment, stimulated by scientists specialized in flood risk management.

Measurement of resilience

According to De Bruijn (2005) the concept of resilience can only become an applicable concept in flood risk management if it is made quantifiable. De Bruijn states that measuring resilience directly is not possible, since it is not clear what to measure and often there is a lack of data. Hence, indicators must be used to quantify resilience.

De Bruijn (2005) has written on the quantification of resilience with respect to flood risk management. De Bruijn uses three reaction aspects to measure resilience: the reaction amplitude, the recovery rate and the graduality of the reaction increase.

- The reaction amplitude is a quantification of the magnitude of the reaction to the disturbance. The reaction amplitude of a system to a flood is an indication of the expected direct tangible and intangible impacts. The amplitude can be quantified as the expected average damage and the expected average number of casualties per year.
- The recovery rate is the speed with which a system recovers from its reaction to a disturbance. The recovery rate is estimated by means of a recovery capacity analysis of the system, which is a qualitative approach. It is related to physical, economic and social aspects.
- The graduality of the reaction is defined by the increase of the systems reaction to the flood waves, when the height or frequency of the flood waves increase. This aspect is quantified by comparing the relative increase of discharge in percentages by the corresponding relative increase of damage.

How do these indicators relate to each other?
De Bruijn (2005) elaborates that the resilience of a system is larger when the amplitudes are smaller, the graduality is larger or the recovery rate is higher. Whether the system reacts or not, depends on the resistance of the system. The resistance is indicated by the reaction threshold, which is the largest disturbance which does not provoke a reaction. In the context of flood risk management this threshold is defined as the recurrence time of the design discharge or as the highest discharge which is not expected to cause floods.

Gersonius *et al.* (2009) and Carpenter *et al.* (2001) argue that it is necessary for the operationalization of resilience to specify the resiliency ‘of what´ and ´to what’. To measure resilience it is crucial to specify what system state is being considered (the resilience *of* what) and what disturbances are of interest (the resilience *to* what).

To determine the actual vulnerability of critical infrastructure, one should identify assets (e.g. transformers) and connections (e.g. cables) by a network analysis by Heilemann *et al*. (2013). From here onwards, one can determine the flood resilience of critical infrastructure, the effects of asset outage on networks and the impacts on society.

Concluding on resilience

The definition of resilience is the ability of a network to maintain and restore its capacity while being subject to disturbances. Four indicators are identified with which resilience is mapped:

- The damage caused by the flood to the network;
- The capacity of the network at the moment the flood start;
- The capacity of the network throughout the recovery process;
- The duration of the recovery process.

Critical infrastructure networks are considered resilient by conformity to the following criteria:

- The damage caused by the flood to the network is small;
- The capacity of the network at the moment the flood start is high;
- The capacity of the network throughout the recovery process is high;
- The duration of the recovery process is short.

João Pereira de Araújo
Taquari District
Rio Branco
Brazil
March 2015
Photo by Gideon Mendel

3 Methodology, data and methods

In this chapter the methodology of the research is outlined (§3.1). The data of the research is outlined (§3.2). The methods that are used to relate the methodology and the data are outlined (§3.3). The validity and reliability of this research are outlined in (§3.4). The relation between the methodology, the research results and the establishment of hypotheses based on the results is outlined (§3.5).

3.1 Methodology

The main aim of this research is to develop a structured approach, with which the aforementioned research questions can be answered and substantiated. The approach that was developed is evaluated on the extent to which it can meet the research objectives.

The methodology has a designing and exploratory character. The designing character concerns the development of a structured approach of mapping the resilience of critical infrastructure networks. The research is exploratory in nature as it concerns the use of this new method to answer the research questions.

The methodology consists of five phases. In Figure 10 the phases of the research methodology are presented.

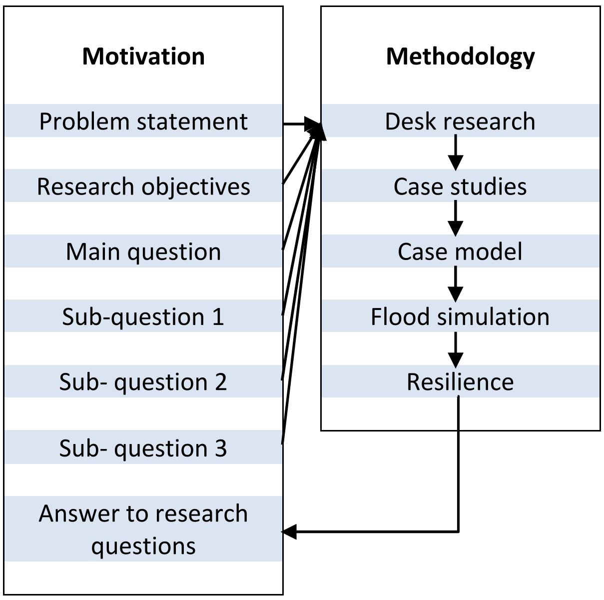


Figure 10 - Relation between research motivation and methodology

The desk research includes literature study, analysis of the internal database of Witteveen+Bos, analysis of the external database of available data on the Internet and project documentation.

The case studies include the analysis of the case areas and the critical infrastructure networks. The case studies were used to declare the features of the network on the basis of spatial aspects in the case areas. The result of the case studies can be found in the case reports in the annexed Atlas of Mapping Resilience. The substantiation for the case areas is outlined in Appendix A.

The case model is developed with which a simplified representation of the case areas and the critical infrastructure networks can be analysed.

Flood simulations are conducted by means of the case model, in order to analyse the effect of flooding on the simplified representation of the case studies. The flood simulations are visualized by means of the program ArcMap10.2.2.

The extent of resilience is determined on basis of the resilience indicators, the data output of the flood simulations on the critical infrastructure networks in the case model.

3.2 Data

In Figure 11 the relation between the methodology and the data used and produced is presented.

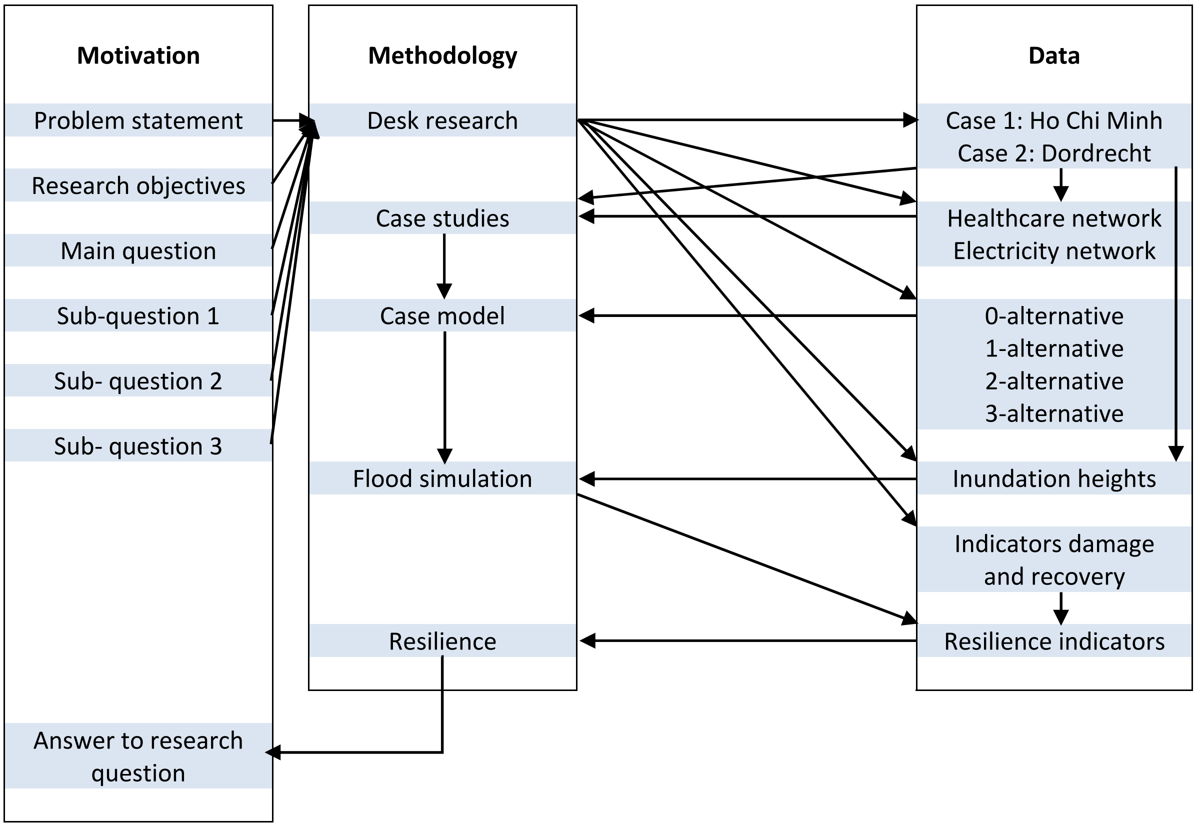


Figure 11 - The relation between research motivation, methodology and data

Cases and critical infrastructure networks

The data of the case studies concern the critical infrastructure networks. The two cases areas are:

- District 4 in Ho Chi Minh City, Vietnam. This case is further referred to as Ho Chi Minh City.
- Dordrecht, in the Netherlands. This case will be referred to as Dordrecht.

The data was collected by means of the desk research. The substantiation for the case study areas can be found in Appendix A.

The two critical infrastructure networks subject to analysis are the healthcare network and the electricity network.

The two networks are described in a highly simplified representation of reality in order to enable the assessment of the networks. The reality is too complex to capture in the model, with the simplified representation of the critical infrastructure network data, the spatial distributions of the assets and the capacity of the networks become feasible.

In practice, healthcare networks consist of several components like hospitals, aid posts, general practices, human resources, specific apparatus, medication and transportation. The simplified representation of the healthcare network is done in assets and represents the locations of the general practices and hospitals within the case area. Each asset is assigned a certain capacity, like the number of patients that is treated simultaneously.

In practice, electricity networks consist of several components like the fuel supply, the production system, the transport system (high voltage grid) and the distribution system (medium and low voltage grid)). Here only the assets of the registered elements of the transport system and, in case the available data is adequate, the distribution system within the case area are used.

Alternatives

The alternatives represent different ways to deal with the flood. The objective of the alternatives of the network is to investigate whether it is possible to increase the networks resilience. The three alternatives are the variations of the spatial distribution of the assets and capacity of the critical infrastructure networks. The 0-alternative is the current situation of the case studies. The alternatives are theoretical variations of the distribution of the assets and capacity of the networks based designed on the basis of desk research and simulated in the case model. The purpose of analysing the three different alternatives is to demonstrate the relation between the spatial distribution of the assets and capacity and the resilience of the networks.

The 1- and 2-alternatives concern measures that are derived from the ClimateApp, developed by Bosch Slabbers, Deltares, Grontmij, Witteveen+Bos and KNMI (2015). This ClimateApp is climate adaptation app was developed for urban designers and engineers to illustrate feasible interventions with specific climate adaptation goals. Further criteria for the alternatives are:

- The alternatives can be simulated in ArcMap10.2.2
- The alternatives have influence on the spatial distribution of assets and capabilities of the network.

Inundation heights

The data of the inundation heights, collected by desk research, are used to simulate a realistic level of inundation. Per case the inundation height is chosen that meets the probability of flooding in future developments.

Indicators for valuation effect of flooding

The indicators for the cascade-effect impact schemes calculations are collected, by means of the desk research, in order to validate the effect of the simulated flooding on the critical infrastructure networks.

Resilience indicators

The data used for the resilience indicators is derived from the flood simulations. It is based on the simulated effect of the flood on the modelled networks. It is valued on basis of the indicators derived from the desk research.
The data output concerns the four resilience indicators:

- The damage caused by the flood to the network, data output of Chapter 5;
- The capacity of the network at the moment the flood start, data output of Chapter 6;
- The capacity of the network throughout the recovery process, data output of Chapter 6;
- The duration of the recovery process, data output of Chapter 6.

In Figure 12 the data output is structured and presented.

In Figure 13 the graphs is presented that is used to visualise the ratio between the values of the resilience indicators of the alternatives. The values are normalised between the values 0 and 1. Therefore, when an alternative has the lowest value of all the alternatives, in this graph the alternative is represented with the number 0. When an alternative has the highest value of the alternatives, in this graph the alternative is represented with the value 1.

To relate these values to resilience; the values that are close to 1, contribute to the resilience of the network. The values that are close to 0, do not contribute to the resilience of the network.

Healthcare network Ho Chi Minh City

Alternatives		Damage	Capacity at t=0	Capacity factor	Recovery
0	The current situation				
1	Survival kit per household				
2	Flood proofing assets				
3	One temporary shelter				

Healthcare network Dordrecht

Alternatives		Damage	Capacity at t=0	Capacity factor	Recovery
0	The current situation				
1	Survival kit per household				
2	Flood proofing assets				
3	One temporary shelter				

Electricity network Ho Chi Minh City

Alternatives		Damage	Capacity at t=0	Capacity factor	Recovery
0	The current situation				
1a	Generator per household				
1b	Solar panels				
1c	Flood proofing households				
2	Flood proofing assets				
3	One central asset				

Electricity network Dordrecht

Alternatives		Damage	Capacity at t=0	Capacity factor	Recovery
0	The current situation				
1a	Generator per household				
1b	Solar panels				
1c	Flood proofing households				
2	Flood proofing assets				
3	One central asset				

Figure 12 - The structure of the data output

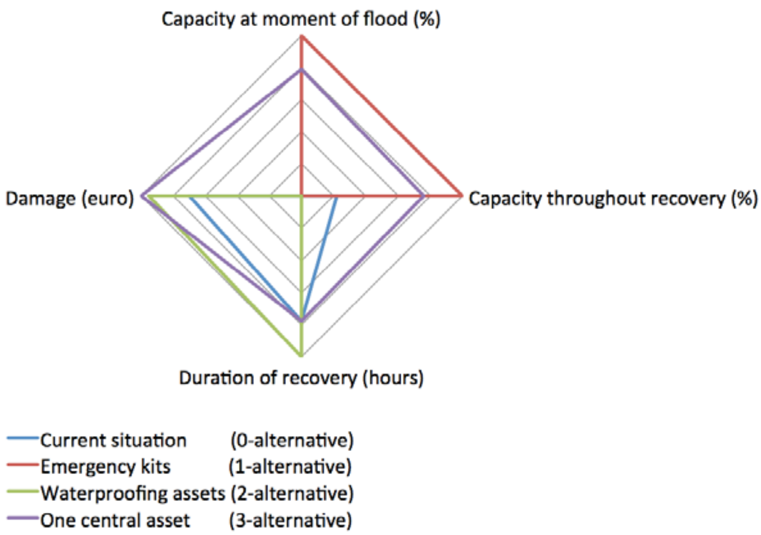


Figure 13 - Visualisation normalized ratio resilience indicators per alternative

3.3 Methods

Three methods are used in order to enable the use and production of data. The methods stand for the systematic manner in which data is used and produced.
The main objective of this research is to develop a method to map the resilience of critical infrastructure networks subject to disturbances. Hence, different methods are developed and used in a designing and exploring manner. The applicability of the methods is discussed on the basis of the results of the investigation in Chapter 8.

In Figure 14 the relation between the methods and the methodology and data is presented. Concluding it is presented how, on basis of which data, the objective is achieved.

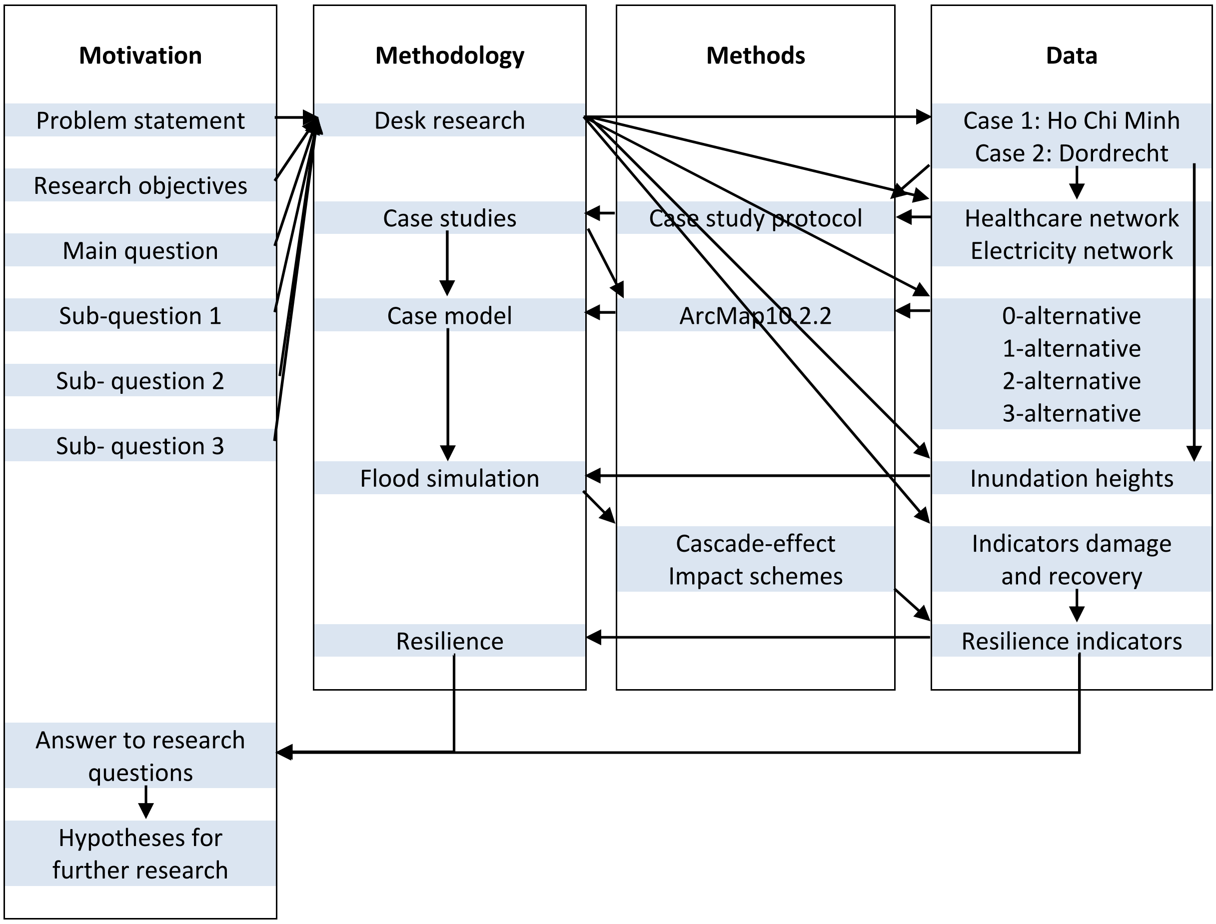


Figure 14 - The relation between the research motivation, methodology, methods and data

The case study protocol

The case study protocol enables to enhance the validity and reliability of the research. The protocol comprises a set of rules and guidelines for the collection and presentation of data.

The case study research is conducted as an embedded multiple-case study. The design consists of multiple cases contributing to the data set with sub-elements embedded in each case (Yin, 2009). The embedded sub-elements are the healthcare network and the electricity network.

Data is collected by means of literature study, analysis of the internal database of Witteveen+Bos, analysis of the external database of available data on the Internet and project documentation. The public and available data on the Internet was validated by comparing different sources of data and the criticising the sources of the data.

ArcMap10.2.2

The modelling of the networks and simulations of the flooding in the case areas is performed by means of the program ArcMap10.2.2. The modelling is done by working with multiple layers:

- Base layer
- Digital elevation map
- Inundation map
- Footprint constructions
- Locations of assets healthcare network
- Locations of assets electricity network

The products of this method are the maps in the case reports, presented in Chapter 4. More detailed information on the modelling and simulating the floods by means ArcMap10.2.2 can be found in Appendix B.

The cascade-effect impact schemes

The cascade-effect impacts schemes are developed to map and visualize the direct and indirect effects of flooded critical infrastructure networks. Another purpose of the schemes is to visualize the manner in which the taken measures influence the direct and indirect effects of the flooding. Because the two networks each encounter very specific effects in case of flooding, two schemes are developed, one per network, in order to connect to reality as much as possible.

The data input for this method is from the flood simulation and valuation of the effect of flooding on the assets. The data output of this method concerns the indicators of the damage and recovery duration.

The use of the cascade-effect impact schemes can be found in Chapter 5. More detailed information on the necessity of the schemes, the development of the schemes, the validation of the schemes and the two format schemes can be found in Appendix C.

3.4 Validity and reliability

In the development of this case study design, four conditions related to the design quality need to be taken into account (Yin, 2009, p. 40):

- Construct validity;
- Internal validity;
- External validity;
- Reliability.

Construct validity

The validity of this research is constructed throughout the process by establishing correct operational measures for the concepts studied. These correct operational measures are the methods that are described in Section 3.3.

Multiple sources of evidence are used, consulted and a chain of evidence is established. This chain outlines the relation between the case study questions, the case study protocol, the citations to sources of evidence in the case database, the case database and the case study report.

The draft report was reviewed by key informants; the supervisor at Witteveen+Bos, the graduation committee at the TU Delft, fellow students in the master program and external experts.

Internal validity

Due to the explanatory nature of this research, the internal validity is a critical aspect. The internal validity is constructed throughout the process by establishing relations between the research methods. Several causal relations within the methodology are outlined:

- The simulations in ArcMap10.2.2 are based in the case study reports;

- The damage calculations are based on the results of the simulations in ArcMap10.2.2;
- The damage and recovery indicators are based on multiple sources of evidence;
- The capacity calculations are based on the damage and recovery calculations.

Concerning causal relationships between different factors; statements concerning the relation between the results of the research and the data are limited to the scope of the research. Causal relationships are substantiated by observations recognizing the exclusion of external influences. The influence of external factors is not included in the scope of this research.

External validity

The external validity of this research is constructed by defining the domain of the research's findings relevance. Concerning the generalisation of findings: no claims for generalising findings are made beyond the case studies. If claims are made in the conclusions of this research, then these claims concern only the data that was analysed in this research. If claims are made that concern data that is outside the scope of research, then these claims are hypotheses. The hypotheses are formulated that contain generalising findings on basis of the results; these form the motivation for further research.

Reliability

The reliability is constructed throughout the process by demonstrating that the research can be conducted repeatedly resulting in the same outcome.

Concerning the use of a case study protocol; throughout the research a protocol was developed, according to which the case studies have been conducted. The protocol itself is not included in this report. The results are presented in Chapter 4 and the annexed Atlas of Mapping Resilience.

Concerning the use of a case study database; throughout the research a case study database was developed in which all data and the references of the cases is presented.

3.5 Methodology to results

In this section the research methodology is related to the research results. On basis of the methodology, data and methods, the research questions can be answered and discussed. Each question with which aspect of the methodology the answer is substantiated and each formulation of resulting hypotheses is outlined.

Sub-research question 1	*How can the resilience of a critical infrastructure network be measured?*

The answer to sub-research question 1 is based primarily on the literature study. In addition, the answer to this question is based on the method that was developed throughout this research to measure resilience. The developed method to measure the resilience of critical infrastructure networks is reflected.

Sub-research question 2	*Which (combination of) features are needed to measure the resilience of critical infrastructure networks?*

The answer to sub-research question 2 is based primarily on the experience of the method development throughout this research. In addition the answer to this question is based on the literature study, which is a component of the desk study. The extent to which the features are workable in the developed method is reflected.

Sub-research question 3	*Is there a measurable difference in the extent of resilience of critical infrastructure networks between the different spatial distributions of the networks assets?*

The answer to sub-research question 3 is based on the data output of the resilience calculations and the comparison of the data to the spatial distribution of the critical infrastructure network assets. The differences in the data output of the resilience calculations are also related to the spatial distribution of assets presented in the maps of the inundation simulation.

Main research question	*How can the resilience of critical infrastructure networks of urbanized delta areas be related to the spatial distribution of its networks assets, with respect to the event of coastal and fluvial flooding?*

The answer to the main research question is based on the answers of the sub-research questions. Additionally the answer to the main research question is substantiated by the experience of the entire research process; therefore there is feedback on the methodology and the extent to which it as compatible of enabling the answer to the main research question.

Hypotheses are formulated on basis of the results. These hypotheses can be found in Chapter 9. Hence, no hypotheses will be assessed throughout this research. On basis of the research results hypotheses are formulated. These will lead to recommendations for further research.

Christa and Salomon Raymond Fils
Decade Village.
Haiti
September 2008
Photo by Gideon Mendel

4 The case models

This chapter outlines the result from the case analyses; the case models. First the cross comparison of the case models is outlined (§4.1). Second, the modifications of the case models into alternatives is outlined (§4.2), in which the current situation of the critical infrastructure networks in the case areas is considered as the 0-alternative.
The case reports, the case analysis and the extensive case analysis can be found in the annexed Atlas of Mapping Resilience.

4.1 Cross comparison of the case models

In this paragraph an overview of the data the two cases is given. Figure 15, Figure 16, Figure 17 and Figure 18 present an overview the two cases on the same scale, by means of is aerial photos and the case models of In Table 3 the general information of the two cases is summarized.

In the figures below the ration between the two scales of the case areas is visualised. The area of Dordrecht is smaller than the area in Ho Chi Minh City. In the left image, the cases are displayed as aerial photographs. In the right image, the cases are shown as models.

In Appendix B the process of developing the maps of the case models is demonstrated.

Ho Chi Minh City	Dordrecht

Figure 15 - Aerial photo Ho Chi Min City scale 1:50.000

Figure 16 - Aerial photo Dordrecht scale 1:50.000

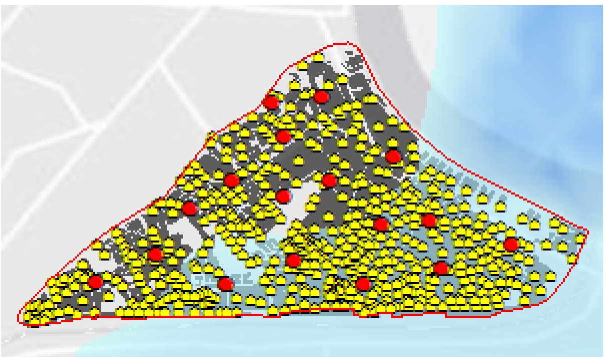


Figure 17 - Case model Ho Chi Minh City scale 1:50.000

Figure 18 - Case model Dordrecht scale 1:50.000

Table 3 - Data overview of Ho Chi Minh City and Dordrecht

Data	Ho Chi Minh City	Dordrecht
Surface (km2)	3.545	0.959
Population (amount of people)	219000	7319
Population density (people/ km2)	61768	1310
GSI	2.646	0.404
FSI	1.557	0.898
Amount of electricity network assets	580	16
Amount of electricity network capacity	29000	4594
Amount of healthcare network assets	17	4
Amount of healthcare network capacity	198	8
Amount of households	29000	4594
Amount of footprints	15487	2067
Probability of flooding	1/100	1/2000

Figure 19 and Figure 20 illustrate the repeating pattern of the flooding is visualised over time per case area based on the probability of the simulated flood. On the x-axis the timeline is outlined. On the y-axis the occurrence of flooding is visualised. This pattern is visualised for 5000 years. In Ho Chi Minh City the flood will occur each 100 years. In Dordrecht the flood will occur each 2000 years.

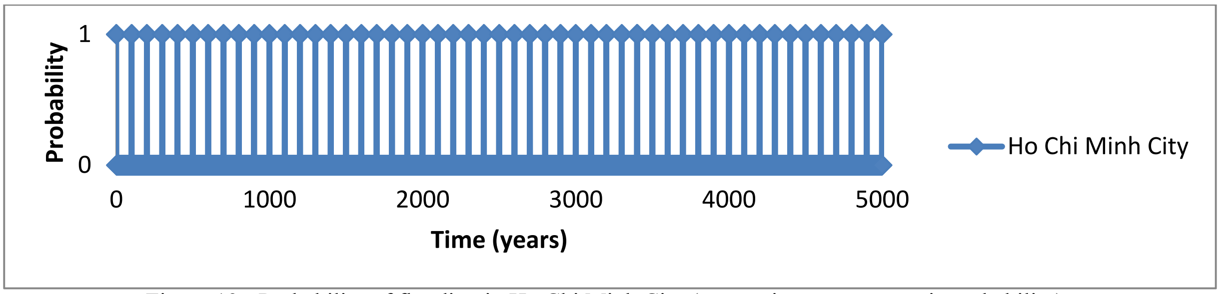


Figure 19 - Probability of flooding in Ho Chi Minh City (on x-axis years, on y-axis probability)

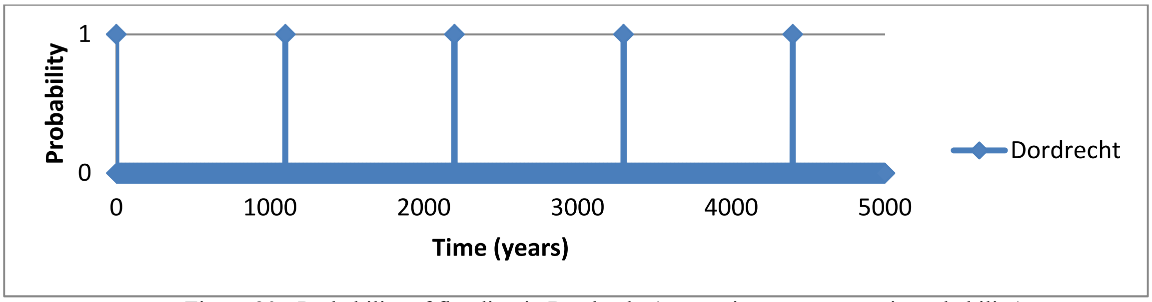


Figure 20 - Probability of flooding in Dordrecht (on x-axis years, on y-axis probability)

Conclusion on cross case comparison

On basis of the cross case comparison the following conclusions are drawn:

- There is a difference in scale between the two case areas, Ho Chi Minh City has a larger scale than Dordrecht
- In Ho Chi Minh City is a relatively higher density of healthcare assets than in Dordrecht;
- In Ho Chi Minh City is a relatively higher density of electricity assets than in Dordrecht;
- The position of the all healthcare assets in Dordrecht is located in the flood prone area
- The probability of flooding is higher in Ho Chi Minh City than in Dordrecht

4.2 Alternatives

In the section the alternatives of the critical infrastructure networks in the cases are outlined, in which the current situation of the critical infrastructure networks in the case are considered as the 0-alternative. The 1-, 2-, 3-alternatives are variations on the 0-alternative.
These alternatives are based on the measures of the ClimateApp, more specifically the alternatives are selected from the climate adaptation measures to coastal and fluvial flooding outlined in the ClimateApp. The ClimateApp is developed by, inter alia, Witteveen+Bos and helps gives engineers insight in feasible measures for a project with a climate adaptation goal (Grontmij, Slabbers, Deltares, Witteveen+Bos, & KNMI, 2015).

