Pilot Vulnerability of vital infrastructure Reimerswaal

Final report

Provincie Zeeland

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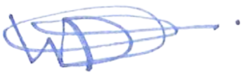
Initials	

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SUMMARY

This report contains the final results of the FRAMES pilot project on the vulnerability of vital infrastructure Reimerswaal. The pilot project studies how flooding risks can be minimised cost-effectively by the application of the concept multilayer safety (MLV).

The pilot project has charted the vital infrastructure within dyke ring 31 (electricity, gas, telecom and ICT, A58, railway, drinking water, sewage, pumping stations) and analysed the vulnerability of the networks against flooding. For 2 dyke breach scenario's (combined Oosterschelde scenario and combined Westerschelde- and Oosterschelde scenario) the impact of flooding on the vital networks and possible chain effects outside dyke ring 31 has been determined. One analysis focused on non-flood proof[1] and the other on flood proof[2] regional barriers. A vulnerability analysis was also carried out for damage due to pluvial flooding caused by rainfall (T=100).

From the vulnerability analysis it follows that every vital network in Reimerswaal encounters damage at a dyke breach. The actual vulnerability of the networks is dependent on the above-ground objects in a network. Many networks are situated underground (for example the main drinking water pipe has no above-ground objects within dyke ring 31) and are therefore less vulnerable. However, for some type of vital infrastructure, there is redundancy present: at interruption of the A58 there is an alternative route via, for example, the Westerschelde tunnel. Further, for the electricity, A58 and railway networks chain effects occur at a dyke breach. The vulnerability analysis shows that these networks are the most vulnerable and have the greatest chain effects. For these networks, the indirect damage due to chain effects is much greater than the direct (material) damage to the networks. The results show that the connecting function of the networks determines the potential indirect damage. The actual level of the indirect damage is dependent on the recovery time. The vulnerability analysis also shows that the impact and consequence of a dyke breach is strongly dependent on the flood proof of the regional barriers. Non-flood proof barriers generally give a more extreme flooding profile in Reimerswaal than flood proof barriers. Therefore, from the perspective of vital infrastructure the maintenance of the regional barriers is important.

Then measures have been identified for the electricity network and the A58 which limit the direct and/or indirect damage in the event of a dyke breach. Measures can be either individual (directed at a specific object) or collective (area focused) and can focus on continued functioning (no more direct and indirect damage) or on quick recovery (reduce recovery time and thus indirect damage). In total 6 different packages of measures have been designed which have been reviewed on their cost efficiency (effectiveness). A package of measures is cost-effective if the sum of the benefits (avoided damage) is greater than the costs. On the basis of the analysis it can be stated that only the measure 'protection of high-voltage switchgear' is a cost-effective measure. For the other measures the benefit/cost ratio is unfavourable. A sensitivity analysis confirms these conclusions.

The results of the pilot show that the inclusion of chain effects in determining the damage is essential in the policy consideration for taking measures. However, with the current return periods and safety standards of the primary barriers, most measures do not seem to be cost-effective. Here it is observed that the current statistic for the failure probability of the primary barriers is based on the climate of the past: return periods can change in the future due to accelerated sea level rise. As a result, measures that are currently not cost-effective can become cost-effective in the longer term (autonomously). The pilot finishes with recommendations for follow-up research, policy and implementation. For follow-up research it is recommended to further study the mechanisms that lead to indirect damage and the flood proof of regional barriers. In policy considerations concerning flooding risk and (dyke) standards, it is important that the chain effects (cf. indirect damage) and the presence of vital functions is included. Future policy should focus on the introduction of measures in the event of investments (new build or replacement) of utility parties or grid authorities.

[1] Non flood proof: In case of flooding, the dike fails

[2] Flood proof: In case of flooding, the dike remains stable

1

INTRODUCTION

1.1 The FRAMES pilot Reimerswaal

This is the final report for the FRAMES pilot Reimerswaal that has been carried out on the directions of the Province of Zeeland. The FRAMES project focuses on developing important insights about vulnerable and vital functions. The project has been made possible by a subsidy from the overarching FRAMES (Flood-Resilient Areas by Multi-layEr Safety) project of the European INTERREG Fund North Sea Region. The Province of Zeeland works together within FRAMES with eleven partners, including regional authorities, universities and area authorities from the Netherlands, Belgium, Germany, the United Kingdom and Denmark. The theme vital and vulnerable functions also plays an important role in the Delta Program Spatial Adaptation (DPRA): one of the tasks that must be a component of climate resistant actions in policy in 2020. In practice there is still relatively little experience about the subject protection of vulnerable and vital functions, both in the Province of Zeeland and in the Netherlands. This project provides for this.

The project is focused on the vulnerability of vital functions in the municipality of Reimerswaal in relation to the flooding risk for dyke ring 31. The research question is how flood risks can be minimised cost-effectively by application of the concept multilayer safety (MLV)[1]. The concept of multilayer safety originally distinguishes three coherent layers. FRAMES added at a later stage a fourth layer aimed at the subsequent recovery (reconstruction):

- layer 1 prevention: measures that prevent flooding;
- layer 2 spatial measures: climate-resistant arrangements that can limit consequential damage;
- layer 3 crisis management: crisis consultancy, operational management, evacuations at high water;
- layer 4 recovery: reconstruction

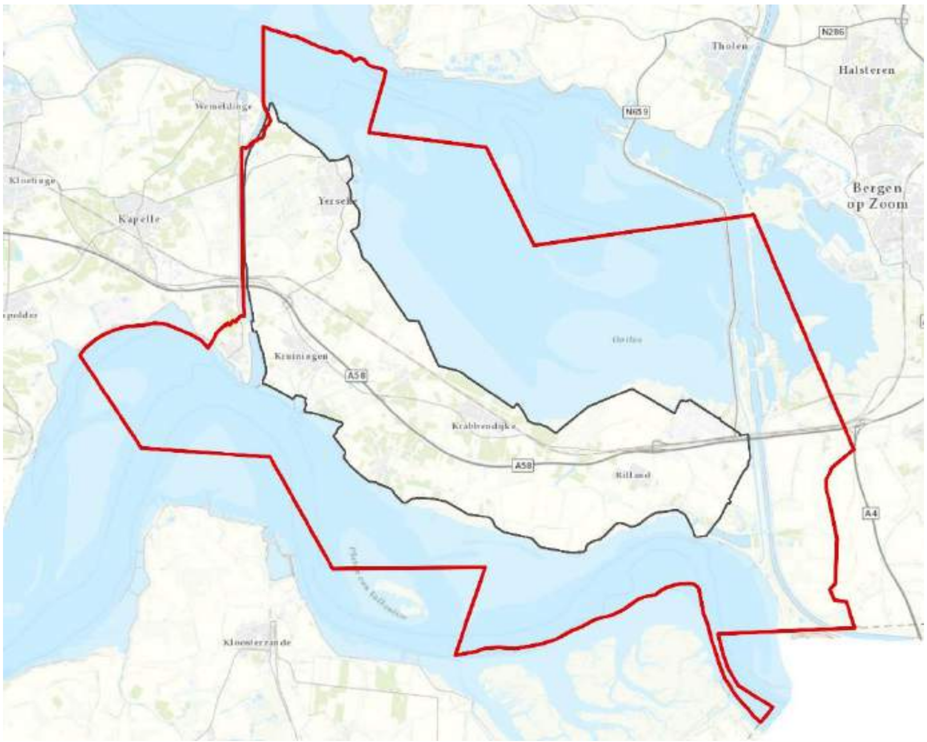
The project analyses the consequences and the measures for the situation where a flood occurs and the consequences are limited as much as possible: layer 2 up to and including 4.

1 See for an explanation the draft National Water Plan (2008).

Figure 1.1 Visualisation layer 1 up to and including 3 multi-layer safety

The FRAMES pilot Reimerswaal has a very important connecting position within the Province of Zeeland and for the Netherlands. Therefore, it is a very relevant case for the analysis of the task and measures for the protection of vulnerable and vital infrastructure. In addition to the local impact of a flood, significant chain effects can be expected outside the municipality. Effects on the A58, the rail infrastructure, the accessibility and operation of the industry at Walcheren have influence at provincial level. Damage to the high-voltage grid has a national impact in view of the connection with offshore wind farms. The project starts therefore with a vulnerability analysis by network. After the analysis of the vulnerability the project focuses on developing measures in layer 2 and layer 3 and a study framework for taking cost-effective measures with public and private stakeholders.

Figure 1.2 Municipality of Reimerswaal (red) and dyke ring 31 (black)



Basic information

The most important basic information for this research study is:

- RAAK project of the HZ University of Applied Sciences: the draft fact sheets of a number of networks and public GIS information have been shared. The draft fact sheets have not yet been checked by the network managers, except for the telecom fact sheet. For the source reference of the used GIS data, see annex I;
- FRAMES pilot electricity network of the Province of Zeeland carried out by Nelen&Schuurmans;
- FRAMES pilot A58: The preliminary study has been completed and shared. The follow-up study is carried out by Witteveen+Bos;
- Standardisation Regional flood barriers (NRK): from the analysis it was found that the VNK2 flood maps were based on different assumptions (non-flood proof flood barriers). In this pilot project we use both the results of the VNK2 flood maps and the flood maps of the NRK project.

1.2 This report

This report serves as the final report of the FRAMES pilot project and bundles all results and insights from the different phases of the pilot. Chapter 2 describes the dyke breach scenarios and flood damage scenarios that are used. Chapter 3 describes the methodology of the research project. Then in chapter 3, the results of the vulnerability analysis are described per network and in chapter 4 the direct and indirect damage of the networks is quantified. In chapter 5 action perspectives and measures are presented for the prevention of function loss ('continued functioning') and speedy recovery. Chapter 6 explores the economic efficiency (effectiveness) of a number of packages of measures. Chapter 7 summarises the conclusions of the study and formulates (policy) recommendations.

Definitions

To ensure a good understanding of the content of the report, the following terms are defined as follows:

- **local effect:** impact of dyke breach or flood damage in the project area: Example: electricity network fails in parts of Reimerswaal;
- **super-local effect:** impact of dyke breach or flood damage outside project area: Example: electricity network fails in whole of South Netherlands;
- **chain effect:** impact of (partial) failure of network on other network or sector. Example: telecom network fails due to failure of electricity network;
- **direct economic impact:** costs or damage due to a dyke breach or flood damage within project area on physical assets: Example: damage to electrical infrastructure, for example a high-voltage station, in Reimerswaal;
- **indirect economic impact:** costs or damage due to a dyke breach or flood damage outside project area or by chain effect: Example: reduced production in Walcheren due to power failure;
- **signaling value:** failure probability of a dyke route, as standard included in the Water Act. All primary water barriers in The Netherlands have obtained a signaling standard between 1:300 per year and 1:1,000,000 per year[1]. If the signaling value is exceeded, a dyke strengthening project must be prepared;
- **lower limit:** the lower limit shows the maximum permissible failure probability for a water barrier. For the barriers that provide for the water safety for Reimerswaal the probability of the lower limit is three times greater than the probability of the signaling value. If the lower limit is exceeded, the dyke strengthening project must be carried out.

[1] Only the dyke route around the nuclear power plant of Borsele has a standard of 1:1,000,000 per year.

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SCENARIOS FOR THE PILOT PROJECT AND RESEARCH METHODOLOGY

2.1 Dyke breach scenarios

Dyke ring 31
The municipality of Reimerswaal is part of Zuid-Beveland and lies between the Oosterschelde and Westerschelde. It has an important connection function and is also called an 'artery' of the Province of Zeeland. The territory of Reimerswaal lies largely within dyke ring 31. Hansweert (core to the west of the Canal through South-Beveland) and the area east of the Schelde-Rhine link up to Brabant and the port of Antwerp are also part of Reimerswaal, but are located in another dyke ring. The FRAMES project focuses on the area of dyke ring 31. Within dyke ring 31 different regional barriers are still present, a trace of the phased land reclamation from the past (figure 2.1).

Figure 2.1 Purple: inner dyke with water management function, green: inner dyke without water management function (source: VNK2 report 'Flood risk Dyke Ring 31 South-Beveland', December 2011)

VNK2 scenarios
The project Netherlands Mapped (VNK2) analysis between 2006 and 2014 dealt with all primary water barriers and dyke rings of the Netherlands. The flooding risks have been charted per dyke ring. Here the dyke ring has been divided up into different dyke sections (sections of dyke that have corresponding strength and load per failure mechanism). For each section a breach location is selected. In VNK2 an attempt was made to establish the failure probability of a dyke section. The failure probability differs thus from dyke section to dyke section.

Figure 2.2 Breach locations in the municipality of Reimerswaal

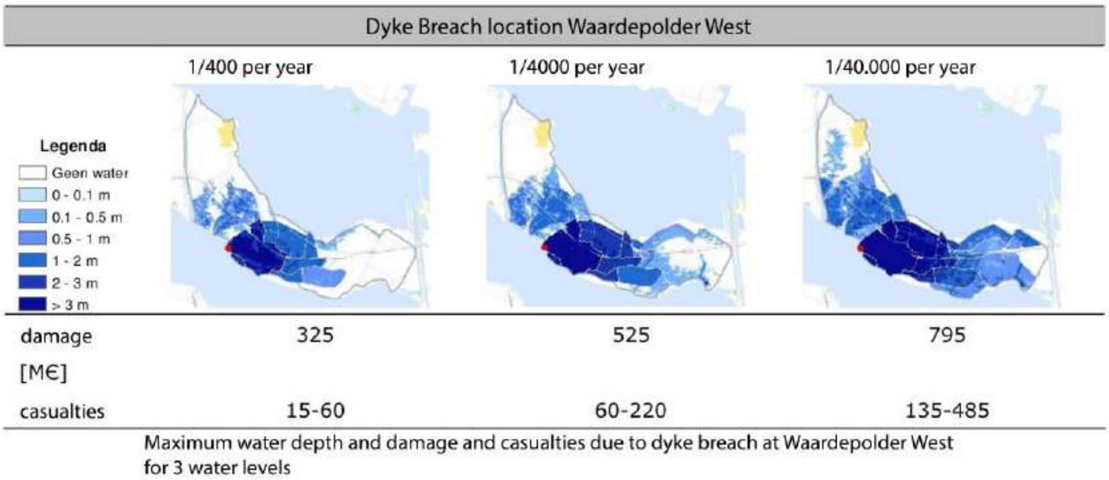
For each breach location, flooding calculations have been carried out for different load conditions (outside water levels): assessment level minus 1 decimation height (tp-1d), tp, tp+1d and tp+2d. The (old) standard prescribed that a water barrier must be able to retain a water level with an overrun frequency of 1/4,000 or 1/40,000 'safe' (=assessment level) (in other words, no damage to the water barrier at this extreme water level). A decimation height is the level variation [1]that is associated with an increase or reduction of the overrun frequency by a factor of 10. In other words, for each breach location the flooding due to a dyke breach is modelled with 3 different water levels: the water level with an overrun frequency of 1/400, 1/4.000, 1/40.000 or the water level with overrun frequency of 1/4.000, 1/40.000 1/400.000 (table 2.1 and figure 2.3). The assumption is that the maximum water level coincides with the moment that a breach occurs.

Table 2.1 Overrun frequencies and decimation heights

Overrun frequency outside water level	Decimation height
1/400	-1D
1/4.000	0D (= assessment level)
1/40.000	+1D
1/400.000	+2D

[1] Along the Oosterschelde the decimation height is 15 cm, along the Westerschelde the decimation height is approximately 65 cm.

Figure 2.3 Example of dyke breach scenario VNK2 (source: VNK2 report 'Flood risk Dyke Ring 31 South-Beveland', December 2011)



Flood proof vs. non-flood proof regional flood barriers

During the period of the project it was recorded that the VNK2 scenarios for dyke ring 31 Reimerswaal have been elaborated with the assumption that the regional flood barriers are non-flood proof. This means that it has been assumed that during a breach of the primary flood barrier all regional flood barriers also fail. This is not in agreement with the agreed national systematics for VNK2. For those reasons new scenarios have been calculated by the Province of Zeeland for Reimerswaal, but then with flood proof flood barriers as the starting point. In this project the analysis for the A58 within Reimerswaal has been carried out for both non-flood proof (calculation 1) and flood proof regional flood barriers (calculation 2).

New standards for flood barriers

From January 1, 2017, the new standard for water safety will apply. This new standard is based on flooding probabilities (risk approximation) instead of the old standard which is based on overrun probabilities. This new method will take into account both the probability and the consequences of a flood. With the old standard a barrier had to be high and strong enough to retain a particular water level (return period: 1/4000). This standard applied for a dyke ring and gave requirements on dyke section level.

With the new standard, the water barrier has a failure probability. This is the probability at which a water barrier may fail (return period: 1/10.000). The new standard has been derived for a dyke section and gives requirements for this. For the layout of a dyke route a study has been carried out of the area that can flood, the scale of the consequences, nature of the threat and the length of the sections. Each dyke section has more or less the same damage profile (expected economic damage and mortality approximately equal) regardless of where in the dyke section a breach occurs. Each dyke section has its own standard. That has been partly determined on the basis of a social cost-benefit analysis (cost of dyke strengthening relative to damage at a breach). If the new standard is not met, a dike strengthening project must be carried out. A dyke section must be able to retain a normative water level so that no breach occurs (thus damage may occur).

The level of the new standards has been derived from the following aims:
- everyone in the Netherlands who lives behind dikes and dunes enjoys at least a protection level of 10^{-5} per year (probability of death as a consequence of a flooding is not larger than 1/100.000 per year);
- more protection is offered in places where there can be a situation of:
  - large groups of victims;
  - and/or major economic damage;
  - and/or serious damage due to failure of vital and vulnerable infrastructure of national interest.

Reimerswaal is located in dyke route 31-1, 31-2 and 31-3. Dyke route 31-3 is not considered in this pilot. Because the water level is regulated in the Schelde-Rhine link, there must be a situation of multiple failure (multiple failure[1]) before dyke route 31-3 will fail due to extreme water levels. The failure probability rates (signaling value and lower limit) of each dyke route can be consulted on waterveiligheidsportaal.nl (see figure 2.4). For the relevant dyke routes these are:

- Dyke route 31-1: failure probability 1/10,000 per year;
- Dyke route 31-2: failure probability 1/3,000 per year.

Figure2.4 Dyke routes Reimerswaal with lower limit values (source: waterveiligheidsportaal.nl)

Choice of dyke breach scenarios for this pilot project

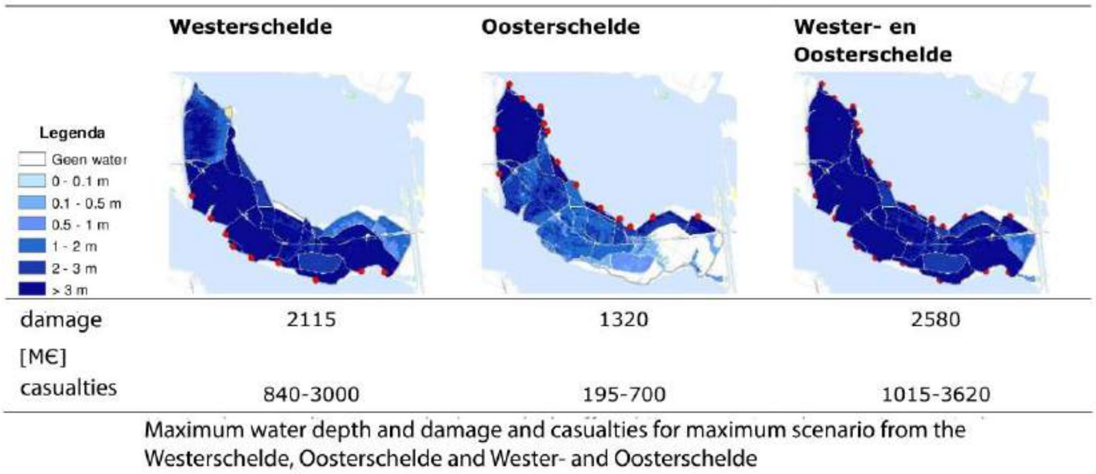
In the FRAMES project 2 worst-case scenarios of VNK2 are used: the maximum scenario Oosterschelde and the maximum scenario Wester-en Oosterschelde (see figure 2.5) at assessment level. The scenario for only flooding from the Westerschelde is not used, since at that moment there will be high water as well on the Oosterschelde and thus also failure will occur there (also with a view to the more stringent standard for the Westerschelde). LIWO (National Information System Water and Flooding) contains the VNK2 scenarios (resolution 100x100 m)[2].

For the probability of these scenarios we take the lower limit of both dyke sections. This is because this is the maximum failure probability that can occur on both dyke sections according to the new standard. The water level on the Oosterschelde and Watersheds has a large measure of correlation. The annual risk is determined on the basis of the standard approach to water safety on the basis of the comparison: 'risk is probability times consequence'.

1 First of all the Oosterschelde barrier should fail, with an increase of the water level in the Oosterschelde. Then the Oesterdam (dyke route 21-9) should fail, which again results in a rise in the water level in the Schelde-Rhine canal. Only then could dyke route 31-3 fail due to extreme water levels.

2 The Province of Zeeland has the separate dyke breach scenario's in larger resolution (25x25m) available in the information portal Lizard. The maximum dyke breach scenarios are however not available in Lizard.

Figure 2.5 Worstcase scenarios VNK2. The Oosterschelde and combined Wester- and Oosterschelde scenario are used in this pilot project



2.2 Pluvial flooding scenarios

In addition to a dyke breach, pluvial flooding by heavy rainfall events is also considered in this pilot project. The PWO scenarios[1]for regional pluvial floodingpluvial flooding with a return period of 10 years, 25 years, 50 years and 100 years (current climate) are used. The precipitation associated with the PWO scenarios shows a precipitation sum for 24 hours.

The scenarios have been delivered by the Scheldestromen water board. In the first instance the vulnerability analysis is carried out at a T=100 years scenario. If components or network components fail, the analysis is then extended to smaller return periods.

2.3 Research methods

For this pilot project different methodological choices have been made. This section describes the research methodology in broad lines of the pilot project (for further explanation the reader is referred to the specific chapters). First, and especially the pilot project focuses on dyke ring 31. In the effect determination the assumption is that a dyke breach only takes place within dyke ring 31. The following steps are completed in the pilot project:

1 vulnerability analysis:
   a. identification of vulnerable objects + determination of critical water depth of each type of object;
   b. determination of water depth at the objects on the basis of dyke breach scenarios or flood damage scenario;
2 damage determination:
   a. direct damage to objects of networks on the basis of investment cost of objects;
   b. indirect damage (chain effects) due to failure of vital networks: for this specific economic valuation methodologies are used.

Table 2.2. shows the framework for determining the damage to a vital network. Only indirect damage is determined outside Reimerswaal (dyke ring 31). Since a dyke breach only takes place within dyke ring 31 there is no direct damage outside Reimerswaal (dyke ring 31).

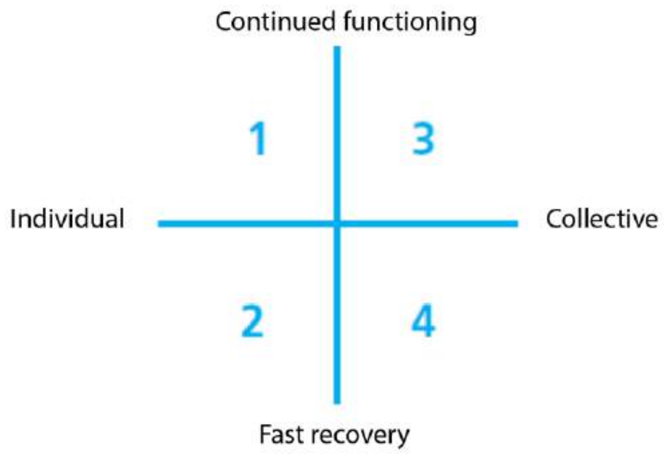
[1] PWO stands for Planning for Water Challenge.

Table 2.2 Framework for determining damage to vital network

	In Reimerswaal	Outside Reimerswaal
direct damage to network	Yes/No/how much	0
indirect damage chain effects network	not considered	Yes/No/how much

3 measures:
   a. identification of measures on the basis of action perspectives. Figure 2.6 shows the conceptual framework of the action perspectives that has been adopted in the pilot project;

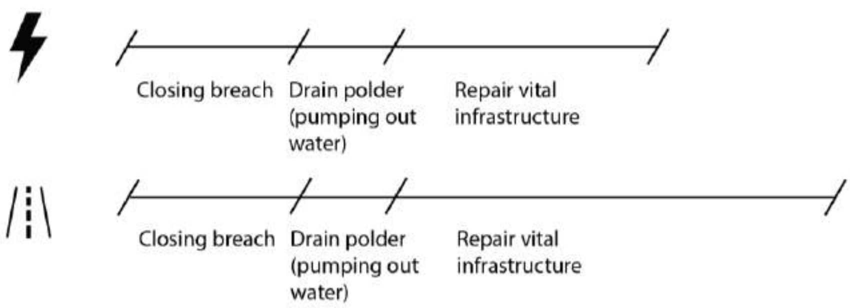
Figure 2.6 Action prospects for measures (individual versus collective (left - right) and continuing functioning versus evacuation and fast recovery time (top - down)



   b. Elaboration and cost estimates of measures;

4 cost benefit analysis
   a. determination of recovery time and total indirect damage. In this pilot the recovery time is split up into different components (see figure 2.7);

Figure 2.7 Basic calculation of recovery time main measures (partly parallel execution possible)



   b. determination of costs and benefits: Costs will include investment costs and maintenance costs. The indirect damage is dependent on the total recovery time (for some networks possibly a reduction factor is applied to take account of behaviour changes and decrease of the indirect damage in time);
   c. determination of benefits/cost ratios;
   d. sensitivity analysis: for the most important starting points a sensitivity analysis is carried out.

3

VULNERABILITY ANALYSIS

The vulnerability analysis builds further on the provisional results of the fact sheets and the GIS data from the RAAK project. In this, all components (objects of vital networks) have been identified and for each component a critical water depth has been determined, in consultation with the network managers. Then for all 23 dyke breach scenarios (1 specific breach location per location), it has been determined which and how many components fail. The following vital networks are considered:
- electricity;
- gas;
- telecom and ICT;
- A58;
- railway;
- drinking water;
- sewage;
- retention and management of surface water.

Figure 3.1 Basic map of vital infrastructure Reimerswaal (for a large view, see Annex II)

3.1 General approach

In this pilot project, 2 dyke breach scenarios are considered (maximum Osterschelde scenario and maximum Oosterschelde and Westerschelde scenario), based on non-flood proof regional flood barriers, and different pluvial flooding scenarios (different return periods for precipitation events). The analysis of these combined scenarios and the flood damage scenarios is new. Therefore on the basis of the critical water depth of the components the vital networks have been analysed again[1]. For the results of the maximum Oosterschelde scenario, see Annex III and Annex V. For the results of the maximum Ooster- and Westerschelde scenario, see annex IV and VI. For the results of the pluvial flooding scenario (T=100 year situation), see Annex VII.

Each network is analysed using the following framework (table 3.1). The quadrants come back in completed form in the following chapter.

Table 3.1 Framework for determining damage of vital network

	In Reimerswaal	Outside Reimerswaal
direct damage to network	Yes/No/how much	0
damage chain effects for network	not considered	Yes/No/how much

For each vital network the direct damage to the network has been determined in broad lines (in EUR’s) on the basis of the existing components (see chapter 4). The starting point is further that no direct damage occurs outside Reimerswaal caused by flooding within Reimerswaal. Indirect damage (due to chain effects) is not considered within Reimerswaal, since the area is considered already as completely unmanageable with the chosen dyke breach scenario. The indirect damage outside Reimerswaal is determined per network (see chapter 4).

3.2 Electricity

Description of network

The electricity network in the municipality of Reimerswaal consists of a chain of 3 connected levels:

1. high voltage (380-110 kV);
2. medium voltage (110-1kV):
3. low voltage (<1kV).

The high-voltage grid is a component of the national network and is managed by TenneT. The medium-voltage network distributes electricity regionally and supplies to large users. The low voltage network distributes electricity to households. In Reimerswaal the medium-voltage grid and low-voltage grid is managed by Enduris.

In Reimerswaal there is a high-voltage grid of 380kV and 150kV . Further, there are 3 main switching stations (2 in Rilland and 1 in Kruiningen)[2]. The high-voltage grid is connected to the Borsele Nuclear Power Station and in the future will be connected to the new wind farms off the coast of Borsele. A main switching station in the municipality converts high-voltage to medium voltage (MV). On the medium-voltage network the electricity is distributed via switching stations of 10 kV (4 pcs) and MV switchgear cabinets (7 pcs). In 10 kV

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[1] In the RAAK project a bandwidth of 20 cm is used to take account of uncertainty. If the critical water depth of an asset is 30 cm, the asset does not fail at a water depth < 10 cm, the failure is uncertain with a water depth between 20 and 50 cm and the failure of the asset is certain at a water depth > 50 cm. In the vulnerability analysis of this pilot project the critical water depth has been adopted as a threshold value and no distinction is made here.

[2] In the RAAK fact sheet it is stated that there are 2 main distribution stations. Further analysis showed that there are 3 main distribution stations in total, but that 2 stations are on the same site. For damage determination, account is taken of both stations on the same site.

distribution stations (280 pcs), the medium voltage is converted to low voltage (LV). Via LV switchgear (207 pcs) the electricity is finally supplied to households. The vulnerability analysis focuses on the main levels of the network: the high-voltage supply and medium voltage to 10 kV.

Results of vulnerability analysis

Table 3.2 summarises how many and which components fail in the event of a dyke breach or pluvial flooding by heavy rainfall. With the considered dyke breach scenarios different components fail each time. The electricity network will fail locally in Reimerswaal. If a main distribution station is also interrupted, there are also regional chain effects. With the pluvial flooding by a rainfall scenario T=100 no components fail. This means that the network is robust against flood damage and that no components fail at lower repetition periods (T= 10, T=25, T = 50).

Table 3.2 Results for electricity network * (flood proof and non-flood proof barriers)

Components	Number of components in dyke ring 31	Critical water depth [m]	# Components that fail with scenario		
			Oosterschelde	Oosterschelde and Westerschelde	pluvial flooding damage (T = 100)
main distribution station 110/150 kV (HVS)	3	1.70	1	1	0
high voltage lines - aboveground	67 km	2.50	No damage	No damage	No damage
high voltage lines - underground	10.5 km	N/A	No damage	No damage	No damage
switching stations 10 kV	4	0.60	4	4	0

* Results are identical for the starting point of flood proof and non-flood proof barriers.

Chain effect

In both scenarios for dyke breach the electricity network fails. In the RAAK analysis the assumption is made that the high-voltage supply lines continue to operate if the water depth is less than 2.5 m. However, with the failure of one or more main distribution stations, the network will be considerably disrupted. In this pilot project it is also assumed that at a dyke breach the main power grid is switched off as a precaution or fails. The economic chain effects of power outage have been determined in chapter 4.

New insights into vulnerability of high-voltage grid

During workshop 2 Enduris indicated that the current 380 kV line runs via the main distribution station at Kruiningen, but is not connected with it. Assuming that the high-voltage supply masts and the main distribution station at Rilland do not fail, the existing 380kV high-voltage line continues to function in the event of a dyke breach. A new 380kV high-voltage line is currently being constructed. Once it is constructed, there will be some redundancy in the electricity network in Zuid-Beveland. A new main distribution station is also being built near Bath (ground level NAP 1.91 m). The station is being built at a higher elevation. Table 3.3 shows the water levels at the new high-voltage distribution station for different scenarios

Table 3.3 Water level at (new) main distribution station Bath

Water level [NAP]	Non-flood regional flood barriers	Flood proof regional flood barriers
Oosterschelde	0.7 NAP	0
Oosterschelde and Westerschelde	1.9 NAP	2.069 NAP (= 16cm water depth)

In workshop 3 further attention was devoted to the complexity of the electricity network. This consists of a primary process (the transmission) and a secondary process (actuation of primary process). The assets and components of the primary process are relatively high above ground level (critical water depth 1.70 m). The assets and components of the secondary process are situated in the service building and are often low relative to ground level. Due to the increased construction height of the new high-voltage distribution stations there is (starting from flood proof regional flood barriers) only a limited water depth (+/- 16 cm) at the new high-voltage distribution station in Bath. In the efficiency analysis (chapter 6) it is assumed that the high-voltage distribution station fails if the surrounding area is submerged. So it can be checked whether protecting a high-voltage distribution station is a cost-effective measure.

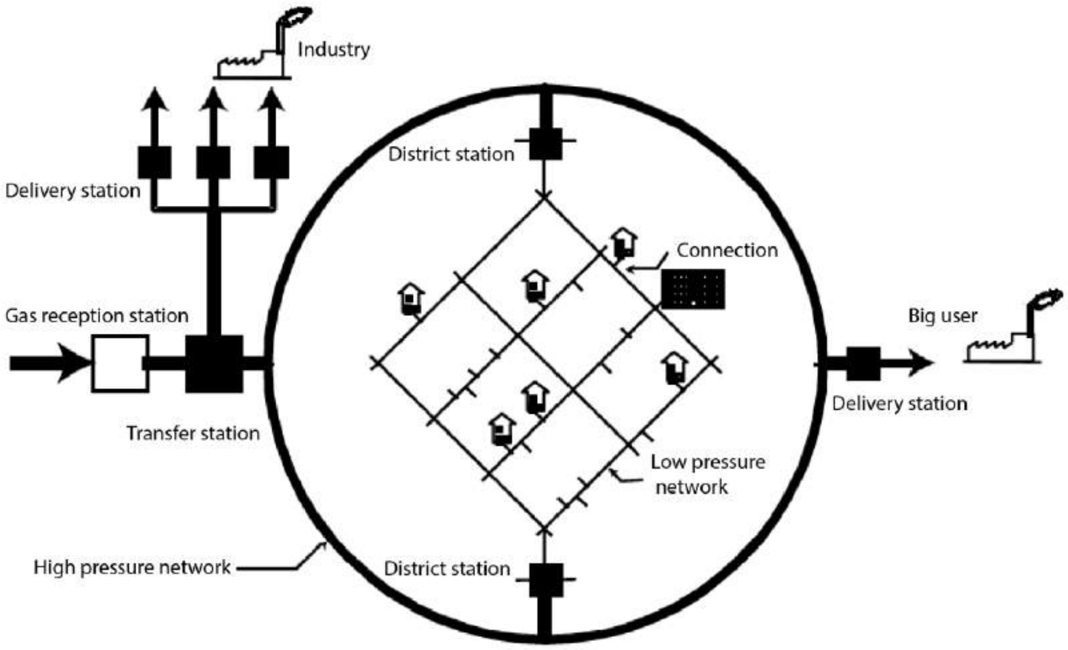
3.3 Gas

Description of network

The gas network in Reimerswaal is divided between the national gas transmission network, managed by Gasunie Transport Services (GTS), and the local distribution networks, managed by regional grid managers. The main gas lines transport the gas under large pressure (66-80 bar) over large distances. In gas reception stations (2 units) the pressure is reduced to 40 bar and the gas is odorized, after which it is brought via the regional grid to transfer stations (2 units). From the transfer stations the gas is distributed further to regional grid managers, power plants and large industries. The local distribution network consists of a high-pressure network and a low-pressure network (with house connections). The high pressure network (4-8 bar) transports the gas to a district station or supplies directly to a large consumer. Via district stations (22 pcs) the gas is distributed under low pressure (30-110 mbar) to the customers (see figure 3.2). The vulnerability analysis focuses on the main gas lines of the network and the gas reception stations.

In addition to the gas network also various pipelines are located in the municipality of Reimerswaal for the supply of the industry in the ports in Walcheren. These are not considered.

Figure 3.2 Structure and components of gas network (source: fact sheet Energie, RAAK project)



Results of vulnerability analysis

Tables 3.4 and 3.5 indicate how many and which components fail at a dyke breach or flood damage. With both flood proof non-flood proof flood barriers for the dyke breach scenario Oosterschelde and Westerschelde, a gas reception station fails. The gas network will fail locally in Reimerswaal. The expectation on the basis of the RAAK-project is that the gas lines are not damaged and the main network and the connecting function to Walcheren thus remains intact. With the dyke breach scenario Oosterschelde (flood proof flood barriers) and the pluvial flooding scenario T=100 no components fail. With non-flood proof barriers one gas reception station fails for the Oosterschelde scenario. The network is robust against pluvial flooding by precipitation and will not fail also at lower return periods.

Table 3.4 Results for network gas (non-flood proof f flood barriers)

Components	Number of components in dyke ring 31	Critical water depth [m]	# Components that fail with scenario		
			Oosterschelde	Oosterschelde and Westerschelde	pluvial flooding (T = 100)
(main) gas pipe	99 km	N/A	No damage	No damage	No damage
gas reception stations (GOS)	2	1.50	1	1	0
delivery stations (AS)	0	N/A			0

Table 3.5 Results of network gas (flood proof flood barriers)

Components	Number of components in dyke ring 31	Critical water depth [m]	# Components that fail with scenario		
			Oosterschelde	Oosterschelde and Westerschelde	pluvial flooding (T = 100)
(main) gas pipe	99 km	N/A	No damage	No damage	No damage
gas reception stations (GOS)	2	1.50	0	1	0
delivery stations (AS)	0	N/A			0

Chain effect

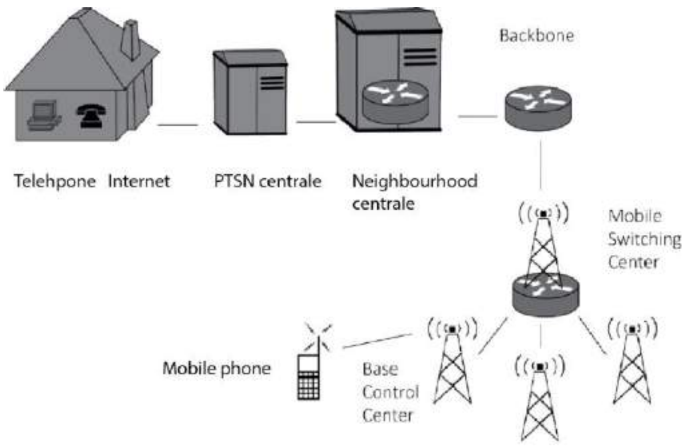
Presumably no chain effects occur outside Reimerswaal, as long as the main gas lines experience no damage in the event of a flood. The main gas lines lie under the ground. The assumption is that these are not damaged by flooding. Presumably failure of local components has no consequences for the main gas lines and the transmission of gas through Reimerswaal is maintained. Consequently no chain effects outside Reimerswaal are analysed in this pilot project.

