BIJLAGEN MER DEEL B BODEM EN WATER OP ZEE

Bijlage VI-A Bronnen bodem en water op zee

Bijlage VI-B Risk Based Burial Depth Export Cables, maart 2018

Bijlage VI-C Seabed mobility study route comparison Windpark Hollandse Kust (Noord), Svasek, November 2017

BRONNEN BODEM EN WATER OP ZEE

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For:

Hollandse Kust (noord) Risk Based Burial Depth Export Cables

March 2018

Please note that white pages are included to have specific pages starting on odd page numbers when printed double-sided.

Client	TenneT TSO bv
Title	Hollandse Kust (noord) Risk Based Burial Depth export cables

Conclusions

1 On the basis of the results of the analyses, the following is concluded:

1. All offshore routes are feasible in the sense that burial of the cables is possible to achieve acceptable risk levels;
2. Offshore routes 1, 2, 3 and 4 do not cross the IJ-geul and achieve the acceptable risk levels with less burial;
3. Route 6 and 7 do cross the IJ-geul and need deeper burial to achieve the required risk level;
4. The Noordzeekanaal sections of route 4 and 5 are feasible and should be further optimised in terms of detailed alignment along the axis of the channel and where and how to cross.

2 In summary (ignoring onshore issues which are outside the scope of this study), the following routes are proposed to assess further:

1. Route route 4 and/or 5, including the Noordzeekanaal section;
2. Route 1 or 2 or 3;
3. Route 6 or 7 (mainly the IJ-geul crossing) only if the other options are not feasible, or are possibly expect to become not feasible.

3 It is proposed to include Signal and Minimum burial limits as permit provisions to (1) define at which burial depths remediation plans are to be prepared and (2) at which burial depths approved remediation plans must be ready to be implemented.

Recommendation

1 After completion of the morphological study and the Burial Assessment Study, it is recommended to evaluate the results of these studies within the framework of the risk based burial approach, and to assess if further optimisation of the installation of the Hollandse Kust (noord) export cables is possible within the then ruling permit provisions. This recommendation holds for the offshore routes (1-7) and the Noordzeekanaal sections of route 4 and 5.

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Abbreviations and definitions

AF	Asset-Factor, the factor that describes the capacity of the asset to resist external loads.
AIS	Automatic Identification System, VHF signal transmitted by vessels including position, speed and other relevant data.
BF	Burial-Factor, the factor that describes the capacity of the soil above the asset to absorb the energy from external threats.
Burial depth	Distance between Top of Cable (ToC) and the seabed reference (see definition below).
CA	Competent Authority.
CoF	Consequence of Failure.
DoB	Depth of Burial, difference between top of the cover on the seabed and Top of Cable.
HDD	Horizontal Directional Drilling.
HKN	Hollandse Kust (noord).
ITT	Information To Tenderers
KP	Kilometre Point, usual measure along linear asset.
KPR	Relative Kilometre Point measured from 0 at the start of the Noordzeekanaal route.
MBES	Multi Beam Echo Sounder.
MDB	Morphological Design Basis.
M€	1,000,000 Euro
MFE	Mass Flow Excavation
NGD	Nautical Guaranteed Depth
NZ-kanaal	Noordzee kanaal, North Sea Canal
PoF	Probability of Failure.
RBBD	Risk Based Burial Depth, abbreviation used for methodology.
Seabed reference or Non-Mobile-Reference Level	The seabed reference level for cable burial under mega-ripples and under sand waves.
RWS	Rijkswaterstaat.
ToC	Top of Cable, absolute level of the top/upper-side of the cable.
Wbr	Wet beheer rijkswaterstaatswerken.

Samenvatting

Doel

Het doel van deze studie is het bepalen van de begraafdiepte voor de zeven mogelijke tracés van de Hollandse Kust (noord) exportkabels op basis van een risico benadering. De resultaten van de studie hebben primair tot doel het bijdragen aan de keuze van het VKA, en secundair het verschaffen van informatie ten behoeve van de informatie naar aannemers, het plannen van optimaal beheer van de exportkabels en het onderbouwen van toekomstige vergunningsvoorwaarden, terwijl de risico's tot een aanvaardbaar minimum beperkt blijven.

Aanpak

De studie betreft twee aspecten, te weten de risico's voor de kabel en de risico's voor 'derden', met name vissers. De risico's voor de kabel worden veroorzaakt door externe mariene bedreigingen: (1) zinkende en (2) strandende schepen, (3) vallende en (4) slepende en hakende ankers en (5) bodemberoerende visserij [1]. De risico's voor bodemberoerende visserij worden veroorzaakt door het mogelijk blijven haken van vistuig achter de exportkabel. Op basis van AIS data, en in beperkte mate radar data, worden de frequenties van de genoemde gebeurtenissen bepaald voor segmenten van 100 m waarin alle tracés van de exportkabels zijn verdeeld. Ook de zeebodem en de toekomstige kabelligging worden voor dezelfde segmenten van 100 m bepaald. Andere mogelijke effecten van de begraafdiepte van de kabel, zoals bodemtemperatuur en elektromagnetische veldsterktes, maken geen deel uit van deze studie.

Risico gestuurde begraafdiepte

Voor de verschillende mariene bedreigingen worden de faalscenario's, bijbehorende faalkansen en gevolgen bepaald, afhankelijk van de begraafdiepte. Op basis van project specifieke risicomatrices met criteria voor 'Veiligheid, Milieu', en voor 'Asset, Reputatie en Kosten', worden de risico's bepaald. De resultaten van deze analyse vormen de basis voor het optimaliseren van de risico gestuurde begraafdiepte.

Conclusies

1. Op basis van de resultaten van de analyses, worden de volgende conclusies getrokken:
    1. Voor alle offshore tracés geldt dat de begraafdiepten die nodig zijn om te voldoen aan de gestelde risico-eisen, haalbaar zijn;
    2. Offshore tracés 1, 2, 3 en 4 kruisen niet de IJ-geul en voldoen met een kleinere begraafdiepte aan de risico-eisen;
    3. Tracé 6 en 7 kruisen de IJ-geul en vereisen een grotere begraafdiepte om te voldoen aan de risico-eisen;
    4. Het deel van tracé 4 en 5 door het Noordzeekanaal is haalbaar en kan verder worden geoptimaliseerd in termen van detail tracé ontwerp langs de kanaal-as, en waar en hoe het kanaal met de kabels zal worden gekruist.

[1] De gegeven volgorde is het gevolg van de analyse methode van de bedreigingen, en geeft NIET de volgorde van belangrijkheid van de bedreigingen. Die volgt als resultaat van de studie.

2. Samengevat (waarbij onshore aspecten die niet tot de scope van deze studie horen, niet worden beschouwd), wordt voorgesteld de volgende tracés nader te onderzoeken:
   1. Tracés 4 en 5, inclusief het deel door het Noordzee Kanaal;
   2. Tracé 1 of 2 of 3;
   3. Tracé 6 of 7 (voornamelijk de IJ-geul kruising) alleen als andere tracés niet haalbaar blijken, of naar verwachting niet haalbaar zullen blijken.

3. Voorgesteld wordt om signaal- en minimum begraafdiepten als vergunningsvoorwaarden op te nemen om de begraafdiepten de specificeren waarbij (1) herstelplannen moeten worden gemaakt (signaal-diepte en (2) wanneer herstelplannen gereed moeten zijn voor gebruik (minimum diepte).

Aanbeveling

Na gereedkomen van de morfologische studie en de Burial Assessment Study, wordt aanbevolen de resultaten van die studies te beschouwen in het licht van de risico-gestuurde aanpak, en te beoordelen of optimalisatie van de aanleg (tracé en begraafdiepte) van de HKN export-kabels mogelijk is binnen de dan geldende vergunningsvoorwaarden. Deze aanbeveling geldt voor alle offshore tracés (1 – 7) en het Noordzee Kanaal van tracés 4 en 5.

1 Introduction

Background

TenneT TSO bv prepares the connection from the Hollandse Kust (noord) (HKN) offshore wind farms to the shore by two export power cables. The cables connect Hollandse Kust (noord) platform to the land station. In total, seven route alternatives have been selected in the offshore route development phase. Routes 4 and 5 are the same at sea and partially the same in the Noordzee kanaal (NZ-kanaal).

To determine the burial depth of the submarine export cable alternatives, various parameters will be assessed by TenneT, including the risk of damage to the cable by external causes. For this reason a risk based burial depth (RBBD) study on the offshore cable routes shall be performed. ACRB was engaged to perform such dedicated RBBD study. The results of this study are to be used in the selection of the preferred route alternative (in Dutch: Voorkeursalternatief, VKA), the permitting and sea cable tender process and the preparation of an operation and maintenance plan for the Hollandse Kust (noord) export cables.

Permitting process

Relevant boundary conditions for this study are the initial burial requirements as specified by the Dutch Competent Authorities. The Dutch authorities require a minimum burial depth of 3 m between 0 and 1 km from the coast [2] and 1 m thereafter. For the crossings of fairways additional burial requirements apply.

Project location

The project location with all cable route alternatives is presented in Figure 1.1 showing the various routes and the main shipping areas, and in Figure 1.2 showing the seabed bathymetry.

[2] Measured from the coast means the distance perpendicular to the coast, which means a longer distance along the cable in case the cable approaches the coast at an angle.

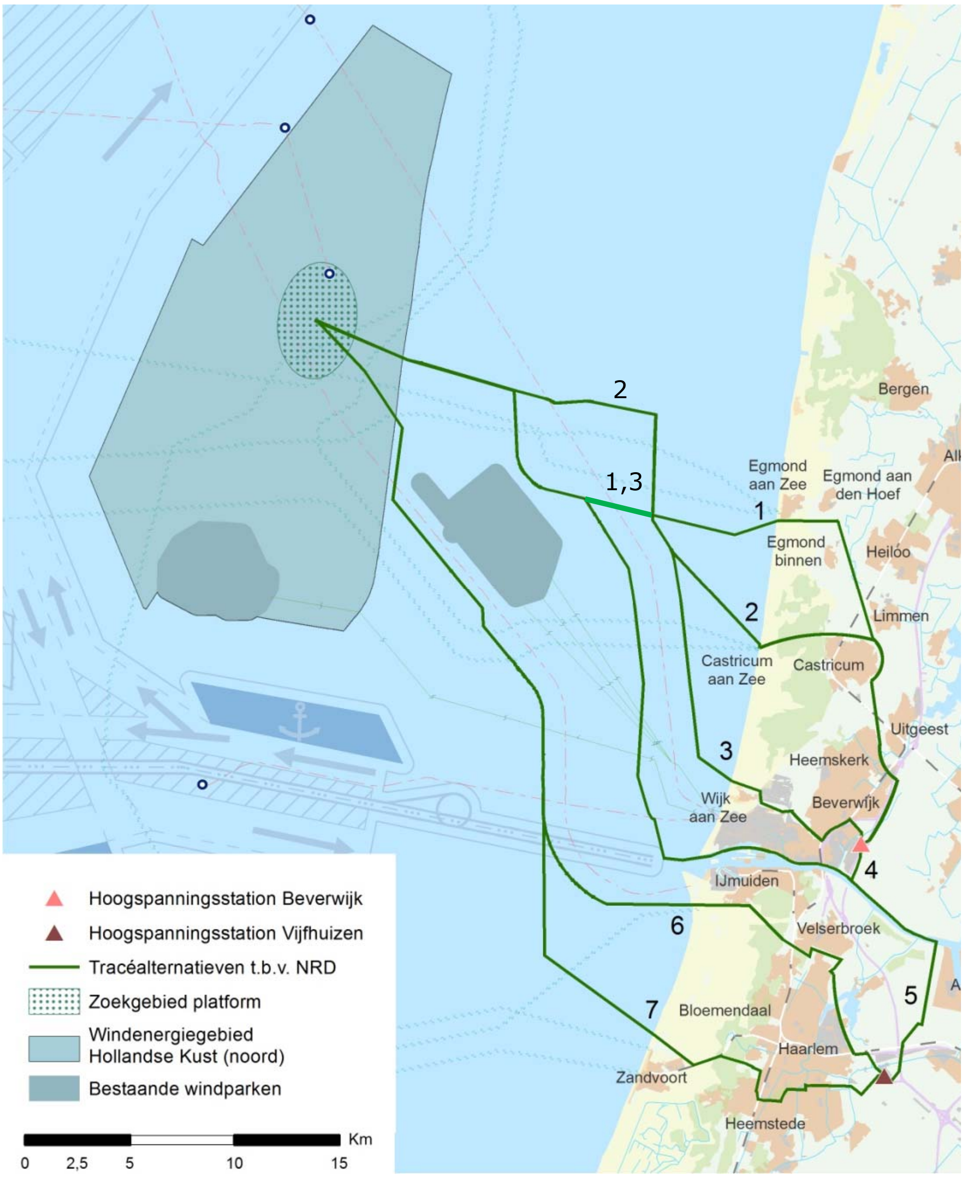


Figure 1.1 *Export cables Hollandse Kust (noord); all seven cable route alternatives are shown;*

- *Route alternative 1 runs via Egmond aan Zee;*
- *Route alternative 2 runs via Castricum aan Zee;*
- *Route alternative 3 runs via Wijk aan Zee;*
- *Route alternative 4 runs via IJmuiden through the Noordzeekanaal to Beverwijk;*
- *Route alternative 5 via IJmuiden through the Noordzeekanaal to Vijfhuizen;*
- *Route alternative 6 runs via IJmuiden zuid;*
- *Route alternative 7 runs via Zandvoort*

Note on route development

In parallel with the execution of this project, optimisations were made to route 1 and 3 as indicated in Figure 1.1 and Figure 1.2. The results of the risk assessments have been updated in accordance with these changes. The results as presented in this report [3] reflect the changes in route 1 and 2.

[3] For information: the results of the assessments of the original routes are presented in revisions of this report before revision 2.

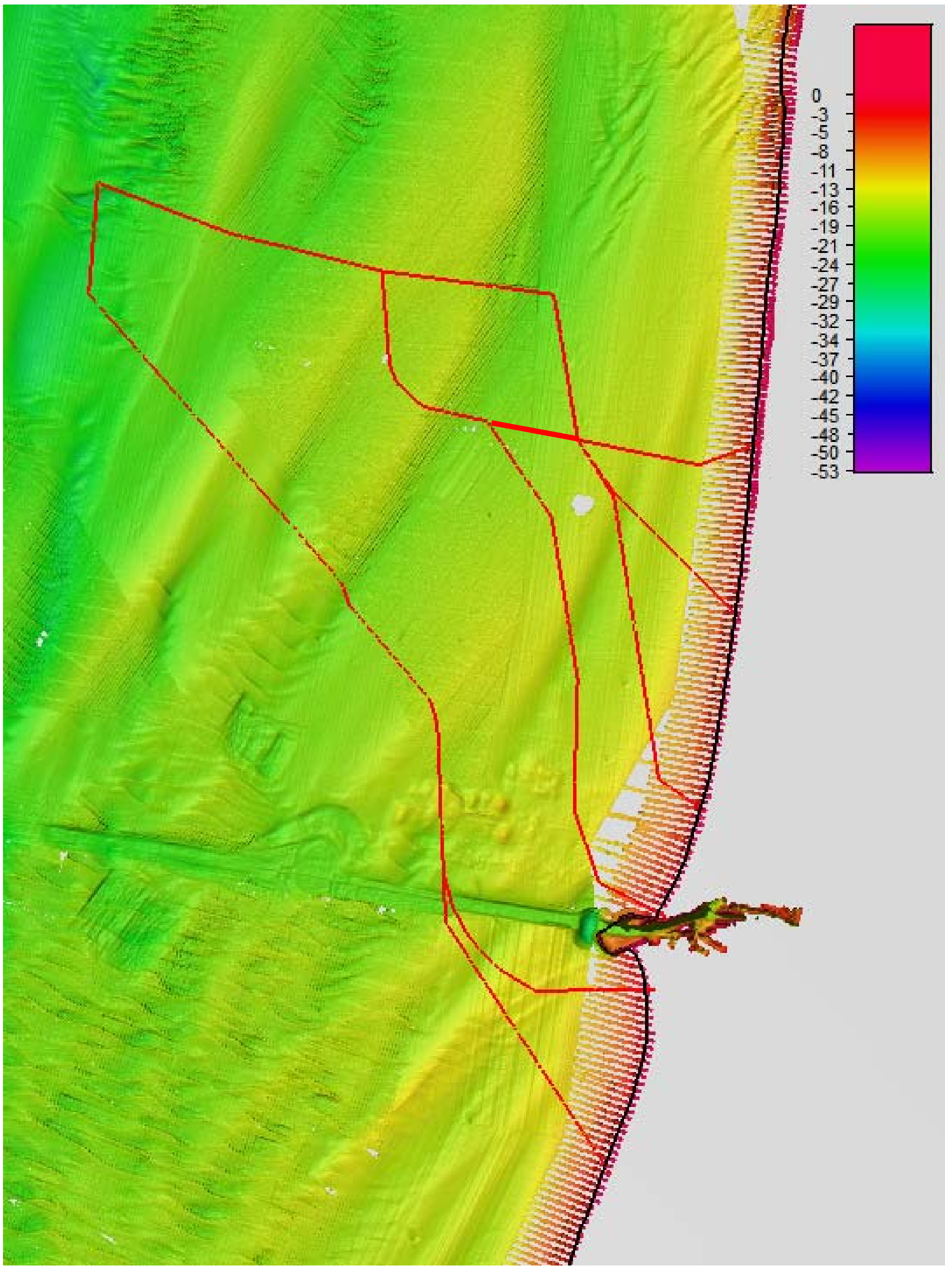


Figure 1.2 *Seabed bathymetry in the project area. All route alternatives are indicated as red lines. Bed levels are in meter relative to LAT.*

Perspective

Although this study focuses on the RBBD for the Hollandse Kust (noord) export cables, the issue at hand has a wider perspective. In fact, most export power cables (and many pipelines as well for that matter) experience comparable issues related to their initial and operational burial depth. Local non-compliance of specific sections of the asset with respect to the burial depth as specified in permits or operating requirements, often appear sometimes relatively short after installation, or after a few years. In general, more often than not, power cables are installed with burial methods based on average soil conditions and not on the worst soil conditions which would have to be anticipated to be present. Thus causing problems for all parties involved. Therefore, the issue concerning the burial depth is approached in this report. This allows the Competent Authority (i.e. Rijkswaterstaat in the Netherlands) to consider this 'generic' approach in view of consequences for other submarine line infrastructure, such as pipelines.

Permits

Since July 2015 the burial depth for export power cables in Dutch waters (including EEZ) is specified in /12/ [4], which in summary requires minimal 3 m burial within three kilometre from the shore (defined as Low-Water line) and minimal 1 m burial further out. It is interesting to note that in accordance with the NEN design code for submarine pipelines (/11/), an oil- or gas-pipeline with comparable diameters in comparable situations may be buried less than a power cable, while the difference in risk is clear: there is for instance no appreciable environmental risk if a cable fails. This potential discrepancy triggered introducing the risk based burial methodology to provide a justification for the best burial depth for such assets taking into account the actual probabilities of failure and the actual consequences of such failure. The essence of the applied approach is to create a balance between the required burial depth and the actual risk to the environment, third parties and cable owner.

Link to existing practice: risk quantification

The approach utilised in this study is based on an industry-wide tendency to accept risk based methodology in design, construction, operation and maintenance. In this case, the risk based burial depth (RBBD [5]) approach provides the basis for optimum permit provisions. The essence of this approach is to quantify the risk, due to the interaction of submarine cables with marine and seabed hazards as function of place (varying along the cable) and time (latest survey and in the future), as function of the burial depth. Based on the compliance check with an agreed (generic and project specific) risk matrix, project specific permit provisions follow in terms of minimum and target burial depth [6] as function of route sections and time. This provides the basis for either an amendment of an existing or a new permit.

As function of place and time…

The determination of the risk as function of place and time, means:

- 'Place': The risk varies along the cable route due to variations in shipping intensity and types, variations in water depth and variations in soil conditions, which all impact the required burial depth;
- 'Time': The risk varies with time due to primarily changes in the seabed and water depth due to sediment transport processes, and in addition to possible future changes in shipping intensity and/or routes.

As far as possible, all above aspects are incorporated in the RBBD.

Authority perspective

The key issues for the Competent Authority (CA) are: (1) safety to other users of the sea and (2) safeguarding the environment. Obviously additional aspects play a role in the way the CA has to manage their role and responsibility in managing the complex usage of the North Sea, but in essence these are the key issues. Financial consequences of certain permit consequences for the project developer or project owner may be considered, but are not given the highest priority. This approach should, however, not necessarily be a problem for the approach as applied. After many years of experience with pipelines and already a few years with cables [7], the

[4] References are indicated with /x/ and are listed in alphabetical order at the end of the report.

[5] RBBD: Risk Based Burial Depth: defined as (1) the burial depth of a cable or pipeline that is determined by a consistent assessment of the risks compromising the integrity of the linear asset.

[6] The concept of 'minimum' and 'target' burial depth requirements allows a pragmatic balance between effective asset management and law enforcement.

[7] For instance BritNed.

authorities realize that, in case of for instance unacceptable exposures, the traditional remediation by rock dumping is not the preferred option: effective on the short term, but in most cases causing problems on the long term, due to edge erosions around the rock-berms. Re-burial is an option, which is technically feasible and has proven to be often effective, but the possible environmental impact, the additional risk to the asset and the actual cost of the re-burial activity, justifies a realistic and sometimes pragmatic assessment [8]. This experience and authority attitude provides the basis for a new approach as applied in this study.

Law enforcement

Recent discussions with RWS on this topic showed two sides of the coin':

- On the one hand: RWS appreciates that the cable-seabed interaction is a dynamic issue that is best treated in a dynamic way, with the objective to minimise risk and impact; the objective should be to minimise remediation as much as possible without jeopardising safety and environment;
- On the other hand: RWS needs to be able to fulfil their responsibility in view of law-enforcement, which means that there need to be 'numbers' in the permit about burial depth, not only promises of assessments in case of non-compliance.

The above resulted in the concept of initial, signal and minimum burial requirements:

- Initial burial requirements define the level at which the top of cable should be installed to reduce the probability of failure (during the lifetime of the export cable) below a certain minimum;
- Signal burial requirements define when remediation plans are to be prepared;
- Minimum burial requirements define when approved remediation plans must be ready to implement [9].

Objective

The objectives of the work are:

1. To determine the Risk Based Burial Depth (RBBD) for the offshore and the Noordzeekanaal parts, of the seven route alternatives for the Hollandse Kust (noord) WoZ export cables. For determining the risk based burial depth the threats will be quantified taking into consideration the various sections along the cable. The risk based burial depth assessment will consider on the one hand the legal, environmental, safety and operational requirements and on the other hand the marine induced threats;

2. To propose initial, signal and minimum burial depth as basis for the installation and operation permit as function of location along the cable route, considering installation, operation and maintenance issues;

[8] There are other remediation options such as gravel or even sand dumping, which all depend on the level of remediation required and environmental conditions.

[9] Approved by (1) the asset owner and (2) the Competent Authorities.

Report outline

Chapter	Description
1	Introduction to the project.
2	Background and elaboration on the risk based burial approach.
3	Available data description that provides the basis for the RBBD.
4	Identification of the hazards and the risks.
5	Assessment of the frequencies of the key hazards to the cable.
6	Assessment of the failure mechanism and associated assumption.
7	The actual risk assessment leading to risk based burial depths.
8	Listing the conclusions and recommendations.

2 Approach

RBBD

The external risk to a power cable is primarily related to the position of the cable relative to the seabed [10]: its burial status, and even more when it is not buried. For external threats, the Risk Based Burial Depth (RBBD) approach is aiming at finding the balance between:

- Safety for other users of the sea, which increases with deeper burial;
- Environmental impact and cost, which also increases with deeper burial.

The RBBD is aiming at optimising the burial depth by appreciating that the conditions, and as such, the required burial depth, vary along the cable:

- If the seabed is (relatively) stable, deep burial is not actually required and causes unnecessary impact to the environment at high cost;
- If the seabed is (very) dynamic, even deep burial will postpone but may not prevent dedicated 'burial maintenance' (e.g. re-trenching).

Burial as function of risk

Furthermore, the risk obviously depends on the various threats (or hazards) along the export cable, and as such, it is the combination of burial depth and threats that determine the risk. The RBBD approach allows the acceptable risk to determine the burial depth:

- Large risk: deeper burial to mitigate the risk;
- Low risk: less burial or even no burial may be acceptable.

The approach allows a 'dynamic risk approach' optimising the initial burial requirement (at installation phase) or the maintenance burial during the operational phase.

The approach requires setting the acceptable risk level, which then determines the burial depth. The acceptable risk levels are discussed in Section 4.

Coastal protection

The risk based burial depth approach means that protection is being applied where necessary. As such it is, to some extent, comparable with the concept of 'weak links' (in Dutch 'zwakke schakels') as the basis for the protection of the Dutch coast: protect where necessary on the basis of risk assessment.

Risk based

Before going into more detail, the following should assist in putting the RBBD approach in perspective:

- Risk = probability * consequence
  - If the consequences are large, the probability of the event must be small, in order to result in an acceptable risk;
  - If the consequences are small, the probability of the event is allowed to be larger, while the risk is still acceptably low;
- Power, oil or gas
  - Safety and environmental consequences of a cable failure (outage) are smaller compared with a gas leakage, which again are smaller compared with oil leakage;
  - With the same risk, the probability of failure (PoF) of a cable may be higher than the PoF of an oil or gas pipeline.

[10] This is the actual seabed. The seabed mobility is taken into consideration to allow assessing the long term risk.

What are the key risks

For the export cables the key risks are:

1. Too often or too long loss of connectivity, which must be below a specified criterion to be defined by the Client; Loss of connectivity, as well as the repair works have significant cost implications and are likely to cause reputational damage as well;
2. Significant injuries or fatalities; the probability of fatalities due to third party interactions must be below a criterion set by relevant authorities, often in the order of 10^{-6} per km per year.

For submarine cables the first criterion is normally governing, but compliance with the second criterion must be confirmed. Use shall also be made of the recent DNVGL Recommended Practice 0301 (/6/) [11] and the relevant parts of other codes and standards related to risk of submarine infrastructure, such as the NEN3656 (/11/) and other DNV codes (/4/,/5/).

Export cables

In the assessment of the consequences the fact that these export cables link many wind parks to the main onshore grid. Outage of one of those export cables affects all connected wind parks, This potential consequence plays a major role in setting the acceptable risk level.

Risk based or deterministic

Although 'risk based thinking' is becoming more and more accepted, it should be appreciated that the key aspect need some explanation. Two examples:

- *'If an anchor can dig into the seabed 3 meters, the cable should be buried at least 3 metres…….'*;
- *'If a fishing vessel can capsize after the trawl gear getting hooked behind an exposed cable, that must never happen…….'.*

In both cases it is the difference between the risk based approach and the deterministic approach that explains the possible confusion:

- If the probability of such a large anchor digging so deep at that specific location is sufficiently small, because, for instance the location is outside a shipping lane, or the number of large ships with large anchors is very small, we can accept the consequence of the failure and as such the risk;
- If the probability of fatalities due to capsizing due to hooking is extremely small, we 'accept' the consequence and as such the risk.

In other words:

- Deterministic design is based on consequences only;
- Risk based design is based on consequences <u>and</u> probabilities.

In perspective

The approach utilised in this study is based on an industry-wide tendency to accept risk based methodology in design, construction and operation. In this case, the risk based burial depth (RBBD) approach should provide the basis for optimum permit provisions and installation specifications. Relevant aspects are:

- RWS specifically invites pipeline operators to update their operational permits (of existing pipelines and cables) to be based on the risk based burial depth approach;

[11] It should be noted that recommendations were made to include the RBBD explicitly in the DNV-RP-J301, demonstrating that 'risk thinking' has become part of the designing process.

- The Dutch codes and standard institute NEN has updated the code NEN 3650 by implementing a new dedicated code NEN 3656 focussing on offshore pipelines (/11/);
- The Norwegian certification company DNV-GL has a range of relevant design codes and recommended practices for submarine pipelines and has recently published a dedicated recommended practice for offshore wind farms and associated cables: DNV-RP-J301 (/6/);
- The Offshore Wind Accelerator is a joint industry project (Carbon Trust) that resulted in a Guidance Note on the depth of cable lowering, which favours the risk based approach (/1/).

Wherever possible, use shall be made of, or reference shall be made to the above codes and RPs to facilitate the authority review and approval process.

Tailored to 'dynamic' environments

The RBBD methodology is based on a probabilistic design approach but tailored to the specific conditions pertaining to linear assets, such as cables and pipelines, with significantly varying conditions and threats along the route. In fact, the 'export cable environment' is too dynamic to design deterministic and 'static':

- Hydrodynamics: 'normal' and 'extreme' wind, wave and current conditions;
- Morphology: the seabed varies along the route, in depth and time;
- The asset: cables are (relatively) flexible and interact specifically with hydrodynamics and morphology.

RBBD in steps

In the context of this study, risk is defined as:

<u>Risk is Probability of Failure (PoF) times Consequence of that Failure (CoF).</u>

Therefore, the key aspects of this study are:

Step	Description	Chapter
1	Identification of the potential threats (hazards): – Marine hazards, like sinking vessels and hooking of anchors; – Damage caused by fishing activities; – Reduced or loss of cover due to seabed mobility.	Ch. 4
2	Determine the Probability of Failure (PoF) with the Design Burial Depth and seabed predictions: – as function of location (KP) and burial status; – PoF = P1 * P2 = P1 * (BF * AF) o P1 = probability of event happening; o P2 = probability of event leading to unacceptable consequences, defined as: ▪ P2 = Burial-Factor * Asset-Factor. Where, the Burial-Factor is burial depth dependent and the Asset-Factor is dependent on the capacity of the asset to resist external loads, which in turn depends on the type of load and the resulting burial resistance.	P1: Ch. 5 P2: Ch. 6 PoF: Ch. 7
3	Assess the Consequence of Failure (CoF) on the basis of: – Existing information of reported failures; – Experience; – Client or project owner specific considerations.	Ch. 7.3

4	Compare PoF with criteria (NEN, DNV and project specific): – If PoF < criteria: compliance → less burial can be considered; – If PoF > criteria: non-compliance → more burial or other remediation or mitigating measure is required.	Ch. 7.2-4
5	Assess the risk by using a risk matrix. The PoF and CoF are determined in the previous steps. Acceptance criteria for the consequences are set by: – Codes (NEN, DNV), primarily for safety and environmental consequences; – Client and project specific criteria, primarily for the asset, cost and reputation.	Ch. 7.4
6	Implement results of previous steps into the Risk Based Burial Depth providing basis and justification for permit provisions and technical specifications for the operational life of the asset.	Ch. 7.4

Schematic

Figure 2.1 shows the schematic presentation of the steps as presented above.

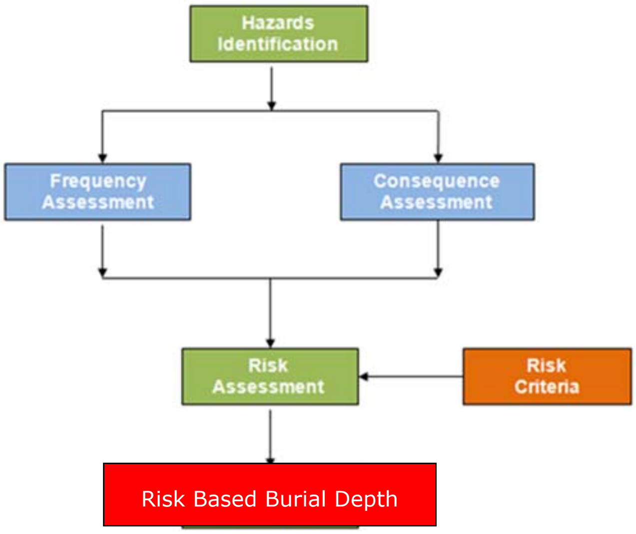


Figure 2.1 *Study approach.*

Risk matrix

As introduced in Step 5 above, a risk matrix will be used to provide guidance to optimise the burial depth in terms of risk as the product of probability of the event times the consequences of the event. The actual implementation, including definitions of the probability classes and consequence classes are presented in Chapter 7.3. Implementing such Risk Matrix for a specific project with specific data is a challenge, but considered the most appropriate way to provide a justifiable basis for the depth of burial permit provisions [12].

[12] It should be noted that a Risk Matrix is included in the NEN 3656 for offshore pipelines, showing that 'risk thinking' has become part of the permitting process.

RBBD in Phases

The RBBD method can be used in both the design and the operational Phase:

- Design Phase to determine the optimum burial depth of the export cable and to provide justification of specific permitting provisions with respect to minimum burial;
- Operation Phase to identify non-compliant locations and test effectiveness of mitigation and/or remediation measures to achieve compliance.

The RBBD allows implementation of any hazard, but for the HKN export cables the focus [13] is on the following external hazards: (a) fishing activities, (b) marine hazards (mainly sinking/ and anchor hooking) and (c) seabed mobility induced hazards.

PoF in time

Essential in the RBBD assessment is looking into the future to enable assessment of the risk development in time, primarily due to seabed mobility, but secondarily to enable incorporation of other changes in external threats.

For existing cables a survey is conducted, mapping the bed level and burial depth of the cable along the route. Several future scenarios of the seabed are used to assess the PoF in time.

For new cables, such as the HKN export cables, however, the depth of burial has to be decided for three cases: 1) the initial (or installation) depth, 2) the target depth and 3) the minimum depth. Several future seabed scenarios and different burial depths are therefore used to assess the PoF in time. This will be further explained in Chapter 6.

Two RBBDs, four cables

The Hollandse Kust (noord) project includes 7 route alternatives for the export cable, with each 4 different cables, shown in Figure 1.1. The cables for each alternative are to be installed closely together within a corridor from the shore to the platforms. Differences in probabilities of events happening and events leading to failure are assumed to be small within the installation corridor. Consequently only one RBBD is made for the assessment of the two cables for each route alternative. The in total 7 RBBDs [14] are based on the 'centre location' of the cables in the route alternatives. This is shown in Figure 2.2.

Failure of one or more cables

The performed study assumes that if one of the cables fail, the system, defined by a minimum of two cables, also fails.

[13] The mentioned failure causes contribute most to the total failure probability. Other causes, such as dropping objects and internal cable failures contribute an order less. This is based on previous RBBD studies for export cables and interconnectors.

[14] As outlined before, the Hollandse Kust (noord) route alternatives include 7 routes. Routes 4 and 5 are exactly the same for the offshore part of the route. Therefore, the RBBD for the offshore route alternatives is combined.

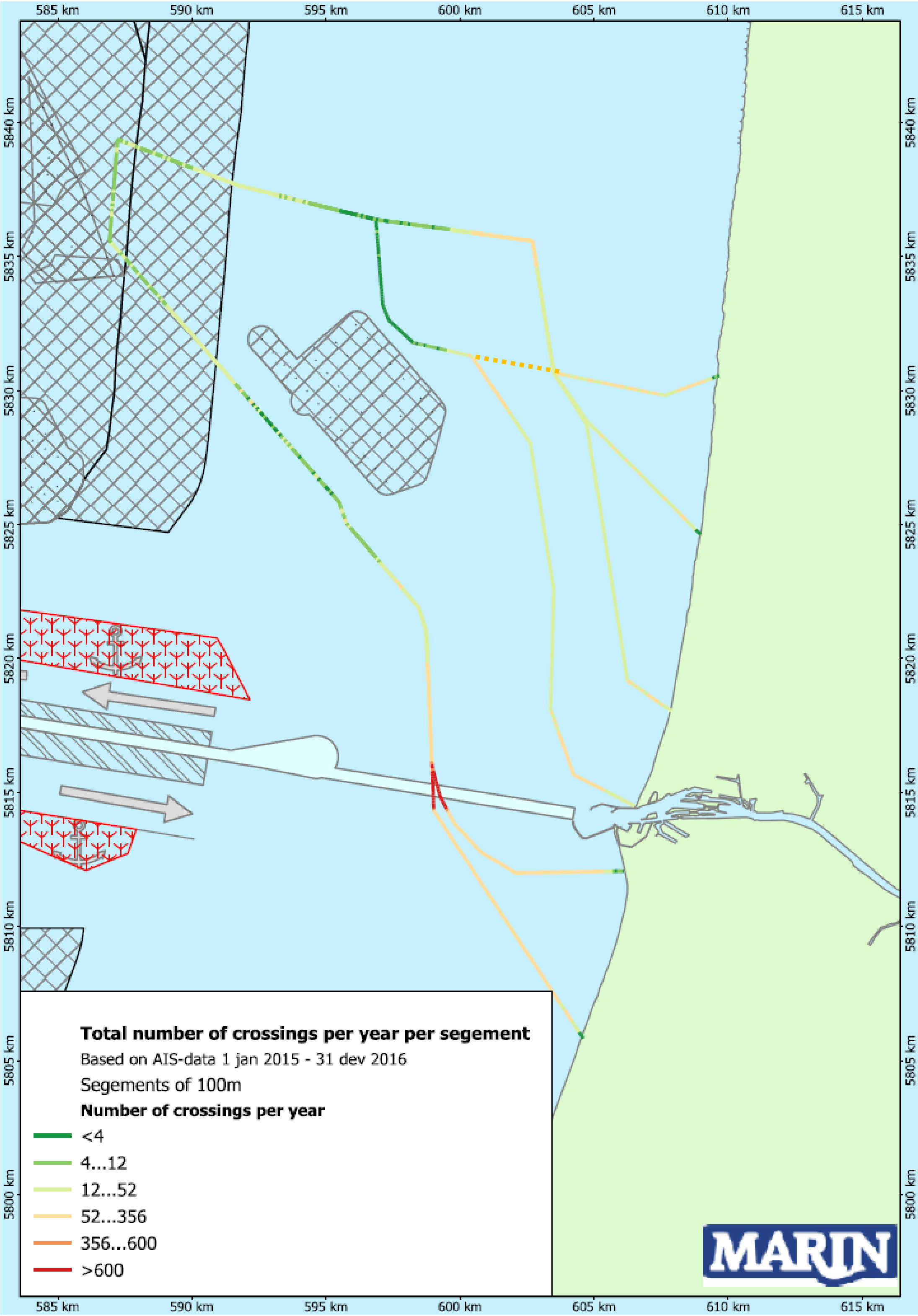


Figure 2.2 *Total passages per 100 m segment per year over all route alternatives based on AIS data from 1 January 2015 – 31 December 2016, coloured by shipping intensity. (Figure 4-3 from Marin report included as Annex 1). With reference to Figure 1.1 and the accompanying Note, the updated routes are indicated by the broken connecting line in above Figure. The crossing frequencies for this new segment have been derived from the crossing frequencies and is further explained in Annex 1.*

3 Available data

General

Available data relevant for this study are described in this Chapter, including:

- Export cable data;
- Ship traffic data;
- Bathymetric data.

The routes 4 and 5 include a section in the Noordzeekanaal. Only when relevant a differentiation between the 'offshore' and 'canal' route is indicated in this Chapter.

Export cable data

The following data are available for this study:

- Export cables locations of the seven route alternatives (/15/);
- Outer diameter (0.25 – 0.30 m).

Ship traffic data

The ship traffic intensity and the distribution of ship classes and types based on the Automatic Identification System (AIS) data and Radar data is taken into account. A detailed description of the ship traffic data is given in the Marin report /9/, included as Annex 1. As an example, Figure 2.2 provides the shipping intensity (per 100 m segment) along the export cable, for the period 1 January 2015 – 31 December 2016.

Ships over 300 GT

Since 2005 all merchant ships over 300 GT are equipped with Automatic Identification System (AIS). This system transmits information about the ship, her voyage and her position, speed and course. For the Dutch part of the North Sea, the Netherlands Coastguard collects the data. The data set contains all ships that have an AIS transponder on board. The last years also ships smaller than 300 GT are observed in the data set. Some larger recreation (mostly sea-going) vessels also have a so-called class B-AIS on board. AIS is also used by smaller fishing and inland vessels.

AIS coverage

The AIS data are transmitted by VHF, which is a radio signal requiring 'line of sight'. That means that the coverage of AIS data by coastal stations reduces with distance to the coast. In case of long distance from the coast, use can be made of platform based receivers or satellites. For the HKN export cables the coastal receiving station have full coverage.

Small ships

The data set received from the Dutch Coastguard also contains radar data for some areas. This gives extra information about small vessels, e.g. recreational vessels, without AIS. The data does not contain any further information about the radar image, so one cannot say which type of vessel was observed. Some radar signals were labelled with the name of the vessel. In the analysis of the data, this name was used to identify other fishing vessels from this radar-data set, purely based on their name. In the analysis the radar signals without further labels of identification were also taken into account. In the risk assessment it is assumed that these vessels are small (pleasure) crafts. The impact of these vessels on the power cable will be small because of their limited size.

Frequency of hazardous events

Based on the AIS and radar data, the crossing and parallel passing [15] frequencies of relevant vessels have been determined. After identifying the potential hazards in Chapter 4, the results of the vessel crossings are presented for the various hazards in Chapter 5.

Changing intensities

The traffic intensities will change when the Hollandse Kust (noord) wind park is operational (/9/). The Hollandse Kust (noord) wind park will block the route between wind park Amalia and Egmond and vessels will change to a more southern route (/9/). The total number of crossings at route 6 and 7 will not change, but the location of these crossing will change. This change in intensities is not included in the traffic data as these are based on historical data. In the RBBD update study, this change in routing will be implemented in case route 6 or 7 has been chosen for further development. This issue is not affecting the relative comparison between the routes.

Bathymetry data

The following bathymetry data are available for this study:

- Large scale survey data from the Dutch Hydrographic Office (/7/), which has a grid size in the order of 25 m by 25 m.

Soil types in RBBD

Based on soil drilling samples in the project area, available from (/3/), a bottom profile of soil-types was made for the upper 3 m of the seabed. These drillings were performed between the year 1985 and 2017. The qualitative soil-type classification presented in the drilling reports was used to determine the soil properties in the RBBD.

100 m segments

Figure 3.1 to Figure 3.3 show the surveyed sea bed (in metres relative to LAT) along the Hollandse Kust (noord) route alternatives based on the large scale survey from the Dutch Hydrographic Office. These data are interpolated on 100 m segments along the export cable, for application in the RBBD assessment.

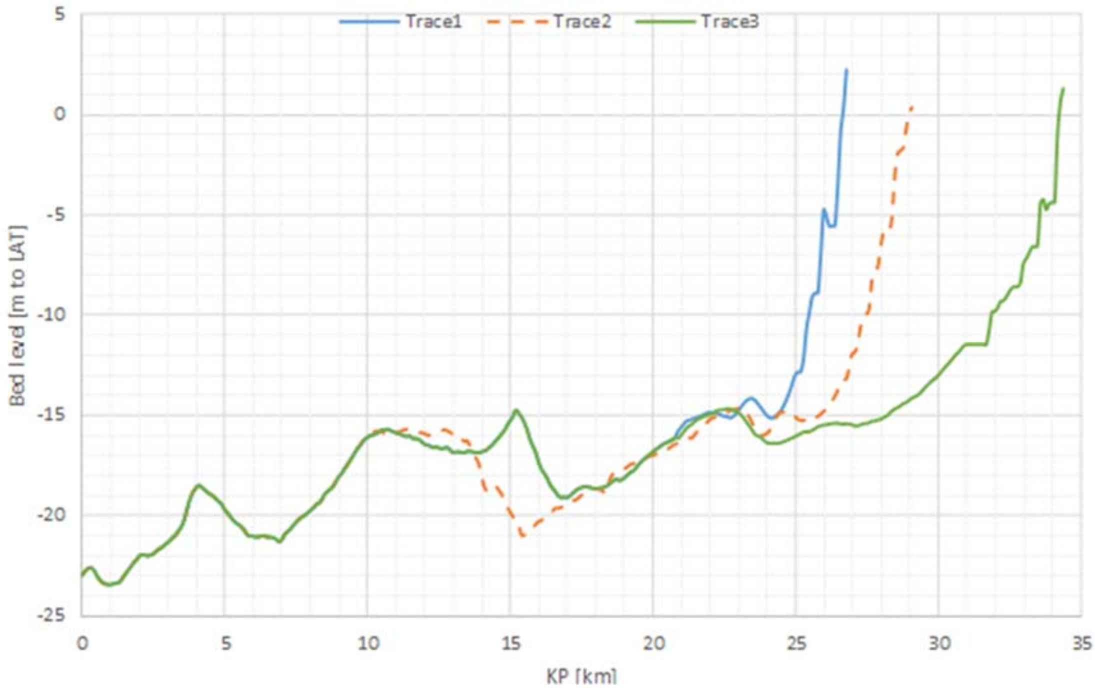


Figure 3.1 *Sea bed (in m relative to LAT) along the Hollandse Kust (noord) export*

[15] For the Noordzeekanaal sections.

cables route alternatives 1,2 and 3 (/7/). Route 1 and 3 show the updated alignment.

Observation bathymetry route alternatives 1 & 1A

As observed in Figure 3.1 and Figure 1.1, the three cables routes have different lengths. The bathymetry along the cables is the same up to KP22 where the three route alternatives bifurcate from each other. The three cables run over a 5 m-high sand bank parallel to the Dutch coastline (KP 8-15). Future development of the bathymetry along the routes is further discussed in Chapter 5.

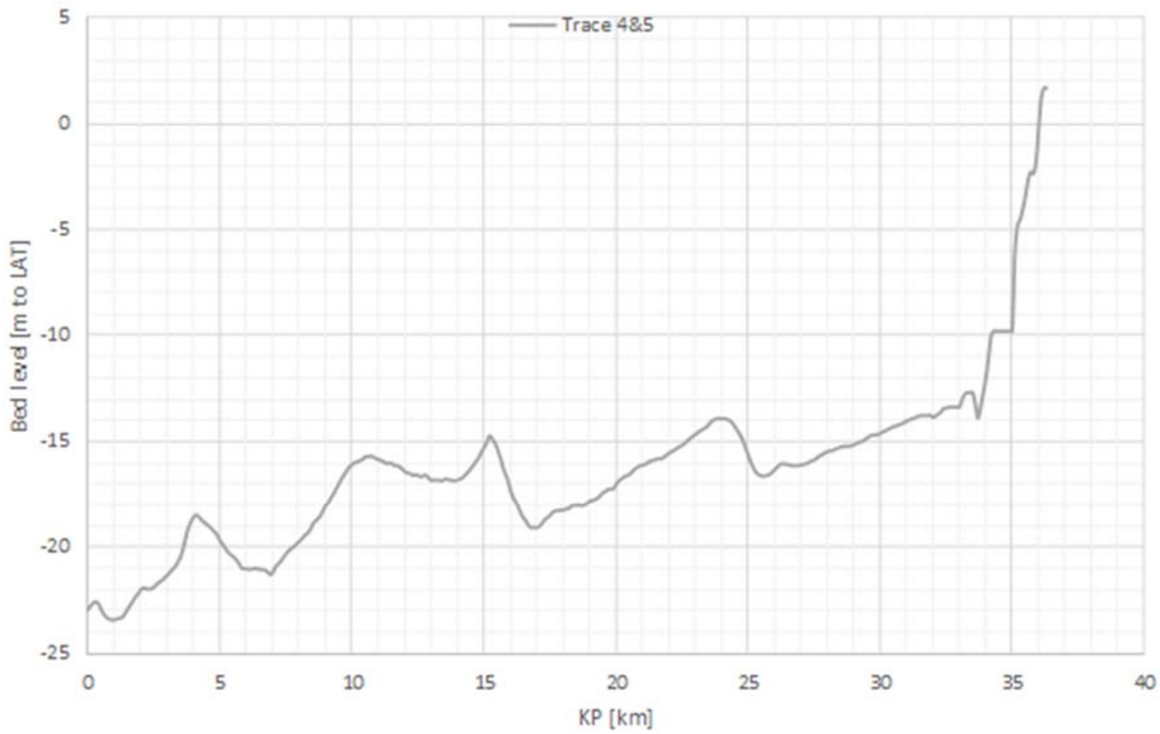


Figure 3.2 *Sea bed (in m relative to LAT) along the Hollandse Kust (noord) export cables route alternatives 4 and 5 (offshore part only) (/7/).*

Observation bathymetry route alternatives 4 & 5

As observed in Figure 3.2 and Figure 1.1, the routes of alternatives 4 and 5 are the same in the offshore part. The routes are longer compared to routes 1-3 and the bathymetry along the cables is dominated by 4 sand banks up to 5 m high. The routes are just north of an planned extraction area between KP16.4 and 18.8. Both routes go via IJmuiden where the cables will run along the locks and into the navigation channels parallel to the shipping. Future development of the bathymetry along the routes is further discussed in Chapter 5.