Besides the 0-alternative, three alternatives are assessed per critical infrastructure network. In Table 4 the overview of the alternatives per critical infrastructure network is presented, the main characteristics and the amount of assets and the capacity of the network are given. Subsequently the alternatives are outlined. The effects of the measurements of each alternative on the cascade-effect impact schemes are presented in Section 5.2. An overview of all the data per alternative can be found in the annexed Atlas of Mapping Resilience.

- The 1-alternative is characterised by its focus on the level of the households.
- The 2-alternative is characterised by its focus on the level of the existing network assets.
- The 3-alternative is characterised by its focus on one single asset to replace the existing network assets.

Note: for the electricity network a distinction was made for the 1-alternative into three sub-alternatives. With these three sub-alternatives it is possible to analyse different options of flood proofing on the level of the households. For the 2-, and 3-alternative no distinction was made into sub-alternatives.

The 0-alternative of the healthcare network

In general the 0-alternative of the healthcare networks concerns the current actual situation in the case areas. The simulations are outlined in Paragraph 4.2. A short overview of the assets and capacity is summarized in Table 4.

Specific in case 1, Ho Chi Minh City, this alternative represents the actual distribution of assets of the healthcare network in the case area. The network consists of 17 locations, of which 15 general practices and 2 hospitals with larger capacities. In the event of flooding 7 of the 17 locations will inundate, 80 of the 198 available beds will become unavailable. Specific in case 2, Dordrecht, this alternative represents the actual distribution of assets of the healthcare network in the case area. The network consists of 4 locations. All 4 locations are general practices with each 2 beds available. In the event of flooding all four locations will inundate, all 8 beds will become unavailable.

The 1-alternative for the healthcare network: survival kits per household

In general, the 1-alternatives concern the increase of network assets as each household is provided with a survival kit. The kit consists of first aid equipment and a stock of food and drink. It is assumed that in the event of flooding people can directly use the survival kits. It is assumed that the survival kit can help 60% of all the disordered persons; therefore 40% of the affected inhabitants are included in the calculations for damage. During the flooding event each generator will function as one asset.

Specific in Ho Chi Minh City, the network consists of 29198 assets as each household has one survival kit, besides the 198 beds in the general practices and hospitals outlined in the 0-alternative. Specific in Dordrecht, the network consists of 4602 assets as each household has one survival kit, besides the 8 beds in the general practices outlined in the 0-alternative.

Table 4 - Overview of the assets and capacity of the alternatives

Healthcare network				
	Alternatives		**Ho Chi Minh City**	**Dordrecht**
0	The current situation	Assets	18	4
		Capacity	198	8
1	Survival kit per household	Assets	29018	4598
		Capacity	29198	4594
2	Flood proofing assets	Assets	18	4
		Capacity	198	8
3	One central shelter	Assets	19	5
		Capacity	396	16

Electricity network				
	Alternatives		**Ho Chi Minh City**	**Dordrecht**
0	The current situation	Assets	580	16
		Capacity	29000	4594
1a	Generator per household	Assets	29580	4610
		Capacity	29000	4594
1b	Solar panels per household	Assets	29580	4610
		Capacity	29000	4594
1c	Flood proofing households	Assets	580	16
		Capacity	29000	4594
2	Flood proofing assets	Assets	580	16
		Capacity	29000	4594
3	One central asset	Assets	1	1
		Capacity	29000	4594

The 2-alternative for the healthcare network: waterproofing the network assets
In general, the 2-alternative concerns protection of the existing locations, as identified in the 0-alternative, against the inundation prior to the event of flooding. Therefore all the general practices and hospitals in the case area are closed before the inundation. It is assumed that per location it takes an average of 4 hours to close and flood-proof one location. During the inundation all the location are closed and cannot be accessed for medical help. It is assumed that per location it takes an average of 4 hours to reopen the location. It is assumed that after the flood and reopening of a location, it can be exploited directly in its full capacity.

Specific in Ho Chi Minh City all the 17 locations are protected against inundation, by flood-proofing them prior to the inundation. Specific in Dordrecht all the 4 locations are protected against inundation.

The 3-alternative for the healthcare network: one central asset
In general the 3-alternative concerns the commissioning of one temporary central emergency shelter, besides the existing locations as identified in the 0-alternative, that is put into use on the moment that the inundation starts and is closed on the moment that the network is recovered. The shelter is located on a flood proof location. The shelter provides an added hundred per cent capacity of the network; therefore the potential capacity of the 0-alternative is doubled in the event of flooding.

Specific in Ho Chi Minh City this temporary emergency shelter provides an added capacity of 198 beds. The shelter is closed when all the 7 inundated locations are restored. Specific in Dordrecht this temporary emergency shelter provides an added capacity of 8 beds. The shelter is closed when all the 4 inundated locations are restored.

The 0-alternative of the electricity network
In general the 0-alternative of the electricity network concerns the current actual situations in the case areas. The simulations are outlined in Paragraph 4.2. A short overview of the assets and capacity is summarized in Table 4.

Specific in Ho Chi Minh City the network consists of 580 transformers that distribute electricity to the household footprints; via the household footprints the electricity is distributed to the floor of the footprint building. In the event of flooding 269 of the 580 will inundate, 13456 of the 29900 households will not have electricity. Specific in Dordrecht the network consists of 16 transformers that distribute electricity to the household footprints; via the household footprints the electricity is distributed to the floor of the footprint building. In the event of flooding 11 of the 16 transformers will inundate, 3736 of the 4594 households will not have electricity.

The 1a-alternative for the healthcare network: emergency power generator per household
In general the 1a-alternative concerns the increase of network assets as each household is provided with an emergency power generator. It is assumed that in the event of flooding people can directly use the generator. During the flooding event each generator will function as one asset. The households that are non-inundated but connected to an inundated transformer can produce their own electricity for the duration of eight hours in total as they are in possession of 4.5 litre fuel.

Specific in Ho Chi Minh City the network consists of 29580 assets as each household has one generator, besides the 580 transformers outlined in the 0-alternative. In the event of flooding 13456 of the 29000 households, due to their own inundation and their connection to an inundated transformer, the use electricity is unavailable. Specific in Dordrecht the network consists of 4610 assets as each household has one generator, besides the 16 transformers outlined in the 0-alternative. In the event of flooding 3736 of the 4594 households, due to their own inundation and their connection to an inundated transformer, the use electricity is unavailable.

The 1b-alternative for the healthcare network: solar panels per household
In general the 1b-alternative concerns the increase of network assets, as each household is equipped with its own solar panels to transfer energy from solar radiation to electricity. The connection of the solar panels and the households is located on the floor of the household itself, therefore as the ground floor of a footprint is inundated, the upper floors can still receive electricity from its solar panels.

Specific in Ho Chi Minh City the network consists of 29580 assets as each household has solar panels, besides the 580 transformers outlined in the 0-alternative. In the event of flooding 7186 of the 29000 households will have no access to electricity as their connection to their solar panels will inundate. 269 of the 580 transformers will inundate, this has no effect on the non-inundated households as they have access to their own electricity supply, the solar panels. Specific in Dordrecht the network consists of 4610 assets as each household has solar panels, besides the 16 transformers outlined in the 0-alternative. In the event of flooding 1683 of the 4594 households will have no access to electricity as their connection to their solar panels will inundate. 11 of the 16 transformers will inundate, this has no effect on the non-inundated households as they have access to their own electricity supply, the solar panels.

The 1c-alternative for the healthcare network: flood proofing the interior per household
In general the 1b-alternative concerns protection of the electricity network on a household level, as all the households are made flood proof by placing all jacks of the network and apparatus above the maximum inundation height.

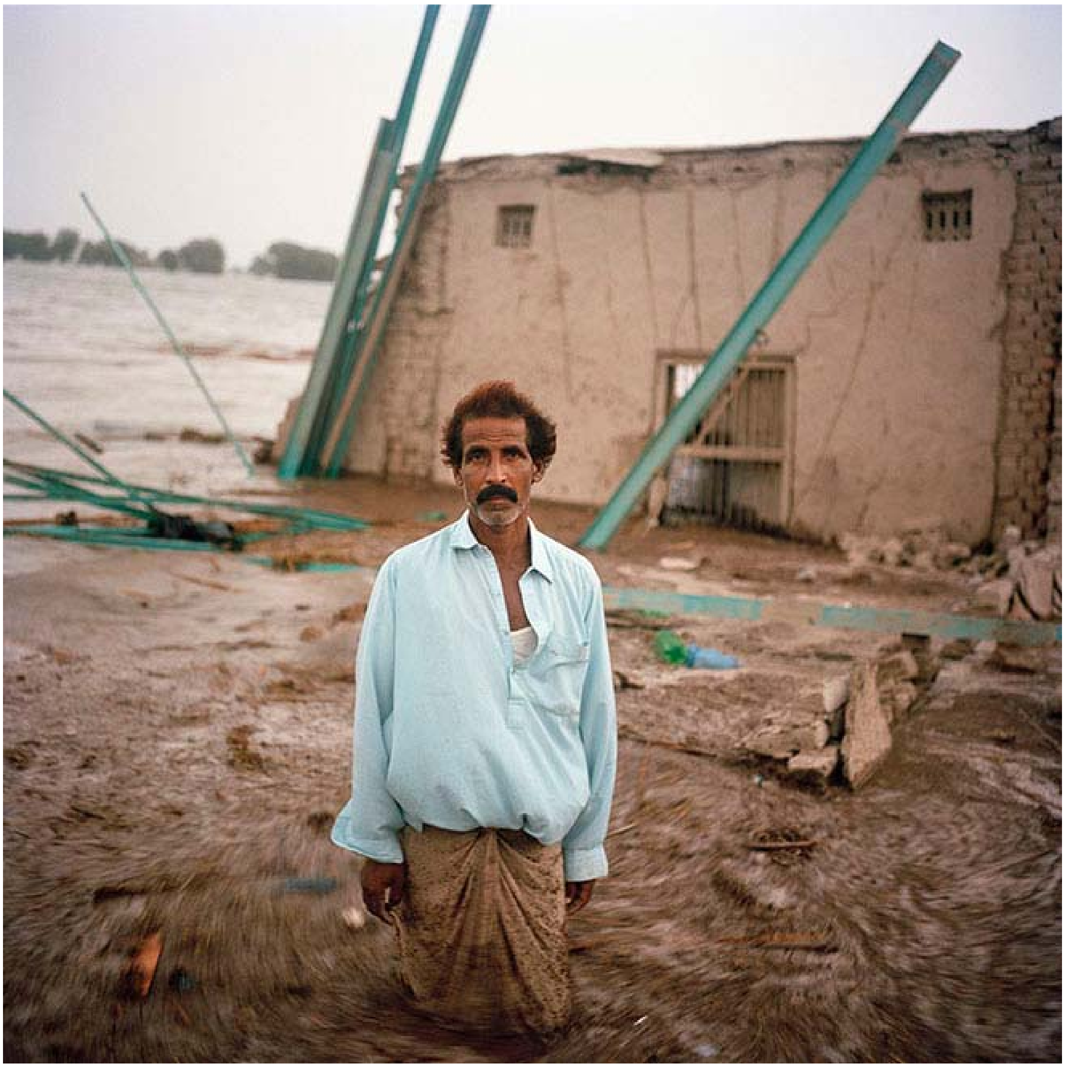
Specific in Ho Chi Minh City the network consists of 580 assets as outlined in the 0-alternative. In the event of flooding none of the households' connection to the electricity network will inundate. However, 269 of the 580 transformers that distribute electricity to the houses inundate. Specific in Dordrecht the network consists of 16 assets as outlined in the 0-alternative. In the event of flooding, none of the households' connection to the electricity network will inundate. However, 11 of the 16 transformers that distribute electricity to the houses inundate.

The 2-alternative for the healthcare network: waterproofing the network assets
In general the 2-alternative concerns the protection of all the transformers in the case area against inundation. In the event of flooding, when the inundation level reaches the height of the transformer or higher, the transformer will not be affected by the water and can maintain to function.

Specific in Ho Chi Minh City all the 269 transformers subject to flooding are protected against inundation. Specific in Dordrecht all the 11 transformers subject to flooding are protected against inundation.

The 3-alternative for the healthcare network: one central asset
In general the 3-alternative for the electricity network concerns the replacement of all existing transformers by one central transformer that distributes electricity to all households. The central transformer is located on a flood proof location. In the event of flooding the transformer will not inundate, the transformer will maintain to supply electricity to all households that are non-inundated.

Specific in Ho Chi Minh City this central asset provides to all 21814 non-inundated households. Specific in Dordrecht this central asset provides to all 2911 non-inundated households.



JHaji Sharif
Kando Khan Bozdar Village
Sindh
Pakistan
September 2010
Photo by Gideon Mendel

5 The cascade-effect impact schemes

This chapter presents the calculations of the resilience indicator damage. This chapter presents the damages calculations based on the flood simulations presented in Chapter 4, calculated by means of the cascade-effect impact schemes.

The cascade-effect impact schemes are developed throughout the research project. The development of this scheme is outlined (§5.1). The use of the cascade-effect impact schemes is demonstrated on two alternatives (§5.2). The values of the indicators that are used throughout the calculations of damage and recovery duration are substantiated (§5.3). Finally, an overview is given of the data output and how these are translated into the cost-benefit analysis (§5.4).

In the annexed “Atlas of Mapping Resilience” the damage calculations of all alternatives according to the cascade-effect impact schemes are documented.

5.1 The development of the cascade-effect impact schemes

The use of the cascade-effect impact schemes is twofold. Firstly, it creates an understanding of the extent of the effects. Secondly, it is possible to calculate the damage vase on the direct and indirect effects.

The schemes, designed throughout this research project, enable to visualize the relation between a flooding event and its impact. The process of calculating the impact is made transparent through mapping the cascade-effects; these are the direct and indirect effects, and their valuation on basis of amount, damage and duration.

The cascade-effect impact schemes are based on brainstorm sessions with engineers from Witteveen+Bos. The data from the brainstorm sessions is structured to one scheme per network. The schemes are validated by three experts that are active in the networks and have professional knowledge. The process of the development of the cascade-effect impact schemes is outlined in Appendix C.

Table 5 - The conceptual framework of the cascade-effect impact scheme structure

Diverging					Converging				
	Order effect						Assessment of impact		
Classification	1st	2nd	3rd	4th	Classification	Affected object (#)	Duration (t)	Value damage (€)	Damage (#t€)
People					People				
Metabolism					Prod.-con.				
Public space					Objects				
Buildings									
Infrastructure									
Surface									
								Total damage (€)	

In Table 5 the composition of the cascade-effect impact schemes is visualised. The composition is based on four components:

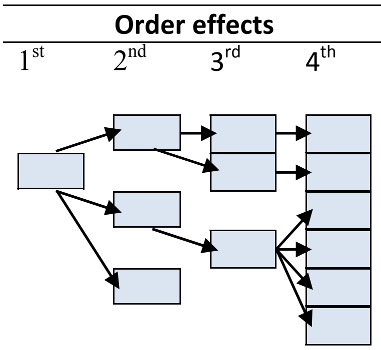
1. The distinction between diverging and converging in the reproduction of reality. By diverging, by mapping the direct and indirect effects of the flood on the network, it is possible to render the reality as precise as possible. By converging, by valuating the effects, it is possible quantify the effects of the flood on the network in monetary terms.
2. The sequence of the effects on the horizontal axis, in the diverging part of the scheme.

3. The valuation of the impact on the horizontal axis, in the converging part of the scheme. The amount of affected objects, the duration of the disturbance per object and the value of damage per object determine the total damage to the network.
4. The distribution of the effects on the vertical axis. In the diverging part this is based on the structure that is maintained in the UCF; people, metabolism, buildings, public space, infrastructure, subsurface. In the converging part this is based on the structure that is maintained in the PPO; people, production-consumption, objects.

5.2 Demonstration of the cascade-effect impact schemes

First the concept of the cascade-effect impact schemes is illustrated by means of example, in order to show how the schemes are used throughout the process to evaluate all alternatives. Second, the cascade-effect impact schemes are demonstrated on two alternatives of the electricity network in Ho Chi Minh City.

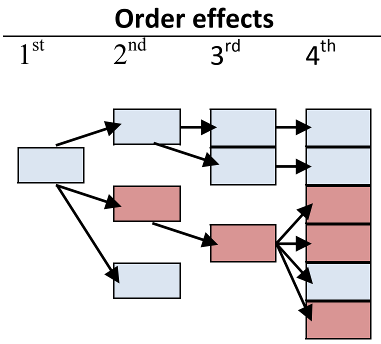
In Figure 21 the application of the cascade-effect impact schemes (CEIS) is illustrated. For the 0-alternative, the current situation of a network, all order effects are included in the calculation of the total damage, resulting in a value of 2,385,000.



Quantification effect			
Affected objects	Duration	Damage indicator	Damage
10	10	50	5,000
1000	200	10	2,000,000
20	100	200	100,000
50	50	100	250,000
10	200	10	20,000
1	500	20	10,000
		Total damage	**2,385,000**

Figure 21 - The application of the CEIS to quantify the damage value

In Figure 22 the implementation of an alternative is illustrated. When implementing an alternative, it is possible to exclude possible effects of the flood on the network. In Figure 22 this is illustrated by the red boxes. For the 1-alternative, a modification of the same network, the damaged is reduced to 2,075,000.



Quantification effect			
Affected objects	Duration	Damage indicator	Damage
10	10	50	5,000
1000	200	10	2,000,000
10	200	10	20,000
		Total damage	**2,075,000**

Figure 22 - The application of the CEIS to visualise the impact of an alternative on the damage value

The use of the cascade-effect is demonstrated on two alternatives of the electricity network in Ho Chi Minh City, the current situation and the alternative in which each household has an emergency power generator.

In Figure 23 the diverging part of the cascade-effect impact schemes is worked out for the 0-alternative in the case of the electricity network in Ho Chi Minh City. In Figure 24 the converging part of the cascade-effect impact schemes is elaborated for this alternative.

In Figure 25 the diverging part of the cascade-effect impact schemes is worked out for the 1a-alternative in the case of the electricity network in Ho Chi Minh City. In Figure 26 the converging part of the cascade-effect impact schemes is worked out for this alternative.

In Figure 23 and Figure 25 the first, second, third and fourth effects of the flood on the network are visualized. The development of this scheme is outlined in Appendix C. Figure 24 and Figure 26 the valuation of the effects is outlined, this is done on the basis of data from the flood simulations. On this basis the flood simulation the amount of the affected assets is determined. The indicators for the valuation of damage are based on literature, an overview of these indicators can be found in Appendix E.

In Appendix D the cascade-effect impact schemes of all alternatives are outlined. In the annexed Atlas of Mapping Resilience the damage calculations on basis of the cascade-effect impact schemes of all alternatives are outlined per alternative.

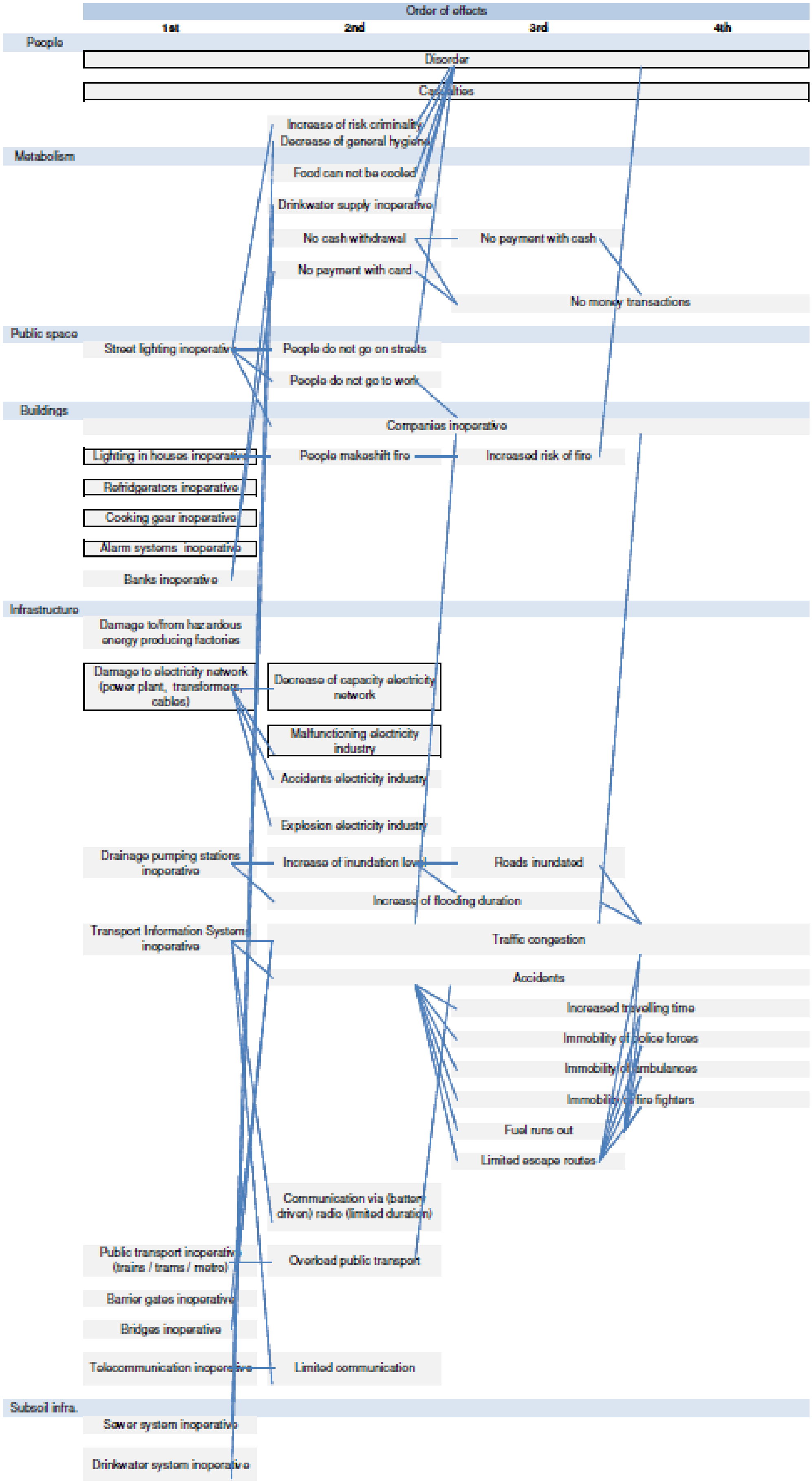


Figure 23 - Demonstration of CEIS for 0-alternative of the electricity network in Ho Chi Minh City; diverging

		Affected object		Duration	Value damage		Damage
People							
Casualties	543	Persons			7000.00	€	€ (3,798,651.36)
Disordered	2713	Persons	898	Hours	0.44	€/hour	€ (1,066,293.31)
Consumption							
Unconsumed electricity	6277	Households	1797	Hours	2.95	€/hour	€ (33,315,488.58)
Unconsumed electricity	909	Services	1797	Hours	14.18	€/hour	€ (23,171,262.26)
Objects							
Repair transformer	269	Transformers			250.00	€/unit	€ (67,250.00)
Repair house/service	7186	Households/services			50.00	€/unit	€ (359,298.40)
Total							**€ (61,778,243.91)**

Figure 24 - Demonstration of CEIS for 0-alternative of the electricity network in Ho Chi Minh City; converging

In the annexed "Atlas of Mapping Resilience" the damage calculations of all alternatives according to the cascade-effect impact schemes are documented.

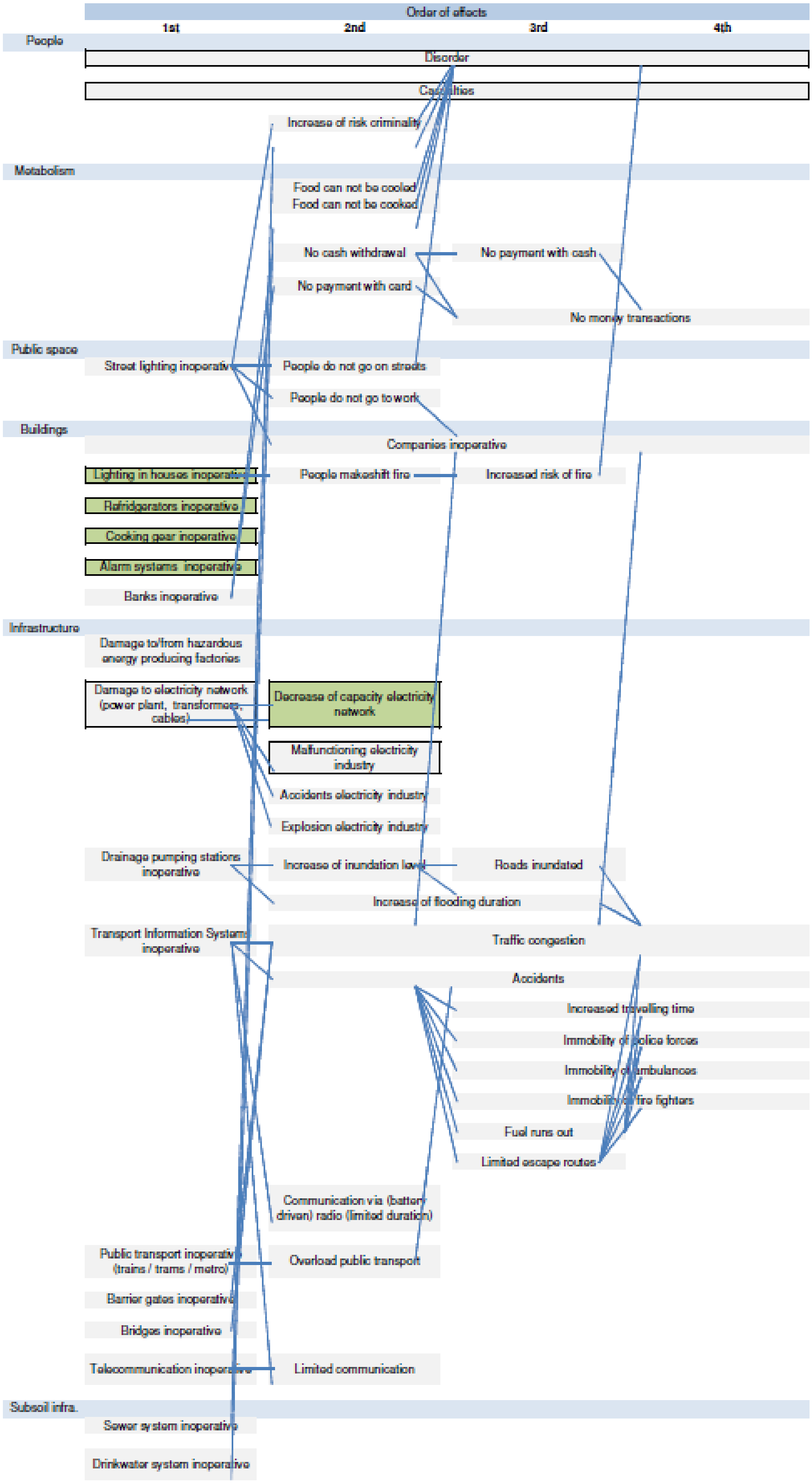


Figure 25 - Demonstration of CEIS for 1a-alternative in electricity network; diverging

	Affected object		Duration		Value damage		Damage
People							
Casualties	2190	Persons			-7000.00	€	€ (15,330,00.00)
Disordered	2713	Persons	890	Hours	-0.44	€/hour	€ (1,056,796.68)
Consumption							
Unconsumed electricity	6277	Households	1797	Hours	-2.95	€/hour	€ (33,315,488.58)
Unconsumed electricity	909	Services	797	Hours	-14.18	€/hour	€ (23,171,262.26)
Objects							
Repair transformer	269	Transformer			-250.00	€/unit	€ (67,250.00)
Repair house/service	7186	Footprints			-50.00	€/unit	€ (359,298.40)
Total							**€ (73,300,095.92**

Figure 26 - Demonstration of CEIS for 1a-alternative of the electricity network in Ho Chi Minh City; converging

In the annexed “Atlas of Mapping Resilience” the damage calculations of all alternatives according to the cascade-effect impact schemes are documented.

5.3 Substantiation for indicators

The indicators that are used for the damage calculations and recovery duration are based on the experience of experts, literature and common knowledge. An overview of the damage indicators can be found in Appendix E.

The following indicators for the recovery duration need further clarification:

- The amount of casualties
- The amount of disordered persons
- The duration of disruption of persons
- The duration of expenses of practices and unconsumed electricity
- The duration of the recovery of assets

The amount of casualties is based on the assumption that one per cent of the affected person is dependent on the network and will eventually not survive. This results in the calculation amount of affected persons by measuring the percentage of flooded area with respect to the total case area. This percentage of flooded area is also the percentage of population that is affected by the flood. One per cent of this percentage is the amount of casualties.

The amount of disordered persons is based on the assumption that five per cent of the affected persons is dependent on the service of the network. Therefore five per cent of the affected persons is disturbed by the malfunctioning of the network. This results in the calculation amount of affected persons by measuring the percentage of flooded area with respect to the total case area. This percentage of flooded area is also the percentage of population that is affected by the flood. Five per cent of this percentage is the amount of casualties.

The duration of disruption of persons is dependent on the duration of the recovery of the network assets, to which the disrupted persons are dependent. This results in the calculation of duration of the recovery of the network assets. The duration of disruption of persons is based on the average amount of recovery duration of recovery of the networks assets. This duration is multiplied with the factor 0.5 as the difference between network dependencies differs between day and night time. During daytime, in general less or no electricity for lightning is needed. During night time, electricity for lighting and heating is needed.

The duration of expenses of general practices or hospital and unconsumed electricity is based on the average duration of the recovery of the networks assets.

The duration of the recovery of assets is based on the amount of affected assets and the average recovery duration.

The presence of assumptions in the calculation in the abovementioned indicators results in uncertainty in the results of this research. To investigate this uncertainty and its effect on the results of this study, a sensitivity analysis will be performed. This is described in Section 7.5.

5.4 Data from the cascade-effect impact schemes

The data derived from the cascade-effect impact schemes that are valuable to map resilience are the damage values. In the subsequent sections the values are outlined with substantiating information. First the damage values are presented, which are one of the four resilience indicators. The damage values are split into the direct and indirect damage. The damage value is converted to the risk value, by means of the risk formula and the flood probability and discount rate. The cost-benefit analysis is performed, to demonstrate which alternatives are feasible.

