Possible secondary consequences of flooding in the municipality of Reimerswaal

An analysis of critical infrastructure vulnerability to flooding and potential cascading effects

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Submitted by Jevgenijs Kuzmins

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Author:

Jevgenijs Kuzmins
student number: 00060129
email_1: kuzm0002@hz.nl
email_2: jevgenij.kuzmin@gmail.com

Supervisors:

HZ:	Jean-Marie Buijs
VRZ:	Marcel Matthijsse, MSc

Abstract

Extreme natural events such as flooding and earthquakes can cause major disruption of lifelines for entire cities and even larger areas. Civil infrastructures such as energy, water, transportation, and telecommunications that provide base for economic prosperity and well-being of a nation, can leave communities in disarray if they are disrupted. This goal of this research project is to analyze the vulnerability of critical infrastructure to a potential flooding event in the municipality of Reimerswaaal in the Netherlands and estimate the overall socio-economic consequences of that infrastructure being disrupted. This implies cascading effects of one critical infrastructure failure on functioning of other infrastructures and the consequent inconveniences and hazards to economy and daily lives of the people within the area experiencing the secondary consequences. The methodology and results of this analysis consider the exposure and vulnerability of critical infrastructure with respect to official expected and modeled flooding events as well as the topology of the area and the socio-economic background.

Contents

List of tables

List of Figures

1. Introduction

Modern day life in an economically active society is hardly imaginable without the availability of some basic commodities such as electricity, gas and water. Entire populations of both developed and developing countries and regions benefit from, and highly depend on immediate and effortless availability of energy, drinking water, transportation and communication in order to sustain their lifestyles as well as the economic activity of the community as a whole. The ability to travel and transport goods as well as the ability to easily utilize modern means of information exchange and processing – although might not be as important for well-being of a given individual - are a fundamental condition for functioning of modern day society. Being so depended upon, such services are expected to be available and accessible to all members of a given community at all times without disruption. Therefore the physical infrastructure that facilitates those highly valuable services is termed as “critical infrastructure” (from here on out referred to as CI). The most basic examples of CI would be roads, drinking water supply lines, electricity lines, sewer lines etc. Modern communication and supply lines are rather complex and - more importantly - interconnected systems. In most cases production and supply of one form of energy, e.g. electricity depends on availability and utilization of another kind of energy carrier – fossil fuels e.g. gas, coal, or oil. (Heilemann, 2013). This illustrates a rather basic example of one supply line being dependent on another. Additional example would be a drinking water supply line depending on availability of electricity to run the pumps in order to maintain sufficient water pressure in the pipelines.

These examples of interdependencies between various CI assets are mentioned to introduce the concept of possible cascading events of one CI line on network failure causing a failure of another. Although cascading events are likely to happen during natural disaster events such as flooding, even a disruption of a single critical infrastructure line caused by a technical failure could potentially have severe consequences.

In the Southwestern Delta, flood safety professionals acknowledge that Reimerswaal is a vulnerable spot in the critical infrastructure services for the whole Mid-Zeeland region. Despite the acknowleged vulnerability, no previous studies have been conducted about the possible consequences of CI failure in Reimerswaal for the rest of Zeeland. The discussions by professionals from the Safety Region, Province Zeeland and Rijkswaterstaat have resulted in following research question:

How vulnerable are the critical infrastructures in the area of Reimerswaal and what would be the secondary consequences of those infrastructures failing?

The goal of this research project is to analyze the vulnerability of CI in Reimerswaal and propose a credible scenario of possible secondary consequences experienced in the Mid-Zeeland peninsula, should any of the CI services in Reimerswaal become unavailable due to a flooding event.

Since there is no published material available on the vulnerability of critical infrastructure in the area, this project is an exploratory research. The methodology of this research however is based on frameworks and experience of such research done elsewhere (see Chapter 2. Research method). The most appropriate and reasonable way of obtaining data or information for this type of research as well as validating conclusions is interviewing relevant stakeholders.

This research is within the context of the EU Floods Directive that require all member states to assess all water courses and coastlines that are at risk of loading and to take coordinated preventive measures (European Parliament, 2007). It is also within the context of the Dutch Multi-layer flood safety (MLS), focusing mostly on layer 3 – disaster management (Horst G. t., 2011), but is also concerning the other two layers in terms of assessing the primary consequences of a flooding (Slomp, 2012). The responsibility of disaster management layer of the MLS in the Netherlands lies on governmental organizations called the Safety Regions. Among the task of the Safety Regions, listed in their official act, are taking stock of fire, disaster and crisis risks, and advising the competent authorities on such risks (Horst G. , 2010). The purpose of this applied study contributes to this role of the safety region - taking stock of disaster and crisis risks in a given area.

Recovery after a disaster event in terms of containing the flood and repairing the critical infrastructure assets afterwards is another key aspect of this research. The longer the infrastructure remains inoperable - the longer the affected community suffers – the deeper the long term consequences on the overall socio-economic atmosphere.

A short summary of the deliverables of the research based on the methodology is –

- Spatial properties of the probable flooding event;
- Spatial properties of the researched infrastructure;
- Analysis of infrastructure vulnerability to the flooding event;
- Analysis of interdependence between infrastructure systems;
- Probable event scenario covering primary consequences, cascading effects, and secondary consequences. Recovery time plays a key role in estimating the extent of the secondary consequences.

Chapter 1.1 that follows, elaborates further on the theoretical background and relevance of this research. **Chapter 1.2.** discusses the definition of critical infrastructure and provides a list of infrastructure products and services that are considered to be critical. **Chapter 1.3** briefly describes the research area including the area expected to be flooded and the area expected to suffer the secondary consequences. **Chapter 1.4** presents the research question of this thesis and the accompanying sub-questions. In **Chapter 2.** the research method is discussed in detail, elaborating on points already briefly mentioned in this chapter. **Chapter 3.** presents the findings and the results of the research following the order of the research procedure discussed in Chapter 2. – first briefly discussing the topology of the research area in **chapter 3.1**, then describing in detail the flooding event model in **chapter 3.2**, and presenting and discussing the critical infrastructure present in the area in **chapter 3.3. Chapter 3.4.** discusses the direct impacts of flooding on the infrastructure. **Chapter 3.5** is the cumulative product of all findings - the scenario of probable cascading effects and secondary consequences. The final conclusions are presented and discussed in **chapter 4.**

1.1. Theoretical scope

Socio-economic dependency on critical infrastructure and the risks of natural disasters

Extreme natural events such as flooding and earthquakes can cause major disruption of lifelines for entire cities and even larger areas. Civil infrastructures such as energy, water, transportation, and telecommunications that provide base for economic prosperity and well-being of a nation, can leave communities in disarray if they are disrupted (Miller, 2008). Besides the divesting effects of a storm surge destroying and flooding property such as houses and other buildings rendering them uninhabitable and leaving casualties there is also a significant aspect of critical services and activities being disrupted. An example would be the nationwide floods in UK in the summer of 2007. Although the floods were mostly riverine and caused by abnormally high precipitation quantities, as opposed to more devastating storm surge events, the effects they had on the infrastructure really put the resilience of the affected communities to the test (Marsh & Hannaford, 2007). In the areas of Yorkshire and Humberside where the flooding had the most severe effects, more than 300 schools were affected, along with transport and utility infrastructure. In Gloucestershire the Mythe Water Treatment plant got flooded, leaving over 300,000 people to rely on bottled water for several weeks (Marsh & Hannaford, 2007). Disruption of water supply had to do not only with the waste water treatment works being flooded, but also with the failures in electricity distribution to those facilities (Bloomfield, Chozos, & Nobles, 2009), which illustrates an example of cascading effects – disruption of one critical infrastructure (electricity) causing a disruption of another (waste water treatment). Another example (from the same source) of a cascading effect on critical infrastructure illustrates a dependency of healthcare sector on the information sector – a disaster destroying the headquarters of an IT company resulted in five hospitals loosing access to patient records and admission/discharge systems. A more severe case would be the secondary consequences of hurricane Katrina that struck the U.S. in summer of 2005. The hurricane had devastating effects mostly just on the coast of Louisiana where, among other disastrous losses, the onshore and offshore oil and gas production facilities were severely damaged and rendered inactive. Given that around 40% of the national oil and gas supply in U.S. at the time came from that area, the disruption of supply led to nationwide negative economic effects due to a significant increase of gasoline prices up to a point that several airline companies went out of business (RMS, 2005). A definition of critical infrastructure and a list of sectors are discussed in Chapter 1.1. of this report.

It is therefore of great importance to evaluate the vulnerability of all critical infrastructure lines and assets in order to fully understand the risks of flooding (and other natural events) and insure proper protection measures (Heilemann, 2013). That includes the spatial allocation of infrastructure assets and their vulnerability to possible flooding events as well as how different infrastructures are dependent on one another in a specific system and in general. Such modeling can then be applied to anticipate scenarios of complex secondary consequences of natural disasters that influence the socio-economic activity, that are beyond direct damage to property and human health/life.

This research is focused on the issue of community's socio-economic dependence on critical infrastructure in the province of Zeeland, the Netherlands. This particular case is somewhat special due to the fact that the research area is a peninsula connected to the mainland by a narrow "bridge" of dry land that is highly susceptible to flooding due to its land elevation being below mean sea level (see Chapter 1.2.). During the planning phase of this project the client has stated that at least some critical infrastructure systems, that the population and economy of Mid-Zeeland depends on, pass exclusively through that area, which is a territory belonging to the municipality of Reimerswaal. Some of the CI lines are not substitutable, namely the railway, and water and gas supply lines, and therefore their disruption could have major consequences on the communities' well-being.

Primary and secondary consequences of critical infrastructure failure

When it comes to CI failure, an important distinction to be made is the difference between the *primary* and *secondary* consequences (Escarameia & Stone, 2013). In the context of this research, primary consequences of a disaster event describe the immediate damage caused only to the critical infrastructure assets that have been exposed to the stresses of the disaster event. An example would be physical damage to roads, supply line pipes and cables and electrical substations, induced by flood water and the sediment/debris that flood water brings and leaves scattered afterwards. The term "secondary consequences" implies no direct damage to people or property, but rather the effects of products and services provided and facilitated by the CI becoming unavailable to the end-user at their designed capacity (or at all) inside and outside of the area impacted by a disaster event (Escarameia & Stone, 2013).

Simply put, when municipality of Reimerswaal suffers from the immediate effects of a flooding event, and the rest of Mid-Zeeland peninsula was not exposed to any flooding, but suffers from the disruption of the products and services that used to be facilitated by the CI in Reimerswaal – in that case the rest of Mid-Zeeland is experiencing some kind of secondary consequences. An important factor when it comes to CI vulnerability has to do with dependencies and co-dependencies between different sectors and services. Secondary consequences are often exacerbated by a cascade of CI failures – the cascading effect (Heilemann, 2013). There is still limited understanding of complex dependencies and co-dependencies of CI sectors and sub-systems on one another, however some general principal cases can be defined. For example, all critical infrastructure sectors and services nowadays depend on uninterrupted supply of electricity and in most cases telecommunication for control and monitoring. In case of natural disasters the disruption of electricity supply would most likely lead – besides the obvious inconvenience to the population in general – to telecommunication and information technology infrastructure failure, which would lead to catastrophic consequences for public administration, maintaining law, order and security, as well as disaster mitigation and rescue efforts. Such was the case in Louisiana during and after hurricane Katrina in 2005, when all the civilian means of telecommunication – land lines, cellphone towers, police and other emergency service radios – were rendered inoperable due to complete electricity grid failure in some of the communities (Miller, 2008).

1.2. What is critical infrastructure

There is no official definition of the term critical infrastructure in the Netherlands; however the definitions found during this research do not vary significantly in their meaning or contradict each other. According to a comprehensive manual "Recommended Elements of Critical Infrastructure Protection for policy makers in Europe" produced by a Dutch research organization TNO, critical infrastructure includes:

"Those infrastructures which are essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have serious consequence" (Klaver, Luiijf, & Nieuwenhuijs, 2011).

Although the definition of CI might seem straightforward, the challenge remains to identify which assets, objects and services are actually critical for a given nation or region (Klaver, Luiijf, & Nieuwenhuijs, 2011). To give a better idea of why certain infrastructure is considered critical, an example would be an electricity distribution sub-station damaged by effects of flooding or hurricane. The purpose of a sub-station is to receive electricity from a transmission line and convert it to a lower voltage current for distribution to the users. Such sub-stations are complex facilities that may take up to a year to restore if severely damaged. That could leave tens of thousands of users without electricity, leading to major inconveniences and economic losses.

Any analysis of critical infrastructure is complicated by the fact that usually an entire network of CI lines and nodes is dedicated to providing the same service or product. Whether a single infrastructure line, asset or object e.g. a road or a power line is actually critical depends on the complexity and redundancy of a given infrastructure system. For example electricity in a disrupted power line might be diverted from another line or source if the network has such a capacity for substitutability. As mentioned earlier in the research scope, in the case of this research the area in question is a peninsula which connects to the mainland via a narrow section of dry land. Most CI lines pass exclusively through that location and are not substitutable, which makes a case for this research assignment.

According to the official Dutch government website, critical infrastructure in the Netherlands is divided into 12 critical sectors, with a total of 31 essential goods and services listed in table below in Table 1. (government.nl, 2014).

Sector	*Goods and services*
Energy	*electricity, natural gas and oil*
Telecommunications and information technology	*land-line and mobile telephony, radio, broadcasting and the internet*
Drinking water	*the water supply*
Food	*the food supply (including in supermarkets) and food safety*
Health	*emergency and hospital care, medicines, vaccines*
Financial sector	*payments and money transfers by public bodies*
Surface water management	*water quality and quantity (control and management)*
Public order and safety	
Legal order	*the courts and prisons; law enforcement*
Public administration	*diplomacy, public information, the armed forces, decision-making*
Transport	*Amsterdam Schiphol Airport, the port of Rotterdam, highways, waterways, railways*
The chemical and nuclear industries	the transport, storage, production and processing of materials

Table 1. List of critical infrastructure by sector. *Retrieved from (government.nl, 2014).*

A more elaborate and detailed list of 37 products and services divided into 11 sectors is proposed in the "Recommended Elements of Critical Infrastructure Protection for policy makers in Europe" (Klaver, Luiijf, & Nieuwenhuijs, 2011) and is used for this research (see Table 2.). An interesting note is that according to the same source, the main differences between nations in approaching such categorization concern mostly "Public and legal order" and "Civil administration" sectors, both of which are least relevant to this particular research.

Sector	Product or service
Energy	1. Oil and gas production, refining, treatment and storage, including the pipelines
	2. Electricity generation
	3. Transmission of electricity, gas and oil
	4. Distribution of electricity, gas and oil
Information	5. Information systems and networks protection
	6. Instrumentation automation and control systems (SCADA etc.)
	7. Internet
	8. Provision of fixed (landline) telecommunications
	9. Provision of mobile telecommunications
	10. Radio communication and navigation (e.g. Loran, GPS and Galileo)
	11. Satellite communication
	12. Broadcasting
Water	13. Provision of drinking water
	14. Control of water quality
	15. Stemming and control of water quantity
Food	16. Provision of food and safeguarding food safety and security
Health	17. Medical and hospital care
	18. Medicines, serums, vaccines and pharmaceuticals
	19. Bio-laboratories and bio-agents
Financial	20. Payment services/payment structure (private)
	21. Government financial assignment
Public &Legal Order and Safety	22. Maintaining public and legal order, safety and security
	23. Administration of justice and detention
Civil Administration	24. Government functions
	25. Armed forces
	26. Civil administration services
	27. Emergency cervices
	28. Postal and courier services
Transport	29. Road transport
	30. Rail transport
	31. Air traffic
	32. Inland waterways transport
	33. Ocean and short-sea shipping
Chemical and nuclear industry	34. Production and storage/processing of chemical and nuclear substances
	35. Pipelines of dangerous goods (chemical substances)
Space and research	36. Space
	37. Research

Table 2. List of critical infrastructure by sector. *Retrieved from (Klaver, Luiijf, & Nieuwenhuijs, 2011).*

1.3. Research area

The overall research area for this project is the Mid-Zeeland peninsula (Walcheren, Zuid-Beveland and Noord-Beveland regions) in the southwestern part of the Netherlands (marked blue on Figure 1.).