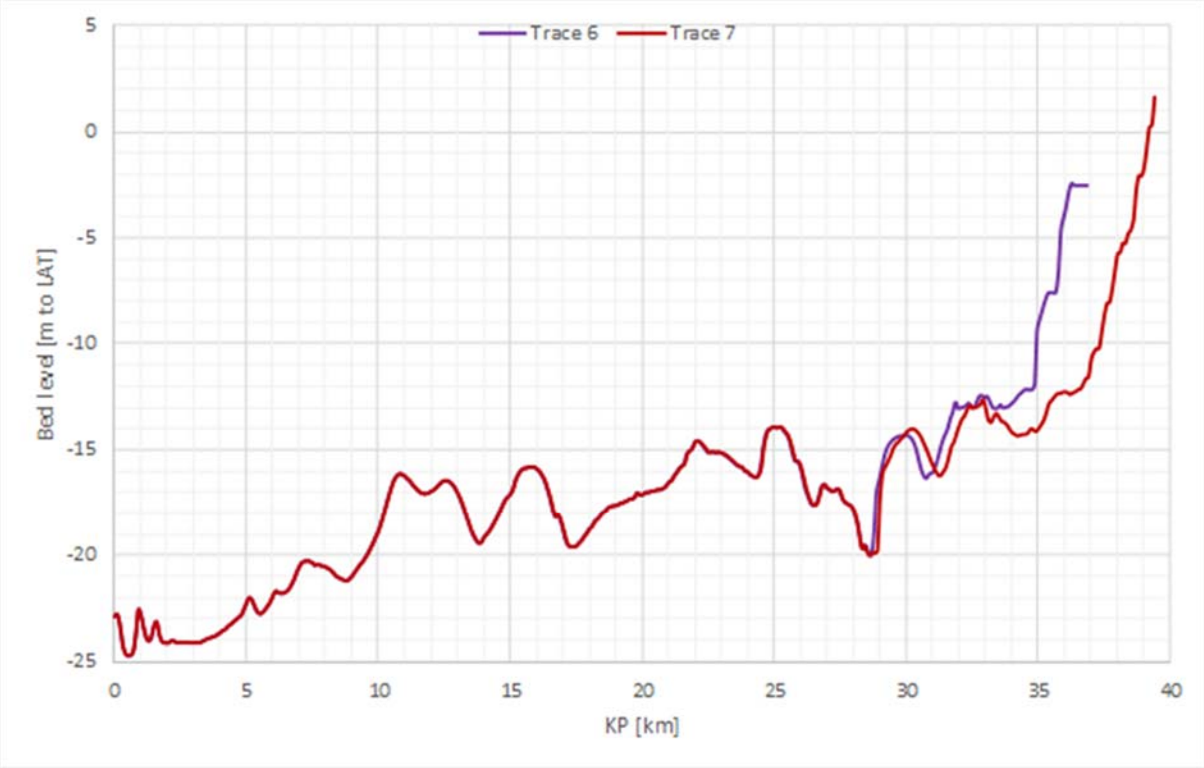


Figure 3.3 *Sea bed (in m relative to LAT) along the Hollandse Kust (noord) export cables route alternatives 6 and 7 (/7/).*

Observation bathymetry route alternatives 6 & 7

As observed in Figure 3.3 and Figure 1.1, the two cables have slightly different lengths and the bathymetry along the cables is comparable, but slightly different due to differences in their specific routes. Both route alternatives leave platform and bifurcate at KP 27.6 after which both cross the IJ-approach channel. Future development of the bathymetry along the routes is further discussed in Chapter 5.

4 Hazards and risk

4.1 Hazard identification

Relevant hazards

The objective of this activity is to identify possible hazards to the Hollandse Kust (noord) export cables. The following hazards were considered relevant for the export cable in this study:

- Marine hazards:
  - Sinking ships, and sinking ships after collision;
  - Dropped objects;
  - Dropped anchors;
  - Dragged (or hooked) anchors;
  - Grounding ships.
- Fishing hazards due to bottom trawling.

Marine hazards

Potential hazards induced by shipping for the Hollandse Kust (noord) export cable include:

- Sinking ships: This is caused by a ship sinking while crossing above the export cable. It includes also sinking ship due to collision of two ships;
- Grounding ships: Grounding ships is the most common type of ship accident in shallow water areas where the water depth is lower than ship draft; this hazard is relevant for (1) the offshore routes due to grounding on shallow nearshore sand banks and stranding on the beach, and for the Noordzeekanaal route due to grounding on the canal embankments;
- Dropped and dragged (or hooked) anchors: This is caused by anchoring operations in allowed prescribed anchoring areas, emergency anchoring due to an emergency on-board inducing the vessel crew to drop the anchor in unplanned areas, or anchoring for other reasons (waiting or small repairs) without carefully looking on nautical charts (so-called erroneous anchoring);
- Dropped objects: This is caused by containers [16] lost from commercial vessels crossing the cable route.

Fishing hazards

Bottom trawling is known to be one of the main threats to cables and pipelines [17] for the offshore routes only. The burial depth of the cable is the obvious key protection against bottom trawling. For sinking, grounding and anchoring it is obvious that the level of penetration into the seabed depend on the vessel, the anchors and the seabed characteristics, all resulting in seabed penetration in excess of a few decimetres. Bottom trawling gear, however, is meant to penetrate as little as possible to reduce the friction of the gear over the seabed. The actual penetration obviously depend on the type of gear and seabed conditions, but for the gear used in the project area is normally much less than and at maximum 20 cm.

New gear

Recent development in gear design reduce this even further to reduce the friction and consequently the fuel consumption as much as possible. The newest gear, called 'SumWing' has one central 'bottom sliding skid' instead of

[16] Containers are considered the only type of cargo that can cause significant damage to an export cable.

[17] Specifically data cables often fail due to hooking by bottom trawl gear. Fishing gear also tend to hook behind free spanning pipelines.

the traditional beam trawl with two bigger skids on either side of the beam, see Figure 4.1. Although the new gear is clearly beneficial in view of fuel reduction and reduced environmental impact of the seabed, the single pointing forward skid is less beneficial for pipelines and cables.

Traditional beam trawl

SumWing

Figure 4.1 *Typical traditional and new bottom trawling gear.*

Specific threat

For large exposed pipelines, the 'SumWing' is posing a significant additional threat. Due to the specific design of the 'nose' of the 'SumWing', being about 50 cm above the seabed, the threat to a cable is only increased in case of a significantly exposed or free spanning cable. As will be explained later, the cable is basically not allowed to become exposed to the level that bottom trawling gear (traditional and new) may hook to the cable. This will further be explained in Chapter 6.

Dumping and dredging area

Routes 6 and 7 pass through a dumping area for dredged spoil (outlined purple in Figure 4.2). Routes 1, 2 and 3 cross a sand extraction zone according to /13/ (outlined blue in Figure 4.2). It should be noted that dumping can result in local scour holes, which are likely to fill-up due to natural backfilling processes.

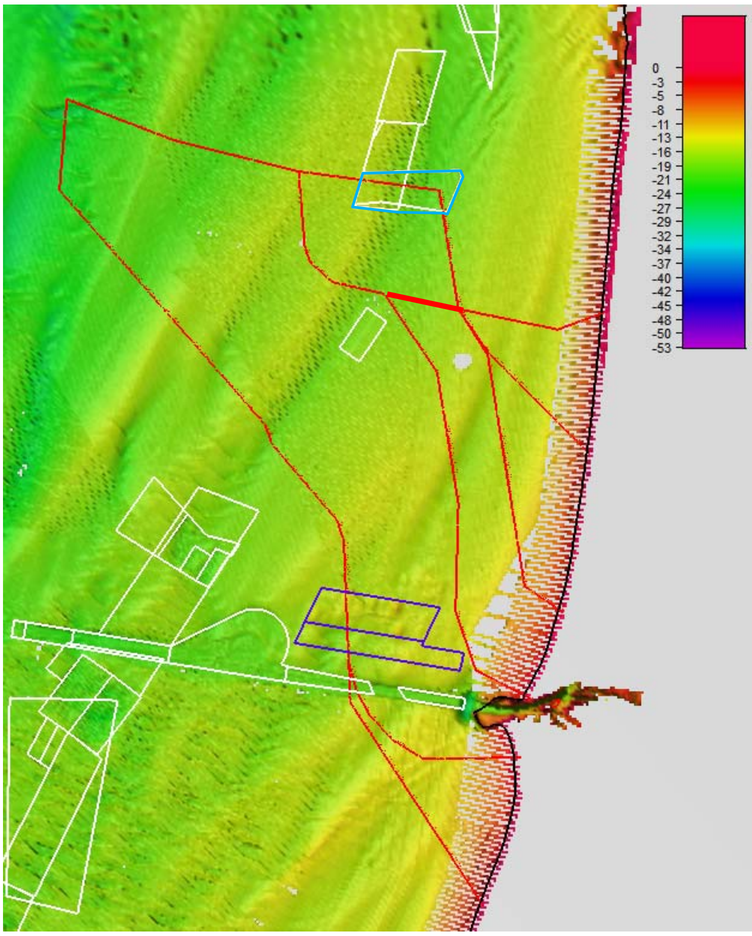


Figure 4.2 *Overview of cable routes (red) and the spoil dumping area (outlined purple) and a sand extraction area (outlined blue).*

Impact on risk

The additional risk associated with the location of the cables in the dredged spoil dumping area is assessed to be marginal and is not affecting the overall result of the RBBD. The justification of this statement is as follows:

- As part of the dredging cycle (dredging → sailing to dump area → dumping → sailing to dredging area → dredging etc.) the dredging vessel is only for a short period of time on the dump location, which does, however, result in a relatively large number of crossings;
- The dumping process is a dedicated process managed from the bridge of the vessel, during which it is justified to assume that the vessel crew will look carefully around if the dumping can start, because during the dumping (which only takes a few minutes) the vessel may be less manoeuvrable;
- With respect to erroneous anchoring it is justified to assume that the crew will be aware of the presence of the cables and will not anchor without looking to the chart.

In summary it is concluded that the increased crossing frequencies are compensated by the reduced probability of sinking (due to collision) and erroneous anchoring, resulting in a negligible effect on the overall probability of failure (/10/).

Noordzeekanaal

The Noordzeekanaal section of route 4 and 5 is included in the quantitative RBBD approach, as described in detail by Marin as presented in Annex 1 (/9/). The frequencies and risks have been determined in a dedicated manner to account for the fact that along most of the route in the Noordzeekanaal the cables run parallel to the canal and direction of ship movements. Therefore the 'standard' approach of the RBBD using the frequencies that ships are crossing the cable can only be applied for where the cable actually cross the channel form one side to the other. Where the cables run parallel a different approach had to be developed and applied. Details are provided in Annex 1. The risk associated to the use of embankment maintenance vessels using spud-poles has also been considered.

4.2 Risk acceptance

Introduction

In this Chapter the risk acceptance criteria are discussed to allow implementation of the results of the probability of failure and consequence of failure assessment, leading to a Risk Based Burial Depth as basis for cable integrity management and permitting.

Risk Matrix

Figure 4.3 shows the standard risk matrix as mentioned in Chapter 2. The generic meaning of the colour code is indicated in the legend below the Figure. The principle works as follows: an event, such as a cable failure, has a probability of happening, and has consequences. The combination gives a location in the risk matrix and from that follows what to do or not to do.

		Consequence				
		Insignificant	Minor	Moderate	Extensive	Significant
Probability	Rare					
	Unlikely					
	Possible					
	Likely					
	Almost certain					

Figure 4.3 *Generic Risk Matrix; colour code:*

	Insignificant
	Low risk: acceptable
	Evaluate action to reduce risk
	Action should be taken
	Immediate action to be taken

Definitions

The above generic Risk Matrix need explicit definition of the consequence and probability classes to allow implementation.

Consequence classes

The consequences are defined for 5 different categories according to the 'PEARC model' as shown in Table 4.1. It should be noted that the first two classes (People and Environment) are basically project independent, and that the three other classes (Asset, Reputation and Cost) are project dependent.

Table 4.1 *Definition of consequence classes for this project.*

		Consequence				
		Insignificant	**Minor**	**Moderate**	**Extensive**	**Significant**
Categories	**People**	No or superficial injuries	Minor injury, a few lost work days	Major injury, long term absence	Single fatality or permanent disability	Multiple fatalities
	Environment	No impact	Minor impact, onsite response	Moderate impact, regional response	Major impact, national response	Catastrophic impact, international response
	Asset	No damage or no un-availability	Minor damage/ Minor un-availability	Moderate damage/ Moderate un-availability	Major damage/ Major un-availability	Catastrophic damage/ Catastrophic un-availability
	Reputation	No reaction	No public concern	Local public concern, regional echoes	Regional public concern, national echoes	National/ international public attention
	Cost	< 0.01 M€	0.01 - 0.1 M€	0.1 - 1 M€	1 - 10 M€	> 10 M€

Probability classes

The probability classes are defined for 5 different categories according to industry practice. But, as already mentioned before, the probability classes are not necessarily the same for all consequence classes: the probability acceptance criteria for Asset, Reputation and Cost are project dependent and may therefore deviate from the probability acceptance criteria for Safety and Environment. This approach is applied for the Hollandse Kust (noord) Risk Acceptance criteria, as shown in Table 4.2 for Safety and Environment and in Table 4.3 for Asset, Reputation and Cost.

Table 4.2 *Definition of probability classes for Safety and Environment for this project.*

	Description	**Probability of event per year**	**Chance event happening in average once per ……. year**
Rare	'Never heard of in the industry'	$P < 10^{-5}$	Less than once per 100,000 year
Unlikely	Failure is not expected	$10^{-5} < P < 10^{-4}$	Between once per 10,000 and 100,000 year
Possible	An accident has occurred in the industry	$10^{-4} < P < 10^{-3}$	Between once per 1,000 and 10,000 year
Likely	Has been experienced by most operators	$10^{-3} < P < 10^{-2}$	Between once per 100 and 1,000 year
Almost certain	Occurs once or several times per year	$10^{-2} < P$	Once or more times per 100 year

Table 4.3 *Definition of probability classes for Asset, Reputation and Cost for Hollandse Kust (noord) Export Cables.*

	Description	**Probability of event per year**	**Chance event happening in average once per ……. year**
Rare	'Never heard of in the industry'	$P < 10^{-3}$	Less than once per 1,000 year
Unlikely	Failure is not expected	$10^{-3} < P < 10^{-2}$	Between once per 100 and 1,000 year
Possible	An accident has occurred in the industry	$10^{-2} < P < 10^{-1}$	Between once per 10 and 100 year
Likely	Has been experienced by most operators	$10^{-1} < P < 1$	Between once per 1 and 10 year
Almost certain	Occurs once or several times per year	$1 < P$	More times per year

Justification

The difference of a factor 100 between the probability acceptance criteria for (a) Safety and Environment, and (b) Asset, Reputation and Cost, is based on the following reasoning.

Safety and Environment

The consequences for safety and environment are in principle project independent and therefore follows industry practice, such as defined in the Dutch NEN code (/11/) and the generally used DNV code for submarine assets (/6/).

Asset, Reputation and Cost

The consequences for Asset, Reputation and Cost are in principle project dependent and have been specified for the Hollandse Kust (noord) export cables by the Client as follows: a loss due to a cable failure (resulting in loss of connectivity and cost of repair) of maximum 10 M€ is considered an 'Extensive' consequence and only acceptable once per 100 – 1000 year, corresponding to a probability of P ~ 0.01 – 0.001/year.

For the Hollandse Kust (noord) project 2 cables are specified, however, both cables are considered by TenneT as 'one' cable system each.

This means in practice that the combination of 'Extensive' and a probability of ~0.01/year is the 'minimum' criteria, and in the Risk Matrix: 'Action to be taken' in order to avoid this happening, corresponding to probability class 'Possible' in Table 4.3.

Risk criteria from NEN 3656

The Dutch design code (NEN 3656, /11/) has been developed for 'steel submarine pipelines' and the risk criteria therefore primarily relates to the consequences of loss of hydrocarbons in case of leak or rupture, thus including the environmental impact. The code, however, also contains risk criteria for consequences related to safety to people, including third parties, such as other users of the sea, such as fishermen. The risk to environment and safety as specified in accordance to NEN 3656, should be less than 10^{-6}/km/year.

Per km or per project?

The NEN 3656 specifies the risk criteria per kilometre per year, while the DNV code and project owners specify the risk criteria per 'project or complete route' per year. Both criteria make sense but for different purposes, and need some explanation.

- Specifying a criterion per kilometre seems illogic because would it also mean a risk of less than 10^{-9}/m/year or 10^{-11}/cm/year? Obviously not because it loses its physical meaning;
- The DNV code specifies a risk criteria of 10^{-5}/project/year for a typical section of 10 km long, which means that both NEN and DNV criteria are comparable in case the asset is about 10 km long;
- The criterion in the NEN originates from its initial set-up and at that time the same criterion was introduced as used for individual risk, being 10^{-6}/year. To make it usable for linear assets, a 'representative' or 'typical' length of 1 km was agreed upon.

Interpretation

The following interpretation of the various criteria is used in the RBBD of this project:

- The risk table for 'Safety and Environment' (as presented in Table 4.2 specifies the probability class 'Rare' as less than 10^{-5}/year, which corresponds to less than 10^{-6}/km/year for a section of 10 km;
- To maintain consistency with the applicable NEN 3656, the risk for criteria 'Safety and Environment' should be less than 10^{-6}/km/year, irrespective of the length of the asset.

Risk to the environment

The presently available EIA's for submarine power cables all assumed a minimum burial depth of 1 m and did not specifically assess the environmental impacts of burial depths of less than 1 m. Possible impacts resulting from burial depth less than 1 m, due to increased bottom temperature and electro-magnetic field, have not been part of the scope of this study. It is expected that there will be no significant negative environmental impact due to local temperature and Electro-Magnetic field increase in case of the power cable buried less than 1 m, since the estimated area of impact due to the cables is limited. In the above, it is therefore assumed that the probability of the risk to the environment is 'Rare'.

Implementation

The actual implementation of the above defined Risk Matrices is presented in Chapter 7.3.

5 Frequency Assessment

5.1 Introduction

Objective and approach

The objective of the frequency assessment is to determine the frequency that a hazard occurs on the Hollandse Kust (noord) export cables. The approach to determine the frequency that a marine induced hazard occurs on the export cable is explained in detail in /9/ (also included as Annex 1) and summarised below. In this chapter, the figures for Hollandse Kust (noord) route alternatives 2,4 and 6 are shown, comparable figures for alternative 1, 3, 5 and 7 are included in Annex 2.

Item	Approach
All	AIS data (and radar data for smaller vessels) to calculate number of crossings of the export cables, specified for different sizes of ships;
	All the frequency hazard data is determined per cable section of ~100 m, per year. As not all sections are exactly the same size, the data is converted to frequency per kilometre per year (/km/yr);
	Not all marine incidents are actual hazards for the export cable. Therefore, for each hazard a factor is applied to the incident frequencies in order to determine the critical incident probabilities.
Sinking	Without collision: based on AIS data and sinking statistics that are utilised in SAMSON;
	After collision/accident: determined based on the relation to the sinking frequency that are not caused by an accident: 'sinking after accident' : 'sinking after no accident' = 1:2;
	The sinking and grounding frequency are determined for 8 different sizes of ships. The smallest ships (i.e. ship size 1) weight less than 300 tons and the largest ships (i.e. ship size 8) weight more than 100,000 tons.
Grounding (stranding)	The grounding frequency is determined by using AIS data of non-route-specific marine traffic.
Anchors	Of all vessels that cross the cable routes and have an incident resulting in engine or steering failure, 5% is assumed to anchor without looking to the chart or calling the coastguard (who will warn the vessel for the cables). The statistics on anchor mooring manoeuvres are based on route-specific marine traffic on the Waddenzee, which is assumed to be representative for the project area. For the large merchant vessels in and around the IJ-geul this assumption is too conservative as ships have to communicate with the harbour authorities and could have a pilot aboard for arrival at IJmuiden. It is assumed that 1% of these large merchant vessels, within a 2km corridor on either side of the IJ-geul, having an incident resulting in engine or steering failure will anchor without looking at the chart. These assumptions are based on the dedicated marine safety study performed for BBL in 2011 (/16/) and recent Marin studies related to drifters (/8/);
	Falling: based on a fixed anchor size and the diameter of the export cable, in combination with anchor mooring manoeuvres;

	Hooking: depending on size of ship by assuming critical anchor corridor of quarter of ship length.
Falling objects	The falling objects frequency is determined by the number of crossing vessels with containers on board, which in turn is based on AIS data.

Crossing frequency all vessels

The number of crossings of all vessels and fishing ships only are shown in Figure 5.1, Figure 5.2 and Figure 5.3 for all individual sections of 100 m of route alternatives 2, 4, and 6 respectively. It should be noted that for none of the assessed frequencies in this chapter the depth of burial is taken into account. That assessment is presented in Chapter 6 and 7.

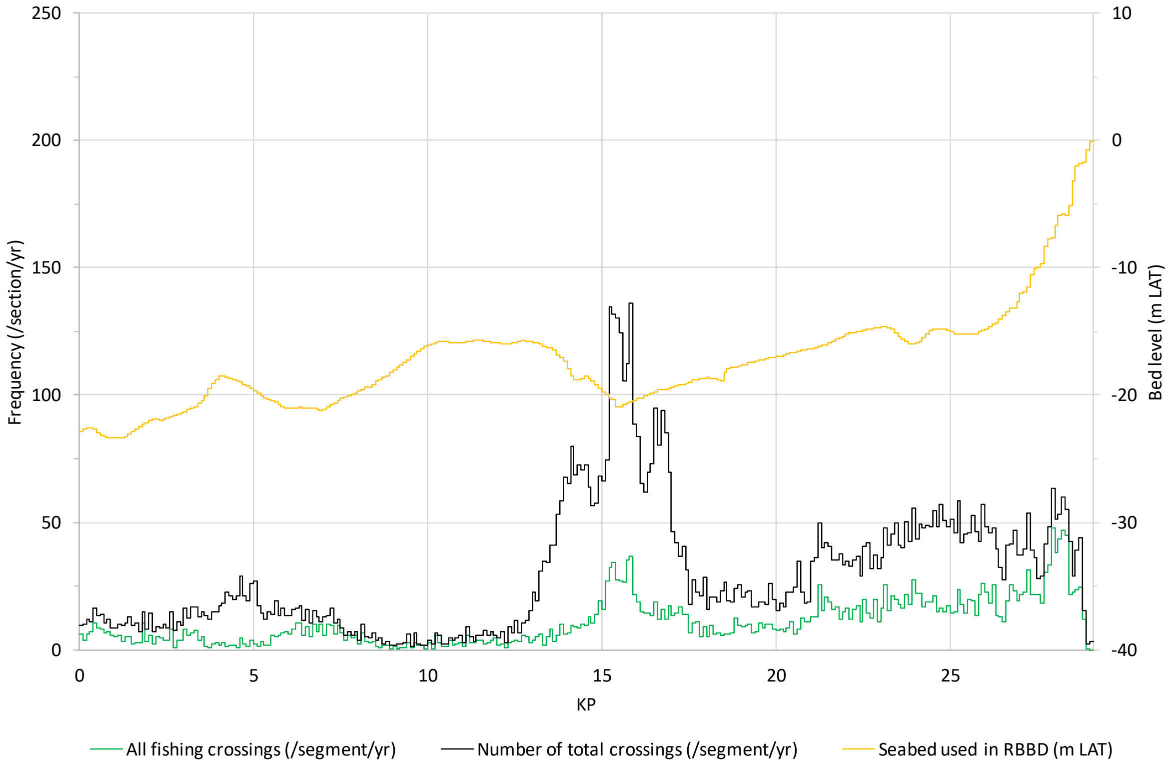


Figure 5.1 *Frequency of all the ships (black line) and fishing ships (green line) that cross route alternative 2 (/section/yr) as function of the cable route (KP). The numbers are based on two year of AIS data (from 1 January 2015 to 31 December 2016) for each segment of ~100 m. The seabed level (yellow line) that is used for the RBBD is presented in order to link the AIS data to the water depth.*

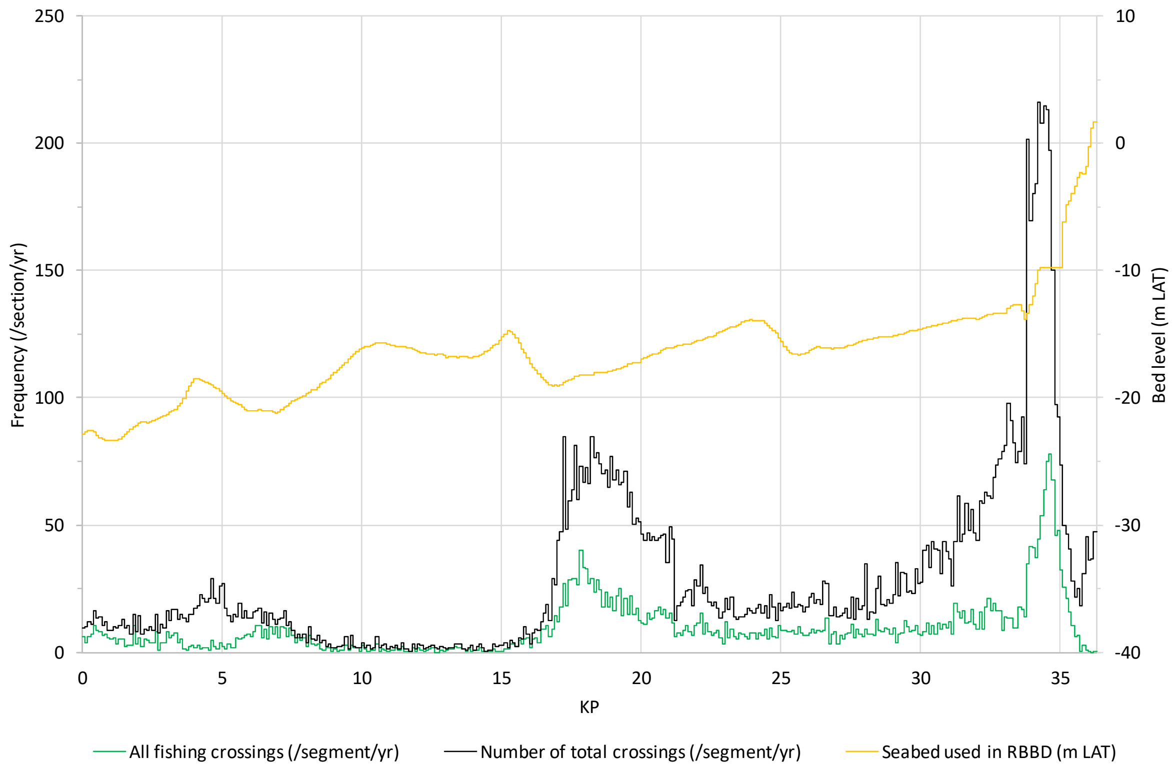


Figure 5.2 *Frequency of all the ships (black line) and fishing ships (green line) that cross route alternative 4 and 5 (/section/yr) as function of the cable route (KP). The numbers are based on two year of AIS data (from 1 January 2015 to 31 December 2016) for each segment of ~100 m. The seabed level (yellow line) that is used for the RBBD is presented in order to link the AIS data to the water depth.*

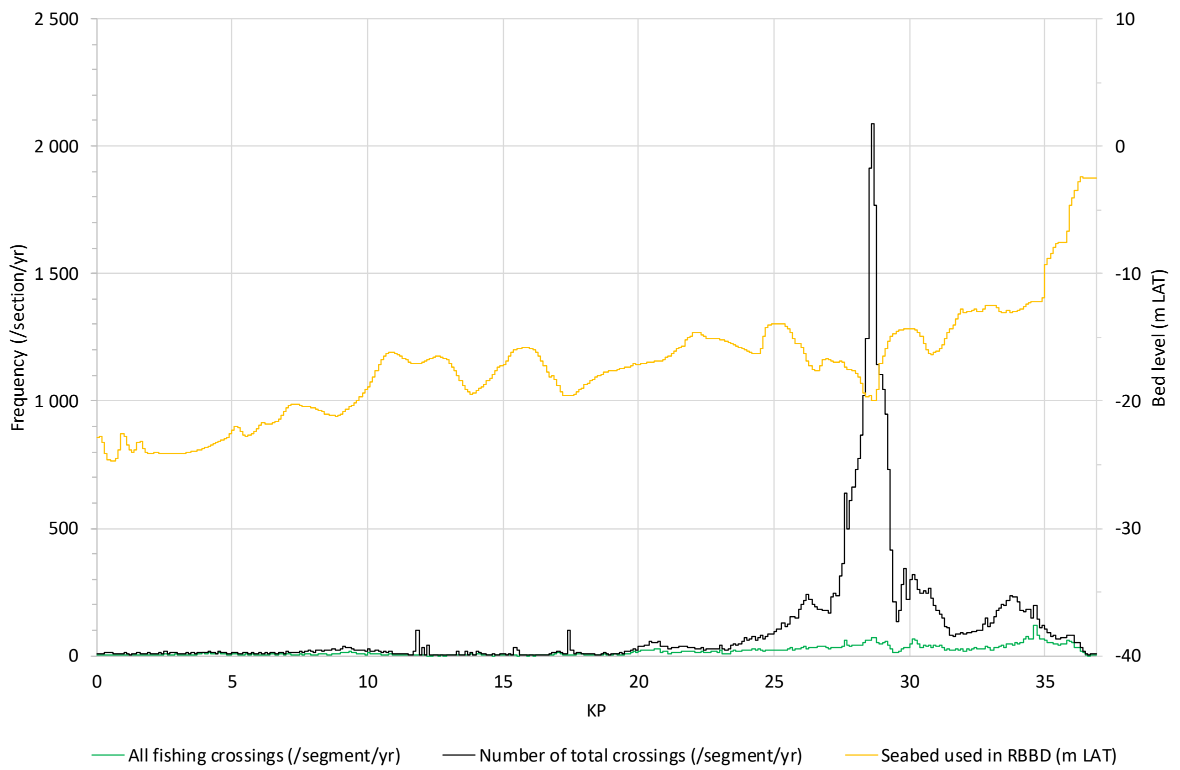


Figure 5.3 *Frequency of all the ships (black line) and fishing ships (green line) that cross*

route alternative 6 (/section/yr) as function of the cable route (KP). The numbers are based on two year of AIS data (from 1 January 2015 to 31 December 2016) for each segment of ~100 m. The seabed level (yellow line) that is used for the RBBD is presented in order to link the AIS data to the water depth.

5.2 Sinking ships

Input

The frequency of sinking ships is determined by (1) the frequency of sinking ships not due to collision (also called foundering) and (2) by the frequency of sinking ships due to collision. The ratio between the former and the latter of 1:2 is applied in the calculations.
In total, 8 different sizes of ships had been observed that contribute to the sinking frequency. The fraction of sinking ships that are regarded as critical sinking ships are listed for the eight different sizes in Table 5.1.

Table 5.1 *Fraction of sinking ships regarded as critical sinking ships for different ship sizes.*

Fraction of sinking ships regarded as critical sinking ships							
Cs-1	Cs-2	Cs-3	Cs-4	Cs-5	Cs-6	Cs-7	Cs-8
100-1000 GT	1000-1600 GT	1600-5000 GT	5000-10000 GT	10000-30000 GT	30000-60000 GT	60000-100000 GT	> 100000 GT
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Frequency of event

The frequency of critical sinking ships per km cable per year along the Hollandse Kust (noord) routes alternatives was calculated and the results are presented in Figure 5.4 for route alternative 7. The results of the other route alternatives are included in Annex 2, as these results are all smaller than those of route 7 and directly linked to the crossing frequencies that are presented in Section 5.1. As Figure 5.4 shows, the ship sinking risk occurs mainly in the navigation channel, since this is the area where the most marine traffic occurs. Totalled over the complete route, the probability that a vessel sinks on the cable is in average once per ~17,800 year.

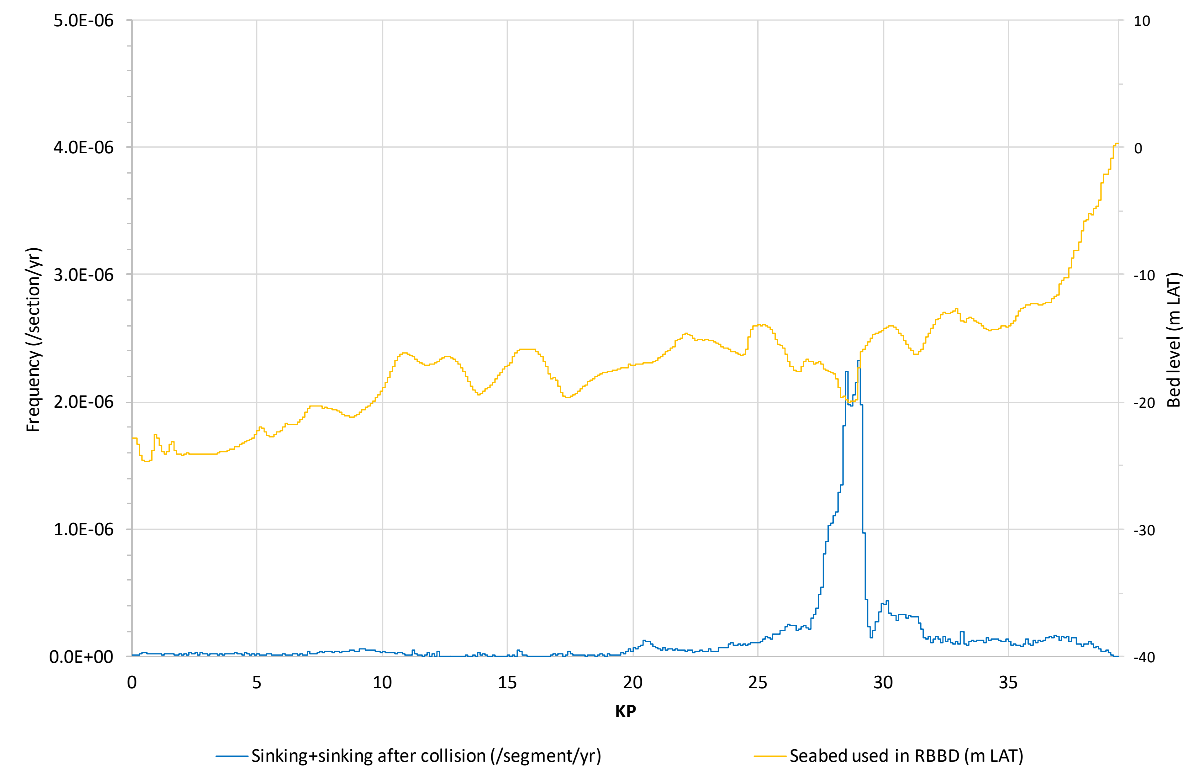


Figure 5.4 *Frequency that critical ship sinking occurs on the Hollandse Kust (noord) route alternative 7.*

5.3 Grounding ships

Input

In total, eight different sizes of ships have been observed that contribute to the grounding frequency. Grounding of ships can be caused by (large) ships that drift away from dense shipping routes towards the export cable area. The fraction of grounding ships that are regarded as critical grounding ships are listed for the eight different sizes in Table 5.2. The results for grounding are presented for route alternatives 2, 4 and 6. The reason for this is that grounding - in contrast to sinking, anchor dropping, anchor hooking and bottom trawling by fishers - is not directly linked to the crossing frequencies. The results for other route alternatives are included in Annex 2.

Table 5.2 *Fraction of grounding ships regarded as critical grounding ships for different ship sizes.*

Fraction of grounding ships regarded as critical grounding ships							
Cg-1	Cg-2	Cg-3	Cg-4	Cg-5	Cg-6	Cg-7	Cg-8
100-1000 GT	1000-1600 GT	1600-5000 GT	5000-10000 GT	10000-30000 GT	30000-60000 GT	60000-100000 GT	> 100000 GT
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Frequency of event

The frequency that critical ship grounding occurs on Hollandse Kust (noord) route alternative 2, 4 and 6 is shown in Figure 5.5, Figure 5.6 and Figure 5.7, respectively. Because the grounding occurs in the shallow areas, the probability is high in the nearshore area and on top of the several sand waves and shallow areas along the route. Totalled over the complete route, the probability that a vessel grounds on the cable is in average once per ~7,500 year for route 2, once per ~2,000 year for route 4 and once per ~3,500 year for route 6.

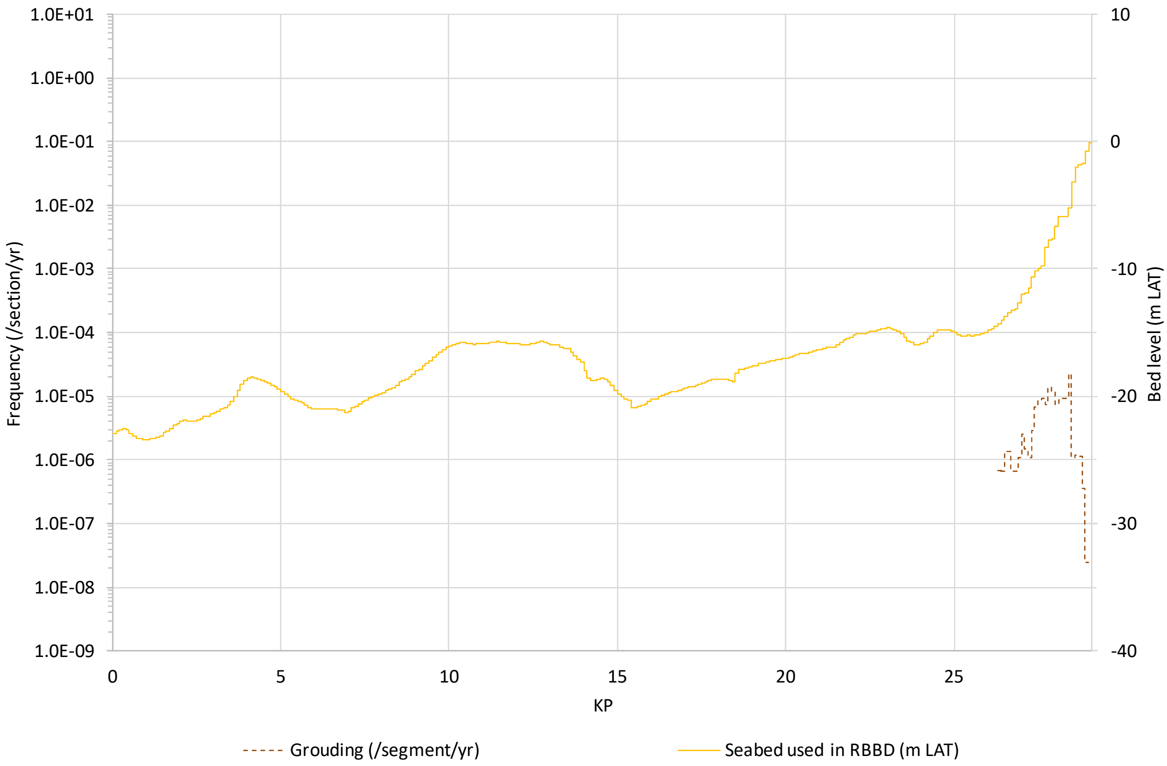


Figure 5.5 *Frequency that critical ship grounding occurs on Hollandse Kust (noord) route alternative 2.*

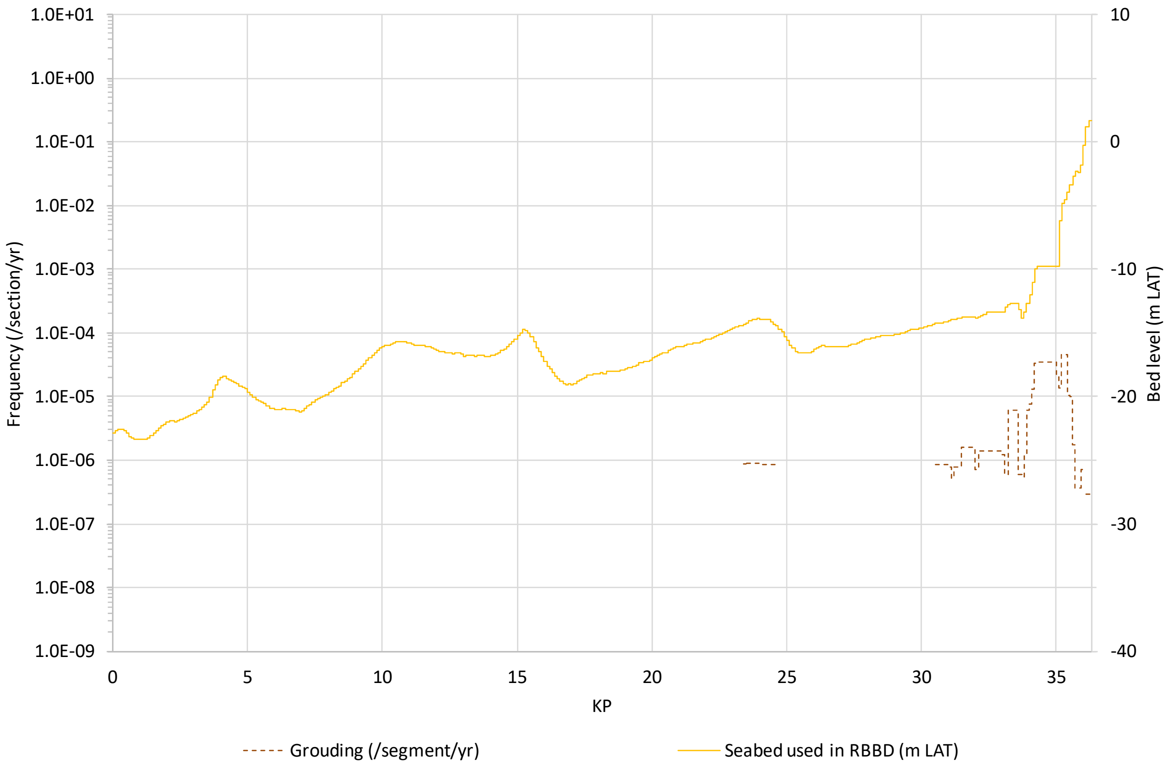


Figure 5.6 *Frequency that critical ship grounding occurs on Hollandse Kust (noord) route alternative 4.*

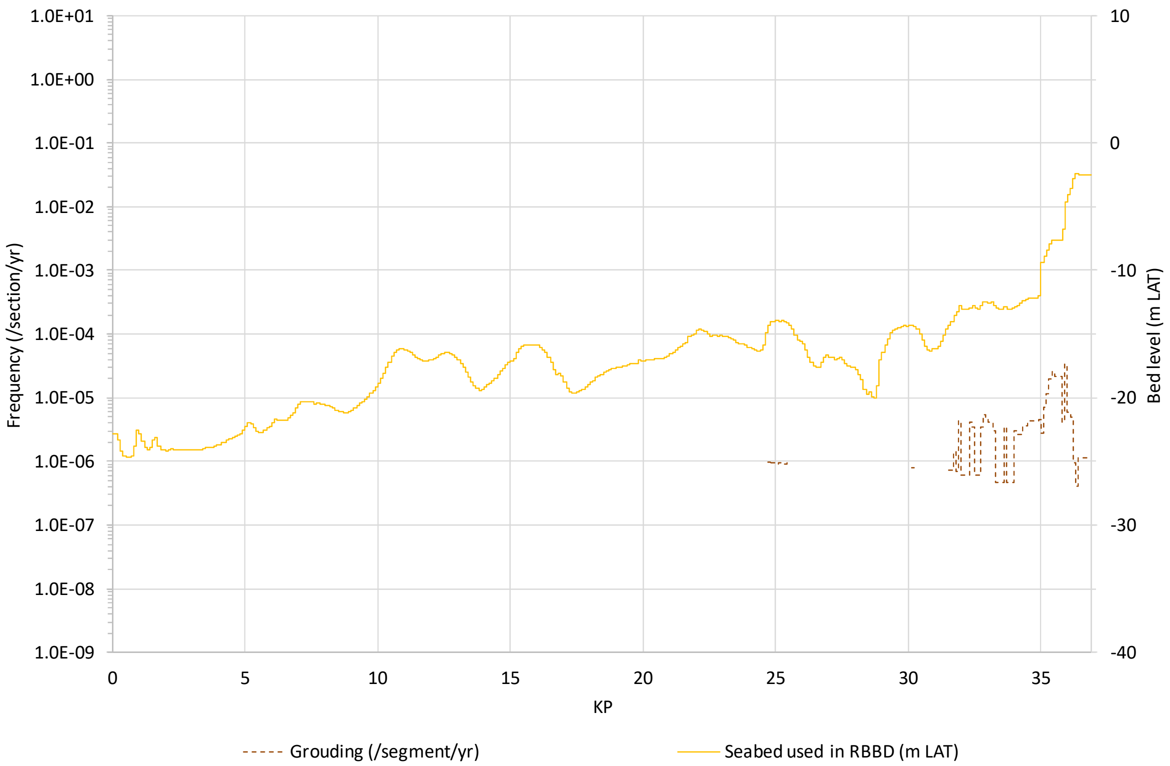


Figure 5.7 *Frequency that critical ship grounding occurs on Hollandse Kust (noord) route alternative 6.*

5.4 Anchor dropping

Input

The anchor dropping frequencies follow from databases that are representative for the project area. The given numbers present the frequency of anchor dropping, not yet the probability of anchor dropping leading to failure, which is dealt with in Chapter 6.

Frequency of event

The frequency that critical anchor dropping occurs on Hollandse Kust (noord) route alternative 2, 4 and 6 is shown in Figure 5.8, Figure 5.9 and Figure 5.10 respectively. The peaks in anchor dropping frequency largely correspond with peaks in the total number of crossings along the routes (see Figure 5.1, Figure 5.2 and Figure 5.3). In the IJ-geul and the nearshore area the frequency of anchor dropping increases due to the amount of marine traffic along that part of the route. Along route alterative 2 and 4 a peak occurs close to and south of the sand extraction zone, see Figure 4.2. Totalled over the complete route, the probability that an anchor is dropped exactly on top of the cable is in average once per ~490,000 year for route 2, once per ~419,000 year for route 4 and once per ~177,000 year for route 6.