Damage

In Table 6 the values for damage, direct damage, indirect damage and the ratio between the direct and indirect damage are summarized. The damage can be divided into direct and indirect damage. The direct damage is caused by the direct effects of the flood, including damage to assets and casualties. The indirect damage is caused by the indirect effects of the flood, including the disorder of inhabitants and expenses of services and inhabitants due to failure of the network.

Table 6 - Values for the direct and indirect damages per alternative

Healthcare network Ho Chi Minh City

Alternatives		Damage (€)	Direct (€)	Indirect (€)	Diret:indiret
0	The current situation	4,095,000	3,800,000	290,000	380:29
1	Survival kit per household	5,284,000	3,800,000	1,930,000	380:193
2	Flood proofing assets	3,925,000	3,800,000	120,000	95:3
3	One temporary shelter	3,890,000	3,800,000	85,000	760:17

Healthcare network Dordrecht

Alternatives		Damage (€)	Direct (€)	Indirect (€)	Direct:indirect
0	The current situation	122,439,000	112,420,000	1,870,000	1022:17
1	Survival kit per household	121,714,000	112,420,000	5,030,000	11242:503
2	Flood proofing assets	113,120,000	112,400,000	780,000	5620:39
3	Oe temporary shelter	113,105,000	112,420,000	530,000	11242:53

Electricity network Ho Chi Minh City

Alternatives		Damage (€)	Direct (€)	Indirect (€)	Direct:indirect
0	The current situation	61,778,000	4,230,000	57,550,000	423:5755
1a	Generator per household	73,300,000	15,760,000	57,540,000	788:2877
1b	Solar panels	72,635,000	15,760,000	56,880,000	197:711
1c	Flood proofing households	38,759,000	15,760,000	23,000,000	394:575
2	Flood proofing assets	72,883,000	15,330,000	57,550,000	1533:5755
3	One central asset	72,883,000	15,330,000	57,550,000	1533:5755

Electricity network Dordrecht

Alternatives		Damage (€)	Direct (€)	Indirect (€)	Direct:indirect
0	The current situation	43,611,000	17,100,000	26,510,000	1710:2651
1a	Generator per household	43,612,000	17,100,000	26,510,000	1710:2651
1b	Solar panels	70,780,000	47,480,000	23,300,000	2374:1165
1c	Flood proofing households	102,656,000	47,480,000	55,180,000	2374:2759
2	Flood proofing assets	38,881,000	17,010,000	21,870,000	7:9
3	One central asset	38,881,000	17,010,000	21,870,000	7:9

Damage to risk

In order to assess the cost-benefit analysis for the implementation of the alternatives, the costs are defined on basis of the risk of flooding. The general formula for risk calculation, outlined below, is used to determine the risk of the flood for the networks in the case areas.

$$risk = \frac{probability \times impact}{discount\ factor}$$

To apply this formula on the data output from the cascade-effect impact schemes, the impact is defined as the damage value resulting from the cascade-effect impact schemes

In Table 7 the data for the risk calculations are summarized. The probability of the simulated flooding in Ho Chi Minh City is 1/100. The probability for the simulated flooding in Dordrecht is 1/2000. The damage value is the data output from the cascade-effect impact schemes and differs per alternative. The discount factor for Ho Chi Minh City is estimated at 0.10/year (Van Gelder, 2000). The discount factor for Dordrecht is estimated at 0.02/year (Van Gelder, 2000).

Table 7 - Conversion from damage value to risk value

Healthcare network Ho Chi Minh City

Alternatives		Damage (€)	Probability	Discount factor	Risk (€)
0	The current situation	4,095,000	1/100	0.10	410,000
1	Survival kit per household	5,284,000	1/100	0.10	528,000
2	Flood proofing assets	3,925,000	1/100	0.10	392,000
3	One temporary shelter	3,890,000	1/100	0.10	389,000

Healthcare network Dordrecht

Alternatives		Damage (€)	Probability	Discount factor	Risk (€)
0	The current situation	122,439,000	1/2000	0.02	3,061,000
1	Survival kit per household	121,714,000	1/2000	0.02	3,043,000
2	Flood proofing assets	113,120,000	1/2000	0.02	2,828,000
3	One temporary shelter	113,105,000	1/2000	0.02	2,828,000

Electricity network Ho Chi Minh City

Alternatives		Damage (€)	Probability	Discount factor	Risk (€)
0	The current situation	61,778,000	1/100	0.10	6,178,000
1a	Generator per household	73,300,000	1/100	0.10	7,330,000
1b	Solar panels	72,635,000	1/100	0.10	7,263,000
1c	Flood proofing households	38,759,000	1/100	0.10	3,876,000
2	Flood proofing assets	72,883,000	1/100	0.10	7,288,000
3	One central asset	72,883,000	1/100	0.10	7,288,000

Electricity network Dordrecht

Alternatives		Damage (€)	Probability	Discount factor	Risk (€)
0	The current situation	43,611,000	1/2000	0.02	1,090,000
1a	Generator per household	43,612,000	1/2000	0.02	1,090,000
1b	Solar panels	70,780,000	1/2000	0.02	1,769,000
1c	Flood proofing households	102,656,000	1/2000	0.02	2,566,000
2	Flood proofing assets	38,881,000	1/2000	0.02	972,000
3	One central asset	38,881,000	1/2000	0.02	972,000

Cost-benefit analysis

On basis of the costs and benefits of the implementation of the alternatives it is possible to perform a cost-benefit analysis. This cost-benefits analysis demonstrates which alternatives are feasible.

In Table 8 the risk values, investments costs, benefits and cost-benefit ratio are summarized. The risk values are based on the damage values derived from the effects mapped in the cascade-effect impact schemes. The values for investment costs are based on the costs for the implementation of the alternative. The cost values are substantiated on the next page. The benefit values are based on the damage of the alternative relative to the 0-alternative; this indicates the prevented damage. The values for cost-benefit are based on the sum of the costs and the benefits. The feasible alternatives are coloured green; the non-feasible alternatives are coloured red.

On basis of this analysis it can be concluded that for the healthcare network in both Ho Chi Minh City and Dordrecht the 2- and 3-alternatives are feasible. For the electricity network in Ho Chi Minh City only the alternative in which the houses are flood proofed is feasible. For the electricity network in Dordrecht only the alternative in which the assets are flood proofed is feasible.

Table 8 - Data output of the resilience indicator damage from cascade-effect impact schemes

Healthcare network Ho Chi Minh City

Alternatives		Risk (€)	Cost (€)	Benefit (€)	Cost - benefit (€)
0	The current situation	410,000	-	-	-
1	Survival kit per household	528,000	44,000	-118,900	-162,900
2	Flood proofing assets	392,000	4,000	17,000	13,000
3	One temporary shelter	389,000	3,000	20,500	17,500

Healthcare networkDordrecht

Alternatives		Risk (€)	Cost (€)	Benefit (€)	Cost - benefit (€)
0	The current situation	3,061,000	-	-	-
1	Survival kit per household	3,042,850	493,000	18,000	-475,000
2	Flood proofing assets	2,828,000	10,000	233,000	223,000
3	One temporary shelter	2,827,625	100,000	233,000	133,000

Electricity network Ho Chi Minh City

Alternatives		Risk (€)	Cost (€)	Benefit (€)	Cost - benefit (€)
0	The current situation	6,178,000	-	-	-
1a	Generator per household	7,330,000	€314,000	-1,152,000	-1,466,000
1b	Solar panels	7,263,000	3,970,000	-1,086,000	-5,056,000
1c	Flood proofing household	3,876,000	€387,000	-2,302,000	1,915,000
2	Flood proofing assets	7,288,000	13,000	-1,110,000	-1,123,000
3	One central asset	7,288,000	988,000	-1,110,000	-2,098,000

Electricity network Dordrecht

Alternatives		Risk (€)	Cost (€)	Benefit (€)	Cost - benefit (€)
0	The current situation	1,090,000	-	-	-
1a	Generator per household	1,090,000	1,265,000	-25	-1,265,000
1b	Solar panels	1,769,000	16,536,000	-679,225	-17,215,000
1c	Flood proofing household	2,566,000	20,670,000	-1,476,125	-22,146,000
2	Flood proofing assets	972,000	22,000	118,250	96,000
3	One central asset	972,000	5,967,000	118,250	-5,849,000

The values for investment costs are based on the costs for the implementation of the alternative relative to the 0-alternative; therefore this indicates the costs of changing from the 0-alternative to the implemented alternative. Substantiation for estimations made for the investment costs are documented in Appendix E.

- **The current situation of the healthcare network (0-alternative)**
  No investment costs are made, as the current situation is modeled without adjustments.
- **The survival kits per household for the healthcare network (1-alternative)**
  In Ho Chi Minh City the investment costs for the implementation of this alternative are €44,000 based on the assumption that one survival kit in Vietnam costs €1.50. In Dordrecht the investment costs for the implementation are €439,000 based on the assumption that one survival kit in the Netherlands costs €60.
- **The waterproofing the network assets of the healthcare network (2-alternative)**
  In Ho Chi Minh City the investment costs for the implementation of this alternative consist of three values: the costs for the practices to be out of service, the costs for the material to waterproof the assets and the costs of manpower to waterproof the assets. In total these costs are €4,000. In Dordrecht the investment costs for the implementation consist of three values: the costs for the practices to be out of service, the costs for the material to waterproof the assets and the costs of manpower to waterproof the assets. In total these costs are €21,000.
- **One central asset for the healthcare network (3-alternative)**
  In Ho Chi Minh City the investment costs for the implementation of this alternative are estimated at €3,000. In Dordrecht the investment costs for the implementation are estimated at €100,000. These are estimations substantiated by the data in Appendix E.
- **The current situation of the electricity network (0-alternative)**
  No investment costs are made, as the current situation is modeled without adjustments.
- **The emergency power generator per household for the electricity network (1a-alternative)**
  In Ho Chi Minh City the investment costs for the implementation of this alternative are €314,000 based on the assumption that a generator in Vietnam costs €20 and fuel costs €0.04/litre. In Dordrecht the investment costs for the implementation are €1,265,000 based on the assumption that a generator in the Netherlands costs €600 and fuel costs €1.59/litre
- **The solar panels per household for the electricity network (1b-alternative)**
  In Ho Chi Minh City the investment costs for the implementation of this alternative are €3,097,000, based on the assumption that installing one solar panel costs €150 per household. In Dordrecht the investment costs for the implementation are €16,536,000, based on the assumption that one solar panel costs €6,000 per household.
- **The flood proofing the interior per household for the electricity network (1c-alternative)**
  In Ho Chi Minh City the investment costs for the implementation of this alternative are €387,000, based on the assumption that flood proofing the interior of households costs €20 per household. In Dordrecht the investment costs for the implementation are €20,670,000, based on the assumption that flood proofing the interior of households costs €800 per household.
- **The waterproofing the network assets for the electricity network (2-alternative)**
  In Ho Chi Minh City the investment costs for the implementation of this alternative are €13,000, based on the assumption that flood proofing of transformers costs €50 per asset. In Dordrecht the investment costs for the implementation are €22,000, based on the assumption that flood proofing of transformers costs €2000 per asset.
- **One central asset for the electricity network (3-alternative)**
  In Ho Chi Minh City the investment costs for the implementation of this alternative are estimated at €988,000. In Dordrecht the investment costs for the implementation are estimated at €5,967,000. These are estimations substantiated by the data in Appendix E.

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Photo by Gideon Mendel

6 Network capacity

This chapter presents the calculations of the three resilience indicators capacity at the moment of flooding, the capacity throughout the recovery process, the recovery duration. The calculations are based on the damage values of Chapter 5. The data output of this chapter consists of the three resilience indicators capacity at the moment of flooding, the capacity throughout the recovery process, the recovery duration.

First the capacity calculations are demonstrated for two alternatives (§6.1). Finally, an overview is given of the data output and how these are translated into results (§6.2).

In the annexed "Atlas of Mapping Resilience" the capacity calculations of all alternatives are documented.

6.1 Demonstration of capacity calculations on two alternatives

In this section the calculation of the networks capacity over time are demonstrated to two alternatives, in order to show how the schemes are used throughout the process to evaluate all alternatives. The two alternatives are the 0-alternative and the 1-alternative of the healthcare network in Ho Chi Minh City. In The annexed Atlas of Mapping Resilience the capacity calculations of all alternatives are outlined.

The data derived from the cascade-effect impact schemes in Chapter 5 provide the amount of damaged assets and the duration of the recovery process. With this data the capacity of the network over time can be calculated, this capacity indicates in which extent the network is able to maintain functioning during the disturbance. The capacity of the network is mapped between the moment of inundation and the moment when the network is fully recovered.
The data input is the amount of damaged assets relative to the total amount of assets and the recovery time per asset.

Demonstration calculation network capacity during disruption 0-alternative healthcare network Dordrecht

In Figure 27 the capacity of the 0-alternative of the healthcare network throughout the recovery process is depicted. The 0-alternative of the healthcare network in case consists of 4 assets. The capacity of this network is expressed in the available places for the medical treatment of patients, thus the capacity is expressed in the amount of available beds. In this case there are 8 beds.

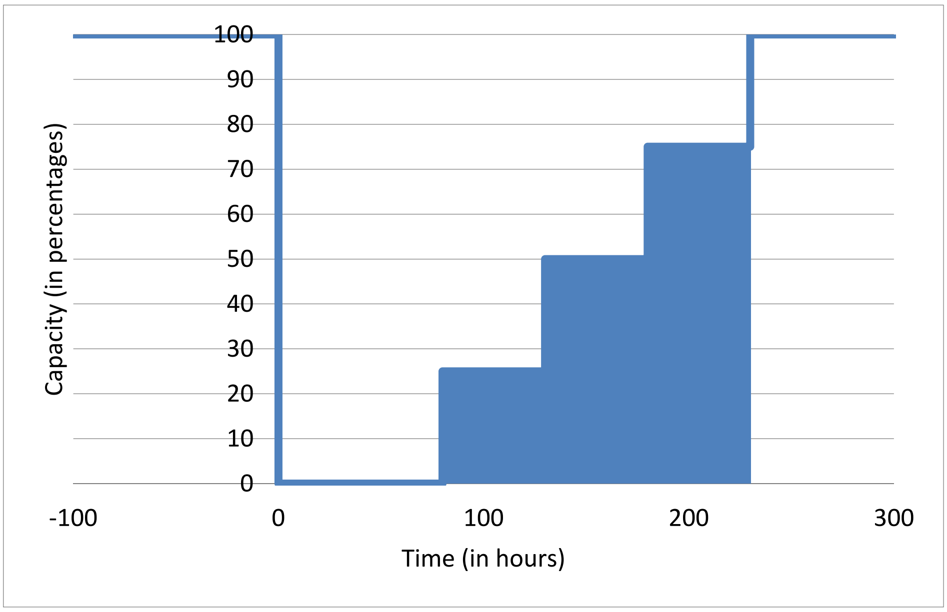

Figure 27 - Recovery of capacity of the 0-alternative of the healthcare network in Dordrecht

- At t=0 the inundation starts. The capacity of this network decreases from 100% to 0%. This decrease is caused by the inundation of 4 of the 4 locations of the network. With the inundation of the 4 locations, 8 of the 8 beds become unavailable.
- At t=35 the inundation is over and the recovery activities can be initiated. The network is recovered per location. In Figure 27 the recovery of the capacity is depicted by the blue surface under the curve. It is estimated that it takes 48 hours to restore one location; therefore per 48 hours an average of 2 beds is restored.
- At t=227 all assets are recovered, therefore the network has recovered to 100% capacity.

To calculate the networks capacity at the moment of flooding, amount of the non-inundated assets is divided by the total amount of assets. In this case this is 0%, there are no non-inundated assets.

To calculate the capacity of the network during the recovery process, the actual capacity of the network is divided by its potential capacity. The surface under the curve is divided by the duration of the disturbance, which is the time between the moment of inundation (t=0) and the moment of recovery (t=227). This percentage is 31.5%.

Demonstration calculation network capacity during disruption 1-alternative healthcare network Dordrecht

In Figure 28 the capacity of the 1-alternative of the healthcare network throughout the recovery process is depicted. The 1-alternative of the healthcare network in case consists of 4598 assets; this is outlined in Paragraph 4.4. The capacity of this network is expressed in the available places for the medical treatment of patients, thus the capacity is expressed in the amount of available beds and survival kits. In this alternative, besides the 4 general practices, all 4594 households have their own survival kit with sufficient first aid equipment, food and drinks to survive the first 35 hours.

- At t=0 the inundation starts. The capacity of this network decreases from 100% to 63.3%. This decrease is caused by the inundation of 4 of the 4 locations of the network. With the inundation of the 4 locations, 8 of the 8 beds are unavailable. Also, 1683 households will inundate and therefore the corresponding 1691 survival kits are considered unavailable assets.
- At t=35 the inundation is over and the recovery activities can be initiated. It is estimated that it takes 48 hours to restore one location; therefore per 48 hours an average of 2 beds is restored. Per 24 hours 50 households are restored, therefore per 48 hours an average of 50 survival kits is restored. In Figure 28 the recovery of the capacity is depicted.
- At t=227 all inundated locations are recovered and 28 houses, together these are 36 assets. The network is recovered to 73.5% capacity.
- At t=843 all households are recovered, all survival kits are available and therefore the network is recovered to 100%.

To calculate the networks capacity at the moment of flooding, amount of the non-inundated assets is divided by the total amount of assets. In this case this is 63.3% as there are no non-inundated assets.

To calculate the capacity of the network during the recovery process, the actual capacity of the network is divided by its potential capacity. The surface under the curve is divided by the duration of the disturbance, which is the time between the moment of inundation (t=0) and the moment of recovery (t=843). This percentage is 82%.

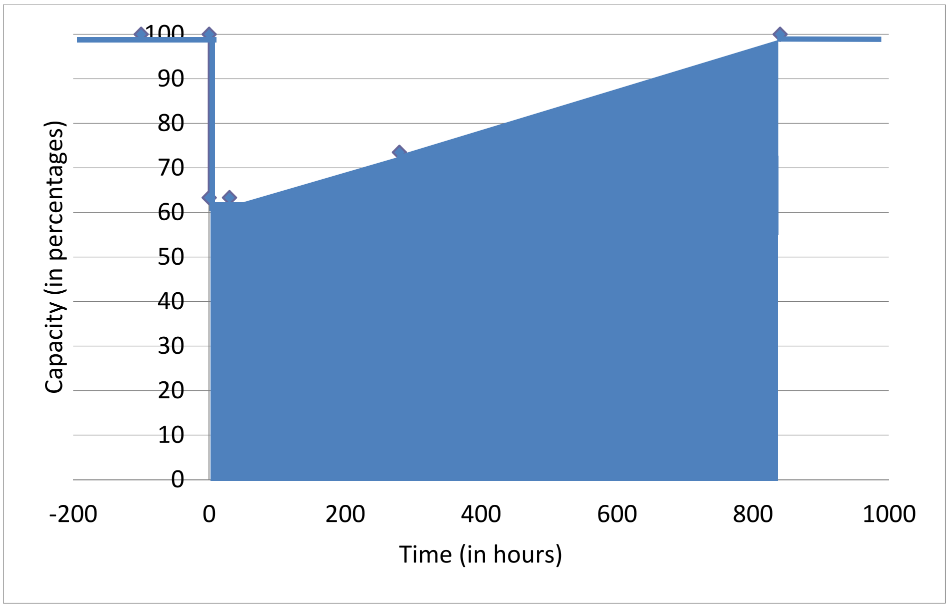

Figure 28 - Recovery of capacity of the 1-alternative of the healthcare network in Dordrecht

6.2 Data from the network capacity calculations

In this paragraph the data is outlined of the network capacity calculations, as demonstrated with the two alternatives above, for all alternatives. In The annexed Atlas of Mapping Resilience the capacity calculations are outlined per alternative, therefore this paragraph gives a summary of the data in the annexed Atlas of Mapping Resilience.
The substantiation for the calculations and resulting values can be found in the annexed Atlas of Mapping Resilience.

In Table 9 the data output of Section 6.1 is summarized. The data consist of 3 resilience indicators:

- The capacity of the network at the moment the flood start (in percentages);
- The capacity of the network throughout the recovery process (in percentages);
- The duration of the recovery process (in hours).

Table 9 - Data output of the three resilience indicators from Section 6.1

Healthcare network Ho Chi Minh City

	Alternatives	Capacity at t=0 (%)	Capacity factor (%)	Recovery (hours)
0	The current situation	60	76	408
1	Survival kit per household	78	92	3159
2	Flood proofing assets	0	31	144
3	One temporary shelter	80	82	408

Healthcare network Dordrecht

	Alternatives	Capacity at t=0 (%)	Capacity factor (%)	Recovery (hours)
	The current situation	0	32	227
1	Survival kit per household	63	81	843
2	Flood proofing assets	0	18	51
3	One temporary shelter	50	66	227

Electricity network Ho Chi Minh City

	Alternatives	Capacity at t=0 (%)	Capacity factor (%)	Recovery (hours)
0	The current situation	54	76	3521
1a	Generator per household	54	76	3521
1b	Solar panels	72	87	3521
1c	Flood proofing households	54	76	1364
2	Flood proofing assets	55	77	3521
3	One central asset	75	77	3521

Electricity network Dordrecht

	Alternatives	Capacity at t=0 (%)	Capacity factor (%)	Recovery (hours)
0	The current situation	19	48	1883
1a	Generator per household	19	59	1883
1b	Solar panels	63	81	843
1c	Flood proofing households	31	65	1883
2	Flood proofing assets	19	58	843
3	One central asset	63	81	843

The data above consists of fairly abstract numbers. In order to get an idea of what these numbers mean, they need to be related to actual examples in practice. In Chapter 7 these abstract values are related to practical examples in the case areas.

In the annexed “Atlas of Mapping Resilience” the capacity calculations of all alternatives are documented.

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June 2007
Photo by Gideon Mendel

7 Results and discussion

This chapter outlines the results and the discussion these results. First the data presented in Paragraph 6.2 is graphed per network per case (§7.1). Second the data presented in Paragraph 6.2 is structured in on basis of the influence on the networks (§7.2). Third, the abstract values in the data are related to practical examples in the case areas in order to substantiate the similarities and differences (§7.3). The limitations of this research are discussed on basis of the validity, reliability and process decisions (§7.4). Finally, a sensitivity analysis is conducted (§7.5).

7.1 Results

On basis of the data presented in Paragraph 6.2 from the case reports, the flood simulations of the alternatives, and the cascade-effect impact schemes, it is possible to distil the resilience indicators per option, case and network. In Table 10 the values of the four resilience indicators is summarized.

Table 10 - Data output of the four resilience indicators

Healthcare network Ho Chi Minh City

	Alternatives	Damage (Euro)	Capacity at t=0 (%)	Capacity factor (%)	Recovery (hours)
0	The current situation	4,095,000	60	76	408
1	Survival kit per household	5,728,000	78	92	3159
2	Flood proofing assets	3,925,000	0	31	144
3	One temporary shelter	3,887,000	80	82	408

Healthcare network Dordrecht

	Alternatives	Damage (Euro)	Capacity at t=0 (%)	Capacity factor (%)	Recovery (hours)
0	The current situation	114,293,000	0	32	227
1	Survival kit per household	117,452,000	63	81	843
2	Flood proofing assets	113,175,000	0	18	51
3	One temporary shelter	112,945,000	50	66	227

Electricity network Ho Chi Minh City

	Alternatives	Damage (Euro)	Capacity at t=0 (%)	Capacity factor (%)	Recovery (hours)
0	The current situation	61,778,000	54	76	3521
1a	Generator per household	73,300,000	54	76	3521
1b	Solar panels per household	72,635,000	75	87	3521
1c	Flood proofing households	38,759,000	54	76	1364
2	Flood proofing assets	72,883,000	55	77	3521
3	One central asset	72,883,000	75	77	3521

Electricity network Dordrecht

	Alternatives	Damage (Euro)	Capacity at t=0 (%)	Capacity factor (%)	Recovery (hours)
0	The current situation	43,611,000	19	58	843
1a	Generator per household	43,612,000	19	58	843
1b	Solar panels per household	70,780,000	63	81	843
1c	Flood proofing households	102,656,000	31	52	88
2	Flood proofing assets	38,881,000	19	58	843
3	One central asset	38,881,000	63	81	843

Healthcare network in Ho Chi Minh City

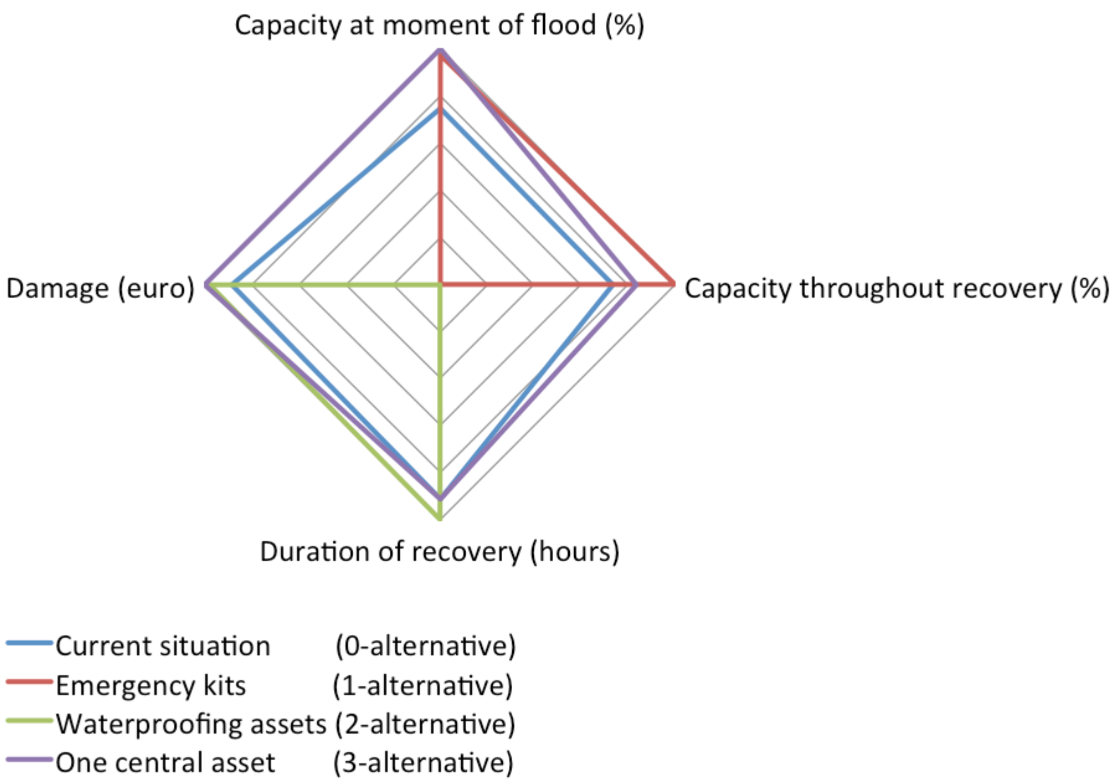

Figure 29 - Normalised ratio between resilience indicators of the alternatives in healthcare network in Ho Chi Minh City

Healthcare network in Dordrecht

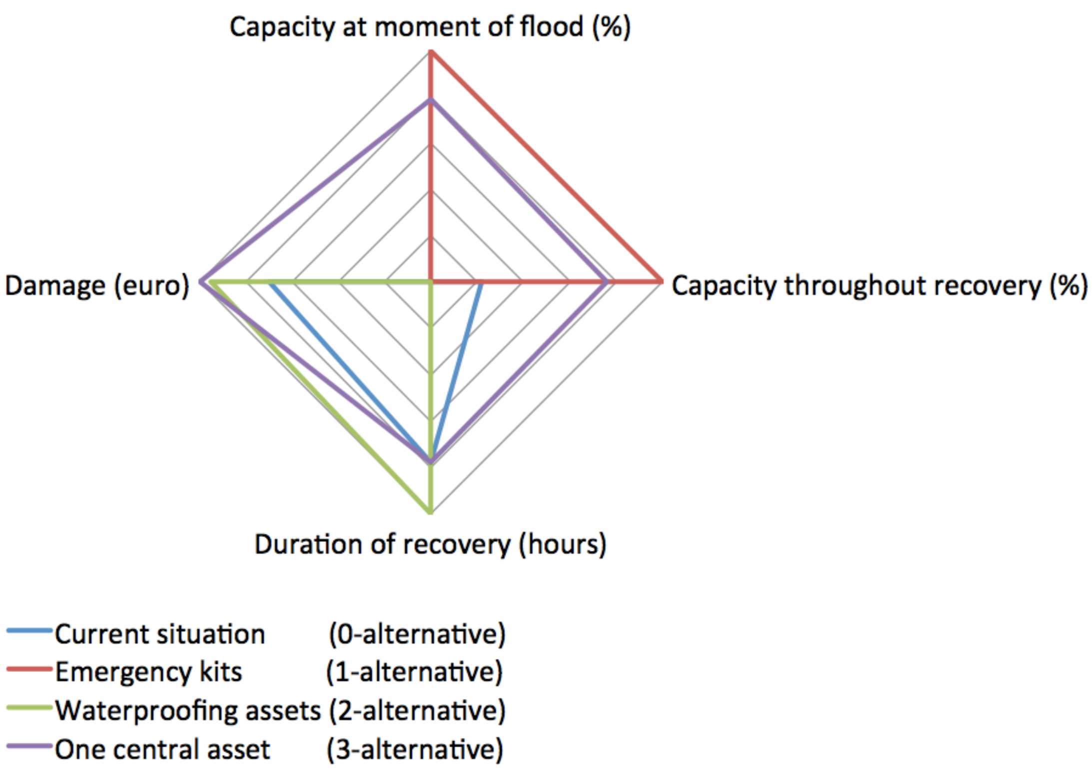

Figure 30 - Normalised ratio between resilience indicators of the alternatives in healthcare network in Dordrecht