3.4 Telecom and ICT

Description of network

The vital telecom and ICT network contains the network of fixed and non-flood proof telecommunication for telephone and Internet. The fixed telephony consists of street cabinets, district cabinets and the backbone. The non-flood proof network consists of different type of masts and networks (GSM900 and GSM1800 masts for 2G network, UMTS masts for 3G and LTE masts for 4G). For every 4 masts there is 1 non-flood proof switching centre (basic receiver). The backbone (fiber optic cables) connects different parts of the network with high-speed-connections. The network is hierarchically built up: a phone user calls up on street cabinets/base control centres and is connected via the district cabinets/non-flood proof switching devices with the backbone (see figure 3.3). If an asset fails, the functionality of the network of the components with a lower hierarchy fails (example: if a district cabinet fails, the associated street cabinets also fail).

Figure 3.3 Components telecom network, exclusive of C2000 network (source: fact sheet Telecom, RAAK project)



Finally the C2000 network is also considered. This is a closed communication network for the Dutch rescue and security services. The network has been set up independently of the commercial telecom network and has its own backbone. In Reimerswaal there are three C2000 masts. Rail and Defense also have their own lines of communication, these have not been included in the analysis.

Results of vulnerability analysis

Tables 3.6 and 3.7 indicate how many and which components fail in the event of a dyke breach or pluvial flooding by precipitation. With the considered dyke breach scenarios different components fail. The telecom network will fail locally in Reimerswaal. With the pluvial flooding scenario T=100 no components fail. For that reason the network is robustly protected against pluvial flooding caused by precipitation and it will not fail also at lower return periods.

When the results of 'non-flood proof' and 'flood proof barriers' are compared, it can be seen that with the Oosterschelde scenario much fewer components sustain damage. The difference with a combined Oosterschelde and Westerschelde scenario is considerably less large. The water depths differences do not differ here in such a way that they come under the limit of the critical water depth (30 cm).

Table 3.6 Results for Telecom and ICT network (non-flood proof barriers)

Components	Number of components in dyke ring 31	Critical water depth [m]	# Components that fail with scenario		
			Oosterschelde	Oosterschelde and Westerschelde	pluvial flooding by precipitation (T = 100)
Backbone[1]	? km	N/A	No damage	No damage	No damage
district cabinets	4	0.60	3	4	0
street cabinets*	29	0.30	21	29	0
GSM 1800	5	0.30	4	5	0
GSM 900	8	0.30	6	8	0
LTE masts	17	0.30	14	17	0
UMTS masts	14	0.30	10	14	0
C2000 masts	3	0.30	3	3	0

* Not included in the damage determination

Table 3.7 Results for Telecom and ICT (flood proof barriers)

Components	Number of components in dyke ring 31	Critical water depth [m]	# Components that fail with scenario		
			Oosterschelde	Oosterschelde and Westerschelde	pluvial flooding by precipitation (T = 100)
Backbone[2]	? km	N/A	No damage	No damage	No damage
district cabinets	4	0.60	2	3	0
street cabinets*	29	0.30	14	28	0
GSM 1800	5	0.30	3	4	0
GSM 900	8	0.30	3	8	0
LTE masts	17	0.30	8	17	0
UMTS masts	14	0.30	6	14	0
C2000 masts	3	0.30	0	3	0

* Not included in the damage determination

1 There is no information available on the backbone in Reimerswaal.

2 There is no information available on the backbone in Reimerswaal.

Chain effect
Presumably no chain effects occur outside Reimerswaal, so long as the buried fibre optic cables (backbone) are not damaged by flooding. The assumption on the basis of the RAAK fact sheet is that this is the case. Presumably failure of local components has no consequences for the backbone and the telecom network continues to function outside Reimerswaal. It is assumed in this pilot project that no chain effects occur outside Reimerswaal.

3.5 A58

Description of network
The national highway A58 goes through Reimerswaal. This roadway consists of different components: motorway, slip roads and exits and different engineering structures (bridges, tunnels). On the basis of an earlier study [1]of the HZ it has been concluded that the slopes of the A58 would not be damaged in the event of heavy precipitation. In the framework of another FRAMES project (vulnerability of national highways on the directions of Public Works and Water Management) this network has still been studied in more detail.

Results of vulnerability analysis
Tables 3.8 and 3.9 indicate how many kilometers of the A58 and which components are interrupted in the event of a dyke breach or pluvial flooding. With the considered dyke breach scenario the A58 is interrupted every time. The transport function is then interrupted. From the FRAMES project of RWS, it is found that the infrastructure itself is only damaged to a limited extent, with the exception of the Vlaketunnel, which becomes flooded in the scenarios with non-flood proof regional barriers. For the detailed vulnerability analysis of the A58 and the Vlaketunnel reference is made to the final report of the FRAMES project A58/National Highways.

With pluvial flooding by precipitation event (T=100) there is no water on the carriageways of the A58. However, the PWO-map indicates water in the Vlaketunnel. In the PWO scenarios it is likely that no account has been taken of the drainage system for the tunnel. This has been further studied in the FRAMES project of RWS.

The difference between the flood proof barriers and non-flood proof barriers is considerable in the Oosterschelde scenario. Here, 300 m of motorway is under water instead of 13 kilometres. This is because the A58 lies just south of the regional barriers. With a dyke breach at the Oosterschelde these regional barriers protect the land behind them.

[1] Bachelor thesis 'Review of the stability and erosion resistance of the National Highway A58 in Reimerswaal', civil engineering student Jesper Steur, 22 May 2016.

Table 3.8 Results for network A58 (non-flood proof barriers)

Components	Number of components in dyke ring 31	Critical water depth [m][1]	# Components that are interrupted		
			Oosterschelde	Oosterschelde and Westerschelde	pluvial flooding by precipitation (T = 100)
motorway	17.5 km	0.30	13 km	17 km	0
Vlaketunnel	1	0.30	1	1	1
slip road and exit	3	0.30	is determined in FRAMES study RWS		
bridge	5	?			
tank station (both sides)	1	?			

Table 3.9 Results for network A58 (flood proof barriers)

Components	Number of components in dyke ring 31	Critical water depth [m][2]	# Components that are interrupted		
			Oosterschelde	Oosterschelde and Westerschelde	pluvial flooding by precipitation (T = 100)
motorway	17.5 km	0.30	300 m	12 km	0
Vlaketunnel	1	0.30	1	1	1
slip road and exit	3	0.30	is determined in FRAMES study RWS		
bridge	5	?			
tank station (both sides)	1	?			

Chain effect

In the event of a dyke breach the A58 is affected and the connecting function interrupted. In chapter 5 the chain effects outside Reimerswaal have been described on the basis of traffic figures and CBS data.

3.6 Railway

Description of network

The railway line Roosendaal - Vlissingen goes through Reimerswaal. This consists of a main railway line and 3 stations (Rilland-Bath, Krabbendijke, Kruiningen-Yerseke). For failure due to flooding the electricity circuits and ICT facilities or slope instability are leading. In the RAAK fact sheet the starting point is a critical water depth of 50 cm below the top of the railway track. A higher water depth possibly leads to track instability.

Results of vulnerability analysis

Tables 3.10 and 3.11 indicate how many and which components fail at a dyke breach or pluvial flooding by precipitation. At the considered dyke breach scenario the railway line is interrupted. It is expected that the infrastructure will be damaged at the railway line. At the pluvial flooding scenario T=100 years the critical water depth is nowhere exceeded. This means that the railway network is robustly protected against pluvial flooding and therefore it will not fail even at lower return periods.

[1] The critical water depth on the A58 fact sheet is about accessibility and not damage. With this threshold value no ordinary vehicle can travel any more by road, but no damage occurs.

[2] The critical water depth on the A58 fact sheet is about accessibility and not damage. With this threshold value no ordinary vehicle can travel any more by road, but no damage occurs.

The difference between the flood proof barriers and non-flood proof barriers is considerable in the Oosterschelde scenario. The difference is the failure of 5 km instead of 11 km track. The reason is that the railway line partly lies to the south of the regional barriers. At a dyke breach at the Oosterschelde these regional barriers protect the land behind them and thus also the rail route.

Table 3.10 Results for the Rail network (non-flood proof barriers)

Components	Number of components in dyke ring 31	Critical water depth [m]	# Components that fail [1]at scenario		
			Oosterschelde	Oosterschelde and Westerschelde	pluvial flooding precipitation (T = 100)
railway.	16 km	0.50 under railway track	11 km	15 km	0
stations[2]	3	0.50	1	3	0
bridges	2	still to be specified per object	provisional starting point: no damage	provisional starting point: no damage	0

Table 3.11 Results for Rail network (flood proof barriers)

Components	Number of components in dyke ring 31	Critical water depth [m]	# Components that fail [3]at scenario		
			Oosterschelde	Oosterschelde and Westerschelde	pluvial flooding precipitation (T = 100)
railway.	16 km	0.50 under railway track	5 km	11.5 km	0
stations[4]	3	0.50	1	3	0
bridges	2	still to be specified per object	provisional starting point: no damage	provisional starting point: no damage	0

Chain effect

In the event of a dyke breach the railway line is affected and the connecting function interrupted. In chapter 5 the chain effects outside Reimerswaal have been quantified on the basis of traffic figures and CBS data.

3.7 Drinking water

Description of network

The drinking water network in Reimerswaal is composed of various components. A water treatment plant produces drinking water outside the municipality (purified to good quality), after which it is transported via the main pipe network and then distributed to the users (residents, businesses). In the transport and distribution network there are still clean water basements (storage of drinking water) and pumping and booster stations. Also process water and irrigation water is produced and transported in an equivalent way.

[1] The physical damage is dependent on the water depth and other local factors and has not been considered in detail.

[2] For stations a critical water depth of 0.50 m is adopted.

[3] The physical damage is dependent on the water depth and other local factors and has not been considered in detail.

[4] For stations a critical water depth of 0.50 m is adopted.

In Reimerswaal no components of the (regional) drinking water network are present. There is 1 production station for process water for a local industrial customer and 1 pumping station for the transport of water for agriculture. The (main)drinking water pipes lie deep under the ground and the starting point of the RAAK analysis is that these are not erosion-sensitive or uplift-sensitive. There are some precarious asbestos cement pipes.

Results of vulnerability analysis

Tables 3.12 and 3.13 indicate how many and which components fail in the event of a dyke breach orpluvial flooding by precipitation. With the considered dyke breach scenarios different local components fail each time. The drinking water pipe network doesn't fail. On failure of one of these components only the customer (local industry or agriculture) will experience damage. With the flooding scenario T=100 no components fail. This means that the network is robustly protected against flood damage and that it will not fail even at lower return periods.

There is only a difference between the flood proof barriers and non-flood proof barriers with the Oosterschelde scenario. With flood proof barriers the production station for process water does not fail.

Table 3.12 Results for drinking water network (non-flood proof barriers)

Components	Number of components in dyke ring 31	Critical water depth [m]	# Components that fail with scenario		
			Oosterschelde	Oosterschelde and Westerschelde	pluvial flooding by precipitation (T = 100)
piping network[1]	2,500 km	N/A	No damage	No damage	No damage
production station process water	1	0.30	1	1	0
pumping station	1	0.30	0	1	0

Table 3.13 Results for drinking water network (flood proof barriers)

Components	Number of components in dyke ring 31	Critical water depth [m]	# Components that fail with scenario		
			Oosterschelde	Oosterschelde and Westerschelde	pluvial flooding by precipitation (T = 100)
piping network[2]	2,500 km	N/A	No damage	No damage	No damage
production station process water	1	0.30	0	1	0
pumping station	1	0.30	0	1	0

1 This information is unavailable Owing to the sensitivity and importance of the drinking water network (there is no redundancy in the network) water company Evides does not wish to share this information.

2 This information is unavailable Owing to the sensitivity and importance of the drinking water network (there is no redundancy in the network) water company Evides does not wish to share this information.

Chain effect
There are presumably no chain effects outside Reimerswaal, as long as the (main)drinking water pipes are not damaged in the event of flooding. Failure of the local components does not lead to interruption of the drinking water network outside the municipality. The (main) drinking water pipes lie under the ground. The assumption is that these are not damaged by flooding. Therefore it is concluded that there are no chain effects outside Reimerswaal.

3.8 Sewage

Description of network
The sewage chain network works as follows: sewage runs from the households via the municipal sewerage system to a sewage pumping station. The sewage pumping system then pumps the sewage via a discharge line to a sewage treatment plant (RWZI). This discharge line can be fitted with valves to shut down a part of the network for maintenance or in case of emergencies. In the sewage treatment plant the sewage is then purified before it is discharged onto surface water. In Reimerswaal there is one sewage treatment plant stands in Waarde with a treatment capacity of around 80,000 resident equivalents and there are 11 sewage pumping units and 6 valves. The RAAK fact sheet considers only the part of the sewage chain that falls under management of the water board. The components of the municipal sewage system (inspection pits, etc.) are not included.

Results of vulnerability analysis
Tables 3.14 and 3.15 indicate how many and which components fail in the event of a dyke breach or pluvial flooding caused by precipitation. With the considered dyke breach scenarios different components fail. The sewage network will be disturbed. If the sewage treatment plant fails, the sewage may get discharged on the Schelde (with the associated ecological impact as a consequence). If a sewage pumping station fails and there is no (emergency) overflow, it may not be possible to discharge the sewage. This involves health risks. The assumption on the basis of the RAAK fact sheet is that the discharge lines will not be damaged in the event of flooding (since these lie under the ground). With the pluvial flooding by precipitation scenario T=100 no components fail. Consequently the network is robustly protected against pluvial flooding and will not fail at lower return periods.

There is only one difference between the flood proof barriers and non-flood proof barriers with the Oosterschelde scenario. A number of sewage pumping stations will not fail.

Table 3.14 Results for sewage network (non-flood proof barriers)

Components	Number of components in dyke ring 31	Critical water depth [m]	# Components that fail with scenario		
			Oosterschelde	Oosterschelde and Westerschelde	pluvial flooding by precipitation (T = 100)
SEWAGE TREATMENT PLANT	1	0.30	1	1	0
sewage pumping station	12	0.30	9	12	0
valves*	6	0.30	3	6	0
discharge lines	35 km	N/A	0	0	0

* Not included in the damage determination

Table 3.15 Results for sewage network (flood proof barriers)

Components	Number of components in dyke ring 31	Critical water depth [m]	# Components that fail with scenario		
			Oosterschelde	Oosterschelde and Westerschelde	pluvial flooding by precipitation (T = 100)
sewage treatment plant	1	0.30	0	1	0
sewage pumping station	12	0.30	4	12	0
valves*	6	0.30	0	6	0
discharge lines	35 km	N/A	0	0	0

* Not included in the damage determination

Chain effect
The sewage chain in Reimerswaal is a local chain within the dyke ring. There are therefore no chain effects outside Reimerswaal.

3.9 Retention and management of surface water (pumping stations)

Description of network
Within dyke ring 31 there are 12 pumping stations for the management of surface water (4 discharge pumping stations, 1 supply pumping station and 6 pumping stations for lowering the water level). Each pumping station has a function in managing the regional water system. The discharge pumping station discharges water in wet periods, the supply pumping stations supplies water to the area in dry periods and the level-lowering pumping stations are used to lower the water level in a smaller area artificially.

Results of vulnerability analysis
Tables 3.16 and 3.17 indicate how many pumping stations fail in the event of a dyke breach or flood damage. There is only one difference between the flood proof barriers and non-flood proof barriers with the Oosterschelde scenario. 2 pumping stations now fail instead of 7.

Table 3.16 Results of for barriers and management of surface water (non-flood proof barriers)

Components	Number of components in dyke ring 31	Critical water depth [m]	# Components that fail with scenario		
			Oosterschelde	Oosterschelde and Westerschelde	pluvial flooding by precipitation (T = 100)
discharge pumping stations	4	0.30 - 0.85	4	4	0
supply pumping stations*	1	0.3	0	0	0
pumping station for lowering the water level*	6	0.3	3	6	0

* Not included in the damage determination

Table 3.17 Results for barriers and management of surface water (flood proof barriers)

Components	Number of components in dyke ring 31	Critical water depth [m]	# Components that fail with scenario		
			Oosterschelde	Oosterschelde and Westerschelde	pluvial flooding by precipitation (T = 100)
discharge pumping stations	4	0.30 - 0.85	2	4	0
supply pumping stations*	1	0.3	0	0	0
pumping station for lowering the water level*	6	0.3	0	6	0

* Not included in the damage determination

Chain effect

The pumping stations within dyke ring 31 have a local function. There are therefore no chain effects outside Reimerswaal. The insights from the vulnerability analysis of the pumping stations are used in chapter 5 for determining the recovery time. In that sense the failure of this network definitely has an influence on the chain effects of other networks.

4

QUANTIFICATION OF DAMAGE

4.1 Direct damage to the network

From the vulnerability analysis it follows that each vital network experiences damage at a dyke breach. In table 4.1 the direct damage to each network is shown per dyke breach scenario. For more detailed results of the direct damage per dyke breach scenario, see annex VIII.

The estimated damage is indicative and intended as an order of magnitude estimate. Furthermore only the direct damage to the main components has been shown. In general terms the damage per object has been determined on the basis of an indication of direct costs of demolition and replacement of the object and repair of the installations. In the case of masts for telecom and ICT only a cost indication of damage to the installations above groundlevel has been included.

Table 4.1 Indication of direct damage to networks (amounts have been rounded off in EUR)

	non-flood proof regional barriers (VNK2)		flood proof regional barriers (PZ)	
Network	**Maximum Oosterschelde scenario**	**Maximum Ooster- and Westerschelde scenario**	**Maximum Oosterschelde scenario**	**Maximum Ooster- and Westerschelde scenario**
electricity	6,700,000	6,700,000	6,200,000	6,700,000
gas	300,000	300,000	-	300,000
telecom/ICT	300,000	400,000	200,000	400,000
A58	26,300,000	29,200,000	-	8,100,000
railway	16,000,000	30,000,000	10,000,000	26,500,000
drinking water	3,000,000	3,000,000	-	3,000,000
sewage	5,500,000	5,900,000	600,000	5,900,000
barriers and management of surface water	600,000	600,000	300,000	600,000
total indirect damage	**58,700,000**	**76,100,000**	**17,300,000**	**51,500,000**

4.2 Indirect damage

From the vulnerability analysis it follows that for the networks electricity, A58 and railway chain effects occur in the event of a dyke breach. These are the networks that are vulnerable in Reimerswaal, where the chain effects are large and for which information is available to carry out a quantitative analysis of the indirect damage. The quantitative analysis offers a first insight into the order of magnitude of the damage on the

basis of quickscan methodologies. More detailed analyses must be carried out for more detailed results. This falls outside the scope of this pilot project.
The possible chain effects of telecom/ICT are not quantified because of the limited insight into the complexity of the different networks and because of the indication from the vulnerability analysis that the network continues to function.

4.2.1 Electricity

Ecorys has quantified on the basis of the vulnerability analysis what the economic chain effects can be of an interruption of the power supply through Reimerswaal. In this main report by Witteveen+Bos a short summary of the approach and results has been included. The memo can be found in Annex IX.

Failure of electricity has an economic effect both on households and on the economic activities of different sectors. On the basis of CBS data for the COROP-area Zeeland except Reimerswaal' the economic chain damage has been determined[1]. The damage for both groups (Reimerswaal and the rest of Zeeland) together gives an indication of the total consequential damage as a result of a power failure and is therefore an important basis for the risk determination. With this a comparison can be made in the following phase at the analysis of the amount that could be invested to prevent power failure or to limit the chain effects of that.

Scenarios
An important variable in the determination of the value loss due to power failure is the duration of the outage. Therefore, use was made of 3 scenarios:
1 'failure of the high-voltage supply network with a large impact in COROP area ' Zeeland except Reimerswaal' for a short period (1 to 4 days)';
2 'failure of the high-voltage supply network and a part of the low voltage network in the COROP-area ' ' Zeeland except Reimerswaal ' for a medium period (more than 14 days)';
3 'failure of the high-voltage supply network and a part of the low voltage network in the COROP-area ' ' Zeeland except Reimerswaal ' for a long period (to 3 months)'.

These scenarios are based on different assumptions:
- both the high-voltage supply network and the low voltage supply network fail in Reimerswaal;
- all municipalities in the COROP area '' Zeeland except Reimerswaal ' suffer damage from this, except for Tholen and Schouwen-Duiveland;
- the damage in Reimerswaal itself is calculated separately, because this research study focusses on the chain effects outside Reimerswaal;
- the network manager Tennet is responsible for ensuring the continuity of power supply for the rest of the Netherlands, so that the power supply does not fail outside the COROP area;
- after 14 days 75% of the power supply has been restored in the COROP area ' ' Zeeland except Reimerswaal ';
- after 3 months the power supply has been restored 100 % in the COROP-area ' Zeeland except Reimerswaal ', with the exception of the municipality of Reimerswaal.

Economic damage to households
For the determination of damage among households in the earlier descriptions of the approach the principles 'willingness to accept' (WTA) and 'willingness to pay' (WTP) have been stated. The first principle is based on compensation whereby people are prepared to accept a power failure. The second principle assumes the costs that people are prepared to incur to prevent the failure. These approaches were found to be insufficiently appropriate to this task during the analysis, since this methodology applies in particular to short-term power failure from hours to a few days and does not provide a clear picture of the economic damage.

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[1]Ecorys has quantified on the basis of the vulnerability analysis what the economic chain effects can be of an interruption of the power supply through Reimerswaal. In this main report by Witteveen+Bos a short summary of the approach and results has been included. The memo can be found in Annex VII.

The value loss for households as a result of a power failure has been determined therefore by Ecorys on the basis of two other methods. The first method is based on the legally established compensation according to the Netcode for electricity. The legally established compensation determines how much compensation electricity suppliers or network managers must pay to compensate households for a power failure. This is partly based on the damage that households suffer through a power failure and thus gives an indication of the damage. The second method uses the valuation of power failures according to the "conjoint analysis method"[1]. In the conjoint analysis method, consumers express their preference for what they want to pay on the basis of a hypothetical network quality and price. In this way they are not asked directly what they want to see in an improvement of network quality or the required compensation for accepting power failure. Here we use the figures from Blauw Report, drawn up for the Energy Office of the Dutch Competition Authority in 2012 (now Consumer and Market Authority).

A disadvantage of the figures from the conjoint analysis is that this methodology is also focused on the short term. The conjoint analysis figures show characteristics of power failure with a duration of 0.5 minute to 24 hours (and never longer than 24 hours). The conjoint analysis can therefore be used as a method generally only for short term scenarios. This limitation is valid for all employed methods of indirect damage determination: current methodologies have been designed for short periods of failure. However, the disruption caused by a dyke breach leads to longer recovery periods and if there are longer power failures, society will adjust (e.g. companies adapt supply routes, people temporarily move elsewhere). The calculated indirect damage is therefore a first finger exercise in quantifying the indirect damage. To take account of adaptation by residents and businesses in the determination of the cost effectiveness of the measures an 'adaptation factor' will be applied.

The results for both methods have been calculated for both the municipality of Reimerswaal and for the COROP area Zeeland, exclusive of Reimerswaal. The results of both methods have been shown in Table 4.2. The ‘conjoint analysis’ method is also found to be a better approach to the valuation short power failures. As a result the long-term values are estimated too low. Therefore, first of all, the results of the first method and the results of the first day of the second method are used. Also the damage in Reimerswaal is not included.

Table 4.2 Potential maximum damage to households for the two methods

	(1) Damage per day in EUR method compensation Netcode for electricity		(2) Damage per day in EUR Method ‘conjoint analysis’ Blauw Report	
damage to households.	Reimerswaal	COROP other Zeeland, without Reimerswaal	Reimerswaal	COROP other Zeeland, without Reimerswaal
scenario 1 (4 days)	1,087,515	11,049,761	45,706	464,399
scenario 2 (14 days)	1,063,976	1,904,665	15,380	156,266
scenario 3 (90 days)	1,056,025	1,890,432	2,929	29,756

Economic damage to branches of business

The value loss for all economic sectors has been determined on the basis of production loss due to the power failure. The production loss as a result of power failure has been calculated on the basis of the gross added value at industry level. Gross added value is a measure of the value created in an industry and is equal to the market value of production minus the value of the purchased raw materials for production. The considered industries are:

- A Agriculture, forestry and fisheries;
- B-E Industry (not construction) and energy;
- F Construction industry;

[1](Blauw Report, 2012)

- G-I Trade, transport and hotel & catering;
- J Information and communication;
- K Financial services;
- L Rental and trading of immovable property;
- M-N Business services
- O-Q Government and care provision;
- R-U Culture, recreation, other services.

The level of production loss depends on the way an industry can respond to the power failure. The following options have been included in the analysis:
- deployment of back-up facilities such as emergency generators or batteries;
- diversion of production to another area.
- adaptation of production process.
- shift of production in time.

The deployment of measures to prevent production loss usually leads to higher costs for production so that the gross added value decreases. The damage per day for the COROP-area 'Zeeland except Reimerswaal' has been summarised in table 4.3.

Table 4.3 Damage to economic activities per day

Duration of outage/scenario	Damage COROP area 'other Zeeland' in EUR per day
scenario 1 (1 day)	6,660,000.00
scenario 2 (14 days)	2.660,000,00
scenario 3 (90 days)	2,760,000.00

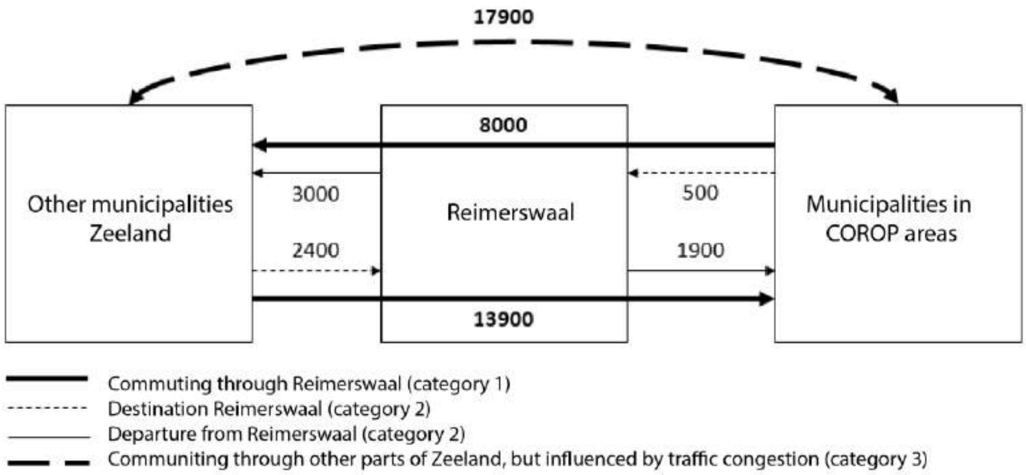
4.2.2 Mobility (A58 and Railway)

On the basis of the vulnerability analysis a graduation research project has been carried out to determine what the economic chain effects can be of a failure or change of commuter flows/commuter traffic due to a dyke breach in Reimerswaal. The A58 and the railway ensure that Reimerswaal fulfils an important connecting function between Zeeland and the rest of the Netherlands. Every day, more than 40,000 commuters travel through Reimerswaal. In the case of a dyke breach both the railway and the A58 will be unusable (chapter 3), so that the commuter traffic will adapt by taking a diversion or by cancelling trips. The methods and results of the graduation research project will briefly be explained below. The detailed analysis has been shared separately.

Commuter flows/commuter traffic

Using commuter traffic data of the CBS the shuttle flows have been established between all municipalities of the ten COROP-areas in the south-west of the Netherlands. Then for all combinations the distance, travel time and used roads have been determined with Google Maps. On the basis of these routes the commuter flows have been classified into three categories, namely the flows that start or end in the municipality of Reimerswaal, flows that go through Reimerswaal and flows that do not pass through Reimerswaal but make use of roads in Zeeland. The size of all these flows has been shown in figure 4.1. The numbers indicate one direction, in other words, daily (2x8.000)+(2x13.900)= 43.800 commuters through Reimerswaal. The following is observed:

Figure 4.1 Traffic flows through Reimerwaal



These 3 categories of commuter flows are influenced in different ways by flooding in Reimerswaal. It has been assumed that all the commuter traffic to and from Reimerswaal stops, because the area is largely impassable. The other 2 categories experience extra travel time due to diversions and/or traffic congestion. The flows that normally pass through Reimerswaal, are forced to choose a different route, this results in extra travel time. In addition traffic congestion will arise on the roads that are used as diversion routes. Due to this traffic congestion the traffic that normally travelled on these roads already experiences extra travel time. Here it is observed that commuter traffic is not included in the estimate of the indirect damage. The real damage due to failure of the A58 is therefore presumably higher.

Costs of cancelled commuter flows and extra travel time

To determine the economic impact of cancelled commuter flows and extra travel time, three different methods have been used. In this way the lower and upper limits of the costs have been established.

1. The costs of cancelled travel and extra travel time have been calculated 100 % with absenteeism costs per sector (TNO, 2014);
2. 50 % of the costs have been calculated with absenteeism costs and 50 % on the basis of 'Value of Time (VoT)';
3. The costs have been calculated 100 % on the basis of 'Value of Time (VoT)'.

To be able to apply the first method firstly the number of employees per sector per commuter flow has been determined on the basis of CBS data. It has been assumed that the economic structure of the commuter flows is proportionally the same as that of the work municipality. For example, the commuter traffic from Goes to Bergen op Zoom consists of 300 people, while in Bergen op Zoom 12 % of the jobs are in the education sector so it is assumed that 36 people in the commuter flow between Goes and Bergen op Zoom work in education. Then the absenteeism costs have been determined per day and per minute, to determine the costs of cancelled commuter traffic to and from Reimerswaal and the costs of extra travel time for the other commuter flows.

For the second method both the absenteeism costs and the 'Value of Time (VoT)' have been used, to calculate the costs of extra travel time. The VoT shows the social costs/benefits of an increase/decrease of the average travel time (KiM, 2013). For commuter traffic this amounts to EUR 9.25 an hour. With this method it has been assumed that half of the travel time is valued with the VoT and the other half on the basis of absenteeism costs. In the third method the costs of extra travel time are completely based on the VoT. These different costs are to be found in table 4.4.

Although this research focuses on commuter traffic freight traffic has been studied for the sake of completeness. Because no data is publicly available for freight traffic in relation to the origin and destination, only the costs of traffic congestion have been calculated. Here it has been assumed that the freight traffic that is normally going through Reimerswaal is distributed in the same way via diversions as the commuter traffic. The costs have been calculated with the VoT for freight traffic, and these amount to EUR 42.20 per hour.

Table 4.4 Costs per day for the 3 categories of commuter traffic.

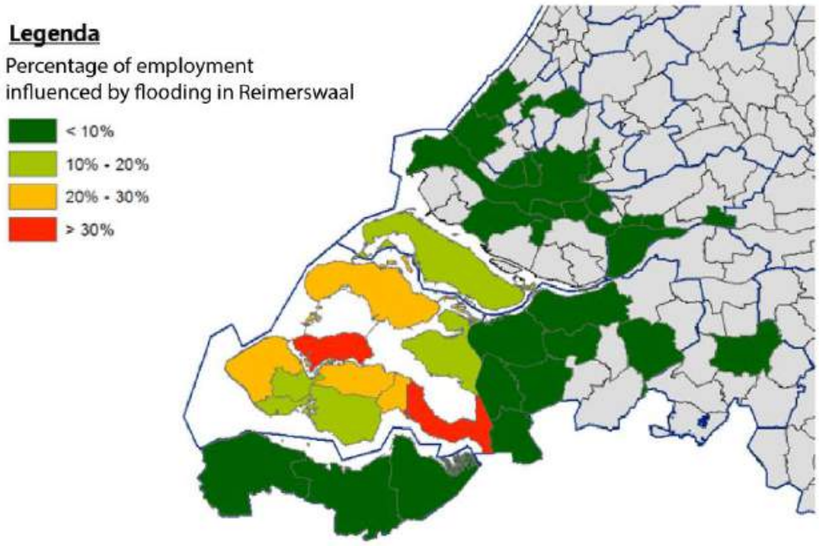
	Origin or destination Reimerswaal, costs in EUR	Through Reimerswaal, costs in EUR	Not through Reimerswaal, costs in EUR	Freight traffic, costs in EUR	Total in EUR
cancelled trips	2,629,000				2,629,000
diversions		min: 122,000.00 max: 375,000.00			min: 122,000 max: 375,000
congestion		min: 416000.00 max: 1,275,000.00	min: 148,000 max: 456,000	246,000	min: 810,000 max: 1,977,000
total	2,629,000	min: 538,000 max: 1.650.00	min: 148,000 max: 456,000	246,000	**min: 3561000** **max: 4,981,000**

In chapter 6 an average value of EUR 4,271,000 will be counted per day. However, this should take into account behavioral changes. In the case of traffic congestion people will decide to travel outside peak times or to choose another route. Also after some time the residents of Reimerswaal will go back to their work or go elsewhere to work, so that the absenteeism costs decrease. In the determination of the cost effectiveness therefore a reduction factor will be applied.

Economic impact per municipality/sector

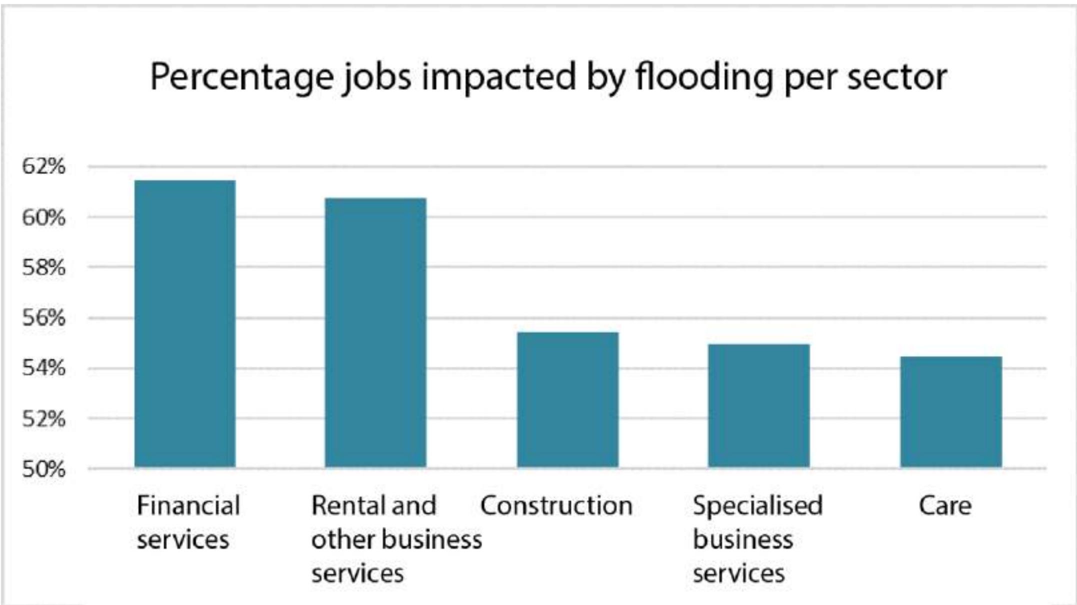
To obtain an impression of the total economic impact on the commuter traffic through Reimerswaal, a study has been made of the impact per municipality and per sector. Figure 4.2 gives the percentage of the employees per municipality that is affected by flooding in Reimerswaal, thus the employees who do not come to work or arrive late at work. As a result it becomes clear on which municipalities the flooding has most impact.

Figure 4.2 Impact per municipality



In figure 4.3 the top five sectors with the largest impact have been shown, this has been calculated by the percentage of employees that does not come to work or arrives late for work per sector relative to the total number of employees in that sector in the COROP area 'other Zeeland'.

Figure 4.3 Top 5 affected sectors for chain effect mobility in COROP area 'other Zeeland'



5

ACTION PERSPECTIVES AND MEASURES

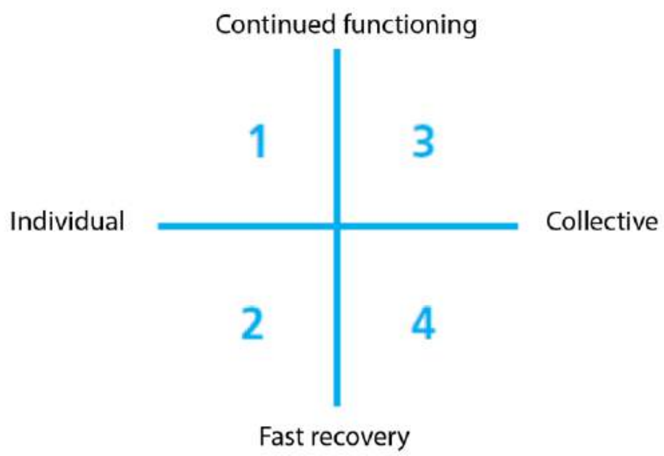
This chapter examines the action perspectives and measures to protect the vital infrastructure and/or to limit the damage due to failure of the infrastructure. On the basis of a conceptual framework of action perspectives and measures, potential measures are elaborated that either prevent failure of functions ('continued functioning') or enable a fast recovery.