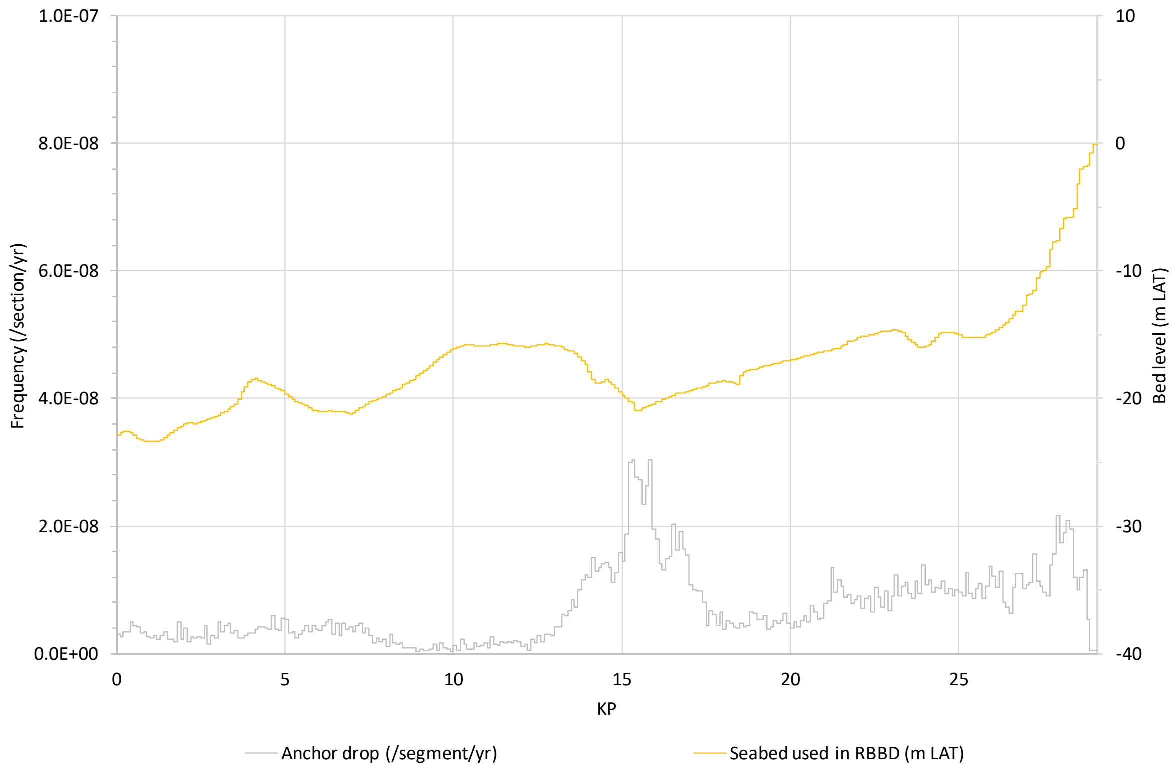


Figure 5.8 *Frequency that critical anchor dropping occurs on Hollandse Kust (noord) route alternative 2.*

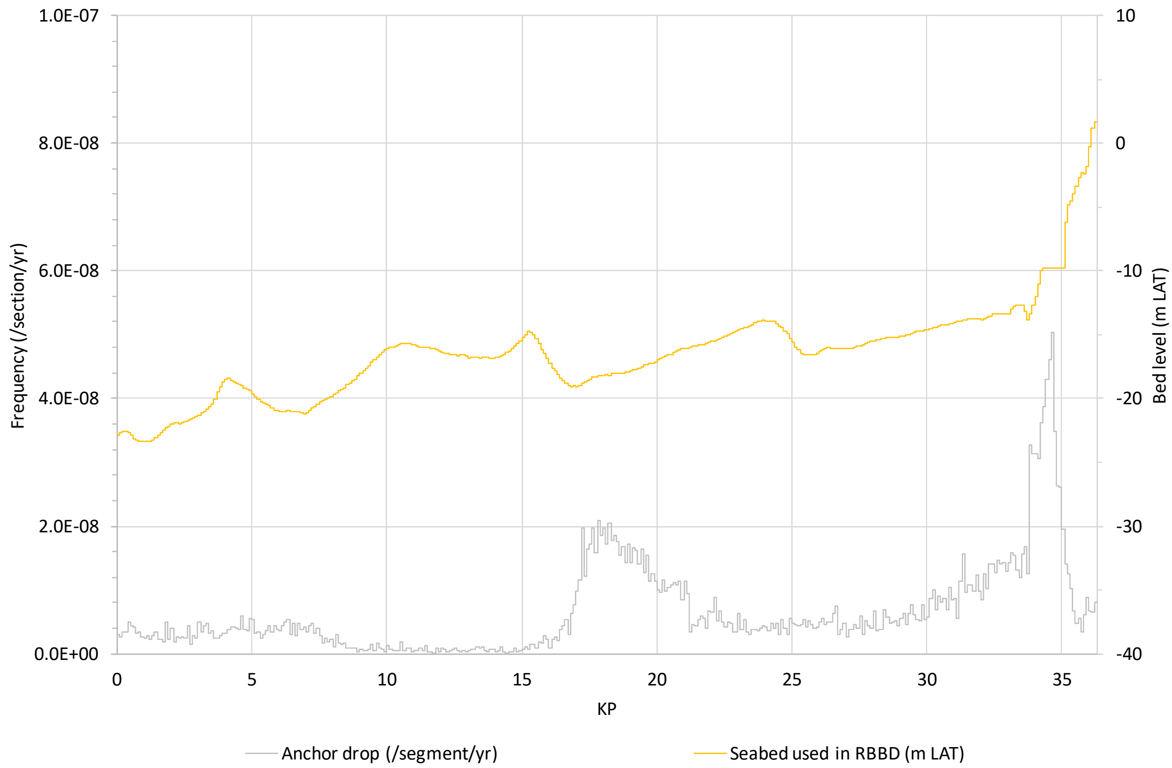


Figure 5.9 *Frequency that critical anchor dropping occurs on Hollandse Kust (noord) route alternative 4.*

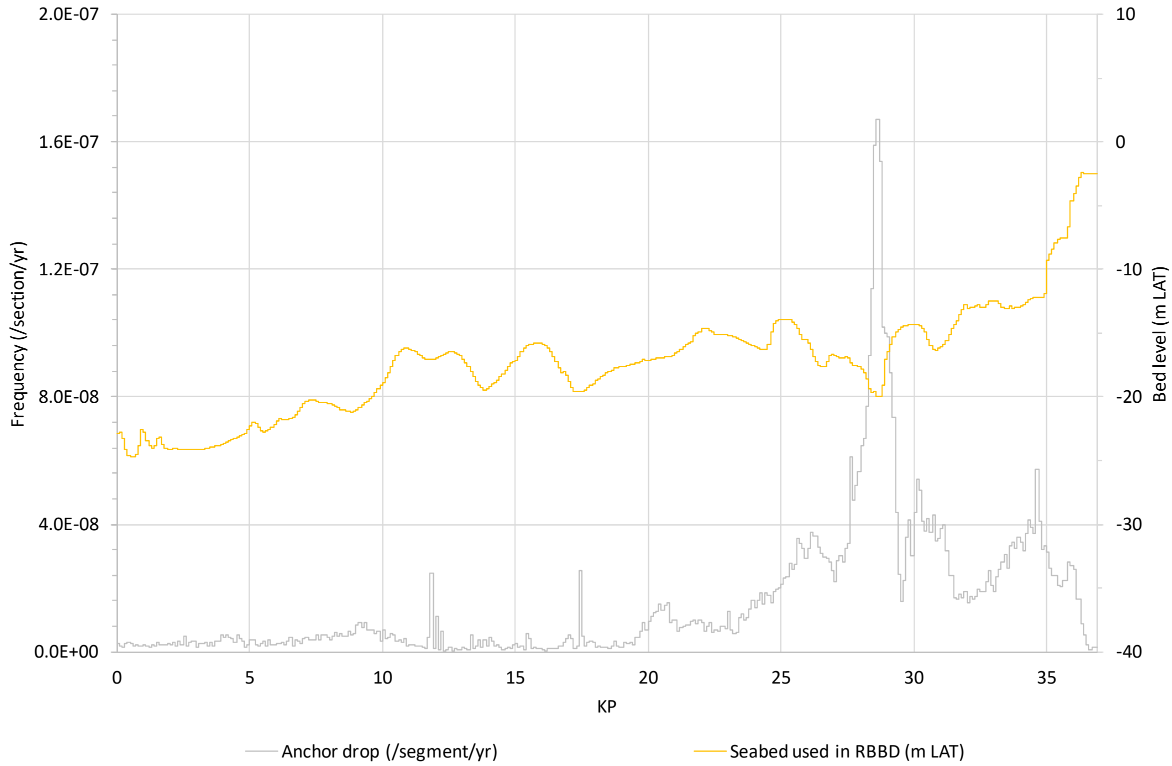


Figure 5.10 *Frequency that critical anchor dropping occurs on Hollandse Kust (noord) route alternative 6.*

5.5 Anchor hooking

Input

The anchor hooking frequencies follow from databases that are representative for the project area. The given numbers present the frequency of anchor hooking, not yet the probability of anchor hooking leading to failure, which is dealt with in Chapter 6.

Frequency of event

The frequency that critical anchor dropping occurs on Hollandse Kust (noord) route alternative 2, 4 and 6 is shown in Figure 5.11, Figure 5.12 and Figure 5.13 respectively.

In the navigation channel and the nearshore area the frequency for anchor hooking increases due to the amount of marine traffic along that part of the route. The probability for anchor hooking obviously is larger than the probability for anchor dropping. Totalled over the complete route, the probability that an anchor will potentially hook behind the cable is in average once per ~7800 year for route 2, once per ~7500 year for route 4 and once per ~3300 year for route 6. If it actually hooks depend on the burial depth and soil type.

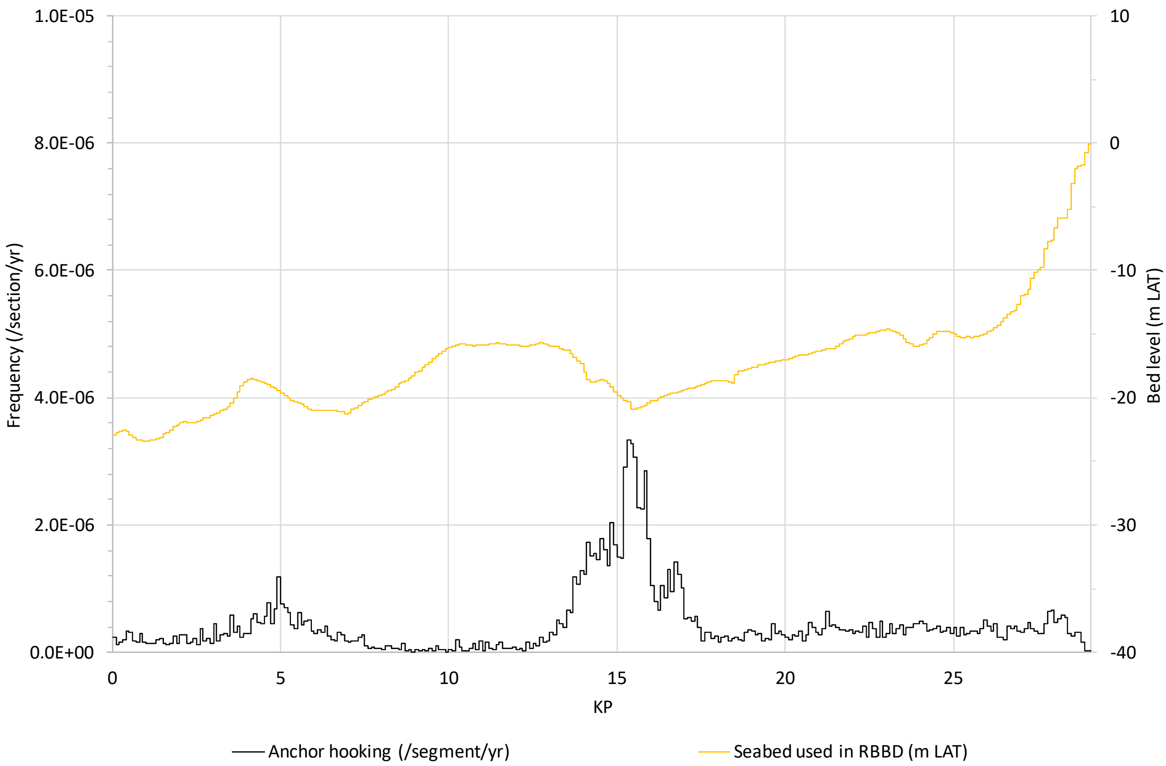


Figure 5.11 *Frequency that critical anchor hooking occurs on Hollandse Kust (noord) route alternative 2.*

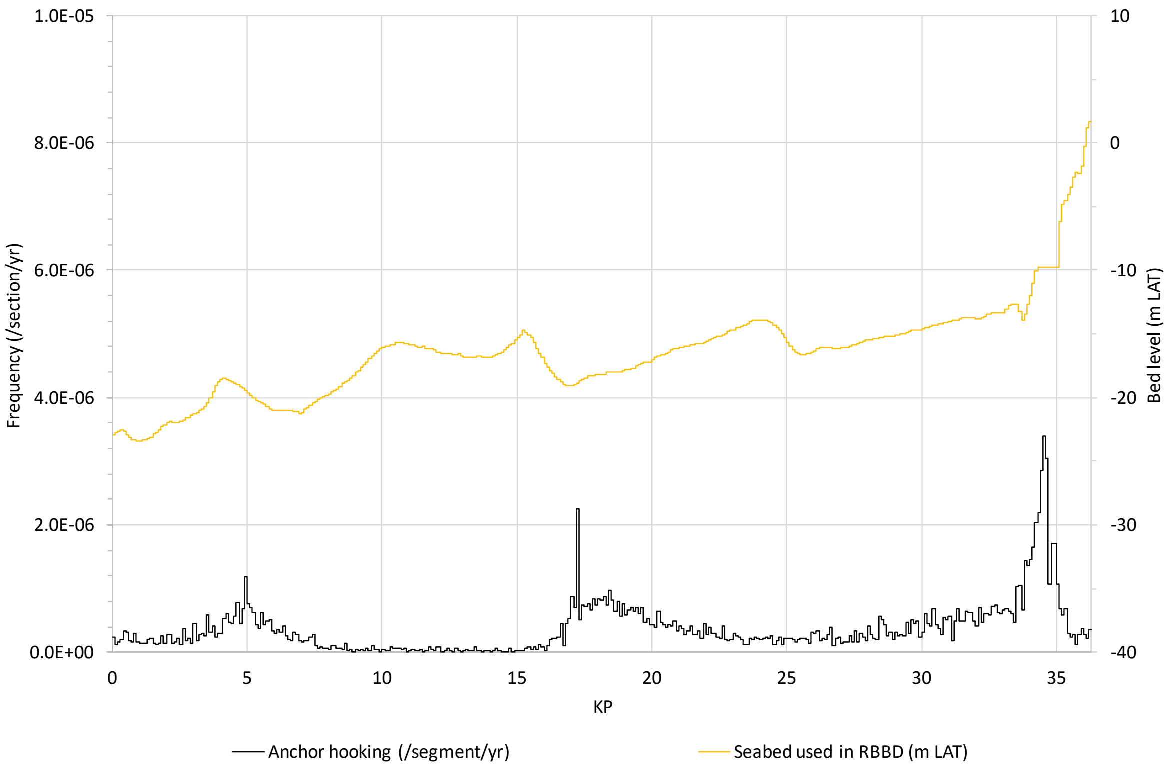


Figure 5.12 *Frequency that critical anchor hooking occurs on Hollandse Kust (noord) route alternative 4.*

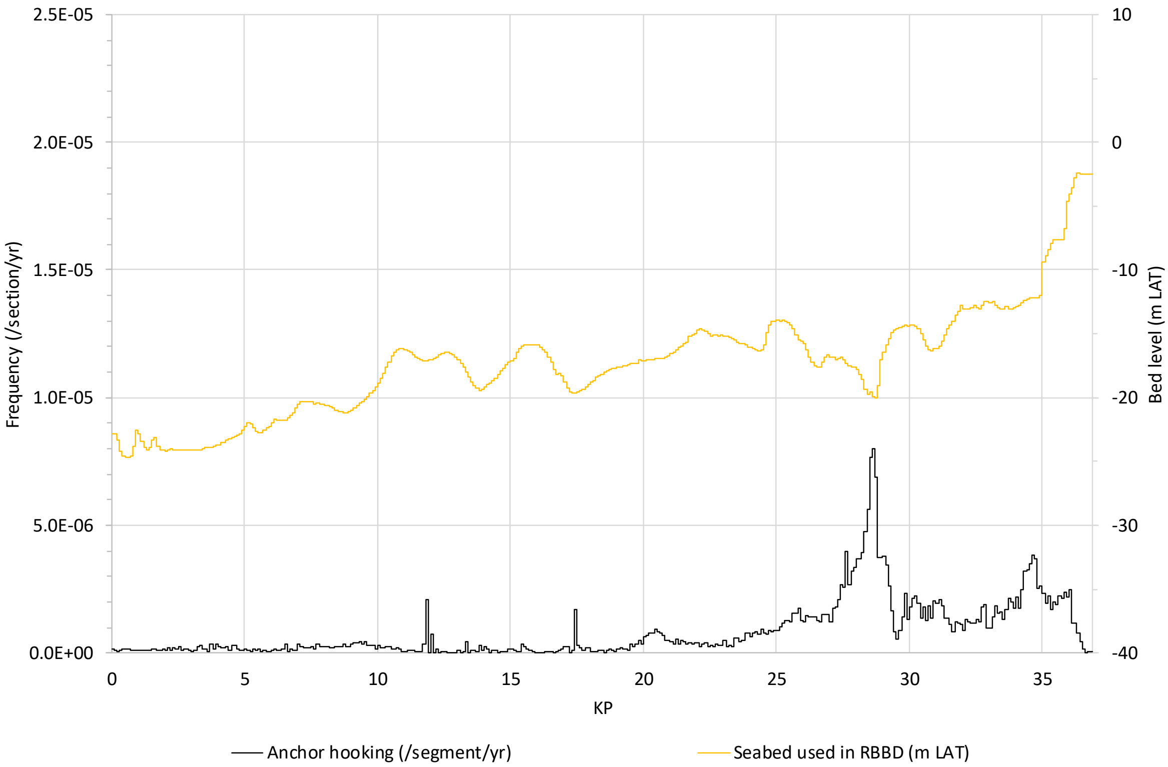


Figure 5.13 *Frequency that critical anchor hooking occurs on Hollandse Kust (noord) route alternative 6.*

5.6 Dropping objects

Result

As described before, the falling objects frequency is determined by the number of crossing vessels with containers on board, which in turn is based on AIS data. After due consideration and discussions with Marin it is concluded that the 'standard' statistics for 'dropping containers' do not apply for the Hollandse Kust (noord) route alternatives. Although the number of crossings of route alternatives 6 and 7 by large container vessel is high, the wave conditions during crossing will be relatively calm. The main reason for containers falling over board is due to extreme weather and wave conditions, which will not apply in this case. This results in a negligible probability for dropping objects (like falling containers) in the Hollandse Kust (noord) WoZ project area (~zero).

5.7 Fishing activities

Input

The frequency of interaction between fishing gear and the export cable was calculated from the AIS data. In addition, it is assumed that when a fishing vessel is sailing more than 5 knots it is very unlikely that she is involved in bottom trawling. Furthermore, a study on the effect of crossing angle [18] and

[18] If the crossing angle is 0 or 180 degrees, the gear runs parallel to the asset; if the crossing angle is 90 or 270 degrees, the gear crosses the asset perpendicular.

pipelines [19], demonstrated that the risk associated to bottom trawling over and along pipelines, and assumed for cables as well, increase with decreasing crossing angle. Therefore, the factors that are listed in Table 5.3 have been implemented.

Table 5.3 *Fraction of crossing fishing ships regarded as critical crossing fishing ships for different crossing angles. Crossing angles are visualized and explained below Figure 5.14.*

Fraction of crossing fishing ships regarded as critical crossing fishing ships					
Cf-180°	Cf-150°	Cf-120°	Cf-90°	Cf-60°	Cf-30°
1.00	0.50	0.10	0.10	0.50	1.00
Cf+30°	Cf+60°	Cf+90°	Cf+120°	Cf+150°	Cf+180°
1.00	0.50	0.10	0.10	0.50	1.00

Frequency of event

The frequency of fishing activities interacting with route 2, 4 and 6 are illustrated in Figure 5.14, Figure 5.15 and Figure 5.16 respectively. The results for other route alternatives are included in Annex 2. The frequency for fishing crossing shows a distinct pattern along the cable route and seems to correlate with specific seabed features. For route alternatives 2, 4 and 6, most fishing activity occurs on the nearshore slopes. Around KP 16 of route alternative 2, a sharp transition is shown in the crossing angles between the trawl gear and the cable, which corresponds with the sharp bend in the cable at this location. From KP 16-21 the fishermen sail mostly parallel to the cable, and parallel to a local sand bar, which is shown as predominantly red between KP 16-21. In the nearshore area most fishing movements occur in alongshore direction, resulting in approximately perpendicular crossings between the fishing gear and the cable, which is shown as green in the figures.

[19] Performed for Nord Stream.

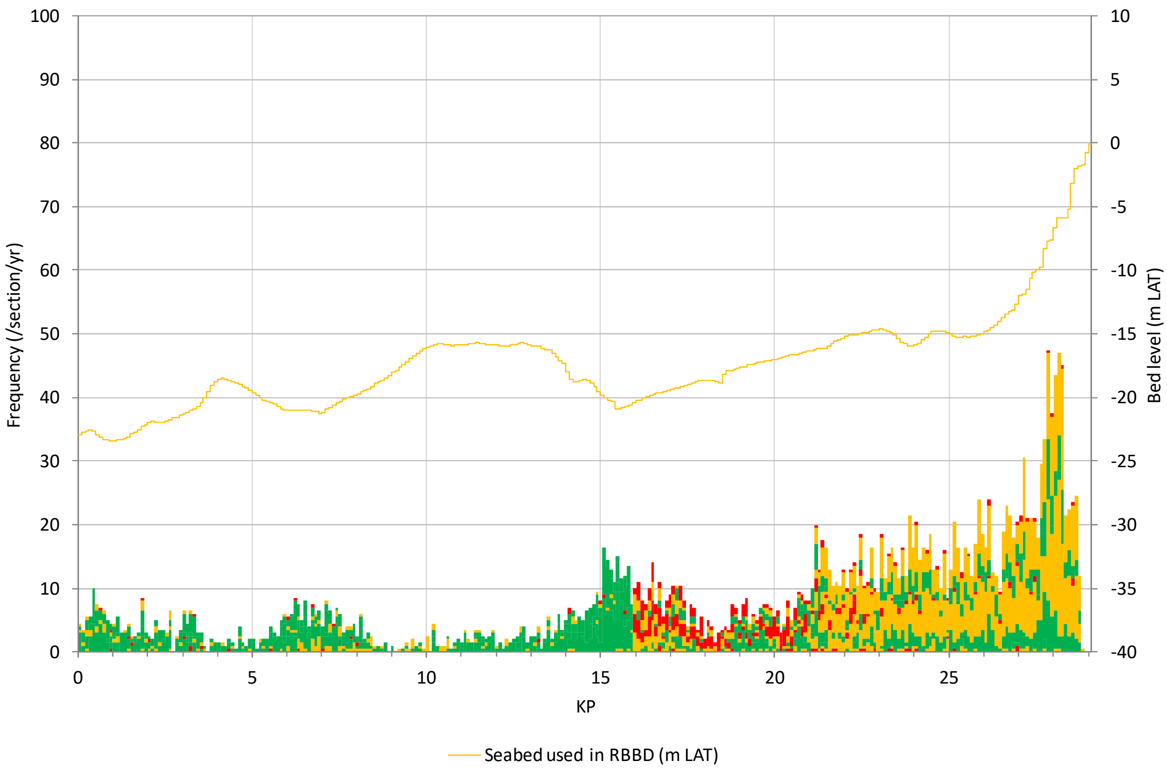


Figure 5.14 *Frequency that fishing activities interacting with Hollandse Kust (noord) route alternative 2. The colours are explained in the next paragraph.*

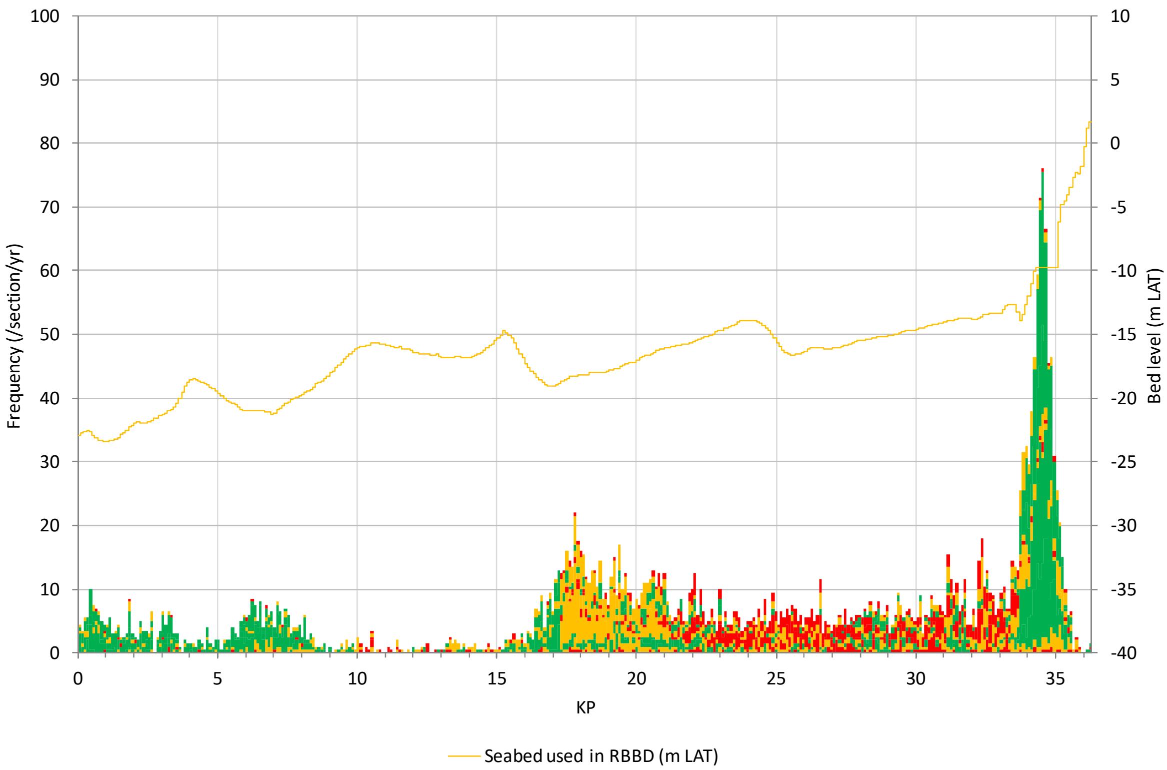


Figure 5.15 *Frequency that fishing activities interacting with Hollandse Kust (noord) route alternative 4. The colours are explained in the next paragraph.*

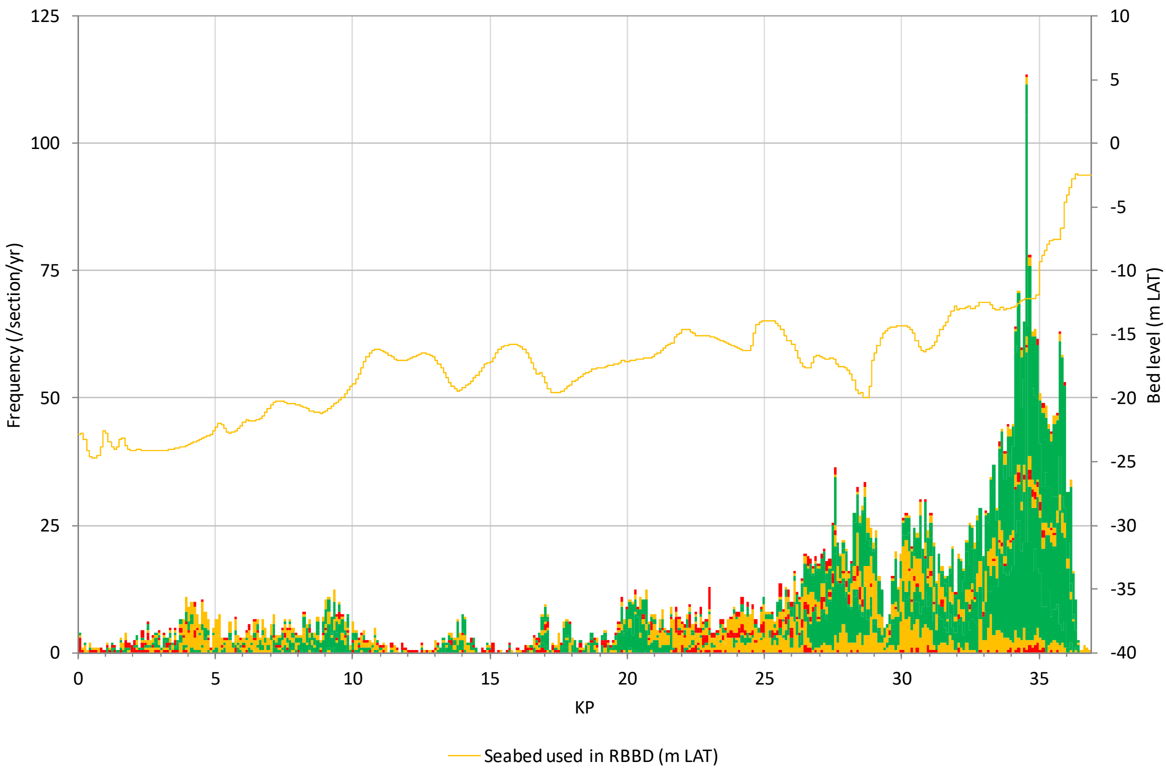


Figure 5.16 *Frequency that fishing activities interacting with Hollandse Kust (noord) route alternative 6. The colours are explained in the next paragraph.*

Explanation of Figure 5.14 - Figure 5.16 This figure presents the number of fishing ships per section, sailing less than 5 knots, that cross the export cable. The different colours represent the crossing angle defined by the following definition 'rose':

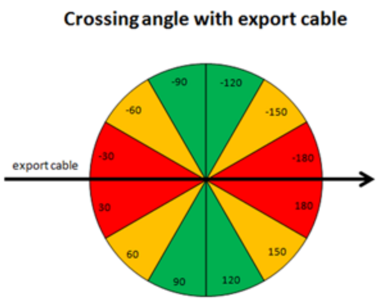


Figure 5.17 *Crossing angles of fishing vessels with respect to the export cable.*

The export cable is indicated with the thick black arrow, with the arrow head pointed in direction of increasing KPs along the export cable [20]. The crossing angles are defined as presented in the above legend of Figure 5.14, Figure 5.15 and Figure 5.16, starting at -180° with twelve steps of 30° in counter-clockwise direction. A crossing angle of 30° indicates that the cable is crossed from approximately the west-south-west, whereas a crossing angle of -120° indicates that the cable is crossed from approximately the north-north-east. Note that small crossing angles are visualised with red as these crossing angles have the

[20] For the Hollandse Kust (noord) export cable, KP's are defined as increasing from the offshore platform towards shore.

most potential of damaging the cables due to hooking and longer wearing tracks. Crossing angles (almost) perpendicular to the export cable are, therefore, indicated with green, since these crossings lead to (relatively) less damage.

5.8 Seabed dynamics

Sand waves

The cable routes pass through areas with dynamic sand waves, which are known to migrate in the order of metres per year. Primary mitigation is to 'route' the cables in such a way that future sand wave mobility is anticipated as much as possible, by for instance routing through the sand waves troughs wherever possible. Second mitigation is by deep trenching or dredging a trench through the sand waves as pre-lay cable trench [21]. The results of a dedicated seabed morphology study should be used in future updates of the risk based burial assessment for Hollandse Kust (noord).

5.9 Other sources

Free spans

Free spans [22] in cables are to be avoided because of the vulnerability of cables to external hazards (especially in case of zero cover), as well as internal vulnerability due to Vortex Included Vibrations [23]. External forces, caused by anchor or fishing gear interaction, do not always lead to total cable breakage, but also high bending forces may lead to internal failure and subsequently cable failure. In case of pipelines the situation is normally different. A steel pipeline is stronger and free spans are often acceptable as long as within project specific free span allowance criteria. In this cable risk study, dedicated free span development studies were not performed because they are in principle to be avoided. It is assumed that if free spans are expected to occur, or have occurred, free span intervention work will be carried out. To provide guidance on the issue of free spans, 'target' and 'minimum' criteria are included in the permit provisions (Table 7.4).

Crossings with other pipelines or cables

It is assumed in this study that the export cable design is such that any crossings with other cables or pipelines will not significantly increase the failure probability, and thus will not affect the total failure probability. Despite this, the total number or crossing are included here for completeness and possible future reference. The number of cables and pipelines that cross the HKN route alternatives were obtained from an overview provided by TenneT (/17/) which is presented in Table 5.4.

[21] As applied to BritNed Interconnector and Borselle export cables.

[22] A free span is a section of the cable where it is not supported by the seabed, allowing the water to flow beneath it. Fishing gear may more easily get hooked under a cable in free span.

[23] Vibrations of the cable caused by the flow velocities and viscosity of the water flowing around the free span. Long term vibrations cause fatigue damage of the cable.

Table 5.4 *Crossings of the Hollandse Kust (noord) route alternatives with other cables and pipelines [24].*

Route	Cable / pipeline							
	Wintershall Noordzee B.V.	Oliepijplijn Petrogas E&P LLC	Geplande Pijpleiding Tulip Oil	PANGEA Segment 2	UK - NL 14	Atlantic Crossing 1 Segment B1	Atlantic Crossing 1 Segment B2	
1	1	0	0	1	1	0	1	
2	1	0	0	1	1	0	1	
3	1	0	0	1	1	1	2	
4	0	0	1	1	1	1	2	
5	0	0	1	1	1	1	2	
6	0	1	1	1	1	1	2	
7	0	1	1	1	1	1	2	

Route	TAT 14 Segment J	Ulysses 2	OWEZ trace A (vh NSW)	OWEZ trace B (vh NSW)	OWEZ trace C (vh NSW)	Prinses Amalia Windparken (vh Q7-WP)	Nuon Beaufort Kabel Zuid	Total
1	1	0	0	0	0	0	0	**5**
2	1	0	0	0	0	0	0	**5**
3	1	0	0	0	0	0	0	**7**
4	1	0	1	1	1	1	1	**12**
5	1	0	1	1	1	1	1	**12**
6	1	0	0	0	0	1	1	**10**
7	1	1	0	0	0	1	1	**11**

5.10 Noordzeekanaal specific hazards

Embankments

The main additional marine hazard related to sailing in a relatively narrow channel like the Noordzeekanaal, is the possible grounding on the embankment of the channel. If an incident happens, such as engine or rudder failure, the vessel may drift on to the embankment. It may decide to drop the anchor to try to prevent or delay the grounding but there is generally not much space to use the anchor effectively. The specifics of this type of anchoring and grounding has been implemented in the RBBD. For example the probability of anchor hooking in the event of an anchor being dropped along a parallel cable is different compared with the 'standard' hooking probability of a vessel crossing a cable. I addition, attention is given to the issue of maintenance activities on the embankments of the channel by work vessels using spud-poles for 'mooring'.

[24] This Table has not been updated for the changes in route 1 and 2. Due to the nature of the changes and the objective of this study, the conclusions are not affected.

6 Failure assessment

Introduction

In Chapter 5 the probabilities of the events were determined (P1 = frequency of event happening), in this Chapter the probabilities of failure if those events happen will be assessed (P2 = probability of event leading to unacceptable consequences), as explained in Step 2 in Chapter 2. The assessment of technical failure requires an engineering study which is outside the scope of this study. However, estimates were made in this study based on available knowledge, our experience and recent investigations with respect to anchor hooking (/14/). This failure assessment holds for all cables of the Hollandse Kust (noord) WoZ project. The sensitivity to these assumptions is further discussed in Chapter 7.

P2 = BF * AF

The probability of failure if an event happens is the result of the 'event specific' Burial-Factor multiplied with the 'event specific' Asset-Factor. The Burial-factor is dependent of the burial depth, while the Asset-Factor is dependent of the damage/failure scenario [25].

Burial-Factor

The Probability of Failure of the asset (in this case cable) due to hazardous events is calculated by multiplying, (1) the probability that an event happens (P1), with (2) the probability of failure if the event happens (P2). The probability of failure is calculated with the 'event specific' Burial-Factor and Asset-Factor. The Burial-Factor depends on the amount of cover above the asset and is assumed to change between:

- '0' (zero): if the asset is sufficiently deep buried;
- '0.1' (10%): if the asset is buried on the depth the probability of causing significant damage to the asset is 10%;
- '0.5' (50%): if the asset is buried exactly on the depth the probability of causing significant damage to the asset is 50%;
- '0.95' (95%): if the asset is buried exactly on the depth the probability of causing significant damage to the asset is 95%;
- '1', if the top of the asset is exposed to the level that significant damage must be assumed.

Change of the Burial-Factor between 0 to 1 is presented in Figure 6.1.

Threshold values Burial-Factor

The value of the Burial-Factor depends on the upper threshold value, 100%, and the 50% and 95% failure criteria for hazard-specific cover above the asset ($c_{t,\text{threshold value}}$):

- 50% failure criterion: this value means that if the asset is exactly buried as deep as this criterion, only 50% of the incidents actually cause significant damage to the asset;
- 95% failure criterion: this value means that if the asset is exactly buried as deep as this criterion, only 95% of the incidents actually cause significant damage to the asset;
- Upper threshold: this value means that if the top of the asset is above this threshold, the asset is assumed to significantly damage.

[25] Please note that the Burial-Factor is the same as the Damage-Factor, and the Asset-Factor is the same as the Failure-Factor, as both used in the Borssele RBBD study. The renaming to Burial-Factor and Asset-Factor is because (1) these names reflect directly the main purpose of the factor and (2) are the result of further discussions with authorities and pipeline operators about the RBBD methodology.

Variation of Burial-Factor with cover

The variation of the Burial-Factor as function of the cover follows an S-curve. The reasons for that assumption are the following:

- It is assumed that the first centimetres or decimetres of the seabed do not immediately mobilise support;
- It is assumed that the Burial-Factor will quickly decrease at a certain (event depending) cover depth, but it will not become zero at a specific depth, the Burial-Factor will reduce to an asymptote.

The S-curve as shown in Figure 6.1 has been derived by specifying the threshold values as explained above.

Sensitivity of PoF on Burial-Factor

In a recent study on a similar project (/1/), a sensitivity analysis was performed by exploring the results of different values for the 50% and 95% cover criteria. The sensitivity analysis showed marginal differences with the 'realistic assumptions'. Therefore, it has been concluded that the cover threshold values for the Burial-Factors result in realistic PoF values.

Implementation of Burial-Factor

Roughly three different soil types are found in the first three meters of the Hollandse Kust (noord) project area (/3/). Sand is most common, varying from fine to medium coarse sand. At specific locations, layers of clay and loam are found below an upper layer of sand. It is assumed that these sandy soils behave similar to dynamic impact as the predominant soil that is found in the WoZ Borssele project area (i.e. fine to coarse sand, /1/). This means that the values for the 50% and 95% cover criteria for soil type B-2 (given in Table 6.1) correspond to the cover criteria that have been applied for the RBBD assessment for WoZ Borssele. Soil-type B-2 is used throughout the Hollandse Kust (noord) project area for all sandy soils. The clay and loam along the Hollandse Kust (noord) routes is assumed to behave similar to the dynamic impact as the clay and loam found in the WoZ Borssele project area.

Table 6.1 *Assumptions for cover threshold values for Burial-Factors (BF) for the* ***Soil type B-2 Medium Loose Sand***

Event	Assumptions for BF cover threshold values (m)		
	$c_{t,0.5}$	$c_{t,0.95}$	$c_{t,0}$
Burial-Factor	0.50	0.95	1.0
Sinking	2.5	1.5	0
Grounding	1.5	0.8	
Anchor dropping	0.75	0.4	
Anchor hooking	1	0.5	
Fishing	0.15	0.05	

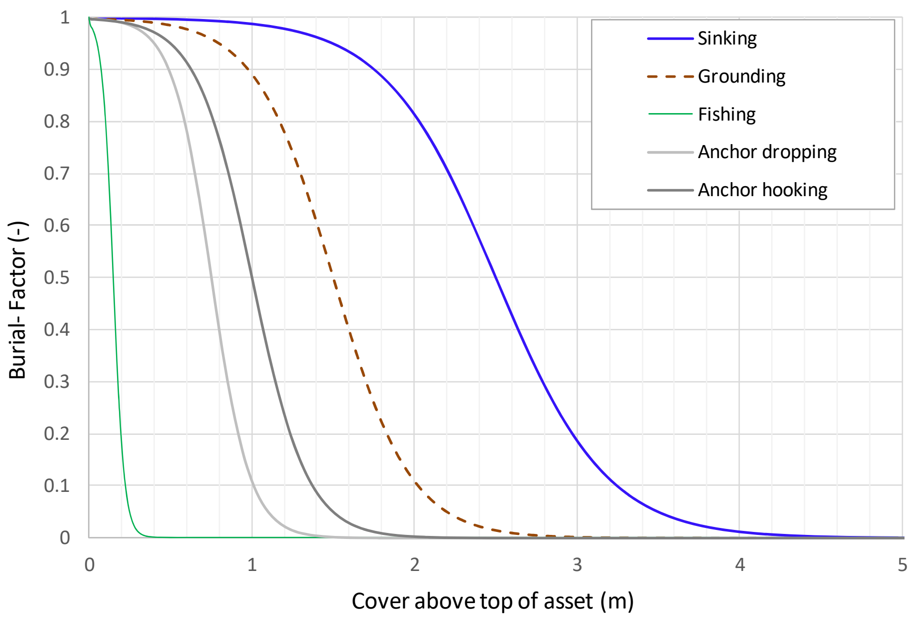


Figure 6.1 *Burial-Factors for sinking, grounding, anchor hooking, anchor dropping and bottom trawling for the* ***B-2 Medium Loose Sand****, as function of cover above the cable.*

Asset-Factor The Asset-Factor is defined as the probability that the cable fails after a specific number of crossing or hits. The Asset-Factor much depends on the damage/failure scenario:

- If a vessel sinks on top of a cable, failure of the cable is assumed because continued operation of the cable with the sunken vessel on top is assumed to be unacceptable:
  → Asset-Factor $_{sinking}$ = 1;
- If a vessel grounds on top of the cable, failure is assumed as well. Continued operation of the cable with a grounded vessel on top is assumed to be unacceptable. Furthermore, grounded ships tend to dig into the soil even deeper as time passes creating even more damage:
  → Asset-Factor $_{grounding}$ = 1;
- If a dragging anchor hooks behind a cable on, or just flush with the seabed, failure is assumed because the cable will also be dragged for some distance and the resulting forces and bending moments are assumed to be unacceptable because they often damage the protection layers potentially leading to damage:
  → Asset-Factor $_{anchor\text{-}hooking}$ = 1;
- If an anchor drops just on top of the cable, the cable can be damaged. Different studies result in diverging results about the energy a cable can absorb before it fails (ranging from 50 J to 2.5 kJ). It is therefore chosen to be conservative and it is assumed that the cable will fail:
  → Asset-Factor $_{anchor\text{-}dropping}$ = 1;
- If bottom trawls cross and hit the cable, the cable will not immediately fail due to the strong protective cover. However, after multiple contacts between the trawls and the cable at the same location, the lead sheath and isolation can rupture which causes direct failing of the cable. It is assumed that only after 100 'hits' on the same 100 m section the cable will fail, which means that the probability of failure is reduced with a factor 100:
  → Asset-Factor $_{fishing}$ = 0.01.

Further on fishing Submarine cables are designed and manufactured with strong armouring to withstand the laying forces and significant impacts from external forces, such as bottom trawling gear. No actual data of failure modes are available for this study and therefore engineering judgement has been used. For this cable it is assumed that only one in thousand crossings is assumed to be a critical crossing leading to failure: AFf = 0.01. This means that it is assumed that the cable fails after 100 times a bottom trawler has crossed the cable at the same section of 100 m, taking the 'crossing-angle-factors' as given in Table 5.3 in account.

Hooking of gear Hooking of bottom trawling gear can only happen if the gear is able to get physically under the cable. This can only happen in case the cable is significantly exposed or in free span. If the cable is buried to at least Top of Cable 'flush' with the seabed, hooking of bottom trawling gear is virtually impossible in sandy seabed as in the Hollandse Kust (noord) WoZ project area.

Hooking / retrieving scenario's In case bottom trawling gear gets hooked under a cable, the following scenario's may develop:

a) The hooked gear may damage the cable but is released after breaking of the cable or breaking loose from the cable;
b) The hooked gear may get stuck under the cable and the fishermen successfully retrieves his gear;
c) The hooked gear may get stuck under the cable and the fishermen may not be able to retrieve his gear and has to let go his gear;
d) The hooked gear may get stuck under the cable and the fishermen cannot retrieve his gear, does not cut his gear and keeps trying, which could result in injuries to the crew or even worse: capsizing and fatalities.

Consequences of gear hooking All above scenarios are expected to lead to some damage to the cable. Only scenario d) may lead to consequences in terms of safety and environmental damage. There are no events known of fishing gear getting stuck under a cable that has led to fatalities or environmental damage. There has been one incident reported about capsizing of a fishing vessel as the result of unsuccessful retrieving gear that had got stuck under a steel submarine pipeline (Westhaven capsizing in March 1997). The probability of scenario d) developing comparable with the Westhaven scenario is small because (1) a power cable is much less strong, and more flexible compared with a heavy and rigid steel pipeline. It is therefore justified to assume that the probability of fatalities and/or environmental damage due to hooking of fishing gear is acceptably low and assumed to be less than 10^{-5}/year and 10^{-6}/km/year. The basis for this assumption is the fact that such accident, due to interaction between fishing gear and a cable, has never been reported and with almost certainty has never happened.

Pipelines and cables Specifically the upper threshold depends on the type of asset. Pipelines are much stronger and less sensitive to impact compared with cables and may be left exposed on the seabed, which means that the upper threshold will be higher for certain events. For instance bottom trawling does occur over free spanning pipelines and the probability of hooking and subsequent damage and failure is related to span length and gap height (and crossing angle…). In brief, a cable is more sensitive to impact compared with a steel pipeline and this is reflected in the assumed Burial-Factors and Asset-Factors.

Used Asset-Factors

The used Asset-Factors for realistic assumptions are given in Table 6.2. In previous studies on similar project (/1/), a sensitivity analysis was performed by exploring the results of conservative and optimistic assumptions for the Asset-Factors. The sensitivity analysis showed marginal differences with the 'realistic assumptions'. Therefore, it has been concluded that the values for the Asset-Factor result in realistic PoF values.

Table 6.2 *Assumptions for Asset-Factors.*

Event	Assumptions for Asset-Factor (-)
	Realistic
Sinking	1
Grounding	1
Anchor dropping	1
Anchor hooking	1
Fishing	0.01

7 Risk Assessment

7.1 Introduction

Objective

In this chapter the Risk Assessment is performed by the following steps:

- Determine the PoF for various scenarios, by multiplying the probability of event happening (P1, Chapter 5) with the probability of the event leading to failure (P2, Chapter 6), including a sensitivity analysis → Section 7.2;
- Locate the present combination of consequence and probability in the project dependent Risk Matrix and assess if there is room for optimisation by increasing the probability of failure while maintaining the acceptable consequences → Section 7.3;
- If there is room for improvement, determine the minimum burial depth that leads to still acceptable risk → Section 7.4;
- Finally, combining all results into a Risk Based Burial Depth proposal for the permitting process → Section 7.5.

Route alternative of preference

This chapter shows the Figures for the offshore part of the Hollandse Kust (noord) route alternative 4 as a typical example, the route which runs to the port of IJmuiden and continues through the Noordzeekanaal to Beverwijk (or Vijfhuizen in case of the similar route alternative 5). As mentioned before, only the offshore part of route 4 is considered here, excluding the Noordzeekanaal. Comparable Figures for the other route alternatives are included in Annex 2.