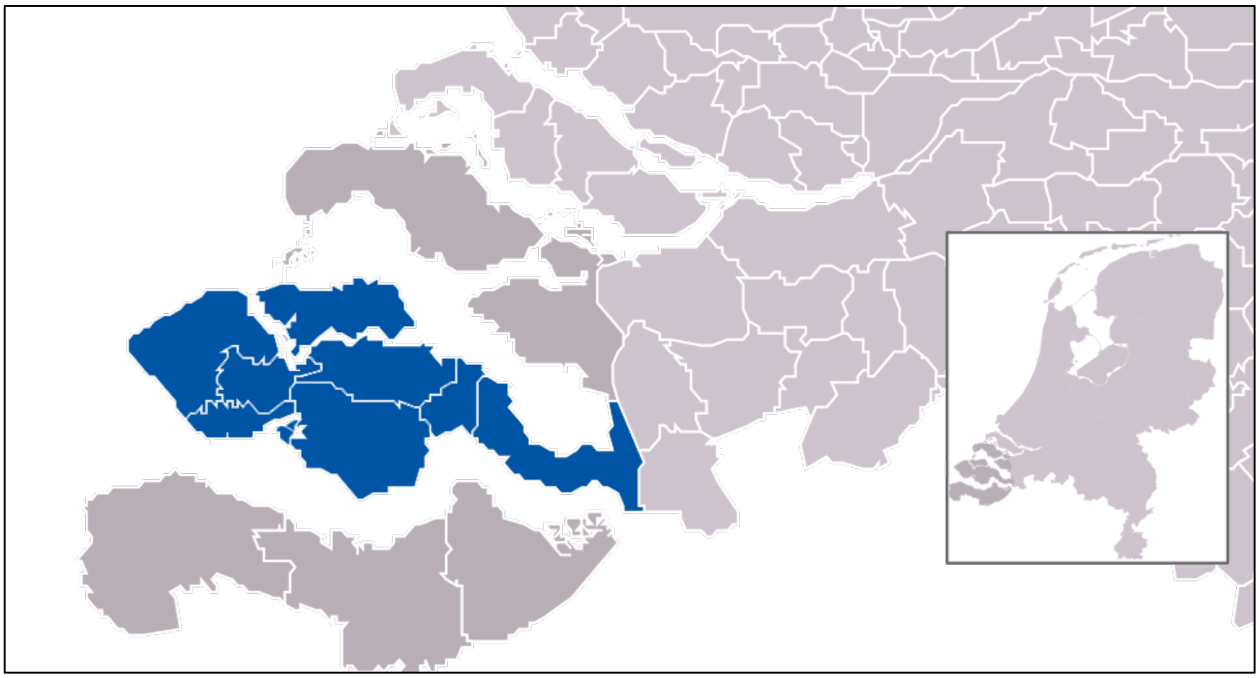

***Figure 1. Schematic map of Mid-Zeeland peninsula**. Modified fromWikipedia.org on May 29, 2014. (http://en.wikipedia.org/wiki/File:Map_-_NL_-_Municipality_code_0703_(2009).svg)*

The research of CI vulnerability to disasters (primary consequences) is focused on the municipality of Reimerswaal which is where the critical infrastructure is analyzed and flooding scenarios take place. Reimerswaal is a municipality in the province of Zeeland in the southwestern part of the Netherlands (marked green on Figure 2.). Geographically it is a relatively narrow section of dry land that connects the Mid-Zeeland peninsula to the mainland. The area is relatively flat and mostly below or near mean sea level with man-made dikes being the only parts of the landscape that are well elevated. The municipality covers a total of 242.42 km^2 with only 101.99 km^2 of it being dry land and has a population of 21,915 inhabitants as of January 2014. The main areas of economic activity in the Mid-Zeeland peninsula are the commercial shipping harbors in Vlissingen and to the east of Vlissingen and tourism sites along the coastline.

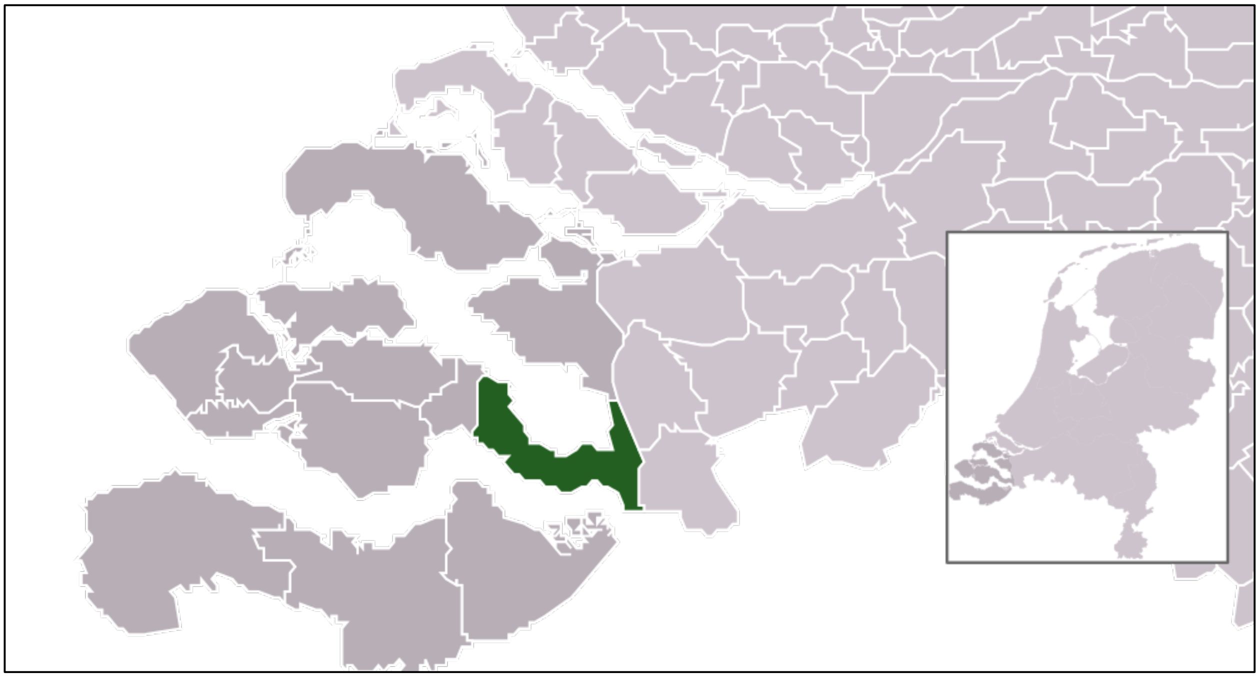

Figure 2. Schematic map of the municipality of Reimerswaal. *Retrieved fromWikipedia.org on May 29, 2014. (http://en.wikipedia.org/wiki/File:Map_-_NL_-_Municipality_code_0703_(2009).svg)*

1.4. Research question

This research focuses on CI vulnerability in the area expected to be flooded and on the potential negative impacts that might have on the socio-economic well-being of the population of Mid-Zeeland, namely the areas of Zuid-Beveland, Noord-Beveland, and Walcheren. This would include both the business losses due to critical assets and services e.g. roads, railroads, energy and drinking water supply lines being unavailable, as well as inconvenience and hazards inflicted upon the population. The question of the research therefore is:

How vulnerable are the critical infrastructures in the area of Reimerswaal and what would be the secondary consequences of those infrastructures failing?

Subsidiary research questions

- **What critical infrastructure assets are present in the municipality of Reimerswaal?**
- **What would be the direct consequences of a flooding in Reimerswaal on those critical infrastructures?**
- **How long would it take to restore the affected critical infrastructure assets and services to their original capacity after the impacts of a flooding have been neutralized?**
- **What would be the cascading effects of critical infrastructure failure in Reimerswaal?**

The results of the research are to be both quantitative and qualitative. Qualitative results are – what kinds CI assets are present in the research area and which ones are expected to fail due to a flooding event. Quantitative results are to include the duration of the immediate negative effects of flooding – inundation of the land, the amount of time it would take to restore the damaged or otherwise inoperable infrastructure to its original designed capacity, and some estimations of how many people will be disconnected from CI supply. Economic losses due to hindered transportation capacity are to be estimated based only on qualitative factors – estimation of monetary losses per unit time of road/railroad being unavailable is outside the limits of this assignment.

2. Research method

The research approach follows a specific structure in both gathering the information, and processing and presenting the results. A research procedure presented in a framework for modeling and analyzing interdependent infrastructure network failures by Pant et al. has been applied (Pant, Hall, Thacker, Barr, & Alderson, 2014). Following the order of the procedures, the research structured and base on:

Step 1. Characterization of spatial external properties of the hazard;

Step 2. Characterization of spatial properties of infrastructures;

Step 3. The uncertainties in infrastructure failure responses;

Step 4. The interdependence within and in between infrastructure systems;

Step 5. The interoperation of physical and economic consequences of infrastructure failures.

As already mentioned in the introduction, this is an exploratory research. Literature research has been conducted on the general subject of critical infrastructure vulnerability, revealing that there is little knowledge available on the matter as of yet. More challenging is the fact that each geographic location and community has a unique combination and configuration of infrastructure assets and services, and cascading failures in complex interconnected systems often take unexpected paths (M. van Eeten, 2011). Additionally, most CI assets and services are owned and/or maintained by private operators that are reluctant to disclose detailed information regarding their assets. Due to the fact that there is no previous research or reference material available for public access, the main method of acquiring information for this research is through interviews with stakeholders.

The interviewed stakeholders have been selected mostly among the representatives of the governmental agencies responsible for maintenance of considered infrastructure and/or for flood safety in general (see Table 3. for a list of CI services considered relevant for this research) Therefore the results of this research are based on and validated by the expertise of professionals with many years of experience and knowledge in the field of safety and infrastructure in this specific geographical area. The list of interviewed stakeholders can be seen in Appendix A. of this report.

The interviews were semi-structured - due to the fact that no detailed information on infrastructure topology and parameters was available for analysis (neither would such analysis be possible within the resource limitations of this research project) the stakeholders were asked to give their expert opinion on the vulnerability of the critical infrastructure and possible consequences of failure. The original universal question and theme of the semi-structured interviews can be seen in Appendix B of this report. The chronological log of the research progress can be seen in Appendix C.

The most probable timeframe of the event scenario taking place is between October 1st and March 31st (Rijkswaterstaat, 2013). This is notable because if the flooding happens in spring, then the secondary consequences could last through the vacation and tourism season and thus have a detrimental effect on the numerous businesses of that sector (restaurants, hotels, summer houses etc.) and therefore on the overall socio-economic climate of the Mid-Zeeland peninsula.

According to the five step procedure discussed at the beginning of this chapter, the starting point of the research process for characterizing the spatial properties of the probable flooding event (step 1) was the *lizard.net* flood scenario model produced and provided by the Province of Zeeland. This model simulates a dike breach as a result of a high tide on the coasts of the Netherlands during a 4000 year storm, which is the official safety standard for the primary flood defense structures in Zeeland. The structure of the model is fairly simple – a number of points are selected along the primary flood defense perimeter with an equal probability of a breach, meaning that the structural integrity is consistent along the entire flood defense perimeter (see full description in Chapter 3.2.1). Illustrations of peak water levels according to the flood scenario models are presented in the Results Chapter of this report. It is impossible to accurately predict how much time it would take to seal a breach in a primary dike and contain the situation. There are too many variables involved, starting with the size of the breach and furthered by complex matters of weather conditions, crisis relief organization quality and logistics, and so on. No case studies of such scenarios exist for the Netherlands therefore there will be several theoretical flood containment time frames considered.

After establishing the spatial characteristics of the probable flooding, including the depth of the flood water and estimated duration of the event, the spatial organization and properties of the studied infrastructure have been considered (step 2). Predictions on most probable infrastructure failure responses to the flooding (step 3) are then learned through the expert interviews. Interview questions included both the vulnerability of CI assets to flooding as well as interdependence between CI systems and possible problems in that regard (step 4). Restoration time for some CI assets, after the effects of flooding have been eliminated, have been estimated by the experts with some certainty and the estimates were added to the flood containment time in order to compose the overall scenario.

The interdependences between infrastructure assets and sectors as well as the probable socio-economic consequences (step 5) have been researched through literature and through interviews. The scenario of probable secondary consequences presented in this report is a set of specific, informed assumptions based both on case study reviews and validated by the client who himself is an expert in the field of disaster management. The scenario is compiled in accordance with and meets the parameters of the manual on disaster scenario building manual by The Assessment Capacities Project (ACAPS, 2011). Refer to appendix D. for a list of key points applied in building the scenario for this research.

Not all the CI services and assets were considered in the process of estimating the direct impacts of flooding in Reimerswaal – the primary consequences. Table 3. illustrates that only energy, water, and transport sectors were considered relevant in terms of estimating the primary consequences that could have potential impacts in the rest of Mid-Zeeland peninsula. It is important to mention here that during the planning phase of this project, the client has stated that some CI lines supplying the Mid-Zeeland peninsula pass exclusively through Reimerswaal, namely electricity, gas, oil, and water supplies. Further analysis of the CI topology maps has proven that most CI lines are indeed not substitutable. Therefore the initial hypothesis was that an event of flooding in that area could potentially cut off the life lines for the entire peninsula. Same applies for the transport sector – the only railway and the only motorway connecting Mid-Zeeland peninsula with the mainland pass through the municipality of Reimerswaal.

Another important point to mention and discuss is that the aspect of pollution and possible consequences on the ecology in the area of Reimerswaal is outside the boundaries of this research project. The soil inundated with sea water for a period of several months would most likely become infertile for decades to come, and the flooded sewer systems would overflow and pollute the flood water. However due to the relatively small area and population of the municipality of Reimerswaal this factor was considered negligible for the purposes of this research assignment, which is focused on the secondary consequenses.

Sector	Product or service	Relevance in Reimerswaal area in terms of possible secondary consequences
Energy	~~1. Oil and gas production, refining, treatment and storage, including the pipelines~~	Relevant due to expected lack of redundancy. No gas production or electricity generation in the area.
	~~2. Electricity generation~~	
	3. Transmission of electricity, gas and oil	
	4. Distribution of electricity, gas and oil	
Information	5. Information systems and networks protection	Irrelevant - No major IT or telecom assets are present in the area.
	6. Instrumentation automation and control systems (SCADA etc.)	
	7. Internet	
	8. Provision of fixed (landline) telecommunications	
	9. Provision of mobile telecommunications	
	10. Radio communication and navigation (e.g. Loran, GPS and Galileo)	
	11. Satellite communication	
	12. Broadcasting	
Water	13. Provision of drinking water	Relevant due to lack of redundancy in water supply. Water quality is outside project limits.
	~~14. Control of water quality~~	
	15. Stemming and control of water quantity	
Food	16. Provision of food and safeguarding food safety and security	Irrelevant – very little food production in the area.
Health	17. Medical and hospital care	Irrelevant – no major or unique medical facilities in the area.
	18. Medicines, serums, vaccines and pharmaceuticals	
	19. Bio-laboratories and bio-agents	
Financial	20. Payment services/payment structure (private)	Irrelevant – no major/ relevant assets in the area.
	21. Government financial assignment	
Public &Legal Order and Safety	22. Maintaining public and legal order, safety and security	Irrelevant – no coordinating agencies for public order and safety present in the area with responsibilities beyond municipality itself.
	23. Administration of justice and detention	
Civil Administration	24. Government functions	Irrelevant – disaster event area covers one municipality with a low population and activity.
	25. Armed forces	
	26. Civil administration services	
	27. Emergency cervices	
	28. Postal and courier services	
Transport	29. Road transport	Relevant due to lack of redundancy. Air transport infrastructure is not present in the research area.
	30. Rail transport	
	~~31. Air traffic~~	
	32. Inland waterways transport	
	33. Ocean and short-sea shipping	
Chemical and nuclear industry	34. Production and storage/processing of chemical and nuclear substances	Relevant – transmission pipelines could be present in the area. Possible storage of substances.
	35. Pipelines of dangerous goods (chemical substances)	
Space and research	36. Space	Irrelevant – no space or research facilities present.
	37. Research	

Table 3. List of critical infrastructure sectors considered to suffer from direct effects of flooding in Reimerswaal. *Modified from (Klaver, Luiijf, & Nieuwenhuijs, 2011).*

3. Results

As already mentioned in the research method, the results of this research are based mostly on opinions of interviewed experts from government and private agencies, that have been conducted during the research phase of the assignment. Some data in form of maps and flood models have also been acquired and applied to the synthesis of the results. This Chapter describes all the findings e.g. topology of the research area, topology of each researched CI line, and the flood model description before moving on to the compilation of those findings into a coherent event scenario.

3.1. Geography and topology of the research area

As already mentioned in the Chapter "Research area" the municipality of Reimerswaal is a considerably small strip of dry land (101.99 km^2) that is exposed to sea from north and south. Most of the terrain in Reimerswaal is relatively flat and a significant area in the western part of the municipality has a topographic elevation ranging from – 2m to +1m relative to the mean sea level - blue and dark green on Figure 3. (Kik, 2014). The scale gauges on Figure 3. have been deliberately placed in the middle of the map to illustrate the point of how small and narrow the area is – mostly less than 5 km wide. The two mentioned factors – low ground elevation and small area of the territory – make any aboveground infrastructure in this area highly vulnerable to effects flooding with virtually no room for buffering the flood water. Figure 4. illustrates the primary (blue line) and secondary (red line) dikes. The orange line defines the borders of the research area.