5.1 Conceptual framework of action perspectives and measures

Action perspectives

In this chapter the focus lies on developing measures in layer 2 of multilayer safety. Focus lies on the determination of action perspectives and measures at network and object level (individual) and area level (collective) that limit the risk of flooding. The measures obtain a sketch design and cost estimate. In the following figure, the four action perspectives have been shown.

Figure 5.1 Four action perspectives (individual vs. collective and continued functioning vs. evacuation and fast recovery)



Clustering of measures

During the workshop of 26 September 2018 measures have been identified within the four quadrants. The report of this workshop is available separately.

Continued functioning

For collective and individual continued functioning the following clustering in three main measures is adopted:

1 collective continued functioning via compartmentalisation with regional water barriers in municipality;
2 individual continued functioning through protection of objects;
3 individual continued functioning through redundancy networks (through alternative connection or local alternative provision).

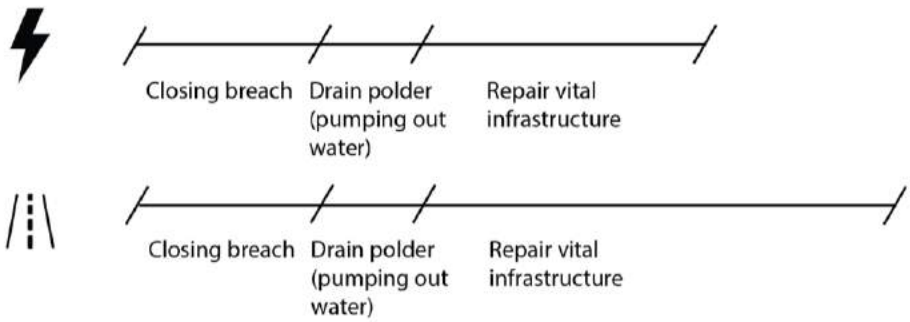
Fast recovery

For the clustering of measures for collective and individual speedy recovery a distinction is made between 3 main measures:

1 collective recovery by (accelerated) closing of breach location(s);
2 collective recovery by (accelerated) pumping-out of dyke ring 31;
3 individual repair of vital infrastructure.

On this basis, the recovery time can be calculated. For component 1 only a consideration of the recovery time has been made. Because the measures are concerned especially with layer 1 (outside scope of this study), these will not be elaborated in a sketch design with a cost estimate.

Figure 5.2 Basic calculation of recovery time main measures (partly parallel execution possible)



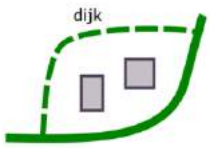
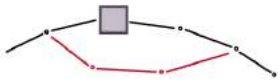
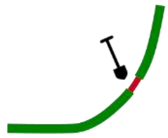
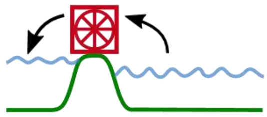
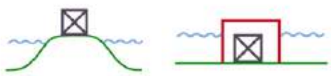
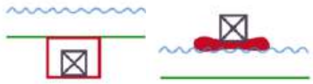
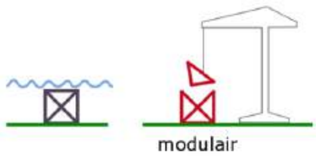
Elaboration of promising measures

Potential measures focus on reduction of the direct damage to the networks and the reduction of the indirect damage. For the reduction of the indirect damage the availability of the A58 and electricity network is considered as normative. These networks also have the greatest indirect damage. For this reason the promising measures are designed precisely for these networks. Individual measures for the A58 are elaborated in the pilot project for the A58 and fall outside the scope of this pilot project.

For the potential measures a sketch design and cost estimate has been prepared in a separate note. The designs give insight into the costs and the spatial feasibility of measures[1]. An important part of the content of the separate note has been included in this main report.

[1] During the course of the pilot project, an investigation conducted by 2 students of the Avans Hogeschool, studied what the support base for grid managers to take measures. This showed that the support base for measures is often limited. In the case of communication with grid managers it is important to outline the context of the study and the specific task.

Table 5.1 Different measures within the action perspectives

	Continued functioning	Fast recovery
collective	 compartmentalisation  redundancy	 close breaches  pump out area
individual	 increase waterproof  underground floating  surround with dykes	 modular

5.2 Measures for collective and individual continued functioning

5.2.1 Collective compartmentalisation for the A58 and other networks

Because the A58 is a largely an above-ground infrastructure, the prevention of flooding is desirable for continued functioning. Compartimalisation is a collective measure that can also protect other networks. Compartimalisation can be done by building regional barriers, so that the A58 itself continues to function at the time of the dyke breaches. The compartmentalisation takes care as well of protection of other critical objects, such as the new 380 kV station at Rilland. Figure 5.3 shows the locations where existing dykes must be raised to protect the motorway and the spots where a new secondary water barrier must be added to protect the motorway from the water.

Figure 5.3 Continued functioning of A58 through compartmentalisation

In figure 5.3 three categories of compartmentalisation barriers have been added and designed:

1 existing barriers that comply in height: length = 12.9 km;
2 existing barriers that must be raised: length = 7.5 km;
3 new barriers: length = 17.1 km.

It is important to observe here that we are dealing with a coarse indication of the dykes and required heights.

5.2.2 Individual protection of transformer

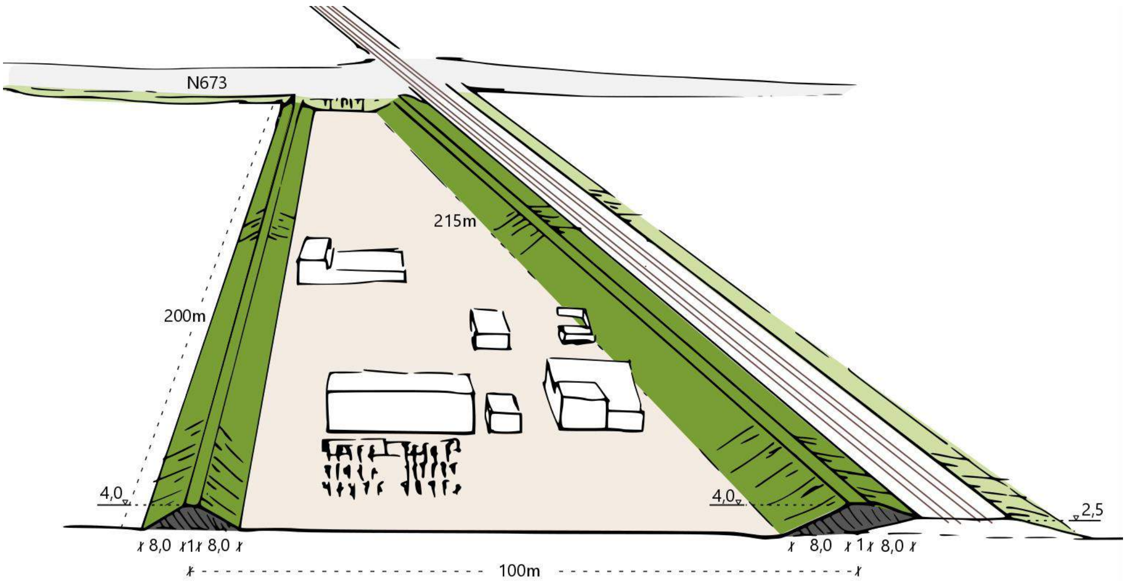
With the individual protection of objects of different networks comparable measures can be taken. Since transformers are vulnerable objects of the electricity network (low at the ground level), measures have been developed for transformers. For the elaboration of measures in Reimerswaal the high-voltage supply station in Kruiningen has been chosen. The vulnerability analysis has shown that this station fails. Measures to protect this existing station ensure a better functioning of the station during flooding. The challenge with the high-voltage supply station is to study how the vulnerability can be reduced by:

- raising the entire station;
- making it watertight/waterproof;
- building a local dyke around the area;
- building up the facility in a modular way: this has not been elaborated, because this relates to the replacement of components and cannot be accommodated in a design.

Figure 5.4 Location and aerial photo of high-voltage supply station

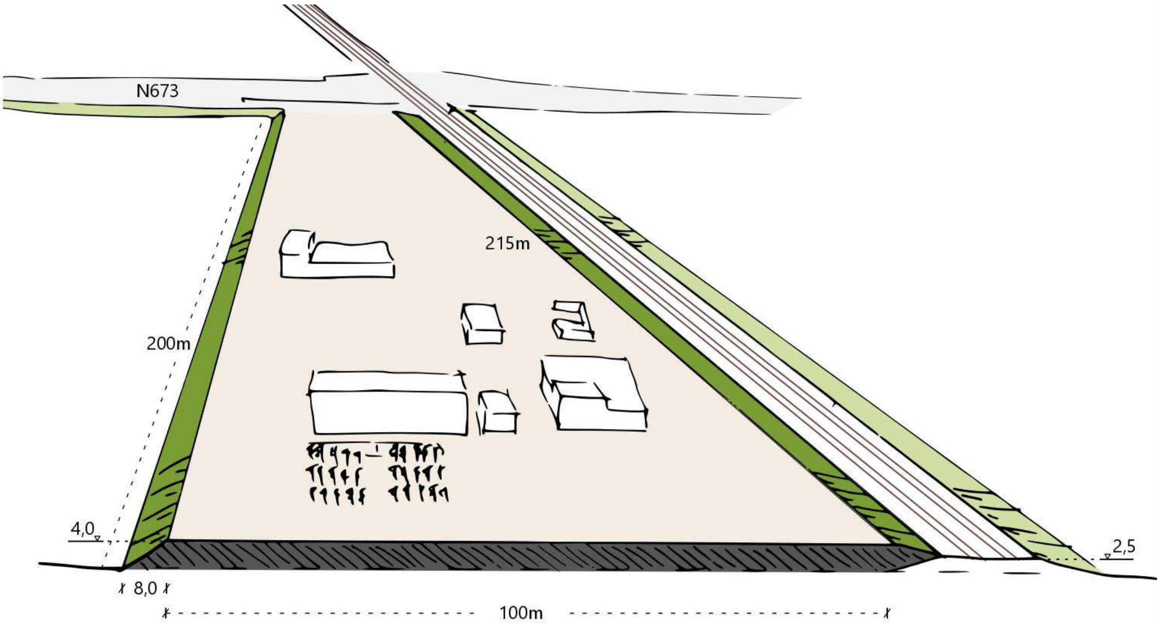
The first option is to build a local barrier. The maximum water height is 3.6 m (maximum scenario), therefore the starting point has been a barrier of 4.0 m in height. On the north-east side of the site (at the back of the drawing) it is possible to connect with a higher area (around 4.2 m above ground level), situated along the N673. The railway track (on the right in the drawing) is around 2.5 m high, thus inadequate to protect the high-voltage supply station against the water. Therefore an extra embankment is added along the track.

Figure 5.5 Local dyke (cross-section and perspective)



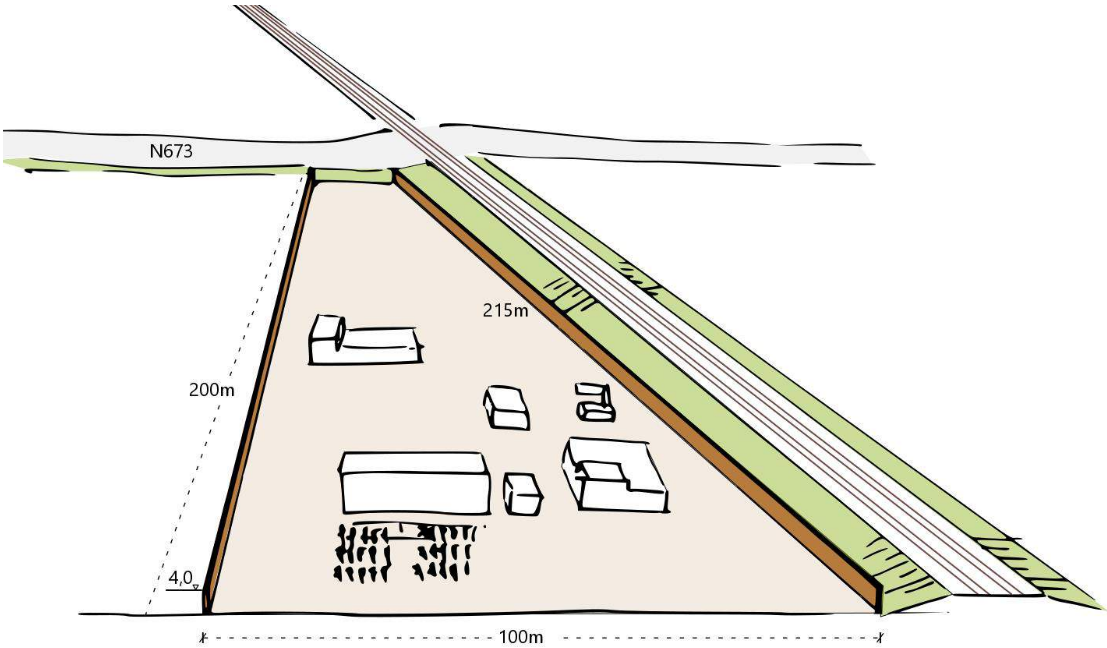
In the second variant the location of the high-voltage supply station is raised as a whole to a height of 4.0 m above ground level. It is also possible to raise specific objects. To avoid limiting the use and accessibility of the site it has been decided to raise the whole site, which also has been done at the new station in Bath. This also ties into the increased height along the N673 and an additional increase in height is added along the railway track. The slope of the new embankment is 1:2.

Figure 5.6 Local increase in height



The third variant is comparable to the local dyke. Around the site of the high-voltage supply station a watertight wall is built with a height of 4.0 meters. The total length of the wall is 515 meters. Also a foundation (for example with a sheetpile wall) is necessary. Further, waterproof doors are necessary, large enough for the plant and freight traffic to approach the site.

Figure 5.7 Local barrier (cross-section and perspective)



5.2.3 Redundancy in individual network

Redundancy of the A58 and the electricity, the construction of alternative connections, requires major investments and a complex design in the existing area. The costs are not expected to weigh up against the risk reduction. Therefore, in terms of redundancy, the starting point is the analysis and optimisation of existing networks.

Electricity

The redundancy for the electricity network:

1 to limit the chain effects the possibilities for individual emergency power supply via generators have been studied by Ecorys in the memo in annex IX. Both the rental and the purchase of diesel generators has been considered in a first sensitivity analysis. The main points are:
   - on the basis of a power output per generator of 65 KW 75 households and 5 business connections can be supplied with electricity;
   - within Reimerswaal a minimum of 120 generators are necessary. In the COROP area outside Reimerswaal at least 1,200 generators are necessary;

2 the new 380 kV-line that is delivered in 2020 introduces redundancy in the high-voltage supply network. As soon as this is operational, the high-voltage supply connection between West-Brabant and Walcheren will be less vulnerable to flooding in Reimerswaal. In the following chapter it is studied which chain effects this prevents and it is assessed whether the network continues to operate in the event of a dyke breach near the new station Bath (height position: +1, 91 m NAP);

3 in the existing high-voltage supply network there is a link between Walcheren and Zeeuws-Vlaanderen and the power plant at DOW Chemical in Terneuzen. These can be deployed to guarantee the power supply in the direction of Walcheren and Zuid-Beveland.

A58

Redundancy of the A58 via an alternative traffic link within the municipality of Reimerswaal is not possible on account of the large water depth that is present. As indicated in paragraph 4.2.2 diversions are possible and the traffic movements have been studied.

5.3 Measures for collective and individual recovery

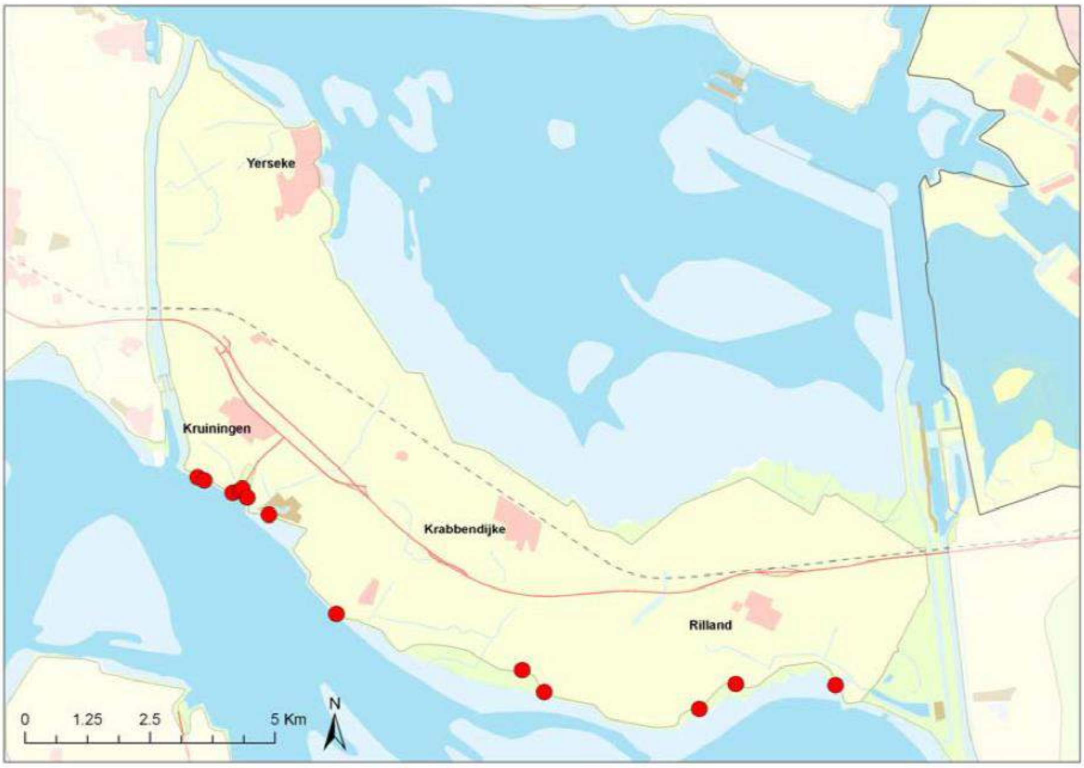
5.3.1 Repair of breach location

To be able to make an estimation of the recovery time for closing off breach locations, a short analysis has been made of the flood disaster in 1953, where Zuid-Beveland was also severely affected. This is supplemented with knowledge about the development of the technology for closing off dikes and how quickly this is done in other areas. From these data an estimate is made qualitatively of a bandwidth in which the recovery works can fall. The design and the costs of closing off the breach are not considered.

Historical analysis: duration of recovery after the flood disaster of 1953

The locations where the dykes were breached in Zuid-Beveland East are shown in figure 5.8. The breaches occurred then only on the Westerschelde side.

Figure 5.8 Breach locations in dyke ring 31 during the flood disaster of 1953



The repair work after the flood disaster in Zealand was in the hands of the department of 'Dyke Repair'. The method chosen was the construction of so-called unit caissons: box-like structures that were deployable in all kinds of variations[1]. In early April 1953 (2 months after the disaster) the largest part of the disaster area was dry. At Kruiningen, three closure gaps were still open, one in Bath and 7 at Schouwen-Duivenland including one at Schelphoek and one at Ouwerkerk. The closures at Kruiningen and Bath ensure that the municipality of Reimerswaal still floods every day:

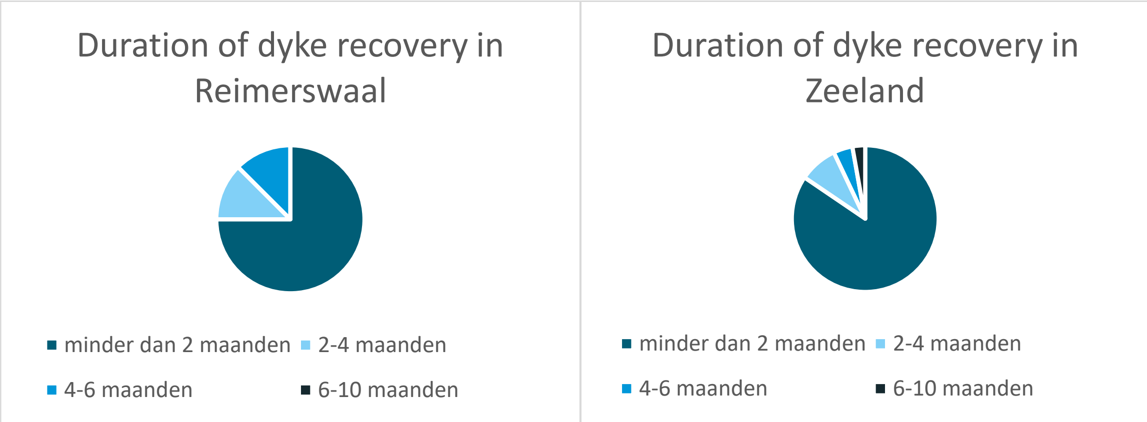
- at Bath, earlier attempts to close the gap by the hydraulic placement of sand failed due to the strong current. The closure gap at Bath was closed on 23 April 1953 by means of a ship's hull. This is two and a half month after the breach;
- at Kruiningen there are still 3 open gaps at the beginning of April: the west gap, the east gap and the gap in the ferry port. First the inner dykes had to be closed, which took a long time and was hard work because the area was not accessible for heavy plants and machinery;
    - afterwards the west gap could be closed quickly by means of clay, rubble and 6 unit caissons. This seemed to go wrong when the connection bolts broke off and the caissons penetrated the polder, but tugboats got them back in their place[2];
    - closing the east gap was more difficult due to violent storms and a depth of 11 m. A ring dyke of 40 caisson elements was made, after which the actual gap was closed with a 33 m long pontoon of unit caissons. This succeeded on 8 July, slightly more than 5 months after the disaster;
    - the gap in the ferry port was the last to be closed, and this succeeded on July 24. After this the train traffic could also be restarted.

For the municipality of Reimerswaal half a year after the day of the disaster, this meant the area was no longer flooded at high tide on a daily basis. On Schouwen-Duivenland, there was less luck. The gaps at Schelhoek and Ouwerkerk were closed on August 18 (6.5 months after the storm) and 24 November (9.5 months after the storm). Figure 5.9 shows in percentage terms the recovery time of the closure gaps for the municipality of Reimerswaal and the whole affected area.

1 http://www.deltawerken.com/herstel-van-het-getroffen-gebied/27.html

2 https://www.cobouw.nl/bouwbreed/nieuws/2003/01/innovaties-gebeuren-het-snelst-onder-hoge-druk-10196071

Figure 5.9 Duration for closing closure gaps, percentage for municipality of Reimerswaal and the whole Province of Zeeland at flood disaster of 1953.



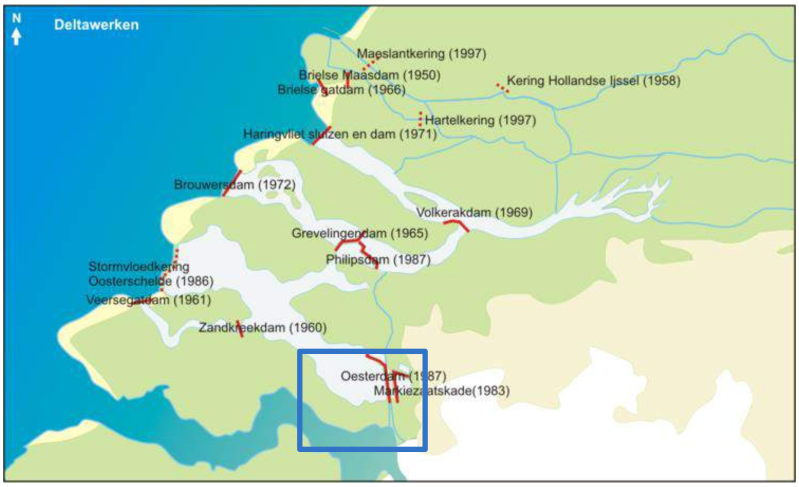
Changes since 1953

The Delta Works program have built new dams and barriers (see figure 5.10). The places where dykes were breached in the municipality of Reimerswaal were not protected by extra barriers, but the dykes have been strengthened (see chapter 2). Since 1953 there are more situations where dykes had to be recovered. The failure of the Veendijk in 2003 due to drought in Wilnis caused a gap of a number of metres, which was closed within a day. The Ringvaart was, however, as good as empty and the gap was only 1/20 of the size of the closure gaps during the great flood disaster in 1953 which made the rebuilding of the dyke much easier.

During the recovery in 1953 available resources from the Second World War were used, including the caissons. If flooding would take place in the present day, these caissons would have to be manufactured first, resulting in an increased recovery time if the same method was adopted as in 1953.

The dredging industry's techniques have developed very rapidly in the last 60 years. The current generation of dredging vessels has more power and a higher capacity than in 1953. As a result, it is likely that the closure of gaps by pumping sand, which failed in 1953, could now succeed. Also the increased shipping capacity makes it easy to carry out rock dumping. Determining factors are the accessibility of the breaches via road, water and the air. For these reasons it is expected that the repair of damage generally should take less time than 65 years ago.

Figure 5.10 New dams and barriers constructed under the Deltaplan



Impact of flooding elsewhere

With the occurrence of a flood it is very probable that more breaches will occur in Zeeland and along the Dutch coast. This can put pressure on the quantity of available plant and money. A (political) prioritisation will have to be made as to which breaches must be closed first. In this scenario it can be expected that the recovery time increases to 3 - 6 months. A recovery time greater than 9 months is considered as the extreme limit. An important starting point is that the dykes are closed again for the following storm season (October - April). During the storm the breaches are expected to grow further and the area must possibly be considered as lost.

Conclusion bandwidth expected recovery time breach locations

At the occurrence of a worst-case Westerschelde or Oosterschelde scenario it is expected on the basis of the above analysis that all breaches can be closed in 3 months.

5.3.2 Collective recovery by pumping out

The collective recovery by pumping out water depends on the availability of the existing pumping stations and emergency pumps. The protection of existing pumping stations is considered first.

Protection of existing pumping stations

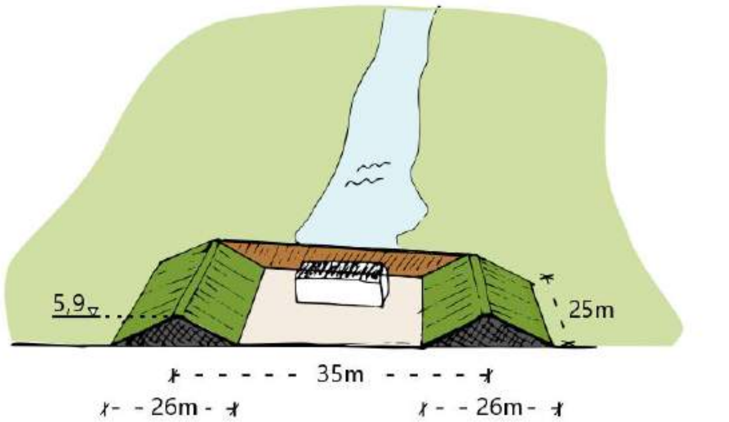
The protection of the existing pumping stations results in a decreasing recovery time of the area and thus a limitation of the indirect damage. In the following phase, for the determination of cost effectiveness, the costs of protection are set off against limitation of the (expected) damage. With the protection of existing pumping stations comparable measures for each pump can be taken. Therefore the protection has been studied on the basis of one pumping station: Waarde pumping station. On the basis of the costs of the measures developed for this pumping station it can be determined which investment is necessary for the protection of the pumping stations. The data for Waarde pumping station are as follows:

- capacity of pumping station: 148 m3/min;
- area of buildings and installations: 180 m2;
- number of inlets: 2;
- dimensions of integration: 35 m x 25 m.

Figure 5.11 Location of pumping station

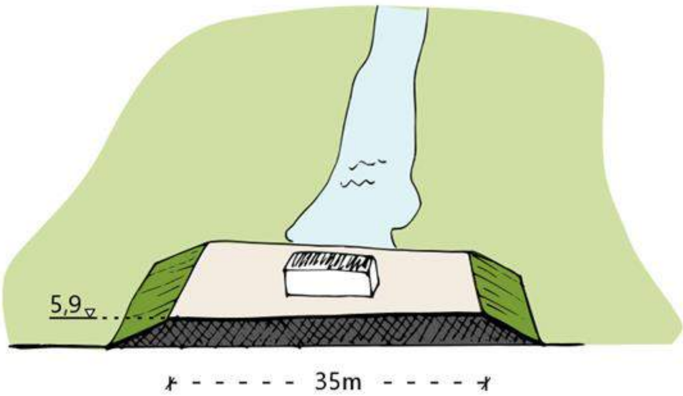
In the maximum dyke breach scenario the level of the water is 5.5 meters relative to the ground level at the place of the Waarde pumping station. The pumping station can be protected from water by means of a dyke. A wall is built at the place of the inlet. The dyke and wall become 5.9 meters high. Also the pump inlets are made closeable, so that no water can flow via that route to the inside. The assumption is that the pump inlets can open, after the gaps have been closed. The integration of the existing roads and the water barrier require extra attention.

Figure 5.12 Protection of pumping station with dyke/separation (cross-section and perspective)



Another, more radical option is to raise the level of the pumping station as a whole by 5.9 meters. Raising the level of the pumping station means in addition that the pumping station will have to be jacked up and adapted or re-built with at least the same specifications as for the raised structure. Also here the integration of the existing roads and the water barrier require extra attention.

Figure 5.13 Raising the pumping station



Sensitivity analysis for pumping out

The time needed to pump the water out of an area can be determined with a simple water balance calculation. The recovery time is dependent on the quantity of water in the area and the available pump capacity. The capacity of the discharge pumping units in Reimerswaal is in total 30.486 m3/hour:

1. De Moer discharge pumping station: 132 m^3/min;
2. J.A.M.P. van de Graaff discharge pumping station 36.1 m^3/min;
3. Waarde discharge pumping station: 148 m^3/min;
4. Joh. Glerum discharge pumping station: 192 m^3/min.

The company Van Heck supplies emergency pumps. These pumps were also deployed during the flooding in Somerset in England. The pump capacity varies between 270 and 9950 m^3/hour. Scheldestromen Water

Board has 4 emergency pumps with a capacity of 3,600 m^3/h. These run on diesel. For the determination of the recovery time, a pump capacity has been used from 1,000 m^3/hour to 15,000 m^3/hour.

Pumping time in the event of a dyke breach

With the Oosterschelde scenario for dyke ring 31 (all breach locations of the Oosterschelde fail) there will be around 145 million m^3 water in the case of non-flood proof regional barriers and 90 million m^3 in the case of flood proof regional barriers. At the maximum scenario for dyke ring 31 (all dyke breach locations of both the Oosterschelde and Westerschelde fail) there will be around 280 million m^3 flood water in the event of non-flood proof regional barriers and 245 million m3 in the case of flood proof regional barriers.

The calculated volumes for both scenarios are the volumes at maximum water depth (dike breach occurs at water level with an overrun frequency of 1/4,000). Due to the natural change from high tide to low tide a large part of this water will run out of the area in a natural way. The average low tide water level is around the NAP - 1.50 m and for high tide NAP + 1.50 m (waterberichtgeving.rws.nl (based on February 2019). To pump out the total amount of water, the starting point is a water level of NAP 0 m. By phasing the pumping-out operation in a smart way, the recovery time can be optimised. Table 5.2 shows the associated recovery times.

Table 5.2 Recovery time with pumping-out operations

Scenario	pump capacity [m^3/hour]	recovery time at average drop to NAP 0 m [weeks]
Volume at a water level of NAP 0.00 m [million m^3]		**16**
All emergency pumps of water board	14,400	7
all pumping stations reinstated	30,486	3
all emergency pumps and pumping stations	44,886	2

5.4 Summary and costs of measures

Continued functioning

The elaborated measures for individual and collective continued functioning have been summarised in table 5.3.

Table 5.3 Measures for collective and individual continued functioning

Measure	Spatial feasibility	Costs (order of magnitude) in EUR	Effect on damage
collective compartmentalisation for A58	integration of regional barriers and acquisition of soil majeure spatial challenge	37.2 million	A58 link is retained: strong limitation of chain effects on road traffic
protection of individual transformer: 1 local dyke; 2 local increase of height and replacement 3 local wall water barrier	Integration per design: 1 complex integration near railway line and national highway; 2 complex integration near railway line and national highway; 3 little integration	costs per design: 1 400,000 2 3,200,000 3 400,000	Electricity supply in the direction of Walcheren and Zuid-Beveland is maintained
alternative electricity supply COROP area: 1 hire of generators; 2 purchase of generators;	space allocation for generators necessary	costs for 3 months: 1 42.5 million 2 40 million	3 months no interruption of power supply outside Reimerswaal

Recovery

The elaborated measures for individual and collective recovery have been summarised in table 5.4. In the following phase the measures are combined in a package of "fast recovery" measures for all pumping stations and the whole electricity network. Via the pilot project for the A58 of Public Works and Water Management measures are introduced for recovery of the national highway.

Table 5.4 Collective and individual recovery

Measure	Spatial feasibility	Costs (order of magnitude) in EUR	Effect on damage
modular repair of transformer	no integration	500,000	quick start-up network
protection of Waarde pumping station: 1 local dyke; 2 local increase of height and replacement 3 modular repair.	Integration per design: 1 complex integration of roads and dyke; 2 complex integration of embankment and roads; 3 no integration necessary.	Costs per design: 1 300,000 2 700,000 3 100,000	Limitation of direct damage and acceleration of pumping-out time for area

6

COST EFFECTIVENESS OF PACKAGES OF MEASURES

This chapter determines the cost efficiency (effectiveness) of the following packages of measures.[1]

1 compartmentalisation - total;
2 compartmentalisation - north
3 protection of pumping stations;
4 protection of high-voltage distribution station (HSV)
5 raising the A58;
6 increasing the height of the Vlaketunnel tunnel protection dyke (kanteldijk).

A package of measures is cost-effective if the sum of the benefits (avoided damage) is greater than the costs[2]. This can be expressed in a cost/benefit ratio. A measure is cost-effective if:

$$\frac{\text{Benefits:}}{\text{Costs}} > 1$$

The benefits of the package of measures consist of a decrease in the annual expectation value (JVW) of the (direct + indirect) damage that occurs at the dyke breach scenarios relative to the situation without extra measures. Here it has been assumed that the packages of measures are effective: through implementation of the measures the damage can be prevented 100 %.

Costs and benefits seldom occur at the same moment. Taking into account a positive time preference, to make the benefits and costs mutually comparable, all amounts are calculated back to the valuation moment (2019). Here in accordance with the Cabinet standpoint a discount rate of 4.5 % is applied[3]. Furthermore the starting point has been perpetual annual benefits (avoided damage) and annual costs. The calculation of the annual costs is based on the method of equivalent annual costs, where the total life cycle costs have been converted to an average per year. In this a percentage of the investment costs has been taken for management and maintenance.

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1 The packages of measures 'compartmentalisation - North', 'raising A58' and 'increase in the height of tunnel protection dyke (kanteldijk) HVS' have been developed in the FRAMES project A58/National Highways of RWS. For additional information on these measures the reader is referred to the final report A58/National Highways. For the completeness of the pilot project the package of measuress are included in the analysis of the cost effectiveness.

2 In previous reports there has been reference to cost effectiveness. Cost effectiveness is the measure of the effectiveness of spending money. In other words, it is examined which measure has the lowest cost to achieve a particular objective. In this pilot project there is no previously defined (safety) objective for vital infrastructure. That is why cost effectiveness is used to weigh the benefits against the costs.

3 Ministry of Finance, 2015

6.1 Summary of direct and indirect damage

Table 6.1 and 6.2 give a summary of the direct and indirect damage to the electricity network and the A58.

Table 6.1 Direct damage to networks (amounts have been rounded off in EUR)

Network	Non-flood proof regional barriers (VNK2)		Flood proof regional barriers (PZ)	
	Maximum Oosterschelde scenario	Maximum Ooster- and Westerschelde scenario	Maximum Oosterschelde scenario	Maximum Ooster- and Westerschelde scenario
electricity	6,700,000	6,700,000	6,200,000	6,700,000
A58	26,300,000	29,200,000	-	8,100,000

Table 6.2 Indirect damage to electricity network and A58

Electricity network		
Duration of outage/scenario	**Damage to economic sectors [EUR/ day]**	**Damage to households [EUR/ day]**
scenario 1 (1 day)	6,660,000	464,399
scenario 2 (14 days)	2,660.000	156,266
scenario 3 (90 days)	2,760,000	29,756

A58	Damage to households [EUR/ day]
cancelled trips, diversions, congestion	4,271,000

The damage amounts in table 6.2 still take no account of behavioral changes during and after a flood. In the case of traffic congestion people will decide to travel outside peak times or to choose another route. Also after some time the residents of Reimerswaal will go back to their work or go work elsewhere, so that the absenteeism costs decrease. In the determination of the total indirect damage of the A58 it is therefore assumed that the damage decreases after 2 à 3 weeks to 60 % of the estimated amount.

Also the indirect damage due to damage of the electricity network will decrease in time, depending on the recuperative power of businesses[1]. For households the declining unit price in time is already taken into account in the conjoint analysis method. This is not the case in the determination of damage caused by power failure to economic sectors. In the analysis it is assumed that 4 weeks after the dyke breaches the largest part of the companies outside Reimerswaal that are affected by the power outage have found a way to restore the production level. In other words, after 4 weeks there is no further indirect damage outside Reimerswaal due to a power outage. Also a sensitivity analysis will be carried out to study the influence of this variable on the conclusions.

[1] This variable is very difficult to estimate and wholly dependent on the extent to which companies themselves have access to alternatives.