7.2 Results burial scenarios

7.2.1 Offshore routes

Introduction

The Probability of Failure (PoF) along the Hollandse Kust (noord) cables (per kilometre per year) and for the cable routes as a whole (per total length per year), has been determined for different burial scenarios, as summarized in Table 7.1.

Table 7.1 *Burial scenarios for PoF assessment.*

Scenario	Description	Figure
Installation scenario	– 3 m constant cover from shore to 3 km perpendicular from the shore, *see Note 1;* – 1 m constant cover thereafter to the platform; – 3 m constant cover below NGD in the IJgeul (route alternatives 6 & 7)	7.1
Signal scenario	– 2 m constant cover from shore to 3 km perpendicular from the shore, *see Note 1;* – 0.5 m constant cover thereafter to the platform; – 3 m constant cover below NGD in the IJgeul (route alternatives 6 & 7)	7.2
Minimum scenario	– 1 m constant cover from shore to 3 km perpendicular from the shore, *see Note 1;* – 0.3 m constant cover thereafter to the platform; – 3 m constant cover below NGD in the IJgeul (route alternatives 6 & 7)	7.3

Note 1: For route alternative 6 the constant 3 m, 2 m and 1 m cover of the

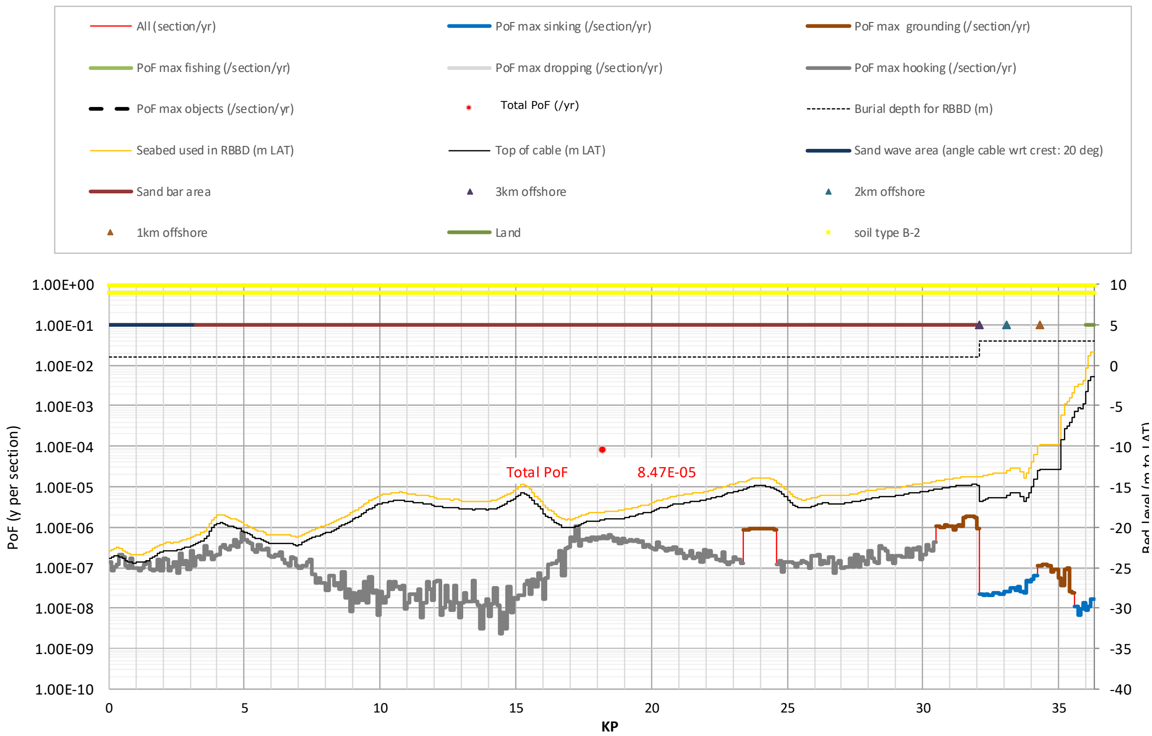
Installation, Signal and Minimum Scenario respectively, is extended just beyond the 3 km offshore boundary (KP>31.0). Doing this makes for a more fair comparison between the route alternatives and eliminates the maximum PoF resulting from grounding at this section.

Installation scenario

This scenario considers a burial scenario based on burial requirements as given in /12/ but including project-dependent interpretation specific for the Hollandse Kust (noord) export cables. A cover of 3 m is required until 3 km from the shore according to RWS (based on /12/). From there on a constant cover of 1 meter is required until the offshore platform. In the sand wave area, the sand wave crests will be pre-swept and in this scenario the cables are installed 1 m below the pre-swept line connecting the troughs of the sand waves. In the IJgeul a burial depth of 3 meter is applied below NGD, which is relevant only for route alternatives 6 and 7. The results of route 4 are presented in Figure 7.1 including the PoF of the whole route: $8.5*10^{-5}$/year.

Reading the Probability of Failure plots:

- ***Horizontal axis**: KP 0 starts at the offshore station, increasing towards the shore;*
- ***Right vertical axis**: Probability of Failure on a logarithmic scale from 1 (1.00E+00) to 10^{-10} (1.00E-10) all per year per section;*
- ***Left vertical axis**: seabed level in metres below LAT to allow visual alignment;*
- ***Total PoF** is presented as values for 100 m sections with a red line that is highlighted by the colour of the dominant threat in that particular section (shown as histogram);*
- ***Horizontal dot:** represents the PoF of the whole route, to be read on the vertical axis (per year per route) and the value is plotted above the dot;*
- ***Dashed line:** represents the cover on top of the export cable, i.e. the difference between the seabed (yellow line) and the Top of Cable (black line);*
- ***Geological formations** are visualised by two thick yellow/green/blue lines that represent the two layered soil implementation;*
- ***'Broken lines':** if the PoF line shows an intermittent line, this is due to the values being lower than the minimum value on the y-axis, being the result of using a logarithmic scale.*



Output - Probability of Failure per section

Figure 7.1 *Probability of Failure (PoF) for Hollandse Kust (noord) route alternative 4: Installation scenario: Burial depth is 3 m (KP>32.1), 1 m (KP<32.1).*

Observations The PoF of 8.5*10^{-5}/year (in average once per ~11,800 year) is well below (less risk relative to) the requirements of TenneT (i.e <10^{-3}/yr). Figure 7.1 shows that anchor hooking and grounding are contributing most to the total PoF. The failure probability due to anchor hooking fluctuates along the route and is strongly correlated to ship crossings (Figure 5.2). 'Grounding' is dominant on the more shallow parts with a relatively high traffic intensity and 'sinking' is dominant closer to shore.

Signal scenario The Signal scenario indicates the burial levels that should initiate the preparation of remediation or mitigation plans. With these burial levels the total Probability of Failure is still acceptable, but it is considered possible that next year's survey shows burial depths (below the minimum scenario) that require remediation or mitigation. If that happens, approved plans must be available to be implemented. The result based on the burial depth as given Table 7.1 is shown in Figure 7.2.

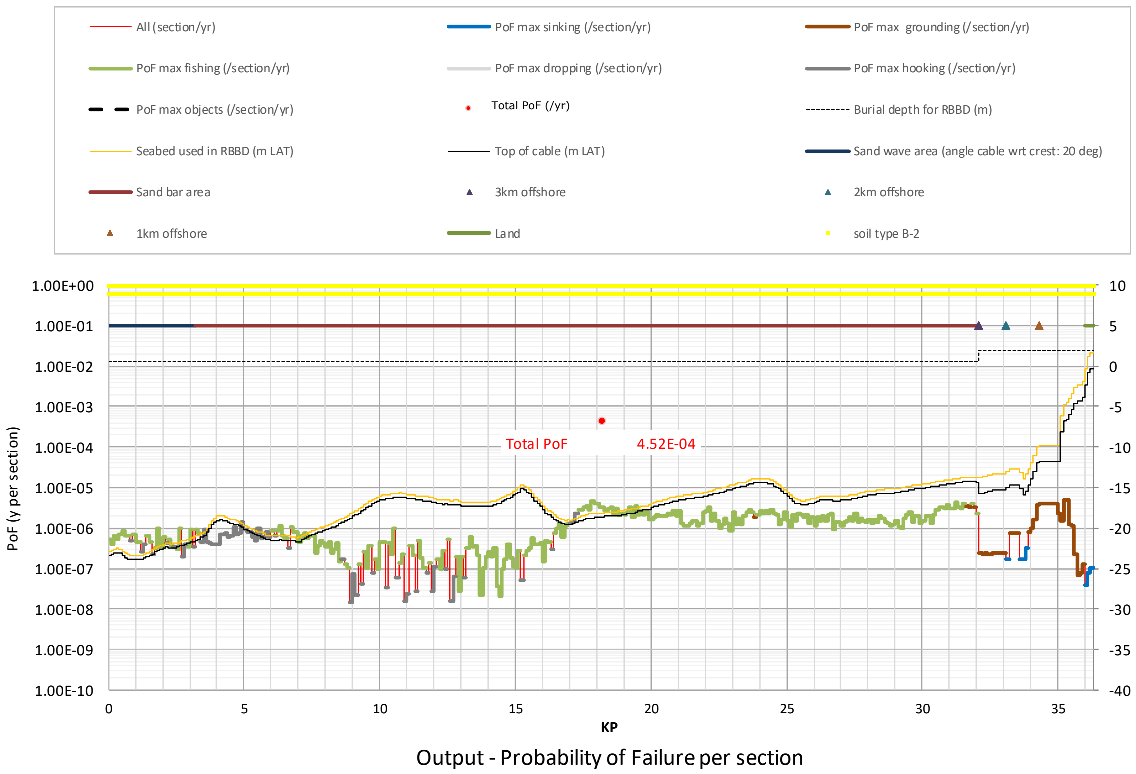


Figure 7.2 *Probability of Failure (PoF) for Hollandse Kust (noord) route alternative 4: Signal scenario: Burial depth is 2 m (KP>32.1), 0.5 m (KP<32.1).*

Observations The PoF of 4.5*10^{-4}/year (in average once per ~2200 year) is still below (less risk compared to) the requirements of TenneT. The plot shows, compared to the Installation scenario, that the fishing rather than anchor hooking contributes most to the total PoF as a result of the reduced burial depths.

Minimum scenario The Minimum scenario indicates the burial levels that should initiate the actual remediation or mitigation plans because the level of burial is such that the total Probability of Failure is at the maximum allowable level as stated by

TenneT. The result based on the burial depth as given in Table 7.1 is shown in Figure 7.3.

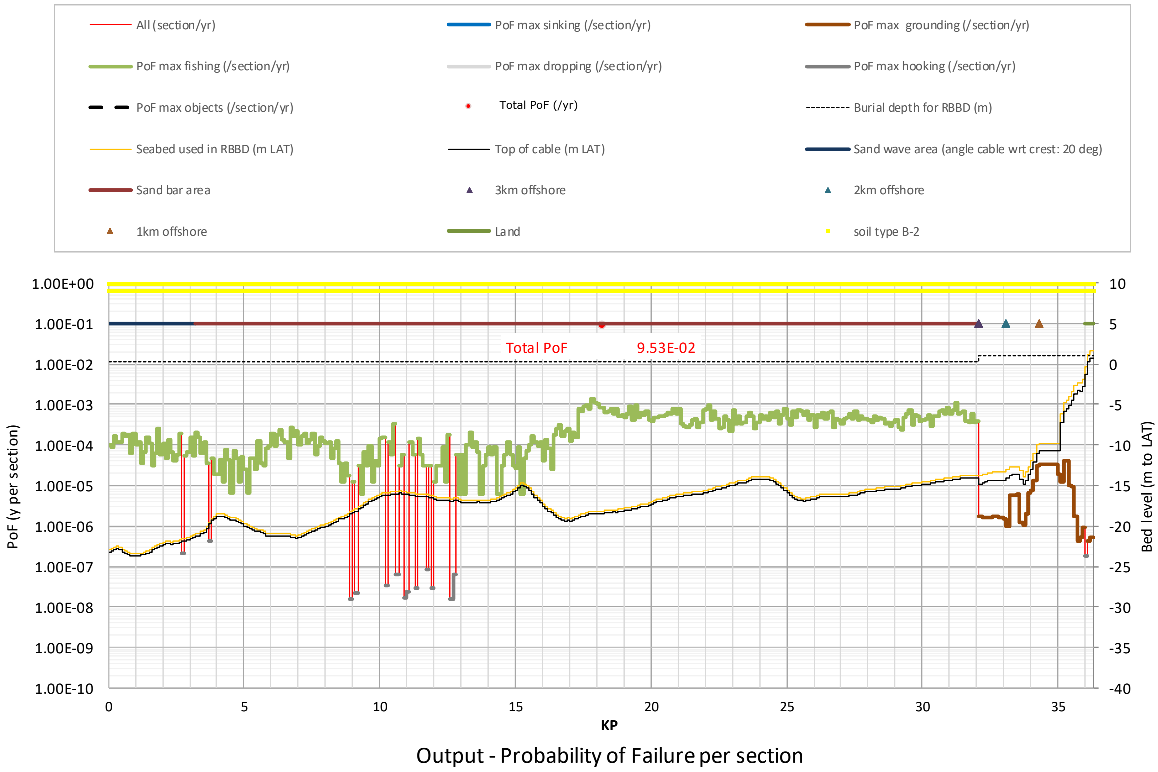


Figure 7.3 *Probability of Failure (PoF) for Hollandse Kust (noord) route alternative 4: <u>Minimum scenario</u>: Burial depth is 1 m (KP>32.1), 0.3 m (KP<32.1).*

Observations

The PoF of $9.53*10^{-2}$/year (in average once per ~10 year) is above (higher risk compared to) the requirements of TenneT. The plot shows a very similar situation compared to the Signal scenario, with fishing being the dominant threat.

Histogram of all scenarios

Figure 7.4 presents the results of all scenarios for all route alternatives. Route alternative 2 results in the smallest PoF for the Installation scenario. For the Signal and Minimum scenarios route alternative 1 results in the smallest PoF.

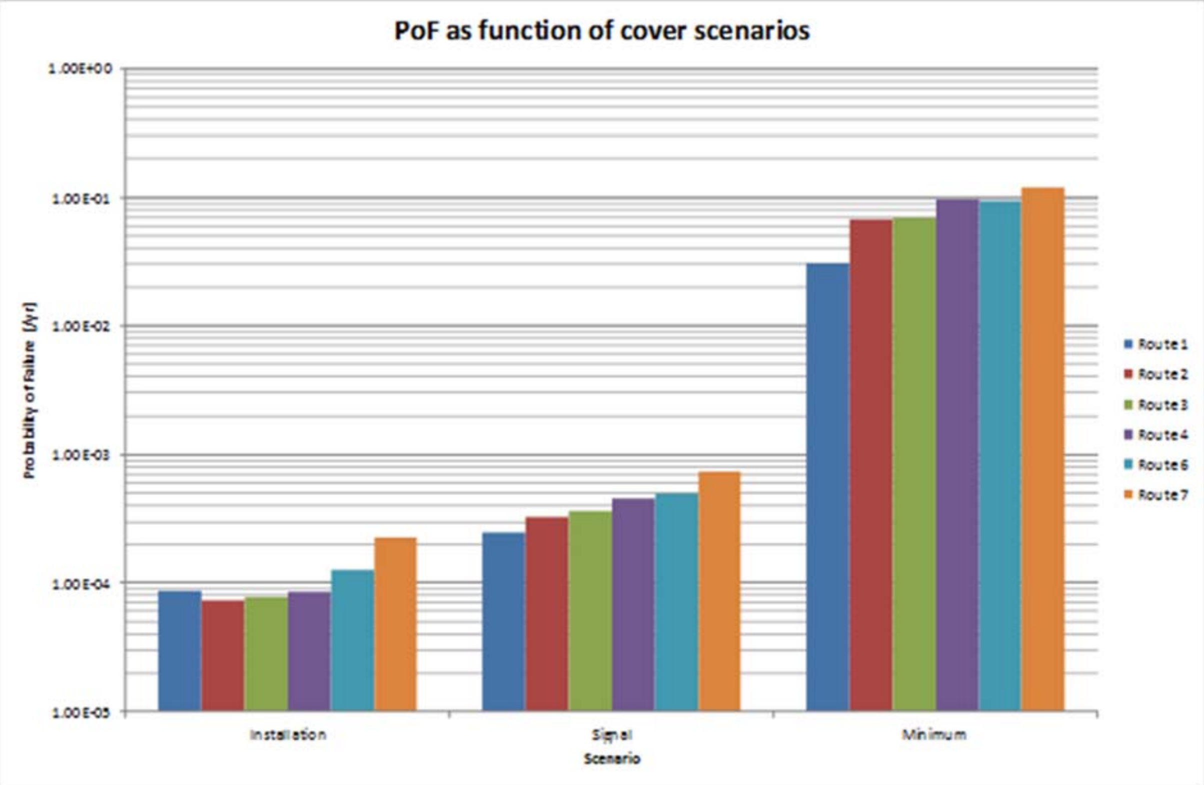


Figure 7.4 *Probability of Failure (PoF) for all Hollandse Kust (noord) route alternatives and all scenarios.*

Results The applied burial levels and PoF values for all route alternatives of Hollandse Kust (noord) and for all three burial scenarios are presented in Table 7.2.

Table 7.2 *PoF for different scenarios for all route alternatives.*

Scenario	Description	PoF / year
Installation scenario	– 3 m constant cover from shore to 3 km perpendicular from the shore, *see Note 1*; – 1 m constant cover thereafter to the platform; – 3 meter constant cover below NGD in the IJgeul (route alternatives 6 & 7)	Route 1: 8.61E-05 Route 2: 7.29E-05 Route 3: 7.71E-05 Route 4: 8.47E-05 Route 6: 1.27E-04 Route 7: 2.25E-04
Signal scenario	– 2 m constant cover from shore to 3 km perpendicular from the shore, *see Note 1*; – 0.5 m constant cover thereafter to the platform; – 3 meter constant cover below NGD in the IJgeul (route alternatives 6 & 7)	Route 1: 2.46E-04 Route 2: 3.28E-04 Route 3: 3.68E-04 Route 4: 4.52E-04 Route 6: 5.03E-04 Route 7: 7.35E-04
Minimum scenario	– 1 m constant cover from shore to 3 km perpendicular from the shore, *see Note 1*; – 0.3 m constant cover thereafter to the platform; – 3 meter constant cover below NGD in the IJgeul (route alternatives 6 & 7)	Route 1: 3.02E-02 Route 2: 6.70E-02 Route 3: 6.91E-02 Route 4: 9.53E-02 Route 6: 9.32E-02 Route 7: 1.21E-01

Note 1: For route alternative 6 the constant 3m, 2m and 1m cover of the Installation, Signal and Minimum Scenario respectively, is extended just beyond the 3km offshore boundary (KP>31.0). Doing this makes for a more fair comparison between the route alternatives and eliminates the maximum PoF resulting from grounding at this section.

7.2.2 Noordzeekanaal routes

Introduction

Routes 4 and 5 run from through the Noordzeekanaal as shown in Figure 7.5. It shows that the cables run for most of the route parallel to the Noordzeekanaal except where it crosses:

- Route 4 crosses from South to North at KPR 4.5, where it makes landfall;
- Route 5 crosses from South to North at KPR5.3 to KPR5.7 and back from North to South at KP10, where it makes landfall.

Figure 7.5 *Schematised route 4 and 5 in the Noordzeekanaal.*

Grounding

The result of the data analysis (see Annex 1) shows that the probability of drifting and grounding on the canal embankments is high in comparison with the probability of anchoring in the actual fairway. In combination with the need for maintenance of the embankments (potential use of work vessels using spud-poles) and the additional risk that imposes, the cables are assumed to be installed outside the slopes/embankments of the Noordzeekanaal.

Probability of failure

If the cables are laid outside the slopes, the probability of failure is determined by anchoring dropping and hooking only. The Probability of failure for both route options are given in Table 7.3 for the Installation, the Signal and the Minimum scenario. In these scenarios the two cables are installed to the side of the fairway: one cable is at the edge of the fairway [26] and the second cable at a distance of 30 m.

[26] The edge of fairway is where the slope meets the edge of the deep part of the canal.

Table 7.3 *PoF for different scenarios for route 4 and 5 in the Noordzeekanaal.*

Scenario	Burial depth in channel	*Offshore part*	Noordzeekanaal	PoF / year
Installation scenario	1.5 m	*Route 4: 8.54E-05*	Route 4: 2.65E-05	**Route 4: 1.12E-04**
		Route 5: 7.29E-05	Route 5: 5.52E-05	**Route 5: 1.28E-04**
Signal scenario	1.0 m	*Route 4: 2.94E-04*	Route 4: 2.65E-04	**Route 4: 5.59E-04**
		Route 5: 3.28E-04	Route 5: 5.52E-04	**Route 5: 8.80E-04**
Minimum scenario	0.5 m	*Route 4: 4.79E-02*	Route 4: 5.03E-04	**Route 4: 4.84E-02**
		Route 5: 6.70E-02	Route 5: 1.05E-03	**Route 5: 6.80E-02**

Observations

The results as presented in Table 7.3 show the following:

- For the installation- and signal burial depth the contribution of the Noordzeekanaal section relative to the offshore section is significant;
- For the minimum burial depth the contribution of the Noordzeekanaal section relative to the offshore section is marginal.

This means that the minimum burial of 0.5 m is adequate but can also be reduced. Given the more stable channel depth in comparison with the offshore routes, the installation and signal depth are considered acceptable. Given the commonly required 2.0 m burial depths for cables, the risk based approach indicates that a significant reduction of the burial depth is justified with maintaining the acceptable risk level.

7.3 Risk Based Burial Depth

Risk to safety and environment

As assessed in the Chapter 4 and 6, the probability of significant consequences for people and the environment for the present burial status is estimated to be less than 10^{-6}/km/year and corresponds with the probability class 'rare' and as such meets the acceptance criterion for 'Safety and Environment' as defined in Chapter 4.2.

Risk to asset, reputation and cost

As presented in Table 7.3 for the Installation burial scenario, the Probability of Failure for Hollandse Kust (noord) route alternative 4 would be $1.1*10^{-4}$/year (in average once per ~9,000 year). The combination of consequence and probability appears as white star in Figure 7.6 for project specific probability classes for Asset, Reputation and Cost as defined in Table 4.3, which is well within the class 'rare' of a probability less than 10^{-3}/year.

		Consequences for Asset, Reputation and Cost				
		Insignificant	Minor	Moderate	Extensive	Significant
Probability	Rare $P < 10^{-3}$				★	
	Unlikely $10^{-3} < P < 10^{-2}$					
	Possible $10^{-2} < P < 10^{-1}$					
	Likely $10^{-1} < P < 1$					
	Almost certain $1 < P$					

Figure 7.6 *Risk position based for Base Case of Route Alternative 2.*

Observation

The risk assessment of the burial status, if installed in accordance with the Installation scenario, shows that there is room for optimisation: the risk of the proposed burial status is conservative and justifies accepting less burial. Effectively this means that less burial can be accepted without jeopardising cable integrity and unacceptable consequences.

Updated risk position

The results of the PoF calculations of the Signal and Minimum permitting scenarios for route alternative 4 are shown in Figure 7.2 and Figure 7.3. Based on the PoF calculations of the Signal and Minimum Scenarios, the risk is shown in Figure 7.7 as black star for the Signal scenario and the red star for the Minimum scenario.

		Consequences for Asset, Reputation and Cost				
		Insignificant	**Minor**	**Moderate**	**Extensive**	**Significant**
Probability	**Rare** $P < 10^{-3}$				★	
	Unlikely $10^{-3} < P < 10^{-2}$					
	Possible $10^{-2} < P < 10^{-1}$				★	
	Likely $10^{-1} < P < 1$					
	Almost certain $1 < P$					

Figure 7.7 *Risk position for Signal scenario (black star) and Minimum scenario (red star).*

Route comparison

The objective of this study is the determine distinctive differences between the 7 route alternatives. On the basis of the results of the RBBD analyses, the following is concluded:

- All offshore routes are feasible in the sense that burial of the cables is possible to achieve acceptable risk levels;
- Offshore routes 1, 2, 3 and 4 do not cross the IJ-geul and achieve the acceptable risk levels with less burial;
- Route 6 and 7 do cross the IJ-geul and need deeper burial to achieve the required risk level;

Choice

If a choice has to be made between the offshore routes, the following is advised:

- Route 6 and 7 should only be chosen if the onshore parts of routes 1, 2, 3 and 4, and for route 4 and 5 the Noordzeekanaal option, are not feasible (in terms of show-stoppers of excessive cost. The increased length and deeper burial through the IJ-geul will lead to significantly higher cost for route 6 and 7;
- Route 4 and 5 (which are the same offshore and only differ in the length in the Noordzeekanaal) seems the most logic options from the risk and permitting perspective: the Noordzeekanaal option is considered feasible to the extent that no show-stoppers have been found and further optimisation is still required. To be more specific, the NZ-Kanaal option still has number of challenges (e.g. many cable crossings), but from risk perspective it is a very interesting option;
- Routes 1, 2 and 3 are obviously preferred from the 'only offshore' perspective because they are shortest and most far away from the IJ-geul;

In summary (ignoring onshore issues which are outside the scope of this study), the following routes are proposed to assess further:

- Route route 4 and/or 5, including the Noordzeekanaal section;
- Route 1 or 2 or 3;
- Route 6 or 7 (mainly the IJ-geul crossing) only if the other options are not, or possibly expect to become not feasible.

7.4 Permitting aspects

Background

The main reasons for the study are (1) ensure a safe burial scenario for the cables and (2) the permitting situation of the Hollandse Kust (noord) export cables, in the sense (1) that there are indications that local permit non-compliances may develop in the course of the coming years, and (2) that there are also indications that the present permit requirements are too conservative. The aim of the RBBD approach is to provide the objective justification of optimum burial depth and align the permit accordingly.

Optimised maintenance

From project owner's perspective, the export cable is considered as one system and the burial depth, and consequently the maintenance (interventions and remediation) is optimised [27]. The objective of the RBBD approach is to optimise the interventions, which means focussing interventions to those sections where mitigation or remediation directly contributes to reducing the overall probability of failure of the system. In other words, no intervention at locations where deeper burial has no impact on the PoF but only has negative impact on the environment and costs.

Permit provisions

The essence of the cable permit are the provisions that describe the criteria for operation and intervention. It is recommended to discuss and develop these provisions together with the Dutch authorities, in this case 'RWS Zee en Delta'. The criteria proposed for discussion are summarised in Table 7.4 and Table 7.5.

Table 7.4 *Proposed burial criteria for the Hollandse Kust (noord) export cables as function of KP for Route Alternative 4.*

<table>
<tr><th colspan="2" rowspan="2">Section</th><th>From KP to KP</th><th>length</th><th>Install</th><th>Signal</th><th>Minimum</th></tr>
<tr><th>km</th><th>km</th><th>m</th><th>m</th><th>m</th></tr>
<tr><td>1</td><td>Sand wave area (fine sand), see Note 1</td><td>0.0 - 3.2</td><td>3.2</td><td rowspan="5">1.0</td><td rowspan="5">0.5</td><td rowspan="5">0.3</td></tr>
<tr><td>2</td><td>Sand bar area 1 (fine sand)</td><td>3.2 - 16.9</td><td>13.7</td></tr>
<tr><td>3</td><td>Sand bar area 2 (medium coarse sand)</td><td>16.9 - 19.5</td><td>2.6</td></tr>
<tr><td>4</td><td>Sand bar area 3 (fine sand)</td><td>19.5 - 26.0</td><td>6.5</td></tr>
<tr><td>5</td><td>Sand bar area 4 (medium coarse/fine sand)</td><td>26.0 - 32.1</td><td>6.1</td></tr>
<tr><td>6</td><td>2-3 km offshore (fine sand)</td><td>32.1 - 33.1</td><td>1.0</td><td rowspan="4">3.0</td><td rowspan="4">2.0</td><td rowspan="4">1.0</td></tr>
<tr><td>7</td><td>1-2 km offshore (fine sand)</td><td>33.1 - 34.3</td><td>1.2</td></tr>
<tr><td>8</td><td>0-1 km offshore (fine sand)</td><td>34.3 - 36.0</td><td>1.7</td></tr>
<tr><td>9</td><td>Beach</td><td>36.0 - 36.35</td><td>0.35</td></tr>
<tr><td>10</td><td>Noordzeekanaal</td><td></td><td></td><td>1.5</td><td>1.0</td><td>0.5</td></tr>
</table>

[27] It should be noted that mobilisation alone contributes significantly to the remediation cost.

Table 7.5 *Proposed principle burial criteria for permitting for all Routes.*

<table>
<tr><th colspan="2">Aspect</th><th>Signal</th><th>Minimum</th><th>Comment</th></tr>
<tr><td>Cover</td><td colspan="3">See Table 7.4</td><td>Averaged over total route, based on cover averaged over 100 m sections</td></tr>
<tr><td rowspan="2">Exposure
(no free span)</td><td>Nearshore</td><td rowspan="2">0 m
(no exposures)</td><td>≤ 50 m</td><td rowspan="3">Averaged over 5 m sections</td></tr>
<tr><td>Offshore</td><td>≤ 1 km</td></tr>
<tr><td>Free span</td><td>Nearshore and offshore</td><td>None</td><td>Span length $<$ 5 m and average span gap height $<$ 0.1 m</td></tr>
<tr><td rowspan="2">PoF leading to unacceptable consequences for….</td><td>Safety, Environment</td><td colspan="2">≤ ~10^{-6} /km/year</td><td rowspan="2">Note 3</td></tr>
<tr><td>Asset, Reputation and Cost</td><td>≤ ~10^{-2} /year</td><td>≤ ~10^{-1} /year</td></tr>
<tr><td colspan="2">Remediation</td><td>Initiate Plan</td><td>Approved plan ready to implement</td><td>Note 4</td></tr>
</table>

Note 1: *For route alternative 4:*
Platform - KP 32.1: offshore.
KP 32.1 – KP 36.35: nearshore;

Note 2: *The minimum criteria for free spans need to be considered in relation to survey inaccuracies and assessed with care.*

Note 3: *The PoF is calculated for the complete route where compliance with two criteria is required: one criterion applicable for the complete route and one criterion applicable for sections of 1 kilometre.*

Note 4: *Approved by (1) TenneT and (2) the Competent Authorities.*

Note 5: *The seabed mobility study refers to potential presence of clayey areas in the nearshore areas, which could impact the installation depth as given in Table 7.4. Because this will have an effect on all route options, it will not affect the conclusions of this comparative study.*

Implementation

Further explanation of the criteria as proposed in Table 7.5 is needed to allow practical implementation. The basis for the assessment is the result of the survey of the seabed and, if available, the position of the cable. Each survey will measure the seabed profile, but not always the Top of Cable. In the latter, the latest ToC will be used to determine the Depth of Burial (DoB). The survey should result in a so-called ‘cover-listing’ with values of the DoB for preferably every metre, but at least every 5 m. The cover list will provide the input for the RBBD. Because the profiles and the calculations are averaged over 100 m sections, the final assessment needs to be carried out on the 1 or 5 m cover-listing to assure that the exposures or free spans are not missed. The MBES survey results over a certain corridor over the route should also be used to assess the detailed and final assessment.

8 Conclusions and recommendation

Conclusions

1. On the basis of the results of the analyses, the following is concluded:
    1. All offshore routes are feasible in the sense that burial of the cables is possible to achieve acceptable risk levels;
    2. Offshore routes 1, 2, 3 and 4 do not cross the IJ-geul and achieve the acceptable risk levels with less burial;
    3. Route 6 and 7 do cross the IJ-geul and need deeper burial to achieve the required risk level;
    4. The Noordzeekanaal sections of route 4 and 5 are feasible and should be further optimised in terms of detailed alignment along the axis of the channel and where and how to cross.
2. In summary (ignoring onshore issues which are outside the scope of this study), the following routes are proposed to assess further:
    1. Route route 4 and/or 5, including the Noordzeekanaal section;
    2. Route 1 or 2 or 3 if onshore connection is considered feasible;
    3. Route 6 or 7 (mainly the IJ-geul crossing) only if the other options are not feasible or are possibly expected to become not feasible.
3. It is proposed to include Signal and Minimum burial limits as permit provisions to (1) define at which burial depths remediation plans are to be prepared and (2) at which burial depths approved remediation plans must be ready to be implemented.

Recommendation

After completion of the morphological study and the Burial Assessment Study, it is recommended to evaluate the results of these studies within the framework of the risk based burial approach, and to assess if further optimisation of the installation of the Hollandse Kust (noord) export cables is possible within the then ruling permit provisions. This recommendation holds for the offshore routes (1-7) and the Noordzeekanaal sections of route 4 and 5.

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Annex 1 MARIN Report

This Annex

Marin (2018), Veiligheidsstudie voor zeven mogelijke tracés voor de exportkabel Hollandse Kust Noord, Report No.: 30449-1-MSCN-rev.2, 19 January 2018.

MARIN

VEILIGHEIDSSTUDIE ZEVEN MOGELIJKE TRACES VOOR DE EXPORTKABEL HOLLANDSE KUST NOORD

Concept rapport

Rapport Nr. : 30449-1-MSCN-rev.2
Datum : 19 januari 2017

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VEILIGHEIDSSTUDIE ZEVEN MOGELIJKE TRACES VOOR DE EXPORTKABEL HOLLANDSE KUST NOORD

Opdrachtgever : ACRB

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0	Concept	6 sept. 2017	Y. Koldenhof	
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2	Concept	19 januari 2018	Y. Koldenhof	

INHOUDSOPGAVE

Page

1 INLEIDING

Voor de ontwikkeling van het net op zee Hollandse Kust (noord) worden onder andere de een Risk Based Burial Depth studie (RBBD) uitgevoerd door ACRB in opdracht van Tennet.

Het uiteindelijke doel van de analyse is het bepalen van de “Risk Based Burial Depth” (RBBD) voor de exportkabel. Met behulp van deze analyse wordt op basis van het risico een minimale begraafdiepte van de exportkabel bepaald, als functie van tijd en plaats.

De activiteiten van MARIN omvatten het verzamelen van de relevante AIS (Automatic Identification System), bepalen van het totaal aantal passages van de scheepvaart over de beoogde locatie van de kabel. Vervolgens zijn op basis van deze intensiteiten de frequenties van verschillende incidenten bepaald die een risico kunnen vormen voor de kabel.

Een deel van tracé 4 en 5 zullen door het Noordzeekanaal lopen. De kwalitatieve analyse wordt beschreven in hoofdstuk 5.2.

Opmerking bij versie 2 (17 januari 2018)
De route van tracé 1, 2 en 3 zijn na de oplevering van de resultaten (rapportage v1, november 2017) aangepast. Er is voor gekozen niet de hele analyse op nieuw uit te voeren. Een deel van de aangepaste route loopt samen met tracé 4, daarom is er voor gekozen de resultaten van tracé 4 te gebruiken samen met de al uitgevoerde analyse over tracé 1, 2 en 3. De resultaten hier van worden toegelicht in een apart hoofdstuk.

Gebruikte afkortingen in de rapportage

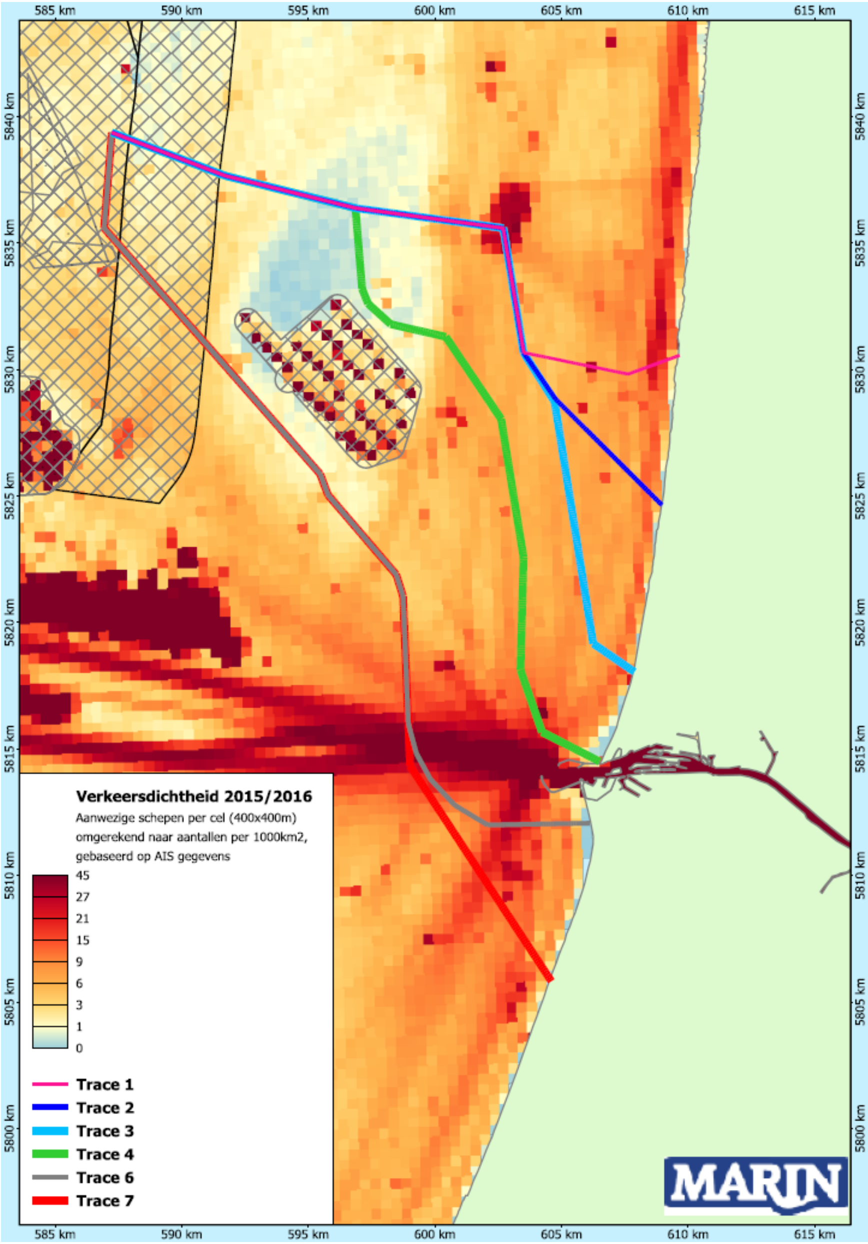
AIS	: Automatic Identification System
IMARES	: Institute for Marine Resources & Ecosystem Studies
MARIN	: Maritime Research Institute Netherlands
MMSI	: Maritime Mobile Service Identity
RBBD	: Risk Based Burial Depth
SAMSON	: Safety Assessment Model for Shipping and Offshore on the North Sea
VMS	: Vessel Monitoring through Satellite
VONOVI	: VerkeersOnderzoek Noordzee Visuele Identificatie
VKA	: VoorKeursAlternatief

2 IDENTIFICEREN VAN DE MOGELIJKE RISICO'S

2.1 Kabel

De eerste stap in de risicoanalyse is het identificeren van de mogelijke risico's. Een overzicht van de mogelijke tracéalternatieven van de kabel is weergegeven in Figuur 2-1. De zwarte lijnen zijn de mogelijke tracé alternatieven[1]. Op de achtergrond is de dichtheidskaart weergeven van het routegebonden verkeer, gebaseerd op AIS-data in de periode juli 2015 tot en met juni 2016.

De route van tracé 1, 2 en 3 zijn na de oplevering van de resultaten (rapportage v1, november 2017) aangepast. Dit is niet weergegeven in Figuur 2-1. In hoofdstuk 4.7 worden de verschillen verder toegelicht.



Figuur 2-1 Mogelijke tracéalternatieven van de kabel tussen de platforms en de kust.

[1] De verschillende tracéalternatieven zijn aangegeven in Figuur 4-1.

Op basis van het verkeer en historische ongevallen zijn de volgende risico's voor de kabels door de scheepvaart geïdentificeerd:
- Een schip zinkt op de kabel zonder ander incident (bijvoorbeeld als gevolg van slecht weer);
- Een schip zinkt na een aanvaring en komt daarbij op de kabel terecht;
- Een anker kan neergelaten worden op de kabel;
- Een anker kan neergelaten worden net voordat een schip de kabel kruist waardoor het anker achter de kabel haakt;
- Een net van een vissersschip kan achter de kabel blijven haken;
- Een schip kan aan de grond lopen ter hoogte van de kabel indien deze in ondiep gebied ligt.

Naast de boven genoemde risico's voor het deel van de kabel dat offshore (op zee) ligt is een aanvullend risico geïdentificeerd voor het deel van de kabel van tracé 4 en 5 dat door het Noordzeekanaal zal lopen. Voor het onderhoud van de wal en kade wordt soms gebruik gemaakt van werkvaartuigen met spud-palen. Deze vormen ook een risico voor een kabel op of in de bodem.

3 WERKWIJZE

De studie bestaat uit twee onderdelen. Het eerste onderdeel is het bepalen van de effecten van de scheepvaart op de verschillende tracéalternatieven van de kabel aan de hand van een verkeersanalyse op basis van AIS-data. Het tweede deel bestaat uit het bepalen van het risico vanuit de scheepvaart voor het deel van het tracé dat door het Noordzeekanaal gaat. Dit laatste risico wordt alleen kwalitatief beschouwd in deze fase van de studie. De werkwijze wordt dus niet verder toegelicht in dit hoofdstuk.

3.1 Effecten van de scheepvaart op de kabel

In hoofdstuk 2 zijn de belangrijkste risico's voor de kabel veroorzaakt door de scheepvaart geïdentificeerd. Alle risico's kunnen voorkomen, ze vormen echter niet allen een relevante bedreiging voor de kabel. Door het combineren van de resultaten van een verkeersanalyse op basis van AIS en verkeersgegevens met algemene ongevalstatistiek is de verwachte incidentfrequentie per jaar bepaald voor de kabel.

3.1.1 Verkeersanalyse

Voor het bepalen van de effecten van de scheepvaart voor de verschillende tracéalternatieven is een verkeersanalyse uitgevoerd op basis van de AIS-data voor de periode tussen 1 januari 2015 tot 31 december 2016. Er is meer AIS-data beschikbaar, maar op basis van ervaring uit eerdere studie is gebleken dat een analyse over 2 jaar data voldoende is. Door de twee meest recente jaren te gebruiken wordt voorkomen dat kleine veranderingen in de routes of tijdelijke activiteiten veel invloed hebben op de resultaten. Hoewel het aantal schepen dat verplicht is uitgerust met AIS de afgelopen jaren is toegenomen, is dit beeld niet volledig; met name voor vissersschepen en recreatieschepen ontbreekt data omdat deze schepen veelal geen AIS aan boord hebben. Daarnaast kan het zijn dat op sommige locaties de AIS-data tijdelijk niet beschikbaar was, bijvoorbeeld vanwege een uitgevallen base station.

Deze verkeersanalyse bestaat uit het presenteren van het verkeer in het gebied in een aantal dichtheidskaarten en het bepalen van het aantal passages over de verschillende stukken van de tracéalternatieven. Het risico voor de verschillende tracéalternatieven is namelijk gecorreleerd met de intensiteiten van de schepen varend boven de locaties. Deze gegevens zullen vervolgens verder geanalyseerd worden.

Dichtheidskaarten

Voor het bepalen van het verkeersbeeld rond de verschillende tracéalternatieven zijn de dichtheden bepaald voor gridcellen met een grootte van 200 bij 200 meter. Om de dichtheid te bepalen wordt elk aanwezig schip (MMSI-nummer) iedere minuut aan een bepaalde gridcel toegewezen. Na het afspelen van de AIS-data voor 2015/2016 is voor ieder schip het aantal minuten per cel bekend. Door te sommeren over alle schepen (of een bepaalde selectie, bijvoorbeeld alleen de routegebonden schepen), en vervolgens te delen door het aantal minuten in 2015/2016, wordt het gemiddelde aantal aanwezige schepen in de cel verkregen.

Het gemiddelde aantal wordt daarna gedeeld door de oppervlakte van de gridcel (0.04 km^2). Omdat het aantal schepen per km^2 meestal erg laag is, wordt daarna vermenigvuldigd met 1000, zodat de schalen beter leesbaar zijn. Voor iedere cel wordt dus de dichtheid uitgedrukt in het aantal schepen per 1000 km^2.

Aantal passages per kabeltracé
Voor het bepalen van het aantal passages per (stuk van de) kabel worden de tracéalternatieven opgedeeld in kleinere stukken. Hiervoor wordt in het algemeen een lengte van 100 meter aangehouden, bij bochten wordt echter gerekend met kleinere lijnstukken voor een zo goed mogelijke benadering van de tracéalternatieven. Per lijnstuk is het aantal passages geteld aan de hand van de beschikbare AIS-data tussen 1 januari 2015 tot en met 31 december 2016. Hierbij is interpolatie toegepast tussen de laatste waarneming voor en de eerste waarneming na het passeren van de lijn, maar gezien de korte tijdsintervallen waarmee AIS-signalen worden uitgezonden, is dit zeer betrouwbaar.

Het aantal passages per segment van de kabel wordt visueel weergegeven in enkele figuren. Daarnaast wordt voor ieder groter stuk van de kabel de aantallen in een tabel weergegeven, per scheepstype en scheepsgrootte.

3.1.2 Ongevalskansen
De ongevalskansen gebruikt binnen deze studie zijn de basis incident kansen voor (1) zinken en (2) motor- en stuurstoring. Beide zijn in meer detail beschreven in referentie [1] en [3] ankergedrag in specifieke gebieden.
De ongevalskansen zijn gebaseerd op een analyse van alle wereldwijde geregistreerde ongevallen tussen 2000 en 2013. Deze gegevens zijn niet beschikbaar voor alle verschillende scheepstypen. Binnen de analyse zijn de ongevalskansen bepaald voor de SAMSON types OBO, Tanker Chemical/Oil, Gas tanker, Bulk carrier, Unitised cargo en GDC.

Een basis ongevalskans is bepaald voor elk ongevalstype en is gebaseerd op het aantal waargenomen ongevallen op zee in relatie tot het aantal bijpassende gevaarlijke situaties, welke afhankelijk zijn van de verkeerssituatie. Vervolgens wordt de basis kans vermenigvuldigd met een specifieke factor gebaseerd op het scheepstype en de scheepsgrootte. De basis kans is bepaald voor de Noordzee en de verschillende factoren zijn bepaald op basis van de wereldwijde statistieken. Aangenomen is dat de factoren voor scheepstype en scheepsgrootte onafhankelijk zijn van de locatie; In algemene zin kan bijvoorbeeld gesteld worden dat de kans op zinken voor grotere schepen kleiner zal zijn dan voor kleinere schepen, ongeacht waar de schepen varen.

Deze basis ongevalskansen zijn gebruikt bij het bepalen van de kans op zinken, anker vallen en haken en de kans op stranden op de kabel.

Ankerkansen
Om de frequentie op een incident met een anker per gevaren nautische mijl te bepalen is de basis ongevalskans op motorstoring gebruikt. Hierbij wordt aangenomen dat op zee een anker alleen gebruikt zal worden wanneer een schip (tijdelijk) niet onder controle is, bijvoorbeeld als gevolg van een motorstoring.

Aanvullend op de basis ongevalskans wordt een gebiedsafhankelijke factor toegepast, welke gebaseerd is op het ankergedrag in een gebied afgeleid uit AIS-data analyse. In eerdere studies is het ankergedrag van schepen (voornamelijk routegebonden schepen) in enkele specifieke gebieden geanalyseerd. Deze gebieden waren een gebied ten noordwesten van de Waddeneilanden, in de Eems en de Westerschelde.

