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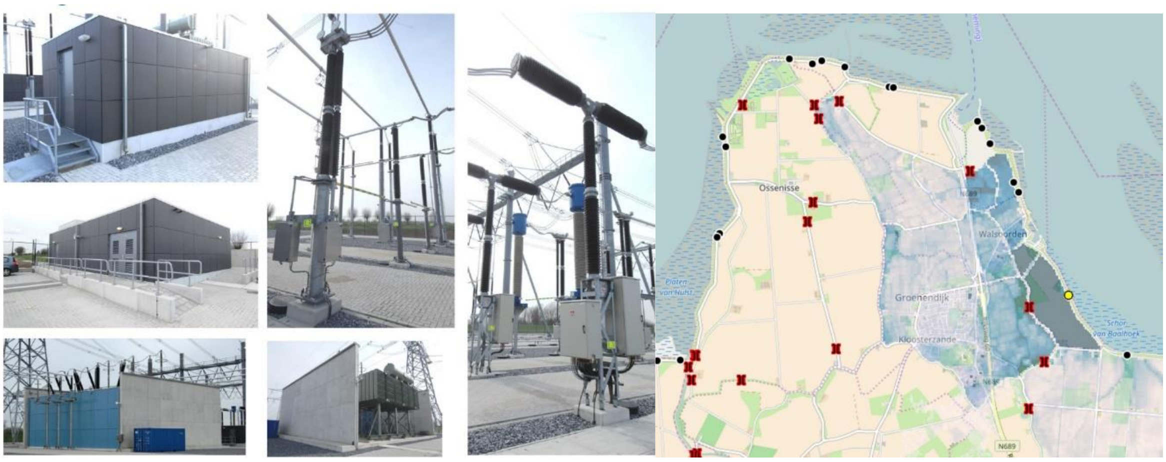

Water Resilient Electricity Network Zeeland

Final report

Provincie Zeeland

Nelen & Schuurmans

25-7-2018

Co-financed by the European Union - European Regional Development Fund

Water Resilient Electricity Network Zeeland

Final report

For
Provincie Zeeland
Postbus 6001
4330 LA Middelburg

Nelen & Schuurmans
Zakkendragershof 34-44
3511 AE Utrecht

www.nelen-schuurmans.nl

Project details

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Contents

1 Introduction

1.1 Incentive

The Province of Zeeland is a partner in the European flood protection project FRAMES (Flood Resilient Areas by multi-layered Safety). Knowledge exchange between Zeeland and other European countries is central to the project.

FRAMES uses the Multi-Layer Safety concept to work with governments and sectors to come up with the most effective solutions to deal with floods and climate change. The Multi-Layer Safety concept looks at the consequences of a possible flooding. Questions that are asked are: In what way can we limit the damage in the event of a dam breach as much as possible? A good analysis of the area is important for this. What exactly happens in case a dam breaches? What is the influence of secondary flood defenses? What impact does a flood have on our vital infrastructure? And how long does the reconstruction take?

In this project, the vulnerability of the electricity network, including cascade effects, as a result of the failure of a water defense or extreme precipitation is shown. The project consisted of a quickscan (Zeeland), followed by an area-oriented pilot (Kloosterzande).

1.2 Goal

The goal of the project was to develop a better integral insight in making the electricity supply network flood resilient. To this end, insight was first provided into the most vulnerable electricity sets. Subsequently, measures were derived to increase the robustness.

1.3 Approach

The project consisted of three parts, namely:

1. Zeeland-wide quick scan of the electricity supply during flooding on the basis of supplied flood scenarios and data on the electricity network. To this end, a risk label has been assigned to each asset in the medium-voltage network. The figure below shows which assets fall under the medium-voltage network.
2. Region-oriented pilot Kloosterzande. An interactive 3Di model has been created for this area. It was used to simulate flooding and extreme rainfall. The flooding images have been translated into hazard maps for vital infrastructure. Cascade effects have been taken into account.
3. Dissemination of the generated knowledge and information in a wiki knowledge system and a web-based geoportal.

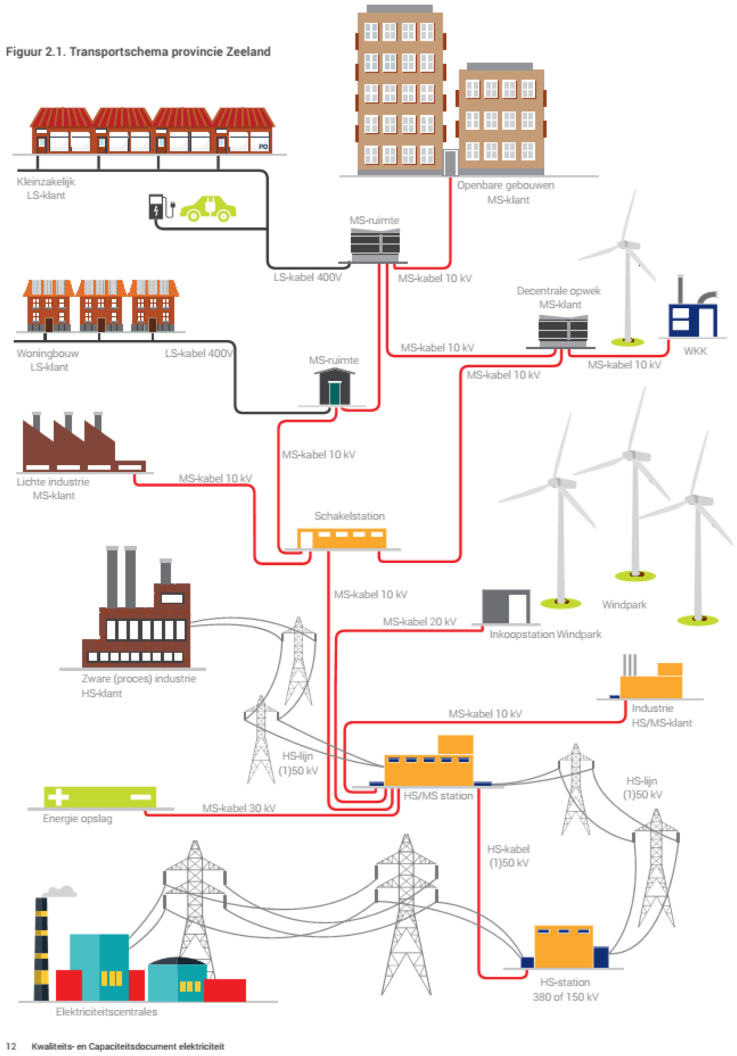


Figure 1-1: Schematic representation of the electricity network. The red lines indicate the medium voltage network

1.4 Reading guide

This report is a brief summary of the project. In chapter 2 the method and the results of the area-wide quick scan are explained. In chapter 3 this is done for the area-oriented pilot Kloosterzande. Chapter 4 describes the most important findings and makes some recommendations for follow-up research.