6.2 Recovery times and costs effectiveness measures

Starting points in baseline scenario

Starting points:

- recovery time for closing breach locations: 3 months;
- recovery time for pumping the water out of the area: only emergency pumps of the Water Board are available. The recovery time is 7 weeks;
- with non-flood proof regional barriers the electricity network and the A58 fail in both the combined Oosterschelde and the combined Westerschelde- and Oosterschelde scenario;
- in the case of flood proof regional barriers, the electricity network [1]and the A58 only fail with the combined Westerschelde- and Oosterschelde scenario. With the combined Oosterschelde scenario both networks are protected from damage and outages;
- with non-flood proof regional barriers the tunnel protection dyke (kanteldijk) of the Vlaketunnel does not comply and undergoes this damage;
- in the case of flood proof regional barriers, the tunnel protection dyke (kanteldijk) does comply and the Vlaktetunnel remains protected;
- recovery time of A58 if Vlaketunnel is flooded: 4 months;
- recovery time of A58 if Vlaketunnel does not become flooded: 2 weeks (no major physical damage occurs to the rest of the network);
- recovery time of electricity network in the event of flooding: 52 weeks (but after 4 weeks no further indirect damage occurs outside Reimerswaal, see paragraph 6.1).

Starting points for packages of measures

Starting points:

- at compartmentalisation - no further damage occurs to the networks;
- at compartmentalisation - no further damage to the networks occurs with the combined Oosterschelde scenario. With the combined Westerschelde- and Oosterschelde scenario damage still occurs;
- with protection of pumping stations the starting point is the pump capacity of all emergency pumps of the Water board and all existing pumping stations. The recovery time for pumping the water out of the area is reduced by 5 weeks;
- with the protection of high-voltage distribution stations no further damage occurs to the electricity network;
- when the A58 is raised no further damage occurs to the A58;
- when the tunnel protection dyke (kanteldijk) is raised no further damage occurs to the Vlaketunnel and the recovery time decreases from 4 months to 2 weeks (but indirect damage can occur since the A58 can still be affected by flooding).

Cost-effective measures with flood proof and non-flood proof regional barriers

The cost effectiveness of the package of measures is determined on the basis of non-flood proof or flood proof regional barriers. In table 6.3 the recovery time and the resulting indirect damage has been shown per scenario on the basis of non-flood proof regional barriers. In table 6.4 the cost effectiveness of each package of measures is determined (non-flood proof regional barriers). In table 6.5 the recovery time and the resulting indirect damage per scenario has been shown on the basis of flood proof regional barriers. In table 6.6 then the cost effectiveness of each package of measures is determined (flood proof regional barriers).

[1] In the analysis it is assumed that the new station has not been built at a higher level (or that the raised construction is not adequate), so it can be investigated whether protecting the HVS (one of the packages of measures) is a cost-effective measure.

Table 6.3 Recovery times and indirect damage with non-flood proof regional barriers

Scenario	Baseline		Compartmentalisati on - total;		Compartmentalisati on - north		Protection of pumping stations		Protection of high-voltage distribution station (HSV)		Raising the A58		Increasing the height of the Vlaketunnel tunnel protection dyke (kanteldijk).	
	OS	OSWS	OS	OSWS	OS	OSWS	OS	OSWS	OS	OSWS	OS	OSWS	OS	OSWS
recovery time at breach locations [weeks]	12	12	12	12	12	12	12	12	12	12	12	12	12	12
recovery time for pumping stations [weeks]	7	7					2	2	7	7	7	7	7	7
recovery time for electricity [weeks]	52	52					52	52	0	0	52	52	52	52
recovery time A58 [weeks]	16	16					16	16	16	16	0	0	2	2
Total recovery time for electricity [weeks]*	4	4	0	0	0	4	4	4	0	0	4	4	4	4
Total recovery time A58 [weeks]	35	35	0	0	0	12	30	30	35	35	0	0	21	21
Total indirect damage electricity [EUR]	83,700,000	83,700,000	-	-	-	83,700,000	83,700,000	83,700,000	-	-	83,700,000	83,700,000	83,700,000	83,700,000
Total indirect damage A58 [EUR]	627,800,000	627,800,000	-	-	-	215,300,000	538,100,000	538,100,000	627,800,000	627,800,000	-	-	376,700,000	376,700,000

* the starting point for indirect damage to electricity is that after 4 weeks no further damage occurs outside dyke ring 31

Table 6.4 Cost-effective package of measures with non-flood proof regional barriers (discount rate 4.5%)

Scenario	Baseline		Compartmentalisati on - total;		Compartmentalisati on - north		Protection of pumping stations		Protection of high-voltage distribution station (HSV)		Raising the A58		Increasing the height of the Vlaketunnel tunnel protection dyke (kanteldijk).	
	OS	OSWS	OS	OSWS	OS	OSWS	OS	OSWS	OS	OSWS	OS	OSWS	OS	OSWS
Total direct damage [EUR]	33,000,000	35,900,000	-	-			33,000,000	35,900,000	26,300,000	29,200,000	6,700,000	6,700,000	13,000,000	15,900,000
Total indirect damage [EUR]	711,500,000	711,500,000	-	-	-	299,000,000	621,800,000	621,800,000	627,800,000	627,800,000	83,700,000	83,700,000	460,400,000	460,400,000
annual risk [EUR]		250,000		-		600,000		220,000		220,000		30,000		160,000
CW_benefit [EUR]				5,600,000		4,200,000		700,000		700,000		4,900,000		2,000,000
investment cost of measure [EUR]				37,200,000		7,800,000		1,200,000		400,000		249,500,000		6,200,000
annual maintenance [%]				3.00%		3.00%		5.00%		3.00%		/		/
life cycle measure [year]				50		50		30		50		/		/
CW_measure [EUR}				43,100,000		9,000,000		1,700,000		500,000		249,500,000		6,200,000
Cost/benefit ratio				0.13		0.47		0.41		1.40		0.02		0.32

Table 6.5 Recovery times and indirect damage in the case of flood proof regional barriers

Recovery times	**Baseline**		**Compartmentalisation - total;**		**Compartmentalisation - north**	**Protection of pumping stations**		**Protection of high-voltage distribution station (HSV)**		**Raising the A58**		**Increasing the height of the Vlaketunnel tunnel protection dyke (kanteldijk)****
Scenario	**OS**	**OSWS**	**OS**	**OSWS**		**OS**	**OSWS**	**OS**	**OSWS**	**OS**	**OSWS**	
recovery time at breach locations [weeks]	12	12	12	12		12	12	12	12	12	12	
recovery time for pumping stations [weeks]	7	7				2	2	7	7	7	7	
recovery time for electricity [weeks]	52	52				52	52	52	52	52	52	
recovery time A58 [weeks]	2	2			N/A	2	2	2	2	0	0	N/A
total recovery time for electricity [weeks] *	4	4	0	0		4	4	0	0	4	4	
total recovery time A58 [weeks]	0	21	0	0		0	16	0	21	0	0	
Total indirect damage electricity [EUR]	-	83,700,000	-	-		-	83,700,000	-	-	-	83,700,000	
Total indirect damage A58 [EUR]	-	376,700,000	-	-		-	287,000,000	-	376,700,000	-	-	

* the starting point for indirect damage to electricity is that after 4 weeks no further damage occurs outside dyke ring 31

** in the case of flood proof regional barriers the package of measures compartmentalisation - North or increase in the height of dykes for tunnel protection (kanteldijken) is no benefit, since these offer no additional protection to the electricity network or the A58

Table 6.6 Cost-effective package of measures with flood proof regional barriers (discount rate 4.5 %)

Scenario	Baseline		Compartmentalisation - total;		Compartmentalisation - North*	Protection of pumping stations		Protection of high-voltage distribution station (HSV)		Raising the A58		Increasing the height of the tunnel protection dyke (kanteldijk)*
	OS	OSWS	OS	OSWS		OS	OSWS	OS	OSWS	OS	OSWS	
Total direct damage [EUR]	6,200,000	14,800,000	-	-		6,200,000	14,800,000	-	8,100,000	6,200,000	6,700,000	
Total indirect damage [EUR]	-	460,400,000	-	-		-	370,700,000	-	376,700,000	-	83,700,000	
annual risk [EUR]	100,000		-			80,000		80,000		20,000		
CW_benefit [EUR]			2,200,000			400,000		400,000		1,800,000		
investment cost of measure [EUR]			37,200,000		N/A	1,200,000		400,000		249,500,000		N/A
annual maintenance [%]			3.00%			5.00%		3.00%		/		
life cycle measure [year]			50			30		50		/		
CW_measure [EUR}			43,100,000			1,700,000		500,000		249,500,000		
Cost/benefit ratio			0.05			0.24		0.80		0.01		

* in the case of flood proof regional barriers the package of measures compartmentalisation - North or increasing the level of tunnel protection dykes is of no benefit, since these offer no additional protection to the electricity network or the A58

6.3 Results of cost effectiveness

Table 6.7 shows the benefits/risks of the different packages of measures according to the employed starting points. This shows that the results depend on the starting points on the permanence of the regional barriers. The measure 'protection of high-voltage distribution station (HSV)' seems to be a no-regret measure, with a cost/benefit ratio greater than 1 in case of flood proof regional barriers. In the case of flood proof regional barriers the measure 'protection of high-voltage distribution station (HSV)' approaches the threshold value for cost effectiveness of 1. The other packages of measures are found on the basis of the analysis not to be cost effective: the costs are in all cases (much) higher than the benefits.

Table 6.7 Cost-benefit ratios of packages of measures

Cost-benefit ratios	Non-flood proof regional barriers (VNK2 scenarios)	Flood proof regional barriers (scenarios for Province of Zeeland)
compartmentalisation - total	0.13	0.05
compartmentalisation - North	0.47	N/A
protection of pumping stations	0.41	0.24
protection of high-voltage distribution station (HSV)	1.40	0.80
raising the A58	0.02	0.01
increasing the height of the tunnel protection dyke (kanteldijk).	0.32	N/A

Sensitivity analysis

The above results are greatly dependent on the adopted starting points. An important uncertain factor is, for example, the duration of the indirect damage for businesses outside Reimerswaal. In the analysis above a period of 4 weeks has been adopted. To check the robustness of the conclusions a sensitivity analysis has been carried out. The following starting points are applicable:

- duration of indirect damage to electricity outside dyke ring 31: 4 weeks, 8 weeks, 12 weeks;
- duration of recovery time for pumping out area: 10 weeks, 15 weeks, 20 weeks;
- investment cost of measures: 1x or 2x as expensive.

Table 6.8 shows the minimum and maximum cost-benefit ratios obtained in the sensitivity analysis. The cost-benefit ratios of all measures except "protection of high-voltage distribution station" are, among other things, not favorable. The cost-benefit ratio of measure "Protection of high-voltage distribution station" varies between 0.78 and 3,.60. This underlines the 'no regret' character of the measure 'Protection of high-voltage distribution station'.

Table 6.8 Cost-benefit ratios for packages of measures with sensitivity analysis

Cost-benefit ratios	**Non-flood proof regional barriers (VNK2 scenarios)**	**Flood proof regional barriers (scenarios for Province of Zeeland)**
compartmentalisation - total	0.07 - 0.19	0.06 - 0.10
compartmentalisation - North	0.26 - 0.69	N/A
protection of pumping stations	0.21 - 0.41	0.12 - 0.24
protection of high-voltage distribution station (HSV)	0.78 - 3.60	0.80 - 2.60
raising the A58	0.01 - 0.03	0.01 - 0.01
increasing the height of the tunnel protection dyke (kanteldijk).	0.16 - 0.32	N/A

7

CONCLUSION

7.1 Vulnerability analysis

The vulnerability analysis shows that Reimerswaal has an important connecting function between West-Brabant and Walcheren. The actual vulnerability of the networks is dependent on the above-ground objects in a network. Many networks are situated underground (for example the main drinking water pipe has no aboveground objects) and are thus less vulnerable. There is also redundancy present: if the A58 is flooded, there is an alternative route via for example the Westerschelde tunnel. The analysis shows that the A58, the railway line and electricity are the most vulnerable and have the largest chain effects.

The indirect damage due to chain effects is much larger than the direct (material) damage to networks. For an estimate of the chain effects a very good understanding of the functioning of the networks is necessary.

The vulnerability analysis also brings out the influence of the regional barriers. Non-flood proof barriers generally give a more extreme flooding profile in Reimerswaal. On the basis of the maps of Scheldestromen Water Board, flooding seems to pose few risks to vital infrastructure in the municipality.

7.2 Measures and packages of measures.

Within the action perspectives various collective and individual measures have been determined. The different measures indicate the possibilities for protection for particularly aboveground objects. Because large-scale networks are involved, implementing measures is expensive, certainly for collective measures for continued functioning. These collective measures are expensive and difficult to integrate in the physical infrastructure. On the other hand network managers are not readily inclined to take individual measures from a flooding perspective. The support base for measures is often limited: in communication with network managers it is important to outline the context of the research and the challenge involved.

7.3 Cost-effectiveness

On the basis of the analysis of the benefits and costs of the packages of measures the following conclusions can be drawn:

- the protection of the high-voltage distribution station at Bath is a cost-effective measure. For the other measures the cost-benefit ratio is unfavorable;
- the connecting function of the networks is determining for the potential indirect damage. The recovery time is very significant for the actual level of the damage;
- including chain effects in the damage determination of failure of vital infrastructure is essential in the policy consideration for taking measures;
- with current return periods and safety standards of the primary barriers most measures do not seem cost-effective;
- it is important to realise that the current statistic for the failure probability of the primary barriers is based on the climate of the past: return periods can change in the future due to accelerated sea level

rise. As a result measures that are not cost-effective now can become so in the longer term (autonomously).

7.4 Recommendations

Research

- further studies of the mechanisms which lead to indirect damage give more insight into the severity of the chain effects. Existing methods for quantifying the indirect (economic) damage have been designed and tested for short-term failure and not for long-term failure due to a disruptive event such as (multiple) dyke breach;
- review of flood stability of regional barriers. Impact and consequence of dyke breach is strongly dependent on the flood stability of regional barriers;
- share results of the pilot studies at national and international level. Internationally the high safety standards are not common and measures for multilayer safety are likely to be cost-effective earlier.

Policy

- include indirect damage and vital functions in damage determination and risk considerations at standardisation of dykes;
- in the case of flood proof regional barriers and dyke gaps a part of the vital infrastructure is protected and the damage profile is lower in the event of flooding. From the perspective of vital infrastructure the upkeep and maintenance of the regional barriers has added value;
- link measures in the case of investments (new build or replacement) of utility owners and network operators. The new high-voltage supply distribution station in Bath is a good example of this: it has been built at a higher level by TenneT. The Province of Zeeland can play a (pro-) active role in putting measures on the agenda and detecting opportunities for linking them to other measures. It is reported that a new high-voltage station is soon to be built in Schouwen-Duiveland. For the location choice and construction level of the station it has been recommended to consider flood risks.

Implementation

For the present request for an available budget for investments (EUR 1,000,000.00) the advice can be linked with planned investments more widely in the Province of Zeeland (for example, planned high-voltage distribution system in Schouwen-Duiveland). The first step is therefore the execution of an inventory of investments by network and then a feasibility study into promising measures that are linked to the anticipated investments.

Annex(es)

ANNEX: SOURCES OF NETWORK DATA

Flooding scenarios

- breach locations: LIWO;
- maximum flood scenarios: LIWO, grid size 100 x 100 m.

Pluvial flooding by heavy precipitation

- pluvial flooding maps of return periods T10, T25, T50, T100: PWO Scheldestromen Water Board, cell size 5 x 5.

Gas

- gas transmission map GTS 2015: Gasunie, received via University of Applied Sciences Zeeland.

Electricity

- main distribution stations: Arcgis online service: hoogspanningsnet_stations_Benelux_052016_v5;
- high-voltage grid: Arcgis online service: hoogspanningsnet_Benelux_052016_v5;
- switching stations: received via University of Applied Sciences Zeeland in figure, not in shapefile.

Waste water and sewage

- sewage chain (sewage treatment plant, sewage pumping stations, valves and waste water transport lines): http://scheldestromen.maps.arcgis.com/apps/webappviewer/index.html?id=69df5948a17946afbcb0122df892ad7f.

Pumping stations

- location discharge and supply pumping stations, and pumping stations for lowering the water level received via Scheldestromen Water Board (contact person: Janna Schoonakker).

Roads and motorways

- national highways: Arcgis online service: hoogspanningsnet_Benelux_052016_v5; National Highways Firefly;
- engineering structures: Self-drawn on the basis of a Google Streetview.

Railway lines

- railway line: ProRail via Open Source WFS server: https://mapservices.prorail.nl/ArcGIS/rest/services.

Data and telecom

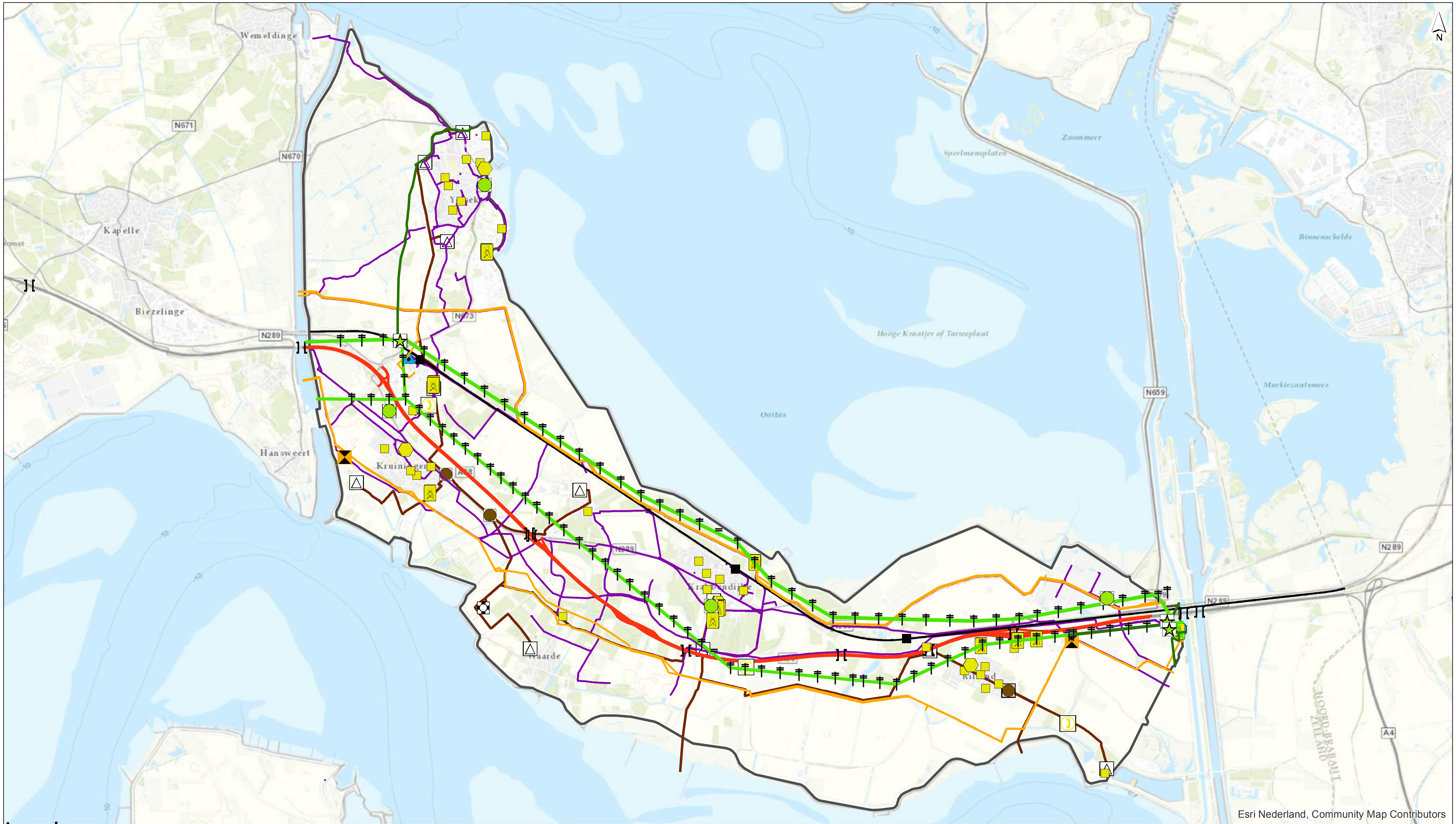
- district cabinets and street cabinets: HZ; Source of HZ: Robbin Flikkema https://vvdsl.robinflikkema.nl/;
- GSM, UMTS, LTE masts: HZ; Source of HZ: http://www.antenneregister.nl/Html5Viewer Antenneregister/Index.html?viewer=antenneregister;
- C2000 masts: HZ; Source of HZ: Patrice Troost of the VRZ.

Other cables and lines

- pipeline network: HZ; Source of HZ: Safety region Zeeland (contact person Patrice Troost);
- drinking water components HZ; Source of HZ: Safety region Zeeland (contact person Patrice Troost).

II

ANNEX: BASIC MAP



Legenda

Dijkring
- 31

Telecom
- C2000
- Wijkkasten
- Straatkasten
- Zendmasten

Afvalwaterketen
- Afsluiters
- RWZI
- rioolgemalen
- Leidingen

Drink- en proceswater
- Industriewater Prod.
- Pomp

Bluswaterleidingen
- d >150 mm

Gas
- Gts Assets
- Gasleiding

Spoorbaan

- Stations

Infrastructuur
- A58
- Kunstwerken

Elektriciteit
- Hoofdverdeelstation
- Masten
- Schakelstation

- Grondkabels
- Luchtlijnen

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Vitale Infrastructuur Reimerswaal

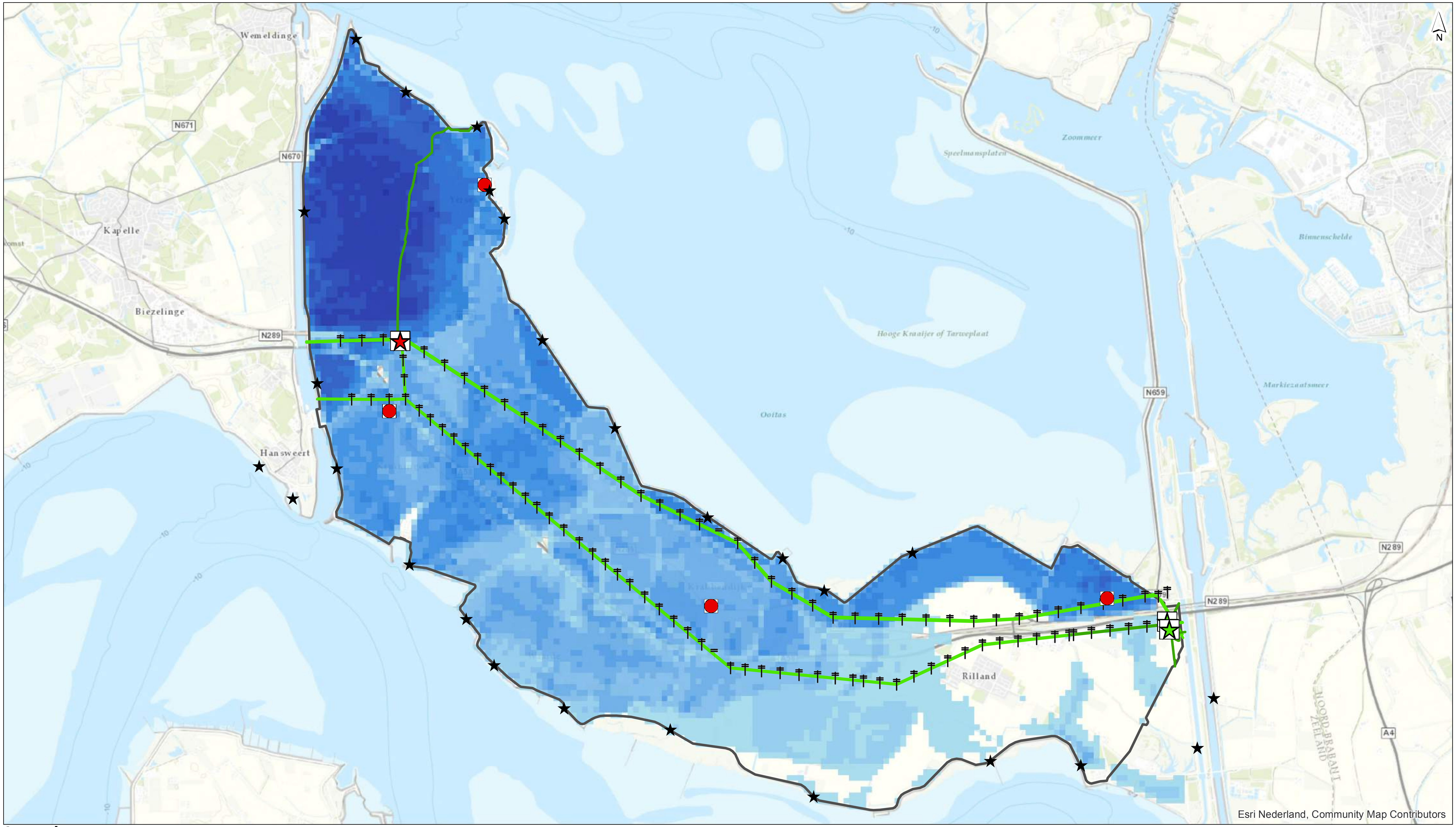
Vitale infrastructuur

client: Provincie Zeeland
project: Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code: 105918

Witteveen + Bos

III

ANNEX: RESULTS OF MAXIMUM OOSTERSCHELDE SCENARIO, NON-FLOOD PROOF REGIONAL BARRIERS



Legenda

Dijkring
- 31
- ★ Breslocaties

waterdiepte (m)
- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Elektriciteit
- Hoofdverdeelstation, geen schade
- Hoofdverdeelstation, schade
- Masten
- Schakelstation geen schade
- Grondkabels geen schade
- Luchtlijnen, geen schade

drawn: ir. I.M. van den Brink
verified: ir. W.R. Debucquoy
approved:
version: 1
date: 24-07-2018
drawing no: 0

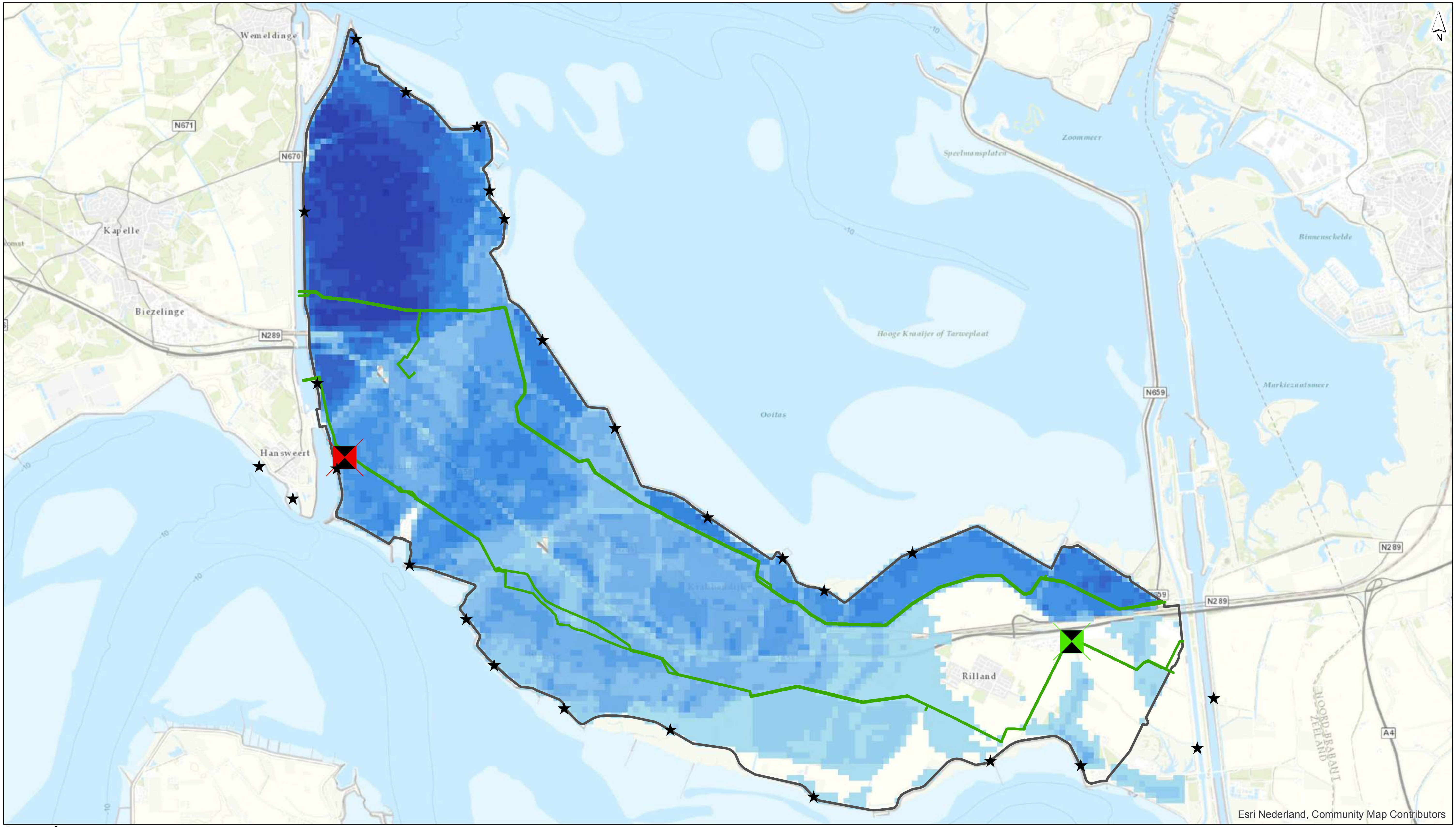
page size: A3 landscape
scale: 1:64360
0 500 1000 1500 2000 2500 m

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max scenario Oosterschelde Netwerk elektriciteit

client: Provincie Zeeland
project: Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code: 105918

Witteveen + Bos



Legenda

Dijkring

31

★ Breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

GTS Assets

geen schade

schade

Gasleiding

geen schade

drawn:	ir. I.M. van den Brink
verified:	ir. W.R. Debucquoy
approved:	
version:	1
date:	24-07-2018
drawing no:	0
page size:	A3 landscape
scale:	1:64360

0 500 1000 1500 2000 2500 m

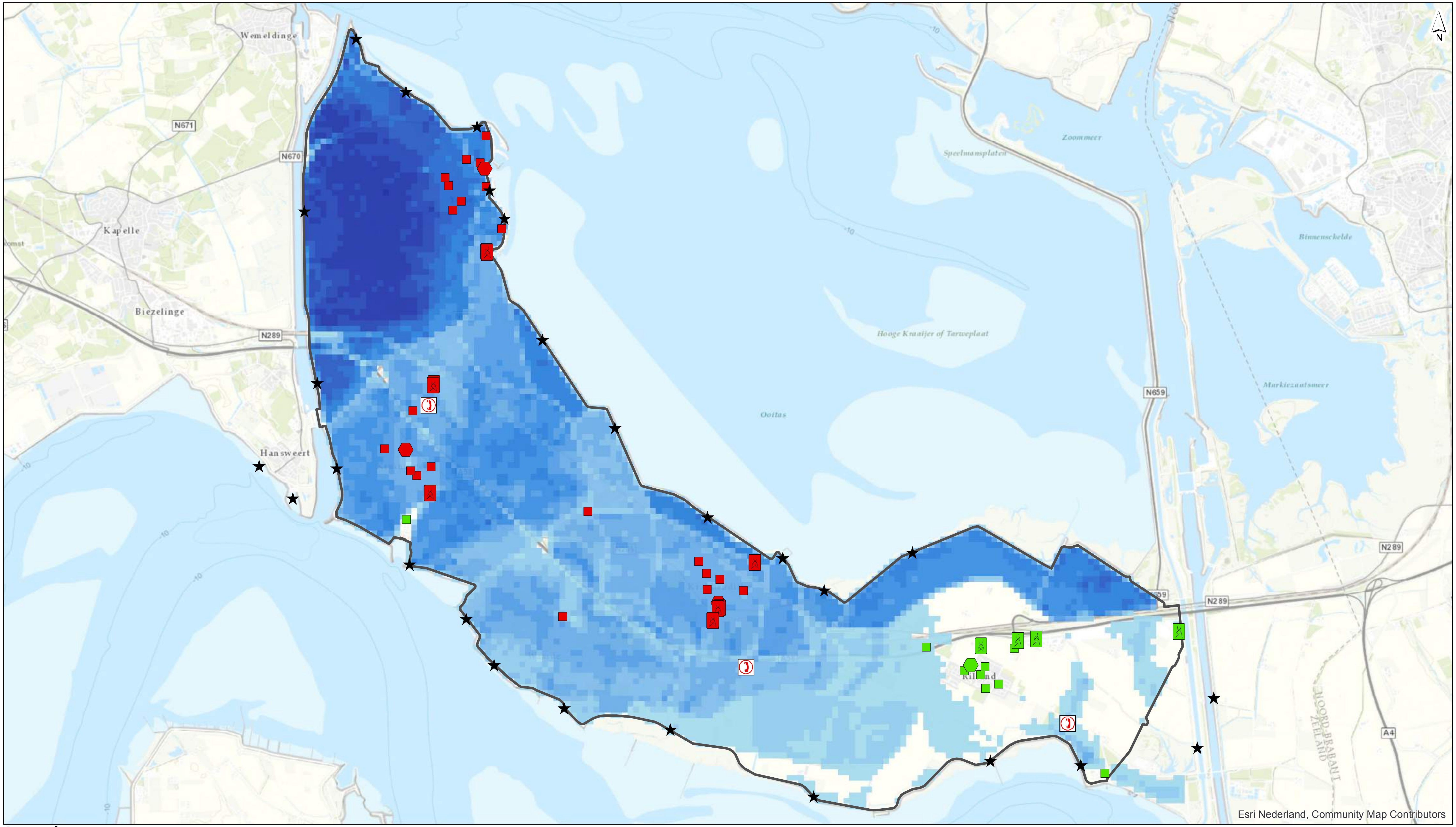
Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max scenario Oosterschelde

Netwerk gas

client:	Provincie Zeeland
project:	Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code:	105918

Witteveen + Bos



Legenda

Dijkring

31

★ Breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Telecom

C2000

- schade

Wijkkasten

- geen schade
- schade

Straatkasten

- geen schade
- schade

Zendmasten

- geen schade
- schade

drawn: ir. I.M. van den Brink
verified: ir. W.R. Debucquoy
approved:
version: 1
date: 24-07-2018
drawing no: 0

page size: A3 landscape
scale: 1:64360

0 500 1000 1500 2000 2500 m

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max scenario Oosterschelde
Netwerk telecom

client: Provincie Zeeland
project: Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code: 105918

Witteveen + Bos

Legenda

Dijkring

31

★ Breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Infrastructuur

- niet doorwaadbaar
- doorwaadbaar

][Kunstwerken

drawn: ir. I.M. van den Brink
verified: ir. W.R. Debucquoy
approved:
version: 1
date: 24-07-2018
drawing no: 0

page size: A3 landscape
scale: 1:64360

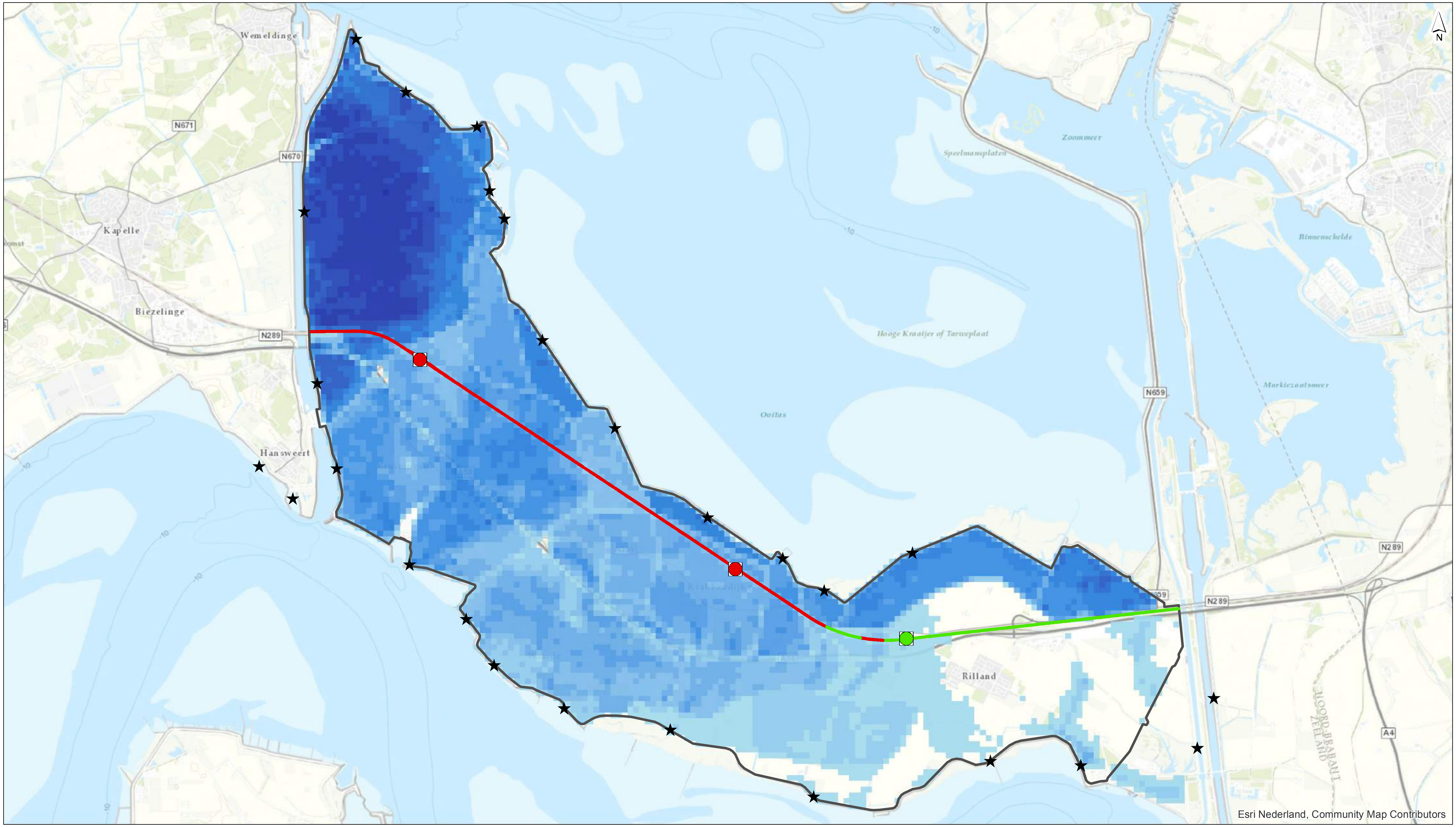
0 500 1000 1500 2000 2500 m

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max scenario Oosterschelde
Netwerk A58

client: Provincie Zeeland
project: Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code: 105918