De basis ongevalskansen voor een incident met een anker zijn gerelateerd aan het aantal gevaren nautische mijlen, dus eens in de x gevaren mijlen zal er een incident met een anker voorkomen. Hiervoor moet dus, voor zowel ankerhaken als ankervallen, de corridor bepaald worden waarbinnen het basis incident ook zal leiden tot schade aan de kabel. Binnen de SAMSON-methode is de corridor voor de kans op ankerhaken gebaseerd op een kwart van de lengte van het schip en de buiten diameter van de kabel, waarbij per scheepstype en scheepsgrootte klasse een gemiddelde lengte wordt aangenomen. Voor de kans op ankervallen wordt de gemiddelde afmeting van een anker gebruikt in combinatie met de diameter van de kabel.

Om uiteindelijk de frequentie van ankerhaken en ankervallen te bepalen, wordt de basis ongevalskans (per gevaren nautische mijl) vermenigvuldigd met de berekende gevaren nautische mijlen binnen de gedefinieerde “gevaarlijke” corridor.
Dit resulteert uiteindelijk in de kans dat er op de locatie van de kabel geankerd wordt. Echter, schepen zullen altijd eerst op de kaart kijken voordat een anker uitgegooid wordt, in verband met eventueel aanwezige kabels en pijpleidingen. Dit zou betekenen dat een dergelijk incident eigenlijk niet voor kan komen. Binnen een studie uitgevoerd voor de BBL-pijpleiding [8] is echter gekeken naar het ankergedrag op basis van AIS. Op basis van deze studie wordt aangenomen dat in 5% van de gevallen waarin een schip voor anker ging buiten de ankergebieden, het ging om zogenaamd “erroneous anchoring”. Dit betekent ankeren zonder dat er goed op de nautische kaart gekeken wordt voor specifieke infrastructuur die het gebruik van het anker niet mogelijk maakt. Hierbij moet wel opgemerkt worden dat de 5% een worst-case aanname is. In de berekeningen betekent dit dat de gevonden kansen vermenigvuldigd worden met 0.05.

3.1.3 SAMSON scheepstypen en scheepsgrootte klassen

De basis ongevalskansen en de informatie over de karakteristieken van de schepen, zoals lengte en diepgang, zijn gedefinieerd per SAMSON scheepstype en scheepsgrootte klassen. In Tabel 3-1 is de indeling in grootteklassen weergegeven, gebaseerd op de GT (Gross Tonnage) van de schepen. De verschillende scheepstypen die worden onderscheiden binnen het model, zijn weergegeven in Tabel 3-2 . Binnen de indeling in scheepstype is ook een categorie “unknown” opgenomen. Hierbij gaat het om schepen waarbij op basis van de AIS-gegevens het scheepstype niet bepaald kan worden. Het gaat hierbij voornamelijk om schepen zonder AIS en waargenomen door de walradar.

Tabel 3-1 Indeling in grootteklassen gebruikt binnen SAMSON

	Grootte klasse [gebaseerd op GT]							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Gross tonnage	100-1000	1000-1600	1600-5000	5000-10000	10000-30000	30000-60000	60000-100000	>100000

Tabel 3-2 SAMSON scheepstypen, routegebonden (R) en niet-routegebonden (N)

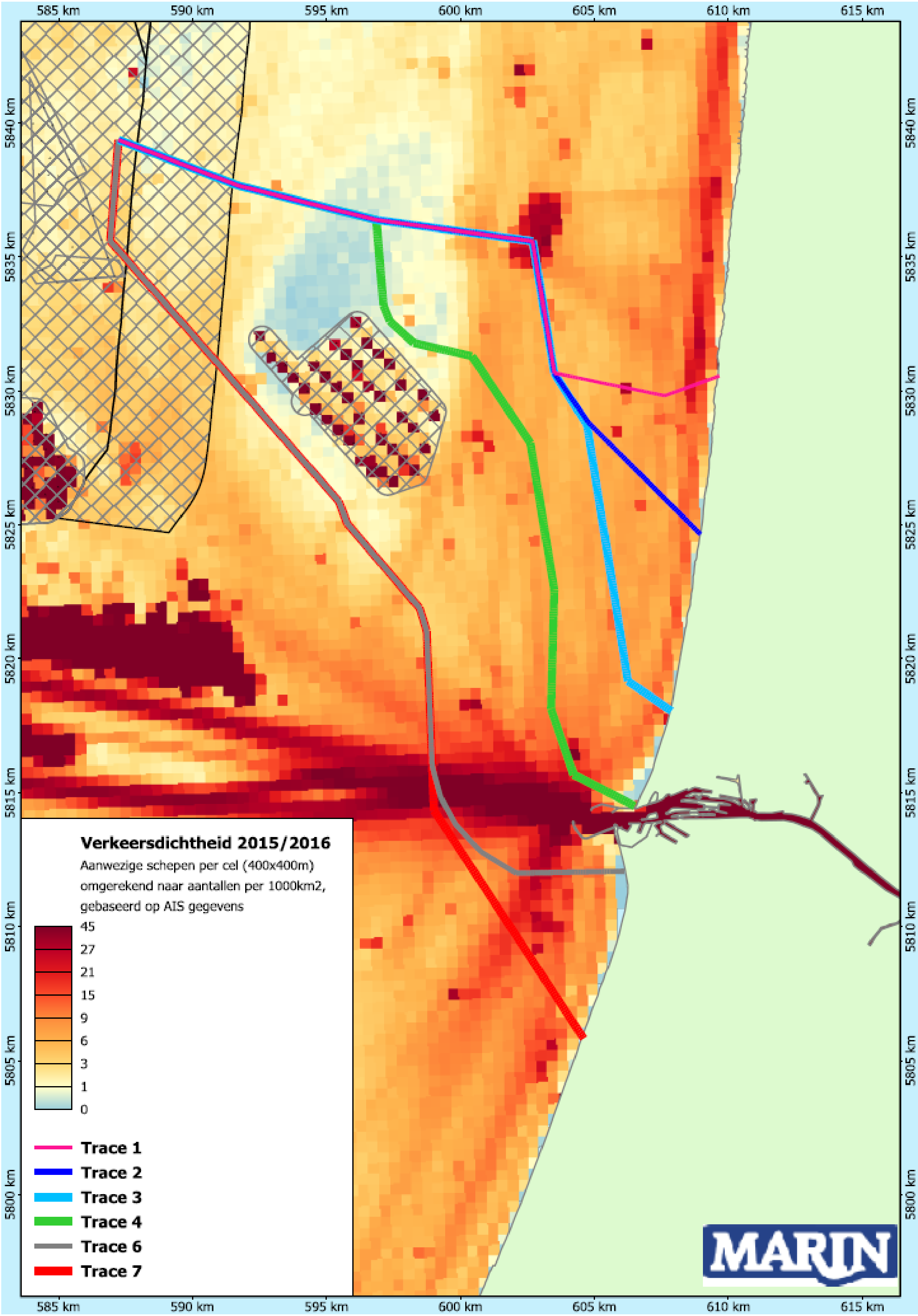
SAMSON Scheepstype	R/N	Omschrijving
Bulker	R	Bulkvracht
Chemical	R	Chemicaliën tanker
Container	R	Containerschip
Fishing	N	Vissersschip
GDC	R	General Dry Cargo: schip dat droge lading vervoert
LPG	R	Liquefied Petroleum Gas
Miscellaneous	N	Overige werkvaartuigen: loodsboten, sleepboten, baggerschepen, etc.
Oil	R	Olietankers
Pass/Ferry	N	Passagiersschepen en veerboten
Platf./dril. ships	N	Schepen die platformen bezoeken en boorschepen
RoRo	R	Roll-on/Roll-off schip: schip dat voornamelijk vrachtwagens en opleggers met lading vervoert
Supply	N	Bevoorradingsschepen en andere schepen die offshore constructies bezoeken

4 RESULTATEN EXPORTKABELS – OFFSHORE DEEL

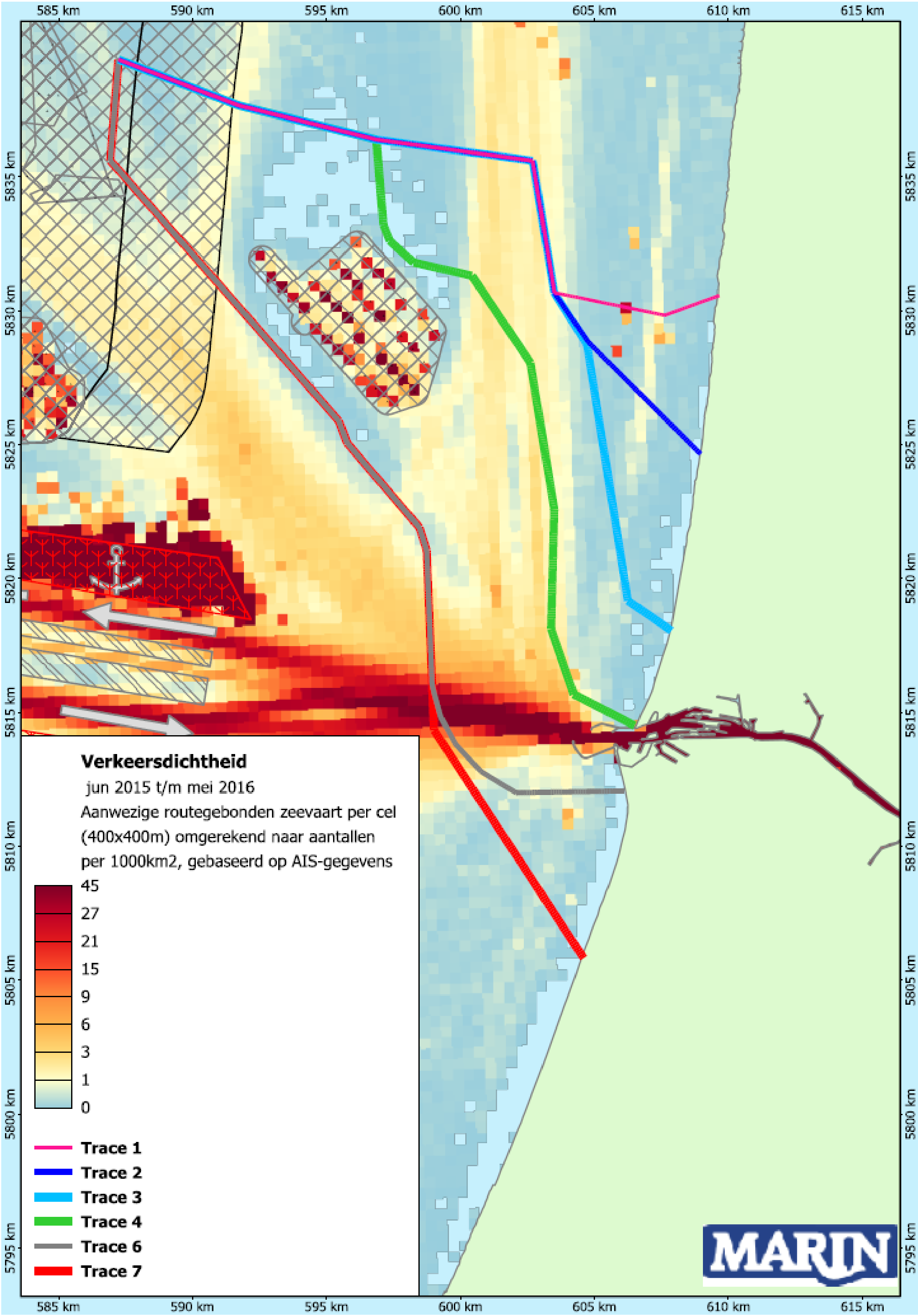
Voor het bepalen van de effecten van de scheepvaart op de verschillende tracéalternatieven wordt een verkeersanalyse uitgevoerd op basis van AIS-data. Paragraaf 4.1 bevat de dichtheidskaarten voor het verkeer rond de tracéalternatieven. In 4.2 wordt het aantal passages per segment weergegeven. Tenslotte worden de incidentfrequenties voor de kabel toegelicht in 4.4.

4.1 Verkeersdichtheid

De verkeersstromen rondom de tracéalternatieven zijn weergegeven met behulp van verkeersdichtheidskaarten voor zowel het routegebonden als het niet-routegebonden verkeer. In Figuur 4-1 is de dichtheidskaart te zien rond de locatie van de kabel voor alle verkeer (route en niet-routegebonden verkeer). Figuur 4-2 laat nogmaals de verkeersdichtheid zien, alleen nu alleen voor het route gebonden verkeer (koopvaardij), deze figuur laat duidelijk de verschillende vaarroutes in het gebied zien.



Figuur 4-1 Verkeersdichtheid in het gebied rond de kabel, alle verkeer (route- en niet routegebonden verkeer)



Figuur 4-2 **Verkeersdichtheid voor het routegebonden verkeer gebaseerd op AIS-data van juni 2015- mei 2016**

4.2 Aantal scheepspassages per tracéalternatief

Voor de zeven tracéalternatieven van de exportkabel zijn het aantal scheepspassages over de verschillende segmenten van de tracéalternatieven bepaald. In Figuur 4-3 wordt dit gevisualiseerd, waarbij voor elk segment het totaal aantal passages per jaar weergegeven wordt. Het gaat hierbij om schepen met AIS.

In Figuur 4-4 zijn de tracks van alle schepen in mei 2015 weergegeven. Elke 5 minuten is de positie van een schip weergegeven, waarbij de kleur een indicatie is van de snelheid en/of de heading van het schip. De rode stippen zijn locaties waar de snelheid van de schepen minder dan 0.01 kn is. Wanneer een schip in oostelijke richting vaart wordt zijn positie met een zwarte stip weergegeven en in westelijke richting met een bruine stip. Duidelijk zichtbaar zijn de hoofdvaarroutes in het gebied.

Tabel 4-1 Gemiddeld aantal passages per jaar per tracé en scheeptype, gebaseerd op schepen waargenomen op basis van AIS in de periode 1 jan 2015 - 31 dec 2016

Tracé	Lengte [m]	Cargo/tanker	Vissers (AIS)	Passagiers	Werkschepen/overig	Recreatie (AIS)	Totaal (AIS)
Tracé 1	27252	2518	3047	70	60	3043	8737
Tracé 2	29051	2513	3149	71	60	2855	8647
Tracé 3	34830	2601	3508	70	65	3104	9348
Tracé 4 / tracé 5	36345	3338	3414	299	81	3449	10579
Tracé 6	36939	14120	6457	2449	4479	11135	38639
Tracé 7	39419	13859	6457	2300	4415	11319	38349

Tabel 4-2 Verdeling van het aantal passages voor de verschillende tracés per scheepstype

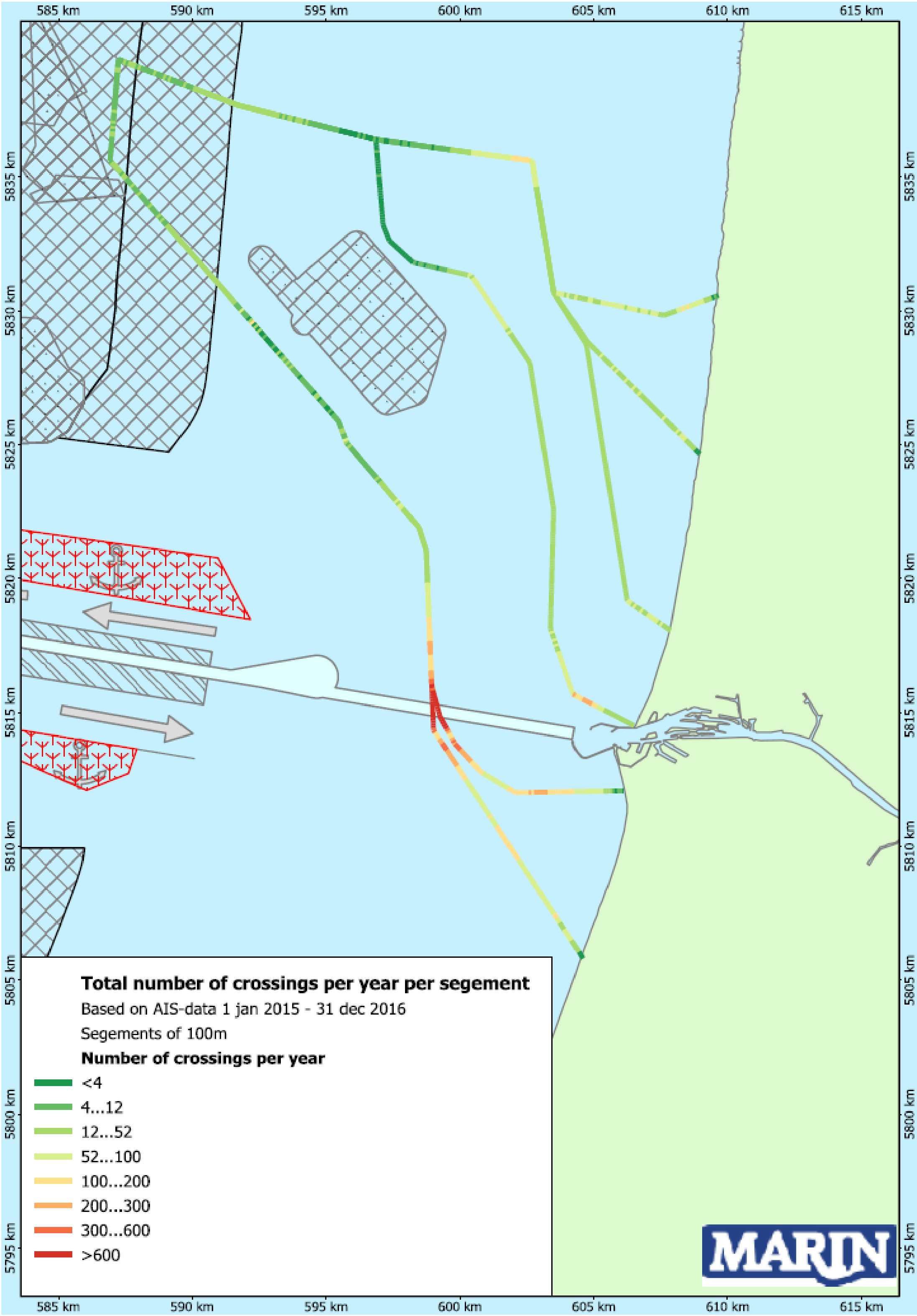
Tracé	Lengte [m]	Cargo/tanker	Vissers (AIS)	Passagiers	Werkschepen/overig	Recreatie (AIS)	Totaal (AIS)
Tracé 1	27252	29%	35%	1%	1%	35%	100%
Tracé 2	29051	29%	36%	1%	1%	33%	100%
Tracé 3	34830	28%	38%	1%	1%	33%	100%
Tracé 4 / tracé 5	36345	32%	32%	3%	1%	33%	100%
Tracé 6	36939	37%	17%	6%	12%	29%	100%
Tracé 7	39419	36%	17%	6%	12%	30%	100%

Tabel 4-3 Gemiddeld aantal passages per jaar per tracé en scheepsgrootte klasse, gebaseerd op schepen waargenomen op basis van AIS in de periode 1 jan 2015 - 31 dec 2016

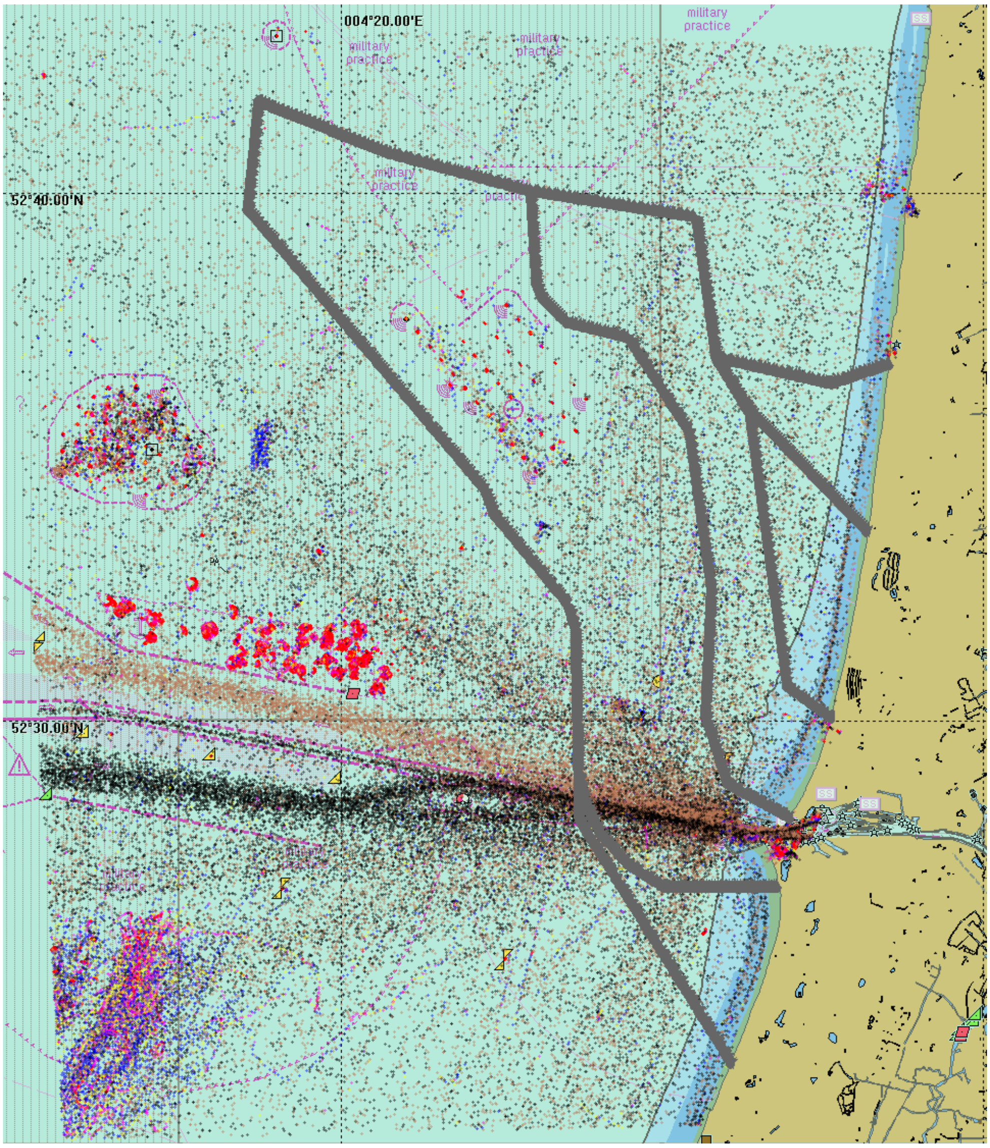
		Grootte klasse [gebaseerd op GT]								
Tracé	**Lengte [m]**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Totaal (AIS)**
Tracé 1	27252	4681	1731	2006	118	191	11	0	0	8737
Tracé 2	29051	4691	1729	1898	132	191	7	0	0	8647
Tracé 3	34830	5309	1806	1905	119	196	13	0	0	9348
Tracé 4 / tracé 5	36345	6074	2704	1516	130	125	30	0	0	10579
Tracé 6	36939	16723	4587	5722	1910	6663	2263	565	208	38639
Tracé 7	39419	16816	4439	5670	1888	6512	2259	560	206	38349

Tabel 4-4 Verdeling van het aantal passages voor de verschillende tracés per scheepsgrootte klassee

		Grootte klasse [gebaseerd op GT]								
Tracé	**Lengte [m]**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Totaal (AIS)**
Tracé 1	27252	54%	20%	23%	1%	2%	0%	0%	0%	100%
Tracé 2	29051	54%	20%	22%	2%	2%	0%	0%	0%	100%
Tracé 3	34830	57%	19%	20%	1%	2%	0%	0%	0%	100%
Tracé 4 / tracé 5	36345	57%	26%	14%	1%	1%	0%	0%	0%	100%
Tracé 6	36939	43%	12%	15%	5%	17%	6%	1%	1%	100%
Tracé 7	39419	44%	12%	15%	5%	17%	6%	1%	1%	100%



Figuur 4-3 **Totaal aantal scheepspassages per jaar (gebaseerd op AIS-data 2015-2016) per tracésegment.**



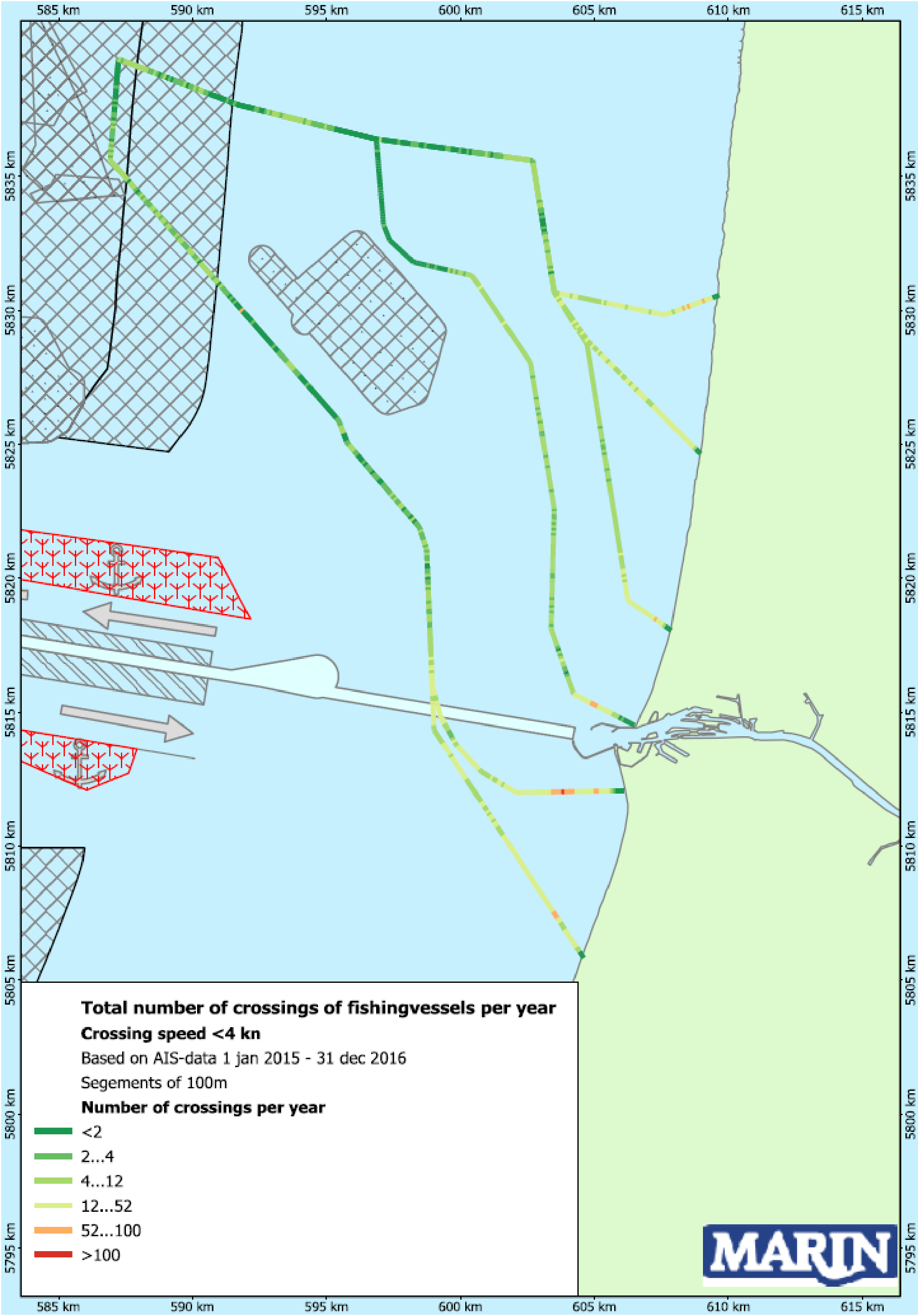
Figuur 4-4 Posities van schepen gebaseerd op AIS-data van mei 2015 (positie elke 5 minuten)

4.3 Passages van vissersvaartuigen

Het gemiddeld aantal vissersvaartuigen per jaar dat de verschillende tracés passeerde is weergegeven in Tabel 4-5. Het gaat hierbij wel om scheepsbewegingen zoals die nu zijn waargenomen, dus zonder de aanwezigheid van de kabel. Er is dus nu geen belemmering om te vissen op de verschillende locaties.
Om een idee te krijgen van het aantal vissers dat vist op de beoogde locaties is gekeken naar de snelheid tijdens het kruisen van de kabel locatie. In de tabel is daarom een uitsplitsing gemaakt naar passeer snelheden lager dan 4kn en 5 kn. Afhankelijk van de grootte van het vissersschip en het type schip en vistuig zal de gemiddelde verwachte maximale snelheid tijdens het vissen variëren tussen de 4 en 5 kn, daarom is er voor gekozen zowel het aantal langzamer dan 5kn als het aantal langzamer dat 4 kn weer te geven.
Het aantal kruisingen door vissers die mogelijk aan het vissen zijn is het hoogst voor tracé 6 en tracé 7. Dit zijn voornamelijk vissers die kruisen aan de zuidzijde van de aanloop naar IJmuiden. In Figuur 4-5 is het aantal passages door vissersvaartuigen met een snelheid lager dan 4 kn weergegeven.

Tabel 4-5 Gemiddeld totaal aantal passerende/kruisende vissersvaartuigen per jaar voor de verschillende tracés (gebaseerd op AIS-data 1 jan 2015 - 31 dec 2016)

	Gemiddeld aantal vissersvaartuigen dat de locatie van het tracé passeert per jaar. (gebaseerd op AIS-data 1 jan 2015 – 31 dec 2016)			% of crossings < 4 kn
	All	Crossing speed < 5kn	Crossing speed < 4kn	
tracé1	3047	2308	1809	59%
tracé2	3149	2411	1911	61%
tracé3	3508	2770	2236	64%
tracé4	3414	2526	1834	54%
tracé6	6457	4306	3280	51%
tracé7	6457	4319	3337	52%



Figuur 4-5 Aantal passages per jaar door vissersvaartuigen met snelheid lager dan 4 kn (gebaseerd op AIS-data 1 jan 2015 - 31 dec 2016)

4.4 Incidenten frequenties

In deze paragraaf worden de berekende frequenties voor de verschillende incidenten voor de kabel samengevat. Alle weergegeven resultaten zijn het verwachte aantal incidenten per jaar voor de hele stukken van de kabel. Voor de uitvoering van de RBBD-studie zijn de resultaten per segment nodig, deze detail resultaten van de individuele segmenten zijn opgeleverd in een Excel bestand 30449_Asset_Trace1_v3 t/m.xlsx 30449_Asset_Trace7b_v3.xlsx

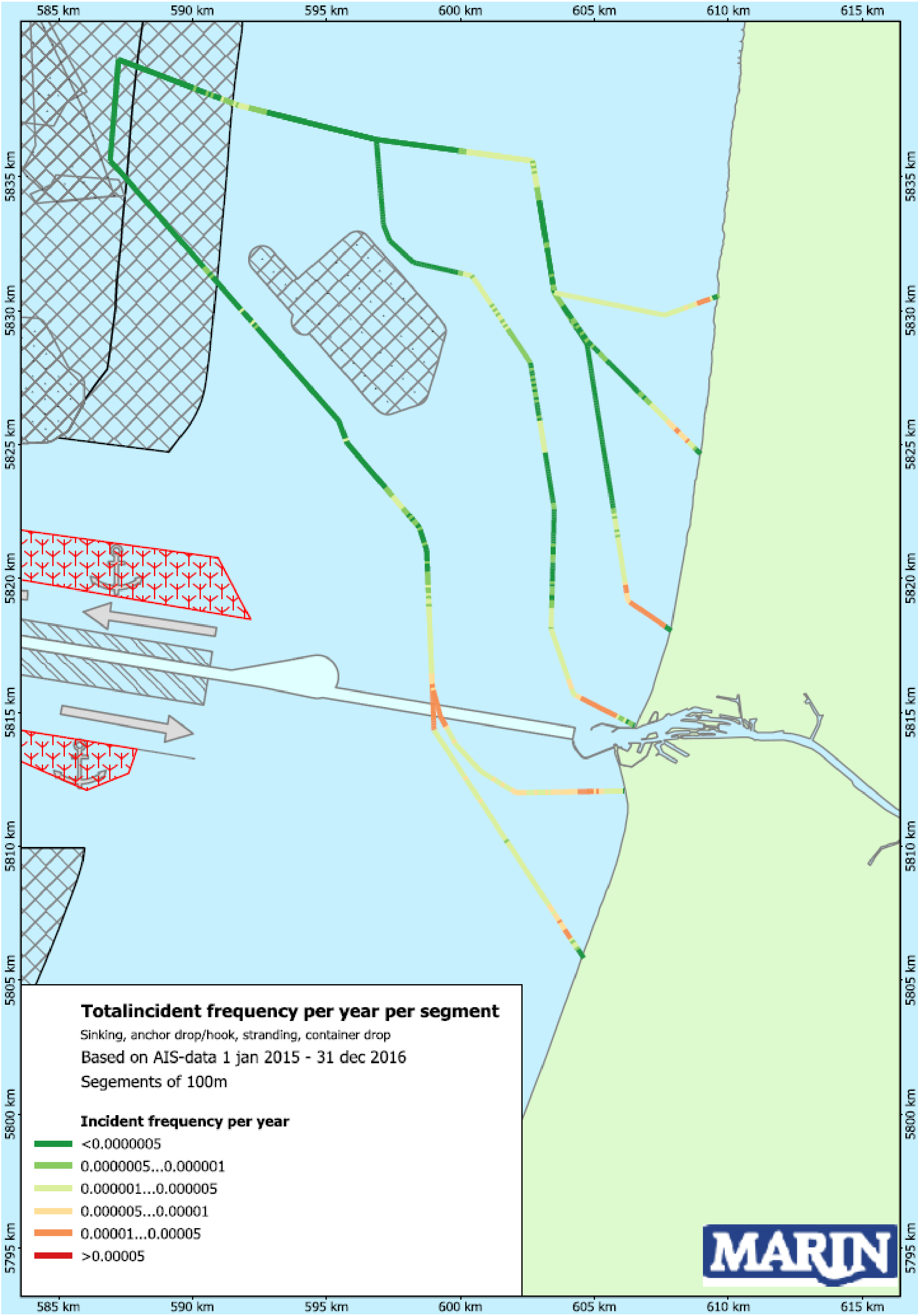
In Tabel 4-6 zijn de resultaten van de verschillende incidenten voor de zeven tracéalternatieven van de kabel naast elkaar gezet. Voor elk tracé zijn de totale incidentfrequenties voor het gehele tracé weergegeven over de gehele lengte van het tracé

Tabel 4-6 Overzicht van de verschillende incident frequenties voor de zeven tracéalternatieven, alleen offshore deel.

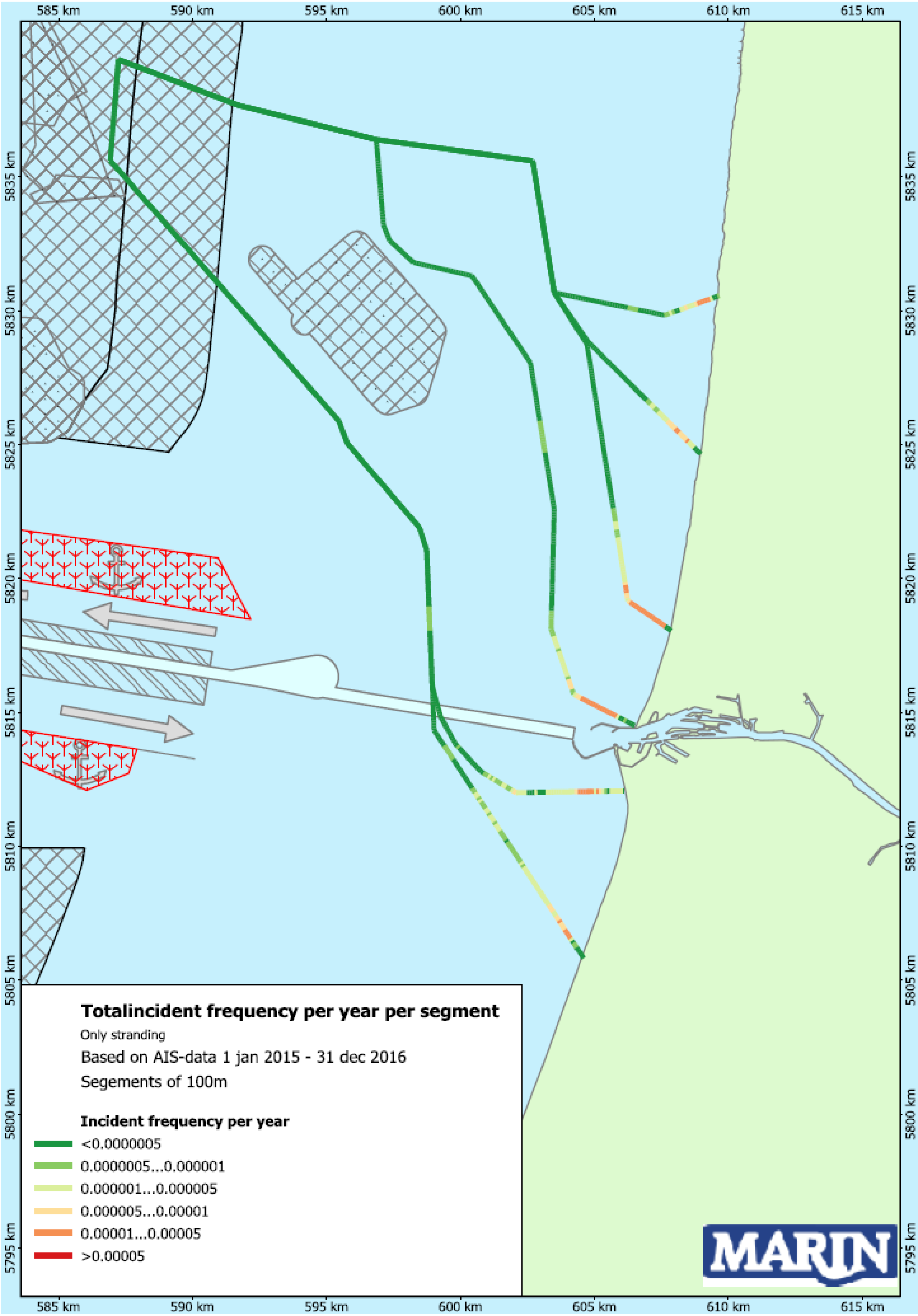
	Totaal aantal passage per jaar (AIS)	Lengte [m]	Zinken (foundering + aanvaring)	Anker incident (haken+ vallen)	Stranden	Container vallen	Totaal	eens in de … jaar
Tracé 1	8737	27252	1.95E-05	1.70E-04	1.06E-04	3.49E-05	3.31E-04	3021
Tracé 2	8647	29051	1.68E-05	1.30E-04	1.33E-04	3.32E-05	3.12E-04	3200
Tracé 3	9348	34830	1.80E-05	1.45E-04	3.92E-04	3.31E-05	5.88E-04	1701
Tracé 4 / Tracé 5	10578	36345	1.82E-05	1.35E-04	5.21E-04	2.54E-05	7.00E-04	1428
Tracé 6	38639	36939	4.95E-05	3.10E-04	2.87E-04	7.22E-05	7.19E-04	1391
Tracé 7	38349	39419	5.61E-05	3.47E-04	2.17E-04	1.15E-04	7.36E-04	1359

Tabel 4-7 Overzicht van de verdeling over de verschillende incident frequenties voor de zeven tracéalternatieven (alleen offshore deel).

	Totaal aantal passage per jaar (AIS)	Lengte [m]	Zinken (foundering + aanvaring)	Anker incident (haken+ vallen)	Stranden	Container vallen	Totaal
Tracé 1	8737	27252	5.9%	51.5%	32.0%	10.6%	100.0%
Tracé 2	8647	29051	5.4%	41.5%	42.5%	10.6%	100.0%
Tracé 3	9348	34830	3.1%	24.6%	66.7%	5.6%	100.0%
Tracé 4 / Tracé 5	10578	36345	2.6%	19.3%	74.5%	3.6%	100.0%
Tracé 6	38639	36939	6.9%	43.2%	39.9%	10.0%	100.0%
Tracé 7	38349	39419	7.6%	47.2%	29.5%	15.7%	100.0%



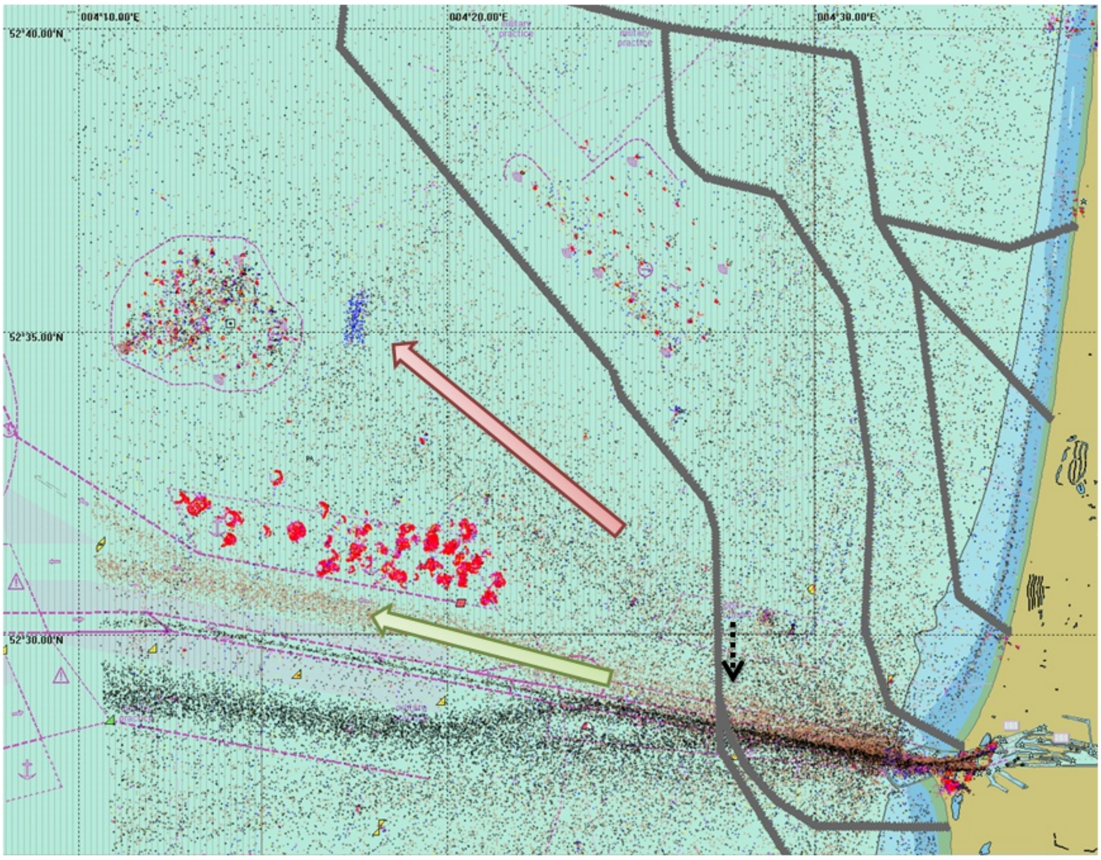
Figuur 4-6 Totale incident frequentie (vanuit scheepvaart) per jaar per segment.



Figuur 4-7 **Strandingsfrequenties op de kabel per segment van 100m per jaar.**

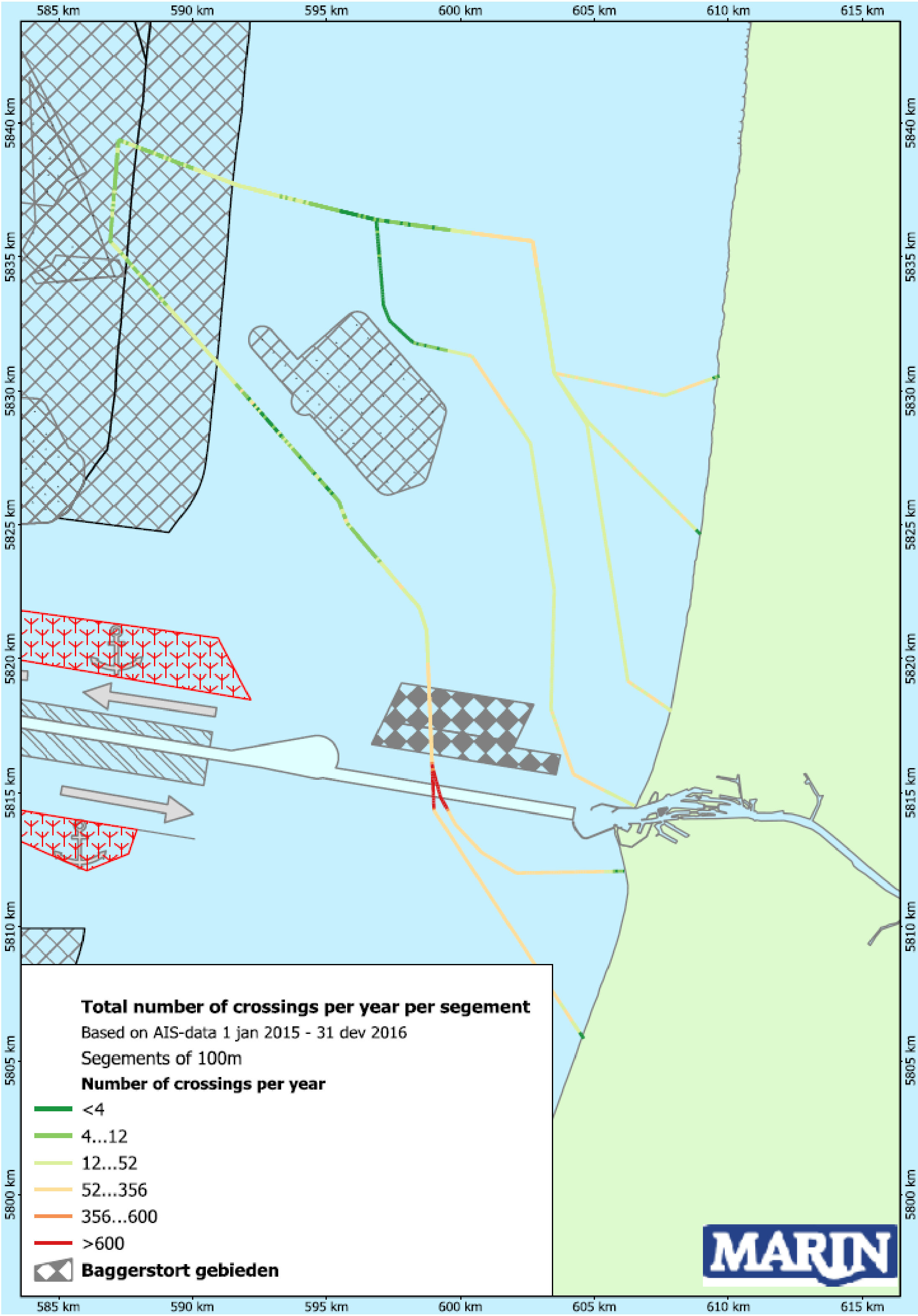
4.5 Opmerkingen m.b.t. verkeersstromen

Door de aanleg van het windpark Hollandse Kust Noord zal een verkeersstroom (rode pijl in Figuur 4-8) die nu tussen Amalia en Egmond door vaart niet meer op die locatie kunnen passeren. Dit betekent dat deze schepen aan de zuidzijde langs zullen passeren (groene pijl). Dit effect is nu niet mee genomen in de eerste fase van de studie.
Het totaal aantal passages over tracé 6 en 7 zal niet wijzigen, echter wel de locatie.
Dit betekent dat de totale incident frequentie niet significant zal wijzigen, echter wel de locatie.