Electricity network Ho Chi Minh City

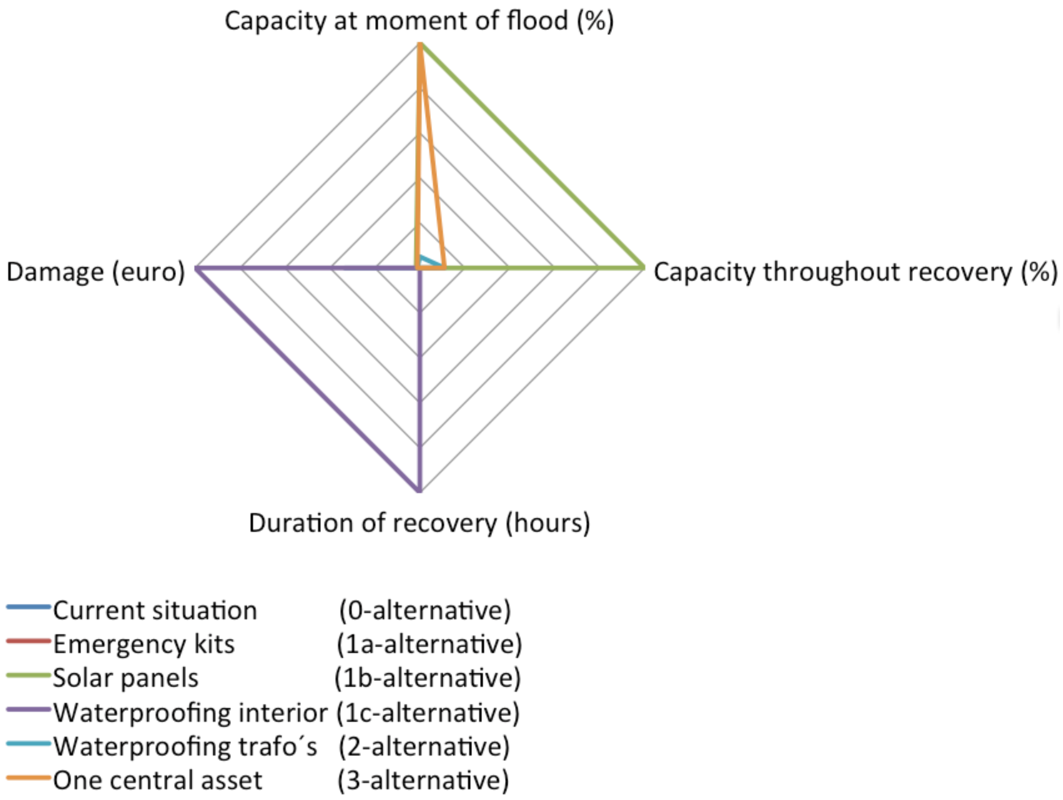

Figure 31 - Normalised ratio between resilience indicators of the alternatives in electricity network in Ho Chi Minh City

Electricity network in Dordrecht

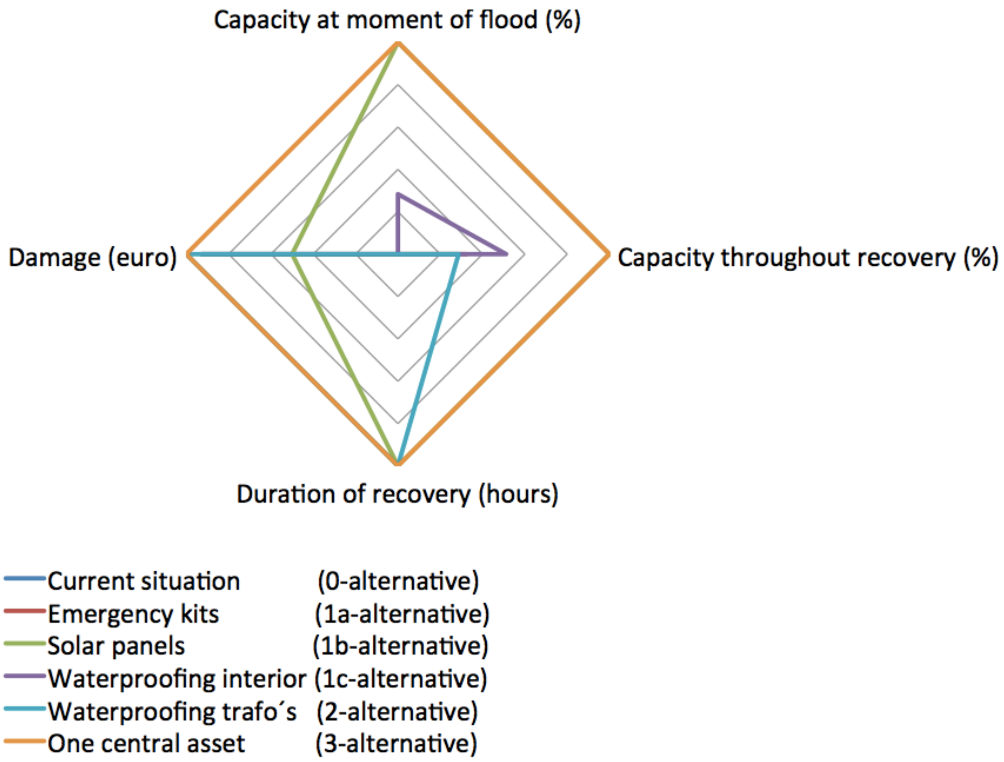

Figure 32 - Normalised ratio between resilience indicators of the alternatives in electricity network in Dordrecht

In Figure 29, Figure 30,
Figure 31 and
Figure 32 the graphs are presented that visualise the ratio between the values of the resilience indicators of the alternatives. The values are normalised between the values 0 and 1. Therefore, when an alternative has the lowest value of all the alternatives, in this graph the alternative is represented with the number 0. When an alternative has the highest value of the alternatives, in this graph the alternative is represented with the value 1.

To relate these values to resilience; the values that are close to 1, contribute to the resilience of the network. The values that are close to 0, do not contribute to the resilience of the network.

7.2 Results ranked with respect to resilience

In Table 11 the data from Paragraph 6.2 and graphed in Paragraph 7.1 is ranked on basis of the influence of the alternatives on the extent of resilience. The distinction is made between the alternatives that positively affect the networks resilience the most and the alternatives that negatively affect the networks resilience. This distinction is made for the four resilience factors.

Alternatives positively affect the networks resilience with a low damage value, high capacity at t=0, high capacity factor, low recovery duration value. Alternatives negatively affect the networks resilience with a high damage, low capacity at t=0, low capacity factor, high recovery duration value.

Table 11 - The alternatives ranked with respect to their influence on the networks resilience

	Positively affecting resilience		Negatively affecting resilience	
Healthcare network Ho Chi Minh City				
Damage	One central shelter	(3-alt)	Survival kit per household	(1-alt)
Capacity at t=0	One central shelter	(3-alt)	Flood proofing assets	(2-alt)
Capacity factor	Survival kit per household	(1-alt)	Flood proofing assets	(2-alt)
Recovery duration	Flood proofing assets	(2-alt)	Survival kit per household	(1-alt)
Healthcare network Dordrecht				
Damage	One central shelter	(3-alt)	Survival kit per household	(1-alt)
Capacity at t=0	Survival kit household	(1-alt)	Current situation	(0-alt)
			Flood proofing assets	(2-alt)
Capacity factor	Survival kit household	(1-alt)	Flood proofing assets	(2-alt)
Recovery duration	Flood proofing assets	(2-alt)	Survival kit per household	(1-alt)
Electricity network Ho Chi Minh City				
Damage	Flood proofing households	(1c-alt)	Generator per household	(1a-alt)
Capacity at t=0	One central asset	(3-alt)	Current situation	(0-alt)
			Generator per household	(1a-alt)
			Flood proof households	(1c-alt)
Capacity factor	Solar panels household	(1b-alt)	Current situation	(0-alt)
			Generator per household	(1a-alt)
			Flood proof households	(1c-alt)
Recovery duration	Flood proofing households	(1c-alt)	Current situation	(0-alt)
			Generator per household	(1a-alt)
			Flood proof households	(1c-alt)
			Flood proofing assets	(2-alt)
			One central asset	(3-alt)
Electricity network Dordrecht				
Damage	Flood proofing assets	(2-alt)	Flood proof households	(1c-alt)
	One central asset	(3-alt)		
Capacity at t=0	Solar panels household	(1b-alt)	Current situation	(0-alt)
	One central asset	(3-alt)	Generator per household	(1a-alt)
			Flood proofing assets	(2-alt)
Capacity factor	Solar panels household	(1b-alt)	Flood proofing households	(1c-alt)
	One central asset	(3-alt)		
Recovery duration	Flood proofing households	(1c-alt)	Current situation	(0-alt)
			Generator per household	(1a-alt)
			Solar panels household	(1b-alt)
			Flood proofing assets	(2-alt)
			One central asset	(3-alt)

7.3 Discussion of the results

In this section the results are discussed. First the results are discussed per network per case. The abstract graphs and values presented in the previous sections are related to the practical aspects of the case areas. By relating the values in the graphs to the cases it is possible to substantiate their significance.
The resilience indicators are outlined with the best values of the alternatives, and next implementations for the increase of resilience are outlined in theoretical and practical sense. Second the similarities and differences between the networks per case are discussed. Concluding, general observations are discussed concerning the networks.

Results for the healthcare network in Ho Chi Minh City

Per resilience indicator the best alternatives are discussed.

- The damage is the lowest in the 3-alternative, in which the indirect but costly effect of disordered people is small. The damage value is low as there are little to no indirect effects of the inundation to the affected people. The duration of people being disordered is the shortest here; 72 hours after the flood people can go to the shelter to receive medical help.
- The capacity at the moment of inundation is the highest in the 3-alternative, in which the shelter provides 198 extra beds besides the 198 existing beds of which 80 will become unavailable due to inundation of the general practices and hospital. In this alternative more beds become available, than beds in the 0-alternative
- The capacity throughout the recovery process is the highest in the 1-alternative, in which besides the existing assets and locations, each household has its own survival kit with which at least the first 72 hours, can be survived. Therefore the capacity increases from 198 to 29198. The decrease of capacity is dependent on the capacity that becomes inundated, located on the ground floor. Therefore, the flood only affects the 6439 units of capacity that are located on the ground floor.
- The recovery time is the shortest in the 2-alternative, in which all 17 locations of healthcare assets are closed and flood proofed prior to the inundation. The preparation takes 72 hours, the inundation takes 72 hours and in within 144 hours after the inundation, the healthcare network is recovered.

In theory, the resilience of the current situation of the healthcare network in Ho Chi Minh City can increase by implementing measures on basis of the alternatives above. Per resilience indicator these improvements are discussed.

- Concerning the extent of damage, on basis of the 3-alternative it is shown that this value is reduced by exposing fewer assets and persons to the direct and indirect effects of the inundation.
- Concerning the capacity at the moment of inundation, on basis of the distribution of capacity in the 3-alternative more capacity can be shifted towards the area that will remain non-inundated.
- Concerning the capacity throughout the recovery process, on basis of the 1-alternative the extent of resilience can with a higher amount of assets and capacity evenly dispersed in the case area will increase the resilience. Also, the extent of resilience can increase with the implementation of one central asset, with a high amount of capacity and located on a flood proof location.
- Concerning the recovery duration, on basis of the 2-alternative it is shown that this duration is decreased by preventing repair works, therefore preventing damage to assets. Also the duration of repair of one asset is decreased.

In practice, the resilience of current situation of the healthcare network in Ho Chi Minh City can increase with several measures.

- Concerning the capacity at the moment of inundation: the capacity during the inundation can increase by either moving general practices or the hospital towards to the flood proof area or by increasing the capacity in the general practices and hospital in the flood proof area in the north and the west. The condition for this is accessibility between the inundated area and the available capacity.
- Concerning the capacity throughout the recovery process: the overall capacity is by giving the recovery a boost in the beginning. This is done by starting to recover with multiple assets simultaneously, for example the first 20 per cent of the time already 80 per cent of the capacity is recovered, and this is a great boost.
- Concerning the duration of the recovery: the recovery time will become shorter by restoring multiple assets at the same time. In practice, two or more general practices are recovered simultaneously. In this study, the duration of recovery is an indicative value this is seen as a limitation of this research and is elaborated in Paragraph 7.4. Also, damage and recovery work is prevented by closing off the general practices and hospitals prior to the flood. Another measure is to evacuate all medical, electronic and costly equipment and furniture to a higher location that will remain dry. The ground floor of the practices will inundate, but the equipment will not be damaged. After the inundation, when the ground floor is dried and cleaned, the equipment is placed back. The conditions for this measure are accurate flood predictions, communication and management between prediction and the flood, and proper techniques for the flood proofing of the general practices and hospitals.
- Concerning the extent of damage: the amount of households that is affected by flooding will decrease by enlarging the amount of floors on existing and new building footprints (increasing the FSI). Fewer households need to be repaired, and fewer residents are disordered or dead. There are two main conditions for this measure. First, the foundation of the buildings must be resistant to deterioration by water. Second, there must be possibilities for the escape of the residents of all apartments.

Results for the healthcare network in Dordrecht

Per resilience indicator the best alternatives are discussed.

- The damage is the lowest in the 3-alternative, in which the indirect but costly effect of disordered people is small. The damage value is relatively low the extent in which people are disordered, in terms of time, is the smallest here. The duration of people being disordered is 35 hours, relative to the 1715 hours estimated for the 0-alternative.
- The capacity at the moment of inundation and the capacity throughout the recovery process are the highest in the 1-alternative, in which, besides the existing capacity in the general practices, each household has its own survival kit with which at least the first 35 hours can be survived. The capacity at the moment of inundation drops according to the amount of inundated general practices and households, which are households located on the ground floor. The households on upper floors remain unaffected. With an average of 2.22 floors per building footprint, the ratio between potentially flooded and non-flooded households contributes to a high capacity at the moment of inundation and throughout the recovery process. The inundation of all general practices has a minor effect on the capacity.
- The recovery time is the shorts in the 2-alternative, in which all 4 general practices are closed and flood proofed prior to the inundation. The preparation takes 16 hours, the inundation takes 35 hours and within 51 hours after the inundation the healthcare network is completely recovered.

In theory, the resilience of the current situation of the healthcare network in Dordrecht can increase by implementing measures on basis of the alternatives above. Per resilience indicator these improvements are discussed.

- Concerning the extent of damage, on basis of the 3-alternative this value is reduced by exposing fewer assets and persons to the direct and indirect effects of the inundation.

- Concerning the capacity at the moment of inundation, on basis of the 1-alternative the resilience can increase by moving, at least a part and preferable the majority of, the networks capacity towards the area that will remain non-inundated.
- Concerning the capacity throughout the recovery process, on basis of the 1-alternative the extent of resilience can with a higher amount of assets and capacity evenly dispersed in the case area will increase the resilience. Also, the extent of resilience can increase with the implementation of one central asset, with a high amount of capacity and located on a flood proof location.
- Concerning the recovery duration, on basis of the 2-alternative this duration can decrease by preventing repair works, therefore preventing damage to assets. Also the duration of repair of one asset is decreased.

In practice, the resilience of the current situation of the healthcare network in Dordrecht can increase with several measures.

- Concerning the extent of damage: the amount of households that is affected by flooding will decrease by enlarging the amount of floors on existing and new building footprints (increasing the FSI). Fewer households need to be repaired, and fewer residents are disordered or dead. There are two main conditions for this measure. First, the foundation of the buildings must be resistant to deterioration by water. Second, there must be possibilities for the escape of the residents of all apartments.
- Concerning the capacity at the moment of inundation: the capacity during the inundation can increase by either moving at least two of the general practices towards the flood proof area in the north or east part of the area. The condition for this measure is accessibility between the inundated area and the available practices.
- Concerning the capacity throughout the recovery process: the overall capacity will increase by recovering two general practices in the first 48 hours after the flood, the speed of recovery is 200 per cent capacity win with respect to the current situation.
  Concerning the duration of the recovery: the recovery time will become smaller by restoring two or more general practices at the same time. Also, damage is prevented by closing off the general practices prior to the. Another measure is to evacuate all medical, electronic and costly equipment and furniture to a higher location that will remain dry. The ground floor of the practices will inundate, but the equipment will not be damaged. After the inundation, when the ground floor is dried and cleaned, the equipment is placed back. The conditions for this measure are accurate predictions for floods, communication and management between prediction and the flood, and proper techniques for the flood proofing of the general practices and hospitals.

Similarities and differences in healthcare networks in the two cases

On basis of the discussions concerning the healthcare network specifically in Ho Chi Minh City and 2, similarities and differences are appointed. The similarities and differences are substantiated, inter alia on basis of spatial characteristics of the case areas.

Three similarities between the cases are discussed below.

- For both cases the 3-alternative had the lowest damage, which is substantiated by the relative small value of damage, determined by the relative short duration of the indirect effect disordered people. The duration of this effect is dependent on the flood duration, in Ho Chi Minh City this is 72 hours, in Dordrecht this is 35 hours.
- For both cases the 2-alternative had the shortest duration of recovery, which is substantiated by the fact that the recovery activities are fewer and shorter. The activities of recovering and replacing are replaced be drying and cleaning, which consume less time and money.

- For both cases the 1-alternative had the longest duration of recovery, which is substantiated by the repair of the household that is taken into account in the recovery process, since the status of the household determines whether the survival kit are used herein or not.

Note: limitations in these similarities are the damage and recovery duration indicators that are used throughout the calculations for the resilience indicators. This limitation is discussed in Paragraph 7.4.

Two differences between the cases are discussed below.

- For Ho Chi Minh City the 3-alternative is the best alternative concerning the capacity at the moment of inundation, for Dordrecht the 1-alternative is the best alternative concerning the capacity at the moment of inundation, which is substantiated by the fact that the spatial distribution of the networks in these cases are relatively best. In Ho Chi Minh City this is due to the majority of the capacity on a flood proof location, in Dordrecht this is due to the presence of capacity above the maximum inundation height.
- For Ho Chi Minh City the 2-alternative is the worst alternative concerning the capacity at the moment of inundation, for Dordrecht the 0-alternative is the worst alternative concerning the capacity at the moment of inundation (besides the 2-alternative), which is substantiated by the fact that the alternatives are not complying with the spatial distribution of the assets. In Ho Chi Minh City all general practices and hospitals are closed in order to protect them, in Dordrecht all general practices are inundated. In Ho Chi Minh City not all general practices and hospitals need to be closed as only some are located below the inundation level. In Ho Chi Minh City all general practices are located under the inundation level.

Results for the electricity network in Ho Chi Minh City

Per resilience indicator the best alternatives are discussed.

- The damage is the lowest in the 1c-alternative, in which the indirect but costly effect of disordered people is small. The damage value is low as there are little to no indirect effects of the inundation to the affected people.
- The capacity at the moment of inundation is the highest in the 3-alternative. The connection of the household to the source electricity is per household and on the heights of its floor. Therefore, only the households on ground floor in the inundated area will have no electricity.
- The capacity throughout the recovery process is the highest in the 1b-alternative. In the 1b-alternative the capacity is decreased either by the households located on the ground floor in the inundated area.
- The recovery time is the shorts in the 1c-alternative, in which the interior of the households is flood proofed. The recovery duration depends on the recovery speed of the transformers.

In theory, the resilience of the current situation of the healthcare network in Ho Chi Minh City can increase by implementing measures on basis of the alternatives above. Per resilience indicators these improvements are discussed.

- Concerning the extent of damage, on basis of the 1c-alternative it is shown that this value is reduced by exposing fewer households and persons to effects of the inundation.
- Concerning the capacity at the moment of inundation, on basis of the connection of the households to the network in the 3-alternative; more capacity can be maintained when more households are located on the same footprint.
- Concerning the capacity throughout the recovery process, on basis of the 1b-alternative; more capacity can be maintained when more households are located on the same footprint.
- Concerning the recovery duration, on basis of the 1c-alternative it is shown that this duration is decreased by preventing repair works, therefore preventing damage to the connection of households to the network. Also the duration of repair of one asset can be decreased.

In practice, the resilience of the current situation of the electricity network in Ho Chi Minh City can increase with several measures.

- Concerning the extent of damage: the damage is decreased by decreasing the amount of transformers and households subject to flooding. Damage to the transformers is decreased by improving the current system in which cables and connections are unprotected to and exposed to external influences. Damage to the houses is decreased by enlarging the amount of floors on existing and new building footprints with respect to the amount of households located on the ground floor (increasing the FSI). There are two main conditions for this measure. The foundation of the buildings is resistant to deterioration by water. Second, there are possibilities for escaping for the residents of both ground and upper floor apartments.
- Concerning the capacity at the moment of inundation: the capacity during the inundation can increase by building more floors on a cultivated footprint for households (increasing the FSI). This is done by increasing the amount of floor heights. As a condition for this measure the foundation of the buildings is resistant to deterioration by water. Further all households have their own connection to the network on their own floor, not via the ground floor.
- Concerning the capacity throughout the recovery process: the overall capacity will increase by boosting the recovery process in the beginning. This is done by recovering the first hundred transformers and 500 houses in the first 500 hours after the flood; the network has a higher capacity with respect to the recovery process in the current situation.
- Concerning the duration of the recovery: the recovery time will become smaller by restoring two or more transformers or households at the same time.

Results for the electricity network in Dordrecht

Per resilience indicator the best alternatives are discussed.

- The damage is the lowest in the 2-, and 3-alternatives, in which the indirect but costly effect of disordered people is small. The damage value is low as there are little to no indirect effects of the inundation to the affected people.
- The capacity at the moment of inundation is the highest in the 1b- and 3-alternatives. In both alternatives the connection of household to transformer is per household on the heights of its floor. More capacity is maintained when more households are located on one footprint.
- The capacity throughout the recovery process is the highest in the 1b-, and 3-alternative. More capacity can be maintained when more households are located on the same footprint.
- The recovery time is the shorts in the 1c-alternative, in which the interior of the households is flood proofed. The recovery duration depends on the recovery speed of the transformers.

In theory, the resilience of the current situation of the healthcare network in Dordrecht can increase by implementing measures on basis of the alternatives above. Per resilience indicators these improvements are discussed.

- Concerning the extent of damage: on basis of the 2, and 3-alternative, it is shown that this value is reduced by exposing fewer households and persons to the effects of the inundation.
- Concerning the capacity at the moment of inundation: on basis of the connection of the households to the network in the 1b and 3-alternative, more capacity can be maintained when more households are located on the same footprint.
- Concerning the capacity throughout the recovery process: on basis of the 1b-alternative, more capacity can be maintained when more households are located on the same footprint.
- Concerning the recovery duration: on basis of the 1c-alternative, it is shown that this duration is decreased by preventing repair works, therefore preventing damage to the connection of households to the network.

In practice, the resilience of the current situation of the electricity network in Dordrecht can increase with several measures.

- Concerning the extent of damage: by decreasing the amount of transformers and households subject to flooding the damage will decrease. This is done by enlarging the amount of floors on existing and new building footprints with respect to the amount of households located on the ground floor (increasing the FSI). There are two main conditions for this measure. The foundation of the buildings is resistant to deterioration by water. Second, there are possibilities for escaping for the residents of both ground and upper floor apartments.
- Concerning the capacity at the moment of inundation: the capacity during the inundation can increase by building more floors on a cultivated footprint for households (increasing the FSI). As a condition for this measure the foundation of the buildings is resistant to deterioration by water. All households have their own connection to the network on the height of their floor, not via the ground floor.
- Concerning the capacity throughout the recovery process: the overall capacity will increase by boosting the recovery process in the beginning. This is done by recovering the first 4 transformers in the first 168 hours after the flood; the network has a higher capacity with respect to the recovery process in the current situation.
- Concerning the duration of the recovery: the recovery time will become shorter by restoring two or more transformers or households at the same time.

Similarities and differences in electricity networks in the two cases

On basis of the discussions concerning the electricity network specifically in Ho Chi Minh City and Dordrecht, similarities and differences are appointed. The similarities and differences are substantiated, inter alia on basis of spatial characteristics of the cases.

Three similarities are discussed below.

- For both cases the 1b- and 3-alternatives have the highest values for the capacity at the moment of inundation and throughout the recovery process. Both values are substantiated by the fact that the capacity at the moment of inundation is high as the inundated capacity depends only on households on the ground floor in the flooded area.
- For both cases the 1c-alternative had the shortest duration of recovery, which is substantiated by the fact that the recovery activities concern only the transformers. With the flood proofing of the households this time consuming recovery was prevented. Depending on the amount of transformers to recover the durations are 9000 hours in Ho Chi Minh City and 400 hours in Dordrecht.
- For both cases the 3-alternative has the highest damage, which is substantiated by the damage caused by the unused electricity. The indirect effect of unconsumed electricity due to the power cut of households and service adds up to 2.7 billion euro in Ho Chi Minh City and 3.1 million euro in Dordrecht. The indirect effect of disordered residents adds up to 41 million euro in Ho Chi Minh City and 1.6 billion euro in Dordrecht.

Limitations in these similarities are the damage and recovery duration indicators that are used throughout the calculations for the resilience indicators. This limitation is discussed in Paragraph 7.4.

The main difference between the cases is concerns the amount of damage. For Ho Chi Minh City the 2-alternative is the worst alternative and for Dordrecht the 3-alternative is the worst alternative. In the two cases different indirect effects determine the magnitude of the damage. In Ho Chi Minh City the indirect effect of disordered people defines the damage; in Dordrecht the unconsumed electricity defines the damage. This difference is caused by the different durations of recovery and the different damage indicators with which the effects are calculated.

Cross comparison between the two cases

On basis of cross comparison of the results outlined in the previous sections, it is possible to state that one case can learn from the other with respect to spatial characteristics described above.
Ho Chi Minh City can learn from Dordrecht with respect to the ratio between its spatial aspects like the average building height, ground space index and floor space. Dordrecht appears to have better resilience in the 1-alternative, resulting from the higher amount of average floors per building footprint.
On basis of the summarized data in Table 12, it can be concluded that of the area in Ho Chi Minh City is more surface is cultivated and there is less open space than in Dordrecht. However, the average amount of floors build per cultivated surface (the FSI) is lower in Dordrecht. In Ho Chi Minh City the value for FSI is smaller than the value for GSI. In Dordrecht the value for FSI is higher than the value of GSI, which indicates that the surface that is cultivated is used more efficient. This explains why the 1-alternative has more advantage resilience indicator values in Dordrecht than in Ho Chi Minh City.

Table 12 - Values for spatial aspects in Ho Chi Minh City and Dordrecht

Spatial aspect	Ho Chi Minh City	Dordrecht
Average amount of floors	1.83	2.22
GSI	2.65	0.40
FSI	1.56	0.90

Dordrecht can learn from Ho Chi Minh City with respect to the spatial distribution of the capacity. Ho Chi Minh City appears to have better resilience in the 0- and 3- alternative, due to majority of the networks capacity that remains available during the flood. Dordrecht can increase its resilience by evenly allocating its capacity over the case area, of which the majority will remain available during the flood depending on the elevation height of the surface.

General discussion

On basis of the resulting resilience indicators and the discussion outlined in the previous sections, it is possible to appoint general statements.

In general, the resilience of a critical infrastructure network can increase on basis of the optimisation of the four resilience indicators.

First, a critical infrastructure network that can maintain the majority of its capacity in the case of a flood can be established by the gradual distributing the total capacity over the case area, of which the majority of the capacitance is located on the section that does not become flooded.

Second, by increasing the density of the built floor area with respect to the cultivated ground area by increasing the ground space index, the number of households or services that are more likely to be affected by flooding is reduced. Herewith, the ratio of the affected number of households or services decreases with respect to the total number households or services.

7.4 Limitations of this research

In this section the limitations of this research are discussed. The limitations of this research concern the validation and verification of the method and data. The limitations of this research are the starting points for recommendations for further research.

The main limitation of the validity of this research is the lack of available data. This is due to the nature of the analysed floods, which are floods that have not yet taken place. However, on the basis of their probability, these simulated floods have the likelihood of taking place soon. The result is that no data is available that is based on the already flood occurred, but that the effects, the harm and duration of the flooding and the recovery are be based on assumptions and extrapolations.

One of the aspects in which this limitation is manifested is in the calculations of the duration of the recovery process. In this study, the duration of the recovery process is based on the recovery of one asset at the time, in which the duration of the recovery of one asset is an assumption based on the recovery activities. While in practice, two or more assets can be recovered simultaneously. The duration of recovery, as calculated in this research study, is an indicative values and an assumed discrepancy of reality.

The second aspect in which this limitation is manifested is the direct and indirect effects that are identified to simulate the effects of the floods. The effects that are identified for this research are developed on basis of the common sense of engineers and the critical eye of experts. Despite the knowledge and insight of these people the schemes will not fully align with the effects of a flood that will occur in practice. The effects identified in this research study are assumed discrepancies of reality.

The third aspect in which this limitation is manifested is the calculations of the damage of the direct and indirect effects of the simulated floods. In this study, the indicators of damage are based on reports of acknowledged institutions, assumptions and extrapolations. The calculated damages in this research study are assumed discrepancies of reality.

Generally, this study is based on a high amount of assumptions retrieved from literature. Concerning the assumptions and extrapolations made in this research study, the information on which these are based is referred to. When no reference was used to make an assumption or extrapolation, the assumption or extrapolation was established by the best effort to come to the right order of magnitude. This however has introduced a human factor in the research methodology that causes a limitation for the research validity.

Concerning the availability of data on the electricity network; data of critical networks is very difficult to obtain, because it is protected for security reasons and because of competition between companies. This is substantiated by De Bruijn *et al.* (in press). De Bruijn *et al.* emphasizes that the network analysis and the analysis of the effect of elements failure on the network can only be carried out by the owners and operators of the critical network, since they have the data and knowledge to take these steps. In Ho Chi Minh City there appeared that almost no data was documented. In Dordrecht the network operator appeared to be not keen on sharing its data, even after having contacted 12 employees, the network operator was unable to provide any data.

The second limitation of this research concerns the validity of the cascade-effect impact schemes. The degree, the manner and type of experts that are involved in the validation of these schemes can be optimized. The validity can be improved hereof. The method by which the cascade effect impact schemes are developed is described in detail in this document, therefore the reliability of this method good.

Concluding, the chosen scope for this research, the case studies, the networks, the alternatives, the type of flooding, has limited the research. When a different scope was defined, other cases, networks, alternatives and types of flooding could have given the study a different outcome.
For this reason, on basis of this research statements and conclusions can only concern the selected aspects. No generalized conclusions can be made on aspects that are outside the scope of this research.

7.5 Sensitivity analysis

The objective to conduct a sensitivity analysis is to investigate how sensitive the data outputs are to the data inputs. The analysis demonstrates which of the variables in the damage calculation by means of the cascade-effect impact schemes need attention in further research. On basis of the analysis it is possible to determine in which objects must be invested in order to avoid damage. It is possible to protect the most vulnerable and expensive objects and thus to reduce the total damage efficiently.
The analysis is focused on the damage calculation, by means of the cascade-effect impact schemes. The analysis concerns four variables that are included in the damage calculations. These values are:

- The amount of casualties
- The amount of disordered people
- The duration of disorder of persons
- The duration of the recovery of affected network assets
- The damage value of disordered people
- The damage value of uncosts for healthcare assets and unconsumed electricity

In Table 13 the input variables that are tested in this analysis are highlighted with a red demarcation. The scheme is a simplified version of the cascade effect impact schemes and the damage calculations in the annexed Atlas of Mapping Resilience.