Witteveen + Bos



Legenda

Dijkring

- 31
- ★ Breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Spoorbaan

- geen schade
- mogelijk schade

Stations

- geen schade
- mogelijk schade

drawn: ir. I.M. van den Brink
verified: ir. W.R. Debucquoy
approved:
version: 1
date: 24-07-2018
drawing no: 0

page size: A3 landscape
scale: 1:64360

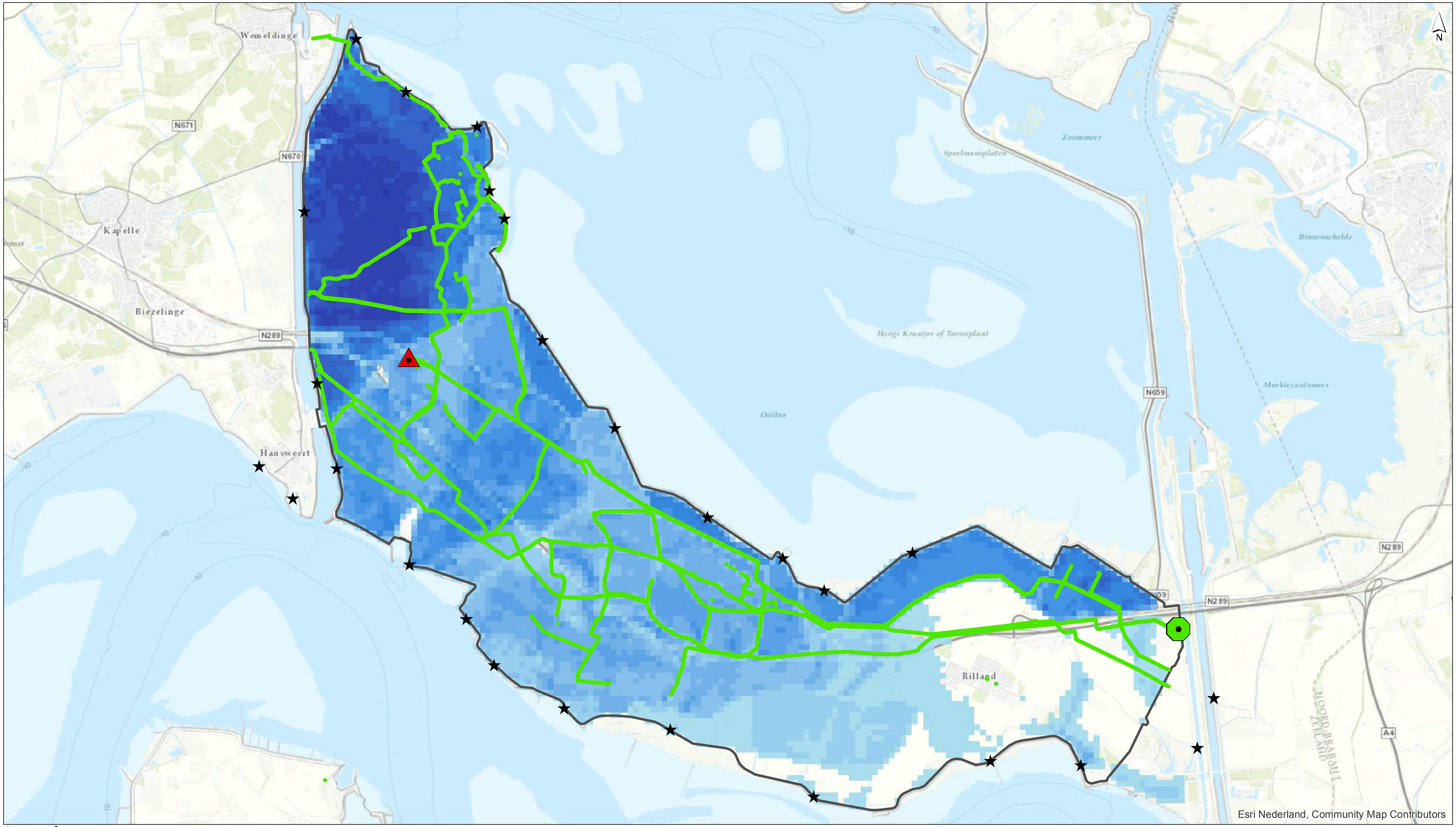
0 500 1000 1500 2000 2500 m

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max scenario Oosterschelde
Netwerk spoorlijn

client: Provincie Zeeland
project: Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code: 105918

Witteveen + Bos



Legenda

Dijkring

31

Breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Drink- en proceswater

- Industriewater Prod. - schade
- Pomp - geen schade

Bluswaterleidingen

- d > 150 mm - geen schade

drawn: ir. I.M. van den Brink
verified: ir. W.R. Debucquoy
approved:
version: 1
date: 24-07-2018
drawing no: 0

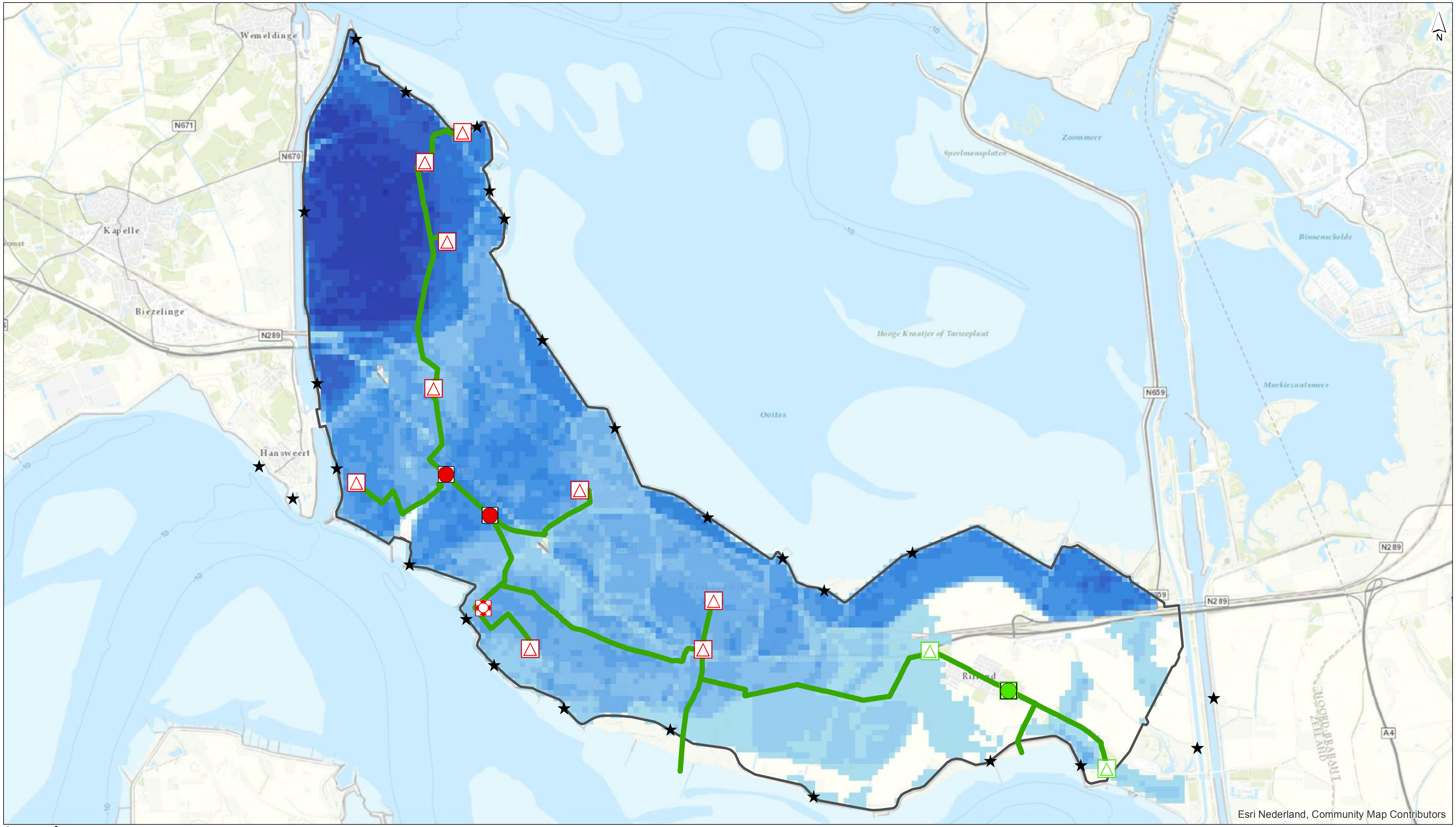
page size: A3 landscape
scale: 1:64360
0 500 1000 1500 2000 2500 m

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max scenario Oosterschelde
Netwerk drink- en proceswater

client: Provincie Zeeland
project: Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code: 105918

Witteveen + Bos



Legenda

Dijkring

31

Breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Afvalwaterketen

Afsluiter

- geen schade
- schade

RWZI

- schade

rioolgemalen

- geen schade
- schade

Leidingen

- geen schade

drawn: ir. I.M. van den Brink
verified: ir. W.R. Debucquoy
approved:
version: 1
date: 24-07-2018
drawing no: 0

page size: A3 landscape
scale: 1:64360

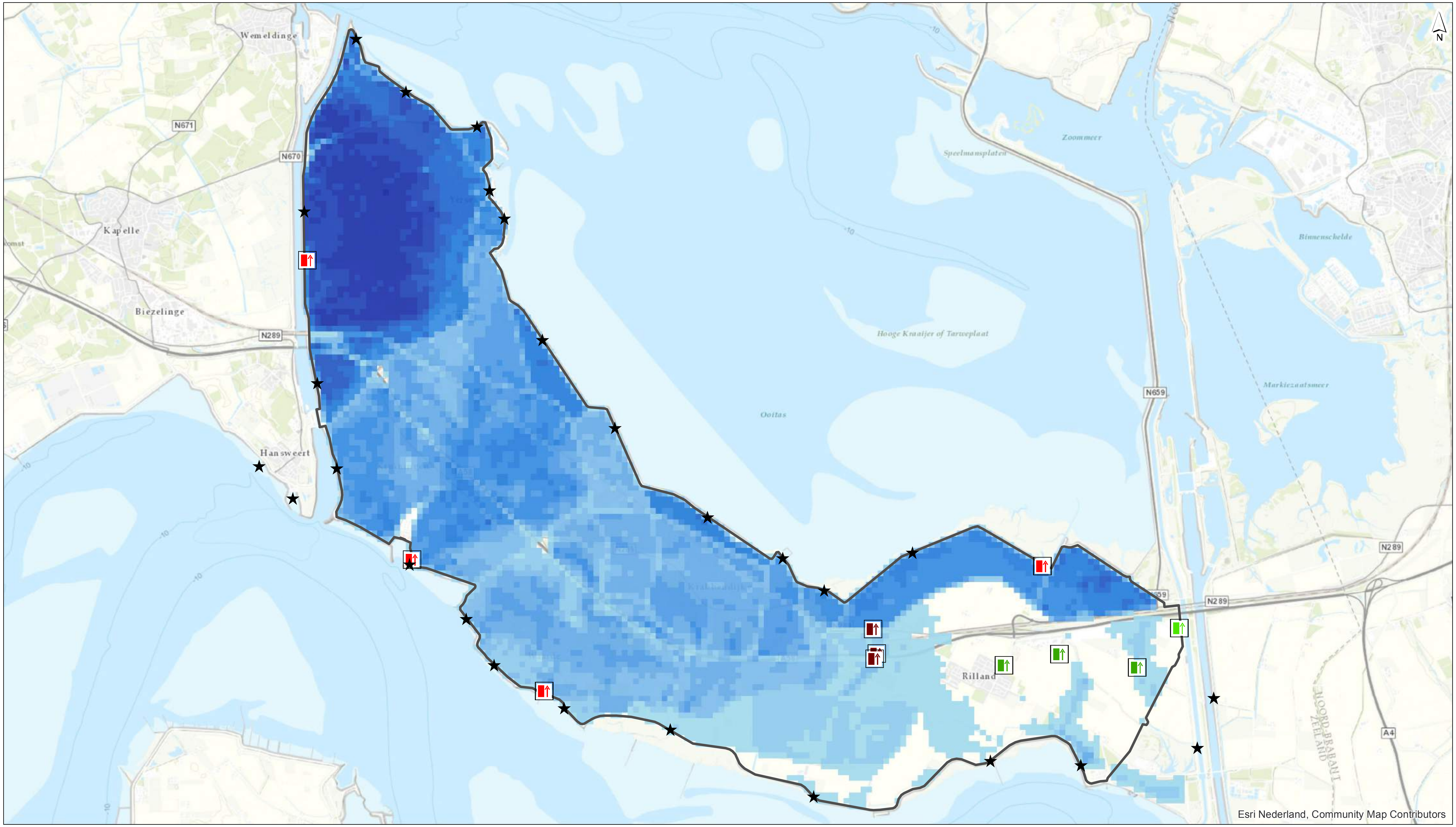
0 500 1000 1500 2000 2500 m

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max scenario Oosterschelde
Netwerk afvalwaterketen

client: Provincie Zeeland
project: Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code: 105918

Witteveen + Bos



Legenda

Dijkring

31

★ Breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Waterbeheer

- aanvoer - geen schade
- afvoer - schade
- onderbemaling - schade
- onderbemaling - geen schade

drawn: ir. I.M. van den Brink
verified: ir. W.R. Debucquoy
approved:
version: 1
date: 24-07-2018
drawing no: 0

page size: A3 landscape
scale: 1:64360
0 500 1000 1500 2000 2500 m

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max scenario Oosterschelde

Netwerk waterbeheer

client: Provincie Zeeland
project: Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code: 105918

Witteveen + Bos

IV

ANNEX: RESULTS OF MAXIMUM WESTERSCHELDE AND OOSTERSCHELDE SCENARIO, NON-FLOOD PROOF REGIONAL BARRIERS

Legenda

Dijkring

31

★ Breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Elektriciteit

- Hoofdverdeelstation, geen schade
- Hoofdverdeelstation, schade
- Masten
- Station, geen schade
- Grondkabels geen schade
- Luchtlijnen, geen schade

drawn: ir. I.M. van den Brink
verified: ir. W.R. Debucquoy
approved:
version: 1
date: 24-07-2018
drawing no: 0

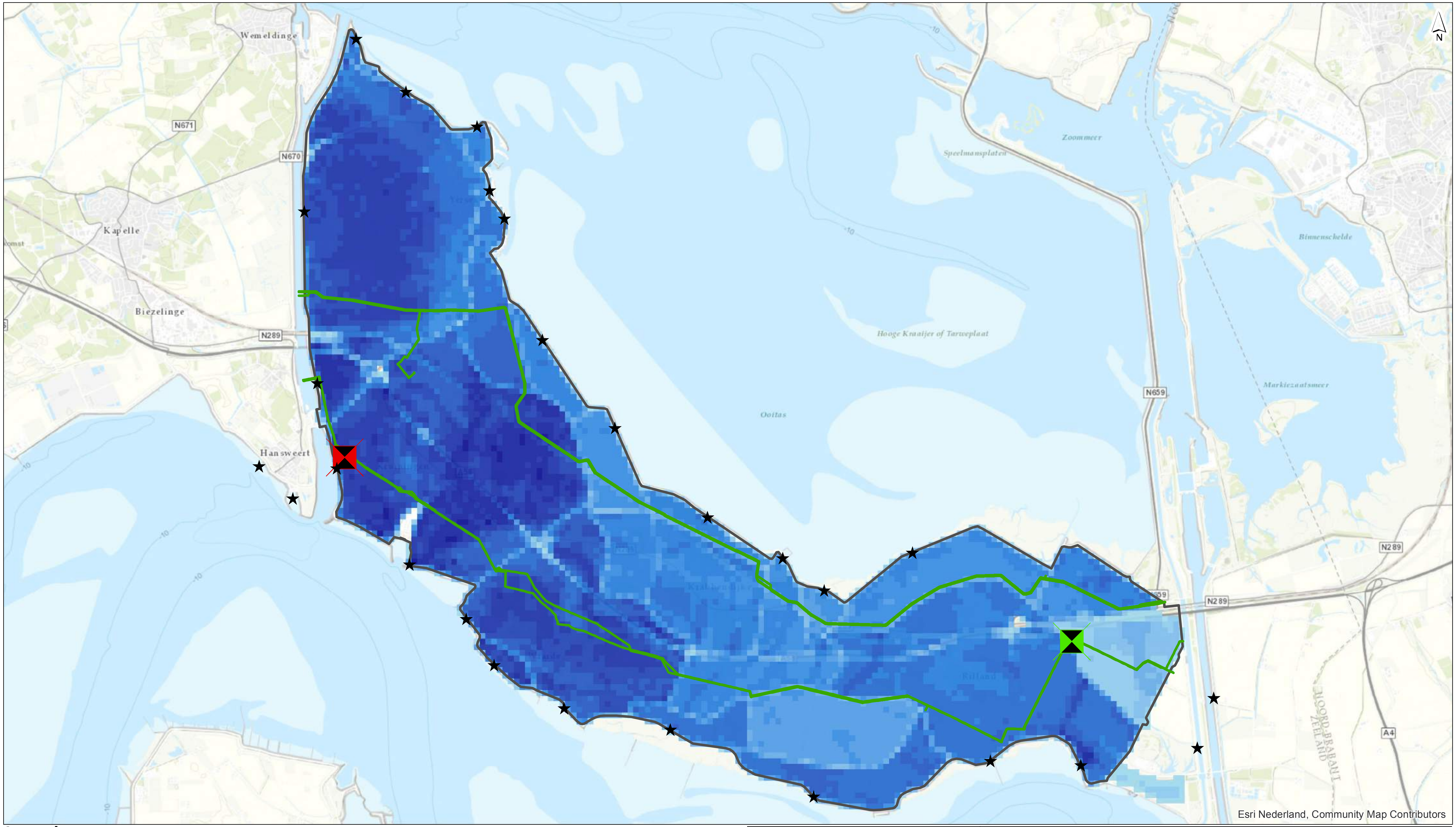
page size: A3 landscape
scale: 1:64360
0 500 1000 1500 2000 2500 m

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max scenario Oosterschelde en Westerschelde
Netwerk Elektriciteit

client: Provincie Zeeland
project: Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code: 105918

Witteveen + Bos



Legenda

Dijkring

31

★ Breslocaties

waterdiepte (m)

0	3.0 - 3.5
0 - 0.5	3.5 - 4
0.5 - 1	4.0 - 4.5
1.0 - 1.5	4.5 - 5
1.5 - 2	5.0 - 5.5
2.0 - 2.5	5.5 - 6
2.5 - 3	6.0 - 6.5

schade

Gasleiding

geen schade

GTS Assets

geen schade

drawn: ir. I.M. van den Brink
verified: ir. W.R. Debucquoy
approved:
version: 1
date: 24-07-2018
drawing no: 0

page size: A3 landscape
scale: 1:64360

0 500 1000 1500 2000 2500 m

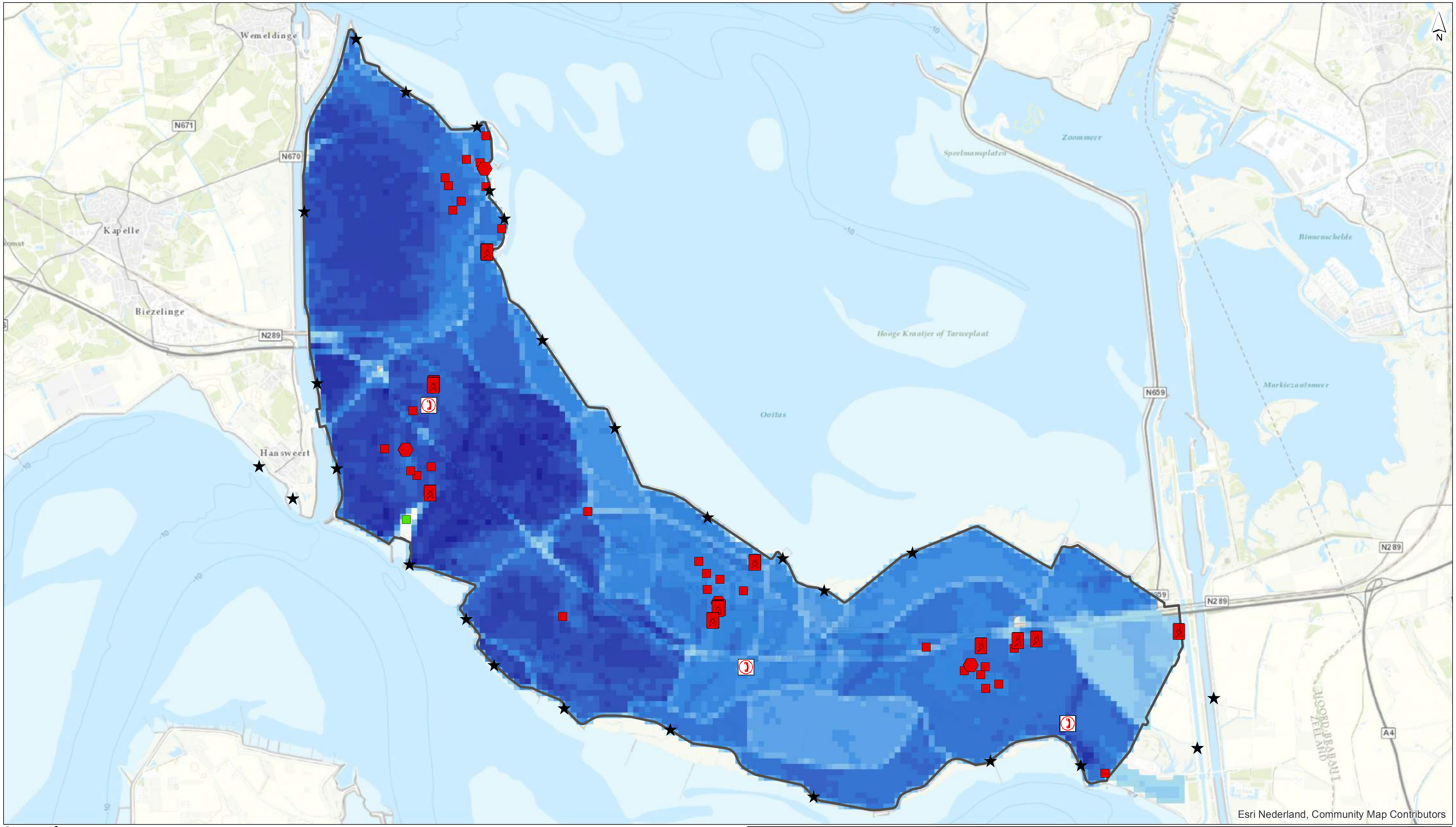
Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max scenario Oosterschelde en Westerschelde

Netwerk gas

client: Provincie Zeeland
project: Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code: 105918

Witteveen + Bos



Legenda

Dijkring
- 31
- ★ Breslocaties

waterdiepte (m)
- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Telecom

C2000
- schade

Wijkkasten
- schade

Straatkasten
- geen schade
- schade

Zendmasten
- schade

drawn: ir. I.M. van den Brink
verified: ir. W.R. Debucquoy
approved:
version: 1
date: 24-07-2018
drawing no: 0

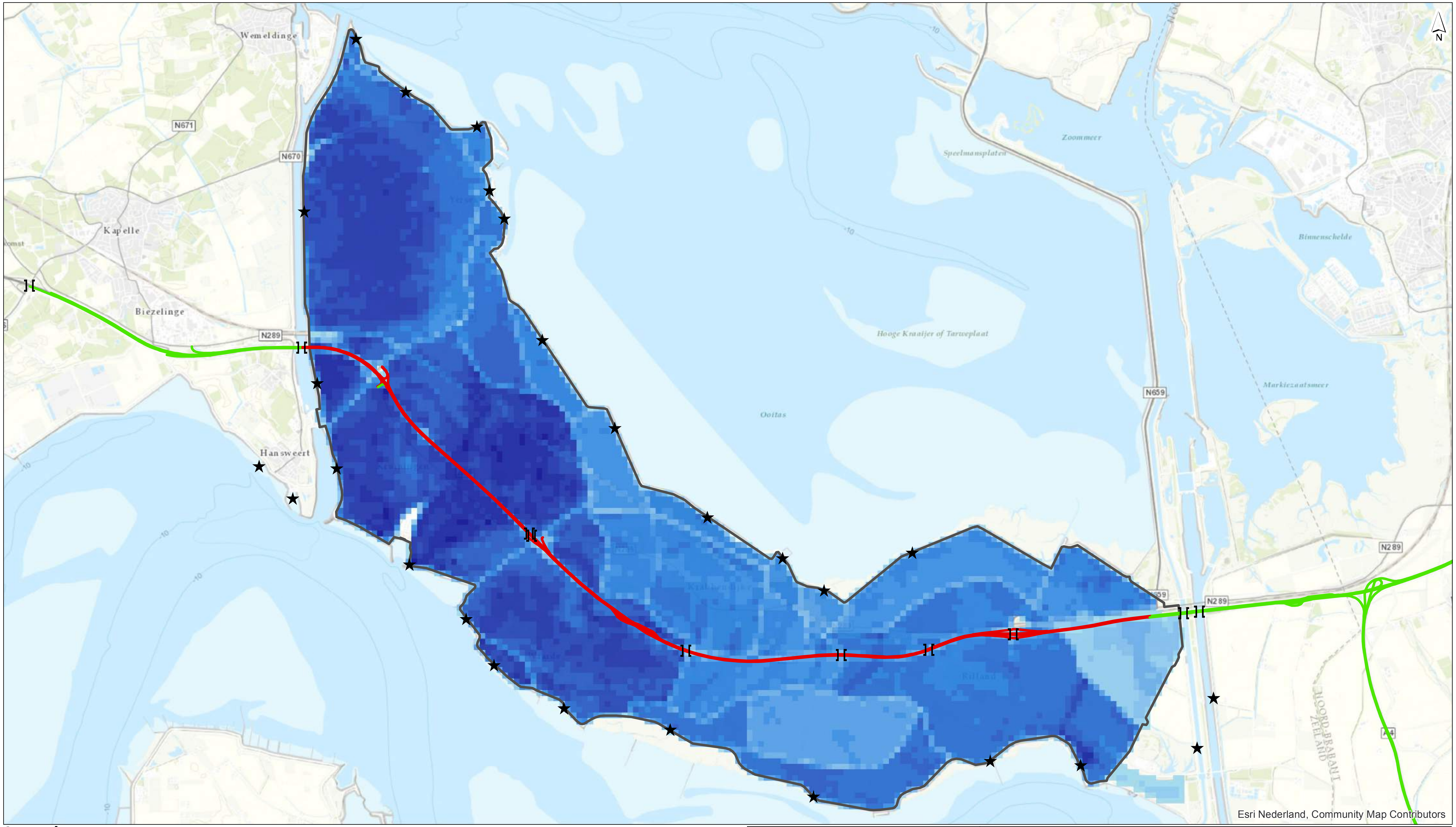
Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max scenario Oosterschelde en Westerschelde
Netwerk telecom

client: Provincie Zeeland
project: Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code: 105918

page size: A3 landscape
scale: 1:64360
0 500 1000 1500 2000 2500 m

Witteveen + Bos



Legenda

Dijkring

31

★ Breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Infrastructuur

- Niet doorwaadbaar
- Doorwaadbaar

][Kunstwerken

drawn: ir. I.M. van den Brink
verified: ir. W.R. Debucquoy
approved:
version: 1
date: 24-07-2018
drawing no: 0

page size: A3 landscape
scale: 1:64360
0 500 1000 1500 2000 2500 m

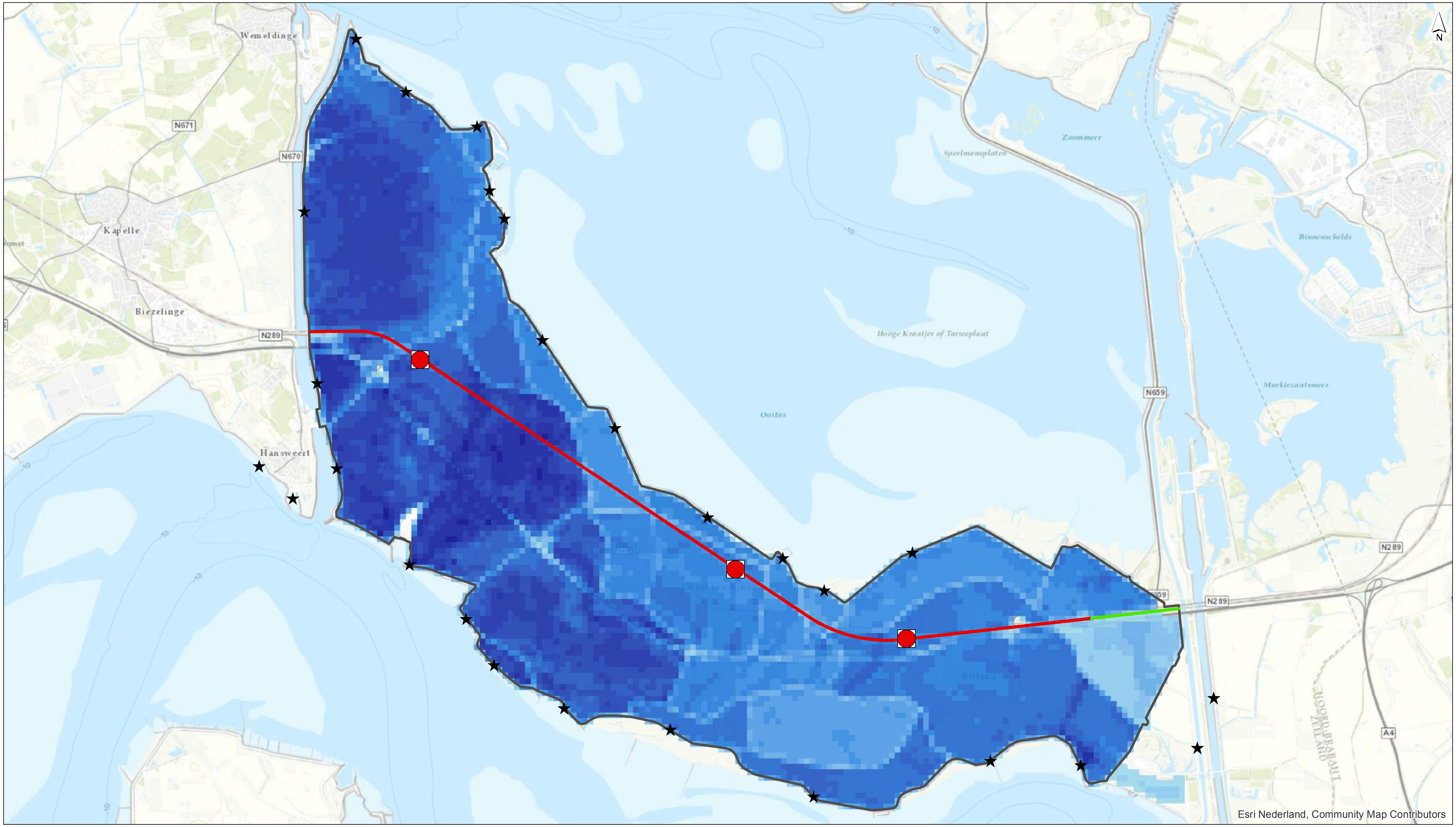
Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max scenario Oosterschelde en Westerschelde

Netwerk A58

client: Provincie Zeeland
project: Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code: 105918

Witteveen + Bos



Legenda

Dijkring

- 31
- ★ Breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Spoorbaan

- geen schade
- mogelijk schade

Stations

- mogelijk schade

drawn:	ir. I.M. van den Brink
verified:	ir. W.R. Debucquoy
approved:	
version:	1
date:	24-07-2018
drawing no:	0
page size:	A3 landscape
scale:	1:64360

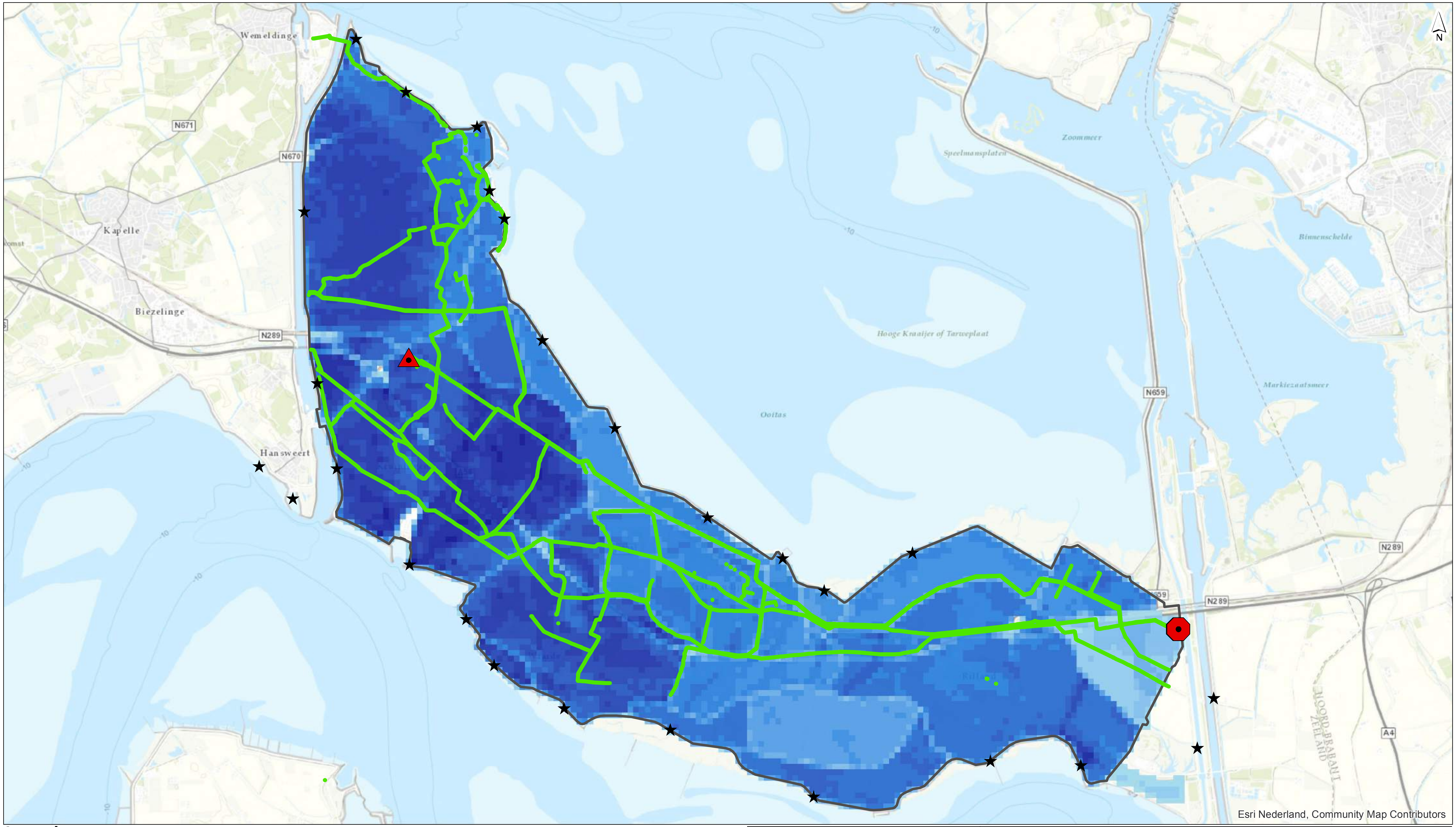
0 500 1000 1500 2000 2500 m

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max scenario Oosterschelde en Westerschelde
Netwerk spoorlijn

client:	Provincie Zeeland
project:	Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code:	105918

Witteveen + Bos



Legenda

Dijkring

31

★ Breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Drink- en proceswater

- Industriewater Prod. - schade
- Pomp - schade

Bluswaterleidingen

- d > 150 mm - geen schade

drawn: ir. I.M. van den Brink
verified: ir. W.R. Debucquoy
approved:
version: 1
date: 24-07-2018
drawing no: 0