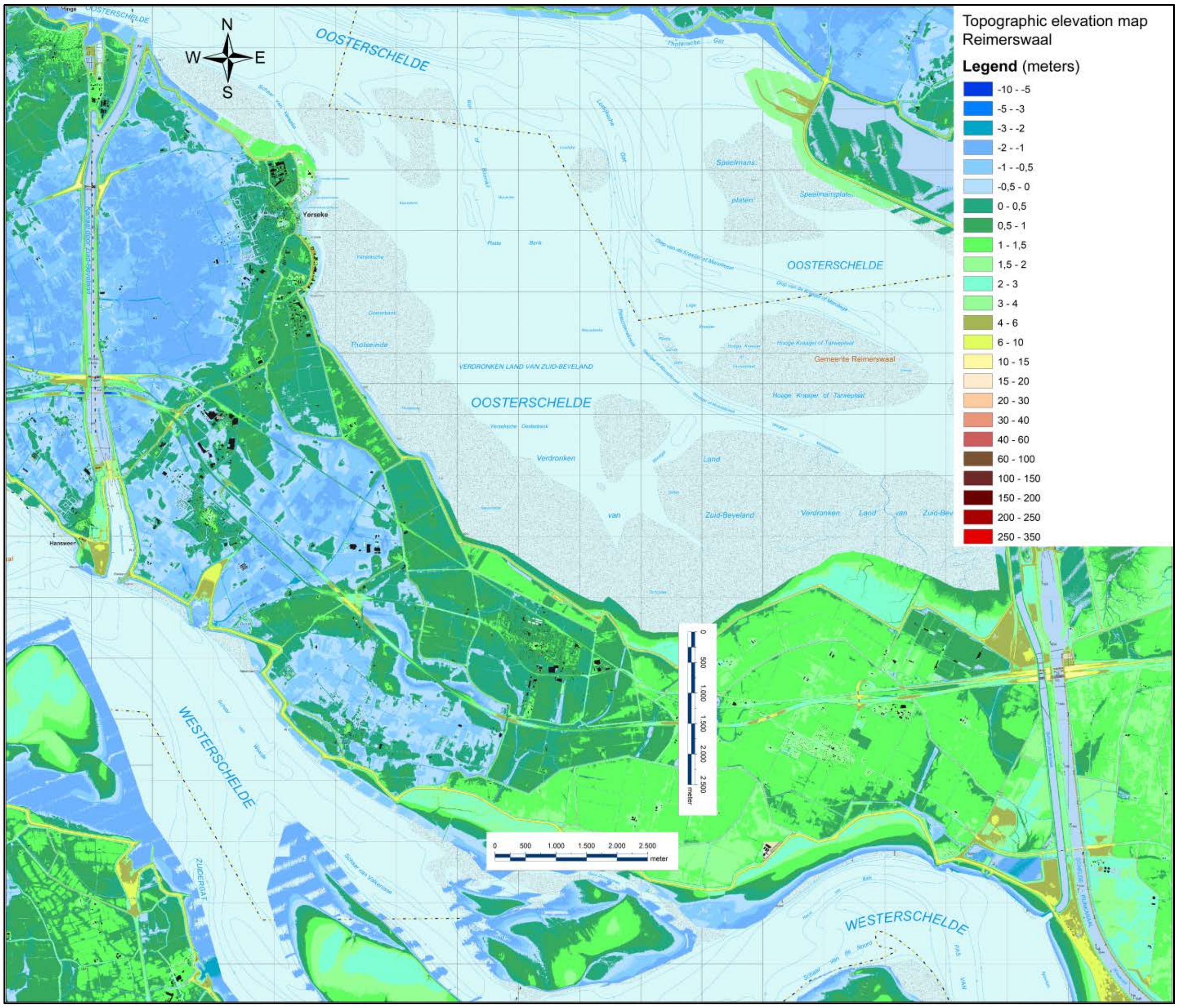

__Figure 3. Topographic elevation map of the research area.__ Modified from (Kik, 2014).

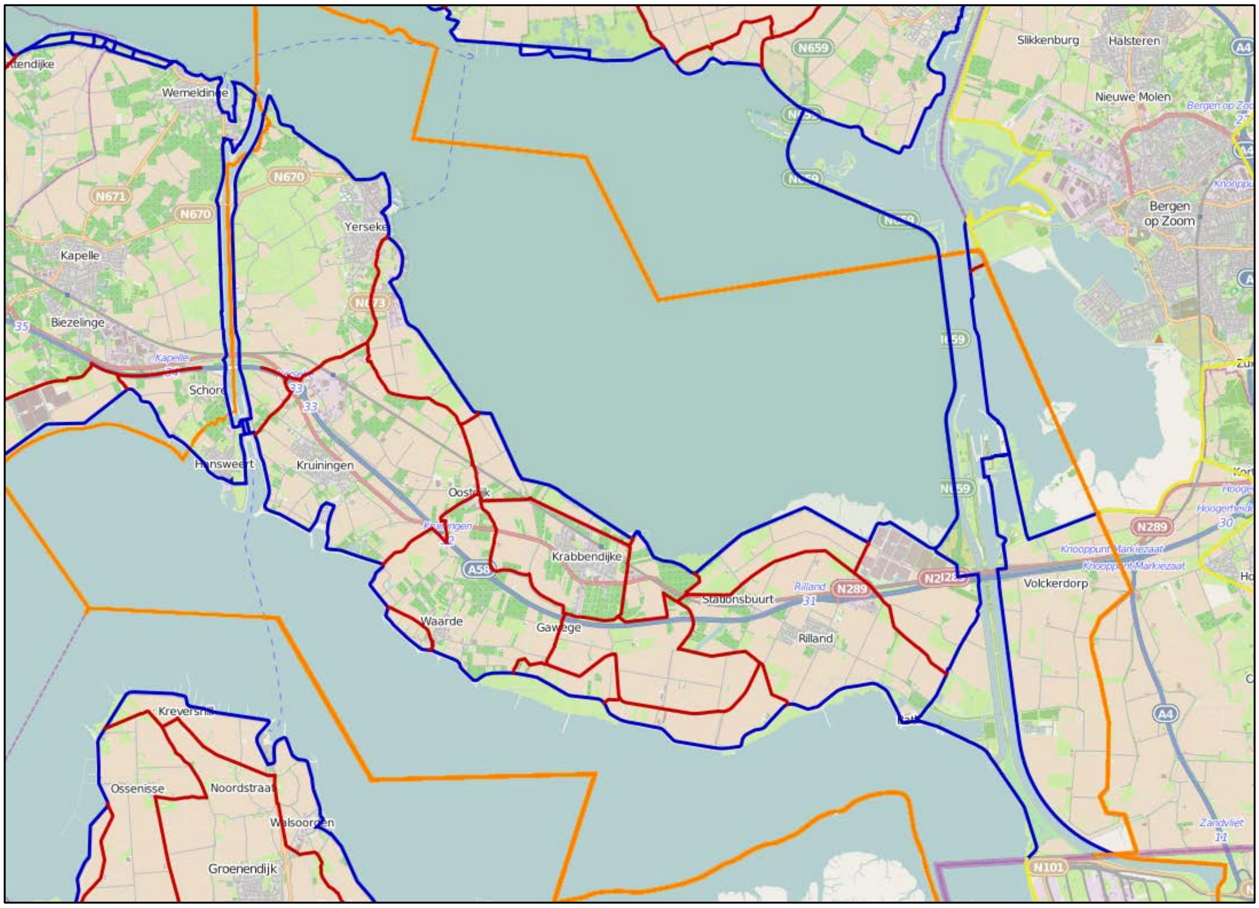

Figure 4. Flood defense structure map. *Generated from (Lizard Flooding, 2012) on May 17, 2014.*

3.2. Flooding event scenario

This Chapter contains a brief description of how the flood model was applied to this research. Sub-Chapter 3.2.1. discusses the input parameters of the model and aspects that define the simulation. Sub-Chapter 3.2.2. Illustrates the graphical representation of the simulation for selected sections of the primary flood defense dike that would be breached. Sub-Chapter 3.3. presents and discusses the primary consequences of the flooding scenario – the direct damage to CI caused by the flood water.

3.2.1. Flood model description and parameters

For this research a SOBEK-based hydrological model, provided by the Province of Zeeland, is applied (Lizard Flooding, 2012). The input parameters for the meteorological event are those estimated by the local water boards for the worst case scenario 1/4000 year storm surge. The most probable timeframe of such an event occurring – the storm season – is officially considered to be between October 1st and April 15th (Rijkswaterstaat, 2013).

For modeling purposes the area on the map is divided into square cells – the smallest measurable units of area - that make up a grid. The cell size for the model is 25 by 25 meters and each cell is assigned a topographic elevation value of the surface, and a surface roughness value based on land use data. The open water bodies – ditches, lakes and so on – are also present in the model and accounted for, as well as culverts. The secondary dikes have openings in them in form of gates, tunnels viaducts etc. that are to be closed in case of a storm surge warning. However the official policy of the Storm Surge Monitoring Plan (Stormvloed Bewakingsplan) does not require all the dike gates in the research area to be closed for reasons of practicality – it is not practical to seal a tunnel or a viaduct for example. Figure 5. is a map of the secondary dike openings in the research area. The ones colored red are to be closed in case of an imminent storm surge event. The green ones are not expected to be closed and therefore not considered in the Storm Surge Monitoring Plan.

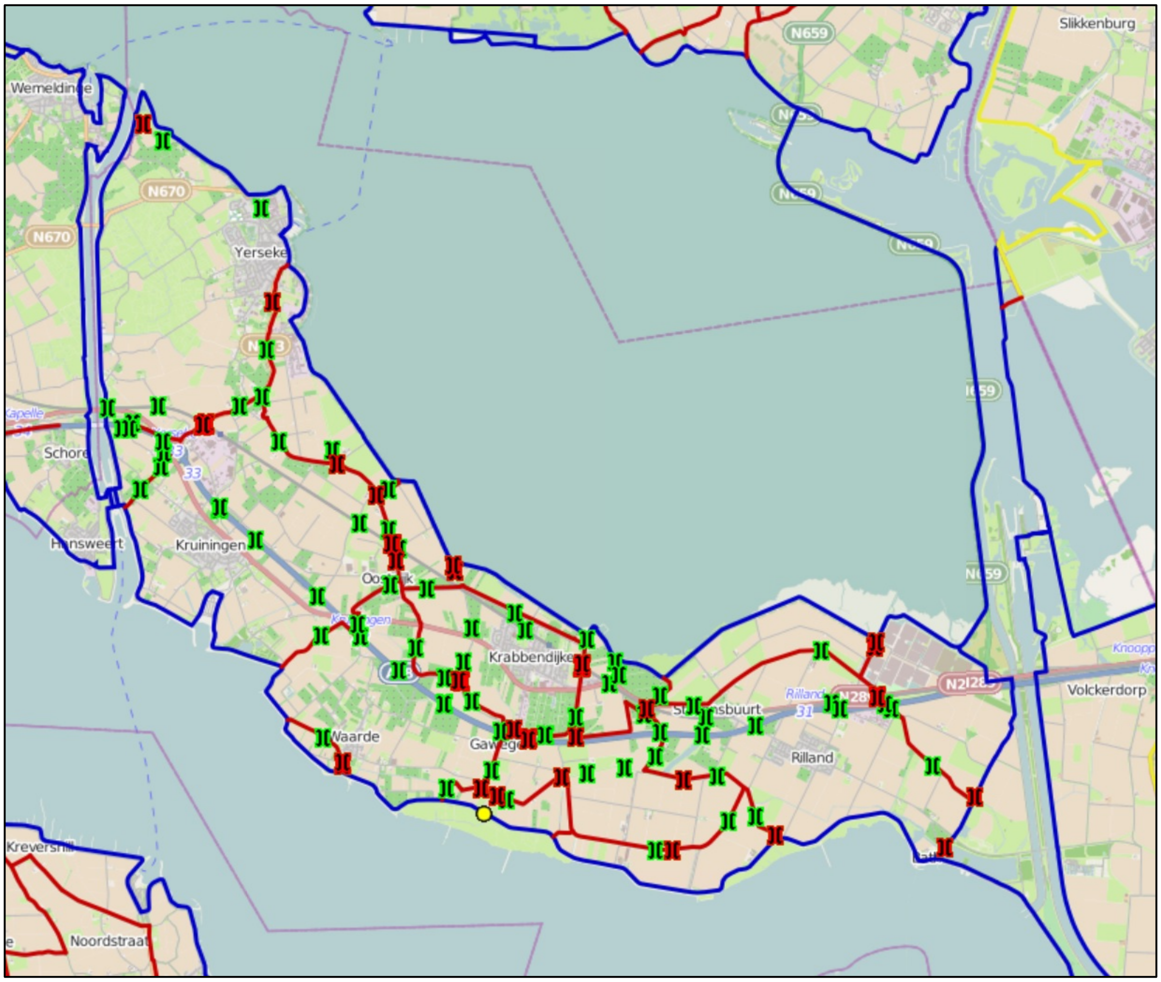

Figure 5. Openings in the secondary dikes. *Generated from (Lizard Flooding, 2012) on May 17, 2014.*

The event model graphically illustrates the flood water depth at the peak level as well as at any point in the time frame of the model with a step of 1 hour, showing the dynamics of the flood water spreading and receding across space, and the changing water depth. The total time frame of the simulation is 144 hours (6 days). The maximum water level *outside* the primary defense perimeter (meaning the water level in the river or sea) varies from point to point depending on the cross section of the water body (the smaller the cross section - the higher the maximum water level). The water level outside the primary defense perimeter along the south coast of Reimerswaal (Western Scheldt river) is estimated to range from 6.05 m to 6.55 m above mean sea water level from west to east. The duration of the storm surge is estimated to be 35 hours.

Figure 6. is a graph representation of the event model: the green line is the mean water level outside of the primary flood defense perimeter with water level of 0 m N.A.P; the red oscillating line is the tidal cycle. As the mean water level rises with the surge, so does the water level of the high tide – the value of the green graph line added with the upper peak of the red line. The duration of the storm surge is expected to be 35 hours. The maximum surge water level (the flat

part at the summit of the green graph spike) is expected to last for 4 hours. The start and end points of the model are defined by blue vertical lines. Therefore the time zero in the simulation is not when the storm surge reaches the breach point in question, but rather when the water level outside the primary defense perimeter is at its highest peak – the point in time during the storm surge when the firs high tide comes. At that moment of most extreme hydraulic conditions is when the primary dike is expected to breach and the water starts to flood the land. The parameters of a primary defense structure failure for all the points in this model are a breach of 10 m wide. That 10 m wide section of a dike is expected (and modeled) to be demolished to the level of the ground behind the dike.

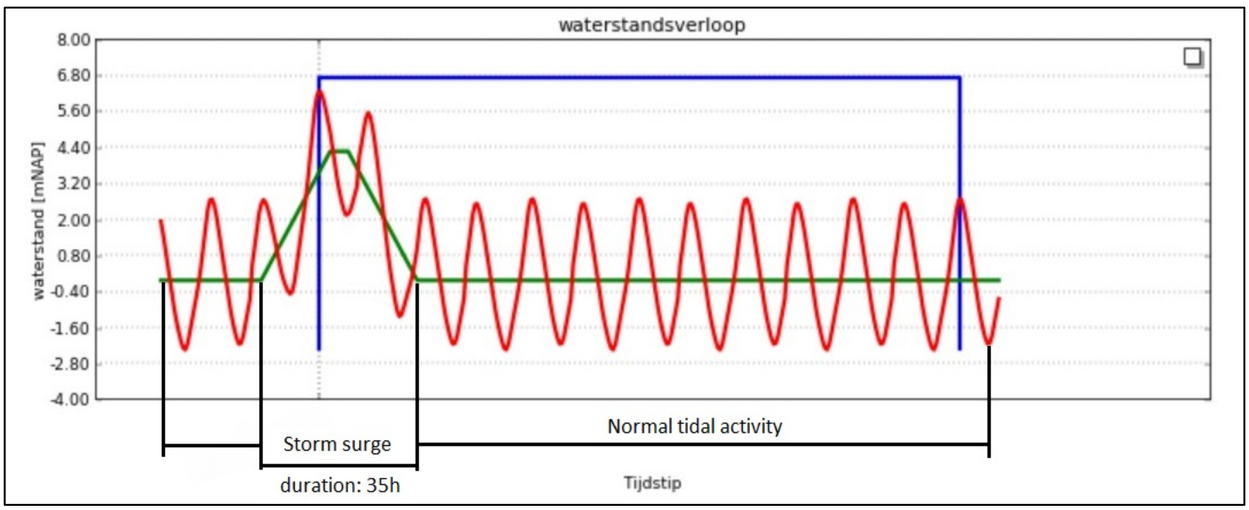

Figure 6. Storm surge scenario graph. *Modified from (Lizard Flooding, 2012) on May 27, 2014.*

3.2.2. Breach areas and flood models

Most of the research area is enclosed in a single primary flood defense perimeter – a dike ring. The model offers 24 hypothetical breach points however that does not mean that the model is only valid for those exact locations. Rather it is an approximation that covers a section of a dike and a breach in between points would render very similar results. Only a few most relevant breach points were selected for this event scenario (Figures 7., 8., and 9.).

It is worth mentioning that only breaches at the south coast (Western Scheldt side) of the research area are considered. The model indicates that breaches along the primary flood defense dike on the Eastern Scheldt side of Reimerswaal render similar and, for some sections, less severe flooding effects in terms of CI exposure to flood water, therefore making them less relevant for this research. Breach point 1. (Figure 7.) was found to be the most critical; according to the model a breach in that section of the primary flood defense perimeter would result in a major part of Reimerswaal area getting flooded with a peak water depth of more than 4 m in some parts and cause the most damage to the CI as well as to other infrastructure e.g. buildings, croplands and other property. Other two breach points would have the same detrimental effect on the roads and the railway, however not necessary on the electrical sub-station (see Figure 10.), therefore only the primary consequences of a breach at point 1 are discussed in this research.

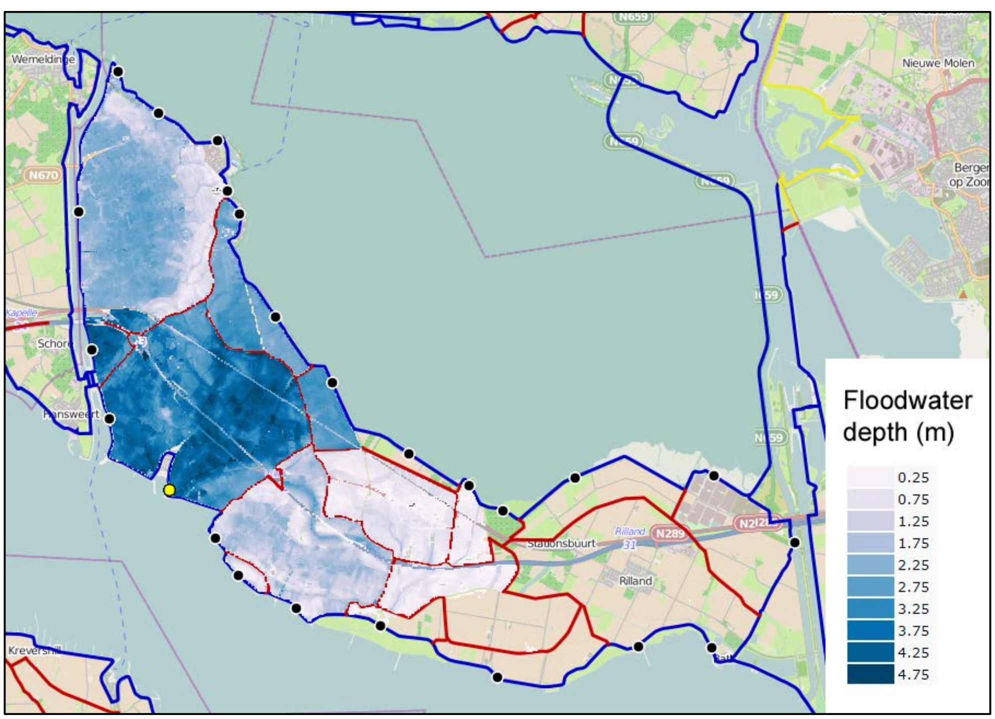

Figure 7. Flooding scenario breach point 1. Peak water depth. *Generated from (Lizard Flooding, 2012) on May 29, 2014.*

As already mentioned above in the flood model parameters description, only a few secondary dike openings are expected to be shut. For that reason – as the models clearly indicate – the secondary dikes would fail to serve their function of compartmentalizing and containing the flood in case of a primary defense perimeter breach. The flood water depth after the storm surge event has ceased, and the peak flood water level has subsided, is slightly less severe and barely influenced by regular tidal action, according to the spatial-temporal animation of the 144 hour time frame. In practice this means that the affected area will remain consistently flooded until the breach in the primary defense dike has been sealed and the flood water has been pumped. Figure 10. Illustrates the depth of flood water after 144 hours, that is at normal tidal conditions. Theoretically this would also be the case is the breach in a dike would occur not during a 4000 year storm, but at normal conditions for some reason, for example due to piping or seepage.