2 Area-wide quickscan

2.1 Introduction

The aim of the area-wide quick scan was to provide insight into the failure of the medium-voltage assets as a result of dyke breaches and extreme precipitation.

The diagram below shows how we derived a area-wide quick scan of the robustness of the electricity network (medium voltage) in Zeeland with the available knowledge sources and methods.

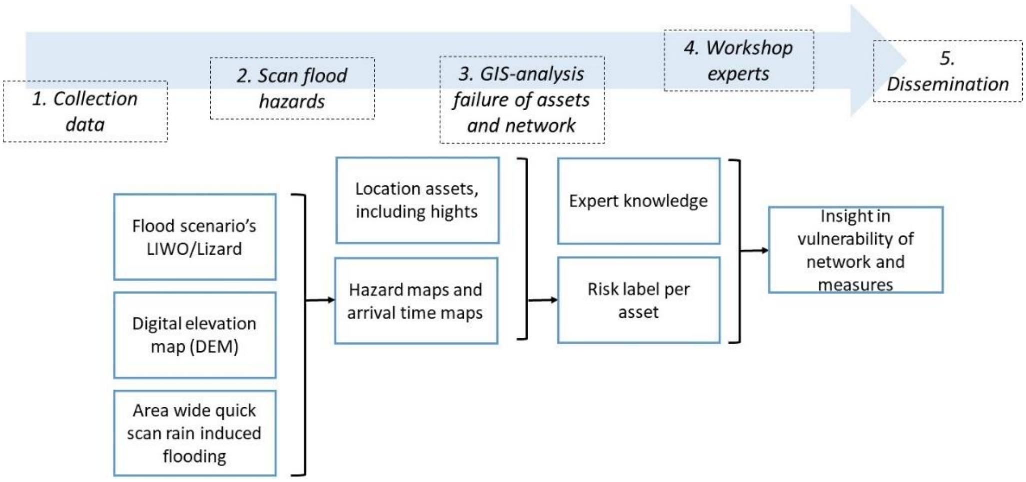


Figure 2-1: Process diagram area-wide quickscan

2.2 Method

2.2.1 *Collection data*

The following data has been collected and applied in the analysis:

- Flood scenarios from the National Database on Flood Scenarios. Only the scenarios from the European Directive on Flood Risks are used.
- Rain induced flood data from the Climate Effect Atlas (http://www.klimaateffectatlas.nl).
- Ground levels (AHN2).
- Critical heights per electrical assembly. Enduris has measured the distance between the floor and the crucial installation. It was possible to determine a critical height for each station based on the type and year of construction of the station.

2.2.2 *Scan flood hazards*

On the basis of the flood scenarios, water depth maps have been made of 4 frequencies: 1: 400, 1: 4000, 1: 40,000 and 1: 400,000 years. Depth maps have been made per frequency.

For rain induced flooding, it was investigated on the basis of the climate impact atlas whether there are locations where the inundation is greater than the critical depth. This was not the case anywhere. The depth was generally in the order of a few centimeters.

2.2.3 GIS analysis of failure of assets and network

Based on the locations of the medium voltage assets and the depth at different repetition times, an insight is gained into the most risky assets. This is indicated by a risk label. The purpose of the risk label is to make clear in broad outlines for technicians and non-technicians which assets and associated networks are most vulnerable to flooding and extreme rainfall

The risk label is derived on the basis of the following four characteristics:

1. Chance of failure. It has been investigated whether the depth of water in case of a flood at a station actually causes a power outage. On the basis of 500 flood scenarios from the National Database on Flood Risks, the probability of flooding was determined for each asset (switching or distribution station). The chance associated with the flood scenarios is used here.

2. Number of affected connections. On the basis of a network analysis, it has been shown which switching and distribution stations can fail and how many home connections are behind these assets. This network analysis was carried out in GIS with an advanced connectivity analysis. The detailed network data of Enduris was used (approximately 4700 km).

3. Vulnerable objects. We only looked at power outages for vulnerable objects with overnight accommodation options, creating a potential risk for victims. These are, for example, old people's homes, hospitals or nursing homes. When a switching or distribution station fails to supply a vulnerable object, it means a lower label, as the consequences are larger.

4. Direct or indirect failure. A distinction has been made between direct and indirect power outage. In case of indirect failure, repair work is easier because the object itself is not flooded. Distribution stations that fall out directly (as a result of a water depth above critical depth) have a lower label. The table below shows the scores to derive the risk label.

Tabel 2-1: Score tabel for flood probability

Probability	Score
No flood	0
1 op 400000	4
1 op 40000	8
1 op 4000	12
1 op 400	15

Tabel 2-2: Scoretabel voor het overstromingsgevolg

Number of connectoins behind failed asset	Score	Vulnerable objects	Score	Direct/indirect	Score
Geen	0	No	0	Indirect	1
0-50	1	yes	5	Direct	5
51-100	2				
101-250	3				
251-500	4				
>500	5				

Tabel 2-3: Score table to derive the label

Score	Label
0-10	A
10-13	B
13-16	C
16-19	D
19-22	E
22-25	F
>25	G

2.2.4 *Workshop experts*

The risk label is the result of a flooding and electricity network analysis. Of course it is important to validate the results with the practical knowledge of the network operators and other stakeholders. To this end a workshop with experts was organized. The input is included in determining the final method for the risk label. The workshop was also used for additional data collection.

2.2.5 *Dissemination*

All maps are made available in standard GIS files for further analysis. These can be accessed in the WIKI or other information platforms. The method and outcomes are disclosed in this report

2.3 Results

The risk labels of the medium voltage systems are shown in the image below.

From this the following becomes clear:

› The risks of electricity outage are greatest for the surroundings of Middelburg / Vlissingen, Goes, Kapelle, Reimerswaal and along the edges of Walcheren and Zeeuws Vlaanderen. Schouwen Duivenland and Tholen have a moderate risk everywhere and a higher risk for residential areas.
› Direct failure as a result of reaching the critical water level determines to a large extent the risk profile. See Figure 2 4 (left).
› Many assets that cannot be directly affected by a flood still fall out due to indirect outages. These assets often have a lower label than label A. See figure 2-4 (right).