Figuur 4-8 Verschuiving van verkeersstromen door de aanleg van het windpark Hollandse Kust (noord).

4.6 Baggerstort gebieden



4.7 Results adjustments Trace 1 and Trace 3

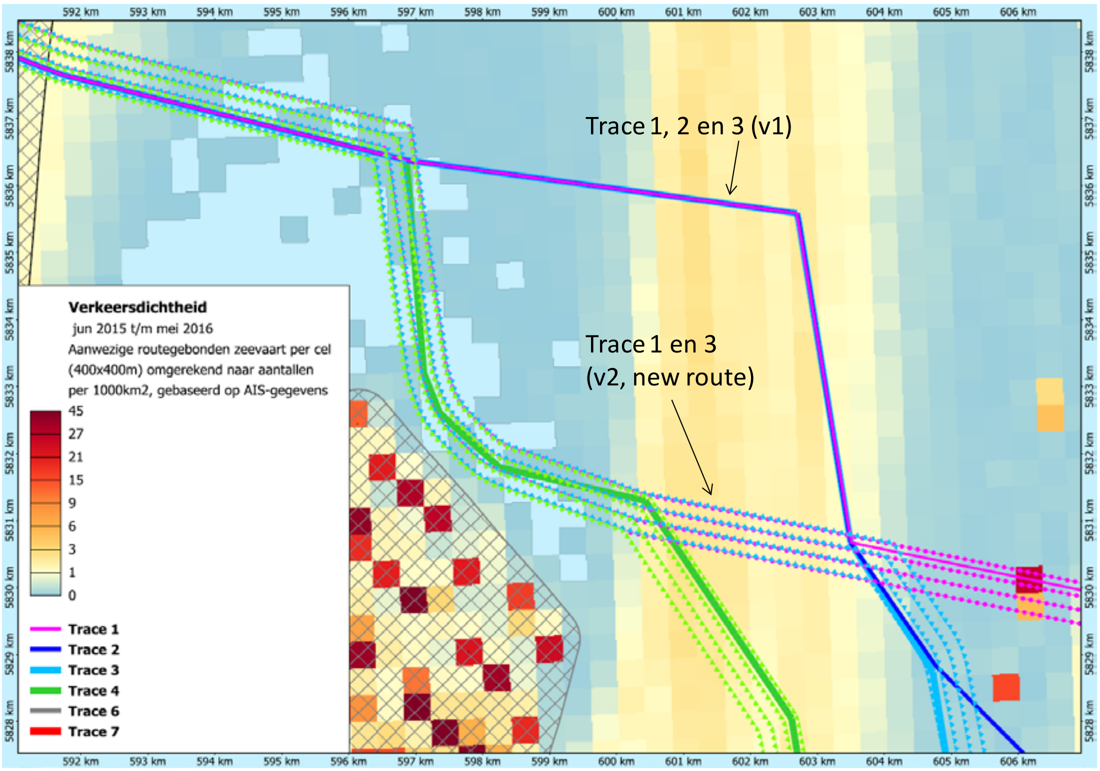
Note: This chapter is written in English. The final version of the report will be in English completely.

The routes of tracé 1, 2 and 3 have been adjusted after the AIS-analysis were conducted. Since most of the adjusted routes are equal to the route of trace 4 it has been decided in a meeting with TenneT (21 November 2017) that the number of crossings and incident frequencies will be adjusted without re-running and recalculating the AIS data.

In 4.7.1 a map is shown to indicating the difference. A short description of the approach is provided in 4.7.2. Finally in 4.7.3 the new crossing frequencies and incident frequencies for trace 1 and 3 are provided.

4.7.1 Difference

In Figure 4-9 both routes are drawn. The dotted version is the adjusted route for trace 1 and 3. Also the ship density is plotted in the background. The map shows that the number of ship crossing the trace will be similar, since the north-south oriented shipping route that crosses the first version also crossed the new, adjusted version. This is also why it has been decided not to rerun the AIS-runs and recalculate the incident frequencies, but only “rearrange” the numbers that were already available.

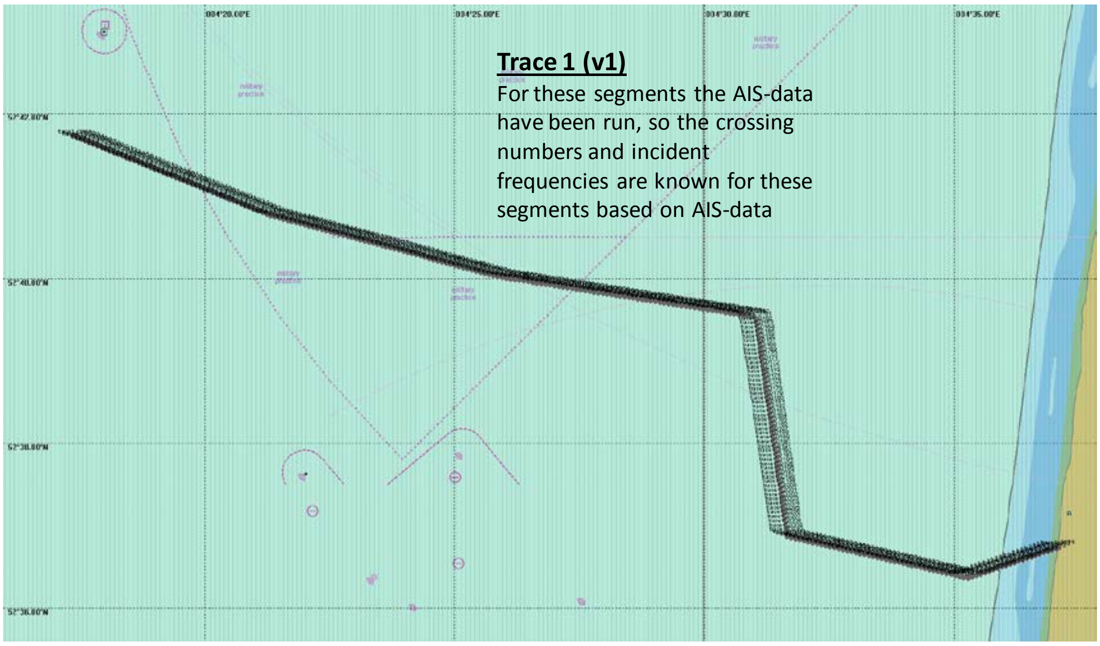


Figuur 4-9 Overview of the changes in route for trace 1 and 3.

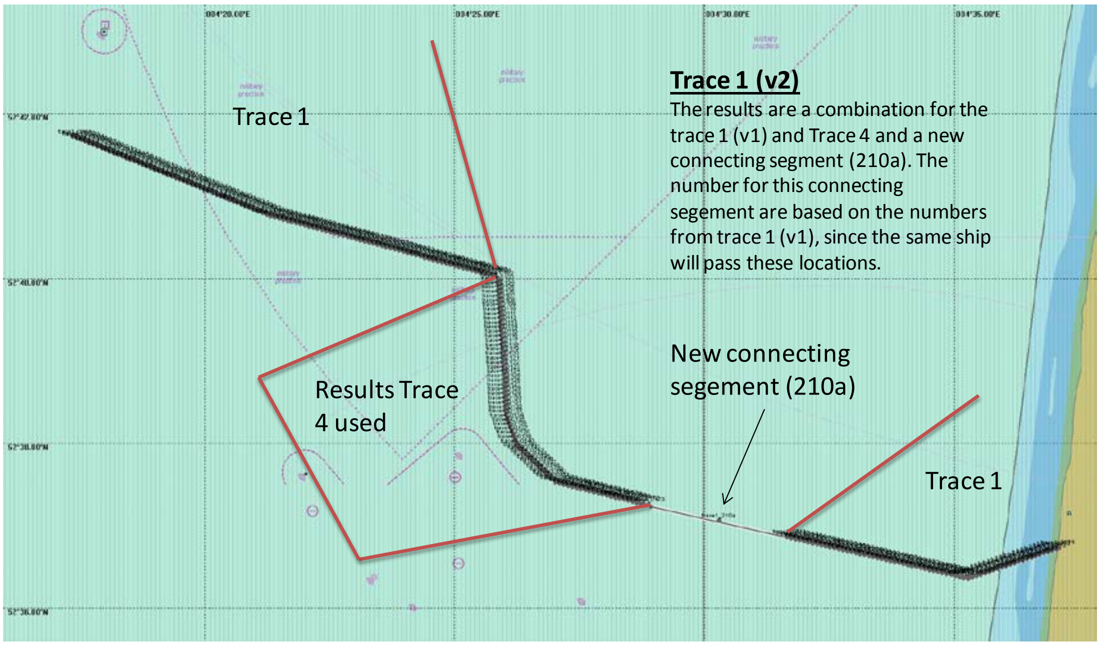
4.7.2 Approach

Figuur 4-10 and Figuur 4-11 show briefly how the new results for the adjusted trace 1 have been determined based on the results for the original routes for trace 1 and trace 4.

For the first part (starting from the offshore platform) the same results for the original trace were used, at one point the route is changed to the route already in place for trace 4. So for this part the results were used calculated for trace 4. At one point the route for trace 4 continuous going south where the adjusted trace 1 continuous in a east direction and picks up the last part from the original route. To connect the end of trace 4 and the start of the original trace 1 route one extra large segment has been added. The number of crossings and frequencies for this segments were based on some of the corresponding segments of the original trace 1 to the north of the new connected segment.



Figuur 4-10 Original segments trace 1



Figuur 4-11 Adjusted segments trace 1

4.7.3 Results

The adjusted number of crossing for trace 1 and 3 are shown in Table 4-8 and Table 4-9. Based on these crossing number the incident frequencies are determined, the results are shown in Table 4-10.

The total number of crossings and the incident frequencies are not significant different from the numbers of the original version of the routes. This means that the treat from shipping is not significant different.

Table 4-8 Average number of crossings per year per ship type, based on AIS-data covering the period 1 jan 2015 - 31 dec 2016

	Number of crossings per year		Distribution	
	Trace 1 (v2)	Trace 3 (v2)	Trace 1 (v2)	Trace 3 (v2)
Lengte [m]	26793	34363		
Cargo/Tanker	2542	2625	29.0%	28.0%
Visser (AIS)	3135	3596	35.8%	38.4%
Passagier	69	69	0.8%	0.7%
Werkschepen/overig	62	67	0.7%	0.7%
Recreatie (AIS)	2952	3013	33.7%	32.2%
Totaal	8759	9370	100.0%	100.0%

Table 4-9 Average number of crossings per year per ship size, based on AIS-data covering the period 1 jan 2015 - 31 dec 2016

	Number of crossings per year		Distribution	
	Trace 1 (v2)	Trace 3 (v2)	Trace 1 (v2)	Trace 3 (v2)
Lengte [m]	26793	34363		
Size 1	4777	5405	54.5%	57.7%
Size 2	1675	1751	19.1%	18.7%
Size 3	1988	1887	22.7%	20.1%
Size 4	114	115	1.3%	1.2%
Size 5	195	200	2.2%	2.1%
Size 6	11	13	0.1%	0.1%
Size 7	0	0	0.0%	0.0%
Size 8	0	0	0.0%	0.0%
Total	8759	9370	100.0%	100.0%

Table 4-10 Number of incident frequencies for the adjusted trace 1 and 3.

	Number of incidents per year		Distribution	
	Trace 1 (v2)	Trace 3 (v2)	Trace 1 (v2)	Trace 3 (v2)
# crossings per year	8759	9370		
lengte[m]	26793	34363		
Sinking	1.64E-05	1.49E-05	5.0%	2.5%
Anchor incident	1.06E-04	3.92E-04	32.2%	66.9%
Stranding	1.72E-04	1.46E-04	52.2%	24.9%
Container dropping	3.46E-05	3.28E-05	10.5%	5.6%
Total	3.29E-04	5.86E-04	100.0%	100.0%
Once every ... year	3039	1707		

5 NOORDZEEKANAAL

Een deel van het tracé 4 en 5 loopt door het Noordzeekanaal. De risico's vanuit de scheepvaart voor dit deel van het tracé kan niet op exact dezelfde wijze worden vastgesteld als het offshore deel van het tracé. De incidentfrequenties zijn niet gelijk omdat de verkeerssituatie op het kanaal anders zijn dat buitengaats op zee. Bijvoorbeeld door de aanwezigheid van sleepboten en loodsen aan boord van de schepen.
In de eerste fase van de studie, waarbij het, het belangrijkste is dat er een keus gemaakt wordt tussen de 7 verschillende varianten, is daarom gekozen voor een kwalitatieve beschouwing van het risico vanuit de scheepvaart. De aanpak en resultaten hiervan zijn weergegeven in paragraaf 5.1

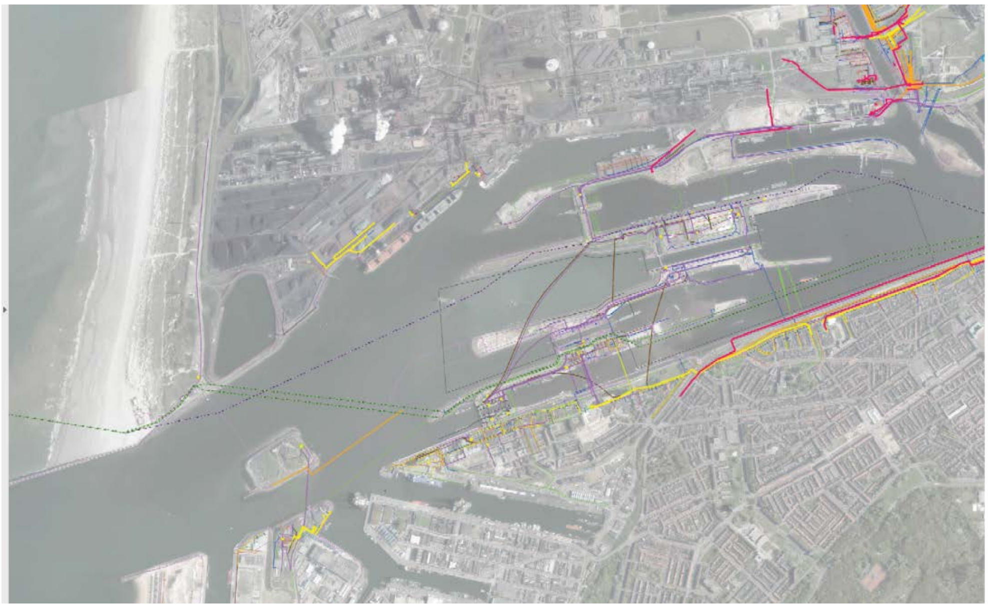
Als aanvulling is in de tweede fase ervoor gekozen de kansen voor het "stranden" in het talud en het laten vallen van een anker kwantitatief te bepalen voor enkele locaties op het kanaal. Deze resultaten zijn vervolgens als input gebruikt voor de RBBD. De resultaten van deze tweede fase zijn weergegeven in 5.2.

5.1 Eerste fase: kwalitatieve analyse

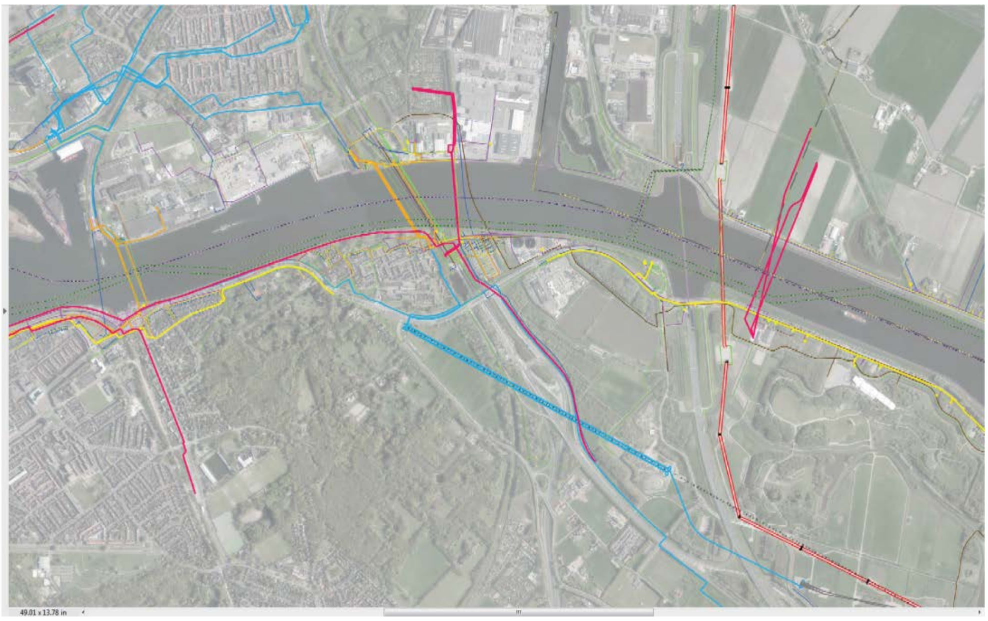
In een eerste fase is op een kwalitatieve wijze naar de risico's voor de kabel door het Noordzeekanaal gekeken. De uitgangspunten, werkwijze en resultaten zijn kort in deze paragraaf toegelicht.

5.1.1 Aannames/uitgangspunten

- Het tracé wordt gebruikt zoals dit is aangeleverd op 17 juni 2017
  - Oversteek naar de zuidelijke oever voor het sluizen complex (gezien vanuit zee)
  - Midden van het kanaal bij oversteek van de pont bij Velsen
  - Eerste deel van het tracé aan de zuidoever (tussen Velsen en net na de Velsertunnel)
  - Na Velsertunnel oversteek naar noordelijke oever
  - In het midden van het kanaal nabij pont Spaandam-Assendelft
  - Na pont weer terug naar noordelijke oever tot voor de ingang van de Afrikahaven
  - Rechte oversteek voor Afrikahaven vaan zuidkant van het kanaal
  - Tracé 4:
    - een keer in het midden van het kanaal
    - een keer oversteek van zuid naar noord
  - Tracé 5:
    - twee keer door het midden van het kanaal
    - twee keer overkeek
  - Let op: Kabel liggen dus grotendeels aan de zijkant van het kanaal
- Intensiteiten op het kanaal alleen bepaald op basis van AIS, dus alleen schepen waargenomen die AIS aan boord hebben en waarvan het signaal is opgevangen
- Bronnen gebruikt voor de kwalitatieve analyse:
  - AIS-data
  - Verslagen van de workshops met RWS (niet aanwezig)
  - Informatie verstrekt door Tennet



Figuur 5-1 Overzicht kabel tracé door het Noordzeekanaal (dd 19 juni 2017), groene lijn is de kabel; locatie 1 (sluizen complex)



Figuur 5-2 Overzicht kabel tracé door het Noordzeekanaal (dd 19 juni 2017), groene lijn is de kabel; locatie 2 (pont bij Velsen, afsplitsing tracé 5 en oversteek)

Figuur 5-3 Overzicht kabel tracé door het Noordzeekanaal (dd 19 juni 2017), groene lijn is de kabel; locatie 3 (pont Spaandam-Assendelft)

Figuur 5-4 Overzicht kabel tracé door het Noordzeekanaal (dd 19 juni 2017), groene lijn is de kabel; locatie 4 (aanlanding voor Afrikahaven)

5.1.2 Werkwijze kwalitatieve analyse

- Op basis van AIS-gegevens is het verkeersbeeld op het Kanaal in kaart gebracht:
    - Intensiteiten
    - Verdeling over de vaarweg

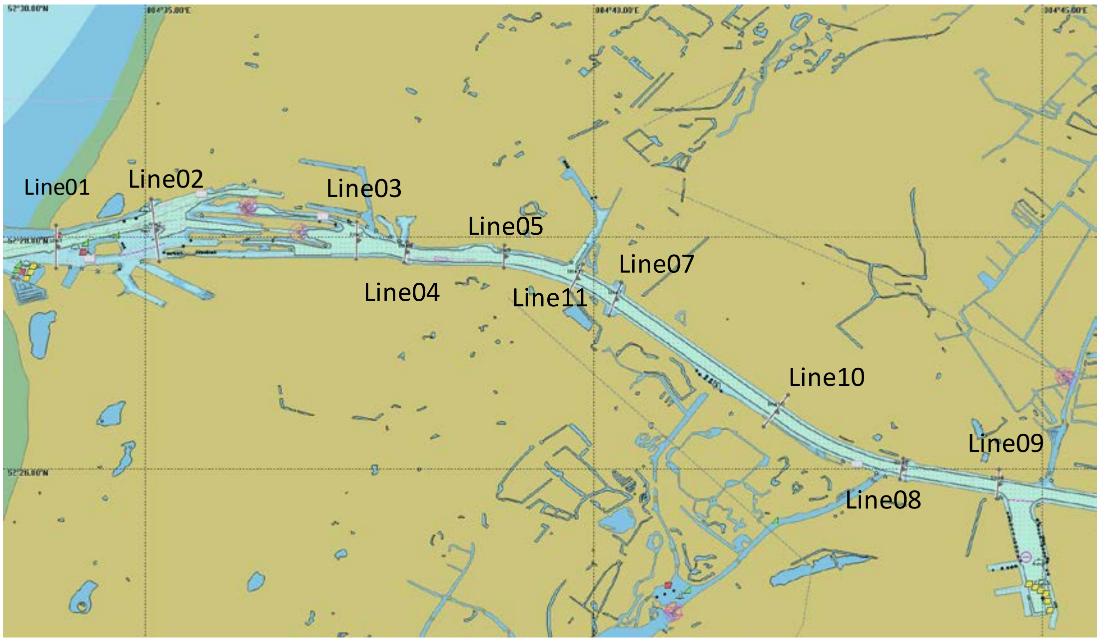
- Kwalitatieve beschouwing van de risico's vanuit de scheepvaart voor de kabel op het Noordzeekanaal in relatie tot de geïdentificeerde risico's (incident frequenties) op zee (het offshore deel)

- Kwalitatieve beschouwing van eventuele aanvullende extra risico's vanuit de scheepvaart voor de kabel op het Noordzeekanaal die niet relevant zijn voor het offshore deel van de kabel.
    - Jack-up in de werkhaven voor de sluis (zuidzijde)
    - Averijhaven (noordzijde)
    - Gebruik van spudpalen bij onderhoud van de oever

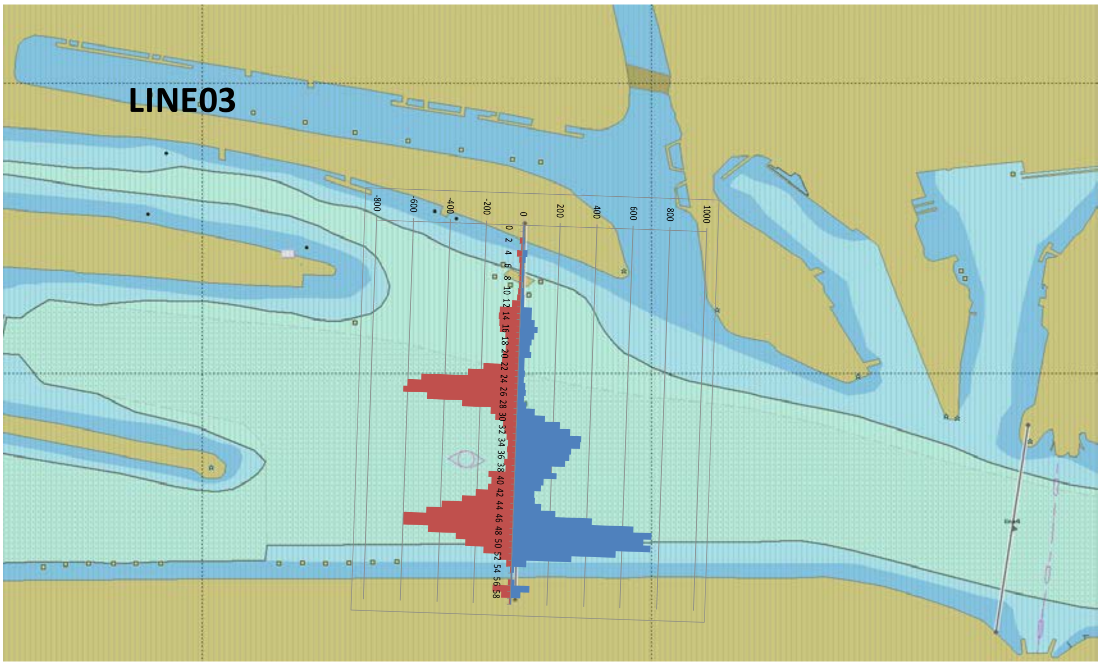
5.1.3 Resultaten AIS-analyse

In het gebied rond de lichterpalen zijn een aantal zogenaamde crossing lines gedefinieerd (zie Figuur 5-5). Voor alle lijnen is bepaald waar, wanneer en door welk schip de lijn gekruist is. Op basis hiervan is de afstand tot het start punt van de lijn bepaald van de passage. Ook is de snelheid bekent van het moment van passeren.
De analyse is uitgevoerd over de periode 1 jan 2016 t/m 31 dec. 2016.

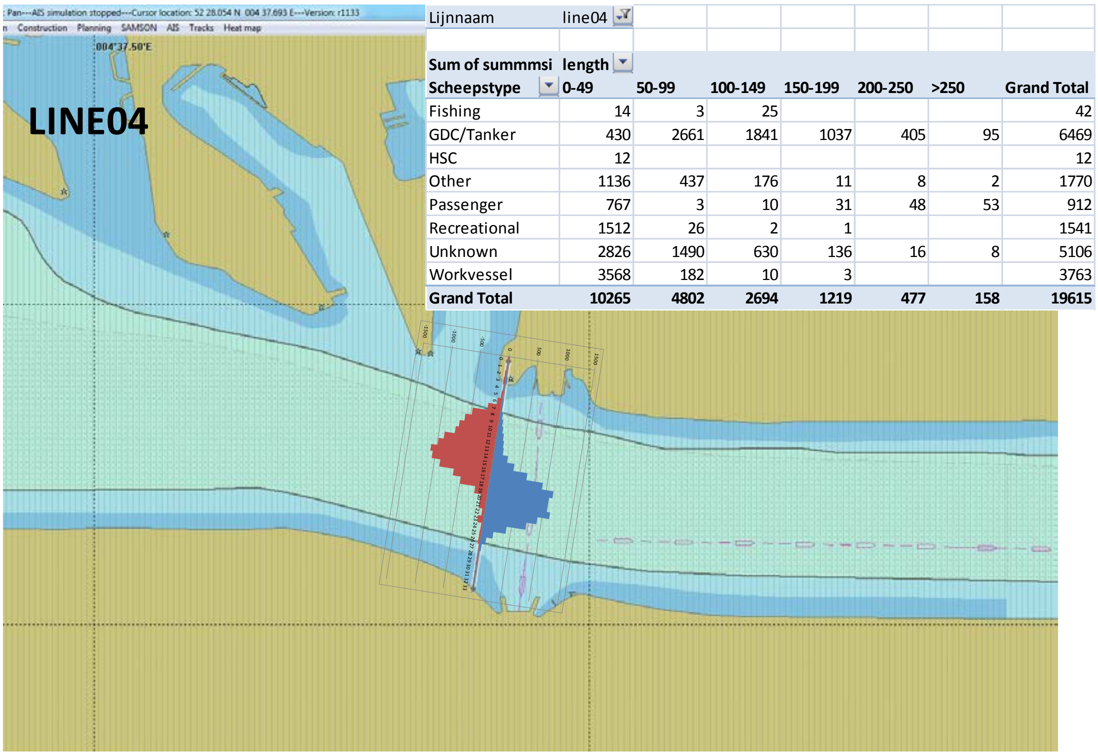
Op basis van de positie van passeren van de gedefinieerde lijn en het startpunt van de lijn is de afstand bepaald tussen het passeren van het midden van het schip (HS) en dit start punt (noordzijde)locatie van de lichterpalen op deze lijn is de passeer afstand tot de lichterpalen bepaald voor alle passages.



Figuur 5-5 Overzicht van de beschouwde doorsnedelijnen in de AIS-analyse

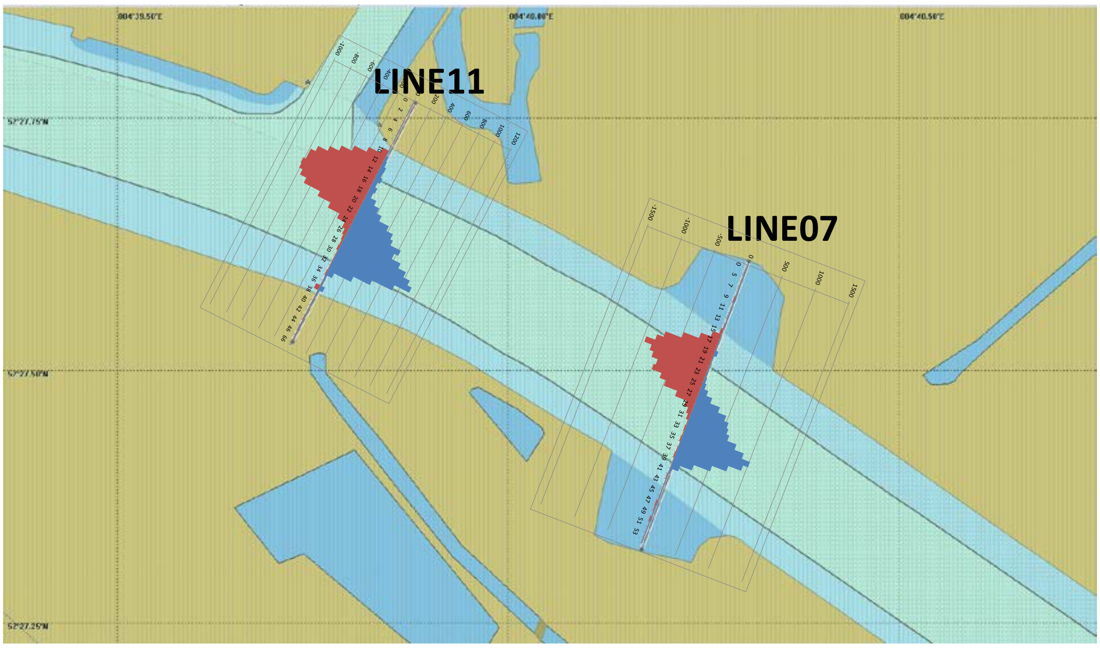


Figuur 5-6 Verdeling van het verkeer over de vaarweg bij line3, net na de sluizen (lanes van 10 m).

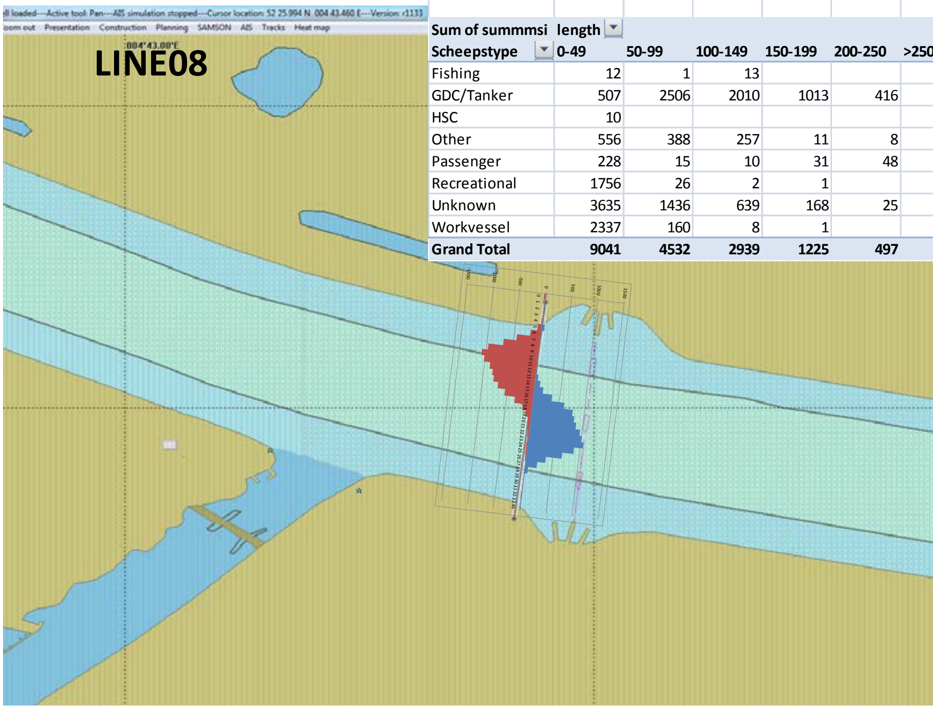


Lijnnaam	line04						
Sum of summmsi	**length**						
Scheepstype	**0-49**	**50-99**	**100-149**	**150-199**	**200-250**	**>250**	**Grand Total**
Fishing	14	3	25				42
GDC/Tanker	430	2661	1841	1037	405	95	6469
HSC	12						12
Other	1136	437	176	11	8	2	1770
Passenger	767	3	10	31	48	53	912
Recreational	1512	26	2	1			1541
Unknown	2826	1490	630	136	16	8	5106
Workvessel	3568	182	10	3			3763
Grand Total	**10265**	**4802**	**2694**	**1219**	**477**	**158**	**19615**

Figuur 5-7 Verdeling van het verkeer over de vaarweg bij line4, bij de oversteek van pont Velsen (lanes van 10 m).



Figuur 5-8 Verdeling van het verkeer over de vaarweg bij line11 en line07, (lanes van 10 m).



Lijnnaam	line08						
Sum of summmsi	length						
Scheepstype	0-49	50-99	100-149	150-199	200-250	>250	Grand Total
Fishing	12	1	13				26
GDC/Tanker	507	2506	2010	1013	416	75	6527
HSC	10						10
Other	556	388	257	11	8	2	1222
Passenger	228	15	10	31	48	52	384
Recreational	1756	26	2	1			1785
Unknown	3635	1436	639	168	25	7	5910
Workvessel	2337	160	8	1			2506
Grand Total	**9041**	**4532**	**2939**	**1225**	**497**	**136**	**18370**

Figuur 5-9 Verdeling van het verkeer over de vaarweg bij line8, (lanes van 10 m).

5.1.4 Vergelijking aantal passages offshore en Noordzeekanaal

- Totaal aantal passages op het Noordzee kanaal vergelijkbaar met het aantal passages over het offshore deel van de tracé 6 en 7 bij de kruising van de aanloop naar IJmuiden/Amsterdam.
- De lengte van het tracé is echter veel kleiner. Dus bij gelijke model uitgangspunten is de incidentfrequentie per segment bij de oversteek op het Noordzeekanaal groter dan de incident frequentie voor de individuele segmenten op het offshore deel.
- Echter de incident frequentie per passage is kleiner (zie paragraaf 5.1.5)

Tabel 5-1 Totaal aantal passages in 2016 over line08 (alleen gebaseerd op AIS-data)

Lijnnaam	line08						
Sum of summmsi	**length**						
Scheepstype	**0-49**	**50-99**	**100-149**	**150-199**	**200-250**	**>250**	**Grand Total**
Fishing	12	1	13				26
GDC/Tanker	507	2506	2010	1013	416	75	6527
HSC	10						10
Other	556	388	257	11	8	2	1222
Passenger	228	15	10	31	48	52	384
Recreational	1756	26	2	1			1785
Unknown	3635	1436	639	168	25	7	5910
Workvessel	2337	160	8	1			2506
Grand Total	**9041**	**4532**	**2939**	**1225**	**497**	**136**	**18370**

Figuur 5-10 Locatie van de geselecteerde segmenten van het offshore deel van tracé 7.

Tabel 5-2 Aantal passages (twee richtingen) per jaar over het offshore deel van tracé 7 aangegeven met rood in Figuur 5-10

Scheeptype	Aantal passages per jaar
Bulk/ GDC	9120
Container	26
Tanker (chem/oil)	673
Gas tanker	92
Pass/ Ferry/ Roro	1615
Work vessel/other	3956
Fishing (AIS)	1997
Pleasure (AIS)	7885
Total AIS	25364

Tabel 5-3 Totale incident frequenties voor het offshore deel van tracé 7 aangegeven in Figuur 5-10

Omschrijving	Totale incident frequentie geselecteerde deel van tracé 7	Gemiddelde kans per passage voor het geselecteerde deel van tracé 7
Total AIS	25364	
Lengte [m]	5066	150
Zinken	2.43E-05	9.58E-10
Zinken na aanvaring	1.22E-05	4.79E-10
Stranden	4.90E-06	1.93E-10
Anker haken	1.89E-04	7.45E-09
Anker vallen	2.73E-06	1.08E-10
Container vallen	9.54E-05	3.76E-09
Totale incident freq.	3.31E-04	1.31E-08
Eens in de … jaar	3019	

5.1.5 Kwalitatieve beoordeling incident frequenties per passage

In deze paragraaf wordt ingegaan op de verschillen tussen de kans op een incident per passage van de kabel voor de risico's geïdentificeerd voor op zee. Hierbij wordt kwalitatief gekeken naar de verschillen tussen de kans per passage op het Noordzeekanaal in relatie tot de kans op zee (offshore deel van de kabel).

<u>**Zinken door weersomstandigheden**</u>

- Effect van slecht weer minder groot dan op zee

→ 1e veronderstelling :Totale kans op zinken kanaal kleiner dan op zee

Zinken als gevolg van aanvaring

- Stappen:
    - Initiële event: Aanvaring tussen schepen →
    - Zinken door schade als gevolg van de aanvaring

- Initiële kans op aanvaring: aanname dat de kans op het kanaal gelijk is aan de kans op offshore. Dit kom door een verwachte verlaging door de aanwezigheid van VTS en loodsen, echter een verhoging door de beperkte uitwijk mogelijke heden.

- Kans op zinken als gevolg van een aanvaring: aanname kleiner op het kanaal ten opzichte van de kans op zee door dat de snelheid lager is en de aanvaring voornamelijk oploop of kop-kop zal zijn

→ 1e veronderstelling :Totale kans op zinken als gevolg van een aanvaring kanaal kleiner dan op zee

Zinken door weersomstandigheden

- Effect van slecht weer minder groot dan op zee

→ 1e veronderstelling :Totale kans op zinken kanaal kleiner dan op zee

Stranden/aan de grond lopen

Stranden speelt met name op de stukken waar de kabel aan de noord of zuidzijde in het talud liggen.

Ankerhaken / anker vallen

- Stappen:
    - Initiële event: een schip raakt op drift door motor/stuur problemen →
    - Afhankelijk van de situatie wordt besloten gebruik te maken van het anker om de drift te stoppen →
    - Door de situatie wordt wel of niet goed op de kaart gekeken voordat anker uitgegooid wordt ("niet op de kaart kijken")

- Initiële kans op driften: aanname dat de kans op het kanaal gelijk is aan de kans op offshore
- Kans laten vallen anker wanneer op drift: deze kans wordt kleiner ingeschat op het kanaal dan op zee omdat:
    - Er sleepboten gebruikt worden op het kanaal, deze kunnen de drift ook al voor komen
    - De maatregel van het laten vallen van het anker is minder effectief op het kanaal aangezien de tijd tussen start drift en raken van een object (kade) kort is.
- Kans "niet op de kaart kijken": Deze kans zal veel kleiner zijn op het kanaal dan offshore. Offshore wordt aangenomen dat slechts 1-5% van de gevallen er niet gekeken wordt voor het laten vallen van het anker. Op het kanaal zal dit percentage nog veel kleiner zijn omdat:
    - Loodsen aanboord
    - VTS

→ 1e veronderstelling: Totale kans op ankerhaken/ankervallen per passage op het kanaal kleiner dan op zee

__Container vallen__

De snelheid van de schepen op het kanaal zullen lager liggen dan de snelheid op zee, daarnaast zal de invloed van wind en golven kleiner zijn. Dus zal de kans dat een container van boord valt ook kleiner zijn dan op zee.

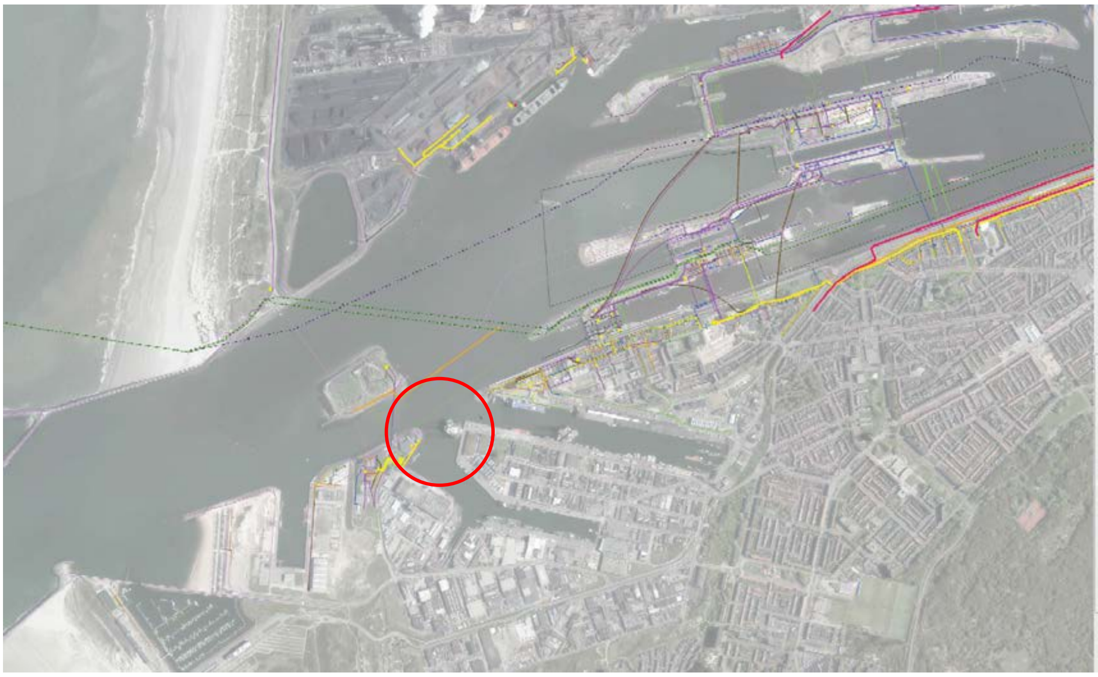
→ 1e veronderstelling: Totale kans op container vallen per passage op het kanaal kleiner dan op zee

Algemene conclusie
De conclusie is dat de totale kans op een incident vanuit de passerende (kruisende) scheepvaart per passage kleiner is op het Noordzeekanaal dan op het offshore deel van het tracé.

5.1.6 Kwalitatieve beschouwing aanvullende incidenten vanuit de scheepvaart

Naaste de incidenten door de scheepvaart zoals beschreven in de voorgaande paragrafen zijn er een aantal aanvullende risico's geïdentificeerd. Echter zijn er te weinig gegevens bekend om een goede kwantitatieve beschouwing van deze risico's op te nemen in deze fase van de studie.

Werkverkeer naar werkhaven aan de zuidzijde
Werkverkeer naar werkhaven aan de zuidzijde van het Kanaal aan de zeezijde van het kanaal (rode cirkel). Het gaat hierbij mogelijk om jack-up vessels die gebruikt worden bij de installatie van windturbines op zee. Dit zijn schepen die gebruik maken van spud-palen. Er bestaat een mogelijkheid dat deze schade aanrichten aan de kabel. Echter kruist de aanvaarroute richting de werkhaven niet het huidige beoogde tracé, dus is het risico klein dat dit tot schade leidt.



Ontwikkeling van een averijhaven (noordzijde)
Aan de noordzijde wordt een averij haven ingericht.

Gebruik van spud-palen bij onderhoud van de oever.
In een “aanwijzingsbesluit” van de gemeente Amsterdam (bijlage B) wordt aangegeven dat in artikel 4.12 van de Regionale Havenverordening Noordzeekanaalgebied 2012 een verbod op het gebruik van spud-palen in het gebied is opgenomen. Er zijn een aantal locatie aangegeven waar het wel toegestaan is om spud-palen te gebruiken of men kan een ontheffing aanvragen. De aangewezen gebieden liggen buiten de locatie van de beoogde kabel tracé’s. Dus alleen wanneer een schip een ontheffing heeft gekregen mag hij/zij spud-palen gebruiken. Dit betekent dat het risico door schade aan de kabel door het gebruik van spud-palen in principe tot een minimum beperkt kan worden.

5.1.7 Resultaten workshop RWS

Op 29 mei 2017 en 19 juni 2017 is een workshop/overleg geweest met onder andere TenneT, RWS, diverse gemeenten, ministerie van Economische zaken, Havenbedrijf Amsterdam en Zeehaven IJmuiden.

Van deze workshops zijn verslagen gemaakt. MARIN, ACRB en Witteveen+Bos zijn niet aanwezig geweest bij de workshops/technische sessie. Maar de verslagen zijn wel gebruikt als achtergrond informatievoor de kwalitatieve analyse.

Enkele conclusies/resultaten:
- Het tracé zoals dat in Figuur 5-1 t/m Figuur 5-4 is weergegeven is het resultaat van de verschillende discussies;
- Voorkeur voor het tracé aan de oeverzijde van het Kanaal i.p.v. in het midden;
- Bij passeren van de veerpont voorkeur om het tracé mee naar het midden te leggen. Het idee is dat het schroefwater van de pont bij het afmeren de bodem kan los woelen.

Algemene conclusie van de deelnemers: er zijn geen duidelijke “show-stoppers” voor de optie om de kabel door het Noordzeekanaal te laten lopen.

5.2 Tweede fase: Kwantitatieve analyse; incident frequenties

In een tweede fase van de studie zijn de incident frequenties bepaald voor ankervallen en stranden in het talud. Hiervoor zijn voor verschillende locaties op het Kanaal de incident frequenties bepaald op basis van de resultaten van de AIS-analyse.

5.2.1 Bepalen incident frequenties

Initieel event
Het initiële event, voor zowel de kans op ankervallen als de kans op “in het talud lopen”, wordt bepaald door de verwachte frequentie van een aanvaring/aandrijving met de kade/wal. Deze frequentie wordt bepaald op basis van het aantal relevante gevaren kilometers in een bepaald segment van het kanaal vermenigvuldigd met een basis ongevals kans (P_{basis}). Deze basis ongevalskans is de kans per gevaren kilometer dat een schip een aanvaring/aandrijving heeft met de kade/wal of afgemeerd schip en is bepaald op basis van een ongevalsanalyse in de Rotterdamse haven. Hierbij is gekeken naar het aantal relevante ongevallen op de Nieuwe Maas (alleen doorgaande vaarweg), vervolgens is dit gerelateerd aan het aantal gevaren kilometers in het stuk. Deze analyse is uitgevoerd in [5], [6] en [7]. Binnen de huidige studie is ervoor gekozen om deze basis kans te gebruiken omdat de situatie vergelijkbaar is met de situatie op het Noordzeekanaal.

Voor de analyse is gekozen voor een segment van de vaarweg van 100m lang.

Kans op vallen anker segment parallel aan de vaarrichting
Om de kans op het vallen van een anker te bepalen is uitgegaan van het aantal initiële events in een bepaald vak (segment) van het kanaal. Hierbij is het aantal passages door een vak vermenigvuldigd met de lengte van het segment (in dit geval 100m) om het totaal aantal relevante gevaren kilometers per jaar te bepalen. Dit aantal vaartuigkilometers is vermenigvuldigd met de basis ongevalskans. Hieruit volgt dus het aantal verwachte incidenten per jaar waarbij een schip in de kade/wal terecht kan komen. De verwachting is dat slechts een heel klein deel van de schepen gebruik zal maken van het anker om een aanvaring/aandrijving van de kade te vermeiden. Hiervoor zijn geen gegevens bekend vanuit de literatuur, maar de aangenomen is dat dit 0.5% van de schepen zal zijn.