It is impossible to establish with any certainty the time it would take to contain a flood in this scenario for there are many unknowns concerning the actual conditions at the breach site as well as the disaster mitigation efforts.

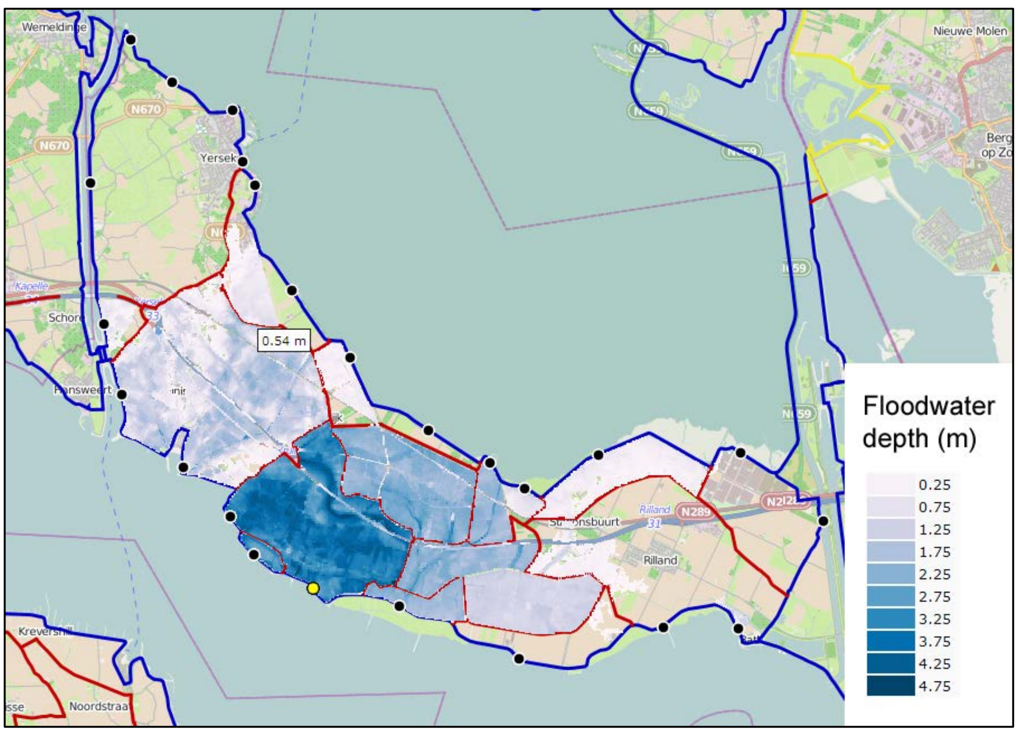

Figure 8. Flooding scenario breach point 2. Peak flood water depth. *Generated from (Lizard Flooding, 2012) on May 29, 2014.*

An expert at the Waterschap Scheldestromen suggests that it could take at least half a year to contain the flood in such an event – again, containment meaning sealing the breach and pumping the flood water outside of the primary defense perimeter.

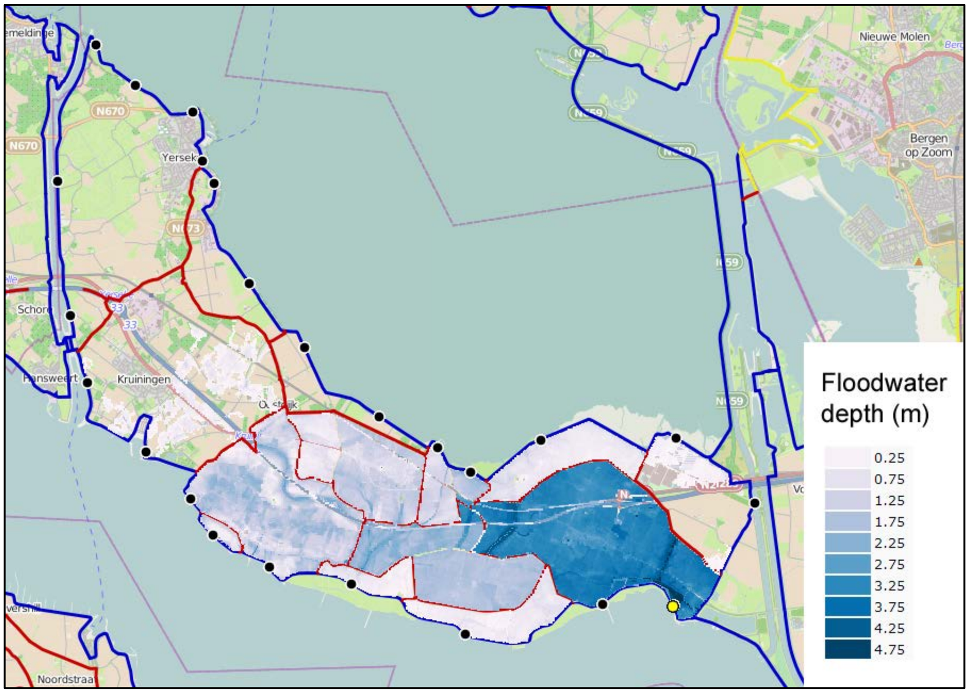

Figure 9.Flooding scenario breach point 3 Peak flood water depth. *Generated from (Lizard Flooding, 2012) on May 29, 2014.*

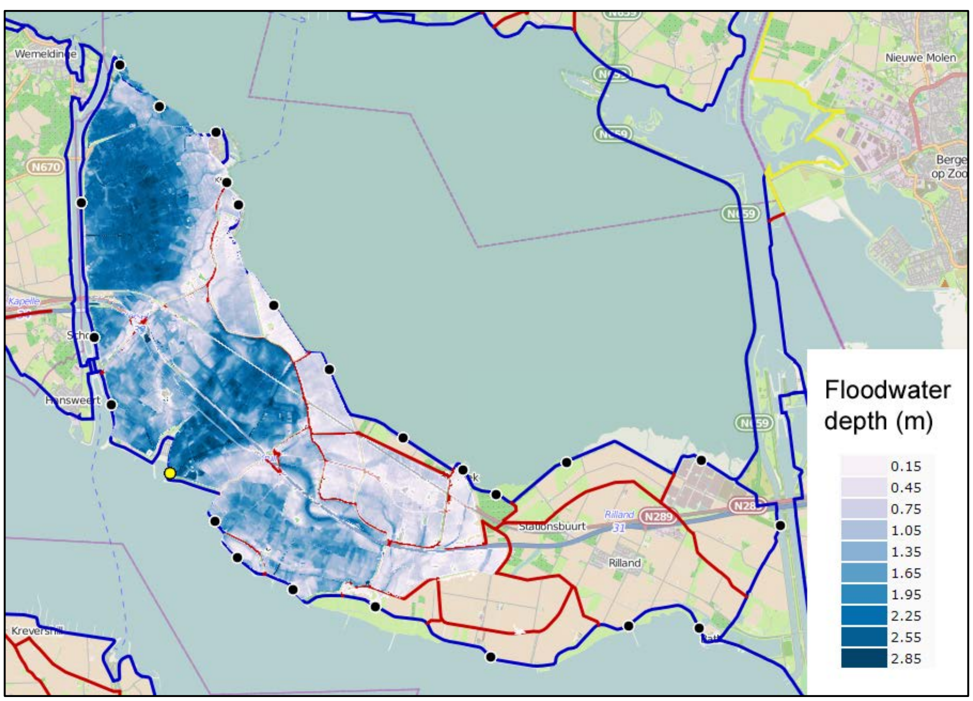

Figure 10. Flooding scenario breach point 1 Normal tide conditions*. Generated from (Lizard Flooding, 2012) on May 29, 2014.*

3.3. Critical infrastructure in Reimerswaal

In this Chapter the researched critical infrastructure is presented and discussed. As mentioned earlier, the scope of the research is focused on a relatively small area that in itself has very little socio-economic activity. It is rather considered in this research to be a bottleneck between the Mid-Zeeland peninsula and the mainland in terms of transportation and supply lines. Therefore the parameters for this research, provided by the client, limit the scope of considered direct effects of flooding on CI sectors to energy, water, and transportation. This also has to do with the limitations of the scenario which presume that only the municipality of Reimerswaal would suffer the impacts of a flooding event. That implies that the event proposed in the scenario will have influence on a relatively small area and population and would not really qualify as a disastrous or catastrophic event.

3.3.1. Energy

The electric power transmission lines that pass through Reimerswaal are depicted in red and orange on Figure 11. They are serviced, monitored and controlled by a private operator - DELTA Netwerkbedrijf B.V. The following information has been acquired from an interview with the DELTA B.V. Middelburg's head of operations. The red line is an overhead 380 kV high tension power line. Overhead transmission means that the cables are suspended above ground by towers. The yellow line on Figure 11. is the underground 150 kV transmission cable line. No detailed information on vulnerability of those lines could be obtained, however the interviewed expert suggested that the lines themselves are not expected to sustain significant damage from a flooding event.

In this case, the weak links in the electricity infrastructure are the electrical distribution sub-stations. Sub-stations are an important part of electrical generation, transmission, and distribution systems. The facilities of the sub-stations are usually situated on the ground, which is also the case in the Reimerswaal area. Points 9 and 26 on the Figure 11. are the two sub-stations present in the research area. Due to the sensitive nature of the information, the exact parameters of those facilities could not be disclosed by the interviewed company representative. However the conditions under which the facilities would most probably be rendered inoperable and consequences to the power grid are known and applied in the event scenario.

Figure 11. Electric power transmission line. *Provided by G. Fokker at DELTA N.V. Middelburg on June 24, 2014.*

The main point to mention in regards to electric energy infrastructure is that the function of the sub-stations in question is transformation of the electric current from 380 kV down to 150 kV and further *local distribution*. This means that if either of the sub-stations in Reimerswaal would get flooded and rendered inoperable, only the distribution to end-users in that area would be affected. The main 380 kV transmission line is expected to be flood-proof. There is still a possibility that the high tension power line towers could get damaged by hurricane winds or floating debris colliding with the towers, however such cases are not considered in this event scenario. Figure 12. is the same map, that also illustrates the areas of distribution for each sub-station. The sub-station at Point 9 on Figure 12. is distributing electricity to the area around it, defined by a blue line that includes around 9000 connected properties and the area around the sub-station at point 26 is around 1000 more connections. The railway is said to draw energy from the sub-station at point 9 and would also be rendered inoperable in case that sub-station gets disabled.

An important point to mention here is that, contrary to the initial assumptions, there is a certain level of redundancy, an even autonomy in the electricity supply in the Mid-Zeeland peninsula. The Borssele Nuclear Power Station located near point 15 is producing energy for export (net output of 485 MW_e) and therefore has plenty of capacity to power the entire peninsula if need be. Additionally there is the ELSTA power plant at point 18 producing electricity (123 MW_e) for the DOW Chemical facilities that it is located next to as well as for public grid (elstacogen.nl, 2014). That power plant is said to be able to meet and sustain the power demands of at least the south-west region of the Mid-Zeeland peninsula, including the commercial harbors.

Figure 12. Electricity distribution areas per sub-station. *Provided by G. Fokker at DELTA N.V. Middelburg on June 24, 2014.*

3.3.2. Drinking water and gas

From the interview with the head of operations of DELTA Netwerkbedrijf B.V Middelburg it became clear that no negative effects on the main water and gas transmission line are expected as a result of flooding. The local distribution network within the municipality Reimerswaal however is likely to be disrupted. This would leave up to 10.000 properties disconnected from gas supply for an estimated time of about 2 months after the flooding has been contained. No exact locations of assets that are part of gas and water distribution networks within Reimerswaal were disclosed, therefore water and gas lines are not presented in the flood event scenario models. To summarize, the transmission lines that convey water and gas to the Mid-Zeeland peninsula are considered to be flood proof, meaning the possible disruption would only take place within the municipality of Reimerswaal.

3.3.3. Transport

Figure 13. is a close-up of Figure 3. that better illustrates the elevation of the transport lines in the research area. Designated by downward-facing arrows is the railway, and upward-facing arrows designate the A58 motorway. In the western part of Reimerswaal both the motorway and the railway are slightly elevated above ground a range of 0.5 to 1 meter above mean sea level, according to the map legend. In the eastern part (a brighter hue of green) the ground level is higher and so is the elevation of both the motorway and the railway – between 1 and 1.5 meters above mean sea level.

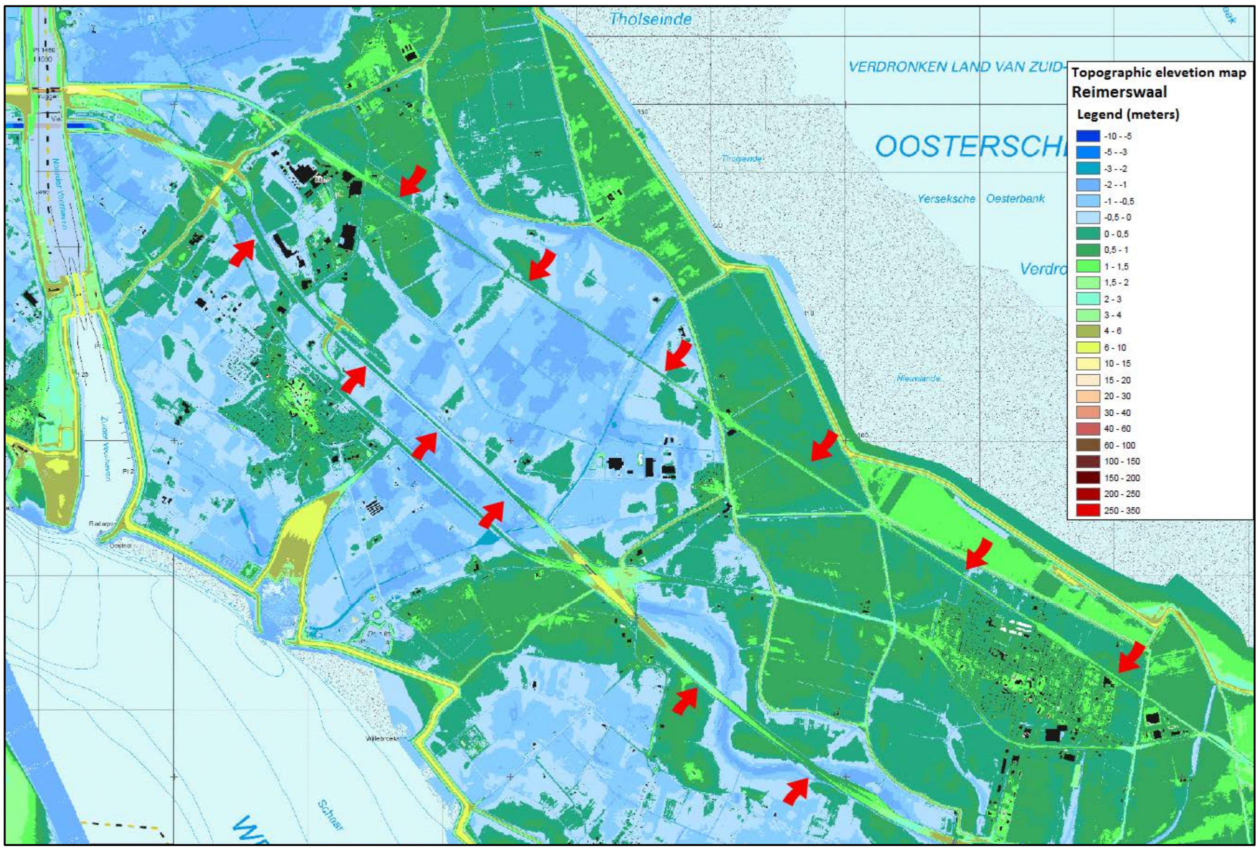

Figure 13. Topographic elevation of the main transport lines. *Modified from (Kik, 2014).*