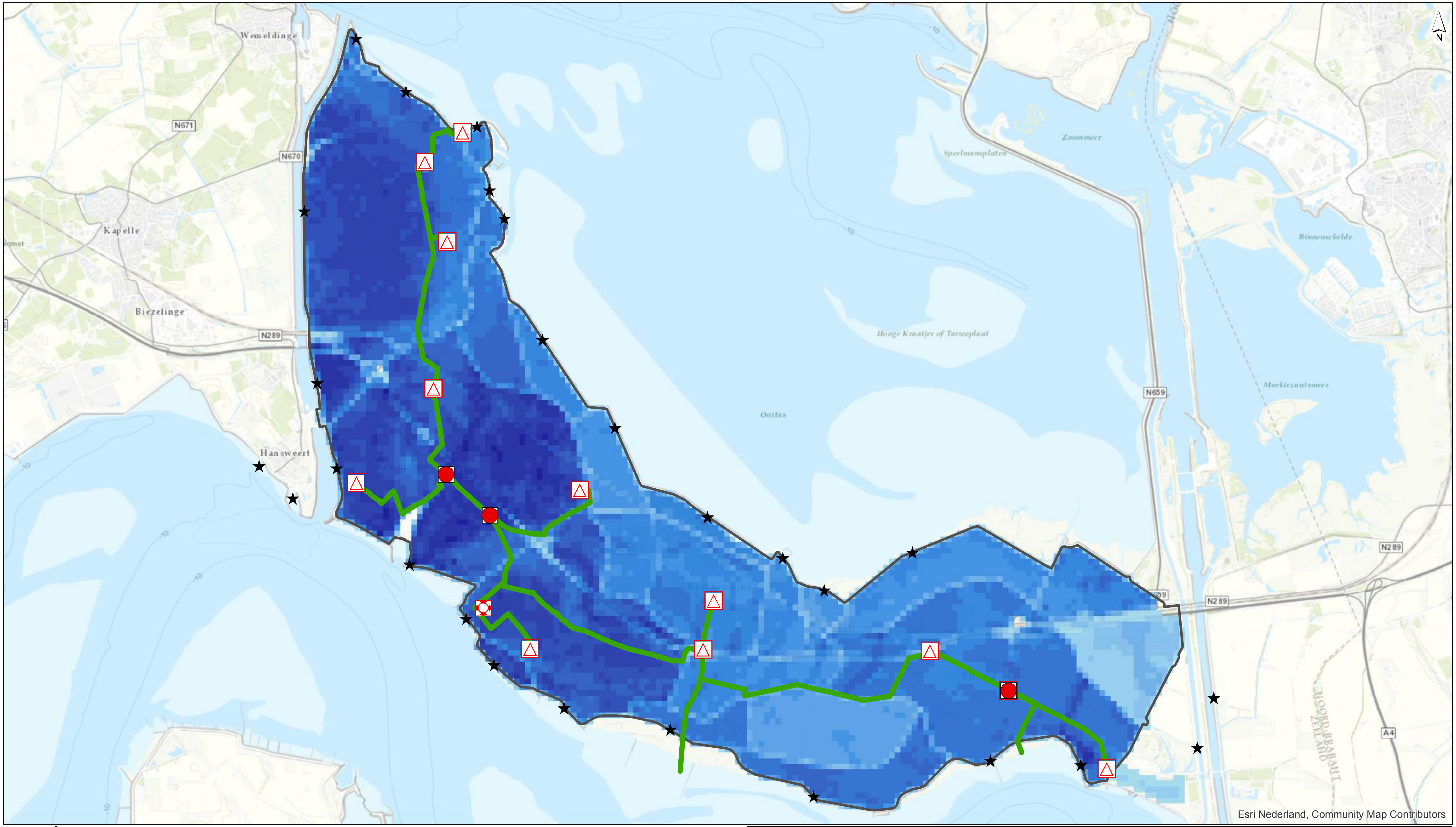
page size: A3 landscape
scale: 1:64360
0 500 1000 1500 2000 2500 m

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max scenario Oosterschelde en Westerschelde
Netwerk drink- en proceswater

client: Provincie Zeeland
project: Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code: 105918

Witteveen + Bos



Legenda

Dijkring
31
★ Breslocaties

waterdiepte (m)
0
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5 - 5
5.0 - 5.5
5.5 - 6
6.0 - 6.5

Afvalwaterketen

Afsluiter
schade

RWZI
schade

rioolgemalen
schade

Leidingen
geen schade

drawn:	ir. I.M. van den Brink
verified:	ir. W.R. Debucquoy
approved:	
version:	1
date:	24-07-2018
drawing no:	0
page size:	A3 landscape
scale:	1:64360

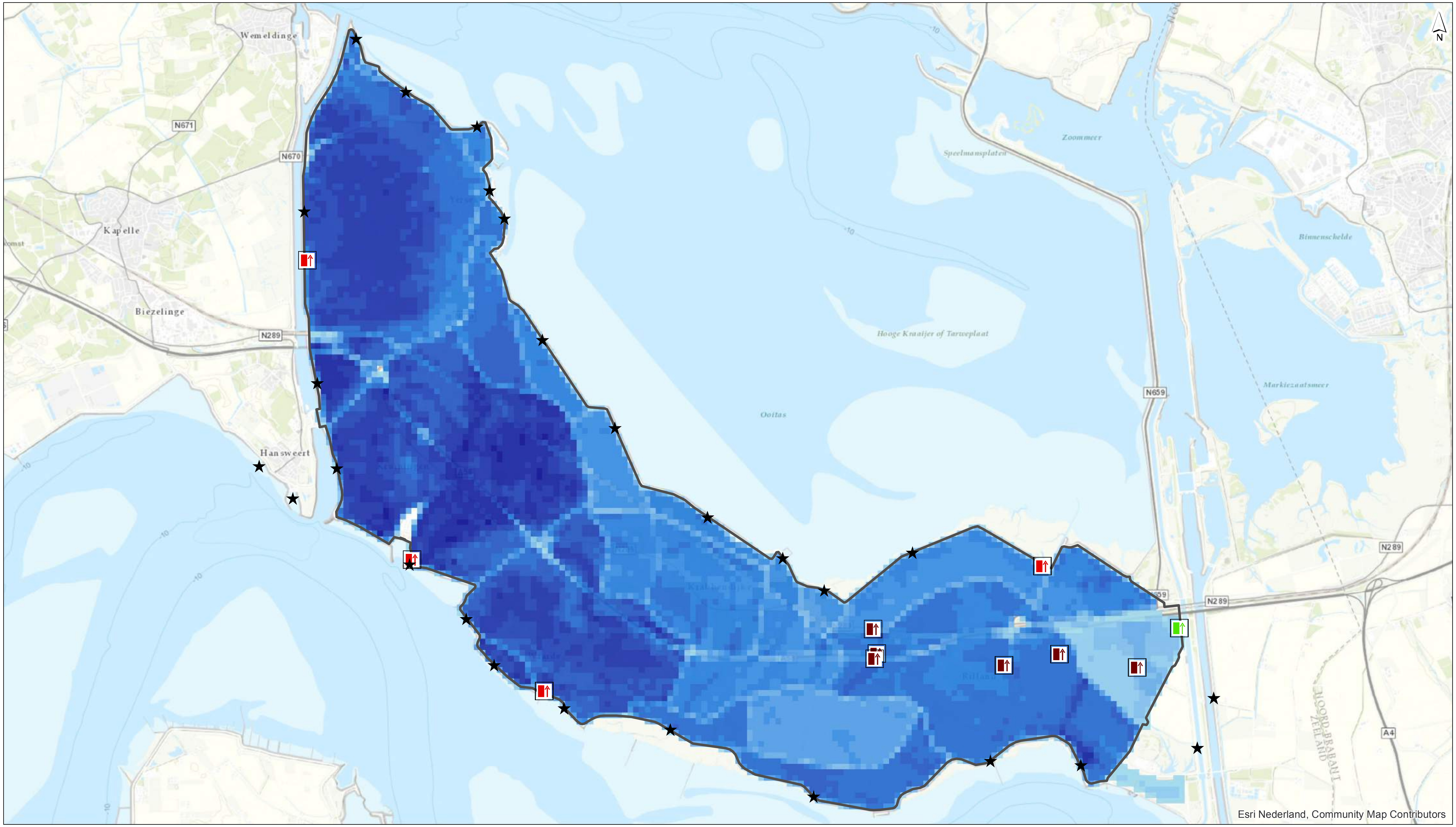
0 500 1000 1500 2000 2500 m

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max scenario Oosterschelde en Westerschelde
Netwerk afvalwaterketen

client:	Provincie Zeeland
project:	Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code:	105918

Witteveen + Bos



Legenda

Dijkring
31
★ Breslocaties

waterdiepte (m)
0
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5 - 5
5.0 - 5.5
5.5 - 6
6.0 - 6.5

Waterbeheer
aanvoer, geen schade
afvoer, schade
onderbemaling, schade

drawn: ir. I.M. van den Brink
verified: ir. W.R. Debucquoy
approved:
version: 1
date: 24-07-2018
drawing no: 0

page size: A3 landscape
scale: 1:64360
0 500 1000 1500 2000 2500 m

Vitale Infrastructuur Reimerswaal

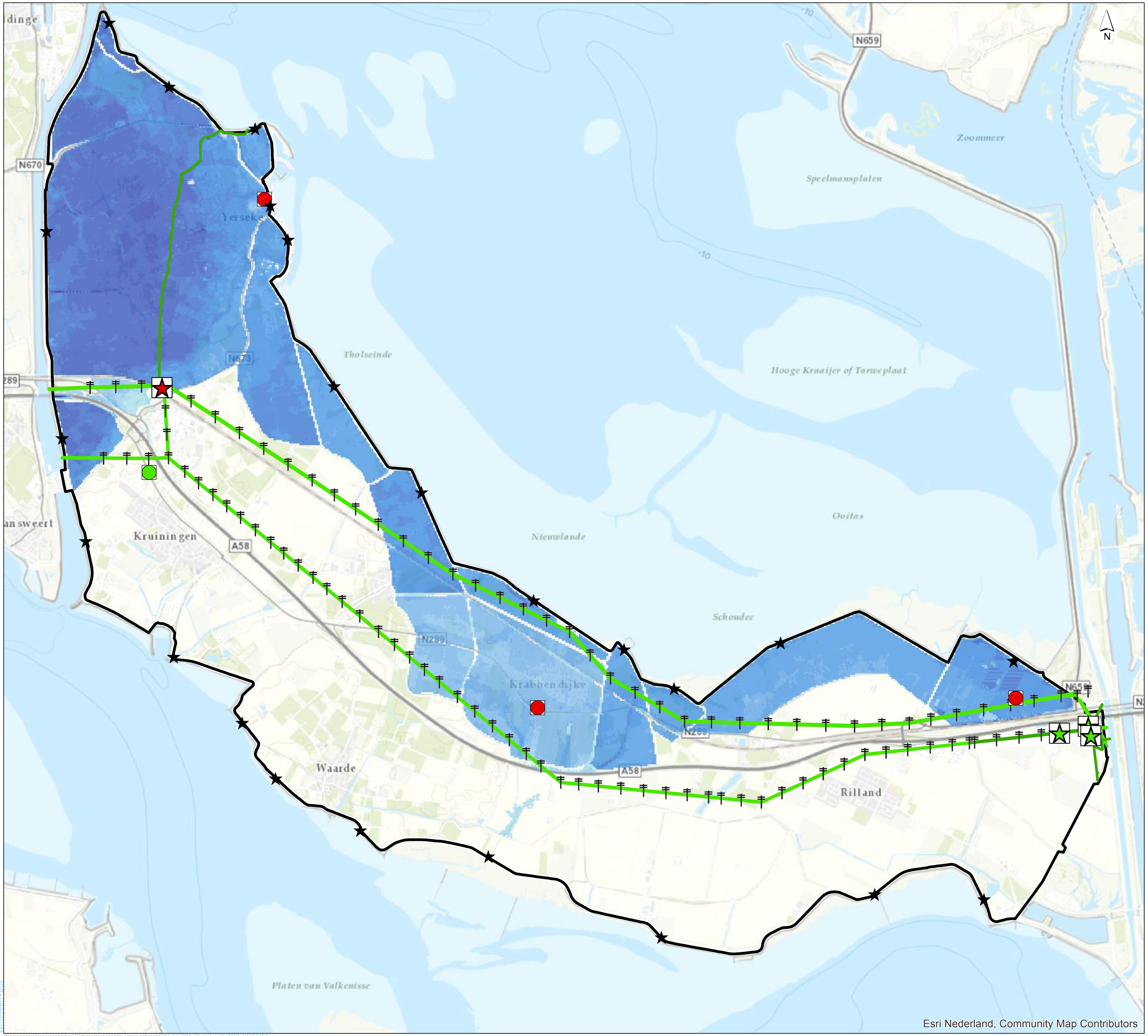
Dijkdoorbraak - max scenario Oosterschelde en Westerschelde
Netwerk waterbeheer

client: Provincie Zeeland
project: Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code: 105918

Witteveen + Bos

V

ANNEX: RESULTS OF MAXIMUM OOSTERSCHELDE SCENARIO, FLOOD PROOF REGIONAL BARRIERS



Legenda

- Dijkring 31
- ★ Breslocaties

Waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Elektriciteit

- Masten
- Hoofdverdeelstation, geen schade
- Hoofdverdeelstation, schade
- Schakelstation, geen schade
- Schakelstation, schade
- Grondkabels, geen schade
- Luchtlijnen, geen schade

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max. scenario Oosterschelde Netwerk elektriciteit

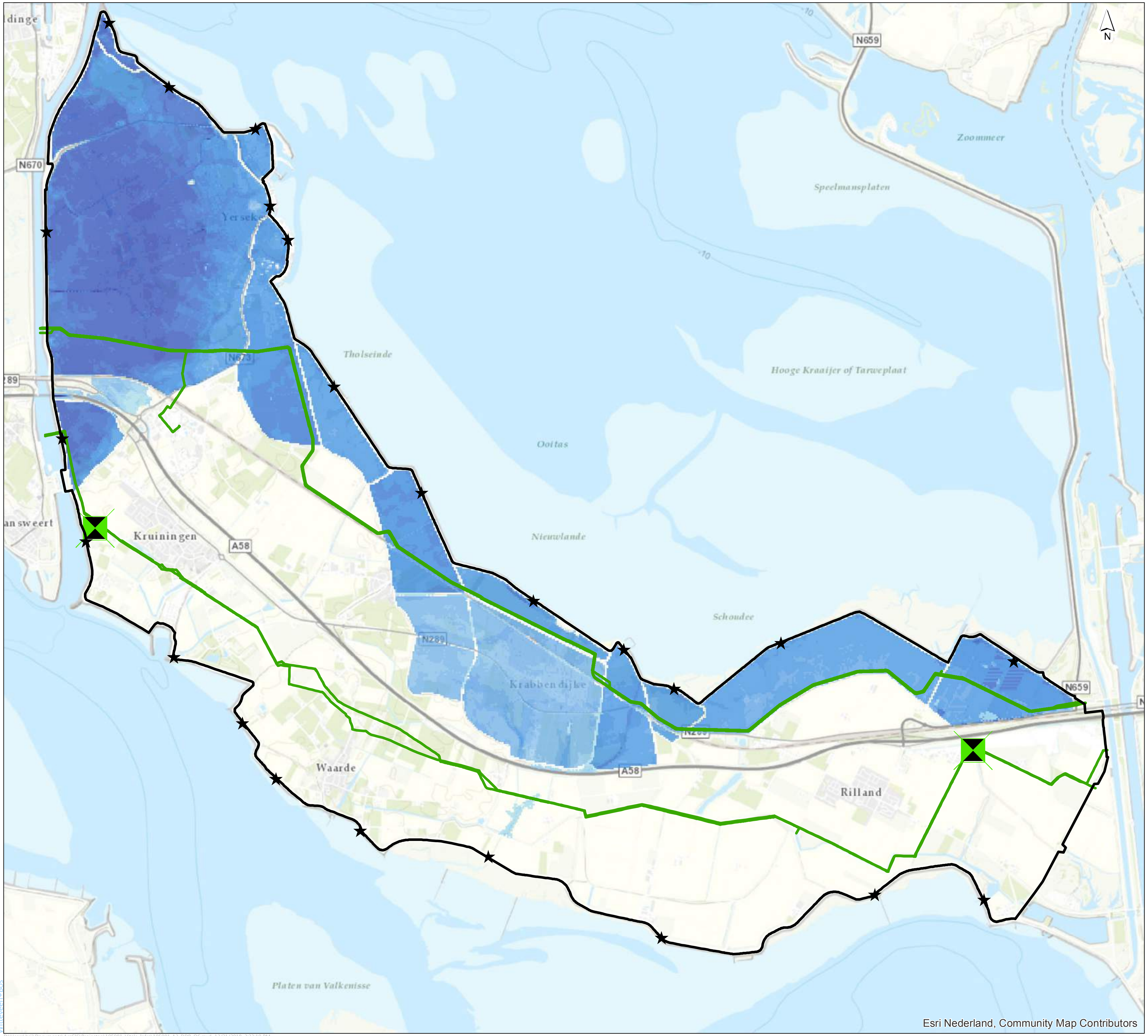
getekend: ir. I.M. van den Brink	versie: 1
gecontroleerd: ir. W.R. Debucquoy	datum: 21-12-2018
goedgekeurd: ir. L.A. Valkenburg	tekeningnr: 0

opdrachtgever: Provincie Zeeland
projectnaam: Kwetsbaarheidsanalyse Vitale Infrastructuur Reimerswaal
projectcode: 105918

formaat: A3 liggend
schaal: 1:55000

0 500 1000 1500 2000 2500 m

Witteveen + Bos



Legenda

Dijkring 31

★ breslocaties

Waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

GTS Assets

- geen schade
- schade

Gasleiding

- geen schade

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max. scenario Oosterschelde

Netwerk gas

getekend: ir. I.M. van den Brink	**versie:** 1
gecontroleerd: ir. W.R. Debucquoy	**datum:** 21-12-2018
goedgekeurd: ir. L.A. Valkenburg	**tekeningnr:** 0

opdrachtgever: Provincie Zeeland

projectnaam: Kwetsbaarheidsanalyse Vitale Infrastructuur Reimerswaal

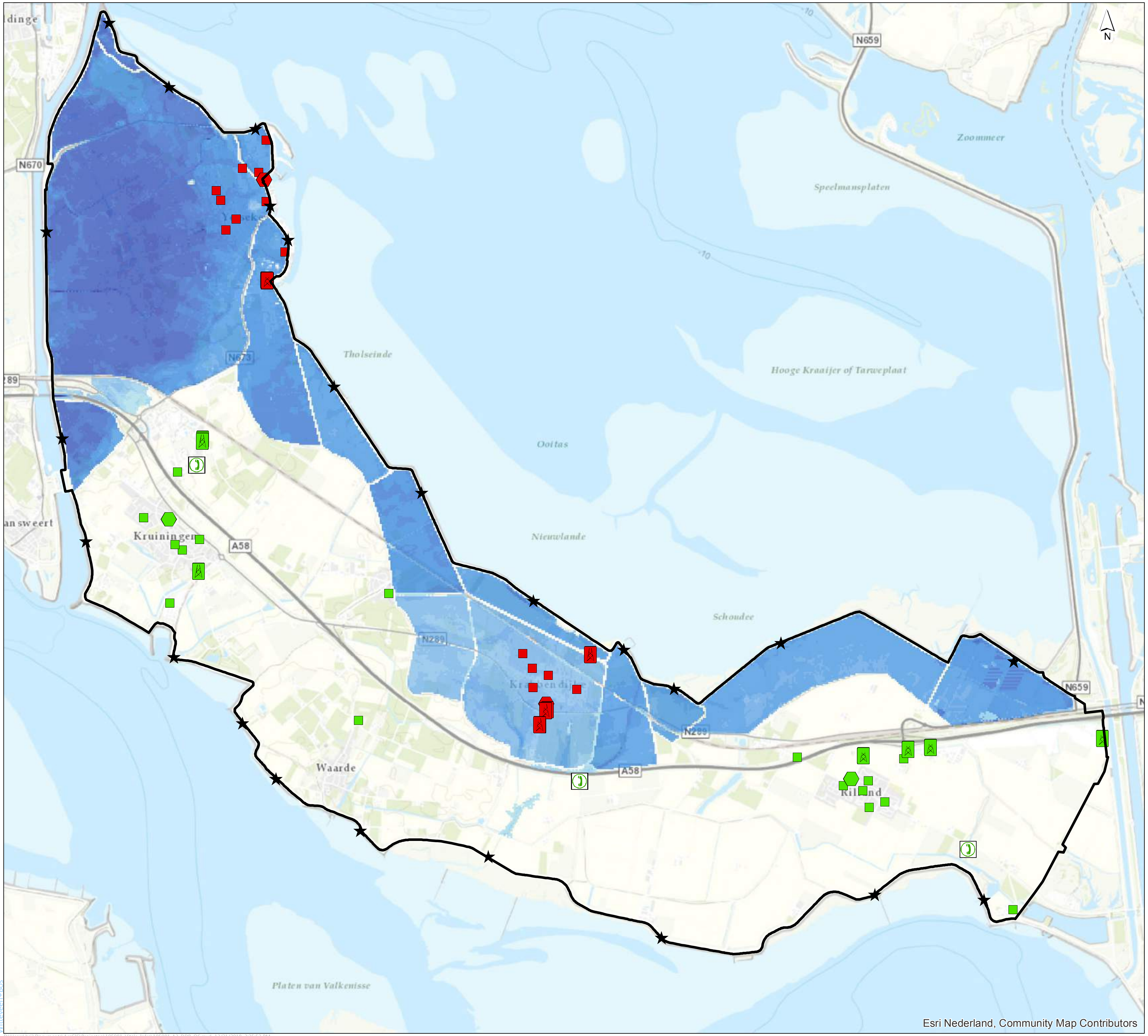
projectcode: 105918

formaat: A3 liggend

schaal: 1:55000

0 500 1000 1500 2000 2500 m

Witteveen + Bos



Legenda

- Dijkring 31
- breslocaties

Waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Telecom

C2000

- geen schade

Wijkkasten

- geen schade
- schade

Straatkasten

- geen schade
- schade

Zendmasten

- geen schade
- schade

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max. scenario Oosterschelde

Netwerk telecom

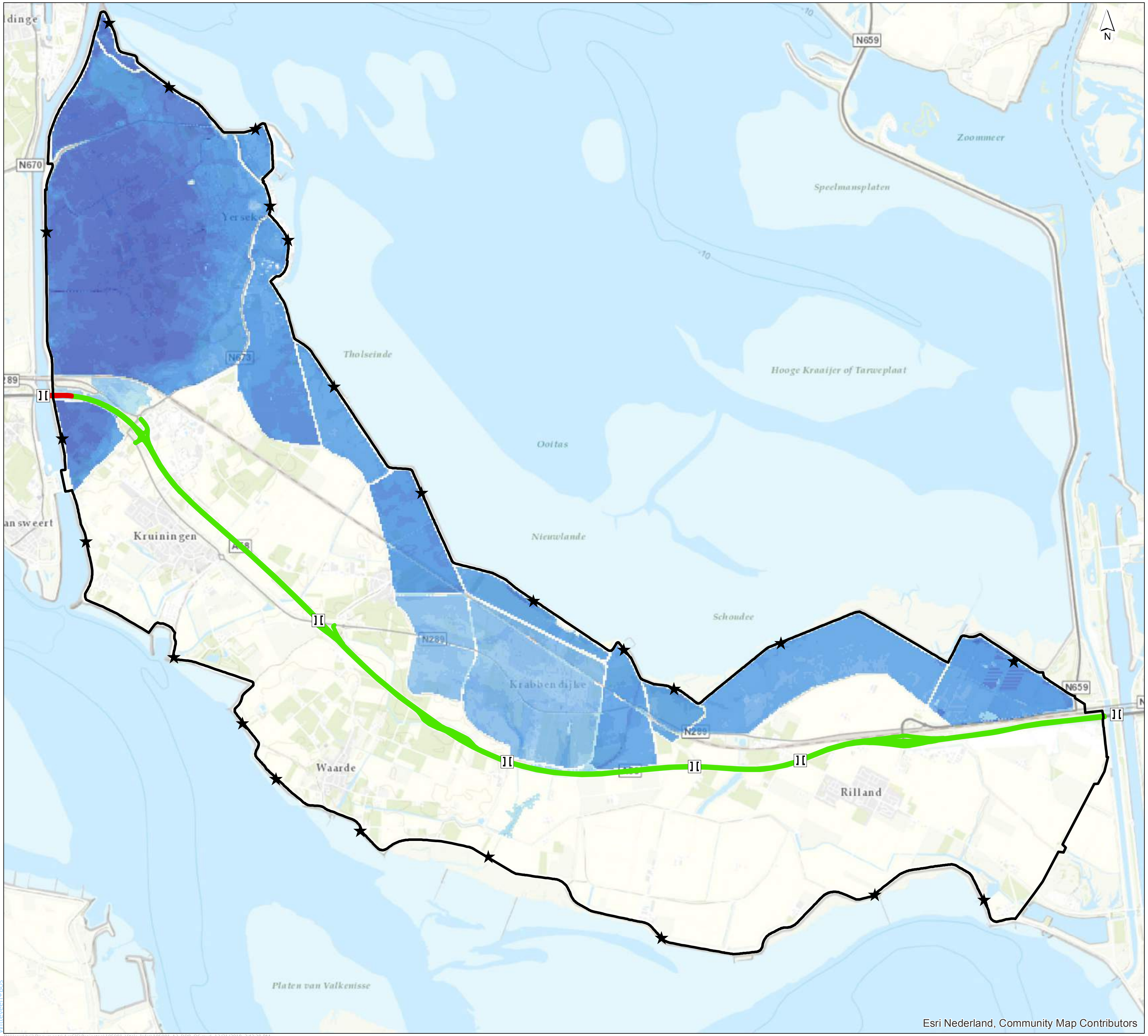
getekend:	**ir. I.M. van den Brink**	**versie:**	1
gecontroleerd:	**ir. W.R. Debucquoy**	**datum:**	21-12-2018
goedgekeurd:	**ir. L.A. Valkenburg**	**tekeningnr:**	0

opdrachtgever: Provincie Zeeland
projectnaam: Kwetsbaarheidsanalyse Vitale Infrastructuur Reimerswaal
projectcode: 105918

formaat: A3 liggend
schaal: 1:55000

0 500 1000 1500 2000 2500 m

Witteveen + Bos



Legenda

Dijkring 31

breslocaties

Waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Infrastructuur

- niet doorwaadbaar
- doorwaadbaar
- Kunstwerken

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max. scenario Oosterschelde

Netwerk A58

getekend: ir. I.M. van den Brink	versie: 1
gecontroleerd: ir. W.R. Debucquoy	datum: 21-12-2018
goedgekeurd: ir. L.A. Valkenburg	tekeningnr: 0

opdrachtgever: Provincie Zeeland

projectnaam: Kwetsbaarheidsanalyse Vitale Infrastructuur Reimerswaal

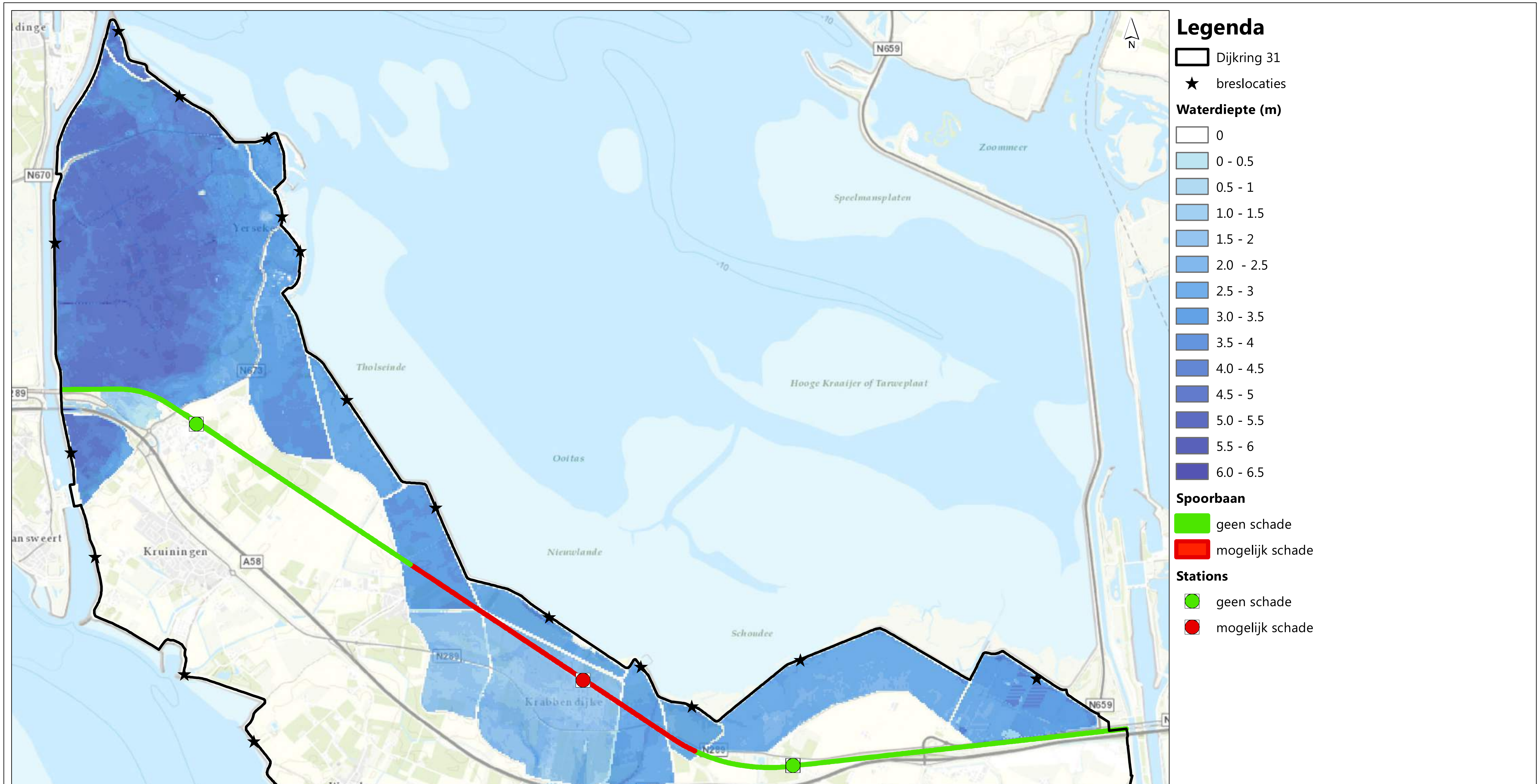
projectcode: 105918

formaat: A3 liggend

schaal: 1:55000

0 500 1000 1500 2000 2500 m

Witteveen + Bos



Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max. scenario Oosterschelde

Netwerk spoorlijn

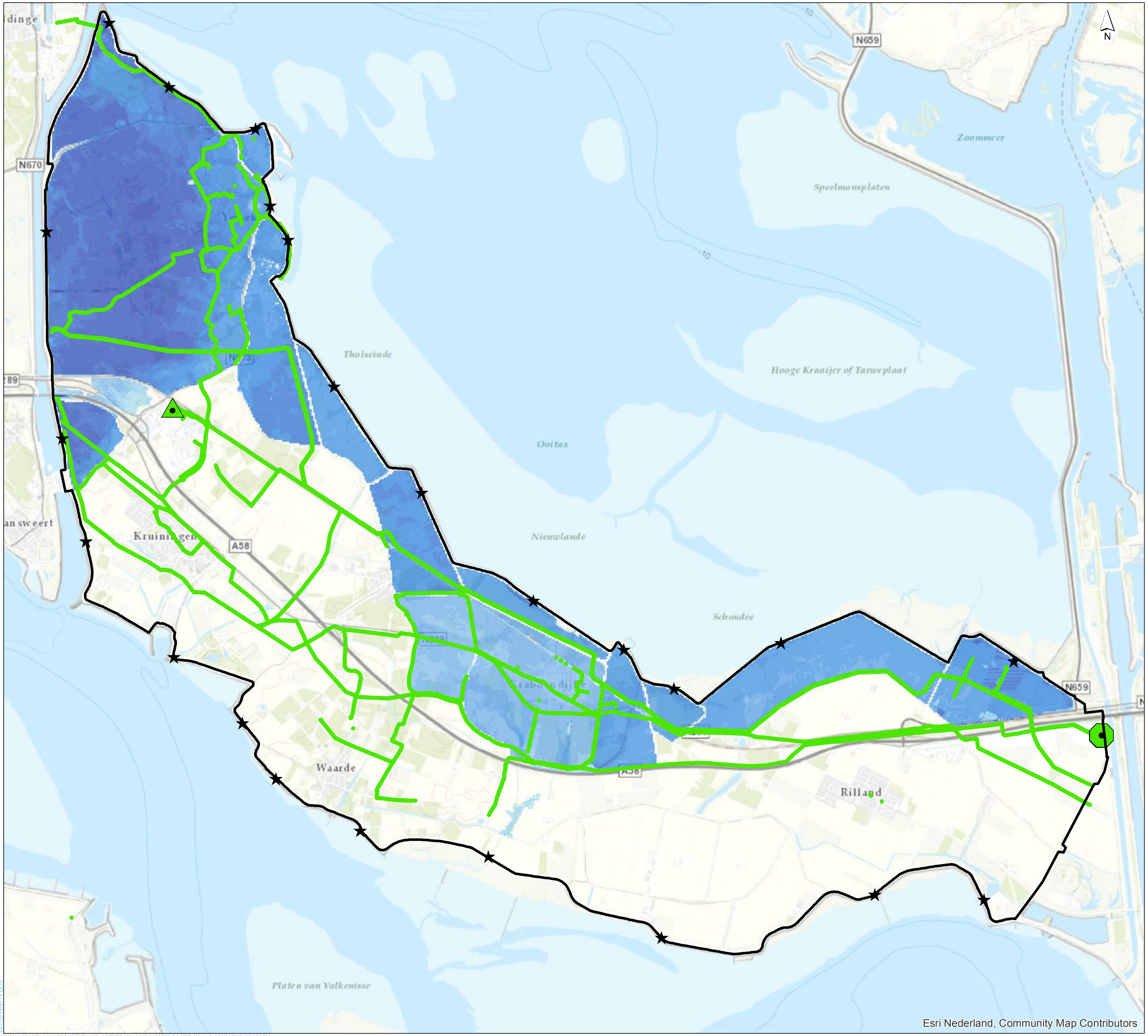
getekend: ir. I.M. van den Brink	**versie:** 1
gecontroleerd: ir. W.R. Debucquoy	**datum:** 21-12-2018
goedgekeurd: ir. L.A. Valkenburg	**tekeningnr:** 0

opdrachtgever: Provincie Zeeland
projectnaam: Kwetsbaarheidsanalyse Vitale Infrastructuur Reimerswaal
projectcode: 105918

formaat: A3 liggend
schaal: 1:55000

0 500 1000 1500 2000 2500 m

Witteveen + Bos



Legenda

- Dijkring 31
- ★ Breslocaties

Waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Drink- en proceswater

- Industriewater Prod. - geen schade
- Pomp - geen schade

Bluswaterleidingen

- d > 150 mm - geen schade

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max. scenario Oosterschelde

Netwerk drink- en proceswater

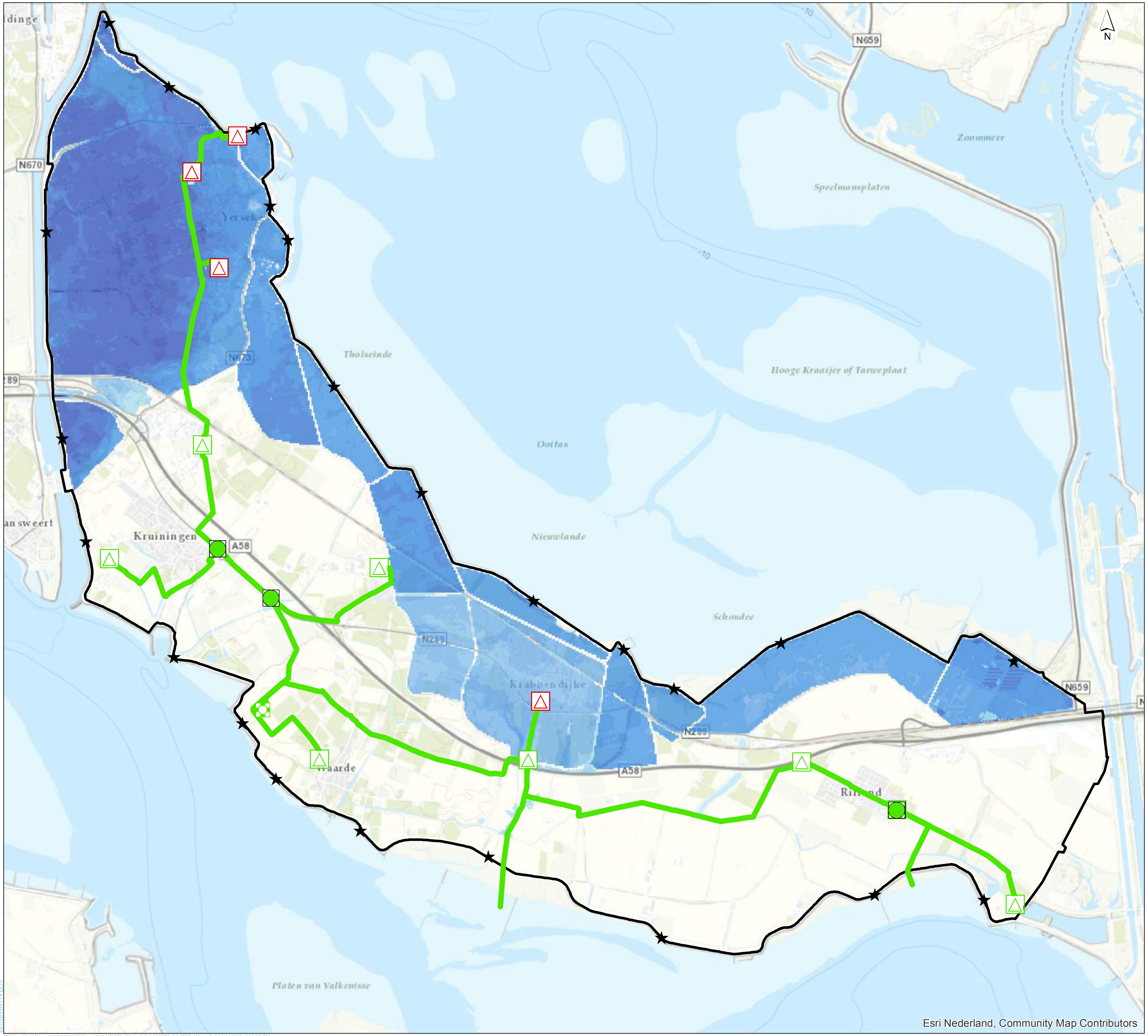
getekend:	**ir. I.M. van den Brink**	**versie:**	1
gecontroleerd:	**ir. W.R. Debucquoy**	**datum:**	21-12-2018
goedgekeurd:	**ir. L.A. Valkenburg**	**tekeningnr:**	0