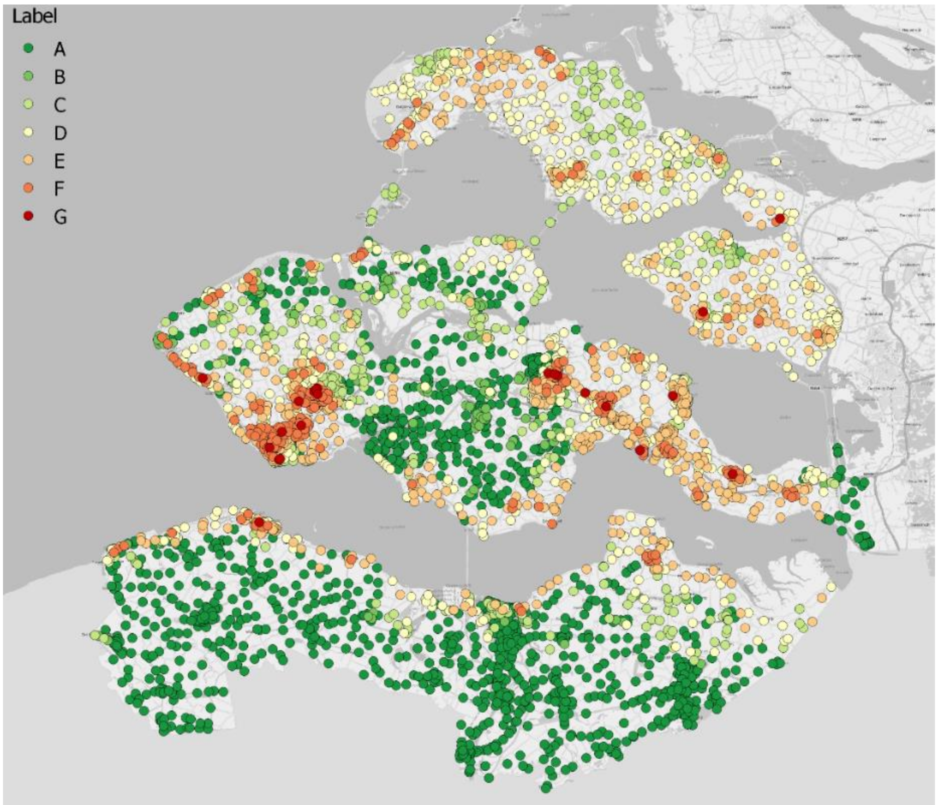
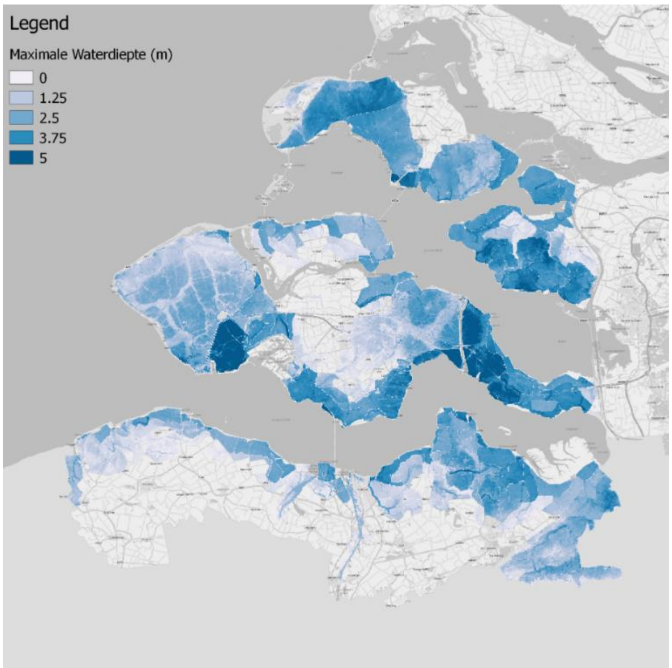


Figure 2-2: Risk labels



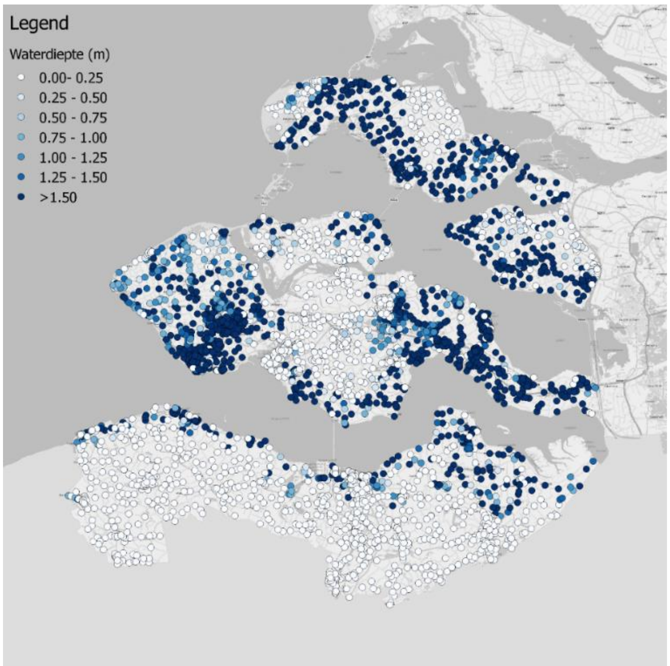


Figure 2-3: Left: combined maximum water depth map based on the VNK2 flood scenarios. Right: Maximum water level per distribution station based on the VNK2 flood scenarios