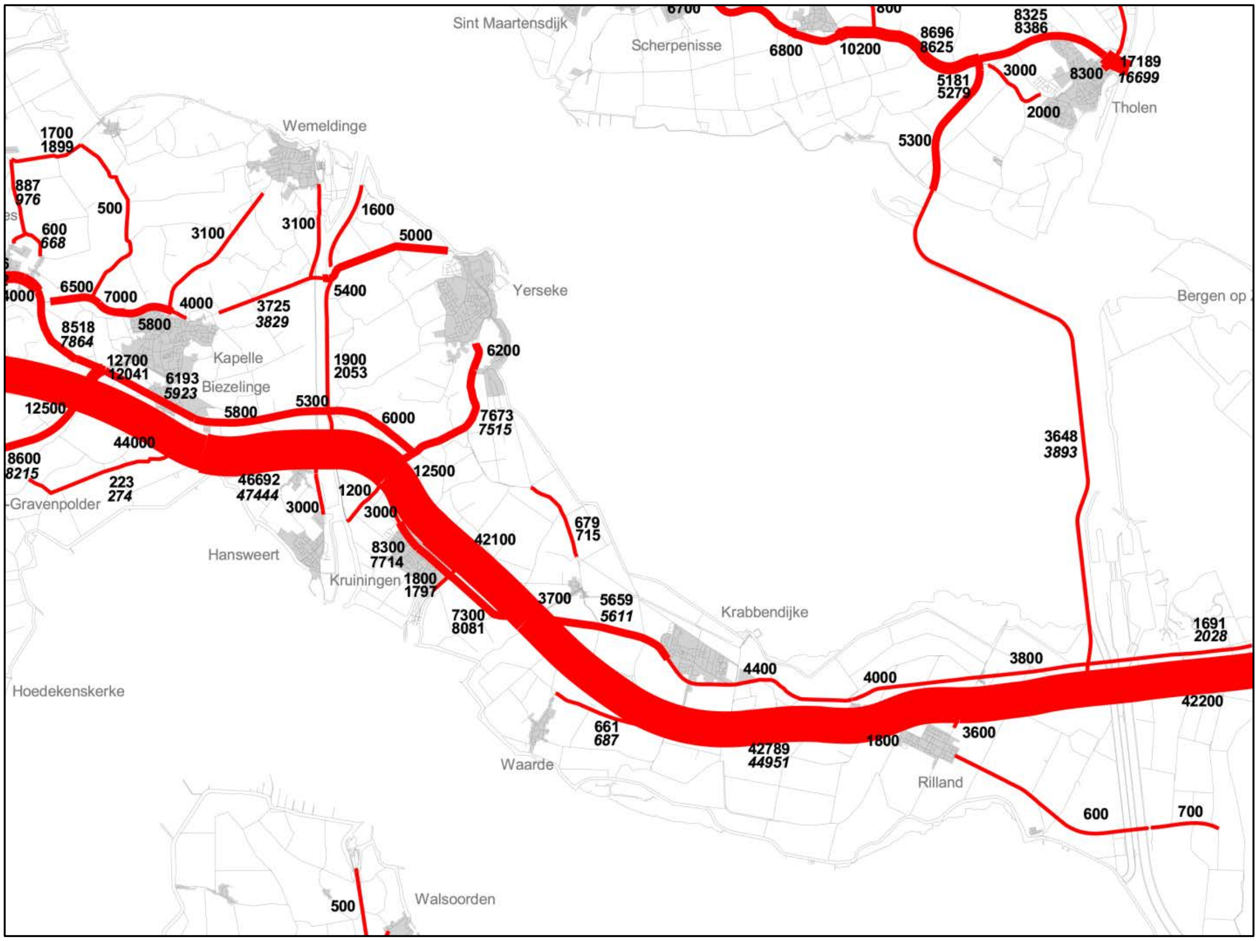

*Figure 14. **Measured average road traffic intensity through Reimerswaal in the year 2008.** Modified from (Provincie Zeeland, Directie Economie en Mobiliteit, 2009).*

Besides Reimerswaal, there are three other roads connecting the Mid-Zeeland peninsula to the mainland from south and north across the Eastern Scheldt and Western Scheldt rivers. All three of those roads however have a noticeably lower capacity both in terms of number of driving lanes and/or maximum allowed traffic speed. The section of the N57 road across the river has two lanes in total and a speed limit of 80 km/h. N256 is a short non-motorway road between Goes and Zierikzee also having only two driving lanes total and a maximum speed limit of 80 km/h. The tunnel across the Western Scheldt (N62) currently also has only two driving lanes total with a speed limit of 100 km/h. The A58 motorway, which is the infrastructure passing through the research area has 4 driving lanes total and a speed limit of 130 km/h for A58 in Zeeland (120 km/h in the eastern part of the motorway).

Figures 14., 15., and 16. are selected fragments of the average road traffic intensity per weekday map in the province of Zeeland (Provincie Zeeland, Directie Economie en Mobiliteit, 2009). The thickest line on Figure 14. Represents the road traffic intensity of the A58 motorway.

Figure 15. Illustrates traffic intensities on routes N57 (to the west) and N265 (to the east) that are the routes across the Eastern Scheldt river to the north of the Mid-Zeeland peninsula. Represented in Figure 16. is the average traffic intensity for the route N62 that is the tunnel through the Western Scheldt. Although there are smaller roads accompanying the A58 motorway through Reimerswaal, the flood models in Chapter 3.2.2. illustrate that those roads will be rendered unusable along with the motorway.

The numbers represent the average number of vehicles passing a certain measurement point per day. There are two values present for most measurement points – one is the traffic intensity during weekdays and another on underneath is during weekdays in the vacation season - months of July and August. The values clearly indicate that traffic intensity of the A58 motorways is higher than the other three routes combined.

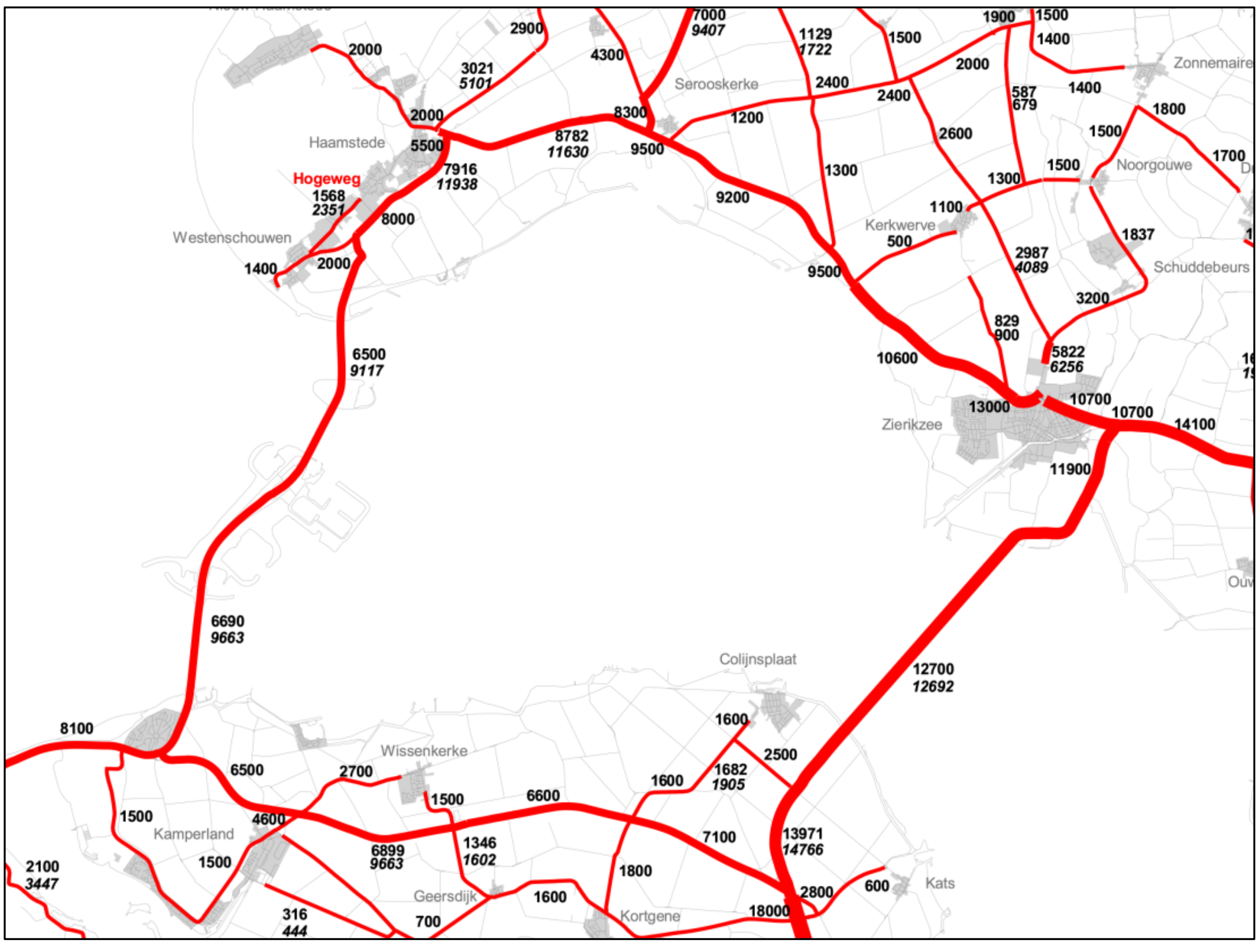

__Figure 15. Measured average road traffic intensity through routes N57 and N256 in the year 2008.__ Modified from (Provincie Zeeland, Directie Economie en Mobiliteit, 2009).

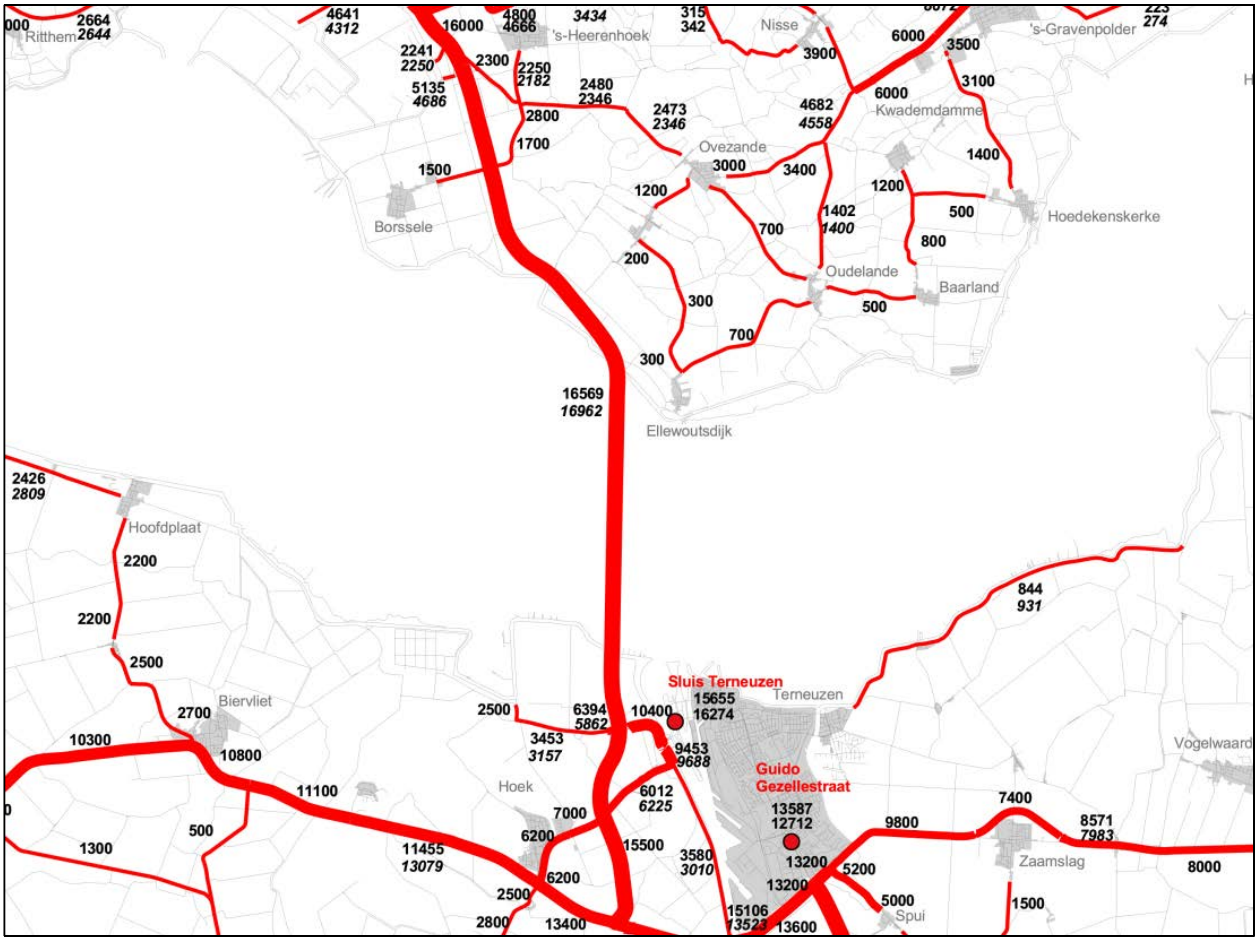

Figure 16. Measured average road traffic intensity through route N62 (Westerscheldetunnelweg) in the year 2008. *Modified from (Provincie Zeeland, Directie Economie en Mobiliteit, 2009).*

Concerning the railway traffic, the average number of passengers for per work day is represented in Figure 17. for InterCity trains and in Figure 18. for Sprinter trains for the year 2005 (Samensporen, 2007). The estimates represent the traffic load per railroad line for both directions. The total estimate average number of passengers per work day traveling to, from and within Zeeland (Breda – Vlissingen section) is < 15.000.

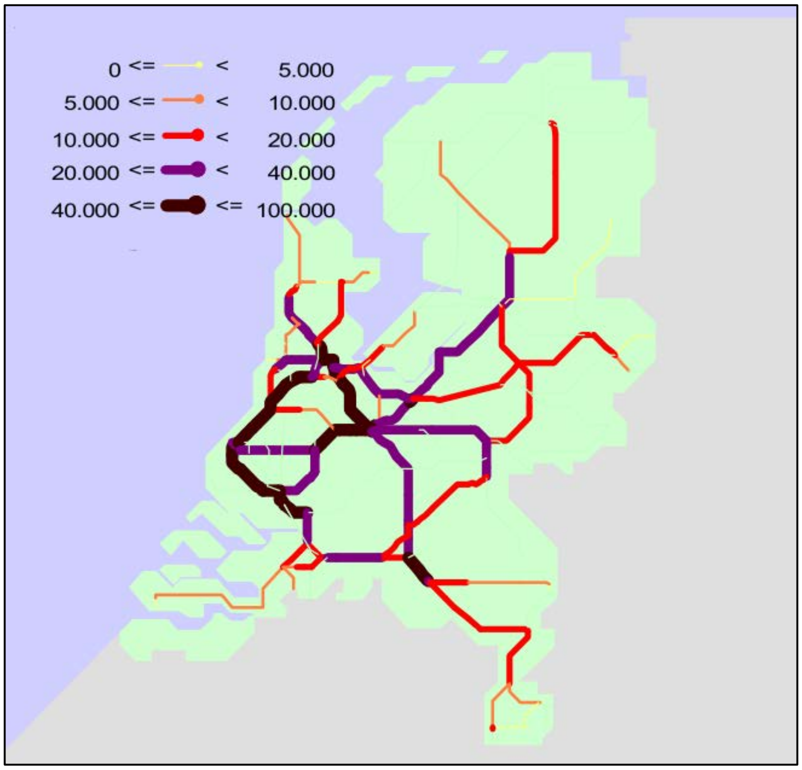

Figure 17. Average number of InterCity passengers per work day 2005*.Retrieved from (Samensporen, 2007).*

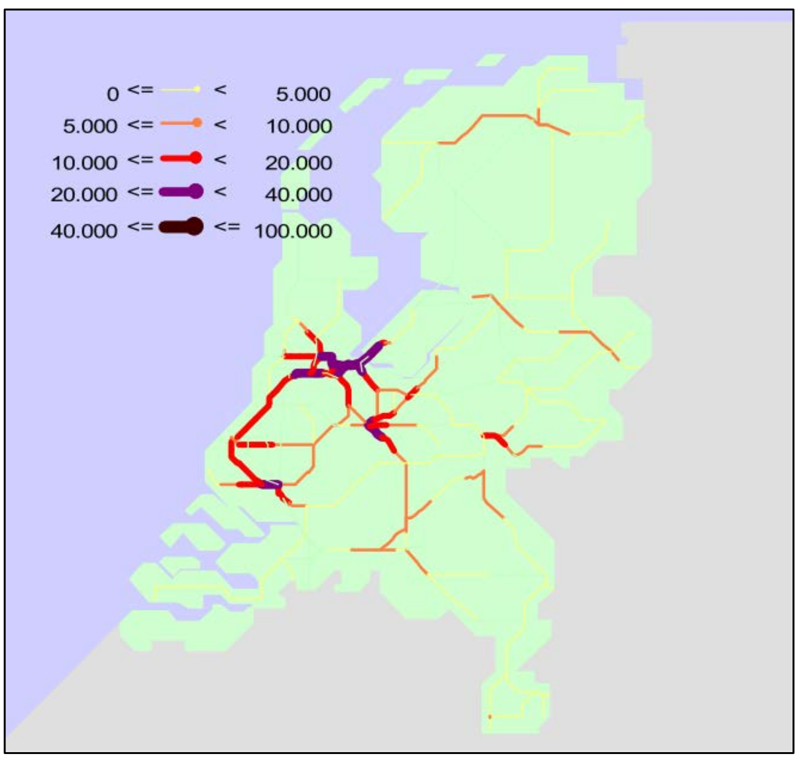

Figure 18. Average number of Sprinter passengers per work day 2005. *Retrieved from (Samensporen, 2007).*

As for the industrial transportation traffic, the modal split for Zeeland sea ports (Figure 19.) indicates that only 6% of the goods are transported by rail and 26% by road. The values include both incoming and outgoing traffic. It is also worth mentioning that those values are accounted not only for ports Buitenhaven (Vlissingen) and Vlissingen-Oost that are located on the Mid-Zeeland peninsula, but also for the port in Terneuzen, which is not connected to the railway in the research area. No detailed information on the percentage of commercial road traffic relative to the total road traffic intensity could be acquired during this research.