Table 13 - Demarcation of tested input variables in sensitivity analysis in simplified damage calculation scheme

	Affected object		Duration		Value damage		Damage
Casualties	x	Persons			x	€	€ (x*x)
Disordered people	x	Persons	x	Hours	x	€/hour	€ (x*x*x)
Unconsumed service network	x	Assets	x	Hours	x	€/hour	€ (x*x*x)
Total damage value							**€ (x*x*x)**

To investigate the sensitivity of the involved variables in the cascade-effect impact schemes, all of the characteristics are varied one by one (keeping the other values to their reference values). The sensitivity of the six values is tested in the 0-alternative of the two cases in the two networks.
In Table 14 the values that have been assessed are summarized. The change in data output is tested with the change of data input from 100% to 80% and from 100% to 120%. The change in data output is given in percentages of change with respect to the data output of 100%.

Table 14 - Sensitivity analysis: change input versus change damage value

Input	**Change damage value**					
	Affected objects		Duration		Value damage	
Relative value of variable →	Casualties	Disordered people	Disordered people	Recovery	Disordered people	Uncosts
Healthcare network in Ho Chi Minh City						
80%	-18.56%	-1.39%	-1.39%	-0.04%	-1.40%	-0.04%
100%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
120%	18.56%	1.39%	1.39%	0.04%	1.40%	0.04%
Healthcare network in Dordrecht						
80%	-19.67%	-0.32%	-0.32%	-0.01%	0.33%	0.01%
100%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
120%	19.67%	0.32%	0.32%	0.01%	-0.33%	-0.01%
Electricity network in Ho Chi Minh City						
80%	-1.23%	-0.35%	-0.35%	-10.79%	-0.35%	-10.78%
100%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
120%	1.23%	0.35%	0.35%	10.79%	0.35%	10.78%
Electricity network in Dordrecht						
80%	-6.24%	-8.76%	-8.77%	-1.24%	11.73%	-20.00%
100%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
120%	6.24%	8.76%	8.77%	1.24%	18.53%	20.00%

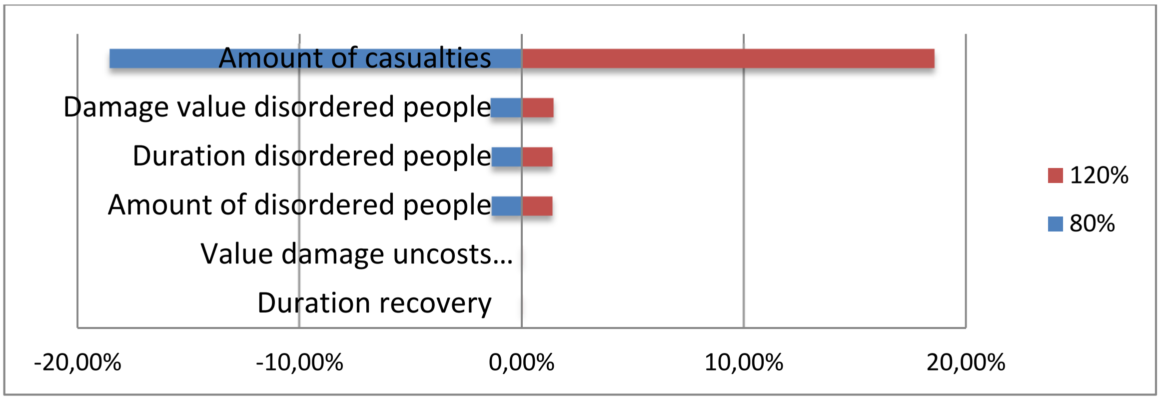

Figure 33 - Sensitivity analysis on damage calculation for healthcare network in Ho Chi Minh City

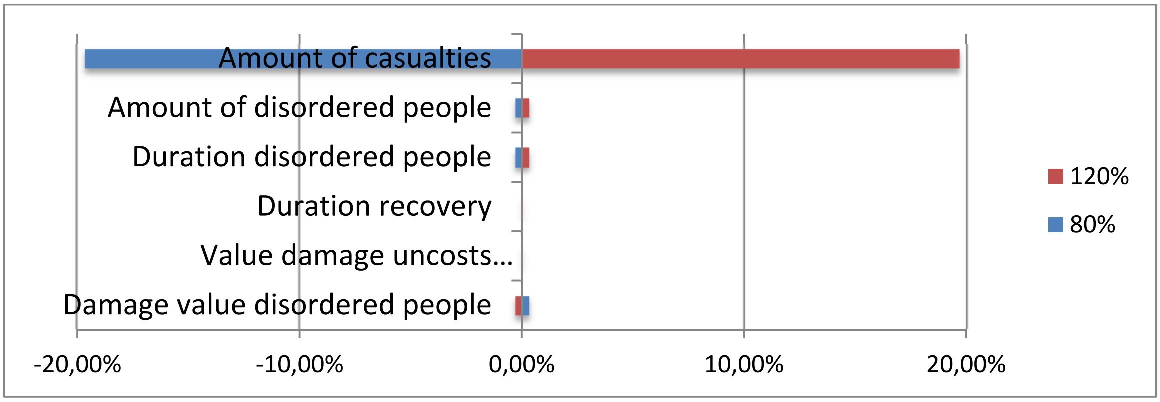

Figure 34 - Sensitivity analysis on damage calculation for healthcare network in Dordrecht

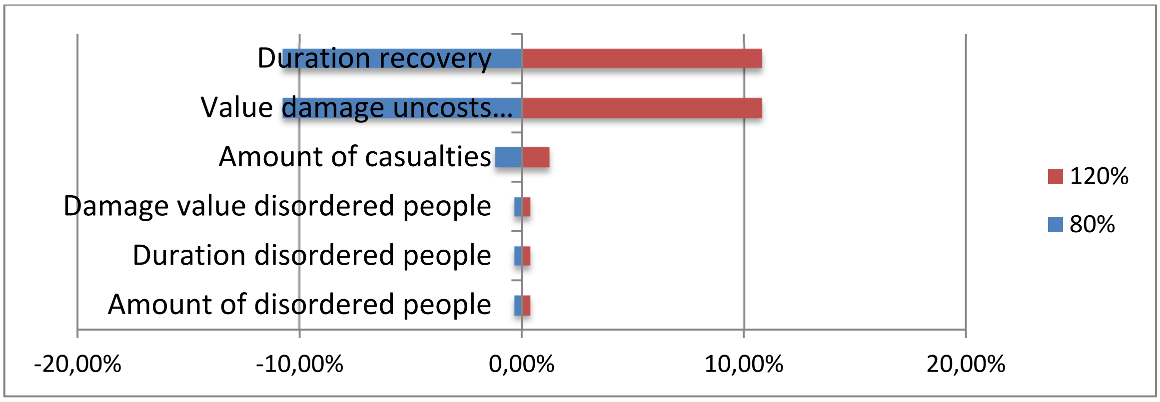

Figure 35 - Sensitivity analysis on damage calculation for electricity network in Ho Chi Minh City

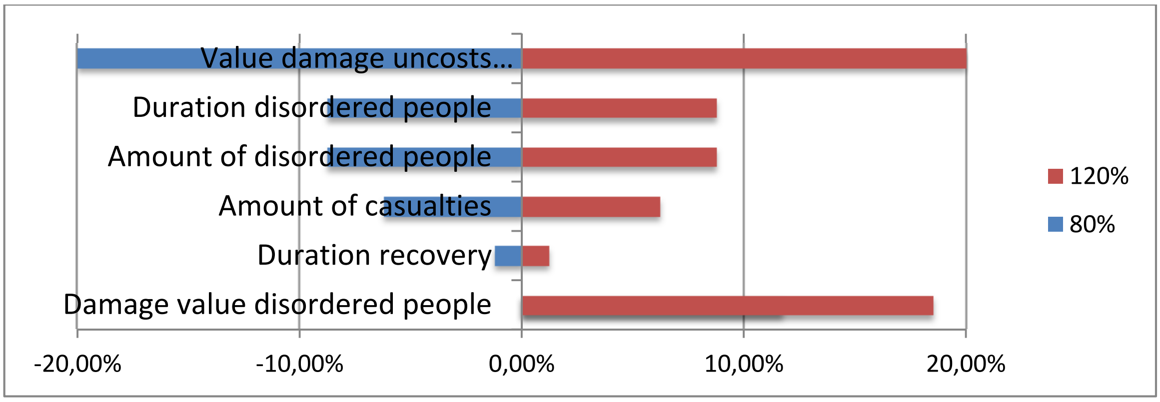

Figure 36 - Sensitivity analysis on damage calculation for electricity network in Dordrecht

The response behavior of the total damage value of the network to 20% change of the input variables depends on the type of network and the case. There is a different ratio between the influence of the input variables per network and per case.

For example, for the electricity network in Ho Chi Minh City the duration of the recovery process has the largest influence on the damage, while for the electricity network in Dordrecht the duration of the recovery process has the smallest influence on the damage.

The variable that has the largest influence on the total network damage differs per case.

The variable that has the smallest influence on the total network damage differs per case.

The variables that have an inverse effect on the change of total damage will show an increase in the damage output as response to a decrease of the variable input, and visa versa. In case of the healthcare network in Dordrecht the damage value per disordered person and damage value for unconsumed services have an inverse effect on the total damage value. The explanation for this phenomenon has not been found in the course of this research. In case of the electricity network in Dordrecht the damage value per disordered person has an inverse effect on the total damage value. The explanation for this phenomenon has not been found in the course of this research. No inverse influences of input change appear in the analysis for both networks in Ho Chi Minh City. The explanation for this phenomenon has not been found in the course of this research.

Remarkably, some changes in damage value are the same for different input variables. For example, in the healthcare network in Dordrecht the changes in damage value are the same for the input variables amount of disordered people and duration of disordered people.

This is a result of the design of the cascade-effect impact schemes. The cause for the similarity between these values is that the input variables are multiplied with each other; this is visualized in Table 15. The amount of disordered persons, the duration is disturbance and the value of disturbance of persons is combined in one product. Therefore, when one product is changed with the factor of 20%, the total product of the variables is changed with the factor of 20%. The change in the total damage value, the sum of all products, will therefore be similar.

Table 15 - Demarcation of tested input variables in sensitivity analysis in simplified damage calculation scheme

	Affected object		Duration		Value damage		Damage
Casualties	x	Persons			x	€	=PRODUCT(x,x)
Disordered people	x	Persons	x	Hours	x	€/hour	=PRODUCT(x,x,x)
Unconsumed service network	x	Assets	x	Hours	x	€/hour	=PRODUCT(x,x,x)
Total damage value							**=SUM(PRODUCTS)**

Practically, it can be stated that for investors it is feasible to invest in the input variables that have the largest influence on the change in the total damage value. In case of the healthcare network in both Ho Chi Minh City and this is the amount of casualties. In case of the electricity network in Ho Chi Minh City these are the duration of the recovery process and. In case of the electricity network in Dordrecht this is the damage value of unconsumed service. It is less feasible to invest in the input variables that have less, no or an inverse influence on the change of the total damage value.

Unnamed boy
Gonaives
Haiti
September 2008
Photo by Gideon Mendel

8 Managerial implications

This chapter outlines the discussion of the managerial implications of the approach to assess resilience developed through this research. First the resilience roadmap is presented that reflects the method outlined in this research to assess the resilience of critical infrastructure networks. Next, the possibilities for practical and theoretical application of this roadmap are described. Concluding, the added value of this approach is outlined with respect to society, science and practice.

8.1 The resilience roadmap

In this section the resilience roadmap is presented that reflects the method outlined in this research to assess the resilience of critical infrastructure networks.

In Figure 37 the resilience roadmap is outlined per step, consisting of the corresponding actions. The resilience roadmap consists of seven steps with which the resilience of networks can be quantified. The seven steps of the resilience roadmap are:

8. Build the case model;
9. Simulate the flood in the case model;
10. Map the effects of the flood on the network;
11. Calculate the damage to the network;
12. Map the recovery of the network capacity;
13. Visualise the values of the resilience indicators;
14. Conduct cost-benefit analysis.

The case model must be built to create a simplified representation of the case area and the analysed network. The model must include all data of the area and network that is relevant for the analysis.

The flood must be simulated in the case model to demonstrate the intersection of the flood and the networks assets indicate the amount of affected objects. The height of the flood in which the assets become flooded can be varied, depending on the characteristics of the assets. The probability of the flood is included in the cost-benefit analysis in Step 7.

The effects of the flood on the network within the area must be mapped. This is done by means of the cascade-effect impact schemes. With knowledge of the direct and indirect effects create the most realistic rendering of reality, this way the resilience indicators can represent reality.

The damage of the flood to the network must be calculated to find the first value of the resilience indicators, by means of the cascade-effect impact schemes and damage indicators. The database with damage indicators must be build.

The recovery of the network capacity must be mapped to find the three remaining resilience indicators. The visualization of the recovery process is created by plotting the time-dependent network capacity in a graph, with time on the x-axis and the network capacity on the y-axis.

The values of the resilience indicators should be visualised in a radar chart. This radar chart has four axes, one for each indicator. When multiple alternatives are plotted herein, these are standardized. The value that contributes most to the network resilience is represented with the value 1; the value with the least impact on the network resilience is represented with the value 0.

The cost-benefit analysis is conducted in order to demonstrate the feasibility of the alternatives. For the cost-benefit analysis the damage is converted to risk value by means of the probability of the flood.

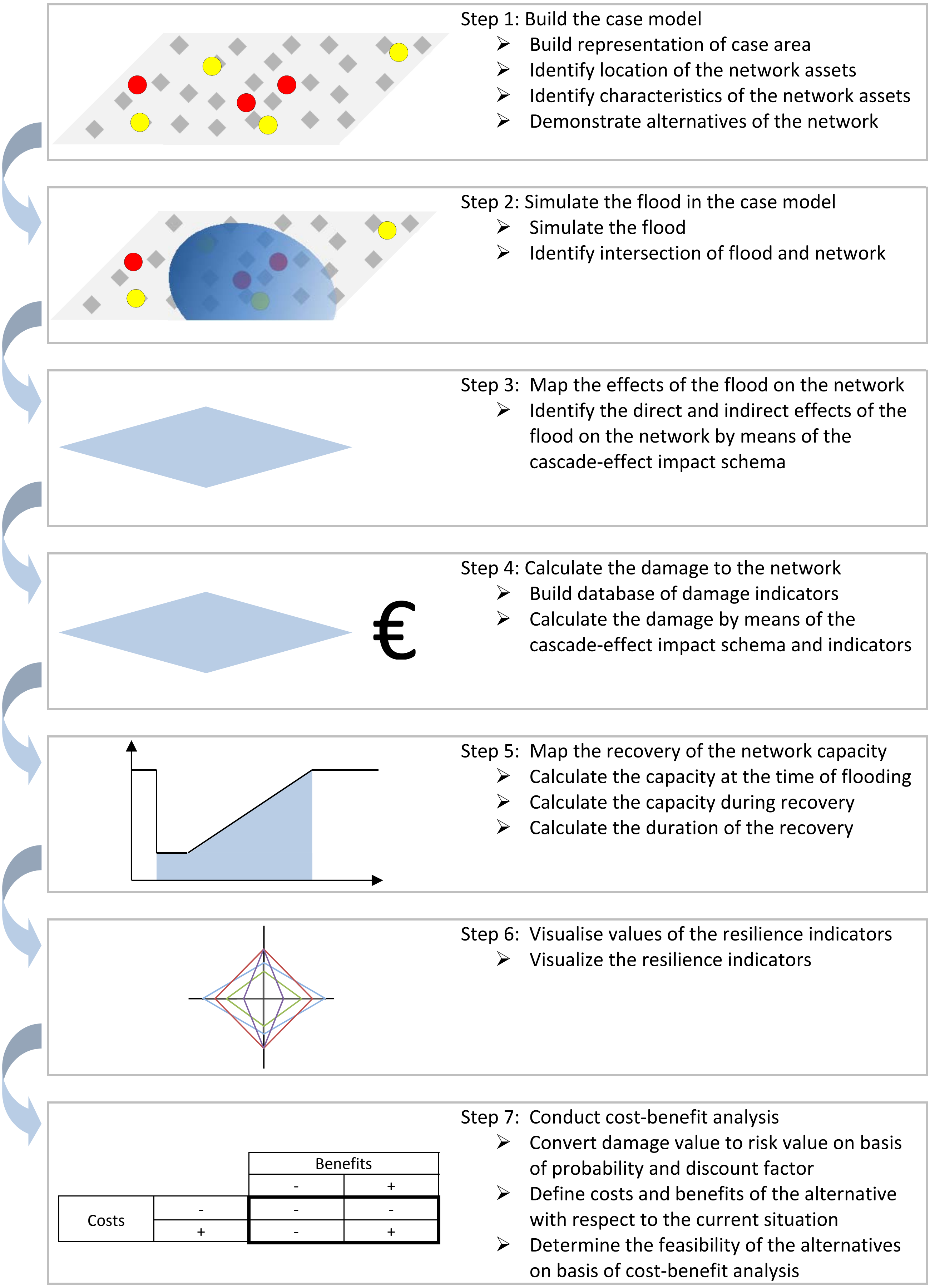

Figure 37 - The resilience roadmap

8.2 Possible implications of the resilience roadmap

The resilience roadmap enables to assess the resilience of all types of networks, with any type of spatial distribution of its assets, in any type of urban context, subject to any kind of disturbance. The resilience roadmap contributes to spatial development of existing networks and new networks.

The resilience roadmap has the following characteristics:

- The method is reproducible and widely applicable;
- The calculations of the resilience indicators are transparent;
- The resilience indicators form a basis for comparing the alternatives in area development;
- The resilience roadmap is a communication tool for stakeholders.

Possible implications of the resilience roadmap are:

- By means of these steps, it is possible to conduct a cost-benefit analysis for alternatives. The costs concern the costs for the implementation of the alternative. The benefits concern the damage reduction with respect to the current situation, in which no measures are taken to reduce the effects of disturbances. The alternative, consisting of a spatial intervention in the distribution of the networks assets, is tested on its feasibility. Based on the cost-benefit analysis, it is possible for stakeholders to test alternatives to their feasibility and thus support their choices.
- The resilience roadmap enables stakeholders to gain insight in the spatial and economic impact of disruption on the network.
- The resilience roadmap provides material with which the assessment of different alternatives within the existing context can be substantiated.

In collaboration with clients, for example local municipalities, it is possible to assess a network on its resilience, specifically on one of the four indicators resilience. The clients can specify which of the four resilience indictor is/are decisive. Alternatives and its spatial distribution of networks assets are evaluated on basis of these decisive resilience indicators. In this way, clients can submit and communicate their focus and priorities.

Suparat Taddee
Chumchon Ruamjai Community
Bangkok
Thailand
November 2011

9 Conclusions and recommendations

This chapter outlines the conclusions and recommendations. The sub-research questions and the main research question are answered on basis of the results (§9.1). Hypotheses for further research are formulated on basis of the discussion of results and the answers to the research questions (§9.2). The chapter is concluded with recommendations for further research, based on the limitations of this research and the formulated hypotheses (§9.3).

9.1 Conclusions

Three sub-research questions were introduced in the first chapter to guide the research through a structured process leading to an answer for the main research question. This section provides the response to these research questions.

Sub-research question 1	*How can the resilience of a critical infrastructure network be measured?*

On basis of this research it can be concluded that the extent of resilience cannot be captured in one number. The resilience of critical infrastructure networks in flood prone urban areas can be mapped by identifying four aspects of the network:

- The damage caused by the flood to the network
- The capacity of the network at the moment the flood start
- The capacity of the network throughout the recovery process
- The duration of the recovery process

To map resilience the four values of resilience indicators must be calculated to describe the resilience in a network.

The extent capacity at the moment the flood starts can be measured by the mapping of the capacitance immediately after flooding, relative to the capacity of the network before flood. The capacitance immediately after the overflow is dependent on the number of assets of the network that is damaged or out of function. For example, when all the assets are damaged, the capacity of the system, relative to the capacity of the overflow, is zero per cent.

The extent of capacity throughout the recovery process is measured by mapping the capacity over time, from the moment of flooding until the moment of complete recovery of the network. First of all look at the capacity immediately after the flood has taken place. Then look at how the capacity develops while the damaged assets are recovered. Over time, the capacity of the network is relative to the capacity of the system before the flood.

The damage is measured by mapping of direct and indirect effects of the flooding, the type and amount of assets that are affected by these consequences, the time at which the assets are affected, the extent to which assets are affected, and the indicators by assets per time period.

The duration of the recovery process is measured by mapping the amount of assets to restore and the recovery time per asset. In theory, the restoration of the assets can be carried out consecutively or with multiple at a time. The recovery time on the basis of a recovery process that is performed by asset consecutively gives an indicative value. The recovery time on the basis of a recovery process in which multiple assets are restored at the same time gives a smaller and more realistic value, provided that the amount of assets to be restored at the same time reflects reality.

On basis of the resilience criteria it is possible to state if the network is resilient. The resilience criteria are:

- The damage caused by the flood to the network is small;
- The capacity of the network at the moment the flood start is high;
- The capacity of the network throughout the recovery process is high;
- The duration of the recovery process is short.

In this research, the capacity of the network is recovered to the capacity that the network had before the flood. In reality however, the flood can function as an incentive to improve the network and increase its capacity.

For example, let's look at a hospital that is in a bad condition and has an insufficient capacity. The hospital gets flooded. The recovery of the hospital would cost more than the hospital itself; the hospital is declared total loss. The construction of a new hospital is feasible. The old hospital is deconstructed. The new hospital is build; it has a good condition and has more capacity than the hospital before. This is an example of which the cost-benefits analysis indicates the construction of a new asset that increases the total network capacity.

In Figure 38 is visualised how the recovery to a potential capacity increase relates to the recovery simulated in this research. On the left, the capacity recovery simulated in this research is depicted with a capacity recovery to 100%. On the right, the potential capacity increase of the network is depicted with a capacity recovery to 200%.

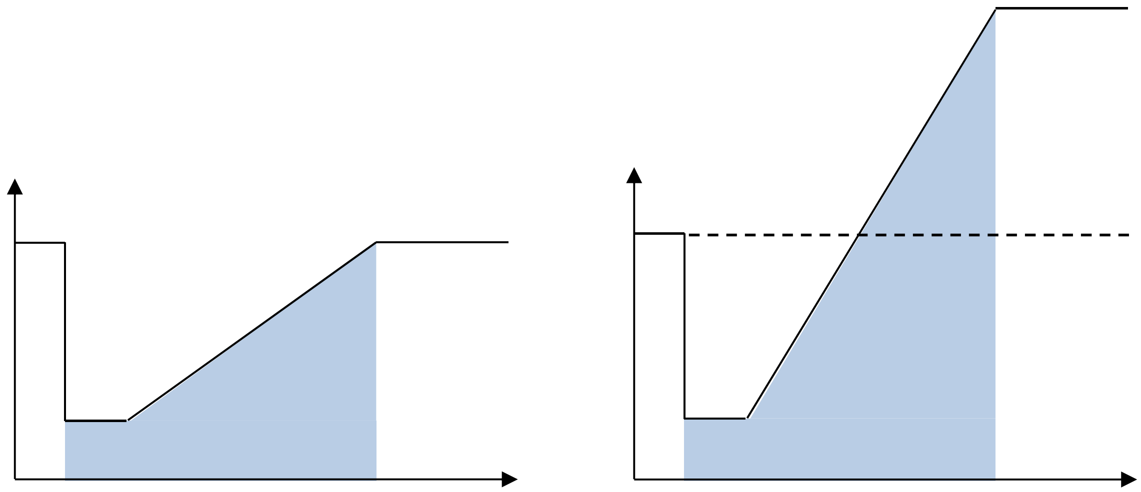

Figure 38 - The analysed network capacity versus the potential capacity increase

Note: no direct relation was studied nor found between the developments of these four factors. However, to find whether there is an optimum ratio between the four aspects, which would results in an optimal resilience, this is a point for further research.

Sub-research question 2	*Which (combination of) features are needed to measure the resilience of critical infrastructure networks?*

To measure the resilience of a critical infrastructure network the features that are relevant are the amount and type of objects of which the network consists, and the capacity of these objects.

To map the number of objects and their location in the case area a simplified representation of reality can be developed. The simplified representations of reality are developed in which the healthcare network includes general practitioners, hospitals and first aid units and the electricity network includes transformers, terminals within households, emergency generators and solar panels.

The capacity of the network is the ability of the network to function. The manner in which this capacity is expressed can differ per network. In this study, for example, the capacity of the health care network is expressed by the number of places where residents can receive medical help, namely beds or first aid units. The capacity of the electricity network is expressed in the number of households that are supplied with electricity. The extent of capacitance is determined by the status of the networks assets. The network will function when status of all assets is good, the network will not or barely function when the status of all assets is poor.

The features and networks are related to the measurement of resilience of critical infrastructure networks as, in the event of disturbance, the features determine the amount of damage, the remaining capacity and the recovery duration of the network.

Note: the selection of assets influences the outcome of resilience of the network. An incomplete or biased selection of assets can result in a theoretically incomplete or incorrect measurement of resilience.

Sub-research question 3	*Is there a measurable difference in the extent of resilience of critical infrastructure networks between the different spatial distributions of the networks assets?*

On basis of this research it can be concluded that, concerning the results of this research, there is a measureable difference in the extent of resilience of the critical infrastructure networks with the different spatial distributions of the networks assets. This measurable difference manifests itself in the four resilience indicators.

On basis of the results, no generalizing conclusions can be drawn with respect to the amount and direction of change of the four resilience indicators. For example, it is not possible to state that an increase of the spatial distribution of assets with the value 'x' will result in a shift of resilience with the value 'y'.

A specific qualitative analysis of the case and the area network must be performed In order to draw a statement on the change of the four resilience indicators of a network.

On basis of the results it is possible to assess differences of the four indicators resilience in the cases in Ho Chi Minh City and Dordrecht with respect to the healthcare and electricity network.

Main research question	*How can the resilience of critical infrastructure networks of urbanized delta areas be related to the spatial distribution of its networks assets, with respect to the event of coastal and fluvial flooding?*

This research presents a resilience roadmap with which the reaction of a city to the disturbance by flooding can be quantified in terms of resilience indicators. On the basis of two cases, two networks and several alternatives to the spatial distribution of the network assets, this research outlines how these networks in the two cases respond to flooding.
Based on this research it is possible to compare the values of the resilience indicators for the two networks and the two cases. The values can be supported by the spatial aspects of the case areas and the spatial distribution of the assets of the networks.

In short the resilience roadmap consists of the following seven steps:

- By building the case model;
- By simulating the flood in the case model;
- By mapping the effects of the flood on the network;
- By calculate the damage to the network;
- By mapping the recovery of the network capacity;
- By visualising values of the resilience indicators;
- By conducting the cost-benefit analysis.

These simulations and calculations result in the four resilience indicators. Based on these four values a statement can be made about the resilience of the audited network. These four values may be underpinned and explain the spatial aspects of the area, such as the percentage of built surface, the total floor area, population density, and the different levels of elevation and inundation of the area. The spatial distribution of the assets of the network may be compared with the spatial aspects of the area.

Concluding, on basis of this research it can be stated that the resilience of critical infrastructure networks of flood prone urban areas can be related to the spatial distribution of the networks assets, with the condition that this relation must be based on a qualitative assessment of the area and network.
This statement is substantiated by the importance of further research in order to increase the validity and reliability of the methodology; this is outlined in Paragraph 9.3.

9.2 Hypotheses for further research

Due to the nature of the methodology, it was not possible to know in advance what would be assessed in order to answer the research questions. Therefore, no hypotheses could have been formulated beforehand. However, it is possible to formulate hypotheses on basis of the research results. These hypotheses lead to recommendations for further research.

On basis of the research the following five hypotheses are formulated:

1. A spatially dispersed critical infrastructure network is more resilient than a concentrated network in the event of disturbance by coastal and fluvial flooding;
2. When a concentrated critical infrastructure network can maintains the majority of its capacity in the event of disturbance, then it is more resilient than a spatially dispersed network;
3. A critical infrastructure network that can maintain the majority of its capacity in the event of disturbance can be established by the gradual distributing the total capacity over the case area, of which the majority of the capacitance is located on the section that does not become flooded;
4. By increasing the density of the built floor area with respect to the cultivated ground area by increasing the ground space index, the number of households or services that are more likely to be affected by flooding is reduced. Herewith, the ratio of the affected number of households or services decreases with respect to the total number households or services;
5. The damage caused by the indirect effects of flooding, in all alternatives considered in this research study, is greater than the damage caused by the direct effects of flooding.

9.3 Recommendations for further research

This section outlines multiple directions for further research. The recommendations for further research are twofold. Firstly, the recommendations are based on the limitations of this research are formulated concerning further validation and verification. Secondly, the recommendations are based on bright moments during the research process.

Recommendations for further research based on the limitations of this research are:

- In order to increase the validity of this research the reliable data needs to be available. The validity of further research on the effects of flooding on critical infrastructure networks can increase, by building a database on basis of an empirical analysis of the hundred greatest floods worldwide of the past century. This database enables to study the recovery process and by what it is influenced. This database enables to investigate whether there are causal relations between the case or network characteristics and the degree of resilience;
- In order to increase the validity of the cascade-effect impact schemes, the adequacy of the schemes should be tested on reality. This can be done by, at the time of the occurrence of a flood or directly afterwards, by identifying the damage within the affected area. These damage documentations can be reflected to the damage calculations of the cascade-effect

impact schemes. On the basis of this comparison it is possible to identify whether the cascade-effect impact can give an adequate representation of reality, or whether deficiencies can be identified in the schemes.

Recommendations for further research based on bright moments during the research process.

- Applying the method for calculating resilience to other networks and disturbances. The method can be useful to create insight in the resilience of other critical networks and other disturbances. Other critical networks may, for example, the drinking water network or to the network fuel. Other possible disturbances are earthquakes, the subsidence of sewage pipes, the failure of water treatment systems, the explosion of kerosene pipes or terrorist attacks.
- Defining the relationship between resilience and the factors of the spatial distribution of the assets: the relief in the substrate, the distribution rate, the line segments between the assets, the availability of the assets.
- Defining the influence of network factors like “betweenness”, interconnectedness, and the centrality on the degree of resilience.
- Finding the ratio between the resilience indicators for the maximum extent of resilience. The challenging question resulting from this research, when there is a way of mapping the resilience of networks; is therefore possible to find the optimum ratio for resilience?

Concluding, to get back to the very first sentence of this report, this sentence states:

‘Heere, geef ons heden ons dagelijks brood en af en toe een watersnood’

This Dutch saying reveals that from time to time the people want to be reminded to the need for its continuous investment in water safety, to justify this continuous investment.
To come back to this issue, this research considers the assessment and possibilities of decreasing the risk of flooding by reducing the impact. To validate this research with respect to practice, the reference to a real flood is required. Hence, the first sentence in this report.