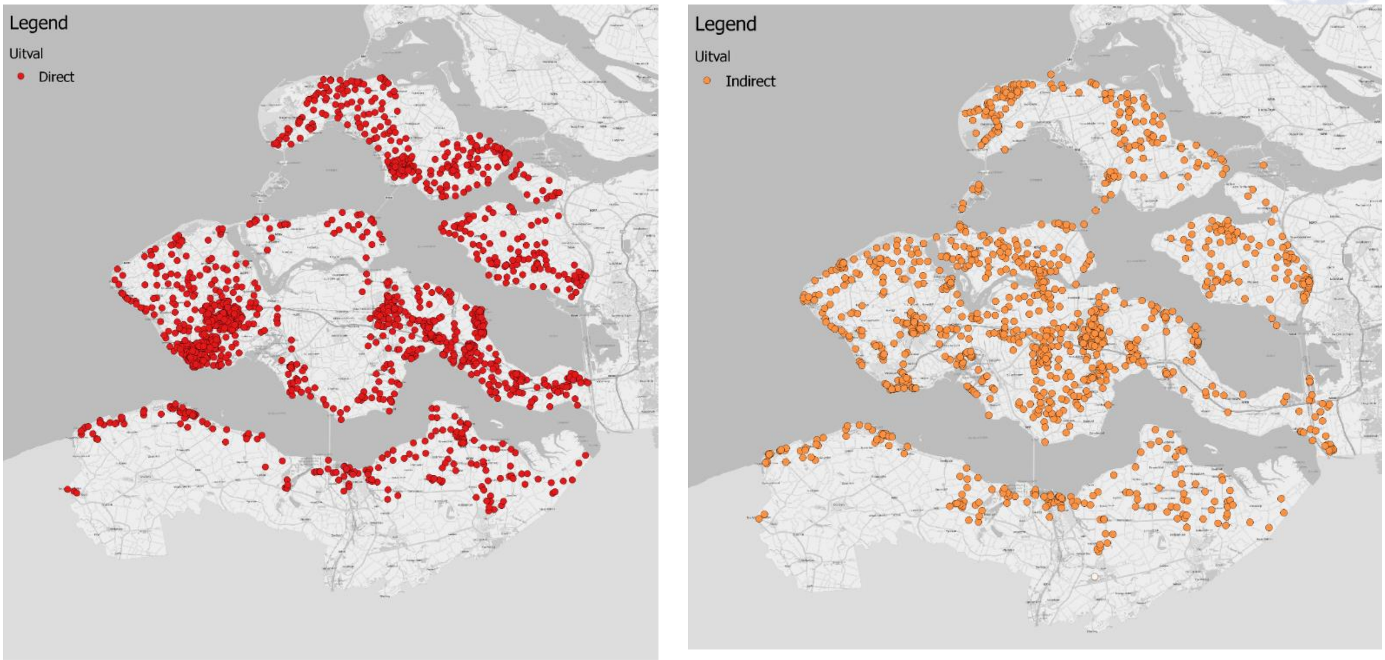


Figure 2-4: Left: direct failure of distribution stations. Right: Indirect failure of the distribution stations as a result of the outfall of a connection to a power supply or switching station

Appendix I gives an overview of the assets with the highest risk (label G). Additional maps are shown in Appendix II.

3 Area-oriented pilot Kloosterzande

3.1 Introduction

In addition to the area-wide quickscan, the area around Kloosterzande has been examined in more detail.

In the area-oriented pilot project Kloosterzande the consequences of flooding and heavy rainfall for the medium-voltage and low-voltage network are investigated. Consequently, it was explored which measures can be taken to increase the robustness. This was discussed in a workshop with stakeholders from the area.

The cascade effects were also taken into account. In this study, cascade effects are defined as the failure of vital infrastructure as a result of the failure of the electricity network. The vital infrastructures examined in this study are the mobile telephone network, water system (ground loss) and the emergency services (in the pilot area these were only fire stations).

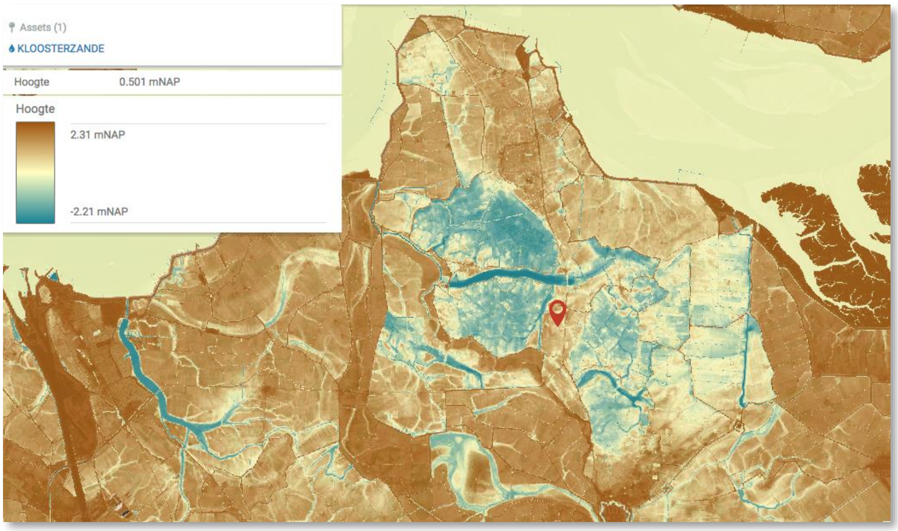


Figure 3-1: Elevation map (DEM) of the Pilot area Kloosterzande (Zeeuws Vlaanderen). Kloosterzande is in a local depression

In the figure below, the method is shown

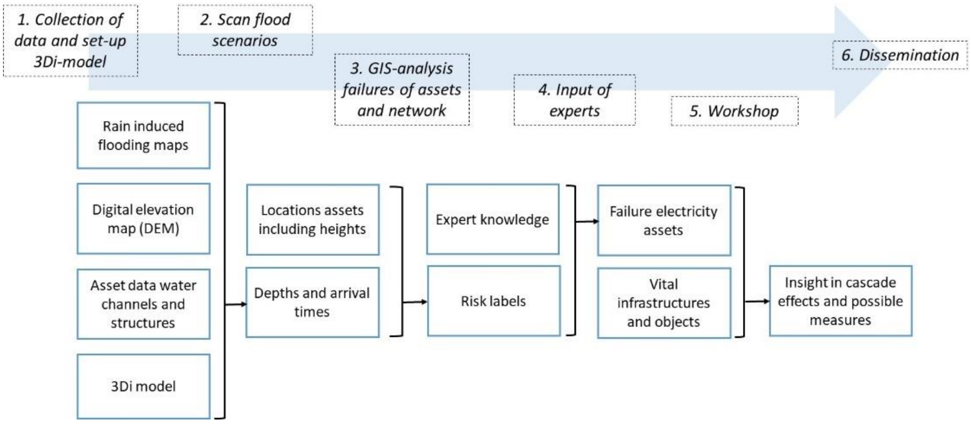


Figure 3-2: Process diagram

3.2 Method

3.2.1 *Collection of data and set-up of model*

In addition to the already collected data in the area-wide quick scan, nodes of vital infrastructure and vulnerable objects have been included in the project database. Telecom hubs, nursing homes, institutions, fire stations and pumping stations were included in the analysis. The low-voltage assets and their critical depths have also been collected. These vary between 20 and 80 cm.

A detailed interactive 3Di model of the area was created based on the height map (AHN2) and data of the water system provided by the Waterboard. The same data as in the project 'PWO Zeeland' (area Campen) were used for this.

3.2.2 *Scan flood scenarios*

On the basis of the flood scenarios, water depth maps have been made of 4 frequencies: 1: 400, 1: 4,000, 1: 40,000 and 1: 400,000 years. Depth maps have been made per frequency.

Based on the outcomes of the 3Di model, it was investigated whether there are locations where the inundation of rain induced flooding is deeper than the critical depth. This was nowhere the case, as the depth was everywhere in the order of centimeters.