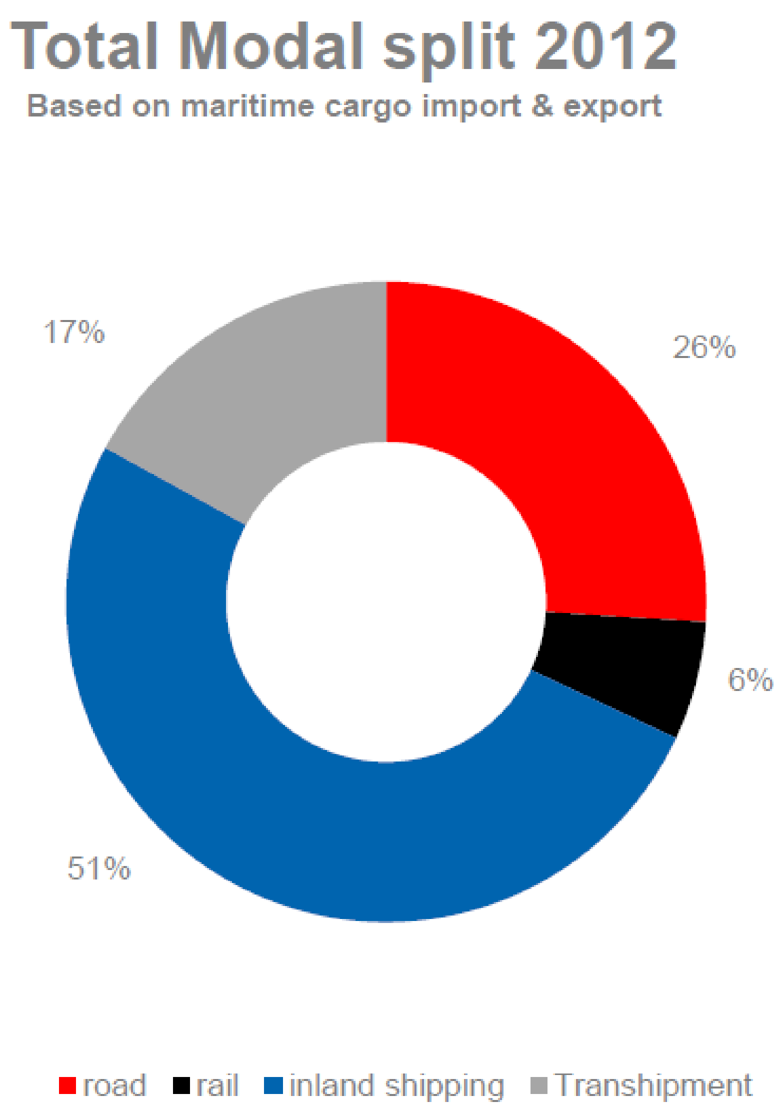

Figure 19. Total modal split of cargo transportation modes for harbors in Zeeland in 2012.*Provided by Hein Verslui at Zeeland Seaports on July 16, 2014.*

3.4. Direct impacts of flooding

The probable primary consequences described in this chapter are the direct results of the modeled flooding event on the CI present in the area of Reimerswaal. This includes both the immediate damage to CI by flood water as well as the duration of the flooding itself that makes the infrastructure in question unavailable for use and/or repair. Figure 20. is a close-up of the peak flood water depth at breach point 1 (Figure 7.) without the graphical representation of the flood water. The flood water depth values illustrate why a breach at this section of the primary dike is considered to be the most critical. The railway, the A58 motorway, and the N289 road going parallel to it, would all be under water more than 2 m deep in some stretches.

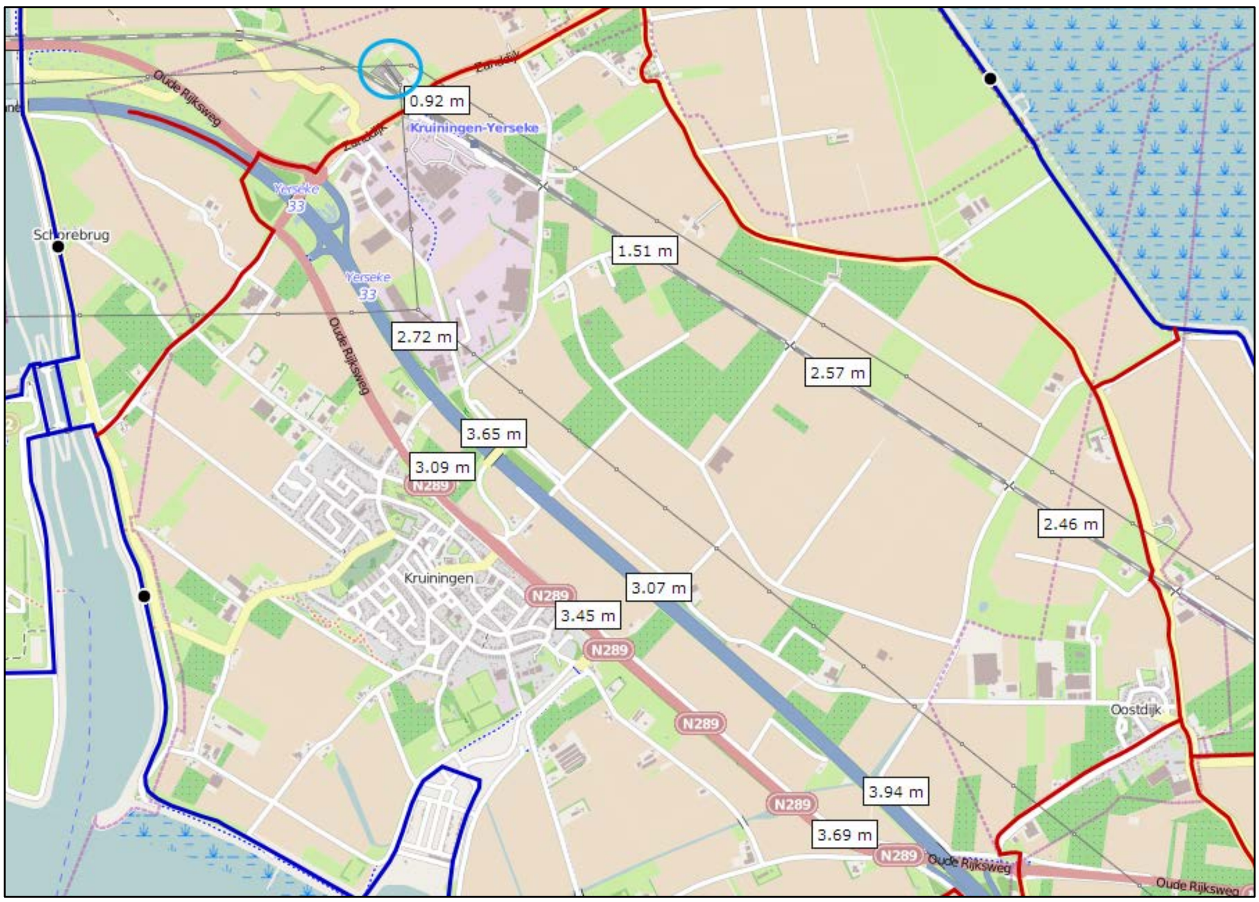

Figure 20. ***Breach point 1 peak flood water depth close-up.*** *Generated from (Lizard Flooding, 2012) on July 18, 2014.*

It is not known if the structural integrity of the roads would be compromised by the flood water in this scenario, however it is safe to say that the surface of the roads will be covered in sediment precipitating from the flood water as well as some debris washed off by the surge. This factor adds up to recovery time since the roads would have to be cleaned to be rendered usable by civilian vehicles. According to the flood model at point 1(Figure 7.) any other roads in the western part of Reimerswaal would also be completely flooded beyond safe use.

Figure 21. Breach point 3 peak flood water depth close-up. *Generated from (Lizard Flooding, 2012) on July 18, 2014.*

The railway is said to be raised above ground level and constructed on a sand dike. It is reasonable to assume that such foundation might not withstand the flooding event, however no factual data on this particular subject was available.

Concerning the supply lines, as mentioned earlier in Chapter 3.1. Critical infrastructure in Reimerswaal, the underground gas and drinking water transmission lines are not expected to sustain any damage or otherwise be affected by the flooding event. The overhead electricity transmission lines are also said to be flood-proof, however there is an important factor to this that is not considered in this research. Although the high tension power line conductors are well above the expected flood water depth, the transmission towers could theoretically collide with debris suspended and transported by surging flood water. The scenarios of such an event, or any other factors that could compromise the structural integrity of the transmission towers are outside the boundaries of this research.

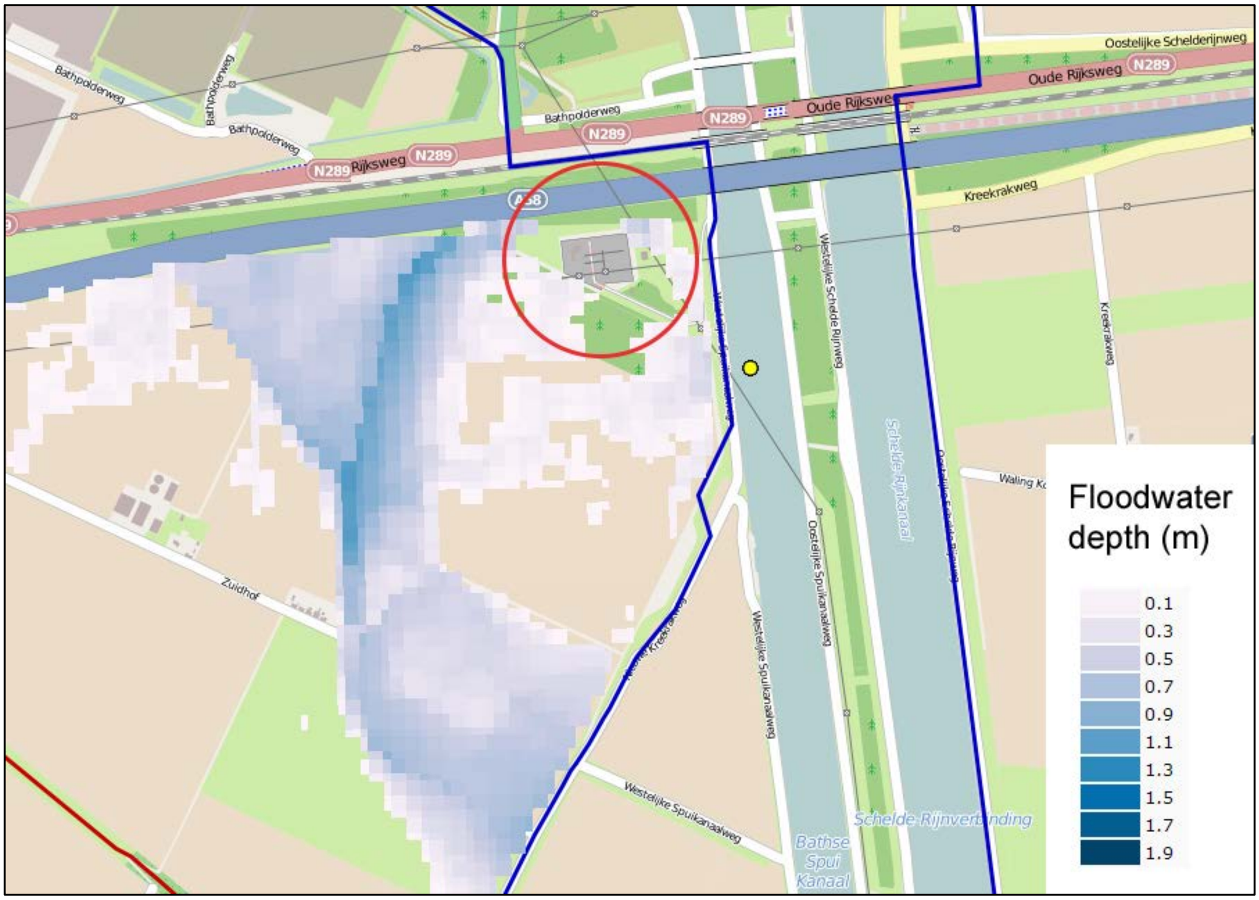

Figure 22. Close-up on the electrical sub-station 26. *Generated from (Lizard Flooding, 2012) on July 18, 2014.*

The local distribution is expected to suffer greatly including electricity, gas, and water. The blue circle on Figure 20. designates the location of electrical sub-station 9 (see Figure 12. in Chapter 3.3.1.). According to the model the facility would be submerged 0.8 to 1.1 meters deep in flood water. The head of operations at Delta Middelburg has stated with certainty the facility will be rendered inoperable in this scenario. This would leave about 9000 properties within the area round the sub-station (see Figure 12.) cut off from electricity supply. According to the same expert, the railway is also powered by the same sub-station at least within that area and therefore would also would not be electrified. The most prominent issue regarding the electrical sub-station is that such a facility uses rather complex machinery to operate that would take 6 to 12 months to repair. That has to do with the fact that such facilities are designed for several decades of service time and are custom built. Another major factor that could complicate the situation even further has to do with a scenario where not only Reimerswaal would suffer from the storm surge event, but also other regions along the coast of the Netherlands (especially Rotterdam), which most likely would be the case. Having to deal with primary consequences in more socio-economically relevant areas, in this context – replacing the damaged electricity line facilities, would make the electricity outage in Reimerswaal a low priority. That would add even more to the recovery time of that particular CI. Figure 21 represents the state of sub-station 26 in the scenario of a breach at point 3. The model clearly indicates that that facility is not going to endure any effects of the flooding what so ever. Figure 22. is a scenario of a breach at a point closest to the facility, within the shipping canal. A breach at such location is much less likely, however even in such a case sub-station 26 is going to withstand, according to the model.

According to the same expert, the gas and drinking water supply are expected to rendered unavailable for local distribution in Reimerswaal and would take approximately 2 months to restore after the flooding has been completely contained.

No other major CI assets in terms of possible secondary consequences are present in the area therefore the flooding scenarios at point 2 would have similar primary consequences to those of a breach at point 1 - sub-station 9, the railway and A58 motorway would be in disrepair. The north-west area of Reimerswaal would remain dry, including the town of Yerseke. An event of a breach at point 3 would only flood the roads, leaving both electrical sub-stations in the area intact.

It is outside the boundaries of this research to estimate which section of the primary dike is most likely to breach then others, therefore a breach between (and outside to some extent) points 1 and 2 are chosen to build a case for this scenario. Point 3 was represented due to the presence of a CI asset – sub-station 26 in that area.

3.5. Probable secondary consequences and possible cascading effects

The probable secondary consequences and cascading effects scenario discussed in this Chapter is structured by sectors as presented in table 2. of this report followed by some general description of how those events would influence social activities in general. Information, Chemical and nuclear industry, and Space and research sectors were not considered in this research. Although there is a nuclear power plant in the Mid-Zeeland peninsula, it is outside the area of direct impact of flooding. Regarding the information sector, no major IT facilities are known to be present in Reimerswaal and a vulnerability analysis of any information transmission lines through the area of direct impact of flooding was considered outside of the research boundaries due to higher priority of the other sectors to this specific research.

The consequences on energy and water sectors have already been discussed in detail in previous Chapters. Disruption of electricity, gas, and water supply are expected to be local within the area of Reimerswaal. The only secondary consequence worth mentioning again in this is that the railway will remain in disrepair even after the flooding has been contained due to lack of electrical power. This is a clear example of a failure in one infrastructure service – distribution of electricity cascading into a failure of a service in a different CI sector – rail transport. It is also an example that illustrates the importance of fast recovery – there is only one railway connecting in Zeeland with the rest of the Netherlands, and each day of it being in disrepair would have severe negative effects on transportation sector and quality of life in for the population of Zeeland.

Based on the results, only the transport sector is expected to be affected outside the flooded area. However the cascading effects of severely diminished land transportation services are expected to be felt across many other CI services in Zeeland. Therefore the secondary effects on road and railroad transport are first discussed in detailed and then followed by cascading negative effects on other sectors and on socio-economic activity in general.

Table 4. visually Illustrates which CI sectors outside of the flooded are expected to suffer from cascading failures. Government functions and armed forces are not considered due to the fact that even the area affected by the secondary consequences in this scenario is not big or relevant enough to cause any disruptions in functioning of the government of the armed forces, even more so with the information sector remaining intact. The results clearly illustrate that a disruption in one sector – transportation can lead to serious problems in six other sectors – food, health, financial, public and legal, civil administration, and even in research sector. However the consequences go beyond other CI sectors, involving socio-economic activities that are outside this table.

Sector	Relevance in Reimerswaal area in terms of possible secondary consequences (see Table 3.)	Cascading effects
Energy	Relevant due to expected lack of redundancy. No gas production or electricity generation in the area.	Electricity, gas and oil transmission through Reimerswaal is not expected to be disrupted.
Information	Irrelevant - No major IT or telecom assets are present in the area.	No major IT or telecom assets are present in the research area and no electricity/telecomm cable disruptions expected.
Water	Relevant due to lack of redundancy in water supply. Water quality is outside project limits.	Water transmission through Reimerswaal is not expected to be disrupted.
Food	Irrelevant – very little food production in the area.	Supplies could be unstable due to hindered road traffic.
Health	Irrelevant – no major or unique medical facilities in the area.	Both emergency services and routine visits could become problematic due to hindered road traffic.
Financial	Irrelevant – no major/ relevant assets in the area.	Cash money supply could be unstable due to hindered road traffic.
Public &Legal Order and Safety	Irrelevant – no coordinating agencies for public order and safety present in the area with responsibilities beyond municipality itself.	Law enforcement could become problematic due to hindered road traffic.
Civil Administration	Irrelevant – disaster event area covers one municipality with a low population and activity.	All cervices are most likely to suffer and deteriorate in quality due to hindered road traffic.
Transport	Relevant due to lack of redundancy. Air transport infrastructure is not present in the research area.	Alternative routes do not have the capacity for traffic that would be redistributed from A58. Major traffic problems expected.
Chemical and nuclear industry	Relevant – transmission pipelines could be present in the area. Possible storage of substances.	Irrelevant – relies mostly on energy, pipelines and sea transport, none of which are expected to be disrupted. Pipelines are expected to be floodproof.
Space and research	Irrelevant – no space or research facilities present.	Research in HZ university could be hindered.

Table 4. List of expected primary consequences (from Table 3.) and predicted cascading failures of CI outside of Reimerswaall.
Modified from (Klaver, Luiijf, & Nieuwenhuijs, 2011).

Transport

As already discussed in Chapter 3.2.3. the traffic intensity of the motorway A58 measured in number of passing vehicles per weekday is higher than that of the three other routes in out of the Mid-Zeeland peninsula combined. Route N289 which is a road going parallel to the A58 also has a traffic intensity that is around 10% of the motorway. It is outside the scope of this research to conduct an in-depth analysis of the probable changes in road traffic dynamics taking place in this scenario, however some basic estimations have been made on the effects of road vehicles having to resort to an alternate route as opposed to taking the direct route through Reimeswaal. Alternative routes around the flooded area are proposed in order to illustrate the example of increased travel distance when taking the direct rout via A58 or N289 is no longer an option. N57 and N256 would be alternative travel routes between Goes and Roosendaal, and N62 would be an alternate route between Vlissingen and Antwerp.