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Appendix A: Substantiation for case studies

The selection of the two cases areas is based on characteristics that are relevant for this research. These characteristics are:

- the cases concern urbanized delta areas subject to climate extreme as flooding in the form of sea level rise, high river discharge and extreme precipitation;
- the scale of the case studies must have a significant relation in terms of area surface and amount of inhabitants;
- the application and testing of the concept "resilience" must be relevant to the chosen area;
- Witteveen+Bos is or has been active in the selected case;
- Witteveen+Bos has an internal database on the area
- in case Witteveen+Bos does not have an internal database on the area, there is sufficient data available (site visit should not be necessary);

On basis of the characteristics, the choice for the case studies was relatively pragmatic. The two cases areas, in which the critical infrastructure networks are analysed, are:

- Case 1: District 4 in Ho Chi Minh City, Vietnam
- Case 2: The nineteenth century expansion ring of Dordrecht, the Netherlands

On basis of the global screening study of Nicholls (2008) to estimate the exposure of the world's large port cities to coastal flooding, the choice for Ho Chi Minh is substantiated.

In the ranking of Nicholls of port cities with high exposure and vulnerability to climate extremes, Ho Chi Minh appears in the top-20 cities with the highest proportional increases of population and assets of the area. Figure 39 shows the highest proportional increases of population. Figure 40 shows the highest proportional increases of assets.

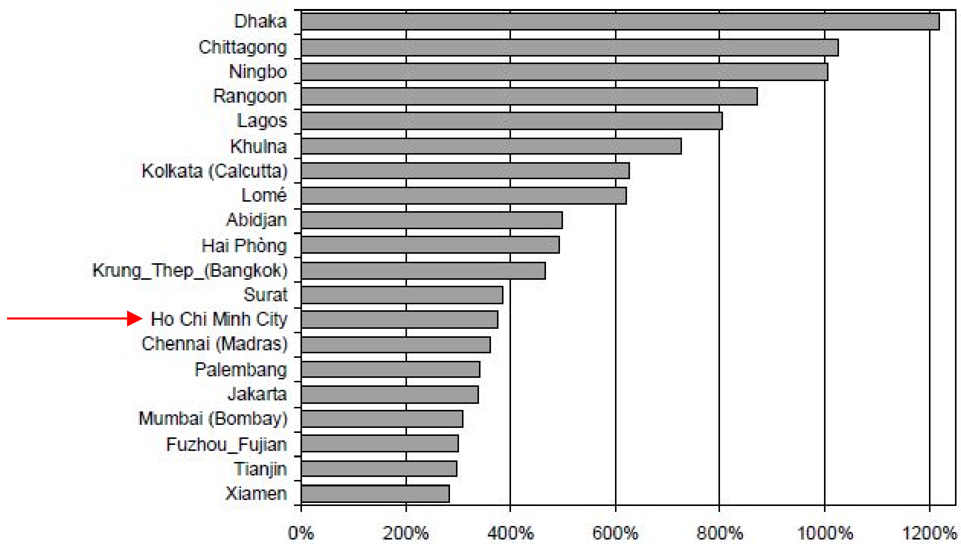


Figure 39 - Proportional increase of population in the world's largest port cities in 2070's (Nicholls, et al., 2008)

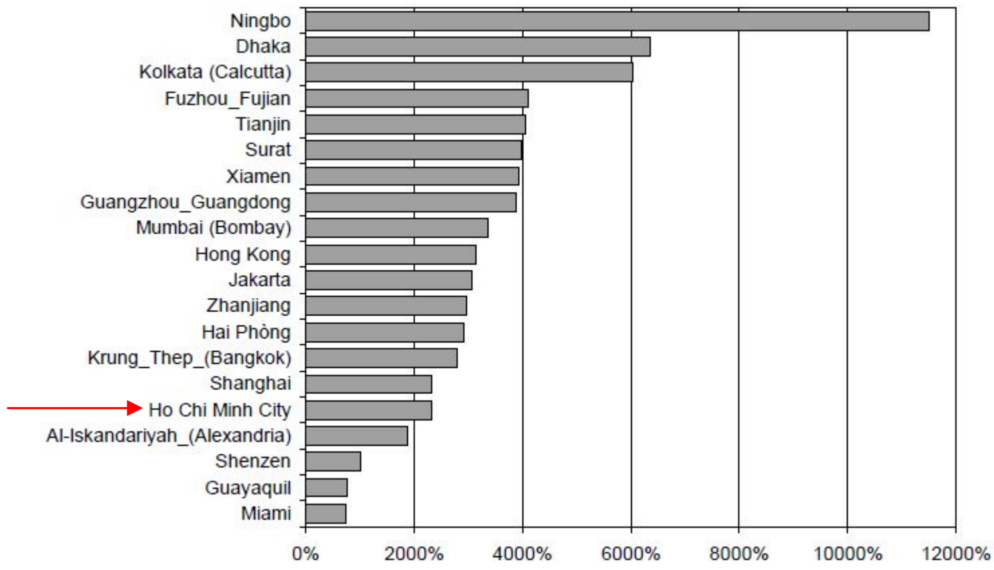


Figure 40 - Proportional increase of assets in the world's largest port cities in 2070's (Nicholls, et al., 2008)

The choice for a case study in the Netherlands is substantiated by the exposure of the population to a 1:100 extreme event compared to the potential to protect, measured by Nicholls (2008). In Figure 41 the protection criteria are given that Nicholls has used. In Figure 42 the top 10 countries is ranked by the population exposed to a 1:100 climate event.
The choice for Dordrecht was based on the fact that Dordrecht is aware of its vulnerability with respect to flooding and is acting pro-actively to increase its resilience towards flooding.

Per capita GDP (PPP) US$	Income classification	Presumed protection standard
>15,000	High	High
15,000 - 3,500	Medium	Medium
>3,500	Low	Limited, ad hoc approach

Figure 41 - Protection criteria (Nicholls, et al., 2008)

Number of cities	Exposed population (000s)	Country	GDP CLASS
15	8,154	CHINA	MEDIUM
17	6,538	UNITED STATES OF AMERICA	HIGH
6	5,412	INDIA	LOW
6	3,683	JAPAN	HIGH
2	2,725	VIETNAM	LOW
2	1,591	NETHERLANDS	HIGH
3	1,540	BANGLADESH	LOW
1	1,330	EGYPT	MEDIUM
1	907	THAILAND	MEDIUM
4	700	INDONESIA	MEDIUM

Figure 42 - Top 10 countries by population currently exposed to a 1:100 extreme event compared to potential to protect (Nicholls, et al., 2008)

Appendix B: Building the case model in ArcMap10.2.2

On basis of the data derived from the case analysis, simulations are conducted and the case areas and critical infrastructure networks are modelled with the ArcMap10.2.2 software package. ArcMap is a geographic information system that is used for modelling 2D simulations. Inundation depths and the effects of flooding can be visualized. The resulting flood inundation depths and inundated assets can be used as input for the cascade-effect impact schemes. The layers that are used in the simulations and the types and characteristics of the data are outlined below.

The base maps of Ho Chi Minh City en Dordrecht are retrieved from the online database of ArcGIS. The georeference coordinate system for Ho Chi Minh City is Hanoi_1972_GK_106_NE. The georeference coordinate system for Dordrecht is RD_NEW.

The elevation map of Ho Chi Minh City digital elevation map was retrieved from the Environment Operations Centre (EOC, 2015) based on Version 4.1 of NASA's Shuttle Radar Topographic Mission (SRTM). The map is produced in 2007. The map contains data of the elevation in meter above sea level, the geometry type is raster, the coordinate system WGS 1984. The elevation map has a spatial resolution of 20×20 m.
The elevation map of Dordrecht was retrieved from the database of Algemene Hoogtekaart Nederland (Algemene Hoogtekaart Nederland, 2015) and obtained through the website of Producten Dienstverlening op de Kaart (PDOK Loket, 2015).

The data of the inundation depths of Ho Chi Minh City is has been provided by the Steering Centre of Flood Control Ho Chi Minh City (Lasage & Veldkamp, 2015). The raster data of the maximum inundation height was imported to ArcMap in a grid-file.

The data of the inundation map of Dordrecht is retrieved from the website Platform Basisinformatie Overstromingen (Platform basisinformatie overstromingen, 2015). The data concerns the inundation scenario of the breach of the so-called BRES22-04. The raster data of the maximum inundation height was imported to ArcMap in a grid-file.

All modelled assets, critical infrastructure network assets and housings, with an inundation level higher than 0.3 meter are considered inundated and therefore not functioning.

The footprint of the build environment in Ho Chi Minh City was retrieved from Google maps. The data is put in ArcMap by hand as polygons. This method was chosen due to the lack of available existing data with a significant level of detail. Due to the limited image quality of Google maps, it is difficult / impossible to identify the boundaries of the buildings. In case of a very high density of construction in this area consisting of multiple planes, this area is displayed by only one or a few planes. Therefore, the accuracy of this method is considered debatable.

The footprint of the build environment in Dordrecht was retrieved from the online Dutch database BAG (Basisregistratie adressen en gebouwen) available via the website www.kadaster.nl (Kadaster, 2015). The data was put in ArcMap in polygons. The accuracy of this method is considered high.

The amount of floors of the build environment in Ho Chi Minh City and Dordrecht are put in ArcMap per polygon. The amount of floors was inputted on basis of information retrieved from Google street view. Due to the limited images available in the area of Ho Chi Minh City, assumptions and generalizations are made on basis of photos and other images. Therefore, the data for this case is considered generalized and debatable. Due to the high amount of available images in the area of Dordrecht, the amount of floors is inputted per polygon. Therefore, the accuracy of the data for this case is considered good.

The location of the assets of the healthcare network in Ho Chi Minh City are based partly on documents of the internal database of Witteveen+Bos concerning the assets with larger capacities like the hospitals, and partly on assumptions as there was no data on the geographical location of the asset with smaller capacities like the ward medical centres. The locations of the assets are put in ArcMap as data point per asset.

The location of the assets of the healthcare network in Dordrecht are based on data found on the registered healthcare online database Zorgkaart Nederland (Zorgkaart Nederland, 2015). The locations of the assets are put in ArcMap as data point per asset.

The locations of the assets of the electricity network in Ho Chi Minh City are based on documents of the internal database of Witteveen+Bos and the online database Flosm. In both data sources little to no data was found on the location and types of assets of the electricity network in the case area. This observation is discussed in Chapter 8.

The location of the assets of the electricity network in Dordrecht are based on documents of the internal database of Witteveen+Bos, the report of Souwer & Den Ouden, Tennet and the online database Flosm. Flosm is an initiative to create a free world map with which everyone can help to develop these maps. Since the database of this website is publically maintained and managed, the trustworthiness of this database can be questioned. However, the data of these cards is the most accurate of all the data found during this research.

The structure of layers in the flood maps is visualised in Figure 43.

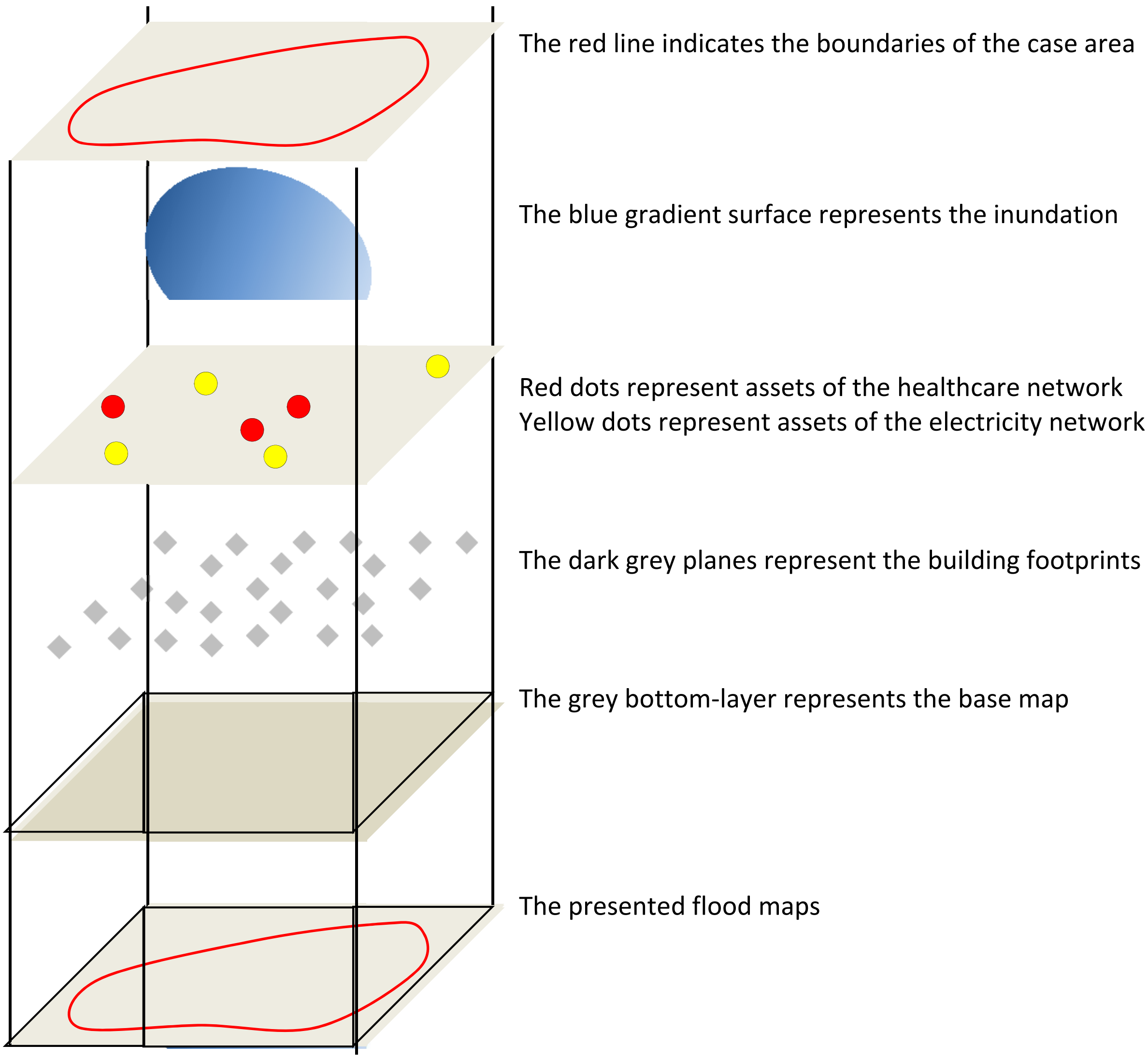


Figure 43 - The structure of layers in the flood maps

Appendix C: The development of the cascade-effect impact schemes

The necessity of the cascade-effect impact schemes is outlined (§C.1). The concept of the schemes is set put (§C.2). The composition of the schemes is outlined (§C.3). The process and the development of schemes is outlined (§C.4), hereby all of the validation steps are explained. The process and the development of model is outlined (§C.5), hereby all of the validation steps are explained. Finally, the two resulting schemes are presented (§C.6). The profiles of the experts that have validated the cascade-effect impact schemes is outlined (§C.7). The validation of the cascade-effect impact scheme are outlined (§C.8). The use of the cascade-effect impact schemes can be found in Chapter 5.

Note: the cascade-effect impact schemes are developed specifically for this research. However, this study does not claim that this is a unique method. Comparable procedures of mapping cause-effect with multiple-order effects already exist in several appearances. This study indicates that these schemes are developed specifically for this research as the approach of cause-effect suits the research objectives.

C.1 The necessity for cascade-effect impact schemes

This chapter focuses on creating insight in the impact of a flooding event by visualizing and outlining the cascade-effects of a flooding event on critical infrastructure networks. The impact is considered as the damage resulting from direct and indirect effect of the flooding events on the specific critical infrastructure networks.

Flooding events are often expressed by means of a depth-damage function. This is an interpolation of real damage data caused by historical flooding events in terms of the depreciation of assets. However, often the relation between the event and its economic impact, based on direct and indirect effects, is not outlined. Calculations that are made to define the impact are often not transparent, not published or not reproducible. Therefore it is difficult to determine where exactly the causes of the total damage lay. This problem is sketched in Figure 44.

The necessity for cascade-effect impact schemes is substantiated with literature. Jonkman (2004) states that the method for calculating damage, according to the depth-damage functions, a commonly used way in damage calculations, is mainly focused on the estimation of the direct economic damage. Jonkman expects that by using this method, the indirect effects of flooding are ignored and consequently resulting in a structural under-estimation of the values of damage. According to Jonkman there are methods that contribute to the economic value of loss of lives, environmental damage; these are generally not included in the cost-benefit analysis.
There is no general accepted framework available where the relevant pieces of information are put together. These schemes are a step towards the required approach of integrated damage estimations.

Prettenthaler (2010) and Merz *et al.* (2004) state that depth-damage functions are essential for floor damage assessments. Prettenthaler states that in general flood damage functions are not necessarily based on direct and indirect damage estimations. Prettenthaler and Thieken *et al*. (2005) emphasize that the damage of indirect effects should gain more attention in damage estimations.

Notaro *et al.* (2014) state that the current method of damage calculation as interpolations of real damage data related to the hydraulic characteristics of the flood e.g. the inundation level, the combination of water depth and velocity, or the duration. As the direct tangible damage are easily assessed in terms of monetary costs, this data is preferred in the damage calculations (Prettenthaler, Amrusch, & Habsburg-Lotheringen, 2010; Merz, Kreibich, Thieken, & Schimdtke, 2004; Meyer & Messner, 2006). The depth-damage functions that are defined are normally based on interpolation flooding depth and damage data usually obtained by means of systematic survey procedures that analyse historical flood events of insurance claims data. Notaro and Dotta *et al.* (2009)hereby emphasizes that the depth-damage functions affected by a degree of intrinsic uncertainty.

C.2 The concept of the cascade-effect impact schemes

The cascade-effect impact schemes, designed during this research, enable to visualize the relation between a flooding event and its impact. The process of calculating the impact is made transparent through mapping the cascade-effects; these are the direct and indirect effects, and their valuation on basis of amount, damage and duration. This solution is sketched in Figure 45. The cascade-effect impact schemes can identify where and how the alternatives can reduce the impact of a flood. The development of the schemes is outlined in Appendix C.4.

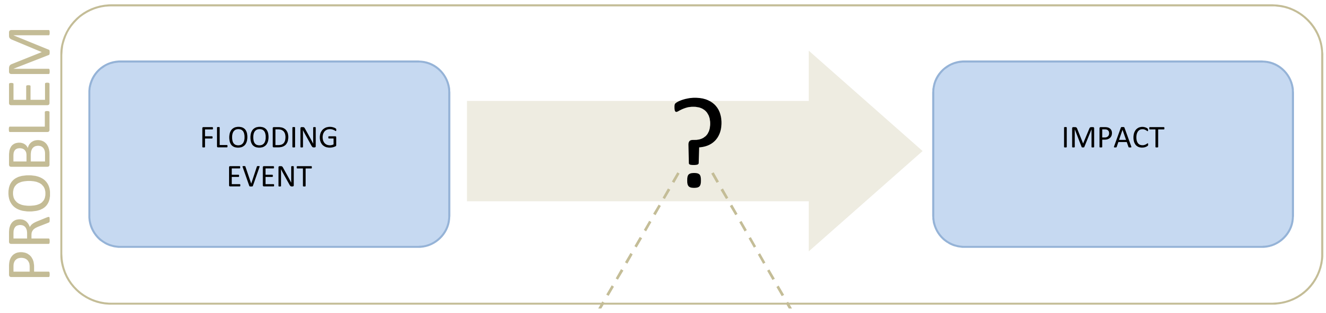


Figure 44 - The problem in current flood impact assessment

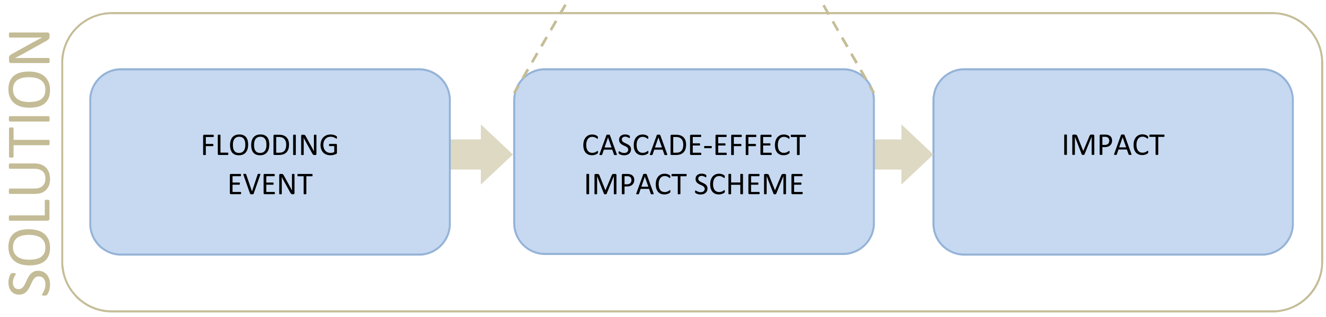


Figure 45 - The solution to flood impact assessment

Concluding, the goal of the development of the cascade-effect impact schemes is threefold:

- To literally visualize the cascade-effects by means of the sequences and their relationships;
- To visualize how the economic impact of an event is calculated;
- To support for assessments of the alternatives.

C.3 The composition of the cascade-effect impact schemes

The composition of the cascade-effect impact schemes is based on four components:

5. The distinction between diverging and converging in the reproduction of reality. This distinction is visible in the top row of Table 16. The purpose of the diverging, working out the cascade-effects, is to reproduce the reality as precise as possible. The cascade-effects, with the four orders of effect, can give an accurate representation of reality. The goal of converging, structuring the cascade-effects, is to manage the representation of reality (outlined in the diverging phase tree) as much as possible. The cascade-effects are structured by a distinction between people / production-consumption / objects (this distinction is mentioned in Paragraph 2.4).
6. The sequence of the effects on the horizontal axis
7. The assessment of the economic impact on the horizontal axis (after the order effects); composed of the amount of damaged objects, the damage value per object over time, the duration of the damage and the economic impact of the effect expressed in monetary value.
8. The distribution of the effects on the vertical axis; this is basis on the structure that is maintained in the UCF; people, metabolism, buildings, public space, infrastructure, subsurface.

The conceptual framework of the cascade-effect impact schemes can be found in Table 16.

Table 16 - The conceptual framework of the cascade-effect impact scheme structure

Diverging						Converging			
	Order effect					Assessment of impact			
Classification	1^{st}	2^{nd}	3^{rd}	4^{th}	Classification	Amount (#)	Damage indicator (#€/t)	Duration (t)	Damage (€)
People					People				
Metabolism					Prod.-cons.				
Public space					Objects				
Buildings					- residential				
Infrastructure					- service				
Surface					-production				
Total damage (€)									

C.4 The development of the cascade-effect impact schemes

The development of the cascade-effect impact schemes consists of 5 phases; these can be found in Figure 46.

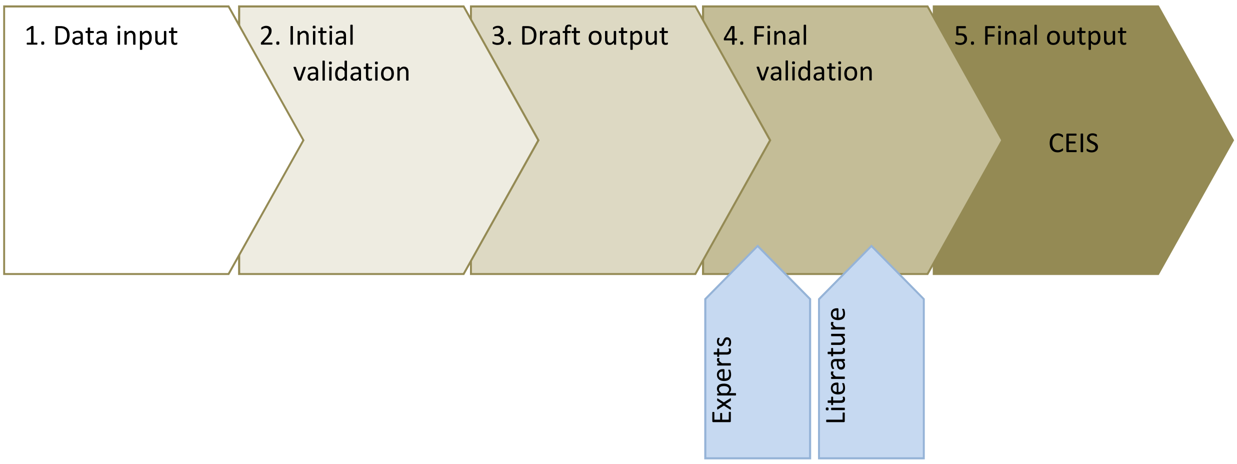


Figure 46 - The development phases of the cascade-effect impact schemes

1. Data input; the data is obtained through two brainstorm sessions involving employees of Witteveen+Bos. The employees of Witteveen+Bos had various specializations such as project management, environmental impact assessment, water management, contract management and systems engineering. The employees of Witteveen+Bos participated on a voluntary basis. The sessions took place during lunch time, which is according to the company culture. These sessions are referred to as the brainstorm sessions. Per brainstorm session one critical infrastructure network is treated. The cascade-effects are mapped on basis of pure "peasants" logic. The cascade-effects are worked out in pairs on an A3 sheet. The brainstorm session, in which the healthcare network was analysed by 13 employees, resulting in 6 documents. In the second brainstorm session the electricity network was analysed by 10 employees, resulting in 5 documents. The result of these brainstorm sessions can be found in Appendix C.8.
2. Initial validation; the data input is validated according to validation criteria. The data that meets the criteria is documented in the draft output.

3. Draft output; the generated data, obtained through the brainstorm sessions, is translated to a draft version of the cascade-effect impact schemes on the basis of validation criteria.
4. Final validation; the draft output is validated by external experts and literature according to final validation criteria. The data that meets the final validation criteria is documented in the final output. The profiles of the experts can be found in Appendix C.7.
5. Final output; the final cascade-effect impact schemes is developed on the basis of these final validation. The results of the final output are the cascade-effect impact schemes.

Validation cascade-effect impact schemes

The data input is validated in two stages, the initial validation and the final validation. Criteria are formulated for the validation stages. The criteria are outlined in the next two paragraphs. The validation criteria are summarized in Table 17. The validation schemes can be found in Appendix C.8.

Table 17 - Scheme with validation criteria for cascade-effect impact schemes

Initial validation		Final validation		In CEIS
Mentioned > 2 times in data input brainstorm session (no final validation needed)	Mentioned 1 time in data input brainstorm session (final validation needed)	Expert	Literature	
Yes				Yes
No	Yes	Yes	Yes	Yes
No	Yes	Yes	No	Yes
No	Yes	No	Yes	Yes
No	Yes	No	No	No
No	No	Yes	Yes	NA
No	No	Yes	No	NA
No	No	No	Yes	NA

Initial validation cascade-effect impact schemes

The criteria to validate the input of the brainstorm sessions are:
- If the effect is mentioned two or more times in the data input, then the effect is validated and is included directly in the cascade-effect impact schemes. No final validation is needed.
- If the effect is mentioned one time in the data input, then the effect is not validated and will not be included directly in the cascade-effect impact schemes. The final validation is needed.

Final validation cascade-effect impact schemes

The final validation is performed for the effects that were not validated in the initial validation stage.

The final validation is based on feedback and knowledge of experts and literature. With experts meaning: persons working outside Witteveen+Bos in relevant working fields (relevant to the specific CIN) or employees of Witteveen+Bos who have not participated in the brainstorm sessions. Per CIN three experts have validated the draft output. An overview of the six experts that were interviewed with a short illustration of their relevance to this research is given in Appendix C.7.

On basis of semi-structured interviews with these experts the draft output was validated. An overview of the experts and the interviews is given in D.

The criteria to validate the draft output are:
- if the effect is confirmed by one interviewee and by literature, then the effect is included in the cascade-effect impact schemes;
- if the effect is confirmed by one interviewee, but no confirmation was found in literature, then the effect is included in the cascade-effect impact schemes;
- if the effect is not confirmed by one interviewee, but the confirmation was found in literature, then the effect is included in the cascade-effect impact schemes;

- if the effect is not confirmed by one interviewee and not confirmation was found in literature, then the effect is not included in the cascade-effect impact schemes;

Note: the precondition is that the cascade-effect impact scheme contains only effects that are mentioned in the brainstorm sessions. Since the data input of the brainstorm sessions is limited, it is possible that an expert and / or literature mention a relevant effect that does not occur in the input data. In this case, the effect is regarded as not applicable, represented as NA. Hence, effects that are not mentioned in the brainstorm sessions are not considered further in the final validation.

C.5 The cascade-effect impact schemes

An overview of the results of the cascade-effects can be found in Appendix D.

C.6 The application of cascade-effect impact scheme

The cascade-effect impact schemes are used to evaluate the alternatives. An alternative is an intervention by which the extent of the impact of a flooding event is reduced. The assumption is that an alternative can stop a branch of the cascade-effects.

The effect of an alternative is visualized by means of the cascade-effect impact schemes. The cascade-effect impact schemes visualize where the alternative interferes in the branching of the cascade-effects, and which branch of effects it disables.

The alternative is evaluated based on a cost-benefit analysis to determine whether the benefits of the measure outweigh the costs. The costs are literally the costs for the implementation of the measure. The benefits are equal to the reduction of the impact. The concept of the application of the cascade-effect impact schemes for the evaluating of an alternative by means of a cost-benefit analysis is sketched in Figure 47. The blue boxes represent the calculation of the impact of the flooding event by means of the cascade-effect impact schemes. The orange boxes represent feedback of the cost-benefit analysis of the specific alternative.