3.2.3 *GIS-analysis failures of assets and network:*

The GIS analysis was performed in the same way as in the area-wide quickscan. The low-voltage assets are also included.

3.2.4 *Input of experts*

In order to include the vital networks in the analysis in a correct manner, regular consultations were held with the network operators of Enduris, Evides, KPN and Delta.

3.2.5 *Network analysis and risk labels*

The network analysis and the determination of the risk labels has been carried out in the same way as in the area-wide quickscan. For the low-voltage network it has been decided not to derive a label. This would require new scoring tables, because the number of connections behind a low voltage range is much lower.

On the basis of the same flood scenarios as in the area-wide quickscan (source: Lizard-flooding, ROR scenarios) and the critical depths of the medium and low-voltage assets, the direct failures and the indirect failures were determined. The failure of vulnerable objects and the vital infrastructure has also been mapped out. The central nodes of vital networks were checked on their proximity of failed electricity networks. For example, in the case of the mobile telephony network, it has been checked whether the electricity assets that are closest to the masts failed.

3.2.6 *Workshop*

On 22 February 2018 a workshop was held with stakeholders (see appendix for list of attendees). In the workshop the results were presented and measures to improve the robustness were inventoried and tested.

The following agenda has been followed at this workshop:

1. Introduction
2. The electricity grid: how does it work?
3. The electricity grid: how vital is it?
4. Lunch
5. Interactive session
6. Closing and drinks

During the interactive session (point 5) the impact of electricity outages due to flooding was studied in three rounds:

1. Electricity outages for households

2. Failure of other networks, such as gas and telecom

3. Failure of vulnerable objects, such as hospitals

The following steps have been worked per round:

- Fact finding (based on digital and analogue maps of the flood image, failure of electricity assets, risk labels, medium voltage assets and arrival times).
- Judgment: how bad is the dropout?
- Decision: what measures can be taken?

The results are described in the next section.

3.2.7 *Dissemination*

All maps are disseminated in standard GIS files and available for further analysis. These files can be accessed in the WIKI or other information platforms. The method and outcomes are also disclosed in this report.

3.3 Results

3.3.1 *Network analysis*

The results of the network analysis are shown in the figures below. In and around Kloosterzande, the risks are relatively high compared to Hulst (most southern part of the pilot area). It can also be expected that the vulnerable objects around Kloosterzande will fall out (fire brigade, pumping station, telecom). The vulnerable objects around Hulst continue to function (institutions, care homes).

The electricity continues to operate west of Kloosterzande. This is a higher part, as a result of which the critical depth is not reached here. These assets do not fail indirect either because they are connected directly to the switching station in Kloosterzande, which continues to function. This switching station is visible in the map below. NB: The other assets in Kloosterzande mostly fail directly.

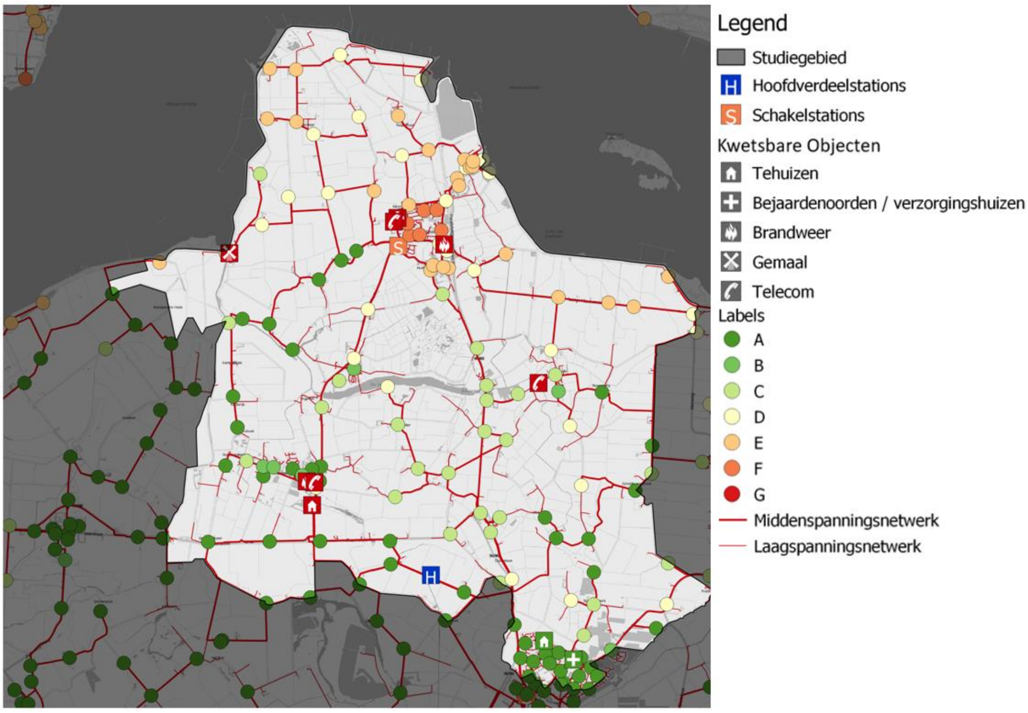


Figure 3-3: Risk labels for the pilot area and the electricity outage of vulnerable objects (red is outage, green is not an outage)

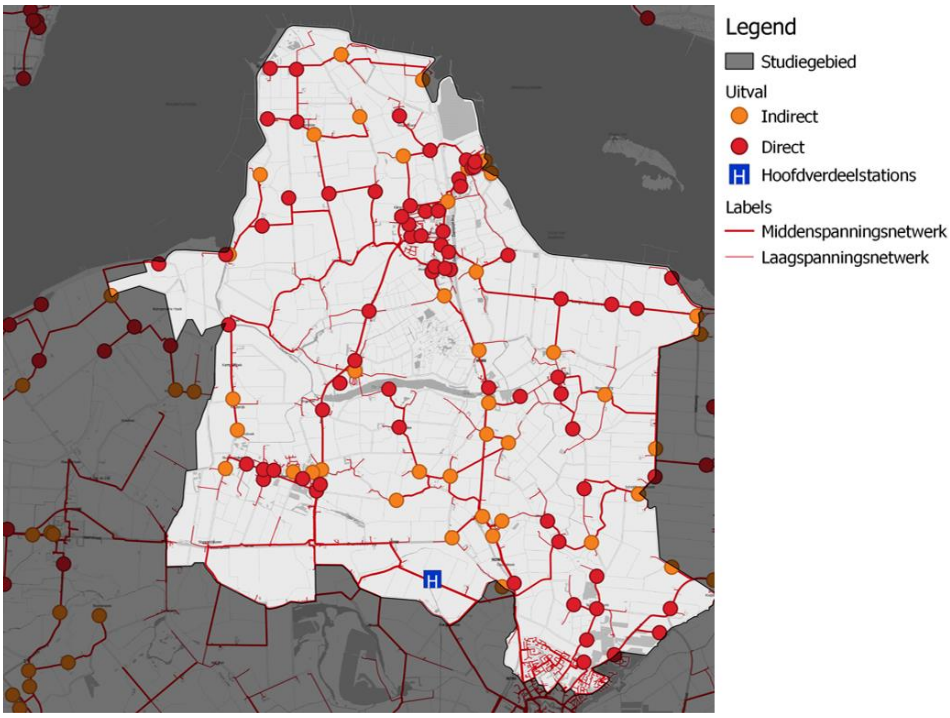


Figure 3-4: Directly and indirectly failed assets (medium voltage and low voltage)