In this scenario the measured vacation time traffic for routes A58 and N289 is redistributed equally among the other three routes – 5611 for N289 + 42289 for A58 from Figure 14. With a total of 47900 vehicles per day. The reason for choosing the peak traffic intensity values in months of July and August is that the flooding, estimated to last around 6 months, very well might last through summer if the dike breach happens in second half of the storm season (closer to May). Considering the sum value of current traffic intensity for the sections of other three roads combined, represented in Figures 15. and 16. which is approximately 40000 vehicles per day, that virtually means that the load on each of those three roads would more than double. The values fluctuate somewhat between different sections of the routes, therefore an approximate average number will be selected for each route. Also these numbers are traffic flow values for the *whole road,* meaning all driving lanes.

According to a specialist from the Rijkswaterstaat, a general value of 1800 vehicles *per hour per lane* is considered normal road traffic capacity in the Netherlands, however there are aspect that can noticeably hinder the traffic flow and decrease the capacity of a road. Such aspects include presence of intersections, traffic lights, roundabouts, movable bridges and so on. For the sections of N265 and N57 that are across the river – the bridge and storm surge barrier respectively – strong, high speed wind are also a factor that negatively impacts driving conditions and reduces traffic speed. Therefore the traffic capacity of these routes is estimated to be 1300 – 1500 vehicles per hour per lane. The difference between a road with a single lane in each direction and a road with two and more lanes in each direction is not only quantitative in terms of traffic throughput capacity, but also qualitative in terms of how it dictates different traffic dynamics. A single lane in each direction offers little (if at all) possibility to separate slow moving and fast moving traffic as well as the possibility to perform an overtaking maneuver (Rijn, 2004). This factor however is too complex and therefore not considered in this research.

The simplified method of estimations used here assumes that the traffic, that no longer can go through Reimerswaal would be equally redistributed among the three alternative routes. It is important to mention that the estimations do not take into account the fact that the railway transport will be completely unavailable as well. Of those approximately 15000 people who used to travel by train (see page 30), many would resort to either personal or public road transportation modes increasing the traffic load even further.

For the purposes of this research, two relevant points on either sides of Reimerswaal are selected to make a simple case of how the traffic load of the A58 motorway and the N289 road would have to circumvent the flooded area. Figure 23. Illustrates a direct route from the city of Goes to Roosendaal via the A58 motorway. The distance is 55 km with an estimate travel time of 40 minutes at maximum allowed travel speed.

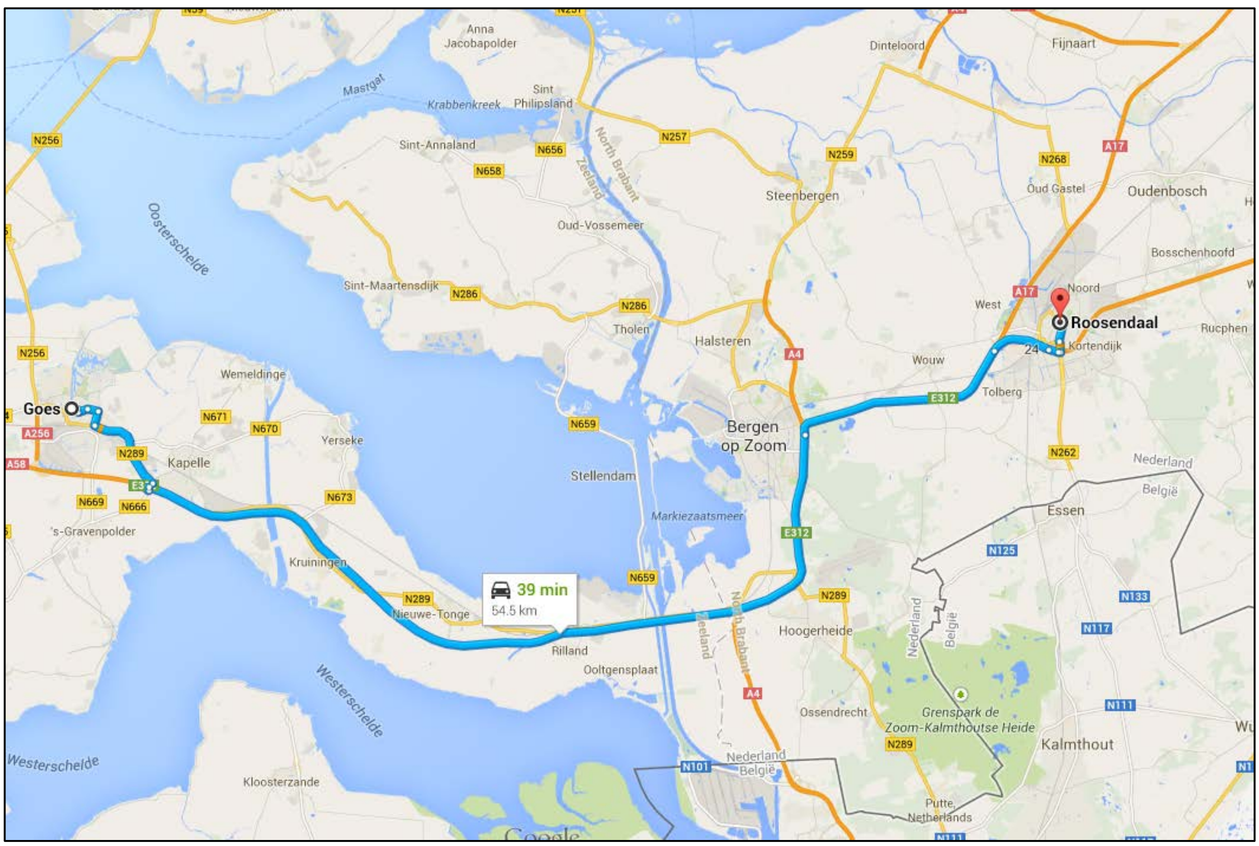

Figure 23. Direct route Goes- Roosendaal via A58. *Retrieved from Google Maps on August 7, 2014 (http://maps.google.nl).*

An alternate route via road N265 represented in Figure 24. is 81 km long with an estimate travel time of 73 minutes at maximum allowed travel speed. With the A58 and N289 roads flooded, this becomes the shortest way to reach Roosendaal. Using the estimations made above, the total value of vacation time daily traffic flow through Reimerswaal (A58+N289) – 47900 vehicles, is divided by three to give the extra load on each alternative route of roughly 16000 vehicles per day. That value is then added to current amount of traffic. For N57 the average intensity is around 15000 according to the traffic intensity map. The sum then is 31000 vehicles per day for the whole road. As mentioned earlier, the road has only one lane in each direction, therefore the value becomes 15500 vehicles per day per lane, or 646 vehicles per hour per lane. That value is well within the estimated capacity of 1300 – 1500 vehicles per hour per lane. However if we divide the daily value by 10 hours which most daily activity takes place, the intensity per hour then would be 1550 vehicles, which is already at the higher threshold of the road's estimated capacity range. And that does not yet take into account the rush hours, during which the traffic would most likely exceed the capacity of the road significantly. Same estimated capacity and calculations apply for the other two routes.

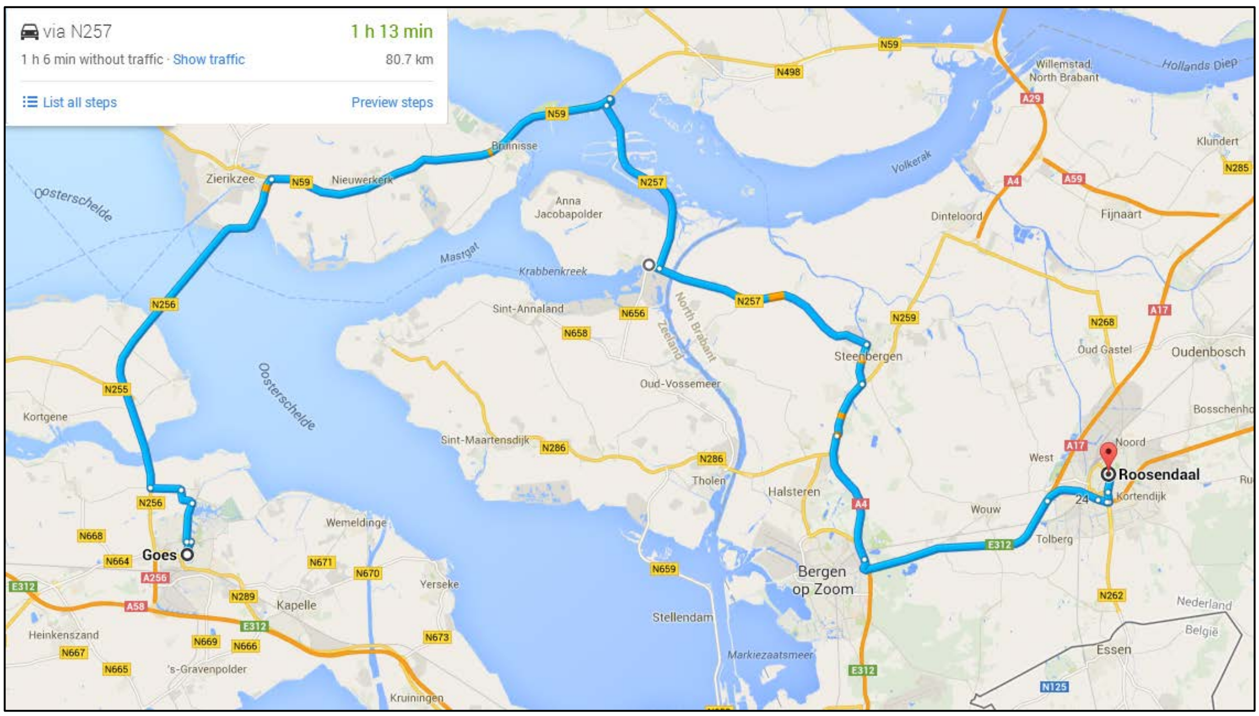

Figure 24. Alternative route Goes - Roosendaal via N257. Retrieved from Google Maps on August 7, 2014 (http://maps.google.nl).

Route via road N57 also has only one lane in each direction throughout its entire distance. Currently the traffic load on that road is around 9500 vehicles per day for the whole road. Adding 16000 diverted from the flooded area we get 25500 vehicles per day for the whole road, or 1275 per hour for a 10 hour day. This calculation indicates that the road has just about enough capacity to accommodate the diverted traffic. However, again, factors such as rush hours and travelers resorting to automobile transport instead of now unavailable railway, would most likely make that value exceed the estimated capacity range. Figure 25. Illustrates that the travel distance would be 115 km, which is twice the distance of the direct route via A58.

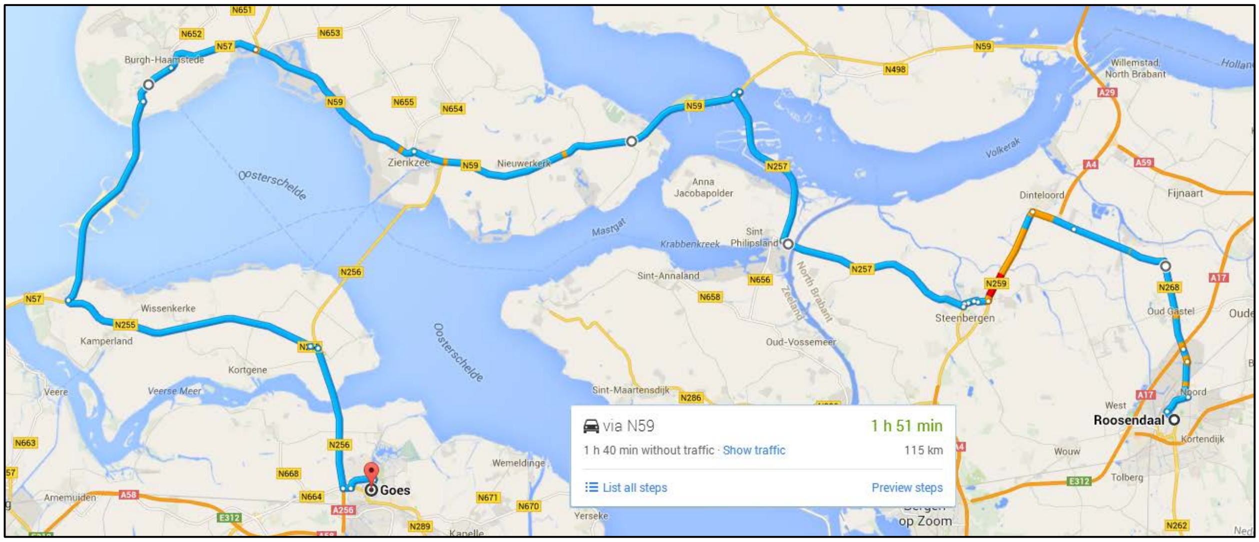

__Figure 25. Alternative route Goes - Roosendaal via n57.__ Retrieved from Google Maps on August 7, 2014 (http://maps.google.nl).

Between Vlissingen and Antwerp the N62 route is rather similar to the A58 route in distance – a 10 km difference (Figures 26. and 27.) however the traffic load capacity is, again, much less. Additional to the limiting factors e.g. intersections, traffic lights and roundabouts, there limiting factor in place which is the movable bridge across the Terneuzen-Gent Canal. Currently the bridge opens 23 times a day amounting to a total of 5 hours of daily road blockage (Wikipedia.org, 2014). There is a tunnel currently in construction to improve this situation which will have the same capacity as the rest of the road, thus not creating a bottleneck. According to the information on the website of the project, the tunnel is due to be open in 2015 with no specific date (sluiskiltunnel.nl, 2014). Currently the traffic flow through the tunnel is measured to be close to 17000 vehicles, again only one driving lane in each direction. Added with the 16000 vehicles per day diverted from the flooded area that makes 33000 vehicles per day, or 1650 vehicle per lane per hour for a 10 hour day. Again this value exceeds the estimated capacity range of 1300 – 1500 without considering rush hours and former railway commuters.

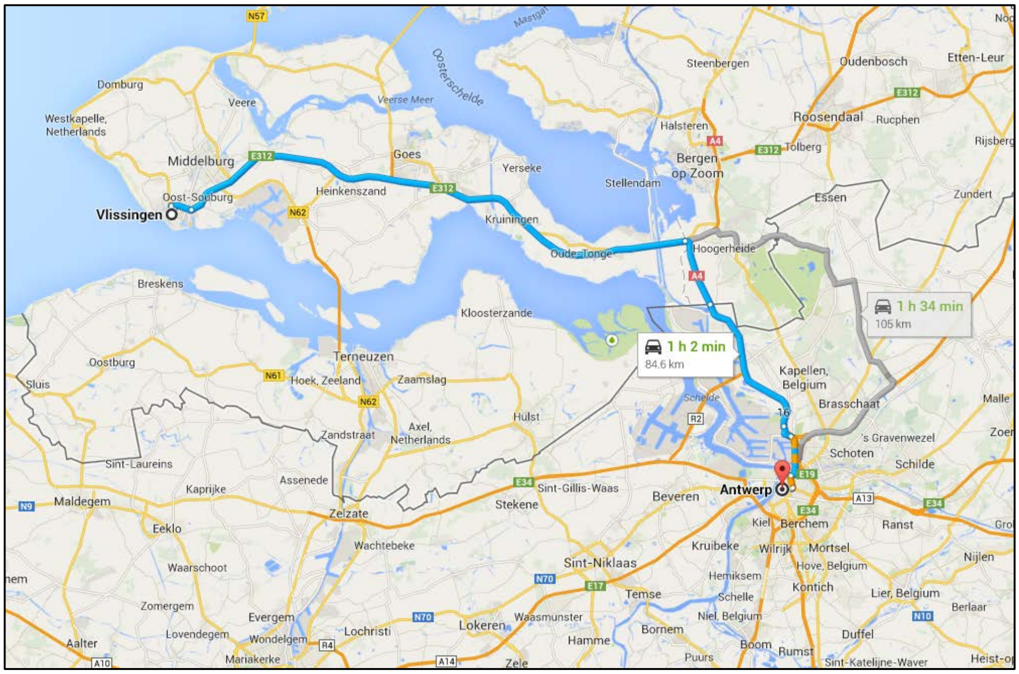

Figure 26. Direct route Vlissingen-Antwerp via A58. *Retrieved from Google Maps on August 7, 2014 (http://maps.google.nl).*

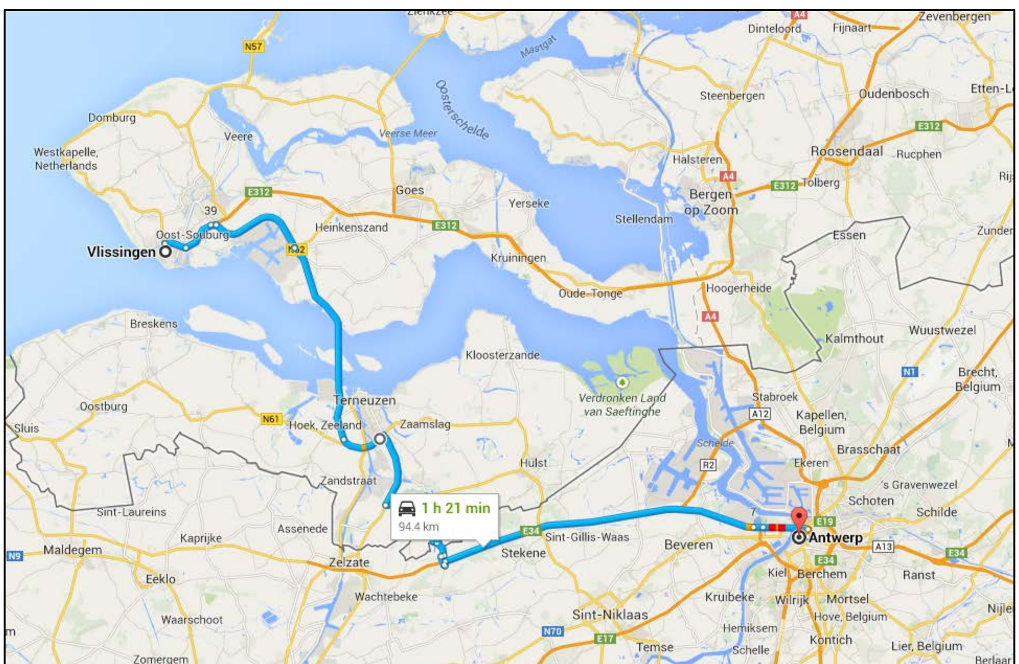

Figure 27. Alternative route Vlissingen-Antwerp via N62. *Retrieved from Google Maps on August 7, 2014 (http://maps.google.nl).*

It is difficult to model the changes in overall traffic dynamics in Zeeland in detail for this scenario, however there is no reason to doubt that the effects of A58 and the railway being completely out of service for many months would be felt by everyone within the province and beyond. Nowadays all socio-economic activity fully depends on effective commercial and personal transportation. Meaning that people need to travel to their work places and to run their work errands, and businesses need to receive and deliver goods. Any daily travel routine would be complicated by increased travel time and distance. Traffic speed would most probably drop to 50 km/h during rush hours regardless of maximum allowed speed. Therefore the lower the efficiency and convenience of transportation, the harder and costlier it is to maintain economic activity.