opdrachtgever: Provincie Zeeland
projectnaam: Kwetsbaarheidsanalyse Vitale Infrastructuur Reimerswaal
projectcode: 105918

formaat: A3 liggend
schaal: 1:55000

0 500 1000 1500 2000 2500 m

Witteveen + Bos



Legenda

Dijkring 31

Breslocaties

Waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Afvalwaterketen

Afsluiter

- geen schade
- schade

RWZI

- geen schade

rioolgemalen

- geen schade
- schade

Leidingen

- geen schade

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max. scenario Oosterschelde

Netwerk afvalwaterketen

getekend:	**ir. I.M. van den Brink**	**versie:**	1
gecontroleerd:	**ir. W.R. Debucquoy**	**datum:**	21-12-2018
goedgekeurd:	**ir. L.A. Valkenburg**	**tekeningnr:**	0

opdrachtgever: Provincie Zeeland

projectnaam: Kwetsbaarheidsanalyse Vitale Infrastructuur Reimerswaal

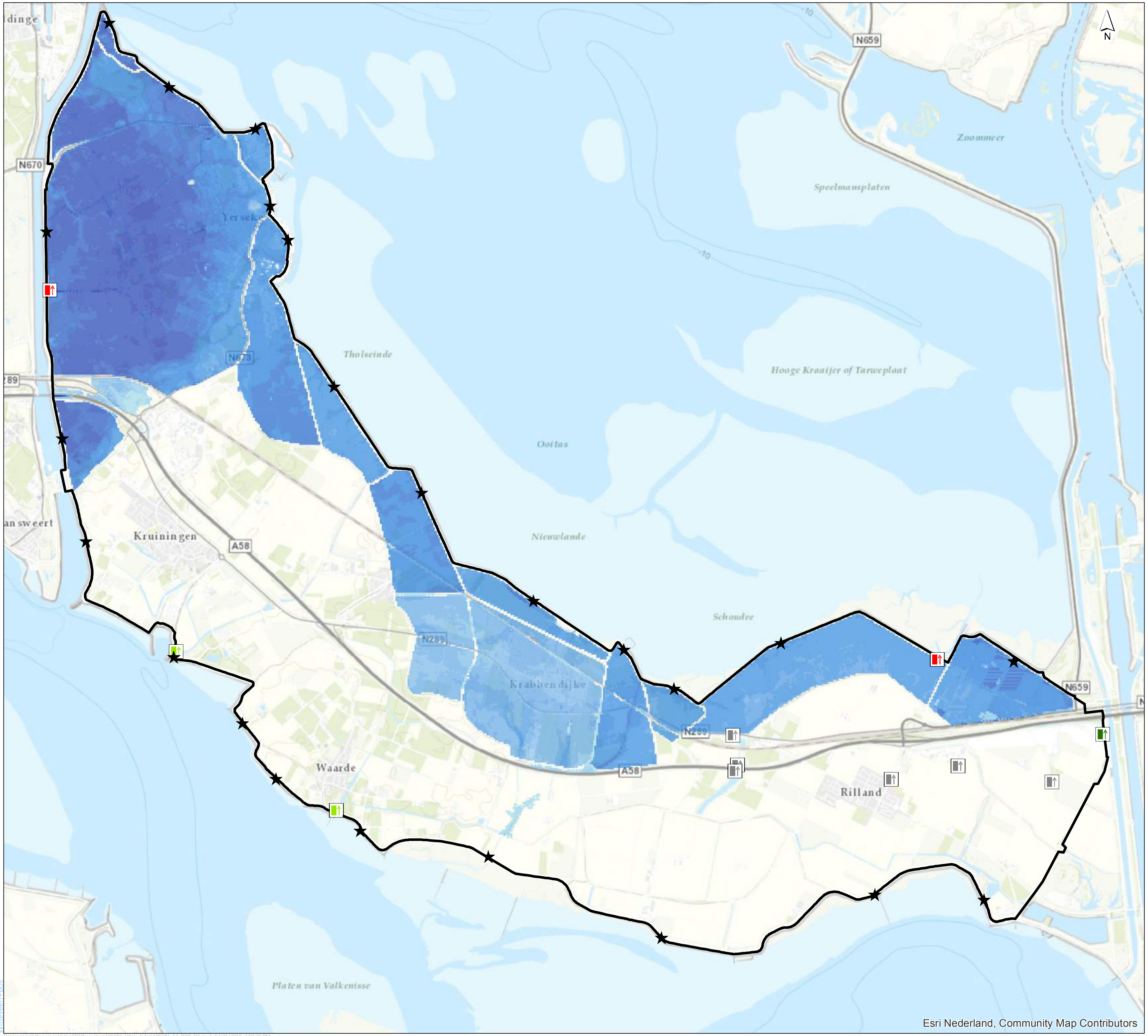
projectcode: 105918

formaat: A3 liggend

schaal: 1:55000

0 500 1000 1500 2000 2500 m

Witteveen + Bos



Legenda

Dijkring 31

★ Breslocaties

Waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Waterbeheer

- aanvoer - geen schade
- afvoer - schade
- afvoer - geen schade
- onderbemaling - geen schade

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max. scenario Oosterschelde

Netwerk waterbeheer

getekend: ir. I.M. van den Brink	**versie:** 1
gecontroleerd: ir. W.R. Debucquoy	**datum:** 21-12-2018
goedgekeurd: ir. L.A. Valkenburg	**tekeningnr:** 0

opdrachtgever: Provincie Zeeland
projectnaam: Kwetsbaarheidsanalyse Vitale Infrastructuur Reimerswaal
projectcode: 105918

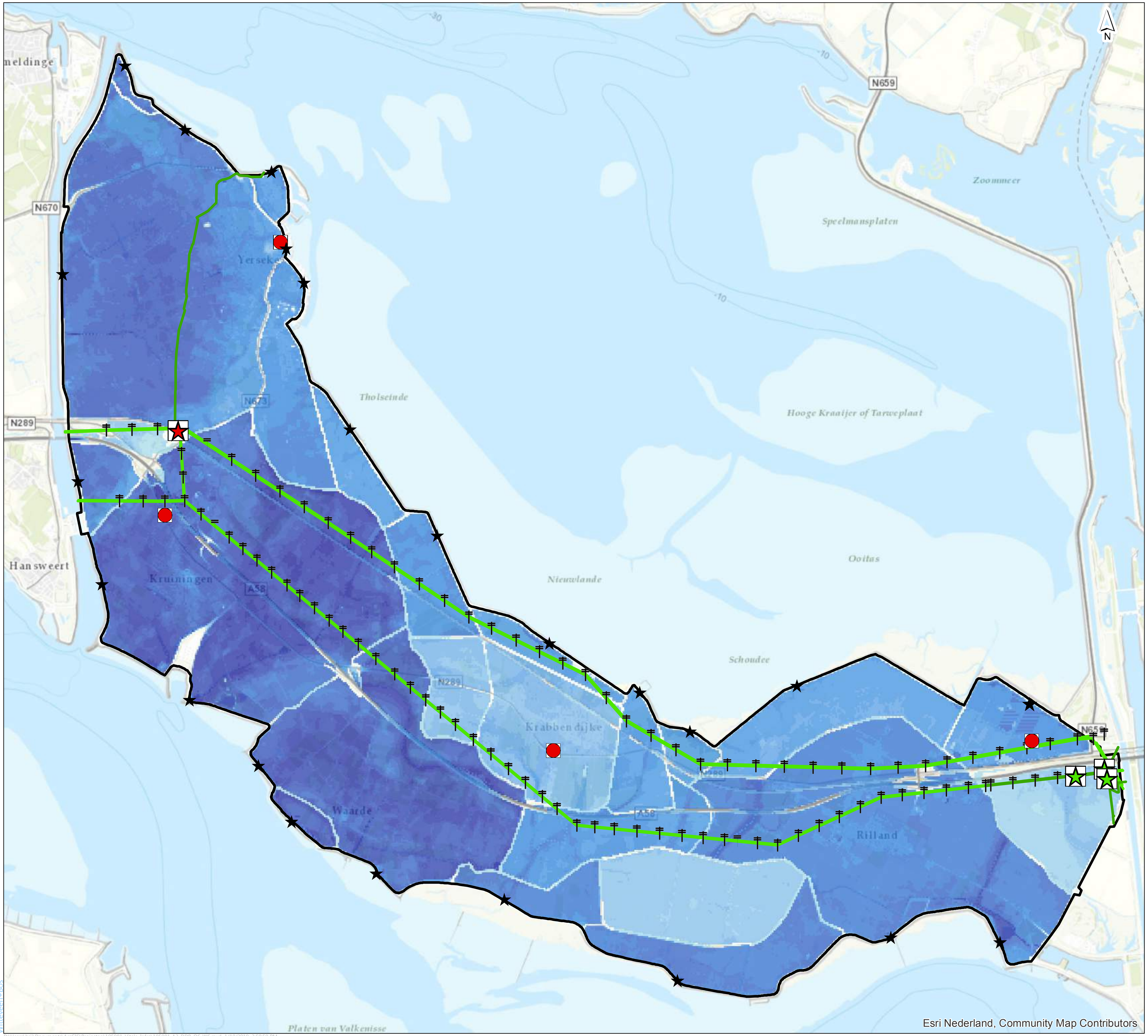
formaat: A3 liggend
schaal: 1:55000

0 500 1000 1500 2000 2500 m

Witteveen + Bos

VI

ANNEX: RESULTS OF MAXIMUM WESTERSCHELDE AND OOSTERSCHELDE SCENARIO, FLOOD PROOF REGIONAL BARRIERS



Legenda

- Dijkring 31
- Breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Elektriciteit

- Masten
- Hoofdverdeelstation, geen schade
- Hoofdverdeelstation, schade
- Schakelstation, geen schade
- Grondkabels, geen schade
- Luchtlijnen, geen schade

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max. scenario OS en WS
Netwerk elektriciteit

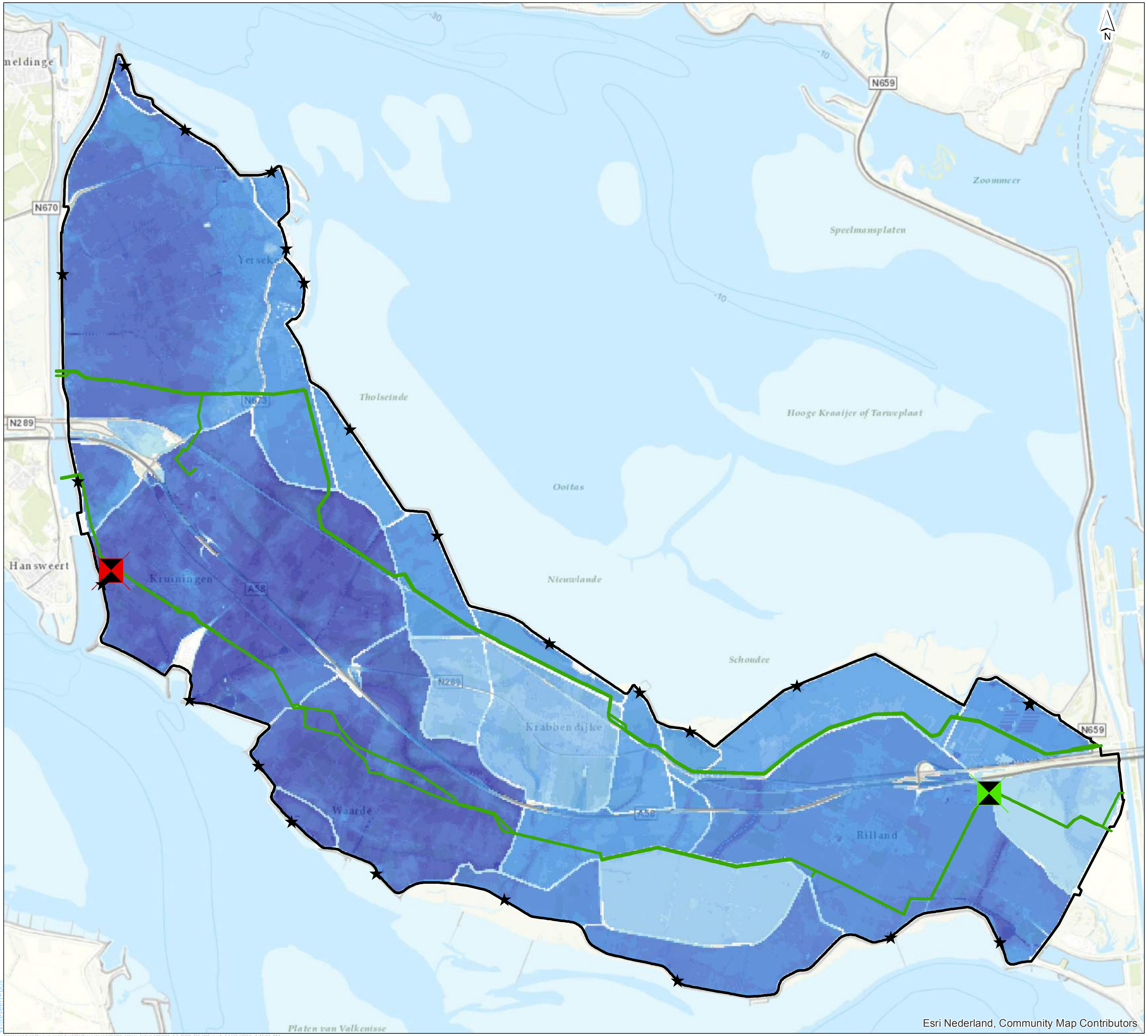
getekend: ir. I.M. van den Brink	versie: 1
gecontroleerd: ir. W.R. Debucquoy	datum: 21-12-2018
goedgekeurd: ir. L.A. Valkenburg	tekeningnr: 0

opdrachtgever: Provincie Zeeland
projectnaam: Kwetsbaarheidsanalyse Vitale Infrastructuur Reimerswaal
projectcode: 105918

formaat: A3 liggend
schaal: 1:55000

0 500 1000 1500 2000 2500 m

Witteveen + Bos



Legenda

- Dijkring 31
- ★ breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

GTS Assets

- geen schade
- schade

Gasleiding

- geen schade

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max. scenario OS en WS
Netwerk gas

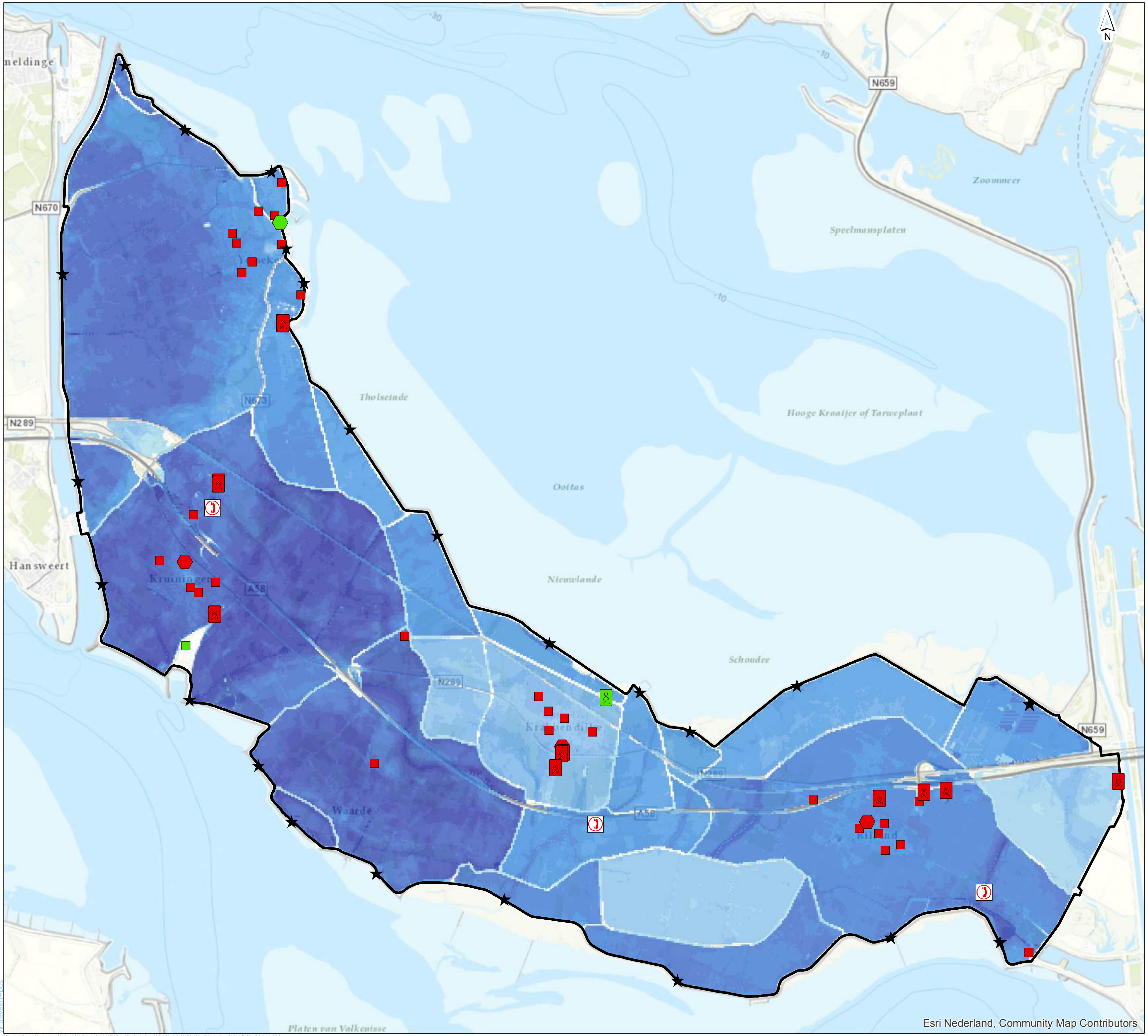
getekend:	ir. I.M. van den Brink	versie:	1
gecontroleerd:	ir. W.R. Debucqouy	datum:	21-12-2018
goedgekeurd:	ir. L.A. Valkenburg	tekeningnr:	0

opdrachtgever: Provincie Zeeland
projectnaam: Kwetsbaarheidsanalyse Vitale Infrastructuur Reimerswaal
projectcode: 105918

formaat: A3 liggend
schaal: 1:55000

0 500 1000 1500 2000 2500 m

Witteveen + Bos



Legenda

Dijkring 31

Breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Telecom

C2000

schade

Wijkkasten

schade

geen schade

Straatkasten

geen schade

schade

Zendmasten

schade

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max. scenario OS en WS
Netwerk telecom

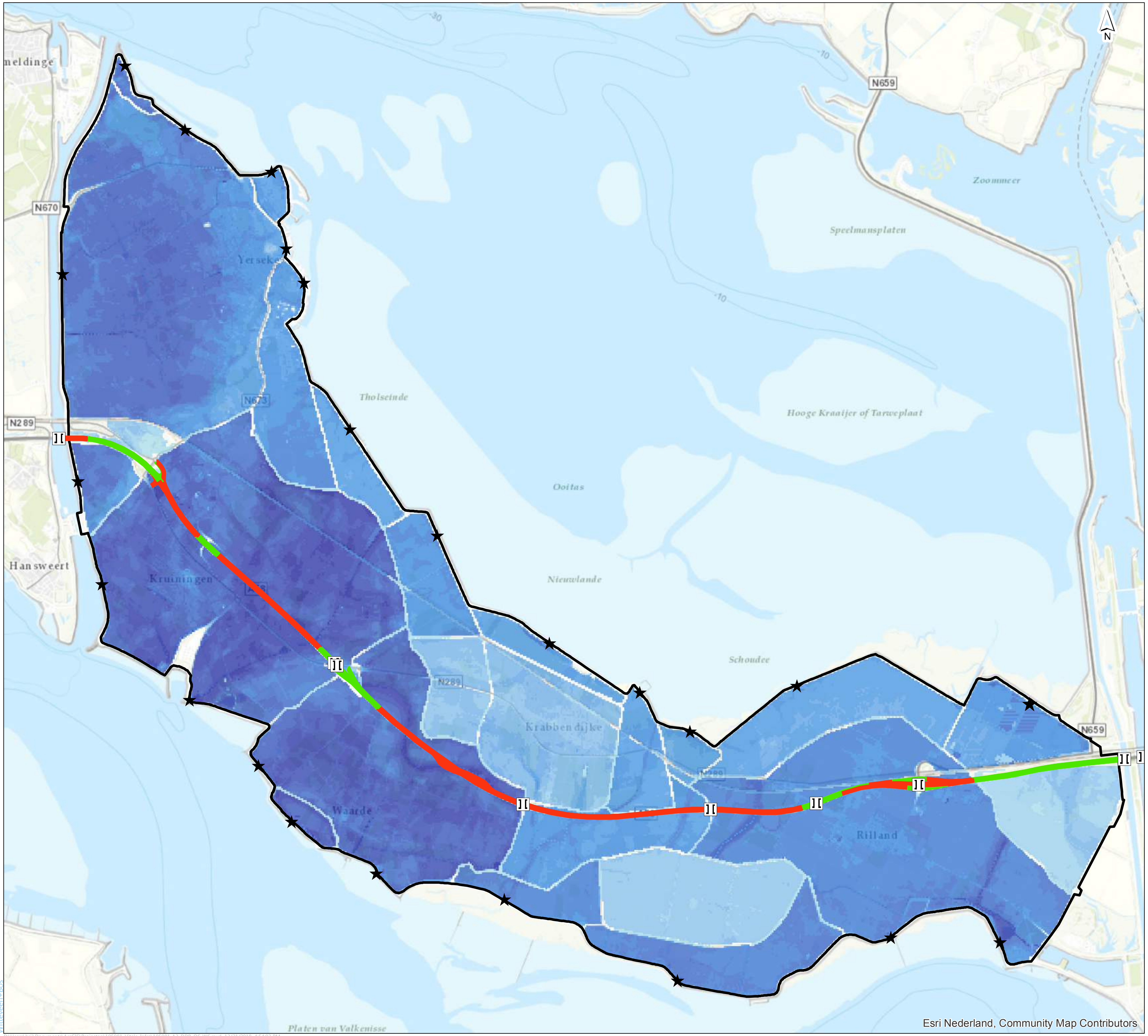
getekend: ir. I.M. van den Brink	versie: 1
gecontroleerd: ir. W.R. Debucquoy	datum: 21-12-2018
goedgekeurd: ir. L.A. Valkenburg	tekeningnr: 0

opdrachtgever: Provincie Zeeland
projectnaam: Kwetsbaarheidsanalyse Vitale Infrastructuur Reimerswaal
projectcode: 105918

formaat: A3 liggend
schaal: 1:55000

0 500 1000 1500 2000 2500 m

Witteveen+Bos



Legenda

- Dijkring 31
- ★ Breslocaties

waterdiepte (m)

- **0**
- **0 - 0.5**
- **0.5 - 1**
- **1.0 - 1.5**
- **1.5 - 2**
- **2.0 - 2.5**
- **2.5 - 3**
- **3.0 - 3.5**
- **3.5 - 4**
- **4.0 - 4.5**
- **4.5 - 5**
- **5.0 - 5.5**
- **5.5 - 6**
- **6.0 - 6.5**

Infrastructuur

- **niet doorwaadbaar**
- **doorwaadbaar**
-][Kunstwerken

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max. scenario OS en WS
Netwerk A58

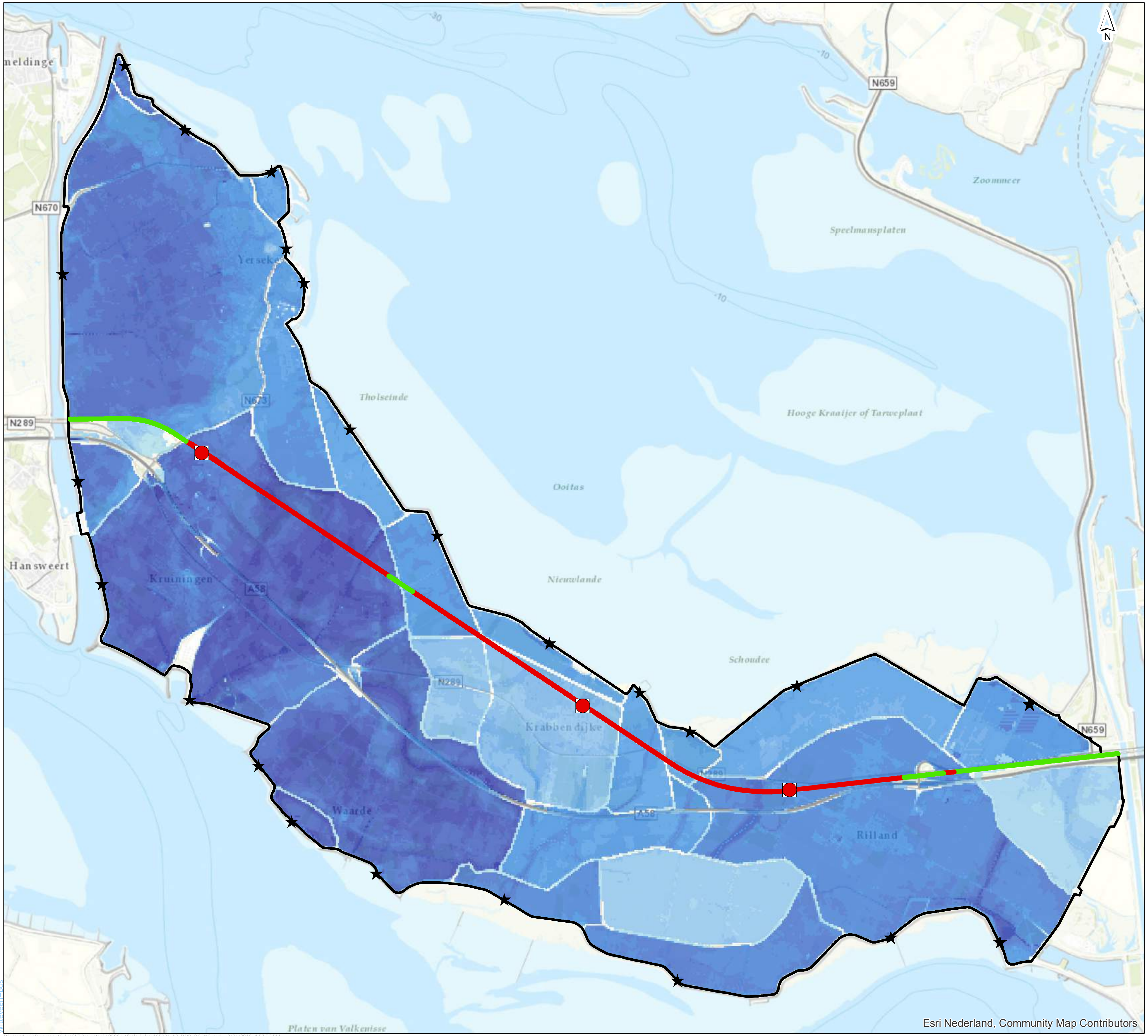
getekend:	ir. I.M. van den Brink	versie:	1
gecontroleerd:	ir. W.R. Debucquoy	datum:	21-12-2018
goedgekeurd:	ir. L.A. Valkenburg	tekeningnr:	0

opdrachtgever: Provincie Zeeland
projectnaam: Kwetsbaarheidsanalyse Vitale Infrastructuur Reimerswaal
projectcode: 105918

formaat: A3 liggend
schaal: 1:55000

0 500 1000 1500 2000 2500 m

Witteveen + Bos



Legenda

- Dijkring 31
- ★ Breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Spoorbaan

- geen schade
- mogelijk schade

Stations

- mogelijk schade

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max. scenario OS en WS
Netwerk spoorlijn

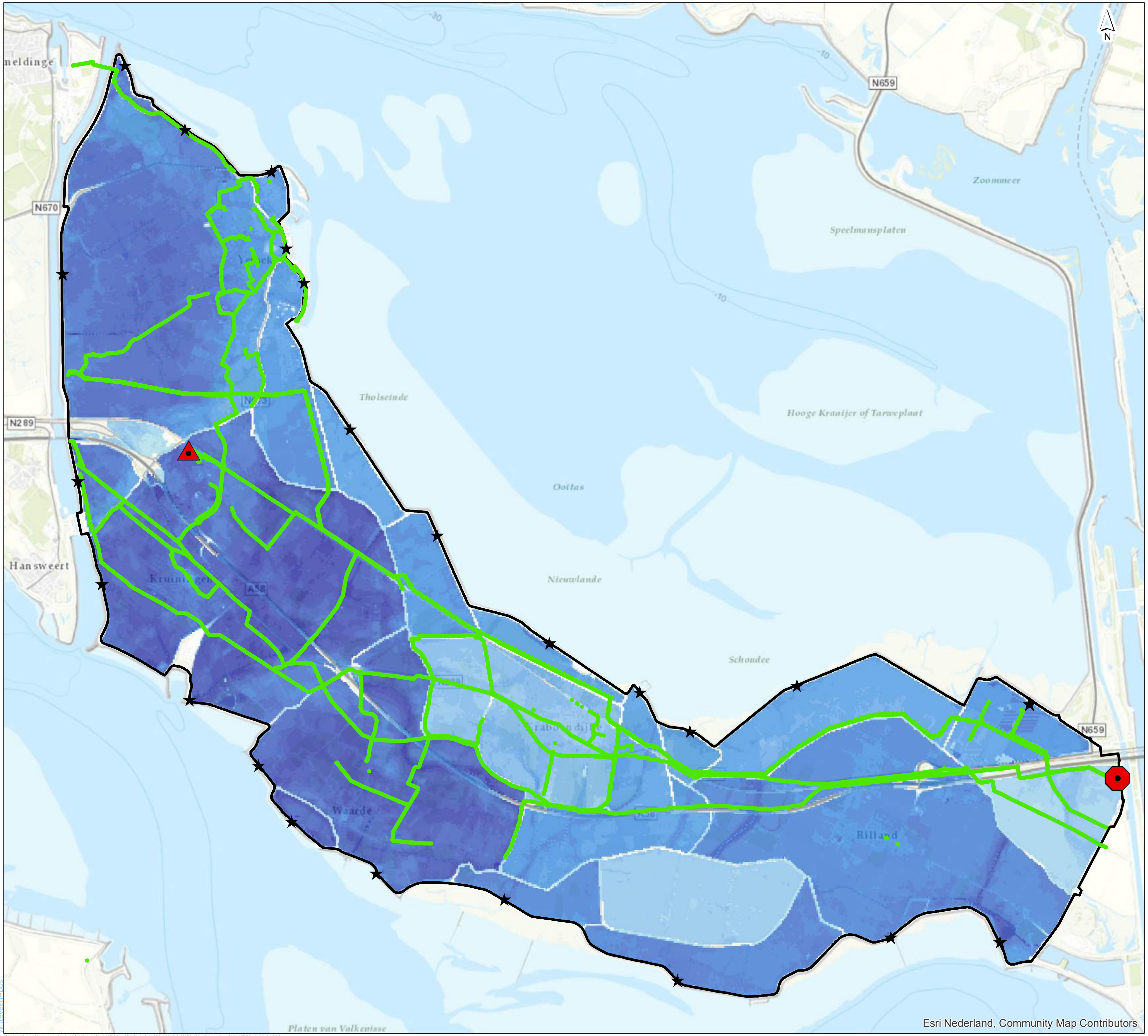
getekend:	ir. I.M. van den Brink	versie:	1
gecontroleerd:	ir. W.R. Debucquoy	datum:	21-12-2018
goedgekeurd:	ir. L.A. Valkenburg	tekeningnr:	0

opdrachtgever: Provincie Zeeland
projectnaam: Kwetsbaarheidsanalyse Vitale Infrastructuur Reimerswaal
projectcode: 105918

formaat: A3 liggend
schaal: 1:55000

0 500 1000 1500 2000 2500 m

Witteveen + Bos



Legenda

- Dijkring 31
- ★ Breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Drink- en proceswater

- **Industriewater Prod. - schade**
- **Pomp - schade**

Bluswaterleidingen

- **d > 150 mm - geen schade**

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max. scenario OS en WS
Netwerk drink- en proceswater

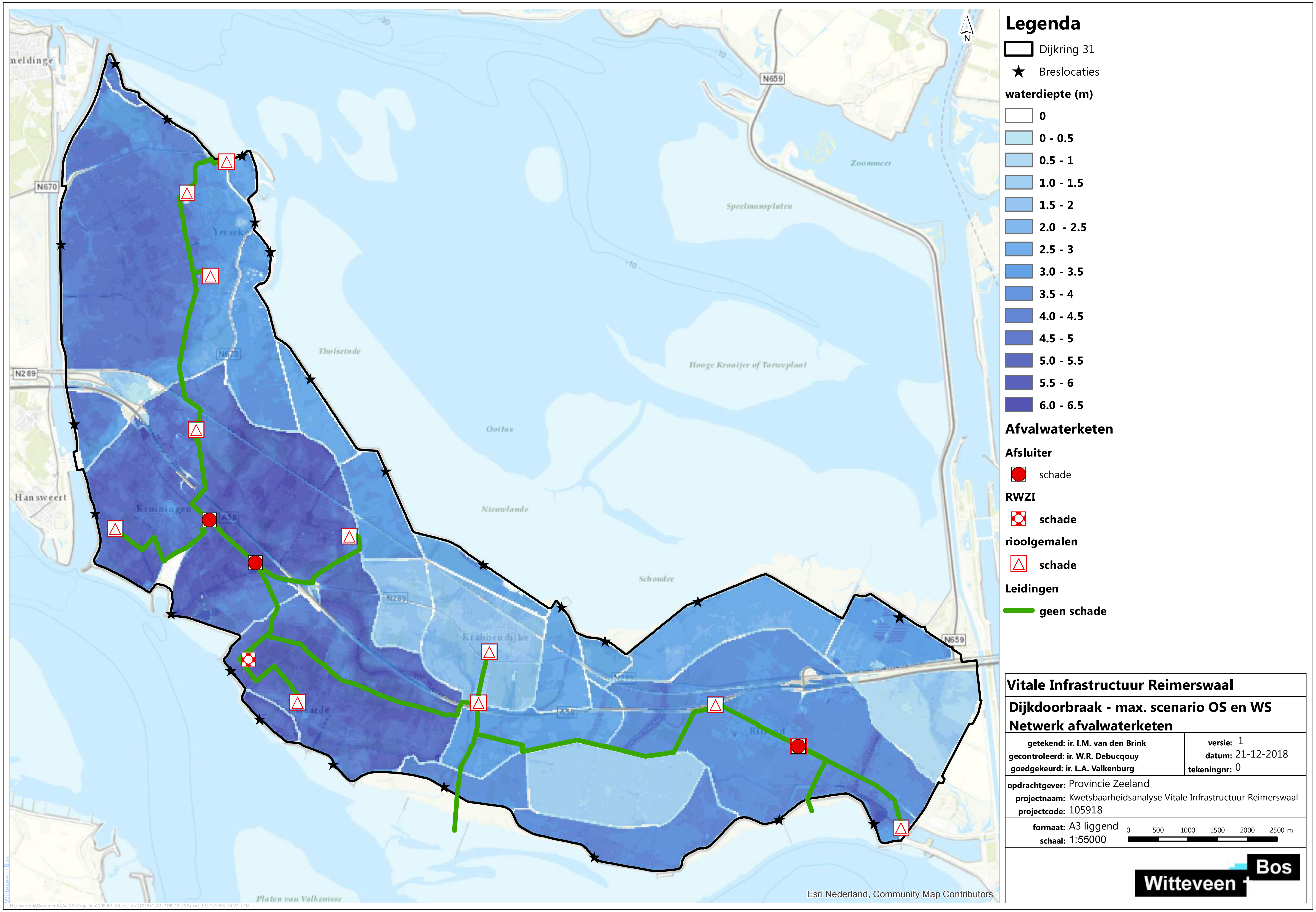
getekend: ir. I.M. van den Brink	versie: 1
gecontroleerd: ir. W.R. Debucquoy	datum: 21-12-2018
goedgekeurd: ir. L.A. Valkenburg	tekeningnr: 0

opdrachtgever: Provincie Zeeland
projectnaam: Kwetsbaarheidsanalyse Vitale Infrastructuur Reimerswaal
projectcode: 105918