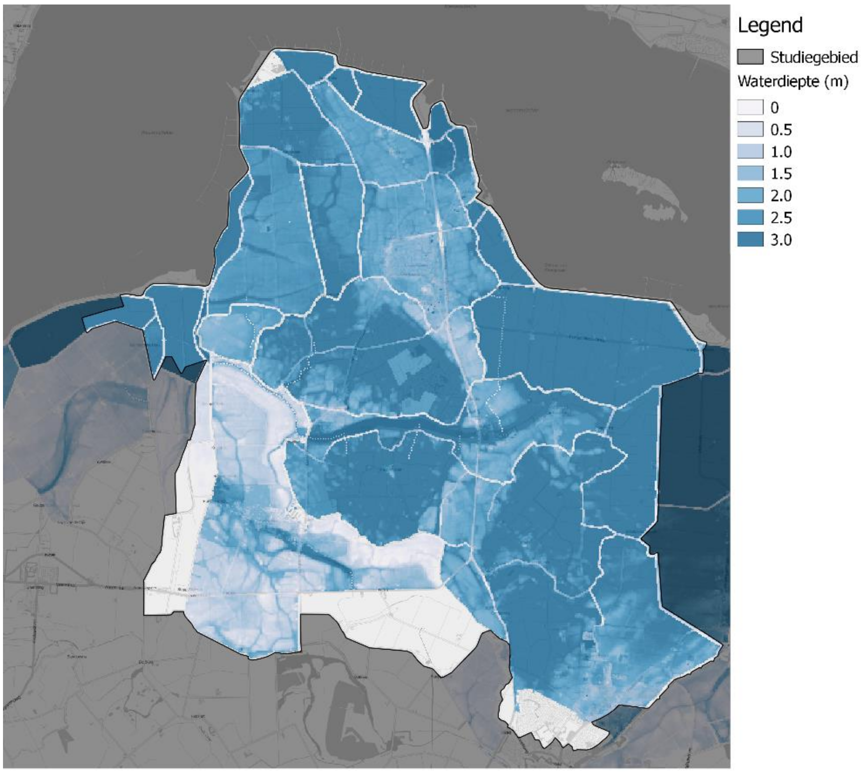


Figure 3-5: Flood map Kloosterzande based on multiple flood scenarios from VNK2 project

3.3.2 *Workshop*

The following promising measures are presented per round by the attendees:

Outcomes round 1: Electricity outages for households

- Evacuation to Hulst.
- Disable the network right before the wave front arrives. This keeps the electricity operational for as long as possible.
- Strengthen inner dikes so that residents and important electricity assets are protected.

Outcomes round 2: Drop out of other networks, such as telecom, gas, water and pumps

- The gas network operates independently of the electricity network. There is therefore no cascade effect.
- Drinking water: There are no booster stations in the area, so no problem is expected in the event of a power failure.
- Sewage treatment at Kloosterzande: This is not applicable, but this is not considered to be a problem during a flood. The sewer system does not have to function during a disaster.
- Drainage pumps of water system: They fall out. As a solution, additional mobile pumps can be places or existing pumps can be better protected or placed higher (they are often already on a dike).
- Telecom: There is currently too little information available. It is proposed to do better research on the electricity supply of telecom and possibly to make own electricity supply manditory.

Outcomes round 3: Drop out of vulnerable objects (hospitals, care homes)

The continued functioning of the electricity in vulnerable objects is not considered crucial, because these locations are still being evacuated.

Nevertheless, it is important to maintain electricity for as long as possible for the purpose of preparing a good evacuation. This can be done by measures mentioned above, such as switching off right before the wavefront arrives or emergency generators.

4 Conclusions and recommendations

4.1 Introduction

The goal of the project was to develop a better integral insight in making the electricity supply network flood resilient. To this end, insight was first provided into the most vulnerable electricity sets. Subsequently, measures were derived to increase the robustness.

4.2 Conclusions

The area-wide quickscan gave the following insights to make the electricity network water-robust (the area-wide quick scan did not look at possible measures):

› The Risk Labels method has proven to be a useful way of mapping out the risks of electricity loss caused by flooding in an understandable way.
› Electricity outage (medium voltage) due to heavy rainfall can be considered as a very small risk. On the basis of the data used (climate effect atlas and 3Di model), the critical depth was never reached.
› The risks of electricity failure due to flooding are the largest for the surroundings of Middelburg / Vlissingen, Goes, Kapelle, Reimerswaal and along the edges of Walcheren and Zeeuws Vlaanderen. Schouwen Duivenland and Tholen generally have a moderate risk, while this is higher in residential areas.
› Direct failure as a result of reaching the critical water level determines to a large extent the risk profile.
› Many assets that cannot be directly affected by a flood still fall out due to indirect failure. These assets often have a worse label than label A. See Figure 2 4 (right).
› The analysis has yielded a list of 23 medium-voltage assets with the highest risk (see Annex I). These assets can be directly affected for 1/400 years, with the water depth exceeding the critical water depth. In addition, there are always vulnerable objects connected that fall out and often a large number of house connections have electricity outage.

The area pilot of Kloosterzande has provided the following insights into cascade effects and solutions:

› Cascade effects on the gas network and the sewer network are experienced as unimportant. The gas network runs on its own pressure (not on electricity) so there is generally no cascade effect. A failure of the sewer system during a flood disaster is not considered to be a problem by those present at the workshop.
› Cascade effects on drinking water can occur if pump stations fail. However, these pumps are not present in the pilot area.
› Cascade effects on the water system can have major consequences because areas that have not been flooded can still be flooded because the water cannot be drained. Emergency electricity generators or the guarantee of electricity supply through additional connections can be solutions.
› Cascade effects on communication networks (fixed line, GSM) are expected to be large. Due to lack of data, this has not been investigated in detail in the area pilot.
› Limiting consequences can be achieved by switching the electricity off right before the wavefront arrives. This means that the electricity supply will be maintained longer, which can help evacuate households or evacuate for example hospitals. Such shutdown plans can be prepared in advance on the basis of the data from this study.