Same consequence applies for commercial harbors in Vlissingen and Vlissingen East. It has been already mentioned that 26% of goods come in and out by road and another 6% by rail. Those numbers however represent the percentage of bulk load, not the relative value of those goods that are being transported on land. Considering that the harbors play a significant part in the economy of the province, the losses sustained due to not being able to efficiently provide services of land transport would have significant consequences on socio-economic climate.

Food

Food provision service is expected to suffer difficulties due to diminished quality of the road transport infrastructure. A major Dutch supermarket chain - Albert Hein, for example, keeps practice of restocking their stores twice a day from centralized warehouses. No, or very little supply of goods is kept off shelves within the stores themselves. The logistics of the supply chain are planned and optimized for existing travel routes and traffic conditions. Therefore it wouldn't be a wild assumption to say that an abrupt and indefinite degradation of traffic flow efficiency would hinder the supply of food products in the Mid-Zeeland peninsula. The secondary effects of the flooding event might influence consumers to stock up on provision, creating at least temporary shortages on some products as bottled water and food products with long storage periods.

Health

Hindered transportation would result in both medical staff and patients to spend more time traveling or having to stay at the hospital for several days in cases where they wouldn't have to resort to such measures otherwise. That would no doubt result in medical staff getting exhausted, arriving with delays or having to cancel appointments altogether, inevitably resulting in a decrease in quality of medical and hospital care. Additionally, individuals who require frequent highly specialized medical treatment that can be performed only in major university-clinics outside of Zeeland would potentially experience serious health risks as a result of not being able travel as easily.

Financial sector

Regarding financial sector, the payment services are expected to experience difficulties. This has to do with transportation of cash currency to and from the banks as well as automated teller machines (ATMs). Beyond that there is nothing else to add on the matter. Any research on cash money transport routines or its usage among population of Zeeland is outside the boundaries of this research.

Public and legal order and safety

Maintaining public order, safety and security is also expected be complicated somewhat by the fact that the traffic on the roads mentioned above would exceed their designed capacity. It is difficult to predict to what extent the driving behavior among the population would change for the worse, however the number of traffic accidents would most likely increase due to extreme traffic intensities. Additionally, the services enforcing public order and safety would also inevitably experience longer travel (response) times.

Civil administration

It is hard to say whether the quality of civil administration services in Zeeland would degrade noticeably as a result of diminished land transportation conditions. It would most probably have to do with appointments being delayed or canceled. Emergency services such as police, fire fighters and medical, as well as postal services on the other hand depend strongly on the road transport services. The response time for the emergency services and delivery time for postal services are calculated and estimated for the current traffic conditions and available routes, therefore the changes in the transportation infrastructure discussed above would most likely have significant cascading effects on those services increasing the threat level to wellbeing, health, and life of the population of Zeeland. Diminished quality of postal services would have less dramatic effects, nonetheless create discomfort and impede economic activity.

Socio-economic activity and quality of life

Another major sector of economy in Zeeland besides the harbors is recreation business – hotels, restaurants and other accommodations. According to the data provided on the official website of the Province, 1,4 million vacations – meaning groups of people or families - were spent in Zeeland In the year of 2013. That includes both Dutch and international tourists (zeeland.nl, 2014). If the secondary consequences were to overlap with, or last through the vacation season that would significantly diminish the attractiveness of the Mid-Zeeland peninsula for tourists. Needless to say that people expect comfort in their time of recreation, and having to deal with traffic congestions wouldn't appeal to the majority of people who come with their own vehicles. Loss of clientele wouldn't be the only problem for the restaurant businesses. As already mentioned, the supply lines would potentially be hindered, causing delays. During the holiday season the amount of food and especially drinks sold is at its peak and problems with timely supply of goods could diminish the quality of service that the restaurants, bars and other catering facilities are able to provide.

The overall day-to-day activity of the population of Zeeland would most likely also change, both by virtue of obstructed land transportation capacity and the cascading effects that have been discussed above. Having to spend more time in traffic or not being able to use the railway is an inconvenience that might cause people to refrain from their cultural, recreation, and other routines or plans. That implies that activities such as shopping for goods that are beyond basic needs, attending cultural events, visiting places or people etc. wouldn't be worth the effort.

Daily routines and responsibilities would become so much more difficult and time consuming to maintain. Getting to work, attending school, visiting your friends or loved ones in another town, any business or social activities and events would become difficult and uncomfortable to attend for a duration of up to a year. There are several colleges and high schools in Zeeland, including HZ University of Applied Sciences where the author of this graduation work has studied. It is difficult to estimate the percentage of the population that works and/or studies in Zeeland, but lives elsewhere, however it is safe to assume that there are many. That fraction of the population would have to either spend more time on traveling, which would noticeably decrease quality of life, or resort to seeking accommodation near their places of work or study. The latter might end up introducing some to financial difficulties, while being not a viable option altogether for others. That aspect connects this research to the subject of community resilience – how many people and businesses will end up not willing or unable to stay in Zeeland.

4. Conclusion, discussion and recommendations

The results of this research suggest that the secondary consequences of a flooding event in Reimerswaal would not have as dramatic of an effect as was initially expected. At the onset of this research project a scenario that would present serious health and safety hazards to the population was anticipated to take place even outside the area of the flooding. Such threats were assumed to stem from the disruption of the critical supply lines – electricity, drinking water and gas. A power outage alone could be a cause for massive evacuation of population just by virtue of not being able to work and perform daily tasks that require access to a personal computer connected to internet, not to mention the businesses seizing their activity. A disruption of domestic drinking water and gas supply would pose a more immediate threat of not being able to properly maintain personal hygiene and cook food. These are only a few basic examples of secondary consequences that were originally anticipated, however the outcome in such a case would have been much more broad and devastating. Ultimately, the results of the research have led to a rather subtle scenario that could hardly be labeled a disaster.

Another noteworthy point of discussion is that there is no coherent knowledge or estimations on the possible effects of flooding on the structural integrity of the roads. None of the interviewed specialists could provide information or refer me to a source that has conducted any studies on that subject. It could potentially add significantly more recovery time and costs to the event scenario if the motorway and any other roads subjected to flooding would have sustained structural damage not only to the road surface, but also the underlying foundation layers. However no such information could be found or recommended by interviewed specialists.

A defining factor in researching and assessing critical infrastructure vulnerability and interdependency is the fact that different critical infrastructure sectors and services are owned and utilized by various private and public stakeholders. Communication between the stakeholders and governmental agencies responsible for flood protection and disaster management often leaves much to be desired (Klaver, Luiijf, & Nieuwenhuijs, 2011).

This report is to be considered groundwork for future, more comprehensive research, considering to the fact that each sector of the critical infrastructure is a separate area of expertise and each deserved to be researched separately. For example, the resulting possible secondary consequences in this scenario for the most part involve the transportation sector and transport logistics, which is a whole separate scientific discipline. There are a lot of factors and data to consider in order to make even the most basic projections or estimations. The assumption proposed in this scenario is rather basic and hypothetical both in terms of actual traffic flow dynamics and behavioral changes among the population. With that said, a detailed, comprehensive analysis and modeling of the potential changes in traffic dynamics would be a great benefit to this research as well as to the general discourse on the importance of of critical infrastructure to the socio-economic well-being.

The scenario of the probable secondary consequences presented in this report, although being hypothetical, does stress the importance of response and recovery time when it comes to infrastructure failure. Community resilience depends on certain conditions that are provided and maintained through sufficient and uninterrupted provision of cervices that critical infrastructure facilitates. The methodology and results of analyzing the vulnerability critical infrastructure in Reimerswaal considering the topology of the area have to do with the first two layers of the Multi-layer flood safety framework. The integrity and reliability of both primary and secondary flood defenses have been put to question as well as land-use planning with regards to allocating critical infrastructure. There is also still room for more detailed research to be done on the topology of the infrastructure lines and assets in the area with respect to their co-dependencies.

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Appendix A. List of interviewed stakeholders.

Marcel Matthijsse, Policy Advisor at Veiligheidsregio Zeeland;

Leo Adriaanse, Senior Water Management Advisor at Rijkswaterstaat;

Ruben Akkermans, Water Policy Officer at Provincie Zeeland;

Conny Buijs, Consultant / specialist in sustainability, nature, landscape, water safety and road traffic at Rijkswaterstaat;

Ylva Peddemors, Flood risk management at Provincie Zeeland;

Ada de Waard, GIS coordinator at Rijkswaterstaat;

Hans van der Sande, Emergency Coordinator and Policy Officer for Flood and Roads, Waterschap Scheldestromen;

Wim Huissen, Public safety advisor at Gemeente Reimerswaal;

Patrice Troost, Senior specialist multidisciplinary crisis management planning

Gerard Fokker, Head of Operations at DELTA N.V. Middelburg;

Appendix B. Theme and structure of the interviews.

In accordance with the research procedure discussed in chapter 2. And after having established the flooding event model, the theme and structure of collecting knowledge from interviewed experts is the following:

1) Which CI assets/services from table 2. are present in the research area?

2) What would be the effects on those CI assets and services in case a given modeled flooding event in Reimerswaal?

    What would happen to the roads?
    What would happen to the railway?
    What would happen to the electricity/gas/oil supply lines?
    How many users would suffer the consequences of being disconnected from the supply/services?

3) How long would it take to contain the flood?

    Approximate time until the breach in the dike has been sealed?
    Approximate time until the flood water has been pumped out of the primary flood defense perimeter?

4) How long would take to restore the affected/damaged CI to its original designed capacity?

5) What would be the long-term secondary consequences on the socio-economic situation in the province of Zeeland in general and Mid-Zeeland peninsula specifically.

Question 5 could not be specified more at the onset of the research due to insufficient knowledge in the subject of CI interdependence and cascading failure effects. That knowledge was being gained through the duration of the research up until the point when the scenario of the secondary consequences on the socio-economic activity was being discussed and constructed.

Appendix C. Research progress log – meetings with experts.

27.03.2014. First meeting took place. It was a meeting of several stakeholders from various governmental agencies including the client – Marcel Matthijse, Leo Adriaanse, Conny Buijs, Ada de Waard and Ruben Akkermans. The area of the research was discussed and established. The research question was still unclear at this point however it was already focused on critical infrastructure.

8.04.2014. Meeting with Marcel Matthijsse. Main question began to take shape. Difference between primary and secondary consequences has been established. At this point the research question was – "What would be the overall consequences for the province of Zeeland in case of a flooding in the municipality of Reimerswaal?" It was also established at that point that the only water supply to the Mid-Zeeland peninsula goes through the area of Reimerswaal. The initial expected scenario was complete disruption of electricity and water supply to the peninsula.

22.04.2014. Meeting with Conny Buijs. At that point in time I was asking question regarding the responsibilities of the various stakeholders – who is responsible for what. Results – primary and secondary flood defenses are the responsibility of the waterschap, electricity supply lines are owned by Tennet B.V. and serviced in Zeeland by DELTA B.V. Roads are the responsibility of Rijkswaterstaat, railway – ProRail is the owner and NS is the service provider.

6.05.2014. Meeting with Marcel Matthijsse. During the discussion of the progress, some advice on how to proceed was given to me. I was referred to Hans van der Sande to inquire about the most critical location of a dike breach and the possible consequences (both primary and secondary).

14.05.2014. Meeting with Ylva Peddemors. This is where I got access to and got familiarized with the *lizard.net* flooding model used in this research assignment. During all the following interviews regarding critical infrastructure assets I have used the print-outs of the probable flooding to make a case for my questions. Same day a meeting with Ruben Akkermans took place. At this point the research has not really begun yet. The topic of the meeting was discussion of the project plan. The critical importance of the A58 motorway was established.

15.05.2014. Meeting with Marcel Matthijsse. An important decision was made to refrain from trying to analyze the CI assets and networks myself, but instead to ask the experts for their conclusion. Such decision was based on two considerations – first, I would not manage to conduct a comprehensive analysis of the entire CI topology in the area of Reimerswaal withing the time constraints of this assignment. And second – detailed information on CI assets and topology is considered sensitive and is classified. A basic research procedure was established – What happens in case of a flooding, how long do the effects of the flooding would last, and how long would it take to recover the damaged CI after the flooding has been contained. In order to find out the possible flooding event parameters, I was referred to Hans van der Sande, the emergency Coordinator and Policy Officer for Flood and Roads, Waterschap Scheldestromen.

23.05.2014. Meeting with Conny Buijs. During this meeting with Conny, questions were asked regarding the primary consequences of a flooding on the roads in the flooded area – would the road surface and underlying layers sustain damage? From the interview I have learned that there is no knowledge available on that particular subject – no models or research publications are known to the expert to be available.

27.05.2014. Meeting with Marcel Matthijsse**.** During the research progress discussion Marcel has proposed that I talk to Hans van der Sande about the possible effects of flooding on the road structure. Additionally he said that I should look into online publication database of the TNO Delft research organization. No material on the subject had been found on that internet resource.

3.06.2014 Interview with Ada de Waard. Ada could not answer any of my questions on critical infrastructure vulnerability and possible cascading failures. She did recommend looking into the Chamber of Commerce (kamer van koophandel) online database for published reports on CI failure scenarios. No such sources were found. Also she has proposed an argument that wave action generated by vessels routing through the Western Scheldt shipping lane, which is dredged close to the banks of the supposed breach area would introduce problems to the effort of containing the flood. Therefore, according to her, the shipping through that route might have to be ceased until the breach in the dike has been sealed, which could have major economic consequences due to high commercial shipping traffic being stopped. That argument got disproven later by Hans van der Sande. He has stated that vessels pass through that area at low speeds and do not generate any noticeable waves.

6.06.2014. Interview with Hans van der Sande. This is the second interview where I got actual tangible results for my research (after acquiring the flood model). Hans has provided me with an estimate time needed for containing a breach in a dike – around 6 months. Also according to his expertise, the roads in the flooded area would be unusable until the flooding has been contained. Another interesting, although finally tangential piece of information was that evacuation from the Mid-Zeeland peninsula would not be hindered should the A58 motorway become disabled – the alternative routes have enough capacity to facilitate timely evacuation by road. Interview with Hans van der Sande. Regarding the effect of a flooding on the roads, Hans could not give an answer on the question of how would the flood impact their structural integrity, he did however mention with certainty that sediment and debris would be present on the surface after the floodwaters have receded that would have to be cleaned before the roads can be used.

18.06.2014. Interview with Wim Huissen. This expert has pointed me to the fact that the shipping canal at the East of the research area - Schelde-Rijnkanaal – is an important commercial shipping route that potentially could become blocked by debris of wreckage cause by a storm surge event. No studies or models have been found regarding that matter and through discussion with the client this issue has been considered to be outside the boundaries of this research assignment.

24.06.2014. Interview with Gerard Fokker, Head of Operations at DELTA N.V. Middelburg. This company services not only the electricity supply and distribution, but also that of gas and water, therefore information learned from this expert was a significant benefit to the cause. All the facts mentioned in the chapters 3.3.1. and 3.3.2. of this report, along with maps of electricity lines, have been learned and acquired from this interview.

16.07.2014. Meeting with Ylva Peddemors. During this meeting all the relevant parameters of the lizard.net flooding model were discussed. The results are presented in chapter 3.2.1.Flood model description and parameters.

25.07.2014. Meeting with Marcel Matthijsee. After having compiled and presented the results of my findings, Marcel and me had a discussion regarding the cascading CI failures and other secondary consequences. All possible outcomes of the scenario were agreed with and validated by Marcel.

There were some undocumented meetings after and between the ones mentioned here. Many of those were the regular progress report meetings with the client, others were interviews with experts that did not produce tangible results, nonetheless still providing valuable clues and guiding my research in the right direction. Literature research continued throughout the entire length of the project time, therefore it is difficult to pinpoint at which stage a certain concept or framework was applied. Four weeks before the hand-in date came the summer holidays, making it impossible to arrange any new interviews. During a meeting with the client it was decided to cease collecting information and proceed to finalizing the results of the research – the secondary consequence scenario. The final version of the presented results was verified and validated by the client himself - Marcel Matthijsse, Policy Advisor at Veiligheidsregio Zeeland.

Appendix D. Key principles applied in scenario building.

(Material from the Technical brief on scenario building by (ACAPS, 2011) (bold text is original).

- Scenario development can be done either on an individual basis or in a group. Always include **support of selected key informants/experts**, who have knowledge of the country context and the current crisis impact.

- Build scenarios around **specific planning objectives**. Planners must consciously define what will be useful for their purposes, and what will not.

- Understand and agree that you need **different levels of details at different time**.

- Base scenarios on, as a minimum, **experience, lesson learnt, secondary information and direct observation**.

- Requires the identification of „**the known unknowns**‟.

- Include **just enough details** to permit planning and to communicate to others the anticipated conditions and needs of the affected population.

- Do not base your scenario **on issues that will certainly take place**. Only select factors that are genuinely variable and subject to significant alternative outcomes.

- **Focus on the impact** of the scenario on people and their livelihoods, and the related needs. Link this analysis to an informed programme or response design.