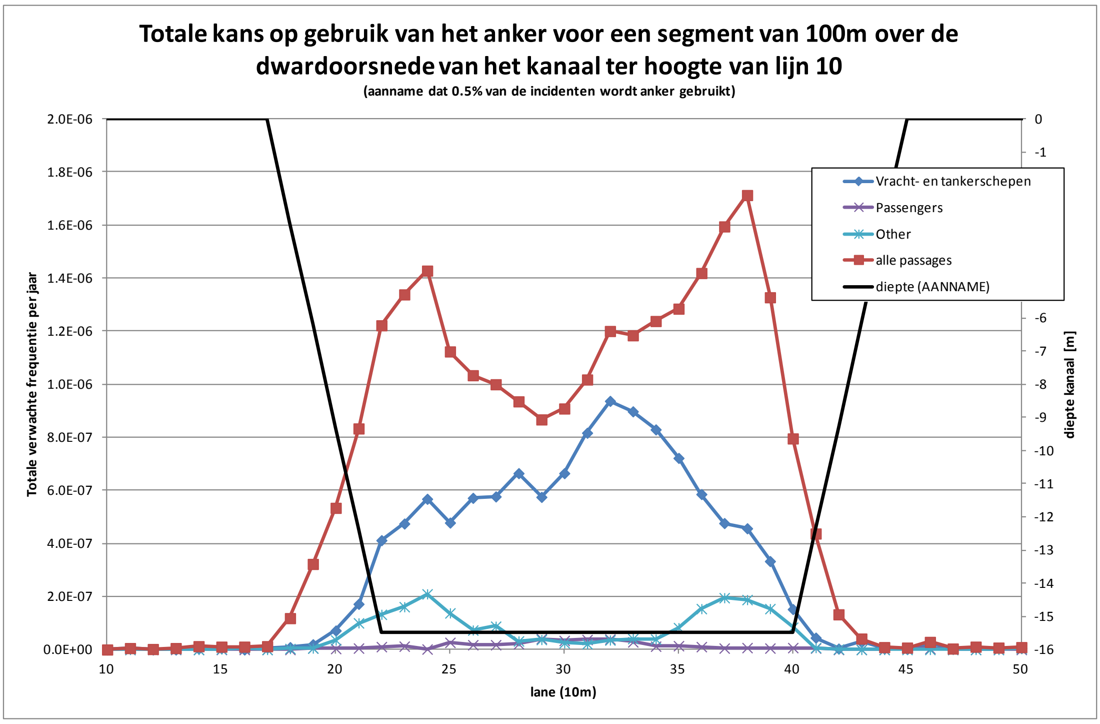
Uiteindelijk is dus bepaald per vak (segment) van 10m x 100m van het verwachte frequenties is dat een schip haar anker zal laten vallen. Deze kansen zijn relevant voor het deel van het tracé waarbij de kabel parallel aan de vaarrichting loopt. Voor een worst-case benadering moet de totale verwachte incident frequenties van alle lanes over de breedte van het kanaal samengenomen worden. Een schip zal niet exact zijn anker laten vallen op de plek waar het gevaren heeft en daarbij zijn schepen breder dan de breedte van de lanes (10m).

Kans op vallen anker segment loodrecht op de vaarrichting
Wanneer de kabel loodrecht op de vaarrichting loopt is de kans op anker vallen bepaald op basis van 0.25 keer de lengte van het schip als maat voor de relevante gevaren kilometers in plaats van de lengte van het segment. Dit is gelijk aan de wijze waarop de kans voor het kruisen van een offshore deel van het tracé bepaald wordt.
Hierbij is het resultaat dus de kans dat een anker gebruikt wordt bij de kruising van een kabel loodrecht aan de vaarrichting.

Kans op aanvaren/aandrijven van het talud
Het bepalen van de verwachte aanvaar/aandrijffrequentie van het talud is vergelijkbaar aan de wijze waarop de kans op ankervallen bepaald is. Voor een segment van 100m is het aantal relevante vaartuigkilometers bepaald. Hierbij is in dit geval echter ook de lengte van de schepen meegenomen. Dit aantal relevante vaartuigkilometers per jaar is wederom vermenigvuldigd met de basis ongevalskans. Hieruit volgt dus het verwachte aantal initiële incidenten per vak van 10m X 100m die kunnen leiden tot het aanvaren/aandrijven van het talud. Het totaal aantal verwachte initiële incidenten per lane zijn uiteindelijk 50/50 verdeeld over de noord en zuid oever.

5.2.2 Resultaten

Kans op gebruik anker
Op basis van de AIS-analyse is voor een aantal lijnen (locaties, zie Figuur 5-5) het aantal passages per richting, scheepstype en lane van 10m bepaald. Dit heeft als basis gediend voor het bepalen van de kans op het gebruik van het anker per lane (vak van 10m x 100m). De resultaten voor lijn 10 zijn weergegeven in deze paragraaf. De overige resultaten zijn weergegeven in de bijlage. In Figuur 5-11 is per lane (x-as) de verwachte frequentie weergegeven per jaar op het gebruik van het anker per lane. Ook is het dwars profiel van het kanaal schematisch weergegeven.



Figuur 5-11 Totale kans op gebruik van het anker per vak van 10m x 100m per jaar ter hoogte van lijn 10.

De locatie waar het anker terecht zou kunnen komen is echter niet gelijk aan die van de passages van de schepen. Daarom is voor een worst case benadering gekeken naar de totale verwachte frequenties per jaar, dus de som van de frequenties weergegeven is in de grafiek weergegeven. Deze frequenties zijn weergegeven in Tabel 5-4 en Tabel 5-5. In Tabel 5-4 staan de resultaten voor het gebruik van het anker in een vak van 10m x 100m voor de situatie dat de kabel parallel aan de vaarrichting loopt. En in Tabel 5-5 zijn de resultaten gegeven voor de situatie dat de kabel het kanaal loodrecht kruist. Hierbij is onderscheidt gemaakt tussen vrachtschepen, tankers, passagiersschepen en tenslotte zijn de kansen bepaald voor alle passages.

Tabel 5-4 Kans op het gebruik van het anker binnen een vak van 100m x breedte van het kanaal per jaar ter hoogte van lijn 10 per lengteklasse.

	Kans op gebruik van het anker binnen een vak van 100m X breedte van het kanaal (per jaar ter hoogte van lijn 10, aanname 0.5%)								eens in de ... jaar
	< 50m	50-100	100-150	150-200	200-250	250-300	>300	totaal	
Cargo	7.42E-07	4.54E-06	3.72E-06	1.82E-06	6.83E-07	1.95E-07	7.17E-09	1.84E-04	5449
Passenger	1.02E-07	2.51E-08	1.61E-08	5.55E-08	8.78E-08	6.09E-08	3.23E-08	3.80E-07	2632685
alle passages	8.79E-06	7.87E-06	5.44E-06	2.14E-06	8.28E-07	2.63E-07	5.20E-08	2.54E-05	39380

Tabel 5-5 Kans op het gebruik van het anker bij de kruising van een kabel loodrechts op de vaarrichting per jaar ter hoogte van lijn 10 per lengte klasse.

	Kans op ankervallen/anker haken bij kruisen van de kabel (per jaar ter hoogte van lijn 10, aanname 0.5%)								eens in de ... jaar
	< 50m	50-100	100-150	150-200	200-250	250-300	>300	totaal	
Cargo	6.16E-08	9.10E-07	1.11E-06	8.24E-07	3.83E-07	1.32E-07	1.79E-09	3.43E-06	291749
Passenger	8.48E-09	5.03E-09	4.83E-09	2.51E-08	4.93E-08	4.13E-08	8.06E-09	1.42E-07	7041423
alle passages	7.30E-07	1.58E-06	1.63E-06	9.69E-07	4.64E-07	1.78E-07	1.30E-08	5.56E-06	179777

Kans op aanvaring/aandrijving talud

In Tabel 5-6 is de verwachte aanvaring/aandrijving van het talud (segment van 100m) weergegeven op basis van de schepen die lijn 10 passeerde. Hierbij is onderscheidt gemaakt in verschillende lengte klassen.

Tabel 5-6 Kans op aanvaring/aandrijving van het talud (segment van 100m) per jaar ter hoogte van lijn 10.

		Kans op aanvaring/aandrijving van het talud (per jaar, lijn 10)								eens in de ... jaar
		< 50m	50-100	100-150	150-200	200-250	250-300	>300	totaal	
Noord talud	Cargo	1.14E-04	8.55E-04	8.27E-04	5.04E-04	2.21E-04	7.18E-05	3.58E-11	2.59E-03	386
	Passenger	1.41E-05	4.84E-06	3.54E-06	1.56E-05	2.85E-05	2.26E-05	1.61E-10	8.91E-05	11218
	alle passages	1.30E-03	1.49E-03	1.22E-03	5.98E-04	2.69E-04	9.70E-05	2.69E-10	4.98E-03	201
Zuid talud	Cargo	8.40E-05	7.67E-04	8.05E-04	5.20E-04	2.21E-04	7.31E-05	3.58E-11	2.47E-03	405
	Passenger	1.31E-05	4.20E-06	3.54E-06	1.56E-05	2.85E-05	2.26E-05	1.61E-10	8.75E-05	11423
	alle passages	1.04E-03	1.33E-03	1.16E-03	6.06E-04	2.68E-04	9.84E-05	2.51E-10	4.50E-03	222

6 CONCLUSIES

Identificeren mogelijke risico's
Op basis van het verkeer en historische ongevallen zijn de volgende risico's voor de kabels door de scheepvaart geïdentificeerd:
- Een schip zinkt op de kabel zonder ander incident (bijvoorbeeld als gevolg van slecht weer);
- Een schip zinkt na een aanvaring en komt daarbij op de kabel terecht;
- Een anker kan neergelaten worden op de kabel;
- Een anker kan neergelaten worden net voordat een schip de kabel kruist waardoor het anker achter de kabel haakt;
- Een net van een vissersschip kan achter de kabel blijven haken;
- Een schip kan aan de grond lopen ter hoogte van de kabel indien deze in ondiep gebied ligt.

De risico's voor de platforms aan het begin van de kabel (op zee) in relatie tot de scheepvaart beperken zich tot de aanvaring of aandrijving van het platform, welke zich onderscheiden door de oorzaak en eventuele consequenties.

Conclusies offshore deel

Op basis van het aantal passages bepaald aan de hand van AIS-data binnen de periode 1 jan 2015 – 31 dec 2016 is de incident frequentie vanuit de scheepvaart bepaald. Het gaat hierbij dus om het initiële event dat mogelijk kan leiden tot schade aan de kabel, vanuit de scheepvaart die boven de locatie van de kabel vaart.

Het aantal passages over tracé 1, 2, 3 is vrijwel gelijk en ligt tussen de 8650 en 9350. Echter de totale incident frequentie voor tracé 3 is hoger dan tracé 1 en tracé 2, dit wordt grotendeels veroorzaakt door de kans op stranden.

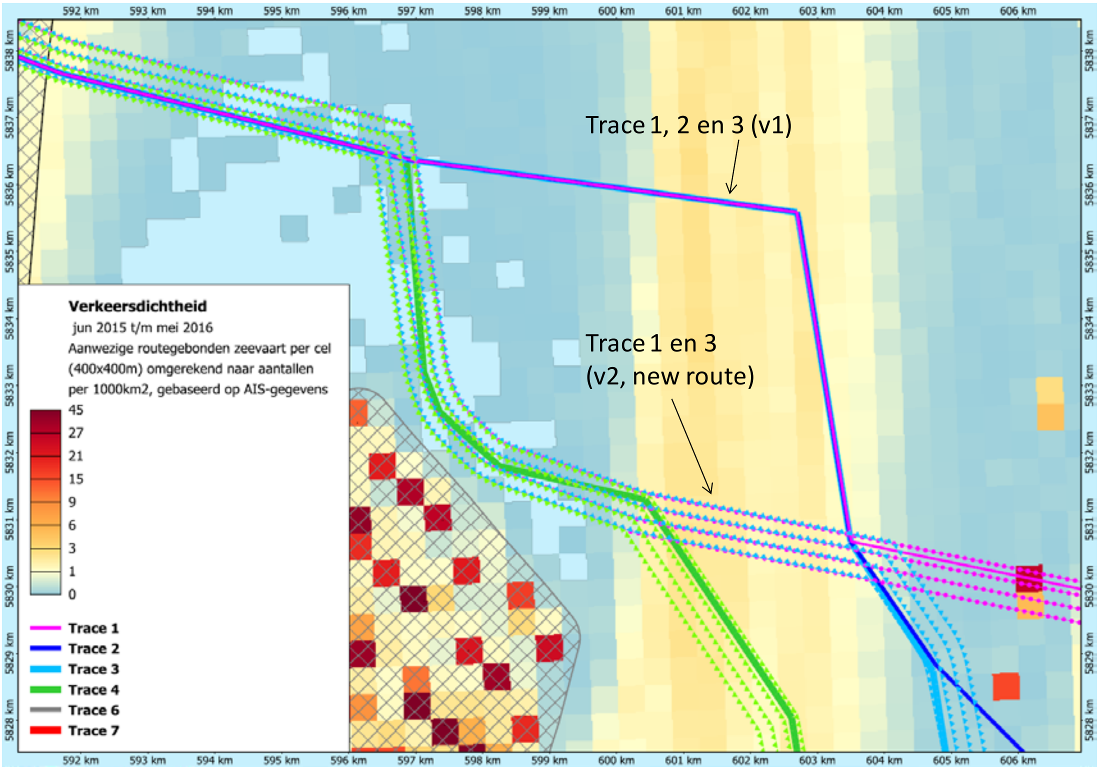
Het aantal passages voor tracé 4 en tracé 5 ligt iets hoger dan voor tracé 1 t.m 3, dit komt doordat de tracé dichterbij de aanloop naar IJmijden liggen.

Tabel 6-1 Overzicht van de verschillende incident frequenties voor de zeven tracéalternatieven, alleen offshore deel (originele routes).

	Totaal aantal passage per jaar (AIS)	Lengte [m]	Zinken (fundering + aanvaring)	Anker incident (haken+ vallen)	Stranden	Container vallen	Totaal	eens in de … jaar
Tracé 1	8737	27252	1.95E-05	1.70E-04	1.06E-04	3.49E-05	3.31E-04	3021
Tracé 2	8647	29051	1.68E-05	1.30E-04	1.33E-04	3.32E-05	3.12E-04	3200
Tracé 3	9348	34830	1.80E-05	1.45E-04	3.92E-04	3.31E-05	5.88E-04	1701
Tracé 4 / Tracé 5	10578	36345	1.82E-05	1.35E-04	5.21E-04	2.54E-05	7.00E-04	1428
Tracé 6	38639	36939	4.95E-05	3.10E-04	2.87E-04	7.22E-05	7.19E-04	1391
Tracé 7	38349	39419	5.61E-05	3.47E-04	2.17E-04	1.15E-04	7.36E-04	1359

Tenslotte is het aantal passages over tracé 6 en 7 het grootst, rond 38500. Dit wordt veroorzaakt door de oversteek van het aanloop gebied naar IJmuiden/Amsterdam. De totale incident frequentie voor deze tracé (6 en 7) is dan ook het grootst.
Ook voor deze tracé's is stranden op de kabel een van de belangrijkste risico's samen met de kans dat een anker haakt achter de kabel.

Aanpassing tracé 1 en 3



Figuur 6-1 Overview of the changes in route for trace 1 and 3.

	Aantal passages per jaar		Verdeling	
	Trace 1 (v2)	Trace 3 (v2)	Trace 1 (v2)	Trace 3 (v2)
# passages per jaar	8759	9370		
lengte[m]	26793	34363		
Zinken	1.64E-05	1.49E-05	5.0%	2.5%
Anker incident	1.06E-04	3.92E-04	32.2%	66.9%
Stranden	1.72E-04	1.46E-04	52.2%	24.9%
Container vallen	3.46E-05	3.28E-05	10.5%	5.6%
totaal	3.29E-04	5.86E-04	100.0%	100.0%
eens in de … jaar	3039	1707		

Conclusies Noordzeekanaal
Kans op raken talud groter dan kans op gebruik van het anker

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BIJLAGE A: DESCRIPTION OF THE PIPELINE RISK MODELS OF SAMSON

MARINE TRAFFIC RELATED THREATS TO A CABLE OR PIPELINE

(The text contains the risk for a pipeline, but the same formulation is valid for a cable. And the text is partly based on the method as it is implemented in SAMSON, these same ideas are transferred to the method using AIS-data)

The marine traffic related risk for a pipeline is assessed in two steps. During the first step the potential threats are quantified in terms of probabilities and scenarios. During the second step the possible consequences are assessed.

In this section the models developed for the first step are described. The following marine traffic related threats to a pipeline are assessed:

a) a ship founders/sinks on the pipeline;
b) a ship founders/sinks on the pipeline after being involved in a collision;
c) a container falls on the pipeline
d) an anchor is dropped on the pipeline;
e) an anchor is dropped by a ship just before passing the pipeline and next the anchor hooks the pipeline before the ship is stopped;
f) a ship strands on the pipeline;
g) a fishing vessel crosses the pipeline while fishing.

The probabilities of these events are assessed based on the pipeline locations and the maritime traffic. To assess the incident frequencies the traffic information from AIS-data and casualty rates of the SAMSON-model are used. The models used are described in more detail. Several threats can be assessed with the same type of model because only the values of the parameters are different. For the above threats a, b, c and d the same model can be used. In all cases an object falls on the pipeline. Only the dimensions of the objects differ and the basic probability on the initial event differs.

In all models it is assumed that the direction of the object when it falls on the pipeline is independent of the sailing direction. For an anchor, a container and a sinking ship after a collision this will be certainly true. For the ship that founders on the pipeline a little dependency may exist between the sailing direction and the final direction of the ship when she strikes the pipeline. However, during the last minutes before the foundering and during the sinking process itself the change in the heading is not predictable. The assumption that all headings have the same probability is not far from the truth; in any case the error made by this assumption will be small.

Model for an object released from a ship that follows a traffic link

Figure 1 shows the situation where an object from the ship or the ship herself falls/sinks on the pipeline (or, with similar formulas to be applied, on a pipeline). If that event occurs in the part of the link depicted as “danger miles”, the object will fall on the pipeline. Thus the event rate is applied to the ships on this part of the link.

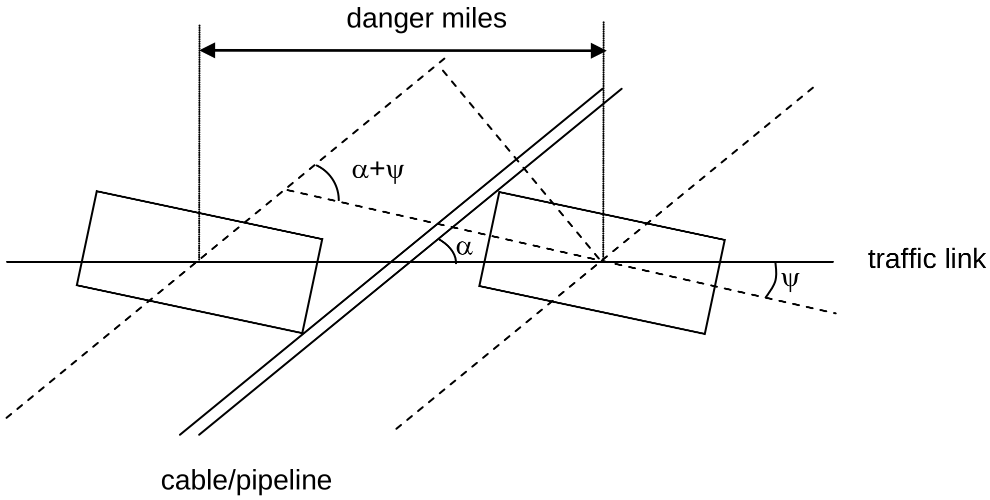

Figure 1 Danger miles on the traffic link for an object, depending on object size and angles

The danger miles for the situation of figure 1 can be represented by:

$$D_{miles} = \left(L_{object} + \frac{B_{object}}{\tan(\alpha+\psi)} + \frac{D_{pipe}}{\sin(\alpha+\psi)} \right) \frac{\sin(\alpha+\psi)}{\sin\alpha} \frac{1}{1852}$$

In which:

D_{miles} Danger miles in nm
L_{object} Length of the object in m
B_{object} Breadth of the object in m
$D_{pipeline}$ diameter of the pipeline in m
α angle between the traffic link and the pipeline
Ψ angle with the traffic link of the falling object

Based on the assumption that all angles ψ are equal likely, the above expression can be integrated over a uniformly distributed ψ. This results in:

$$D_{miles} = \frac{4}{2\pi} \int_{-\alpha}^{-\alpha+\pi/2} \left(L_{object} \sin(\alpha+\psi) + B_{object} \cos(\alpha+\psi) + D_{pipe} \right) \frac{1}{\sin\alpha} \frac{1}{1852} d\psi$$

or

$$D_{miles} = \left(\frac{2}{\pi}(L_{object} + B_{object}) + D_{pipe} \right) \frac{1}{\sin\alpha} \frac{1}{1852}$$

The previous formula contains the danger miles for one ship sailing over a link that crosses the pipeline. The total threat to the pipeline per year from several ships of type i and size j follows from:

$$Cable\,contacts = \sum_k \sum_i \sum_j n_{ijk}\ D_{miles}(i,j,k)\ FR(i,j)$$

Herein is:

i	the type of the ship
j	the size of the ship
k	the link that crosses the pipeline
n_{ijk}	the number of passages per year of ship type i and size j over link k
FR(i,j)	the event rate per nautical mile

For the calculation of the risk of containers falling from ships of various types and sizes, the factor D_{miles} in the previous formula will depend on the angle between the link and the pipeline, while FR(i;j) will be zero for ships without containers.

When using AIS-data to calculate the incident frequency of an object dropping on the pipeline or pipeline, the actual size of the ship, sailing direction and the crossing location are used in the calculation.

Model for hooking a pipeline or pipeline

If a ship is in trouble due to malfunction of the main engine or steering engine she can drop the anchor to prevent the ship from drifting away. The anchor is dropped with such a ship speed (1 to 1.5 knots) that the anchors chain will not break. During the time that the anchor is decelerating the ship by providing a dragging force to the ship, the anchor may hook a pipeline. It is assumed that for patent anchors the dragging distance of the anchor is one quarter of the length of the ship, which corresponds with a speed of 1-1.5 knots at the moment the anchor is dropped. This means that the threat in danger miles for hooking the pipeline follows from the number of crossings of the pipeline times 0.25 L_{ship} for a pipeline on the seabed.

The number of passages is based on the AIS-data.

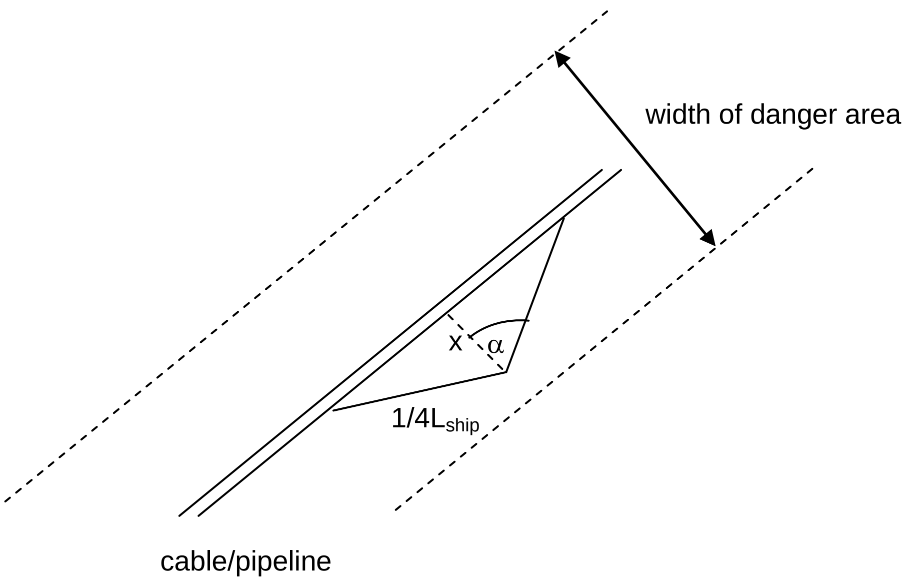

Figure 3 Danger area for hooking the pipeline

The calculation starts with assessing the number of anchoring where the anchor first hits the ground in a "danger area" that stretches $1/4L_{ship}$ on both sides of the pipeline. This $1/4L_{ship}$ is applied on 70% of the ships. For 30% of the ships 2/3 of this length (= 1/6 L_{ship}) is used for the new anchor types with higher holding craft. However, in contrary with the model where an object sinks on the pipeline, not all ships in this danger area really threat the pipeline. Only the ships with a course within a certain course sector will threat the pipeline, particularly if the anchoring manoeuvre starts at the outer parts of the danger area. Ships with other courses can anchor within the danger area without hooking the pipeline. The range of courses, for which the line of the pipeline is reached during the anchoring manoeuvre, depends on the distance x to the pipeline. Based on the uniform distribution of all courses, the reduction factor for the threat on distance x of the pipeline is $2\alpha/2\pi$, thus the threat to the pipeline is:

$$threat\_hooking(x) = d(x)\frac{\alpha(x)}{\pi} = d(x)\frac{\arccos\dfrac{x}{0.25L_{ship}}}{\pi}$$

in which

d(x) density on distance x from the pipeline, which is assumed to be constant in the neighbourhood of the pipeline

α(x) the maximum angle for which the pipeline can be reached during anchoring from a position at a distance of x from the pipeline (see figure 3)

$$threat\_hooking = d\int_0^{0.25L_{ship}} \frac{\arccos\dfrac{x}{0.25L_{ship}}}{\pi}dx$$

or

$$threat\_hooking = d\,\frac{0.25L_{ship}}{\pi}\left[\frac{x}{0.25L_{ship}}\arccos\frac{x}{0.25L_{ship}} - \sqrt{1-\left(\frac{x}{0.25L_{ship}}\right)^2}\,\right]_0^{0,25L_{ship}} = \frac{0.25L_{ship}}{\pi}d$$

Based on this result the total number of hooking per year can be expressed by:

$$Cable\,hookings = \sum_k\sum_i\sum_j d_{ijk}\,\frac{2}{\pi}\,\frac{0.25L_{ship}(i,j)}{1852}\,L_{pipe}(k)\;FR(i,j)\;8760\,v_{harm}(i,j)$$

Herein is:

i the type of the ship

j the size of the ship

k the grid cells through which the pipeline runs

$L_{pipeline}$ the length of pipeline (in nm) in grid cell k

d_{ijk} the density of ships(ships per nm^2) of type i and size j in grid cell k

v_{harm}(i,j)the harmonic mean of the velocity of ship type i size j (knots)

FR(i,j) the event rate per nautical mile for ship type i size j

Ship characteristics and event rates

The threats to the pipelines can be assessed with the models from 3.2. In table 1 a survey is given of the values of the parameters.

Threat to pipeline	L_{object}	B_{object}	Event rate	Required for consequence assessment
a ship founders on the pipeline	L_{ship}	B_{ship}	foundering rate (SAMSON)	displacement of ship
a ship sinks on the pipeline after being involved in a collision	L_{ship}	B_{ship}	calculated with collision models and consequence models of SAMSON	displacement of ship
a container falls on pipeline	20 feet	8 feet	reference [1]	weight container
deck cargo falls overboard on pipeline	$0.025{*}L_{ship}$	$0.025{*}B_{ship}$	reference [2]	weight deck cargo
an anchor dropped by a ship above the pipeline	L_{anchor}	B_{anchor}	anchor frequency	weight of anchor
an anchor dropped by a ship just before passing the pipeline and next hooks the pipeline before the ship is stopped	$0.25\ L_{ship}$ (70%) $0.17\ L_{ship}$ (30%)	0	anchor frequency	kinetic energy in ship and depth of anchor in bottom
a ship strands on the pipeline	L_{ship}	B_{ship}	stranding model of SAMSON	displacement of ship

Table 1 Survey of the most important variables for the risk assessment for pipelines

Table 1 also contains a column with the sources of the event rates. Several of the required event rates are available in SAMSON. Others are estimated.

REFERENCES OF APPENDIX A

[1] W.H.G. Klomp
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Waterloopkundig Laboratorium, November 1995.

[2] C.C. Glansdorp, C. van der Tak
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Inshore alternatives in EMS and Jade
Marine Analytics BV, September 1991.
Report prepared for STATOIL

[3] C. van der Tak, C.C. Glansdorp
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[4] S. Hassing, F.L.A. Bloot
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Rijswijk, Januari 1995

BIJLAGE B: AANWIJZINGSBESLUIT LOCATIES GEBRUIK SPUDPALEN IN HET HAVENGEBIED VAN AMSTERDAM

Gemeente Amsterdam
GEMEENTEBLAD
Officiële uitgave van de gemeente Amsterdam
Nr. 142024
14 augustus 2017

Aanwijzingsbesluit locaties gebruik spudpalen in het Havengebied van Amsterdam en aangrenzende hoofdvaarwegen en vereisten ontheffing spudpalenverbod.

LET OP: Rectificatie van eerdere publicatie: Gemeenteblad 2017, 134177 (https://zoek.officielebekendmakingen.nl/gmb-2017-134177.html?zoekcriteria=%3fzkt%3dUitgebreid%26pst%3dGemeenteblad%26dpr%3dAlle%26spd%3d20170810%26epd%3d20170810%26jgp%3d2017%26nrp%3d134177%26sdt%3dDatumPublicatie%26planId%3d%26pnr%3d1%26rpp%3d10&resultIndex=0&sorttype=1&sortorder=4)

De havenmeester van Amsterdam
Brengt ter algemene kennis dat zij op 1 augustus 2017 het volgende besluit heeft genomen in het kader van de Regionale Havenverordening Noordzeekanaalgebied 2012:
Aanwijzingsbesluit locaties gebruik spudpalen in het Havengebied van Amsterdam en aangrenzende hoofdvaarwegen en vereisten ontheffing spudpalenverbod.
Besluit:

Burgemeester en wethouders

van de Gemeente Amsterdam

namens deze

de havenmeester,
M.F. van de Kerkhof
Besluit nr 35 /201 7 /RHN
Amsterdam, 1 augustus 2017
Besluit locaties gebruik spudpalen in het Havengebied van Amsterdam en aangrenzende hoofdvaarwegen en vereisten ontheffing spudpalen verbod.
Overwegende dat:

- de binnenvaart steeds vaker uitgerust is met spudpalen;
- deze spudpalen kunnen worden gebruikt om op de bodem van de vaarweg af te meren;
- het gebruik van spudpalen schade tot gevolg kan hebben voor de waterbodem en zich daarin bevindende objecten (infrastructurele voorzieningen, leidingen, beschermingsmatten e.d.);
- artikel 4.12 van de Regionale Havenverordening Noordzeekanaalgebied 2012 een verbod bevat om spudpalen te gebruiken, tenzij het geschiedt op door het bevoegd gezag aangewezen locaties;
- het gebruik van spudpalen op bepaalde locaties in het havengebied geen bezwaren oplevert, omdat het geen schade op kan leveren in verband met de aanwezigheid van objecten in de bodem;
- op aangewezen locaties geen ontheffing vereist is voor het gebruik van spudpalen, en de ontheffing op andere locaties nog steeds vereist en mogelijk is;
- in het besluit tevens voorwaarden zijn opgenomen waar een ontheffingsaanvraag voor het spudpalen verbod aan moet voldoen.

Gelet op:
•Artikel 4.12 van de Regionale Haven Verordening (RHN)
Besluit vast te stellen:
Besluit gebruik spudpalen,inhoudende de aanwijzing van locaties om af te meren op spudpalen in de havens van Amsterdam en de aangrenzende vaarwegen, het Noordzeekanaal en het Afgesloten IJ alsmede de voorwaarden waaraan een ontheffingsaanvraag (artikel 4.12, tweede lid, Regionale Havenverordening Noordzeekanaalgebied 2012) moet voldoen en onder welke voorwaarden een ontheffing mogelijk is.

Artikel 1: Intrekking Verkeersbesluit Besluit nr.048/2014/RHN
Het verkeersbesluit 048/2014/RHN wordt met ingang van de dag na de dag van publicatie van dit besluit ingetrokken.

Artikel 2: Gebruik spudpalen
Het is toegestaan zonder toestemming gebruik te maken van spudpalen op de volgende locaties:
a) Het Slik;

Gemeente
Amsterdam

b) Houthaven wachtsteigers noordzijde;
c) Minervahaven wachtsteigers noordzijde;
d) Mercuriushaven wachtsteiger worteleinde;
e) Sonthaven steigers worteleinde;
f) Suezhaven palen zuidzijde;
g) Cacaohaven zuidzijde korte kades;
h) Zanzibarhaven wachtpalen zuidzijde.

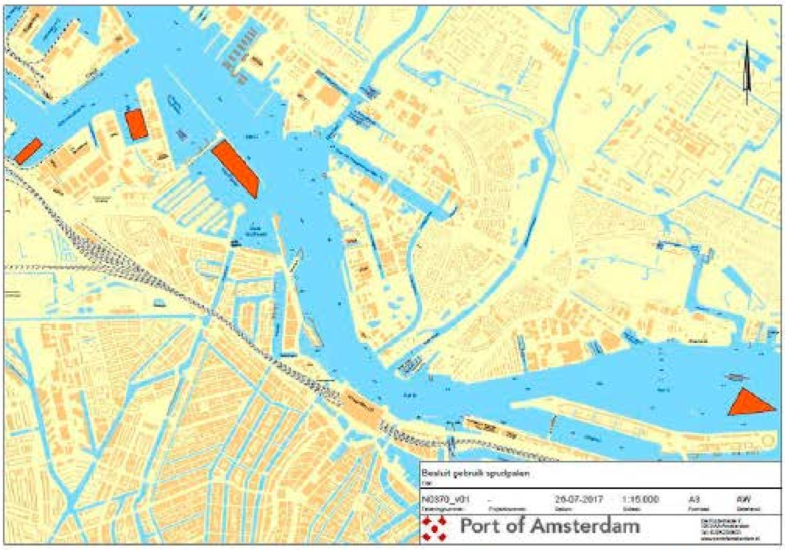
Artikel 3: Voorwaarden gebruik
Aan het gebruik van de spudpalen zijn de volgende voorwaarden verbonden:
1. Afmeren langszij eventueel andere afgemeerde schepen dient direct langszij deze schepen plaats te vinden.
2. Indien een schip op een binnenvaartlocatie op spudpalen ligt afgemeerd, moet de afloop naar de wal voor de overige scheepvaart veilig zijn.

Artikel 4: Aanvraag ontheffing
1. Voor locaties die niet zijn genoemd in artikel 2, is het gebruik van spudpalen uitsluitend toegestaan indien het bevoegd gezag daarvoor conform het bepaalde in artikel 4.12, tweede lid, van de Regionale Havenverordening Noordzeekanaalgebied 2012 een ontheffing heeft verleend.
2. Bij het verzoek om ontheffing dient de aanvrager de locatie aan te geven waar hij wil afmeren, de termijn van het afmeren ter plaatse te vermelden alsmede een clickmelding toe te voegen van de desbetreffende locatie.
3. Aan het geven van ontheffing kan het bevoegd gezag voorschriften en beperkingen verbinden.
4. Deze ontheffing geldt tevens voor vaartuigen ten behoeve van (ver)bouw- en baggerwerkwerkzaamheden binnen de oliehavengebieden.

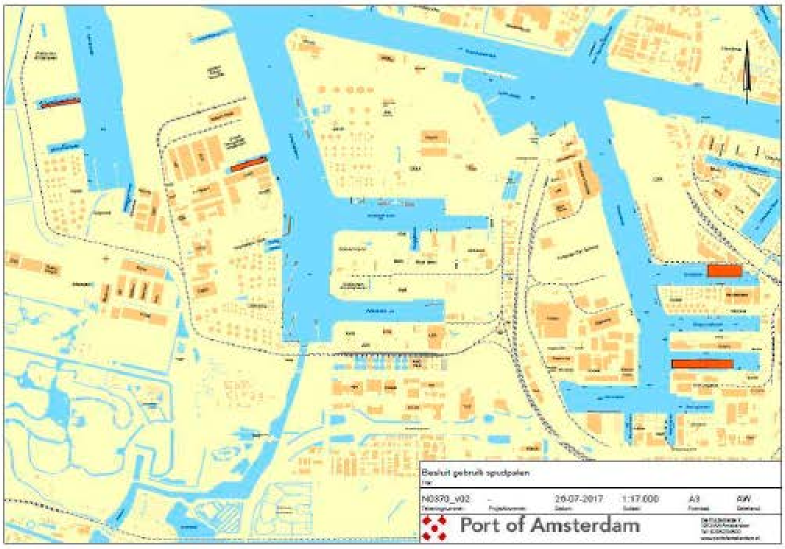
Artikel 5: Toepasselijkheid Regionale Havenverordening/Havenreglement Noordzeekanaalgebied 2012:
Alle overige bepalingen uit de Regionale Havenverordening Noordzeekanaalgebied 2012, Havenreglement Noordzeekanaalgebied 2012 en overige wetgeving blijven van kracht.

Artikel 6: Bijlagen
De bij dit besluit behorende drie bijlagen zijnde overzichtskaarten waarop gebieden zijn aangegeven waar men zonder toestemming gebruik mag maken van spudpalen, maakt onderdeel uit van het besluit.
Artikel: 6 Inwerkingtreding/werking
Dit besluit treedt in werking de dag na plaatsing in het Gemeenteblad.
Datum: 1 augustus 2017
Namens Het college van Burgemeester en Wethouders van Amsterdam
De Havenmeester van Amsterdam,
M.F. van de Kerkhof
In gevolge de Algemene Wet Bestuursrecht kan een belanghebbende binnen zes weken na bekendmaking bezwaar maken tegen dit besluit door het indienen van een bezwaarschrift. Het bezwaarschrift dient te worden gericht aan Burgemeester en Wethouders van Amsterdam, Postbus 202, 1011 PN Amsterdam. Het bezwaarschrift dient te worden ondertekend en bevat ten minste de naam en het adres van de indiener, de dagtekening, een omschrijving van het besluit waartegen het bezwaar is gericht, alsmede de gronden van het bezwaar. Indien u er voor kiest om u te laten vertegenwoordigen, verzoeken wij u om een machtiging te (laten) overleggen.
Het indienen van een bezwaar heeft geen schorsende werking. Indien onverwijlde spoed dit vereist kan, hangende de bezwaarschriftenprocedure, een schorsing of voorlopige voorziening worden gevraagd van de Voorzieningenrechter van de Rechtbank Amsterdam, Sector Bestuursrecht Algemeen, Parnassusweg 226, Postbus 75850, 1070 AW Amsterdam. Hieraan zijn griffiekosten verbonden.
Bijlagen: 3 tekeningen
Tekening 1: Bijlage bij het Besluit nr 35/2017/RHN waar het gebruik van spudpalen zonder ontheffing is toegestaan in het Havengebied van Amsterdam en aangrenzende hoofdvaarwegen

Gemeente
Amsterdam

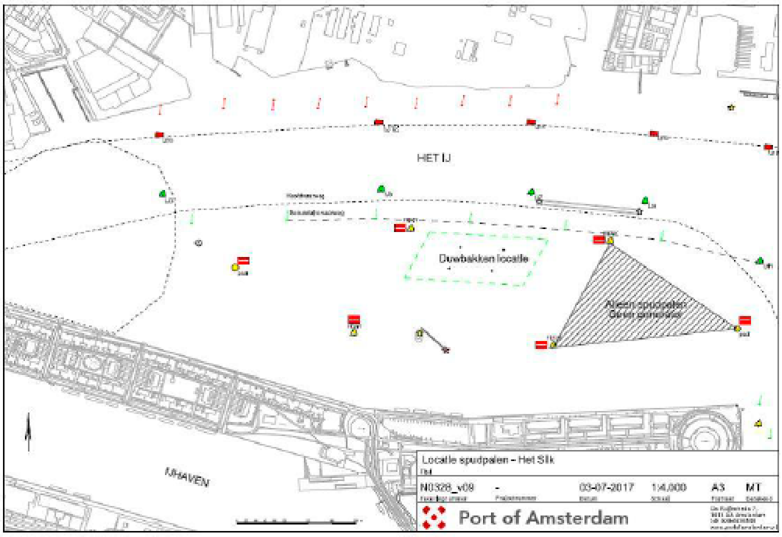


Tekening 2: Bijlage bij het Besluit nr 35/2017/RHN waar het gebruik van spudpalen zonder ontheffing is toegestaan in het Havengebied van Amsterdam en aangrenzende hoofdvaarwegen



Tekening 3: Bijlage in het besluit nr.35/2017/RHN waar het gebruik van spudpalen zonder ontheffing is toegestaan in het Havengebied van Amsterdam. Verduidelijking locatie Het Slik

Gemeente Amsterdam



Toelichting

De laatste jaren komt het steeds meer voor dat schepen zijn uitgerust met spudpalen. Het gebruik daarvan kan schade tot gevolg hebben voor de waterbodem en zich daarin bevindende objecten. Men moet dan denken aan onder andere infrastructurele voorzieningen zoals tunnels, leidingen, kabels en beschermingsmatten.
Op 27 mei 2014 is het Besluit gebruik spudpalen in het Amsterdamse havengebied (Besluit nr.048/2014/RHN vastgesteld. Dit Besluit vervangt het Besluit van 27 mei 2014 om twee redenen.
In het oude besluit nr. 048/2014/RHN was de IJ-haven, kade zuidzijde oostelijk van de Jan Schaeferbrug opgenomen. Deze locatie staat ook bekend onder de naam Veemkade.
Na onderzoek is gebleken dat de oude kadewand en ondergrond op die locatie niet bestand zijn tegen het in de bodem drijven van spudpalen. Bovendien liggen in de nabijheid leidingen en kabels waardoor de kans aanwezig is dat spudpalen deze kunnen beschadigen.
In het oude besluit nr.48/2014/RHN is ook Het Slik aangewezen als locatie waar het is toegestaan om zonder toestemming gebruik te maken van spudpalen.
Met de bewoners van de Sumatrakade Surinamekade is afgesproken dat er vanaf 1 augustus 2017 het gebruik van de ankerplaats is komen te vervallen.
Er komt een nauwkeuriger aangegeven locatie in Tekening 3 dan in het oude besluit in Tekening 2 was opgenomen om onduidelijkheid voor de gebruikers weg te nemen.

BIJLAGE C: RESULTATEN KWANTITATIEVE ANALYSE NOORDZEEKANAAL

		Kans op aanvaring/aandrijving van het talud (per jaar, lijn 10)								
	Lijn	< 50m	50-100	100-150	150-200	200-250	250-300	>300	totaal	eens in de ... jaar
Noord talud	lijn 4	1.98E-03	1.64E-03	1.10E-03	6.16E-04	2.53E-04	9.90E-05	4.48E-10	5.69E-03	176
	lijn 5	1.49E-03	1.42E-03	1.06E-03	5.57E-04	2.58E-04	9.37E-05	4.21E-10	4.88E-03	205
	lijn 8	1.54E-03	1.50E-03	1.17E-03	6.30E-04	2.66E-04	9.84E-05	2.60E-10	5.21E-03	192
	lijn 9	1.58E-03	1.49E-03	1.16E-03	5.95E-04	2.67E-04	9.77E-05	2.78E-10	5.19E-03	193
	lijn 10	1.30E-03	1.49E-03	1.22E-03	5.98E-04	2.69E-04	9.70E-05	2.69E-10	4.98E-03	201
	lijn 11	1.20E-03	1.39E-03	1.17E-03	5.99E-04	2.76E-04	9.90E-05	2.60E-10	4.74E-03	211
Zuid talud	lijn 4	1.82E-03	1.46E-03	1.02E-03	6.10E-04	2.53E-04	9.90E-05	4.48E-10	5.26E-03	190
	lijn 5	1.44E-03	1.33E-03	9.63E-04	5.45E-04	2.32E-04	9.24E-05	4.21E-10	4.61E-03	217
	lijn 8	1.31E-03	1.42E-03	1.14E-03	6.02E-04	2.66E-04	9.70E-05	2.42E-10	4.84E-03	207
	lijn 9	1.55E-03	1.43E-03	1.13E-03	5.93E-04	2.68E-04	9.77E-05	2.42E-10	5.08E-03	197
	lijn 10	1.04E-03	1.33E-03	1.16E-03	6.06E-04	2.68E-04	9.84E-05	2.51E-10	4.50E-03	222
	lijn 11	1.34E-03	1.51E-03	1.20E-03	6.03E-04	2.69E-04	9.90E-05	2.78E-10	5.03E-03	199

	Kans op gebruik van het anker binnen een vak van 100m X breedte van het kanaal (per jaar, aanname 0.5%)								
Lijn	< 50m	50-100	100-150	150-200	200-250	250-300	>300	totaal	eens in de ... jaar
lijn 4	1.42E-05	8.60E-06	4.83E-06	2.18E-06	7.81E-07	2.67E-07	8.96E-08	3.10E-05	32256
lijn 5	1.10E-05	7.63E-06	4.61E-06	1.96E-06	7.56E-07	2.51E-07	8.42E-08	2.63E-05	38027
lijn 8	1.07E-05	8.12E-06	5.27E-06	2.19E-06	8.21E-07	2.63E-07	5.02E-08	2.74E-05	36481
lijn 9	1.18E-05	8.12E-06	5.21E-06	2.11E-06	8.24E-07	2.63E-07	5.20E-08	2.84E-05	35264
lijn 10	8.79E-06	7.87E-06	5.44E-06	2.14E-06	8.28E-07	2.63E-07	5.20E-08	2.54E-05	39380
lijn 11	9.55E-06	8.07E-06	5.39E-06	2.14E-06	8.40E-07	2.67E-07	5.38E-08	2.63E-05	38012

	Kans op ankervallen/anker haken bij kruisen van de kabel (per jaar, aanname 0.5%)								
Lijn	< 50m	50-100	100-150	150-200	200-250	250-300	>300	totaal	eens in de ... jaar
lijn 4	1.18E-06	1.73E-06	1.45E-06	9.87E-07	4.38E-07	1.81E-07	2.24E-08	5.98E-06	167168
lijn 5	9.13E-07	1.53E-06	1.38E-06	8.86E-07	4.24E-07	1.70E-07	2.11E-08	5.33E-06	187785
lijn 8	8.88E-07	1.63E-06	1.58E-06	9.92E-07	4.60E-07	1.78E-07	1.25E-08	5.74E-06	174329
lijn 9	9.77E-07	1.63E-06	1.56E-06	9.55E-07	4.62E-07	1.78E-07	1.30E-08	5.77E-06	173177
lijn 10	7.30E-07	1.58E-06	1.63E-06	9.69E-07	4.64E-07	1.78E-07	1.30E-08	5.56E-06	179777
lijn 11	7.92E-07	1.62E-06	1.61E-06	9.67E-07	4.71E-07	1.81E-07	1.34E-08	5.66E-06	176757

Annex 2 Figures Other Route Alternatives

This Annex

This annex shows the Figures for all investigated Hollandse Kust (noord) route alternatives and referred to in Chapter 5, 6 and 7. These Figures include the updated routes 1 and 2.