- When deciding on the enforcement of secondary inner dikes, the protection of important electricity assets can be taken into account.

4.3 Recommendations

Based on this study, the following recommendations are made:

- Further research is needed into the cascade effects on the telecom network. This requires more data of the location and functioning of the network.
- On the basis of the data from this research, it is possible to examine for each asset whether measures are necessary and, if so, which measures are most effective. For example: if the flooding depth is just above the critical depth, it may be possible to achieve a higher robustness at a limited cost.
- A switch-off plan can be made in advance for each potential flooding location. These swith-of plans can then be used in the event of a crisis.
- The Risk label method can be used for other areas and for multiple networks applied. This can be useful in other FRAMES studies or in the impact analysis.

I. Appendix: Overview of high risk assets (label G)

asset id	Kritical water depth	Water depth	Direct failure	Indirect failure	Exceedence time	Number of residential connections	Score chance	Score number of connections	Score direct/indirect	Score vulnerable objects	Score total	Label
4110	1	2.36	ja	nee	400	300	15	4	5	5	29	g
5261	1	5.17	ja	nee	400	267	15	4	5	5	29	g
7091	0.9	5.42	ja	nee	400	326	15	4	5	5	29	g
116887	0.75	3.49	ja	nee	400	257	15	4	5	5	29	g
7636	0.9	1.74	ja	nee	400	318	15	4	5	5	29	g
5028	0.75	1.76	ja	nee	400	386	15	4	5	5	29	g
4731	0.75	4.78	ja	nee	400	107	15	3	5	5	28	g
6819	0.9	3.04	ja	nee	400	129	15	3	5	5	28	g
4885	0.62	1.6	ja	nee	400	240	15	3	5	5	28	g
216744	0.75	5.25	ja	nee	400	193	15	3	5	5	28	g
6760	1	4.5	ja	nee	400	137	15	3	5	5	28	g
5289	0.62	5.31	ja	nee	400	175	15	3	5	5	28	g
26312	1	5.06	ja	nee	400	138	15	3	5	5	28	g
39752	0.95	3.23	ja	nee	400	210	15	3	5	5	28	g
4977	0.62	1.39	ja	nee	400	150	15	3	5	5	28	g
4639	0.95	1.44	ja	nee	400	189	15	3	5	5	28	g
6715	0.9	1.63	ja	nee	400	206	15	3	5	5	28	g
5800	1.15	2.41	ja	nee	400	87	15	2	5	5	27	g
274680	0.75	3.19	ja	nee	400	0	15	1	5	5	26	g
5424	0.75	2.1	ja	nee	400	4	15	1	5	5	26	g
156584	1.15	5.58	ja	nee	400	41	15	1	5	5	26	g
6242	0.75	2.89	ja	nee	400	1	15	1	5	5	26	g
7267	0.95	1.78	ja	nee	400	35	15	1	5	5	26	g