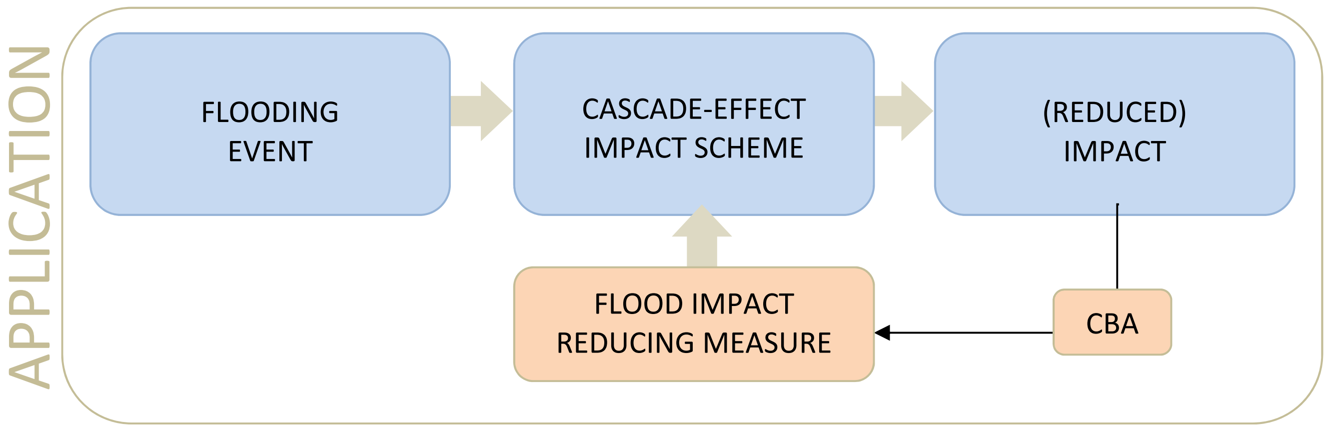


Figure 47 - The application of the cascade-effect impact scheme to asses flood impact reducing measures

An alternative is viable when the costs are smaller than the benefits. An alternative is not viable when the costs are higher than the benefits. The cost-benefit analysis outcome is inconclusive when the costs of an alternative are equal to the benefits; more research for substantiation is needed.

The cascade-effect impact schemes in combination with the cost-benefit analysis make it very clear whether an alternative is viable. The alternatives are evaluated and strategically chosen.

C.7 Profiles of experts

In this section an overview is presented of the profiles of the six experts that were interviewed. A short illustration of their relevance to this research is given.

Name	Ellen Kelder
Current profession	Project manager MARE at the municipality of Dordrecht
Experience	Program manager water in municipality (2000 - now) Publication "Process design and management for integrated flood risk management: exploring the multi-level safety approach for Dordrecht, the Netherlands"
Network	Healthcare network

Name	Nico van Os
Current profession	Project manager at "veiligheidsregio Zuid-Holland Zuid"
Experience	Project Manager European projects. Was involved in project MARE. General policy and management consultancy relating to the promotion of multidisciplinary cooperation and the formation of the security in South Holland South. Administrative secretary of the Security Board and risk management program leader.
Network	Healthcare network

Name	Pim van Dam
Current profession	Specialist in the field of the Medical Combination in the region South-Holland South at the GHOR ZHZ (emergency medical assistance organization in the region South-Holland South)
Experience	Involved in the national developments on behalf of the Ministry of internal Affairs, planning of disaster preparedness plans, active in the Action Center GHOR ZHZ both during emergencies (as Head Action Center) and in the preparation time.
Network	Healthcare network

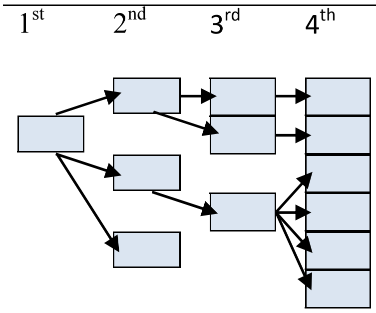
Name	Berry Gersonius
Current profession	Lecturer in Urban Flood Resilience at UNESCO-IHE
Experience	Publication "Managing flood risk in the urban environment: linking spatial planning, risk assessment, communication and policy. In: Adaptive and Integrated Water Management: coping with complexity and uncertainty."
Network	Electricity network

Name	Bert van Dorp
Current profession	Energy development at Witteveen+Bos
Experience	Renewable energy, Solar energy (PV, heat), Energy storage, Energy saving built environment, Simulate and optimize energy networks, Energy Scenarios
Network	Electricity network

Name	Srirama Bhamidipati
Current profession	PhD researcher at TU Delft Associate at RoyalHaskoning DHV
Experience	Specializes in urban transportation planning, focused on the development of simulation models for transportation asset management.
Network	Electricity network

In Figure 48 the application of the cascade-effect impact schemes is illustrated. For the 0-alternative, the current situation of a network, all order effects are included in the calculation of the total damage, resulting in a value of 2,385,000.

Order effects



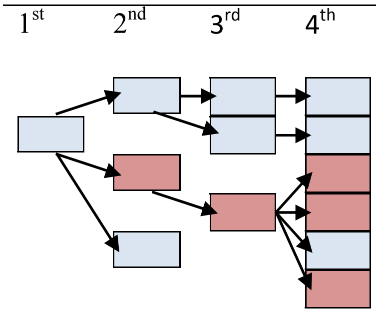
Quantification effects

Affected objects	Duration	Damage indicator	Damage
10	10	50	5,000
1000	200	10	2,000,000
20	100	200	100,000
50	50	100	250,000
10	200	10	20,000
1	500	20	10,000
		0-alternative total damage	2,385,000

Figure 48 - The application of the cascade-effect impact schemes to simulate alternatives

In Figure 49 the implementation of an alternative is illustrated. When implementing an alternative, it is possible to exclude possible effects of the flood on the network. In Figure 49 this is illustrated by the red boxes. For the 1-alternative, a modification of the same network, the damaged is reduced to 2,075,000.

Order effects



Quantification effects

Affected objects	Duration	Damage indicator	Damage
10	10	50	5,000
1000	200	10	2,000,000
10	200	10	20,000
		1-alternative total damage	2,075,000

Figure 49 - The application of the cascade-effect impact schemes to simulate alternatives

C.8 Validation schemes of the cascade-effect impact scheme

The validation of the cascade-effect impact scheme of the electricity network is presented below.

Effect	Data input: Amount	Percentage	Order	Initial validation (amount of times mentioned in data input): ≥ 2	< 2	Final validation: Expert	Literature	In CEIS: yes/no	Order
Casualties	10	200,00%	2,3,4,6	yes				yes	1,2,3,4
Malfunctioning electricity industry	7	140,00%	0,1,2	yes		Bert van Dorp		yes	2
Increased risk of fire	6	120,00%	3,4	yes		Bert van Dorp		yes	3
Traffic congestion	6	120,00%	2,3	yes				yes	2,3,4
Lighting in houses inoperative	4	80,00%	1,2	yes				yes	1
People makeshift light with fire	4	80,00%	2,3	yes				yes	2
Telecommunication inoperative	4	80,00%	2	yes				yes	1
Limited escape routes	4	80,00%	2,4	yes				yes	2
Accidents	3	60,00%	2,3	yes				yes	2,3,4
Street lighting inoperative	3	60,00%	1,3	yes				yes	1
Traffic Information System inoperative	3	60,00%	1	yes				yes	1
Increase of travelling time	3	60,00%	2,3	yes		Berry Gersonius		yes	3,4
Disorder	3	60,00%	2,3	yes		Ellen Kelder, Bert van Dorp		yes	1,2,3,4
Decrease of level general hygiene	3	50,00%	2,3,4	yes				yes	2
Fuel runs out	3	60,00%	1,3	yes				yes	3
Increase of flooding duration	3	60,00%	2,3	yes				yes	2,3
Increase of risk criminality	2	40,00%	2,4	yes		Bert van Dorp		yes	2
Public transport inoperative (trains / trams / metro)	2	40,00%	1	yes				yes	1
Drainage pumping stations inoperative	2	40,00%	1	yes				yes	1
Increase of inundation level	2	40,00%	2	yes				yes	2
Damage to/from hazardous energy producing factories	1	20,00%	1	no	yes	Bert van Dorp		yes	1
Damage to electricity network (high voltage pylons, substations, cables)	1	20,00%	1	no	yes	Bert van Dorp		yes	1
Decrease of capacity electricity network	1	20,00%	1	no	yes	Bert van Dorp		yes	2
Accidents electricity industry	1	20,00%	2	no	yes	Bert van Dorp		yes	2
Explosion electricity industry	1	20,00%	2	no	yes	Bert van Dorp		yes	2
People do not go on streets	1	20,00%	3	no	yes	Pim van Dam		yes	2
People do not go to work	1	20,00%	4	no	yes	Berry Gersonius		yes	2
Alarmsystems inoperative	1	20,00%	1	no	yes	Bert van Dorp		yes	1
Companies inoperative	1	20,00%	5	no	yes	Berry Gersonius		yes	1,2,3,4
Cooking equipment inoperative	1	20,00%	1	no	yes	Pim van Dam		yes	1
Food can not be cooked	1	20,00%	2	no	yes	Pim van Dam		yes	2
Refridgerators inoperative	1	20,00%	1	no	yes	Pim van Dam		yes	1
Food can not be cooled	1	20,00%	2	no	yes	Pim van Dam		yes	2
Immobility of ambulances	1	20,00%	3	no	yes	Pim van Dam, Nico van Os		yes	3,4
Immobility of fire fighters	1	20,00%	6	no	yes	Bert van Dorp		yes	3,4
Immobility of police forces	1	20,00%	4	no	yes	Bert van Dorp		yes	3,4
Sewer system inoperative	1	20,00%	2	no	yes	Ellen Kelder, Nico van Os		yes	1
Drinkwater system inoperative	1	20,00%	2	no	yes	Bert van Dorp		yes	1
Overload public transport	1	20,00%	2,3	no	yes	Ellen Kelder, Berry Gersonius		yes	2
Communication via radio (on battery) (finite duration)	1	20,00%	1,2	no	yes	Ellen Kelder		yes	2
Limited communication	1	20,00%		no	yes	Pim van Dam		yes	2
Banks inoperative	1	20,00%	1	no	yes	Berry Gersonius		yes	1
No cash withdraw	1	20,00%	2	no	yes	Berry Gersonius		yes	2
No payment with cash money	1	20,00%	3	no	yes	Berry Gersonius		yes	3
No payment with card	1	20,00%	2	no	yes	Berry Gersonius		yes	2
No money transactions	1	20,00%	2,3	no	yes	Berry Gersonius		yes	2,3
Roads inundated	1	20,00%	3	no	yes	Ellen Kelder		yes	3
Inflation	1	20,00%	6	no	yes			no	
People leave the area	1	20,00%	4	no	yes			no	
More use of bikes	1	20,00%	2	no	yes			no	
Bridges inoperative	1	20,00%	1	no	yes			no	
Barrier gates inoperative	1	20,00%	1	no	yes			no	
Parking garages inaccessible	1	20,00%	1	no	yes			no	
Deteriorating quality nature	1	16,67%	2	no	yes			no	
Deteriorating quality livability	1	16,67%	3	no	yes			no	
Sewer pipes will float in weak subsoil	0	0,00%		no	yes	Sriram Bhamidipati		no	
Floating sewer pipes will damage roads	0	0,00%		no	yes	Sriram Bhamidipati		no	
Drinkwater pipes will float in weak subsoil	0	0,00%		no	yes	Nico van Os		no	
Communication with air traffic inoperative	0	0,00%		no	yes	Berry Gersonius		no	
Plane traffic limited	0	0,00%		no	yes	Berry Gersonius		no	
Plane to divert to alternative location	0	0,00%		no	yes	Berry Gersonius		no	
Plane to crash when fuel runs out	0	0,00%		no	yes	Berry Gersonius		no	
Plane is forced to land	0	0,00%		no	yes	Berry Gersonius		no	

Literature:		
Reference	Reference in scheme	
Bhamidipati (2015)	A	not yet
Bhamidipati (2014)	B	not yet

The validation of the cascade-effect impact scheme of the healthcare network is presented below.

Effect	Data input			Initial validation (amount of times mentioned in data input)		Final validation		In CEIS	
	Amount	Percentage	Order	≥ 2	< 2	Expert	Literature	yes/no	Order
Electricity network in hospital inoperative	6	100,00%	1,2	yes				yes	1
Injured	5	83,33%	1,2	yes				yes	1
Decrease of accessibility aid workers	5	83,33%	2,3	yes				yes	3
Work overload aid workers	5	83,33%	1,2,3,5	yes				yes	2,3,4
Decrease of health (physical/mental)	5	83,33%	2,4,5	yes				yes	2,3,4
Decrease of safety	4	66,67%	2,3,4	yes		Nico van Os		yes	1,2,3,4
Roads inundated	4	66,67%	1,3	yes				yes	1
Medicine supply runs out	4	66,67%	2,3	yes				yes	3
Lack of capacity health care	4	66,67%	2,3,5	yes				yes	2
Telecommunication inoperative	3	50,00%	1,3	yes				yes	1
Decrease of accessibility patients	3	50,00%	3	yes				yes	3
Decrease of accessibility houses	3	50,00%	1	yes				yes	1
Immobile patients must be evacuated	3	50,00%	2	yes				yes	2,3,4
Response time of emergency aid increases	3	50,00%	1,3	yes				yes	3
Decrease of hospital capacity	3	50,00%	1,3,4	yes				yes	1
Limited communication	2	33,33%	2	yes				yes	2
Drinkwater supply inoperative	2	33,33%	1,3	yes		Nico van Os		yes	1
No drinking water	2	33,33%	2			Nico van Os			2
Casualties	2	33,33%	4,5	yes		Pim van Dam, Ellen Kelder, Nico van Os		yes	1,2,3,4
Decrease of accessibility hospitals	2	33,33%	1	yes				yes	1
Decrease of accessibility utility services	2	33,33%	1	yes				yes	1
Damage to hospital by flood water	2	33,33%	1,2	yes				yes	1
Damage to medical devices by flood water	2	33,33%	1			Nico van Os			1
Overload (uninundated) roads	2	33,33%	2,3	yes				yes	2
Epidemie / outbreak disease	2	33,33%	3,4	yes				yes	3,4
Medical devices inoperative	2	33,33%	1,2	yes		Ellen Kelder, Pim van Dam		yes	2
Cooled medicine warm up	2	33,33%	2	yes		Nico van Os		yes	3
Medicine become unusable	2	33,33%	2	yes				yes	2,3
Patients can not be treated	2	33,33%	2,3	yes				yes	2,3,4
Hospitals witch to emergency power aggregate	2	33,33%	1,2	yes		Ellen Kelder, Nico van Os		yes	2
Emergency power aggregate runs out	2	33,33%	1,2	yes		Ellen Kelder, Nico van Os		yes	3
No electricity in hospital	2	33,33%	3			Pim van Dam, Nico van Os			4
Digital records of patients are unservicable	2	33,33%	2	yes		Nico van Os		yes	2
Providing assistence remotely through communication	1	16,67%	2	no	yes	Pim van Dam		yes	2
Drowning	1	16,67%	2	no	yes	Ellen Kelder		yes	1
Immobility ambulances	1	16,67%	4	no	yes	Pim van Dam		yes	2
Immobility fire fighters	1	16,67%	2			Pim van Dam		yes	2
Patients must be replaced	1	16,67%	3	no	yes	Pim van Dam		yes	2,3,4
Cooling systems of medicines inoperative	1	16,67%	1	no	yes	Nico van Os		yes	2
Hospital employees can not access hospital	1	16,67%	1	no	yes	Pim van Dam		yes	2
Set priority on treatment patients	1	16,67%	2	no	yes	Pim van Dam		yes	3
Decreased quality of health care network	1		5	no	yes	Nico van Os		no	
Psychiatric patients in public	1	16,67%	1	no	yes			no	
Health care network malfunctions	1	16,67%	1	no	yes			no	
Availability financial resources	1	16,67%	2	no	yes			no	
Availability healthcare resources	1	16,67%	3	no	yes			no	
Availability healthcare	1	16,67%	2	no	yes			no	
Community building	1	16,67%	3	no	yes			no	
Temporary injury to patients	1	16,67%	3	no	yes			no	
Less mobile/self-reliant	1	16,67%	4	no	yes			no	
New medical staff	1	16,67%	2	no	yes			no	
Use of innovative local solutions	1	16,67%	3	no	yes			no	
Insufficient power supply for whole hospital	1	16,67%	2	no	yes			no	
Trauma helicopter	1	16,67%	4	no	yes			no	
Home care	1	16,67%	4	no	yes			no	
Subsoil pipes (sewer, drinking water) float up	0	0,00%		no	yes	Nico van Os		no	

Literature:	
Reference	Reference in scheme

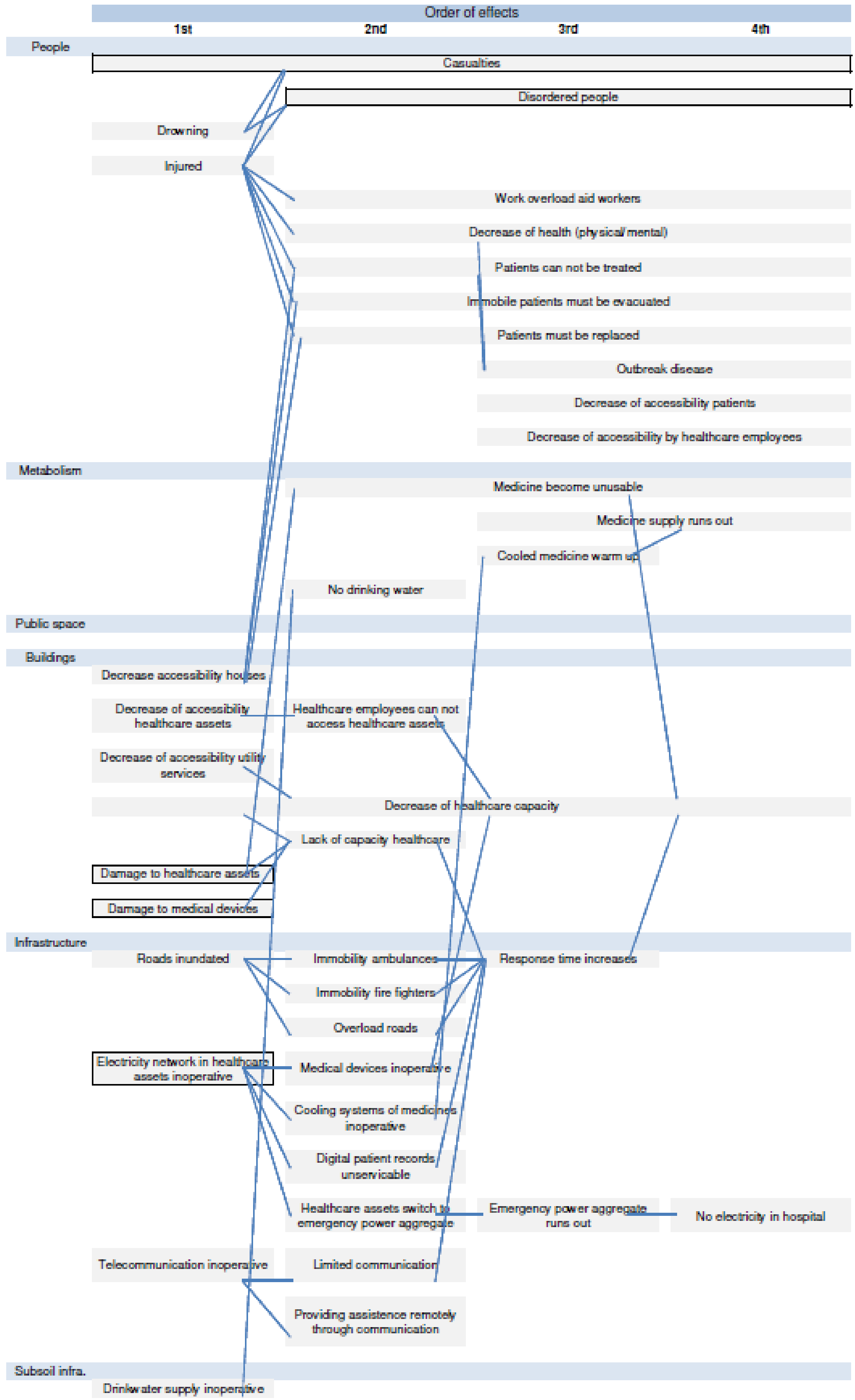
Appendix D: The resulting cascade-effect impact schemes

In this appendix the resulting cascade-effect impact schemes are presented per alternative per network. No distinction is made between the case studies.

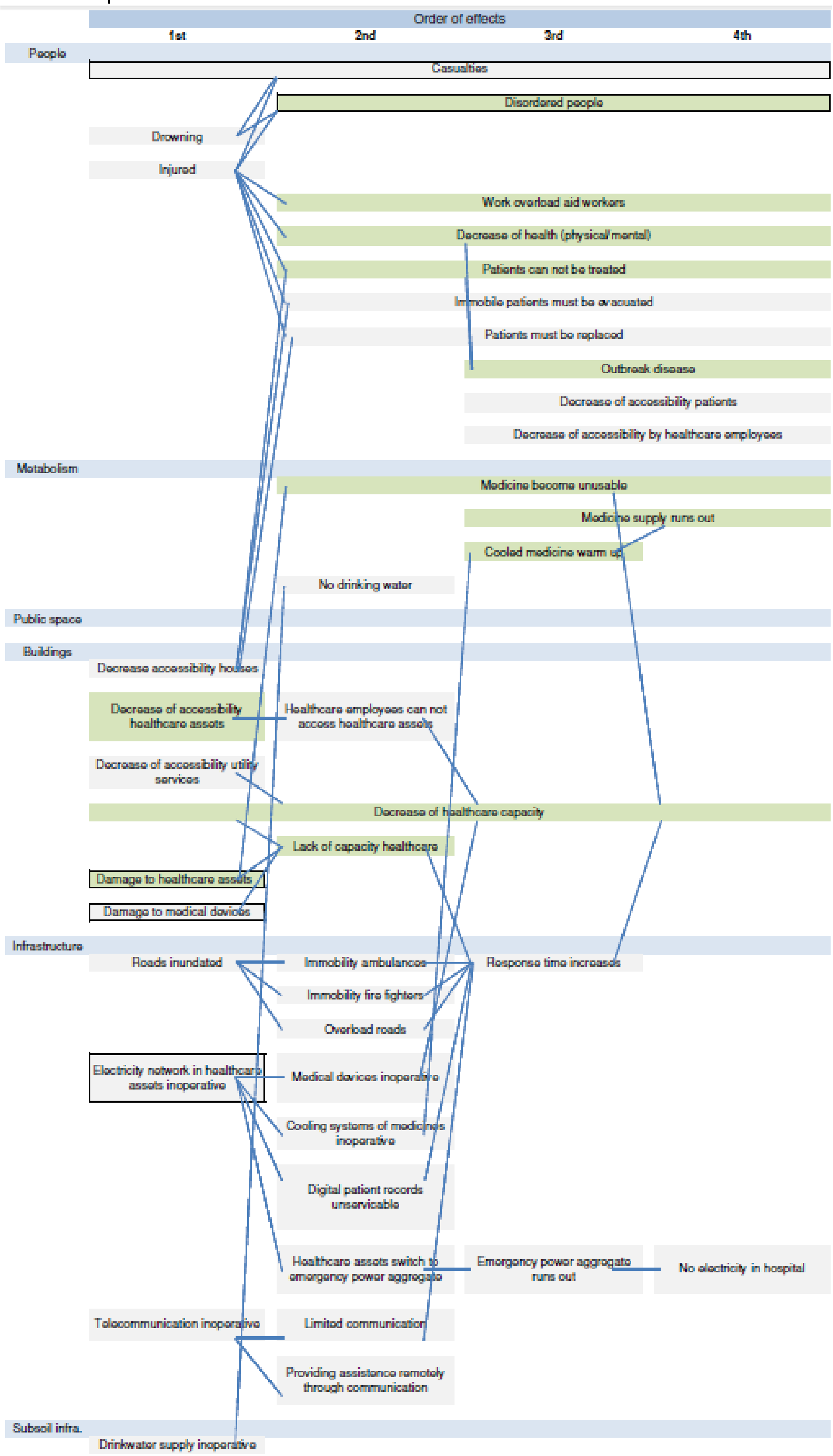
In the schemes multiple indications are used for the effects, these are outlined below.

effect x	The effect with the grey background was identified during the development of the schemes, but it is not taken into account in the damage calculations.
effect x	The effect with the grey background was identified during the development of the schemes, and is taken into account in the damage calculations.
effect x	The effect with the green background was identified during the development of the schemes as prevented by the alternative, but it is not taken into account in the damage calculations.
effect x	The effect with the green background was identified during the development of the schemes as prevented by the alternative, and is taken into account in the damage calculations.

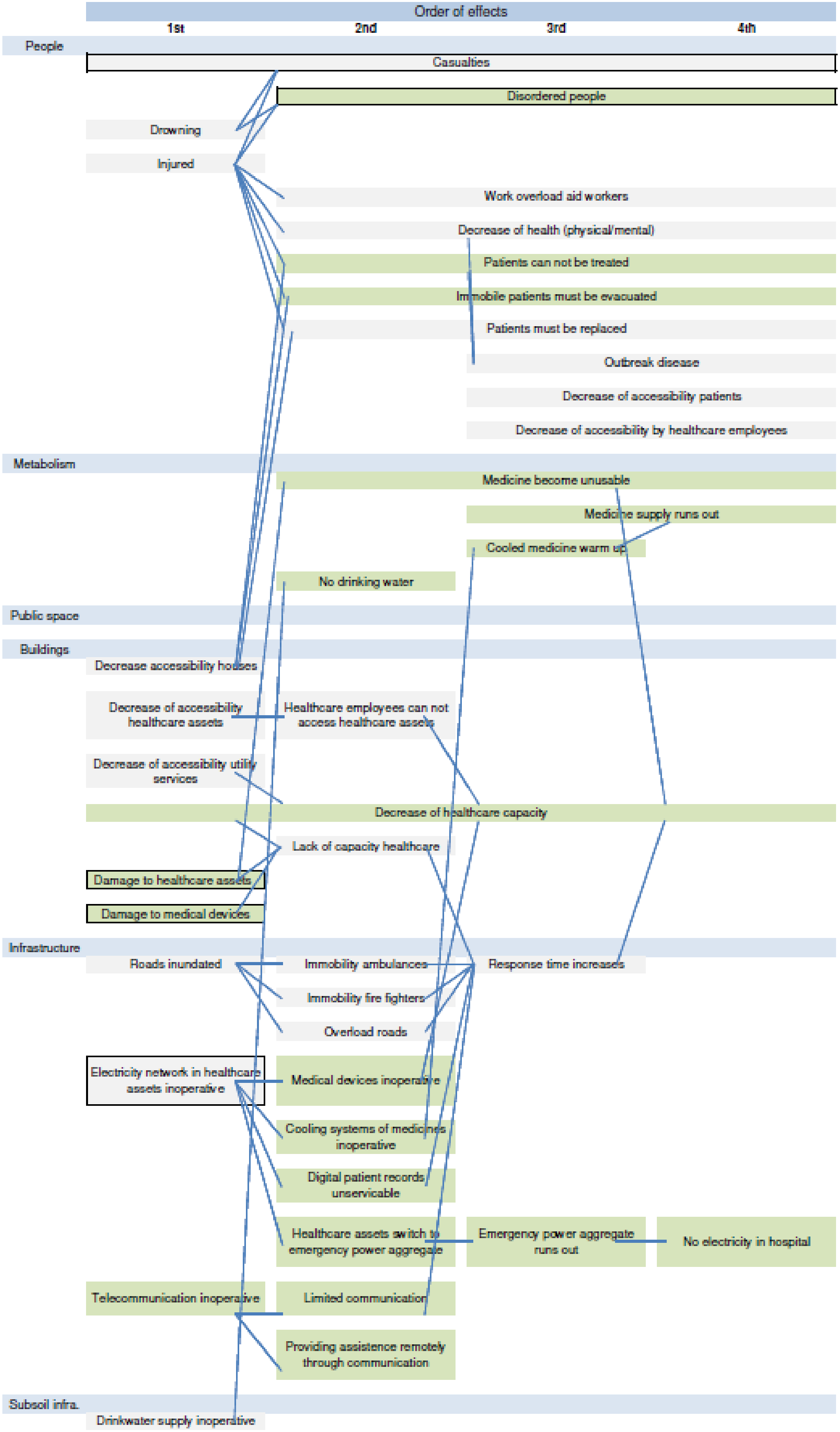
Cascade-effect impact scheme for 0-alternative in healthcare network



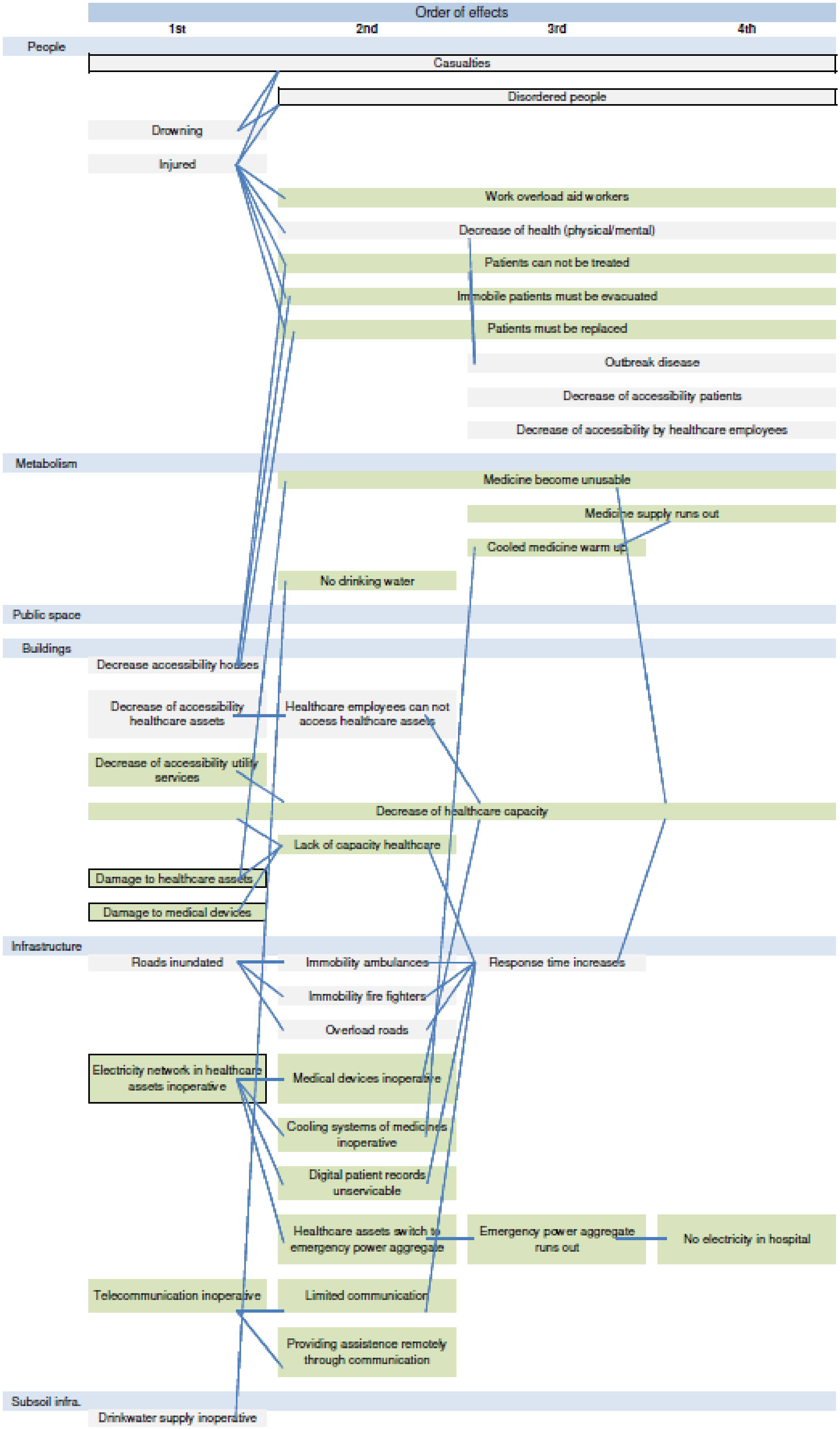
Cascade-effect impact scheme for 1-alternative in healthcare network