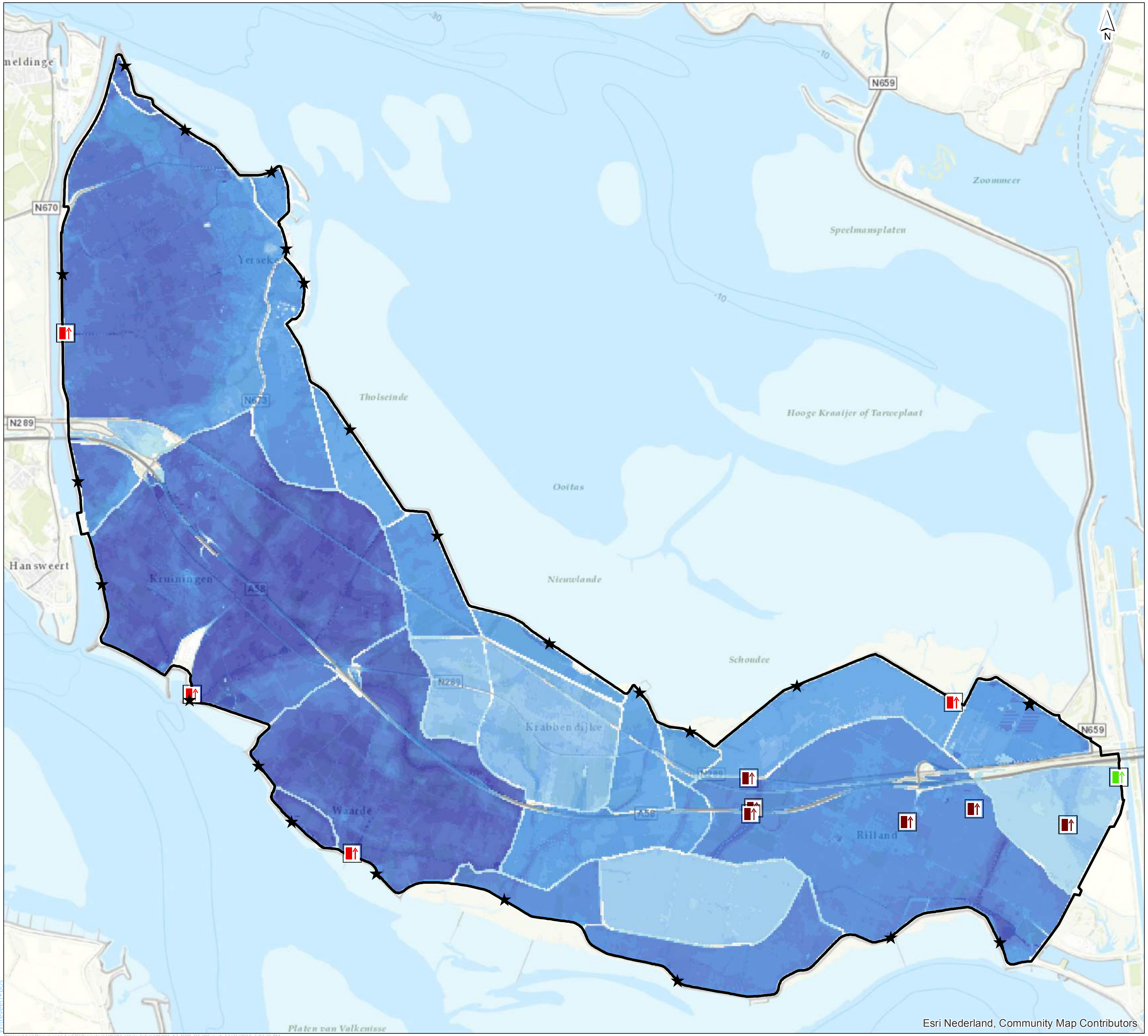
formaat: A3 liggend
schaal: 1:55000

0 500 1000 1500 2000 2500 m

Witteveen+Bos



Legenda
Dijkring 31
Breslocaties
waterdiepte (m)
0
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5 - 5
5.0 - 5.5
5.5 - 6
6.0 - 6.5
Afvalwaterketen
Afsluiter
schade
RWZI
schade
rioolgemalen
schade
Leidingen
geen schade
N
N670
N289
N673
N659
A58
Hansweert
Kruiningen
Yerseke
Tholseinde
Ooitas
Nieuwlande
Schoudee
Krabbendijke
Zoommeer
Speelmansplaten
Hooge Kraaijer of Tarweplaat
Platen van Valkenisse
Esri Nederland, Community Map Contributors
Vitale Infrastructuur Reimerswaal
Dijkdoorbraak - max. scenario OS en WS
Netwerk afvalwaterketen
getekend: ir. I.M. van den Brink
gecontroleerd: ir. W.R. Debucquoy
goedgekeurd: ir. L.A. Valkenburg
versie: 1
datum: 21-12-2018
tekeningnr: 0
opdrachtgever: Provincie Zeeland
projectnaam: Kwetsbaarheidsanalyse Vitale Infrastructuur Reimerswaal
projectcode: 105918
formaat: A3 liggend
schaal: 1:55000
0 500 1000 1500 2000 2500 m
Witteveen + Bos



Legenda

- Dijkring 31
- ★ Breslocaties

waterdiepte (m)

- 0
- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- 5.0 - 5.5
- 5.5 - 6
- 6.0 - 6.5

Waterbeheer

- aanvoer, geen schade
- afvoer, schade
- onderbemaling, schade

Vitale Infrastructuur Reimerswaal

Dijkdoorbraak - max. scenario OS en WS Netwerk waterbeheer

getekend: ir. I.M. van den Brink	versie: 1
gecontroleerd: ir. W.R. Debucquoy	datum: 21-12-2018
goedgekeurd: ir. L.A. Valkenburg	tekeningnr: 0

opdrachtgever: Provincie Zeeland
projectnaam: Kwetsbaarheidsanalyse Vitale Infrastructuur Reimerswaal
projectcode: 105918

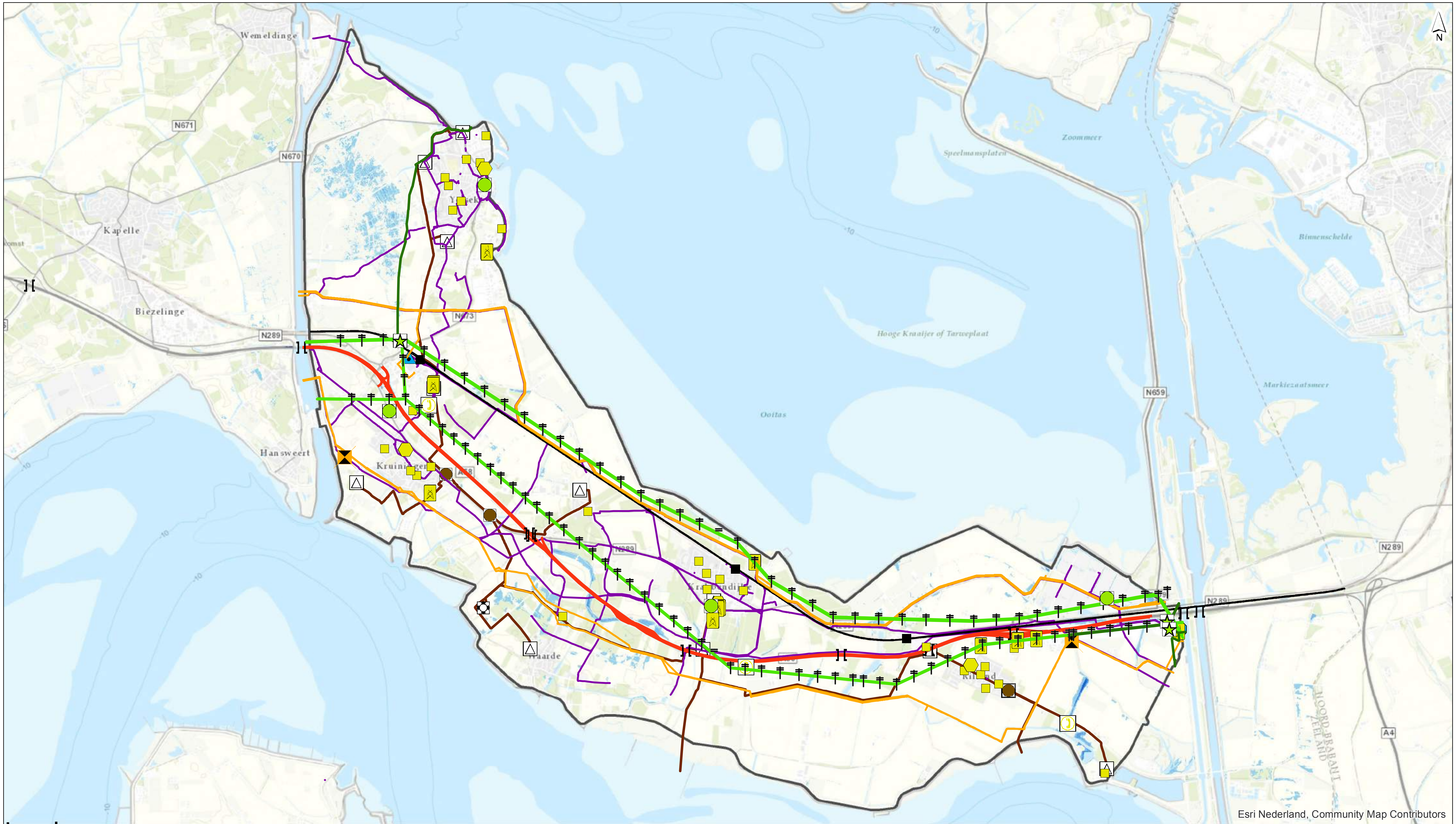
formaat: A3 liggend
schaal: 1:55000

0 500 1000 1500 2000 2500 m

Witteveen + Bos

VII

ANNEX: RESULTS OF PLUVIAL FLOODING (T=100)



Legenda

Waterdiepte (m)
- 0
- 0 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00
- 2.00

Dijkring
- 31

Telecom
- C2000
- Wijkkasten
- Straatkasten
- Zendmasten

Afvalwaterketen
- Afsluiters
- RWZI
- rioolgemalen
- Leidingen

Drink- en proceswater
- Industriewater Prod.
- Pomp

Bluswaterleidingen
- d >150 mm

Gas
- Gts Assets
- Gasleiding

Spoorbaan
- Stations

Infrastructuur
- A58
- Kunstwerken

Elektriciteit
- Hoofdverdeelstation
- Masten
- Schakelstation
- Grondkabels
- Luchtlijnen

drawn: ir. I.M. van den Brink
verified: ir. W.R. Debucquoy
approved:
version: 1
date: 24-07-2018
drawing no: 0

page size: A3 landscape
scale: 1:64360
0 500 1000 1500 2000 2500 m

Vitale Infrastructuur Reimerswaal

Wateroverlast - T100

client: Provincie Zeeland
project: Kwetsbaarheidsanalyse Vitale Infrastructuur RW
project code: 105918

Witteveen + Bos

VIII

ANNEX: ESTIMATION OF DIRECT DAMAGE

Table VIII.1 Indication of direct damage to networks with maximum Oosterschelde scenario (non-flood proof regional barriers)

Network	Type of object	Number of objects	Damage indication per unit in EUR	Total damage in EUR
electricity	main distribution station 110/150 kV (HVS) 1,000 m^2 building and 9,000 m^2 transformer bay	1	4,750,000	4,750,000
	switching stations 10 kV	4	475,000	1,900,000
gas	gas reception stations (GOS) (120 m^2)	1	300,000	300,000
telecom/ICT	district cabinets (8 m^2)	3	52,000	156,000
	GSM 1800	4	5,000	20,000
	GSM 900	6	5,000	30,000
	LTE masts	14	5,000	70,000
	UMTS masts	10	5,000	50,000
	C2000 masts	3	5,000	15,000
A58	Vlaketunnel (327 m tunnel, 774 m total)	1	provisional sum for recovery of installations 20,000,000	20,000,000
	motorway	13 km	(further determined in FRAMES pilot Public Works and Water Management)	6,300,000
railway	railway.	11 km	provisional sum for recovery 1,000,000	11,000,000
	stations	1	provisional sum for recovery 5,000,000	5,000,000
drinking water	production station process water (lot 5,000 m^2 buildings 1,200 m^2)	1	3,000,000	3,000,000
sewage	SEWAGE TREATMENT PLANT	1	4,250,000	4,250,000
	sewage pumping station	9	140,000	1,260,000
barriers and management of surface water	pumping stations (average 150 m^3/min, 40 m^2)	4	140,000	560,000
total indirect damage				**58,661,000**

Table VIII.2 Indication of direct damage to networks at maximum Oosterschelde and Westerschelde scenario (non-flood proof regional barriers)

Network	Type of object	Number of objects	Damage indication per unit in EUR	Total damage in EUR
electricity	main distribution station (HVS)	1	4,750,000	4,750,000
	switching stations 10 kV	4	475,000	1,900,000
gas	gas reception stations (GOS)	1	300,000	300,000
telecom	district cabinets	4	52,000	208,000
	GSM 1800	5	5,000	25,000
	GSM 900	8	5,000	40,000
	LTE masts	17	5,000	85,000
	UMTS masts	14	5,000	70,000
	C200 masts	3	5,000	15,000
A58	Vlaketunnel	1	20,000,000	20,000,000
	motorway	17 km	(further determined in FRAMES pilot Public Works and Water Management)	9,200,000
railway	railway.	15 km	1,000,000	15,000,000
	stations	3	5,000,000	15,000,000
drinking water	production station process water	1	3,000,000	3,000,000
sewage	SEWAGE TREATMENT PLANT	1	4,250,000	4,250,000
	sewage pumping station	12	140,000	1,680,000
barriers and management of surface water	pumping stations	4	140,000	560,000
total indirect damage				**76,083,000**

Table VIII.3 Indication of direct damage to networks with maximum Oosterschelde scenario (flood proof regional barriers)

Network	Type of object	Number of objects	Damage indication per unit in EUR	Total damage in EUR
electricity	main distribution station (HVS)	1	4,750,000	4,750,000
	switching stations 10 kV	3	475,000	1,425,000
gas	gas reception stations (GOS)	0	300,000	-
telecom	district cabinets	2	52,000	104,000
	GSM 1800	3	5,000	15,000
	GSM 900	3	5,000	15,000
	LTE masts	8	5,000	40,000
	UMTS masts	6	5,000	30,000
	C200 masts	0	5,000	-
A58	Vlaketunnel	0		-
	motorway	0		-
railway	railway.	5	provisional sum for recovery 1,000,000	5,000,000
	stations	1	provisional sum for recovery 5,000,000	5,000,000
drinking water	production station process water	0	3,000,000	-
sewage	SEWAGE TREATMENT PLANT	0	4,250,000	-
	sewage pumping station	4	140,000	560,000
barriers and management of surface water	pumping stations	2	140,000	280,000
total indirect damage				**17,219,000**

Table VIII.4 Indication direct damage to networks at maximum Ooster- and Westerschelde scenario (steadfast regional barriers)

Network	Type of object	Number of objects	Damage indication per unit in EUR	Total damage in EUR
electricity	main distribution station (HVS)	1	4,750,000	4,750,000
	switching stations 10 kV	4	475,000	1,900,000
gas	gas reception stations (GOS)	1	300,000	300,000
telecom	district cabinets	3	52,000	156,000
	GSM 1800	4	5,000	20,000
	GSM 900	8	5,000	40,000
	LTE masts	17	5,000	85,000
	UMTS masts	14	5,000	70,000
	C200 masts	3	5,000	15,000
A58	Vlaketunnel	0	20,000,000	-
	motorway	10 km	(further determined in FRAMES pilot Public Works and Water Management)	8,100,000
railway	railway.	11.5 km	10000.000	11,500,000
	stations	3	5,000,000	15,000,000
drinking water	production station process water	1	3,000,000	3,000,000
sewage	SEWAGE TREATMENT PLANT	1	4,250,000	4,250,000
	sewage pumping station	12	140,000	1,680,000
barriers and management of surface water	pumping stations	4	140,000	560,000
total indirect damage				**51,426,000**

IX

ANNEX: MEMO ECORYS

Memo ‘Waardering van schade ten gevolge van uitval elektriciteitsnetwerk’

Datum: 21-10-2018
Auteurs: Alexander Oei (Ecorys) en Robert Haffner (Ecorys)

Overstromingen kunnen leiden tot substantiële schades aan vitale infrastructuren zoals het *elektriciteitsnetwerk*. Naast directe kosten ten gevolge van fysieke schades aan de elektriciteitsinfrastructuur dient men tevens rekening te houden met indirecte kosten, ten gevolge van de uitval van deze infrastructuur. In dit document beschrijven we: **(1)** de uitgangspunten, **(2)** de aanpak en **(3)** de resultaten van de doorrekeningen die wij hebben uitgevoerd in opdracht van Witteveen+Bos. De memo sluit af met een korte reflectie.

1. Uitgangspunten

In het kader van het ‘FRAMES-project’ hebben wij ten behoeve van de pilot Reimerswaal een doorrekening gedaan van de indirecte schade aan huishoudens en economische activiteiten binnen de provincie Zeeland.

Hierbij zijn de volgende uitgangspunten gehanteerd:

- De doorrekening is primair gericht op de effecten van uitval van het elektriciteitsnetwerk in de gemeente Reimerswaal en de bijbehorende keteneffecten van uitval voor de directe omgeving en de provincie Zeeland.
- Het gehele elektriciteitsnetwerk in de regio is beschouwd, dat wil zeggen, elektriciteitsproductie, transport (hoogspanning en laagspanning), en consumptie.
- De schade ten gevolge van uitval wordt gerapporteerd op gemeenteniveau. Daarnaast wordt er een globale schatting gegeven van de keteneffecten op het COROP-gebied[1] waartoe de gemeente Reimerswaal behoort, overig-Zeeland, en Nederland.

Wat-als-scenario’s

De schade ten gevolge van elektriciteitsuitval wordt bepaald op basis van wat-als-scenario’s. Er zijn drie scenario’s doorgerekend:

1. Uitval van het hoogspanningsnetwerk met grote impact op COROP-gebied ‘overig Zeeland’ voor korte duur (1 tot 4 dagen, respectievelijk $S1_{min}$ en $S1_{max}$);
2. Uitval van het hoogspanningsnetwerk en een gedeelte van het laagspanningsnetwerk in het COROP-gebied ‘overig Zeeland’ voor middellange duur (meer dan 14 dagen, S2)';
3. Uitval van het hoogspanningsnetwerk en een gedeelte van het laagspanningsnetwerk in het COROP-gebied ‘overig Zeeland’ voor lange duur (tot 3 maanden, S3).

2. Aanpak

De schade voortkomend uit de indirecte kosten kan op verschillende wijzen worden gewaardeerd. Wij bespreken hier eerst de aanpak voor de doorrekening van de schade aan huishoudens, vervolgens de aanpak voor de doorrekening van de schade aan economische activiteiten.

2.1 Huishoudens

Literatuur over de schade van elektriciteitsuitval focust zich voornamelijk op de korte termijn, enkele minuten tot een paar dagen. In de gevraagde doorrekening zijn we echter ook specifiek geïnteresseerd in de middellange termijn (S2, meer dan 14 dagen) en de lange termijn (S3, meer

[1] Een COROP-gebied is “een geografische indeling op basis van een ‘kern’ met verzorgingsgebied of regiofunctie”. Zie de RegioAtlas van het Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. Link: https://www.regioatlas.nl/indelingen/indelingen_indeling/t/corop_regio_s

dan 3 maanden). We hebben er daarom voor gekozen om meerdere doorrekeningen te doen zodat er een breder beeld ontstaat van hoe schade voor huishoudens gewaardeerd zou kunnen worden.

De doorrekeningen zijn uitgevoerd op basis van drie verschillende uitgangspunten:
1. De wettelijk vastgelegde compensatie volgens de Netcode elektriciteit.
2. De 'vignettenmethode'
3. De kosten van het realiseren van een noodvoorziening door de lokale netbeheerder

Wettelijk vastgelegde compensatie.
In de Netcode elektriciteit[2] is vastgelegd dat wanneer de stroom langer dan vier uur uitvalt de lokale netbeheerder verplicht is om huishoudens te compenseren. Een onderbreking van 4 tot 8 uur kost de netbeheerder €35,- per huishouden toenemend met €20,- voor elk blok van 4 uur langer dan de eerste 8 uur. Goed om te vermelden is dat deze compensatie niet geldt in het geval van een overstroming omdat dit buiten de macht van de netbeheerder valt (zie artikel 6.3.2 b). Desalniettemin geeft de totale schade op basis van de compensatiebedragen een indicatie van de 'maatschappelijke schade' ten gevolge van stroomuitval gezien deze bedragen de compensatie voor stroomuitval weergeven.

Vignettenmethode
In de literatuur zijn er verschillende concepten bekend om de schade aan huishoudens ten gevolge van stroomuitval te waarderen. Twee veelgebruikte principes zijn (1) het 'willingness-to-pay principe' (WTP) en (2) het 'willingness-to-accept principe' (WTA).

In het geval van WTP, gaat men op zoek naar de bedragen die respectievelijk huishoudens, en bedrijven bereid zijn om te betalen om een stroomonderbreking te *voorkomen* (zie bijvoorbeeld Nederlandse en internationale literatuur[3]). In het geval van WTA, gaat men op zoek naar de bedragen die respectievelijk huishouden en bedrijven bereid zijn om te betalen om een stroomonderbreking te *accepteren*. In beide gevallen kan men op basis van de vastgestelde bedragen door middel van een prijs maal hoeveelheid (cumulatieve hoeveelheid verlies van energie) berekening afschatten wat de schade is ten gevolge van een stroomonderbreking.

De WTA en WTP principes kennen echter een paar nadelen. Ten eerste is het nodig om middels een directe vraagstelling in enquêtes de preferenties van consumenten te achterhalen. Een directe vraagstelling leidt mogelijk tot strategisch gedrag waardoor het lastig is om preferenties goed te meten. Bovendien blijkt uit onderzoek van OFGEM (de Engelse regulator voor energie) dat bij herhaling van WTP studies de preferenties van consumenten kunnen veranderen. Een belangrijke mogelijke oorzaak hierachter is dat bij het vragen naar de preferenties van consumenten middels deze methode consumenten het huidige kwaliteitsniveau van het elektriciteitssysteem meewegen waardoor de resultaten gekleurd zijn[4]. Met andere woorden: Een consument van wie de kwaliteit van elektriciteitslevering slecht is, is bereid om meer te betalen voor een verbetering van het kwaliteitsniveau dan een consument van wie de levering van elektriciteit reeds goed is.

Een methode die bovengenoemde nadelen niet kent is de 'vignettenmethode'[5]. In de vignettenmethode spreken consumenten hun voorkeur uit op basis van een hypothetische

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2 Zie: https://zoek.officielebekendmakingen.nl/stcrt-2016-21423.html

3 Zie bijvoorbeeld: Overlegtafel Energievoorziening (2017). 'Marktdesign elektriciteitsvoorziening: Toetsing van marktontwerpen en stimuleringsmaatregelen voor de Nederlandse elektriciteitsmarkt op weg naar een duurzame toekomst'; Mulder, M. (2017). 'Energy transition and the electricity market: an exploration of an electrifying relationship'; en Surendran, R. et al. (2016). 'Scarcity Pricing in ERCOT'.

4 Zie SEO (2011). Waardering van stroomstoringen. P. 26.

5 Een verdere beschrijving van de principes achter de berekeningssystematiek is te vinden in een rapport uit 2012 dat onderzoeksbureau Blauw heeft opgesteld in opdracht van De Energiekamer (nu ACM) getiteld 'Waardering Stroomonderbrekingen 2012: Onderzoek onder MKB-bedrijven en huishoudens naar de gewenste compensatie bij stroomonderbrekingen'.

netwerkkwaliteit en prijs. Op deze wijze worden ze niet direct gevraagd naar wat ze over hebben voor een verbetering van netwerkkwaliteit of de benodigde compensatie voor het accepteren van stroomstoringen. Daarnaast kan er ook rekening worden gehouden met de kwaliteit van het netwerk. Wij gebruiken in onze doorrekening de cijfers uit Rapport Blauw, opgesteld voor de Energiekamer van de Nederlandse Mededingingsautoriteit in 2012 (nu Autoriteit Consument en Markt).

Een nadeel van de cijfers uit de vignettenanalyse van onderzoeksbureau Blauw is dat het genoemde onderzoek tevens op de korte termijn is gericht. De 'vignetten' hebben kenmerken van stroomstoringen met een duur van 0,5 minuut tot 24 uur (en nooit / langer dan 24 uur). De vignettenanalyse kan daarom enkel voor de korte termijn scenario's als methode worden gebruikt.

Kosten realiseren noodvoorziening

Vanwege de wens om ook de langere termijn te bekijken hebben we tevens de schade uitgerekend in het geval dat er een noodvoorziening wordt uitgerold door de netbeheerder. We zien dit als een realistisch alternatief wanneer het laagspanningsnetwerk nog functioneert, maar er enkel geen stroomvoorziening voor beschikbaar is – het hoogspanningsnetwerk is uitgevallen en er is geen decentrale opwek van elektriciteit beschikbaar.

In deze ruwe inschatting zijn er een aantal uitgangspunten gehanteerd:

- Voor de noodvoorziening worden er diesel-generatoren ingezet welke aangesloten kunnen worden op transformatorhuisjes in de wijk.
- We gaan uit van 75 huishoudens per generator
- De huishoudens kennen een 'gelijktijdigheidsfactor' van 0,7; dat wil zeggen dat huishoudens niet precies tegelijkertijd hun piekvraag gebruiken.
- Er wordt een overcapciteit van 25% geïnstalleerd
- We rekenen een variant door waarin de benodigde diesel-generatoren kunnen worden gehuurd en waar ze worden aangekocht.
- De kosten voor de benodigde brandstof, diesel, worden tevens meegerekend. De generator heeft een typische efficiëntie van 35%.

Deze doorrekening is een ruwe doorrekening voor een wat-als-scenario, namelijk enkele de stroomvoorziening hoeft geregeld te worden, het laagspanningsnetwerk is nog volledig intact. Bovendien worden de kosten van planning en inzet van personeel niet meegerekend. Deze doorrekening dient als vingeroefening om een gevoel voor de ordegrootte van de schade te krijgen.

2.2 Economische activiteiten

Voor het inschatten van de schade aan economische activiteiten in de regio gaan we uit van het *productieverlies* ten gevolge van de stroomuitval. De maximale schade aan economische activiteiten is gelijk aan de totale uitval van de economische activiteiten. Als indicatie voor het productieverlies kijken we naar de *bruto toegevoegde waarde* op bedrijfstakniveau. De bruto toegevoegde waarde is een maat voor de waarde die gecreëerd wordt in een bedrijfstak en is gelijk aan de marktwaarde van productie minus de waarde van de ingekochte grondstoffen voor productie.

Inzet van maatregelen om productieverlies te voorkomen.

In werkelijkheid hoeft elektriciteitsuitval echter niet altijd te leiden tot een volledige uitval van activiteiten. Afhankelijk van de bedrijfstak onder beschouwing zijn er verschillende mogelijkheden om productieverlies te voorkomen. Bedrijfstakken kunnen beschikken over back-up faciliteiten (bijvoorbeeld noodaggregaten of batterijen) of hebben bijvoorbeeld mogelijkheden tot uitwijking, aanpassing van productieprocessen en verschuivingen in planningen. Een belangrijke variabele hierin is de duur van de stroomuitval. Het inzetten van maatregelen om productieverlies te voorkomen leiden veelal wel tot hogere kosten voor de productie waarmee de bruto toegevoegde waarde afneemt. Verder is het denkbaar dat afhankelijk van de situatie de maatregelen een gedeelte van de productie in stand kunnen houden versus de gehele productie.

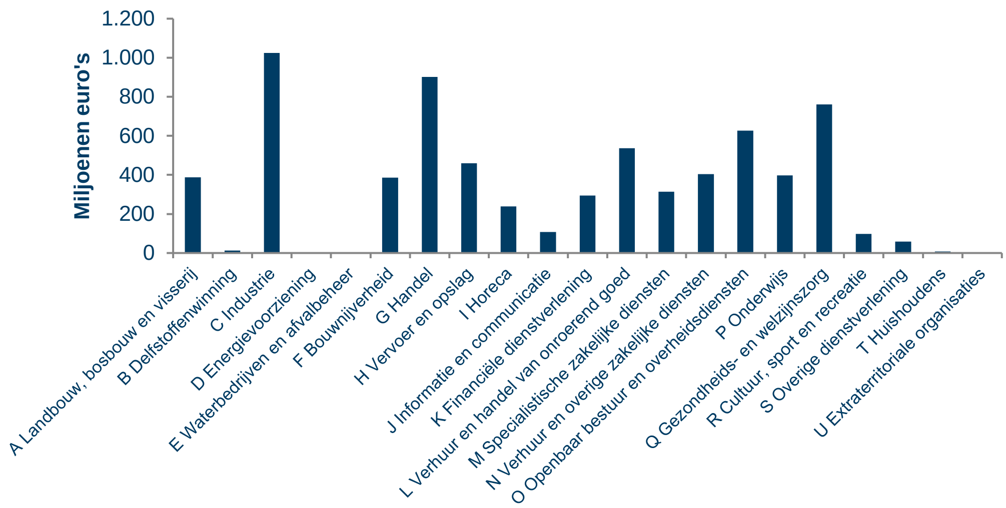
Op basis van bovengenoemde redeneerlijn hebben wij voor de economische activiteiten in het onderzoeksgebied een inschatting gemaakt in hoeverre deze in staat zijn om productieverlies te voorkomen door middel van bovengenoemde inzet van maatregelen. Deze analyse hebben wij op basis van een expert judgment uitgevoerd door middel van een brainstorm. Witteveen+Bos heeft feedback op deze analyse gegeven om de cijfers aan te scherpen.

Input voor totale maximale schade aan economische activiteiten

De bruto toegevoegde waarde van economische activiteiten is in de CBS StatLine database beschikbaar per SBI bedrijfstak en op COROP gebiedsniveau. De gemeente Reimerswaal behoort tot het COROP-gebied ‘Overig-Zeeland’ samen met negen andere gemeenten. Deze gemeenten zijn Borsele, Kapelle, Noord-Beveland, Schouwen-Duiveland, Veere, Goes, Middelburg, Tholen en Vlisssingen.

De bruto toegevoegde waarde van economische activiteiten in het COROP-gebied ‘Overig-Zeeland’ zijn geschaald naar de gemeente Reimerswaal voor cijfers op gemeenteniveau. Deze cijfers vormen de input voor de maximale inschatting en zijn ‘afgepeld’ volgens de beschreven aanpak. Onderstaande figuur geeft een beeld van productiewaarde van het COROP-gebied overig-Zeeland. Onderstaande cijfers betreffen de jaarlijkse bruto toegevoegde waarde, deze zijn geschaald naar de duur van de stroomuitval (zie scenario’s).

Figuur 1 Bruto toegevoegde waarde basisprijzen COROP regio 'overig Zeeland (CR)' 2015



NB1: De CBS data is onvolledig. Voor de categorieën (D) energievoorziening en (E) waterbedrijven en afvalbeheer zijn geen cijfers beschikbaar hoewel er wel degelijk bedrijven actief zijn in deze COROP regio. Denk aan bijvoorbeeld de kerncentrale Borssele, de Sloecentrale van PZEM en EDF en het drinkwaterbedrijf Evides.

Bron: CBS Open data StatLine (2017), *Productieproces; bedrijfstakken, regio*, 82797NED, geraadpleegd op 18-7-2018. Link: https://opendata.cbs.nl/statline/portal.html?_la=nl&_catalog=CBS&tableId=82797NED&_theme=326

3. Resultaten

Hieronder geven wij de resultaten van de doorrekeningen weer zoals hierboven beschreven voor huishoudens en voor economische activiteiten. De analyse van de resultaten is terug te vinden in het analyse rapport van de ‘Pilot Kwetsbaarheid Vitale Infrastructuur Reimerswaal’.

3.1 Huishoudens

Tabel 1 Schade inschatting 'compensatiebedragen netcode' - prijspeil 2018

Schade aan huishoudens	Reimerswaal	Overig-zeeland minus Reimerswaal
Scenario 1 (minimum; 1 dag)	€ 1,186,380	€ 12,054,285
Scenario 1 (maximum; 4 dagen)	€ 4,350,060	€ 44,199,045
Scenario 2 (14 dagen)	€ 14,895,660	€ 26,665,316
Scenario 3 (3 maanden)	€ 95,042,220	€ 170,138,876

Tabel 2 Schade inschatting 'vignettenmethode' - prijspeil 2018

Schade aan huishoudens	Reimerswaal	Overig-zeeland minus Reimerswaal
Scenario 1 (minimum; 1 dag)	€ 146,870	€ 1,492,285
Scenario 1 (maximum; 4 dagen)	€ 182,824	€ 1,857,596
Scenario 2 (14 dagen)	€ 215,315	€ 2,187,720
Scenario 3 (3 maanden)	€ 263,574	€ 2,678,060

Tabel 3 Schade inschatting 'kosten energiegebruik + huren generatoren' - prijspeil 2018

Kosten voor getroffen huishoudens	Reimerswaal	Overig-Zeeland minus Reimerswaal
Scenario 1 (minimum; 1 dag)	€ 46,471	€ 472,171
Scenario 1 (maximum; 4 dagen)	€ 185,884	€ 1,888,683
Scenario 2 (14 dagen)	€ 650,593	€ 6,610,391
Scenario 3 (3 maanden)	€ 4,182,385	€ 42,495,373

Tabel 4 Schade inschatting 'kosten energiegebruik + aankoop generatoren' - prijspeil 2018

Kosten voor getroffen huishoudens	Reimerswaal	Overig-Zeeland minus Reimerswaal
Scenario 1 (minimum; 1 dag)	€ 1,411,540	€ 14,342,039
Scenario 1 (maximum; 4 dagen)	€ 1,498,225	€ 15,222,806
Scenario 2 (14 dagen)	€ 1,787,175	€ 18,158,694
Scenario 3 (3 maanden)	€ 3,983,190	€ 40,471,443

3.2 Economische activiteiten

Tabel 5 S1min: Schade aan economische activiteiten - bruto toegevoegde waarde jaarlijkse productie basisprijzen - inclusief inflatiecorrectie naar prijspeil 2018

SBI Bedrijfstakken	Overig Zeeland (CR)	Zeeland (PV)	Nederland
A Landbouw, bosbouw en visserij	0.3	0.5	11.1
B-E Nijverheid (geen bouw) en energie	1.5	3.4	128.7
F Bouwnijverheid	0.4	0.8	37.6
G-I Handel, vervoer en horeca	1.7	3.2	171.6
J Informatie en communicatie	0.1	0.2	39.6
K Financiële dienstverlening	0.3	0.5	62.9
L Verhuur en handel van onroerend goed	0.6	1.0	47.9
M-N Zakelijke dienstverlening	0.8	1.3	119.8

SBI Bedrijfstakken	Overig Zeeland (CR)	Zeeland (PV)	Nederland
O-Q Overheid en zorg	0.8	0.0	0.0
R-U Cultuur, recreatie, overige diensten	0.2	0.3	21.7
Totaal: alle economische activiteiten	1.7	11.1	640.9

Tabel 6 S2: Schade aan economische activiteiten - bruto toegevoegde waarde jaarlijkse productie basisprijzen - inclusief inflatiecorrectie naar prijspeil 2018

SBI Bedrijfstakken	Overig Zeeland (CR)	Zeeland (PV)	Nederland
A Landbouw, bosbouw en visserij	1.8	3.1	65.4
B-E Nijverheid (geen bouw) en energie	8.7	19.8	757.5
F Bouwnijverheid	2.6	4.9	235.2
G-I Handel, vervoer en horeca	10.6	19.8	1,073.1
J Informatie en communicatie	0.2	0.3	58.3
K Financiële dienstverlening	0.5	0.7	92.5
L Verhuur en handel van onroerend goed	3.5	6.1	299.7
M-N Zakelijke dienstverlening	1.1	1.9	176.4
O-Q Overheid en zorg	7.2	0.0	0.0
R-U Cultuur, recreatie, overige diensten	1.1	1.7	135.7
Totaal: alle economische activiteiten	37.2	58.4	2,893.8

Tabel 7 S3: Schade aan economische activiteiten - bruto toegevoegde waarde jaarlijkse productie basisprijzen - inclusief inflatiecorrectie naar prijspeil 2018

SBI Bedrijfstakken	Overig Zeeland (CR)	Zeeland (PV)	Nederland
A Landbouw, bosbouw en visserij	14.5	25.2	525.2
B-E Nijverheid (geen bouw) en energie	70.1	159.4	6,087.3
F Bouwnijverheid	19.3	36.9	1,778.7
G-I Handel, vervoer en horeca	80.0	149.8	8,115.9
J Informatie en communicatie	1.1	1.7	375.1
K Financiële dienstverlening	2.9	4.7	594.7
L Verhuur en handel van onroerend goed	26.8	46.4	2,266.4
M-N Zakelijke dienstverlening	7.2	12.1	1,133.9
O-Q Overheid en zorg	17.8	0.0	0.0
R-U Cultuur, recreatie, overige diensten	8.2	13.2	1,026.5
Totaal: alle economische activiteiten	248.0	449.4	21,903.5

Reflectie op doorrekeningen

Door middels verschillende benaderingen de schade ten gevolge van elektriciteitsuitval voor huishoudens door te rekenen ontstaat er een vollediger beeld van de ordegrootte van de schade. Dit beeld geeft een indicatie van de waarde van schade en daarmee ook welke waarde er geïnvesteerd zou kunnen worden om uitval te voorkomen.

De analyse voor economische activiteiten betreft tevens een ruwe inschatting. Desalniettemin geeft de ruwe inschatting inzicht in de ordegrootte van de schade ten gevolge van elektriciteitsuitval.

In de doorrekeningen is een drietal *wat-als-scenario's* doorgerekend. De overstromingskans en de kans dat er daadwerkelijk deze mate van elektriciteitsuitval zal plaatsvinden ten gevolge van een overstroming zijn hierbij buiten beschouwing gelaten.

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