II. Appendix: Additional maps

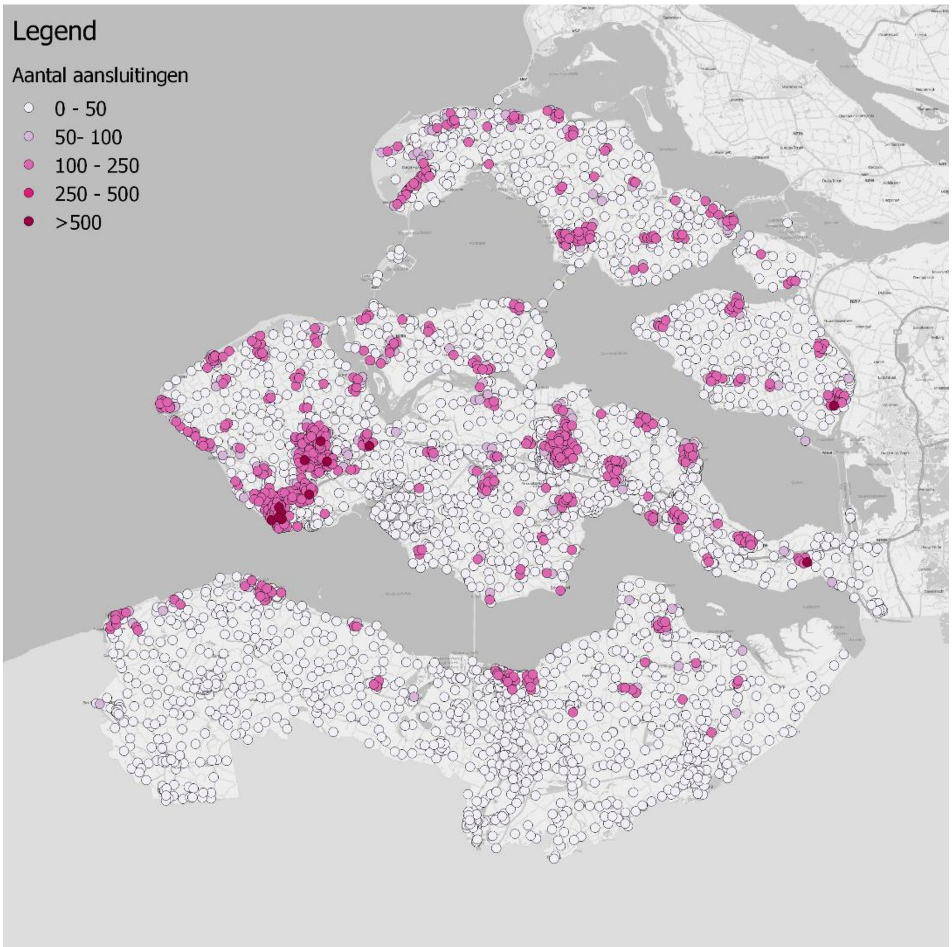


Figure 4-1: Number of connections per distribution station

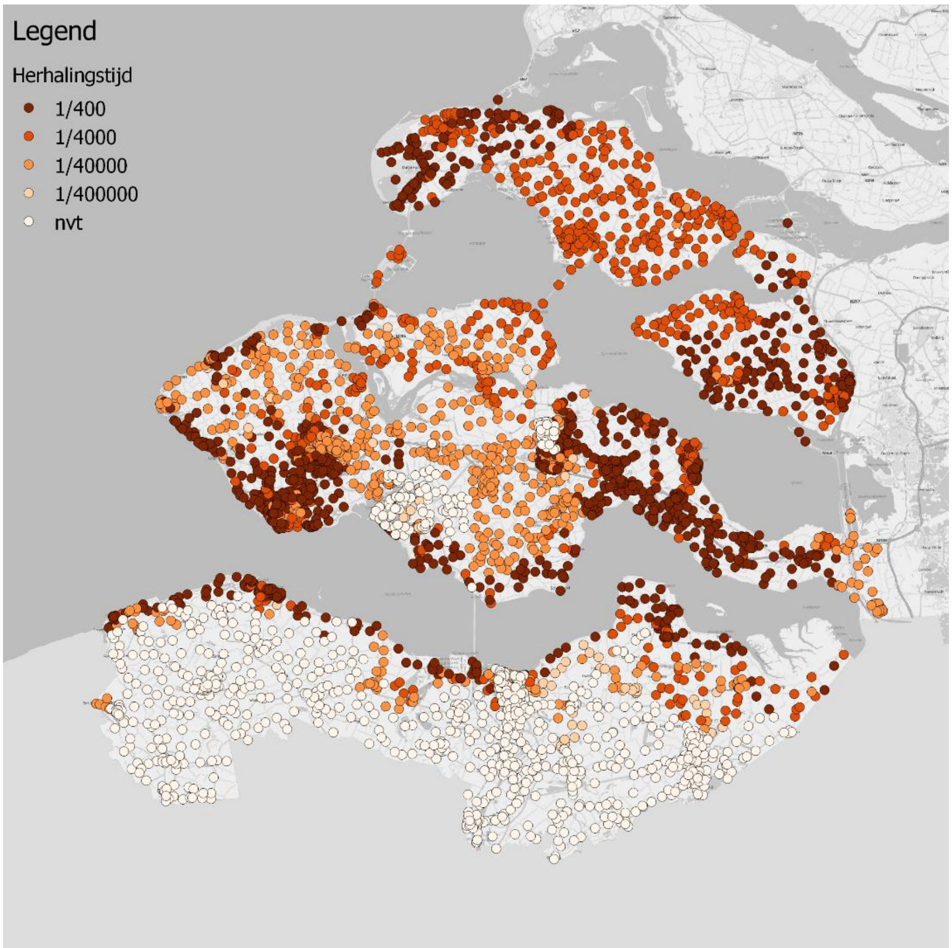


Figure 4-2: Repetition time per distribution station based on VNK2 exceedance probabilities at the breaches

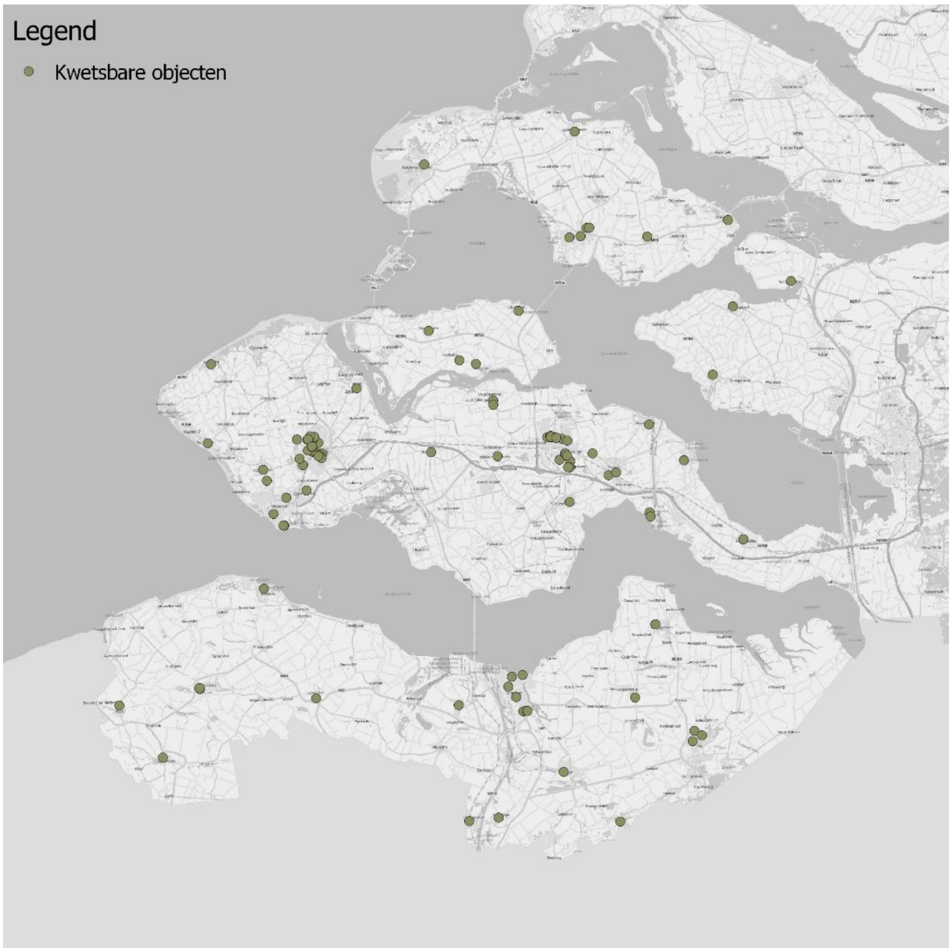


Figure 4-3: Vulnerable objects (Dutch risk map) with residence function

III. Attendee list workshop

Interreg North Sea Region FRAMES

European Regional Development Fund

ATTENDANCE LIST FRAMES		
Meeting	**Date**	**Location**
Workshop FRAMES – Elektriciteitsnetwerk	**22 February 2018**	**Hotel van Leuven, Kloosterzande, NL**

Name	Organisation	Signature
R. van Damme	Gemeente Hulst	
Jelle Degen	Nelen Schuurmans	
Bob Ent	Ministerie EZ	afgemeld
Marco de Feiter	Waterschap Scheldestromen	
Frans Hamelink	DNWG	
Martijn van Kalmthout	Waterschap Scheldestromen	
Hugo Krijger	Delta	afgemeld
Ingrid de Kubber	Provincie Zeeland	
Carel Lauwereis	DNWG	
Eddy Leenknecht		
Anne Leskens	Nelen Schuurmans	
Marcel Matthijsse	Veiligheidsregio Zeeland	
~~Karel~~ Minderhoud Kristiaan	DNWG	
Wouter de Neijs	Enduris	
H. Raanhuis	Gemeente Hulst	afgemeld
Erik Schumacher	Provincie Zeeland	
Aart van Steveninck	Gemeente Hulst	Ziek
Paul van der Zweth		afgemeld
Luke Woltman		afgemeld
Martijn Krol		