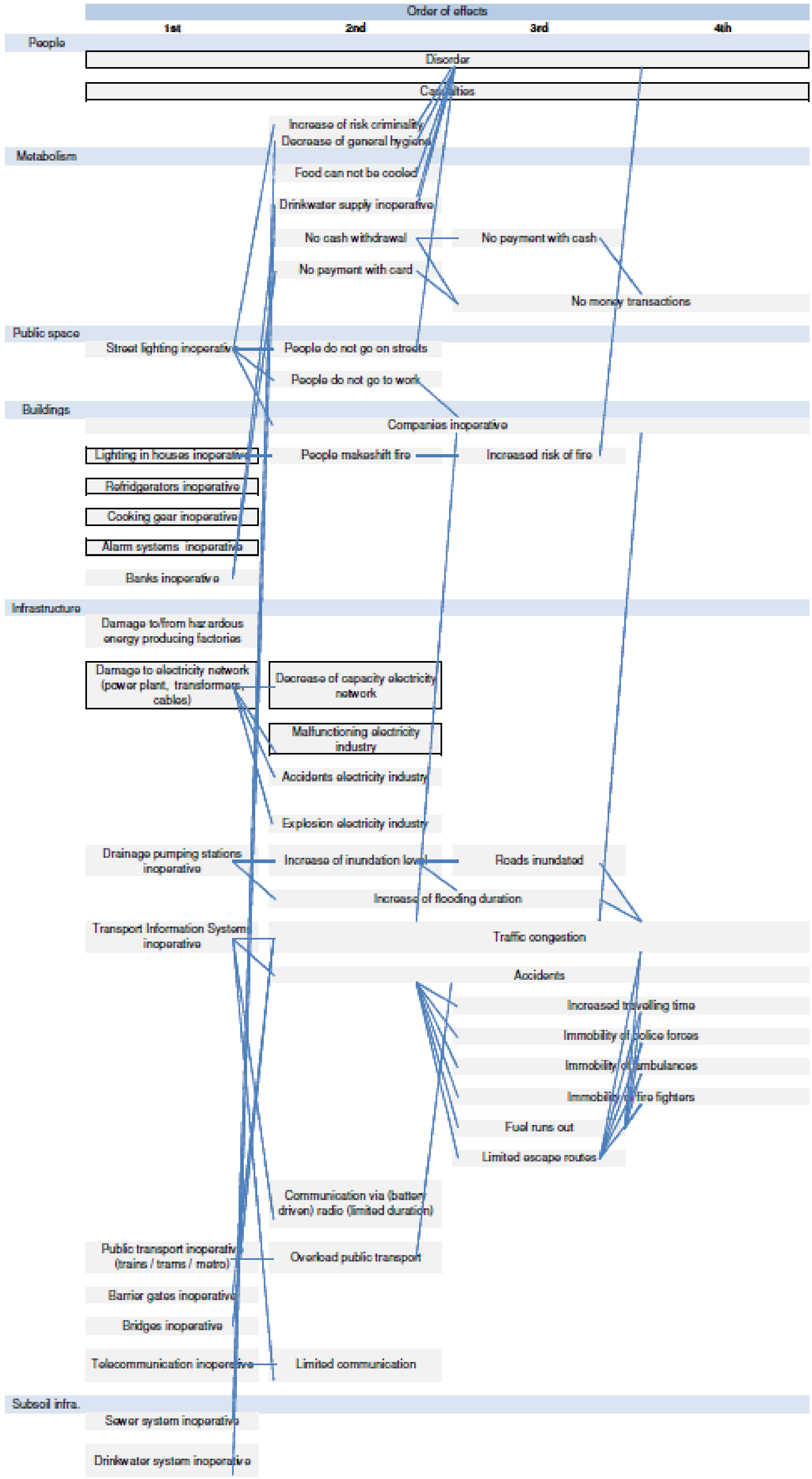
Cascade-effect impact scheme for 2-alternative in healthcare network



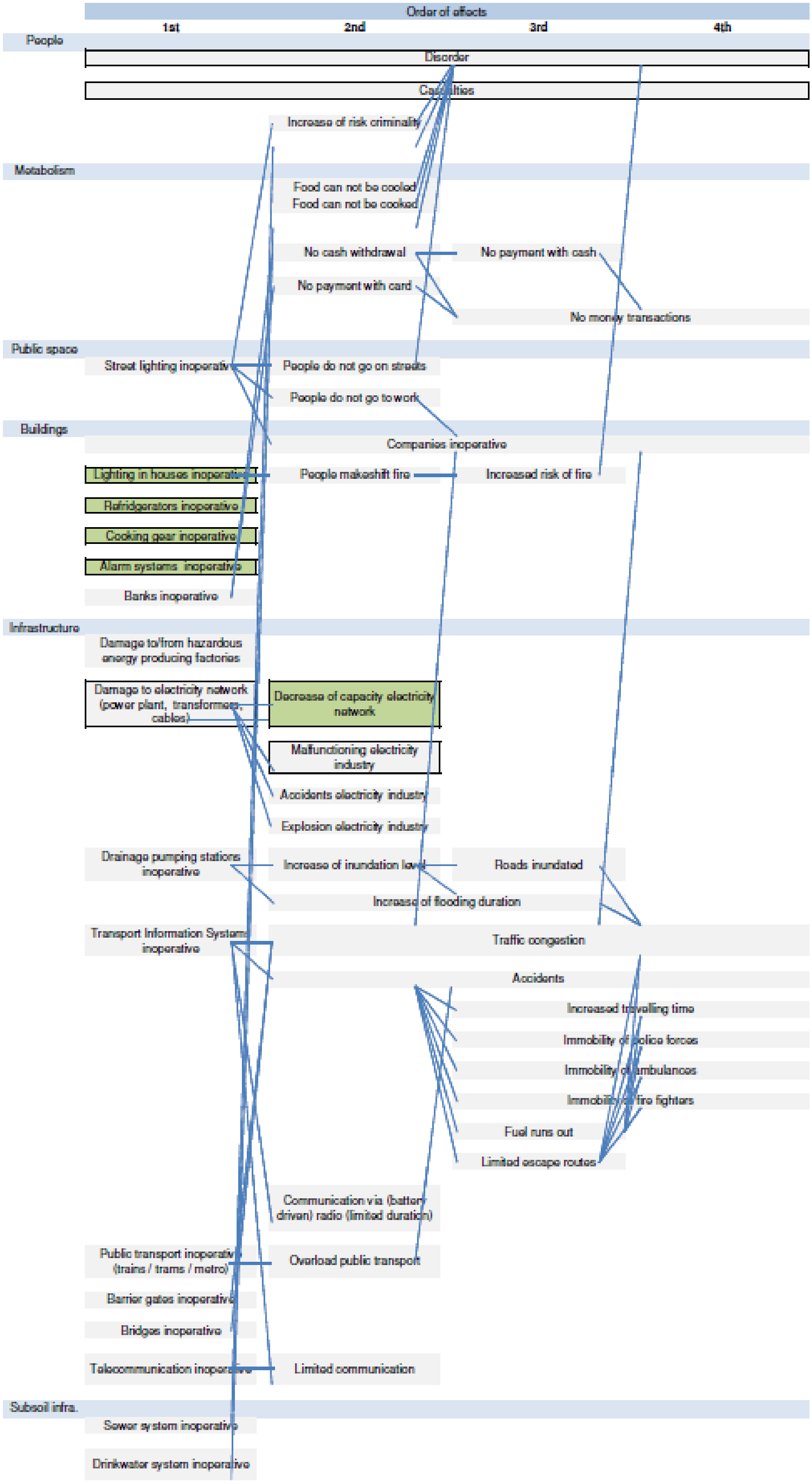
Cascade-effect impact scheme for 3-alternative in healthcare network



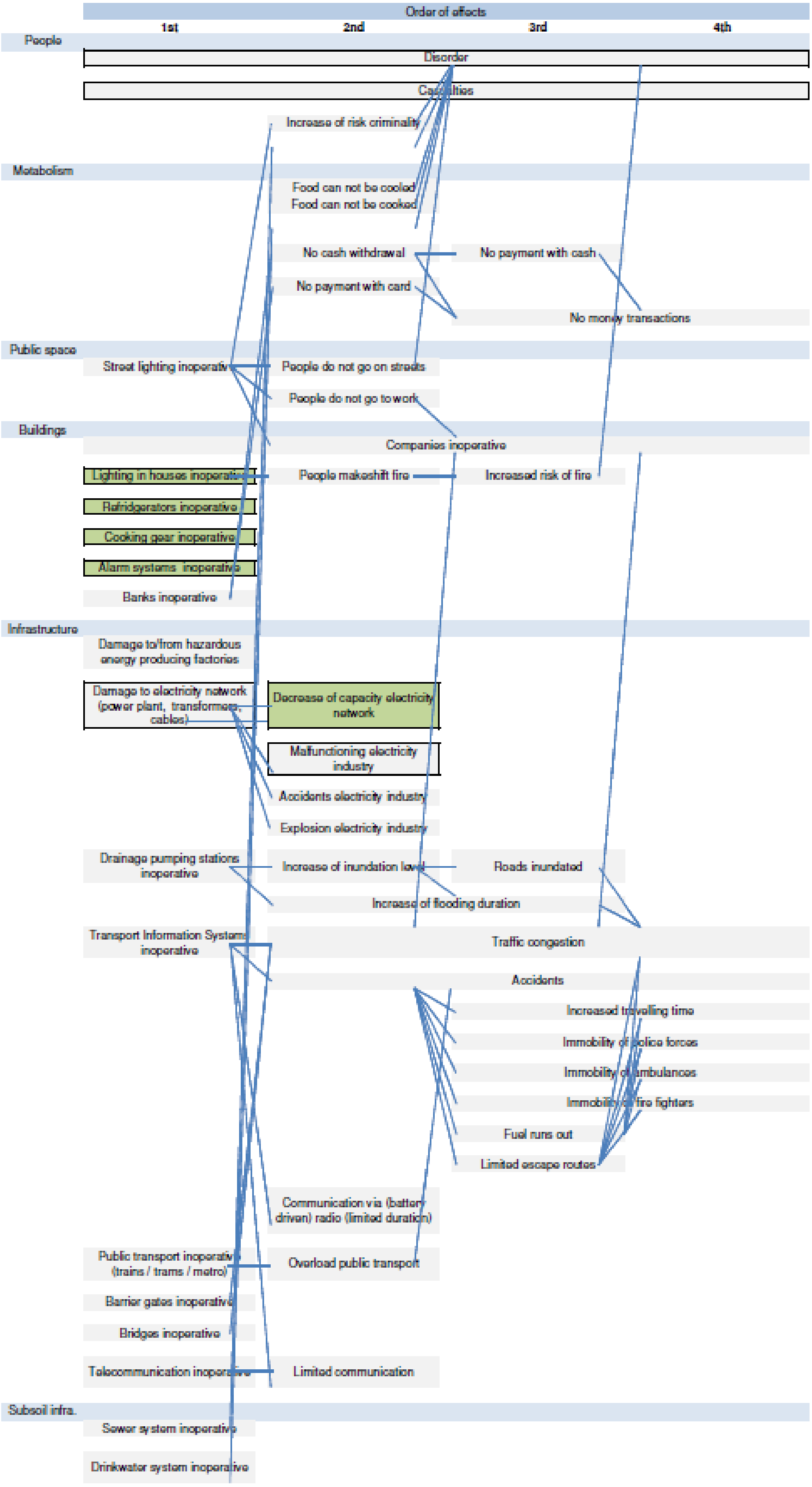
Cascade-effect impact scheme for 0-alternative in electricity network



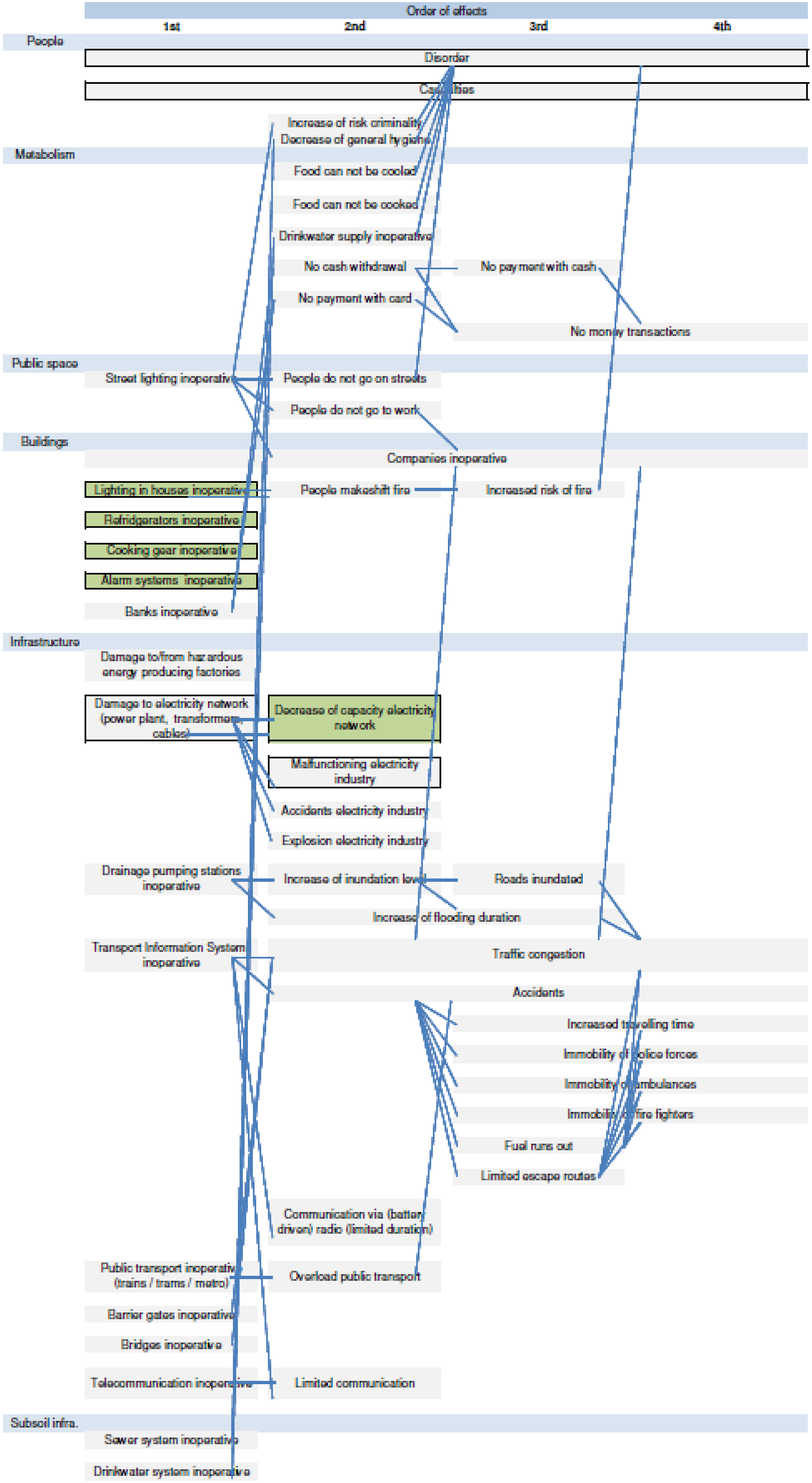
Cascade-effect impact scheme for 1a-alternative in electricity network



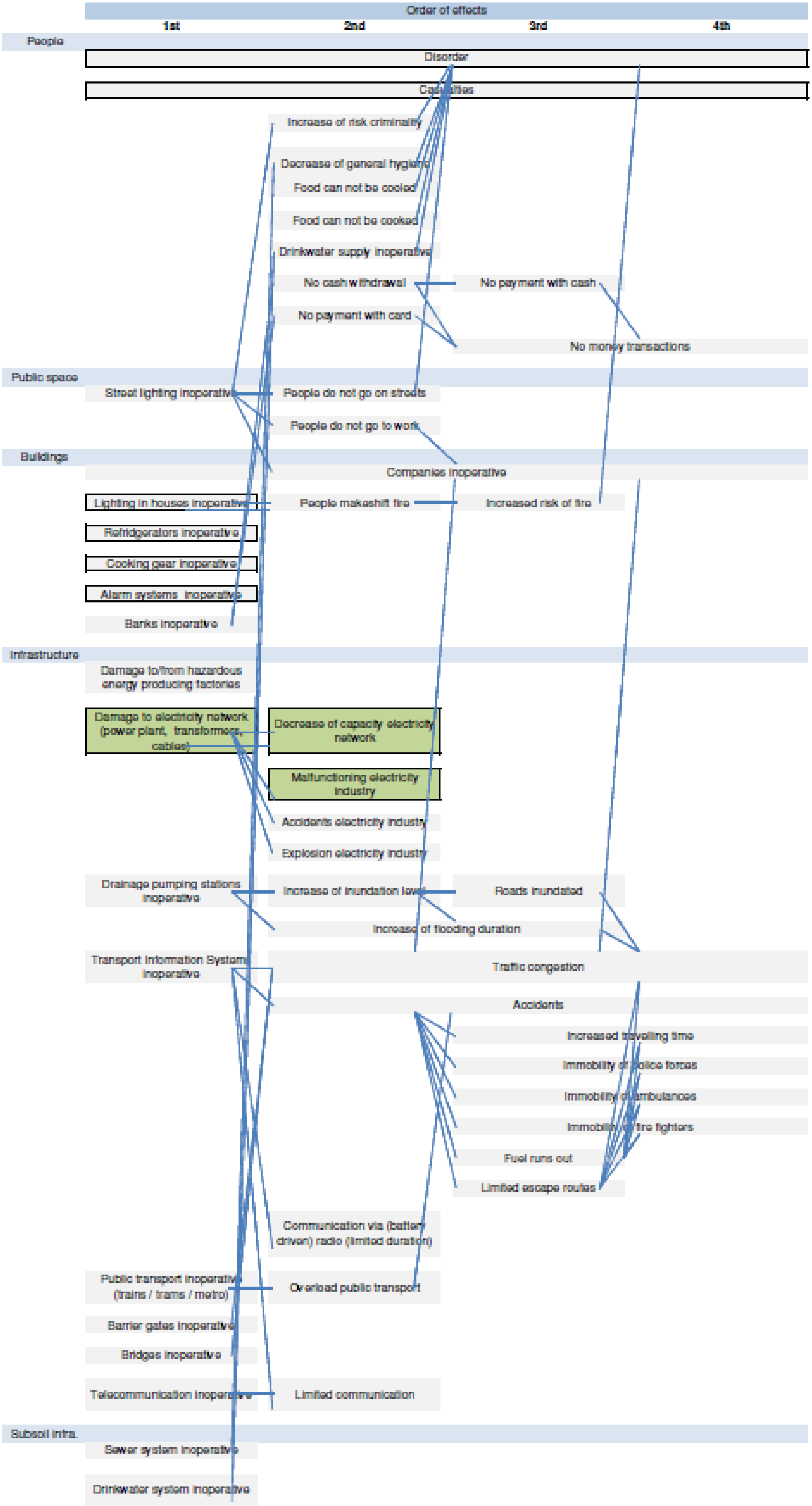
Cascade-effect impact scheme for 1b-alternative in electricity network



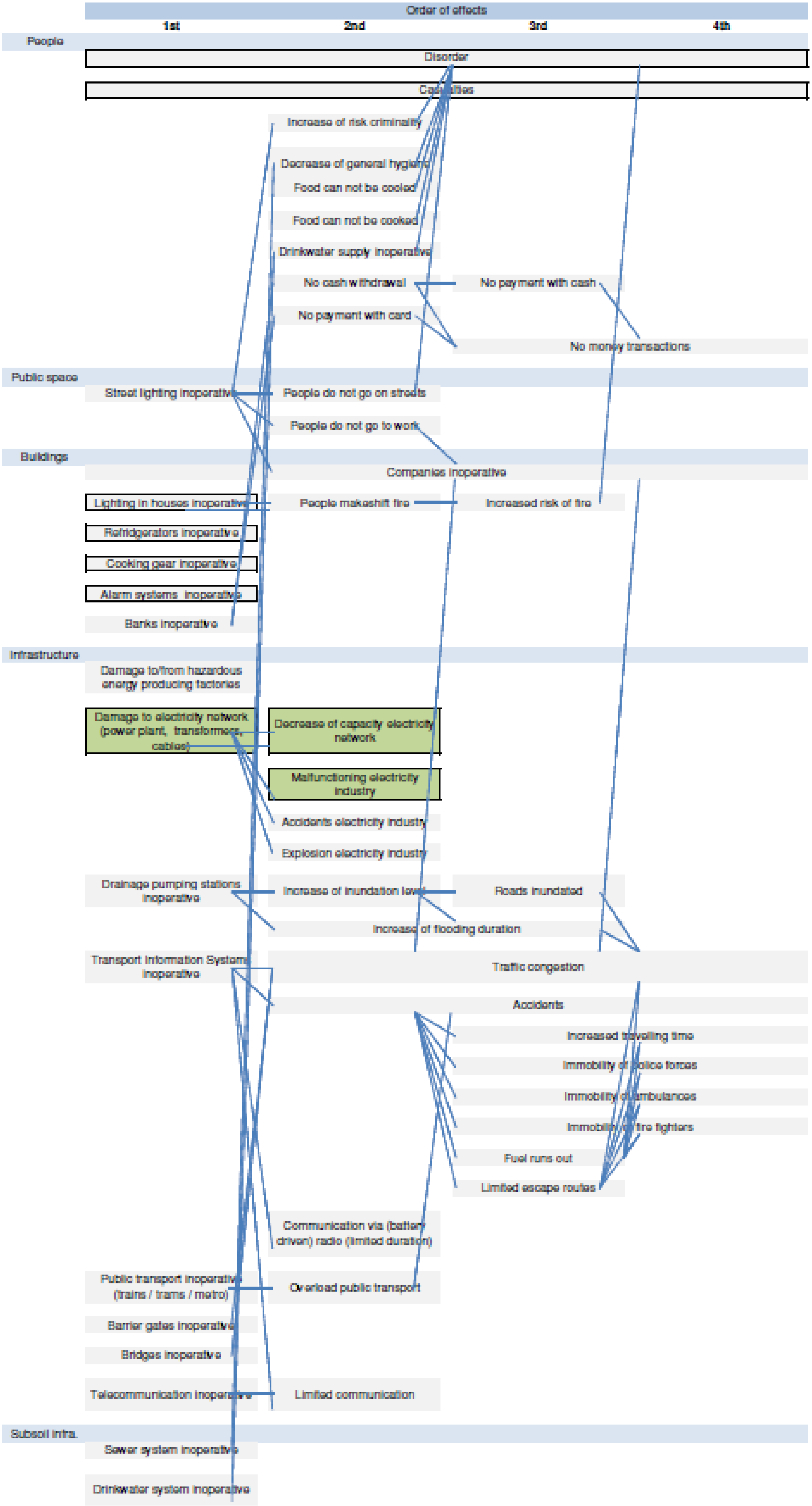
Cascade-effect impact scheme for 1c-alternative in electricity network



Cascade-effect impact scheme for 2-alternative in electricity network



Cascade-effect impact scheme for 3-alternative in electricity network



Appendix E: The damage indicators

In this appendix the damage indicators are presented that are used to calculate the damage of the effects outlined in Chapter 5 and the annexed Atlas of Mapping Resilience. First the damage indicators for the healthcare network are outlined. Second the damage indicators for the electricity network are outlined.

Damage indicators healthcare network

Effect	Quantity	Unity	Source
VIETNAM			
Dead	7000.00	€/p	www.comparaivegeometrcs.orpres.cm
Disordered	0.44	€/p/hr	Estimation on basis of data Netherlands
Patients visting asset	8.96	p/day	WHO CHOICE unit costs estimates 2007-2008
Costs per patient	1.73	€/p	WHO CHOICE unit costs estimates 2007-200
Asset closedfor 24 hours	1.5	€	Estimation on basis of WHO
Asset closed for 1 hour	0.65	€	Estimation on basis of WH
Repair asset	125.00	€	Estimation on basis of data Netherlands
Survival kit (1-alt)	1.50	€	Estimation on basis of data Netherland
Waterproofing assets (2-alt)	2.50	€	Estimation on basis of data Netherlands
One centralized (3-alt)	2500.00	€	Estimation on basis of data Netherlands
NETHERLANDS			
Dead	400000.00	€/p	Jongeman, Jonkman, Vrijling (2004), Vrijling, Van Gelder 00
Disordered	1000	€/p/hr	Estimation o bsis of order of magnitude
Patients visiting asset	8.96	p/day	WHO CHOICE unit cot estimates 2007-2008
Costs per patient NL	60.85	€/p	WHO CHOICE unit costs estimates 2007-200
Asset closed for 24 hours	522	€	Estimation on basis of WH
Assetcle for 1 hour	13.63	€	Estimation on basis of WHO
Repair asset	5000.00	€	Estimationo basis of order of magnitude
Survival kit (1-alt)	60.00	€	Estimation on basis of order of magnitude
Waterproofing assets2alt.	2500.00	€	Estimation on basis of order of magnitude
One centralized (3-alt)	100000.00	€	Estimation on basis of order of magnitude

Damage indicators electricity network

Effect	Quantity	Unit	Source
VIETNAM			
Dead	7000.00	€/p	https://comparativegeometrics.wordpress.com /2014/02/26/value-of-a-life/
Disordered	044	€/p/hr	Calculation on basis of comparativegeometrics and economic ratio Netherlands-Vietnam
Consumption households	23.64	kWh	Estimation on basis of reports Witteveen+Bos
Unconsumed electricity per household	0.13	€/kWh	Calculation on basis of Rathenau (1994) and economic ratio Netherlands-Vietnam
Costs unconsumed electricity household	2.95	€/hr	Calculation on basis of reports Witteveen+Bos and Rathenau
Energy consumption service	9.45	kWh	Estimation on basis of reports Witteveen+Bos
Unconsumed electricity service	1.50	€/kWh	Calculation on basis of Rathenau (1994) and economicratio Netherlands-Vietnam
Costs unconsumed electricity service	1.18	€hr	Calculation on basis of reports Witteveen+Bos and Rathenau
Repair transformer	250.0	€	Estimation on basis of WHO and economic ratio Netherlands-Vietnam
Repair household/service	50.00	€	Estimation on basis of WHO and economic ratio Netherlands-Vietnam
Emergency power generator (1a-alternative)	20.00	€	Estimation on basis of WHO and economic ratio Netherlands-Vietnam
Fuel for emergency power generator 1a-alternative)	0.04	€/liter	Estimation on basis of WHO and economic ratio Netherlands-Vietnam
Cost of installation solar panel (1b-alternative)	150.00	€	Extrapolation on basis of www.zonnepanelen.nl and economic ratio Netherlands-Vietnam
Energy production solar panel (1-alternative)	40000	kWh/yr	Extrapolation on basis of www.zonnepanelen.nl and economic ratio Netherlands-Vietnam
Energy production solar panel (1b-alternative)	0.39	kWh/hr	Calculation on basis of www.zonnepanelen.nl and economic ratio Netherlands-Vietnam
Energy production benefits (1b-alternative)	0.05	€/kWh	Calculation on basis of www.zonnepanelen.nl and economic ratio Netherlands-Vietnam
Flood proofing household/service (1c-alternative)	20.00	€	Estimation on basis of WHO and economic ratio Netherlands-Vietnam
Flood proofing transformer (2-alternative)	50.00	€	Estimation on basis of WHO and economic ratio Netherlands-Vietnam
One central asset (3-alternative)	20000.00	€	Extrapolation on basis of Stedin and newspapers and economic ratio Netherlands-Vietnam
Connection to central asset (3-alternative)	12.50	€	Extrapolation on basis of Stedin and newspapers and economic ratio Netherlands-Vietnam
NETHERLANDS			
Dead	400000.00	€/p	Jongeman, Jonkman, Vrijling (2004), Vrijling, Van Gelder (2000)
Disordered	1.00	€/p/hr	Estimation on basis of order of magnitude
Consumption households/services	3360.00	kWh/yr	www.nibud.nl (2015)
Consumption households/services	0.38	kWh/hr	www.nibud.nl (2015)
Unconsumed electricity per household	6.00	€/kWh	Estimation on basis of Rathenau (1994), Bijvoet (2003), EPRI (1989), Woo and Pupp (1992)

Costs unconsumed electricity household	1.92	€/hr	Estimation on basis of www.nibud.nl (2015) and Rathenau (1994)
Unconsumed electricity service	60.00	€/kWh	Estimation on basis of Rathenau (1994)
Costs unconsumed electricity service	23.01	€/hr	Estimation on basis of www.nibud.nl (2015) and Rathenau (1994)
Repair transformer	10000.00	€	Estimation on basis of Stedin and newspapers
Repair household/service	000.00	€	Estimation on basis of Stedin and newspapers
Emergency power generator (1a-alternative)	800.00	€	www.gamma.nl
Fuel for emergency power generator (1a-alternative)	1.50	€/liter	Estimation on basis of prices fuel
Cost of installation solar panel (1b-alternative)	600000	€	www.zonnepanelen.nl
Energy production solar panel (1b-alternative)	3400.00	kWh/yr	www.zonnepanelen.nl
Energy production solar panel (1b-alternative)	0.39	kWh/hr	Calculation on basis of www.zonnepanelen.nl
Energy production benefits (1b-alternative)	1.94	€/kWh	Calculation on basis of www.zonnepanelen.nl
Flood proofing household/service (1c-alternative)	800.00	€	Estimation on basis of Stedin and newspapers
Flood proofing transformer (2-alternative)	2000.00	€	Estimation on basis of Stedin ad newspapers
One central asset (3-alternative)	800000.00	€	Estimation on basis of Stedin and newspapers
Connection to central asset (3-alternative)	500.00	€	Estimation on basis of Stedin and newspapers