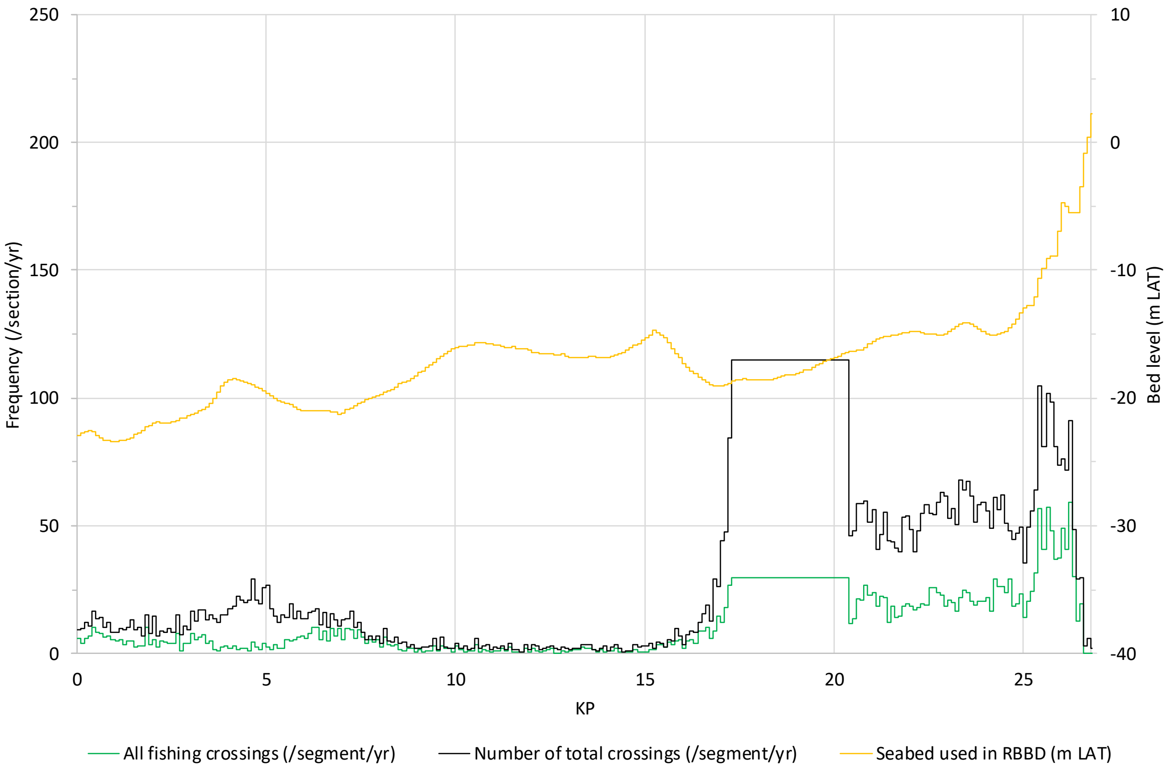


Figure A2.1 *Frequency of all the ships (black line) and fishing ships (green line) that cross* ***Hollandse Kust (noord) route alternative 1*** *(/section/yr) as function of the cable route (KP). The numbers are based on two year of AIS data* ***(from 1 August 2013 to 1 August 2015)*** *for each segment of ~100 m.*

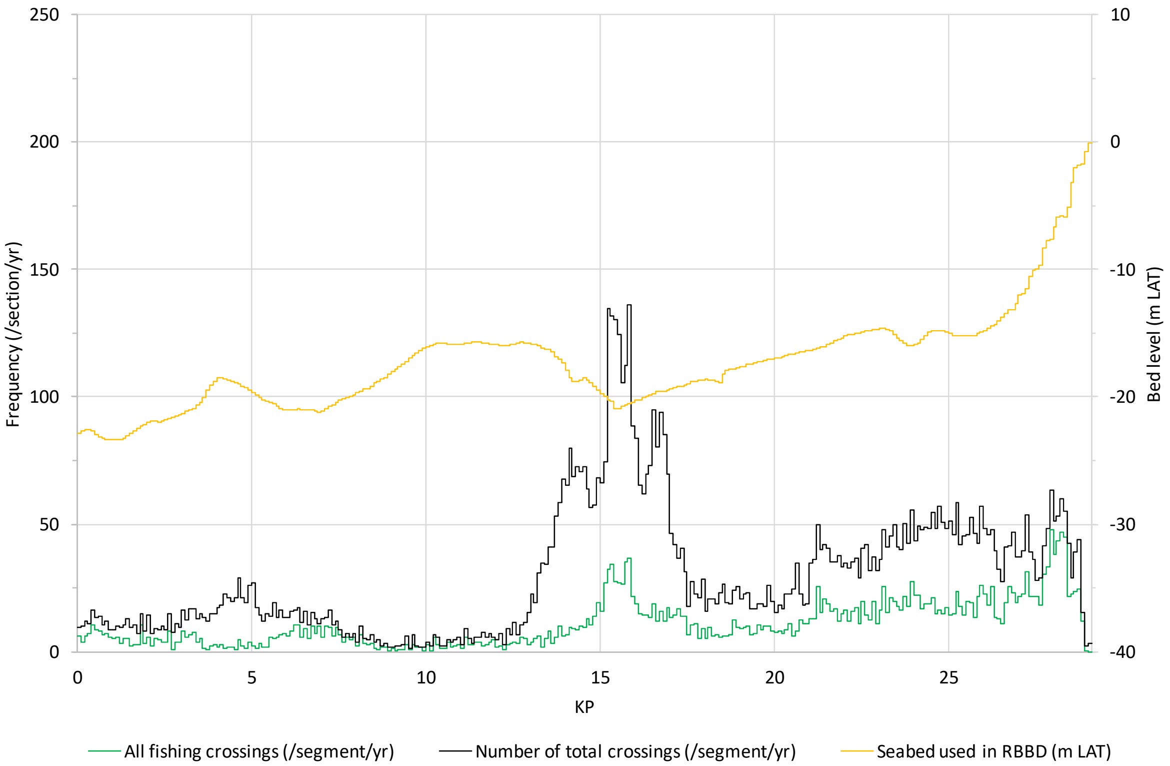


Figure A2.2 *Frequency of all the ships (black line) and fishing ships (green line) that cross* ***Hollandse Kust (noord) route alternative 2*** *(/section/yr) as function of the cable route (KP).*

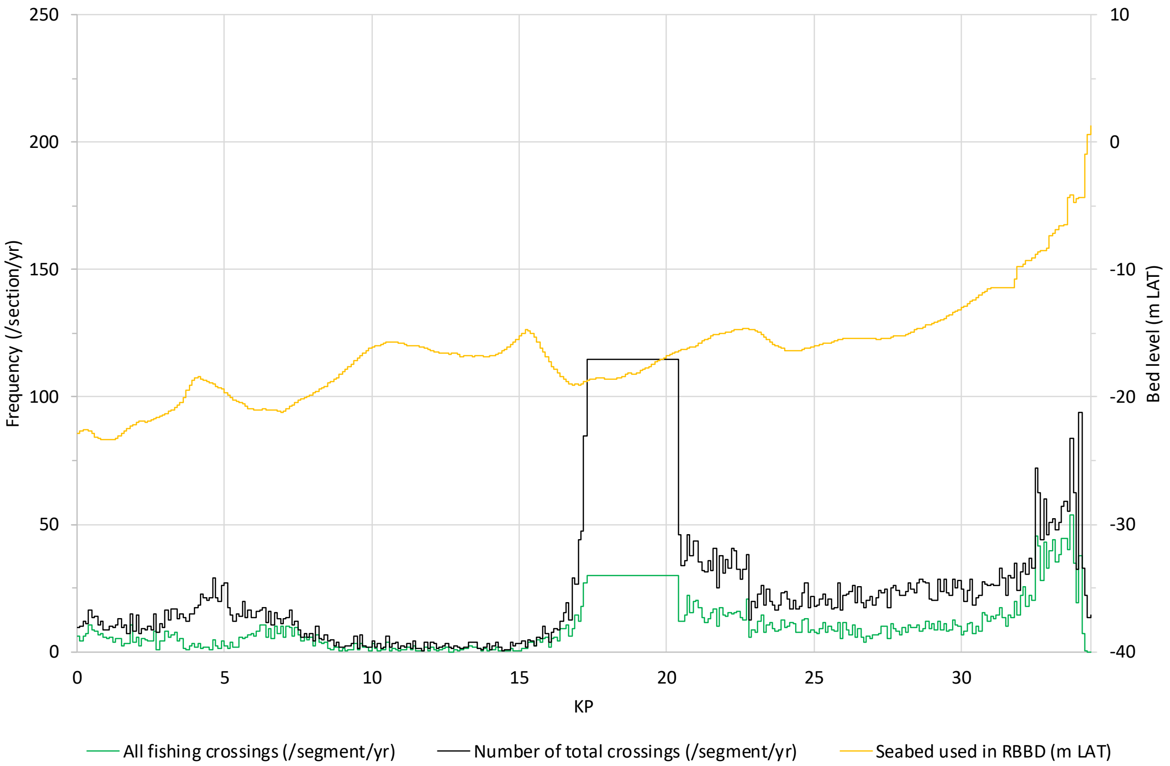


Figure A2.3 *Frequency of all the ships (black line) and fishing ships (green line) that cross* ***Hollandse Kust (noord) route alternative 3*** *(/section/yr) as function of the cable route (KP).*

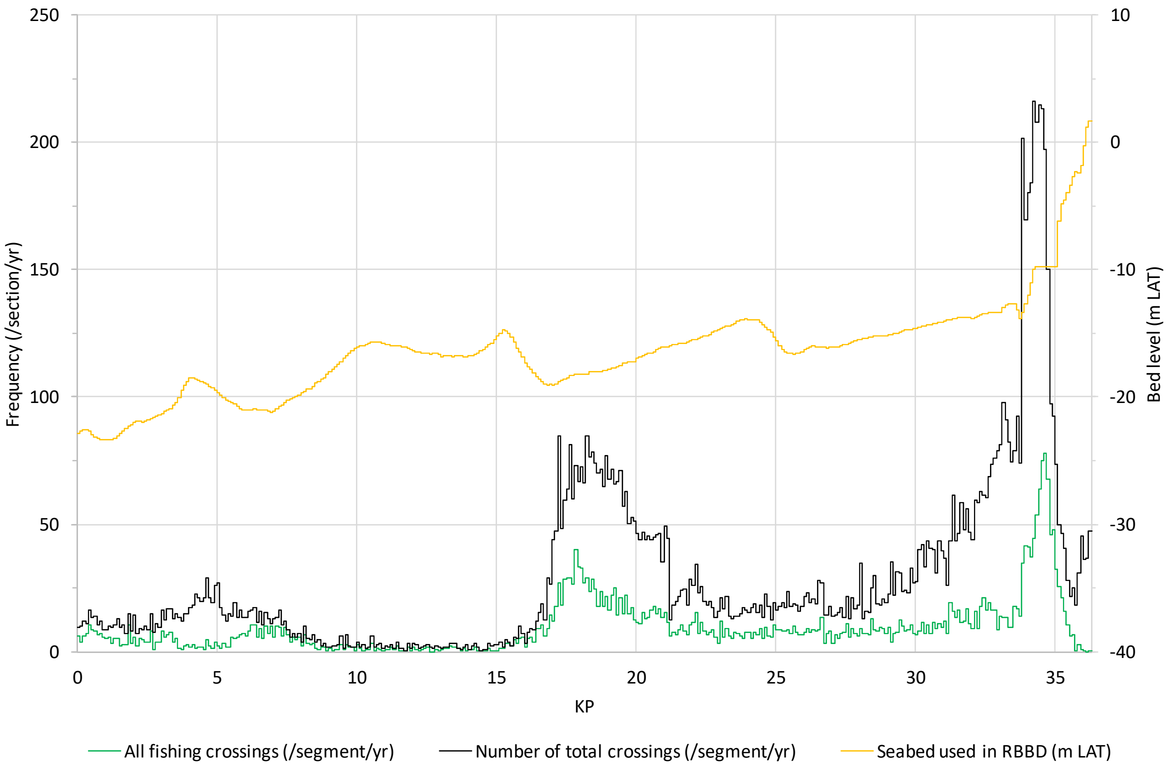


Figure A2.4 *Frequency of all the ships (black line) and fishing ships (green line) that cross* ***Hollandse Kust (noord) route alternative 4 en 5*** *(/section/yr) as function of the cable route (KP).*

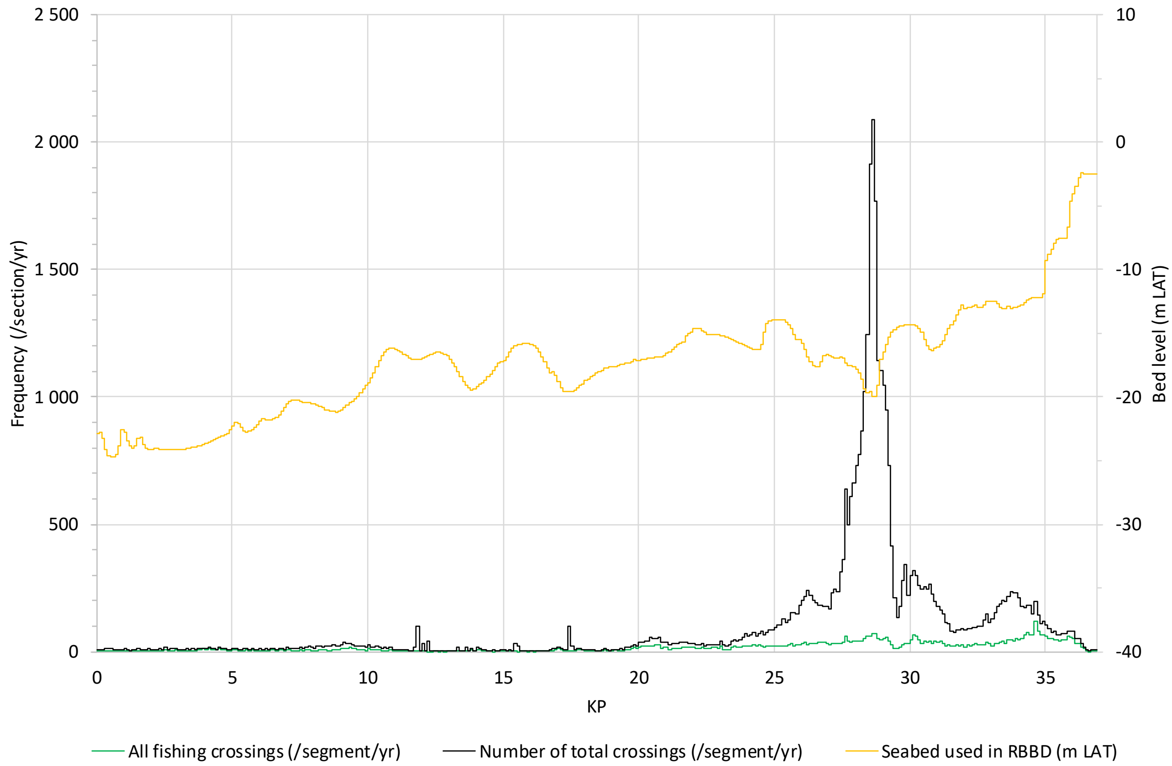


Figure A2.5 *Frequency of all the ships (black line) and fishing ships (green line) that cross **Hollandse Kust (noord) route alternative 6** (/section/yr) as function of the cable route (KP).* Note: The scale of the y-axis is a factor 10 larger compared to routes 1-5.

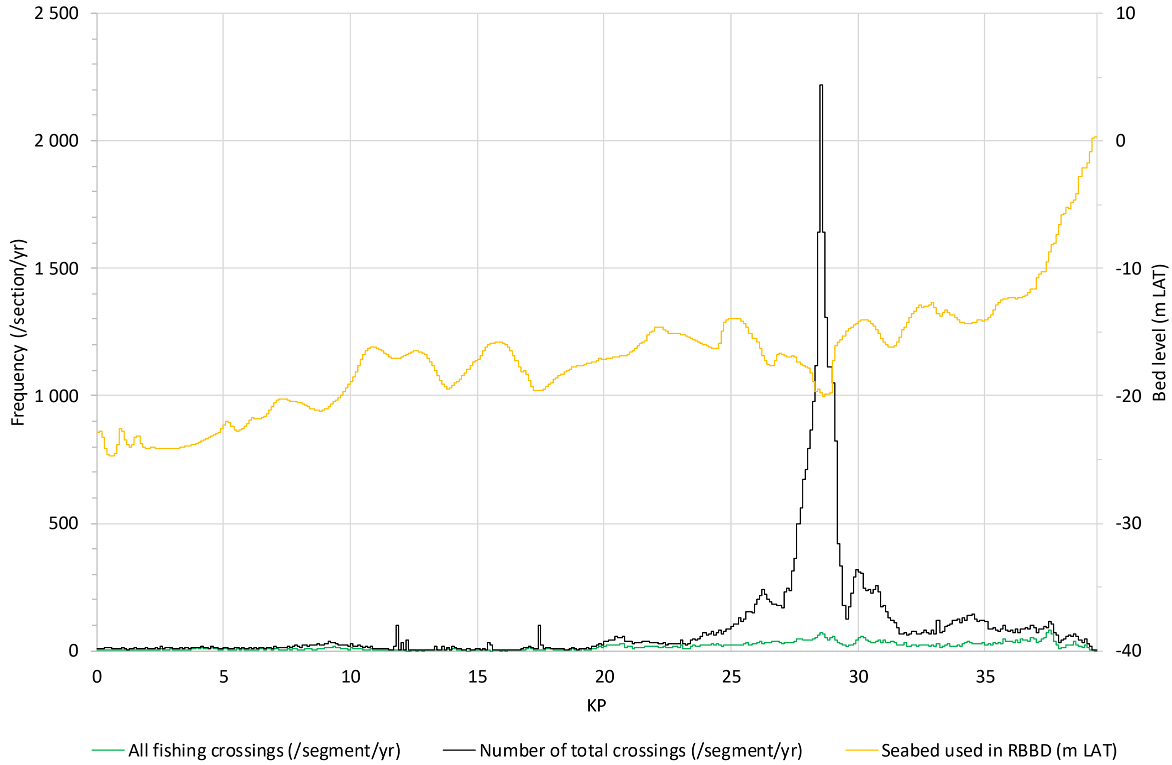


Figure A2.6 *Frequency of all the ships (black line) and fishing ships (green line) that cross **Hollandse Kust (noord) route alternative 7**(/section/yr) as function of the cable route (KP). Note: The scale of the y-axis is a factor 10 larger compared to routes 1-5.*

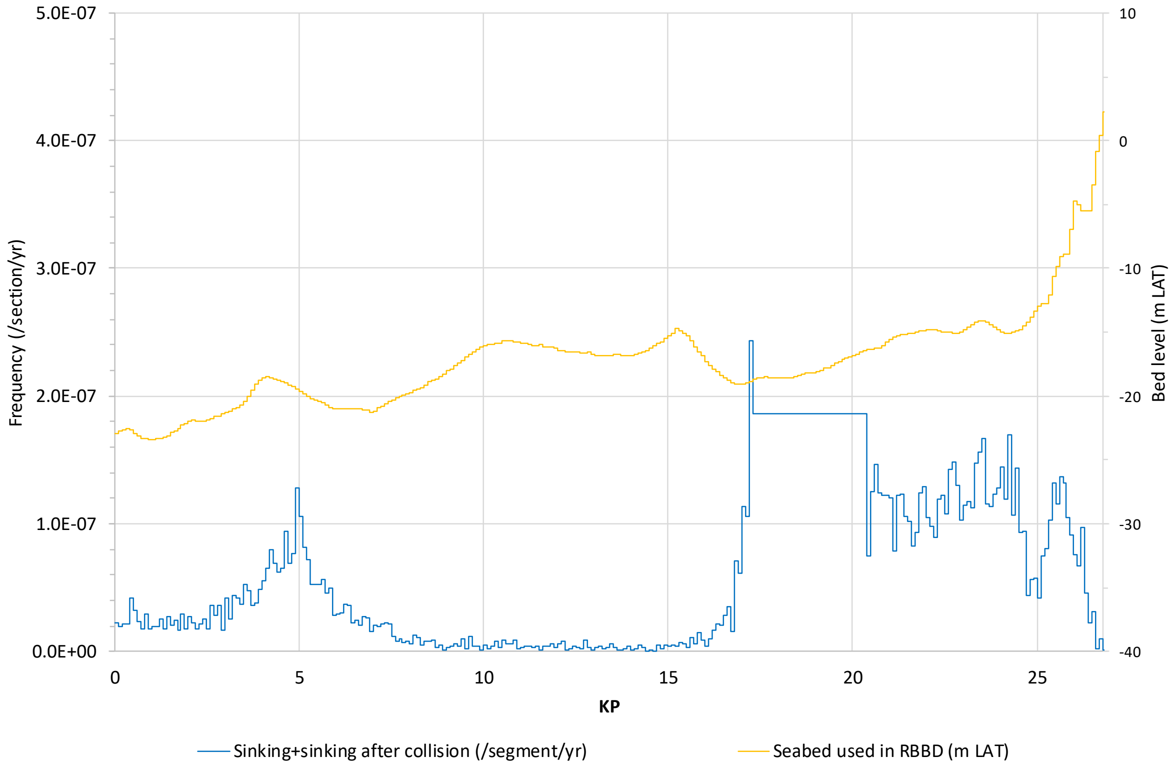


Figure A2.7 *Frequency that critical ship sinking occurs on **Hollandse Kust (noord) route alternative 1**.*

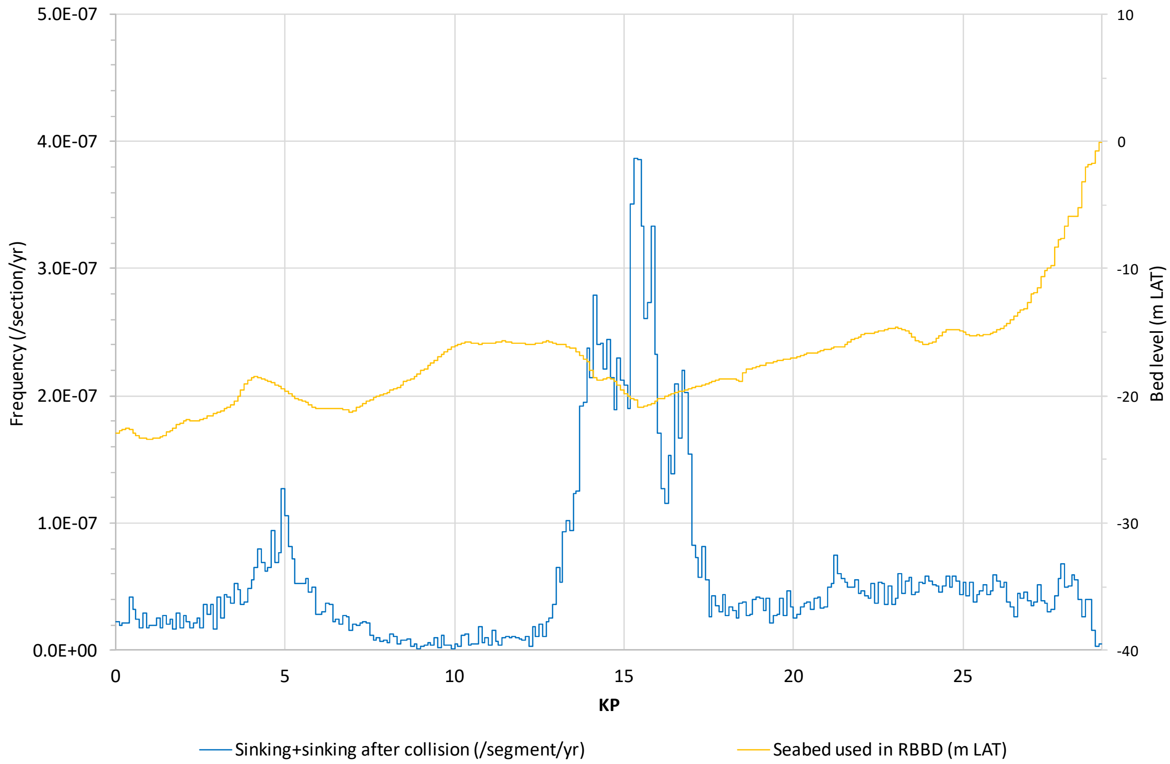


Figure A2.8 *Frequency that critical ship sinking occurs on **Hollandse Kust (noord) route alternative 2**.*

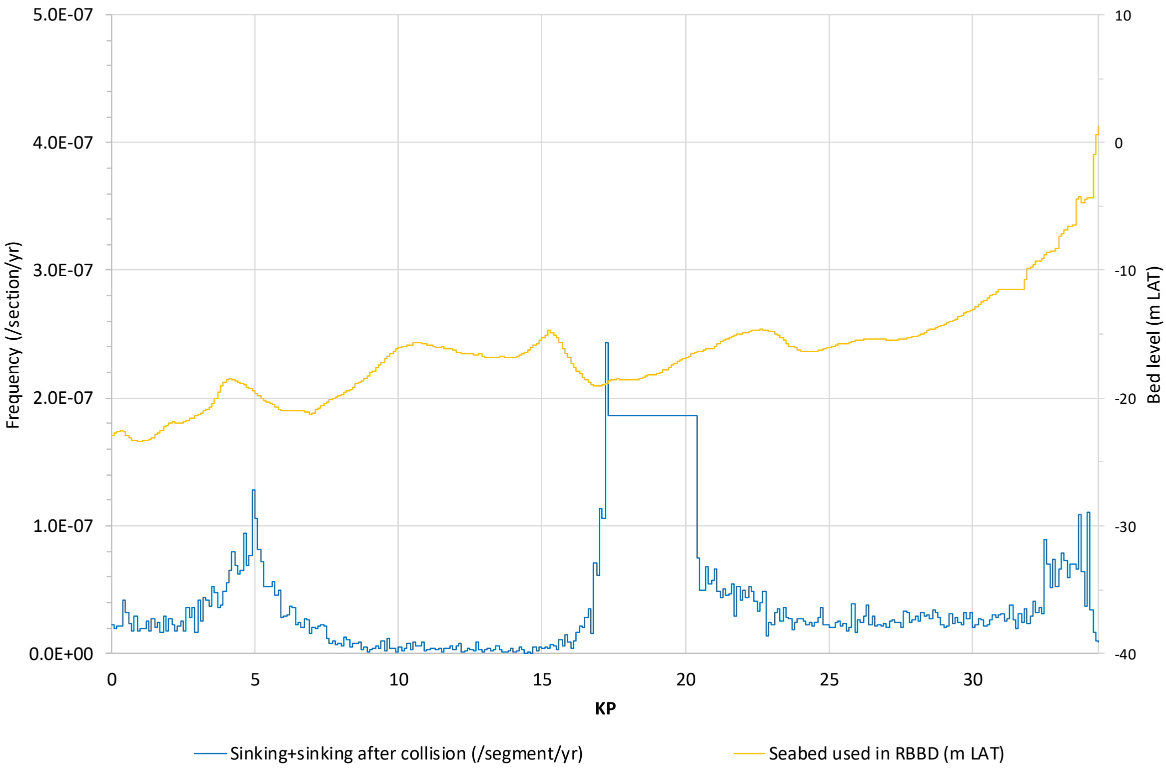


Figure A2.9 *Frequency that critical ship sinking occurs on* ***Hollandse Kust (noord) route alternative 3****.*

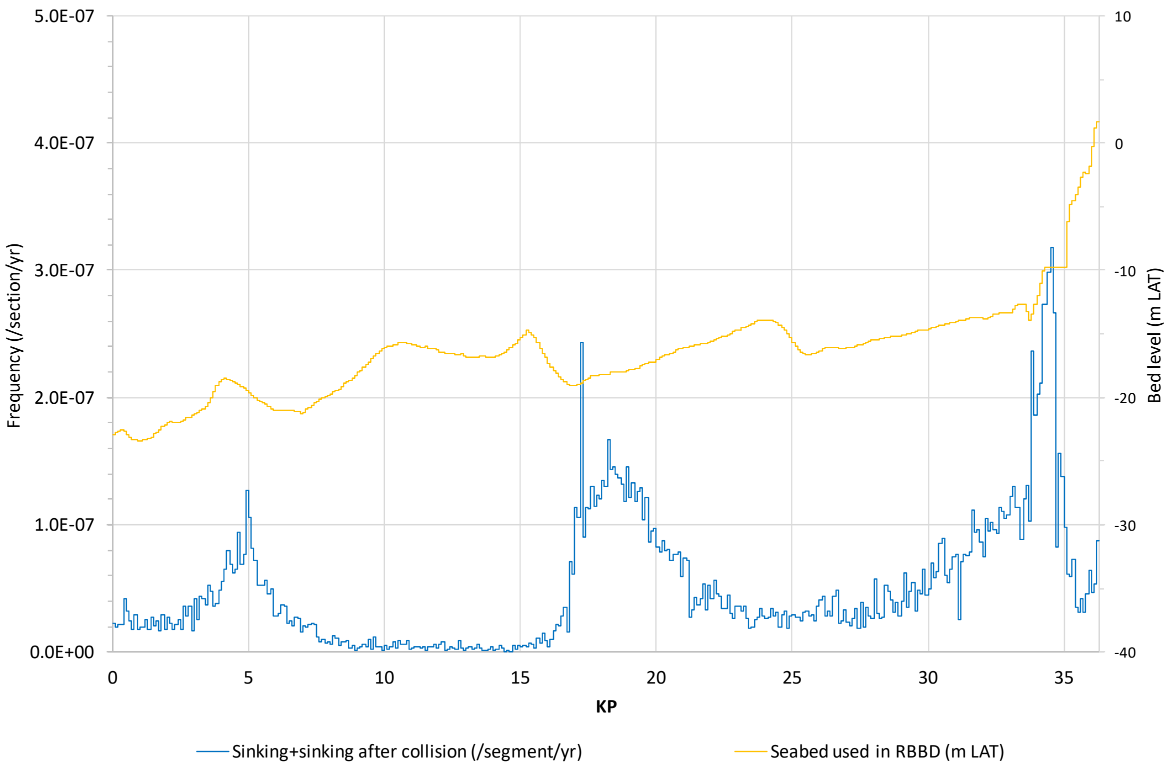


Figure A2.10 *Frequency that critical ship sinking occurs on* ***Hollandse Kust (noord) route alternative 4 and 5****.*

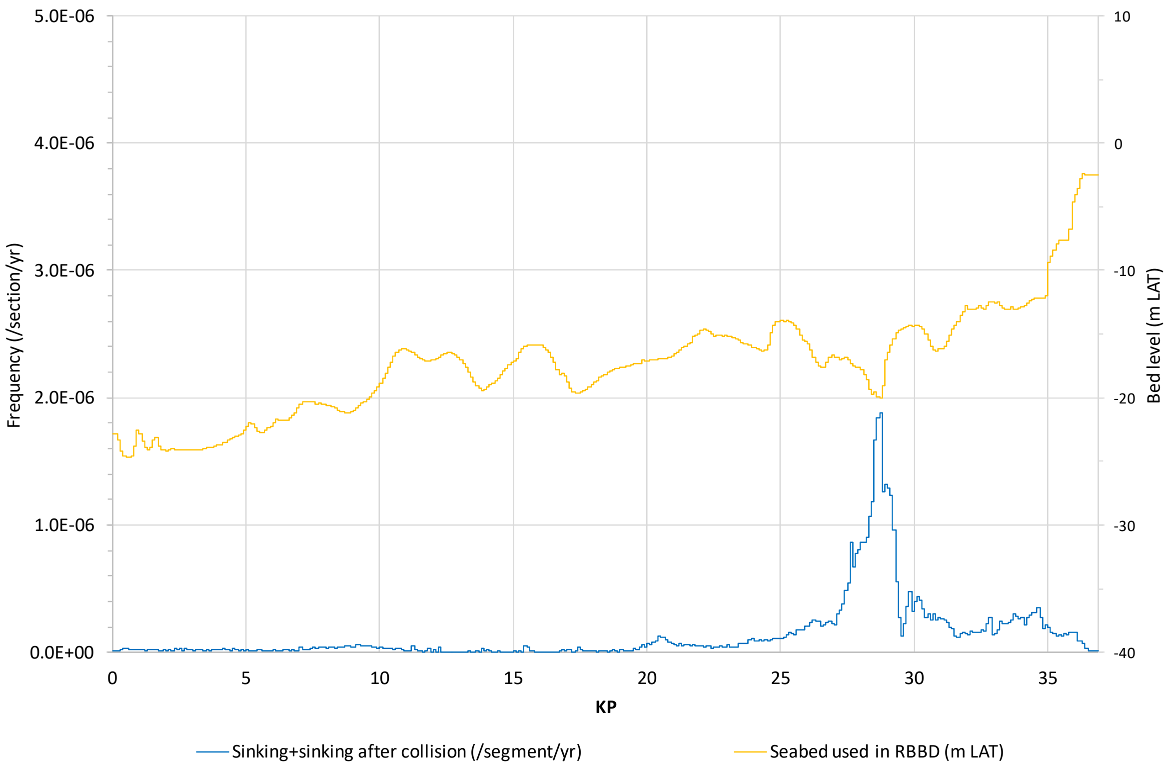


Figure A2.11 *Frequency that critical ship sinking occurs on* ***Hollandse Kust (noord) route alternative 6****. Note: The scale of the y-axis is a factor 10 larger compared to routes 1-5.*

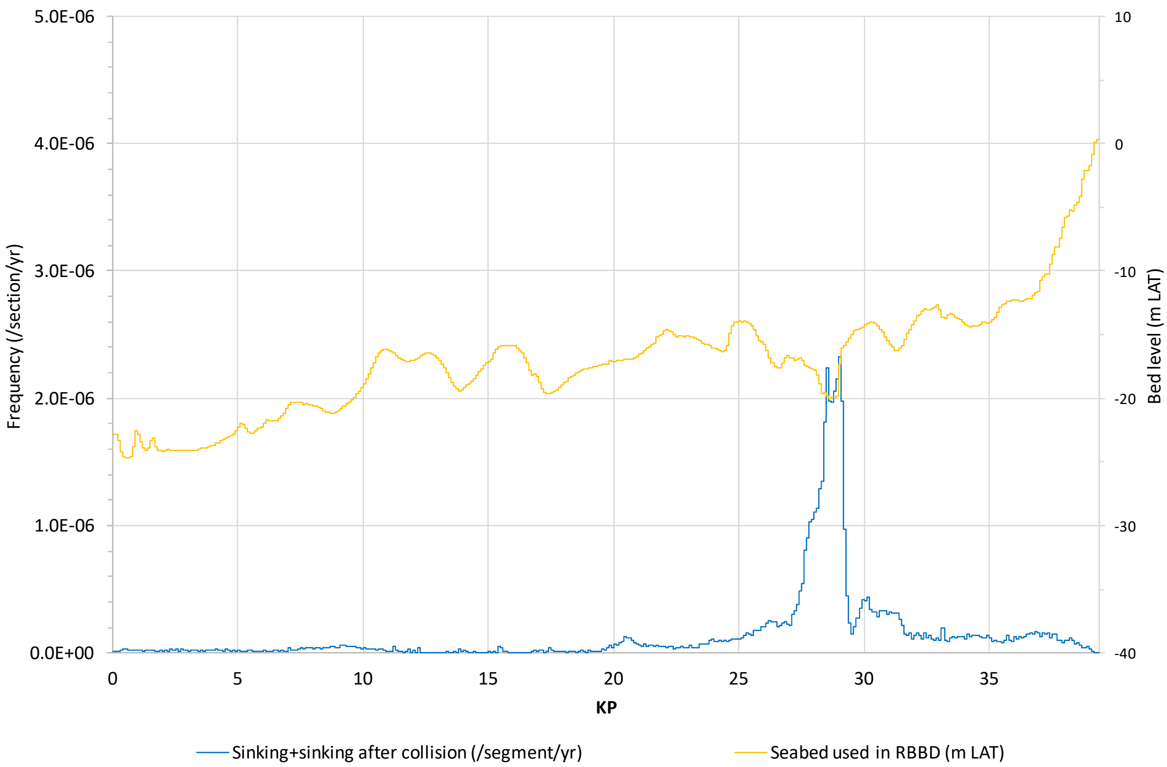


Figure A2.12 *Frequency that critical ship sinking occurs on* ***Hollandse Kust (noord) route alternative 7****. Note: The scale of the y-axis is a factor 10 larger compared to routes 1-5.*

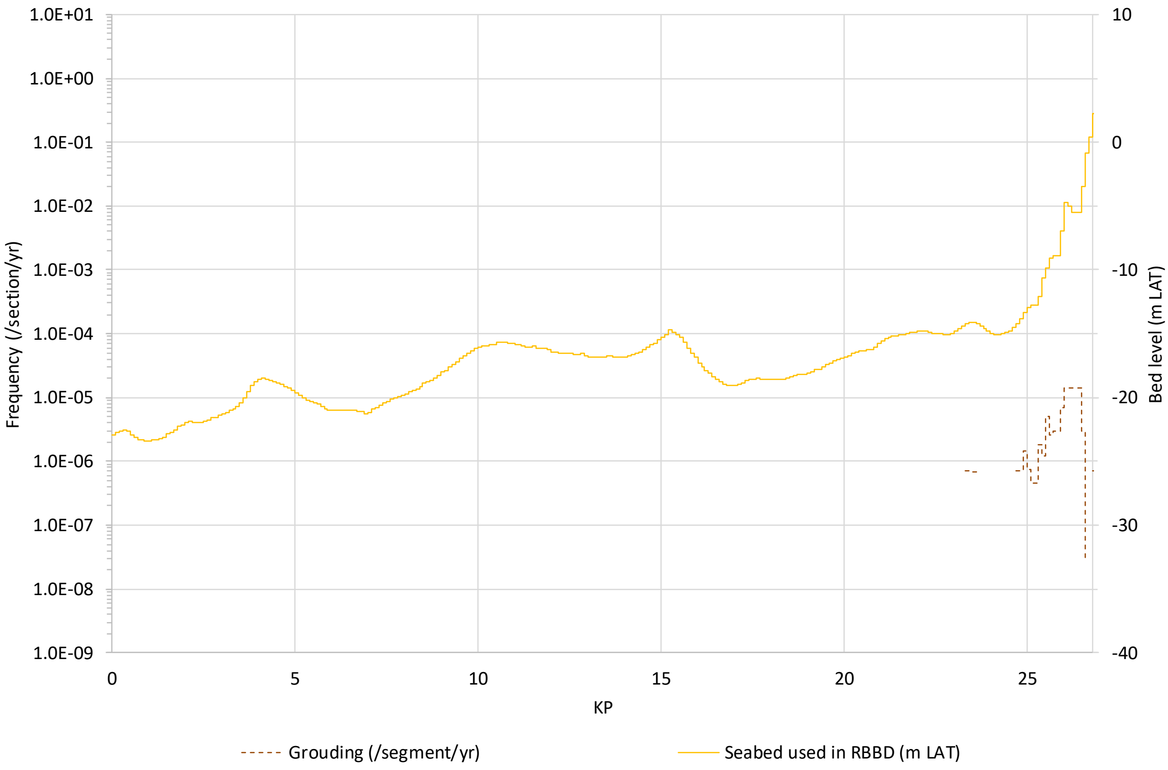


Figure A2.13 *Frequency that critical ship grounding occurs on* ***Hollandse Kust (noord) route alternative 1****.*

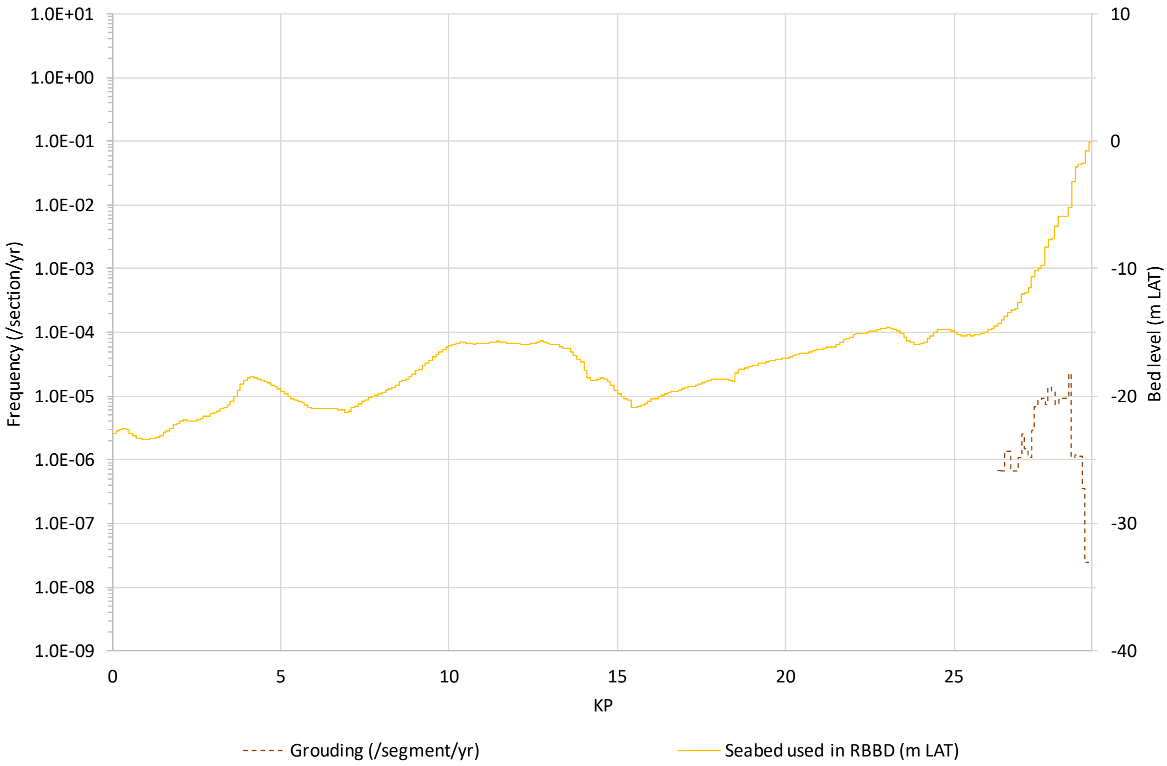


Figure A2.14 *Frequency that critical ship grounding occurs on* ***Hollandse Kust (noord) route alternative 2****.*

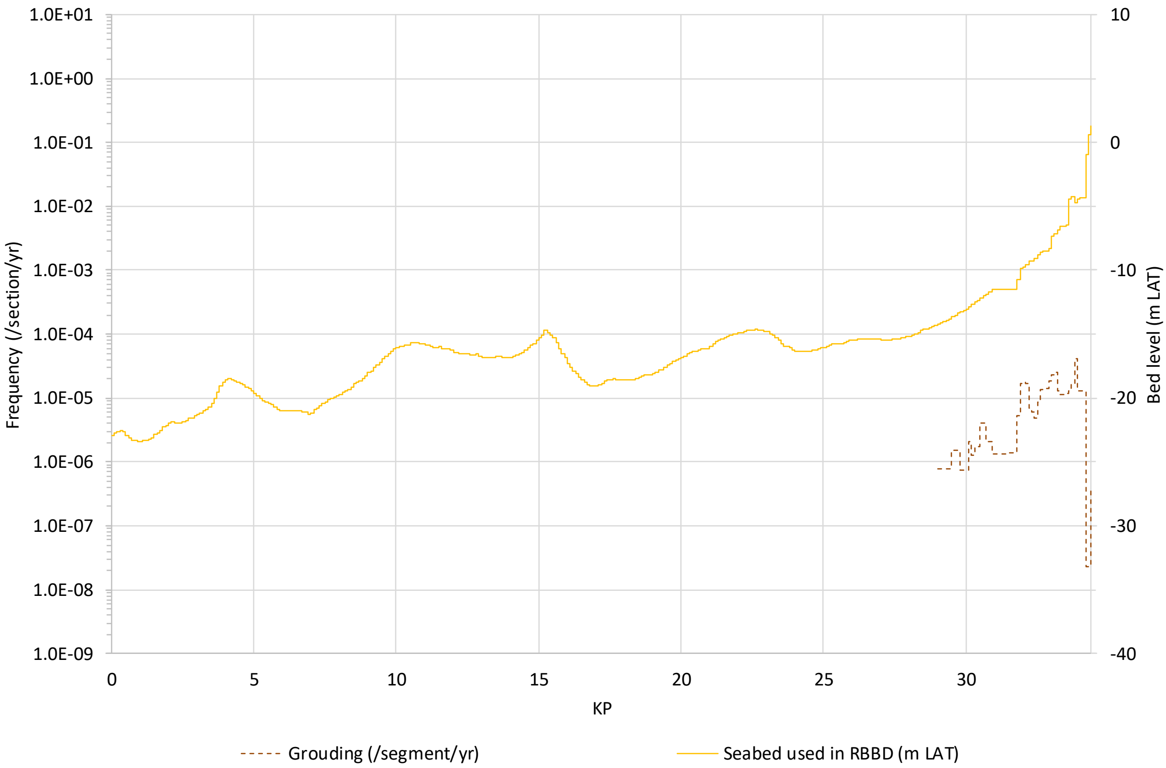


Figure A2.15 *Frequency that critical ship grounding occurs on **Hollandse Kust (noord) route alternative 3**.*

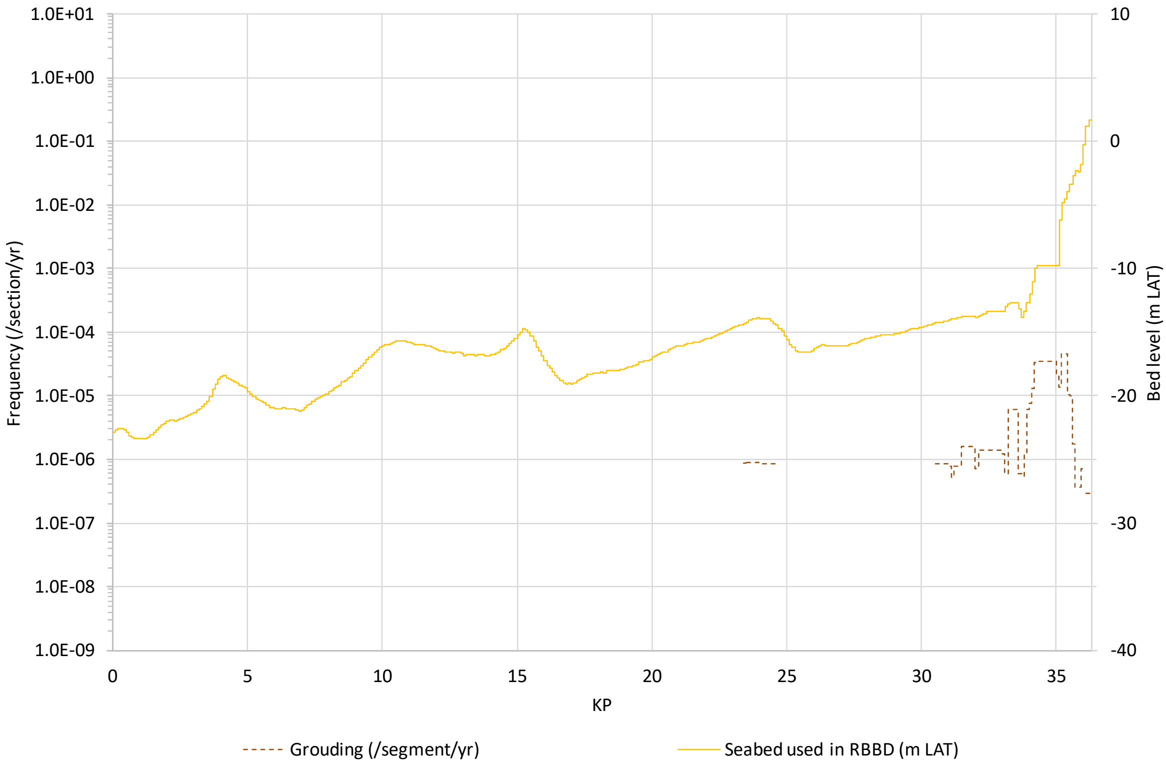


Figure A2.16 *Frequency that critical ship grounding occurs on **Hollandse Kust (noord) route alternative 4 and 5**.*

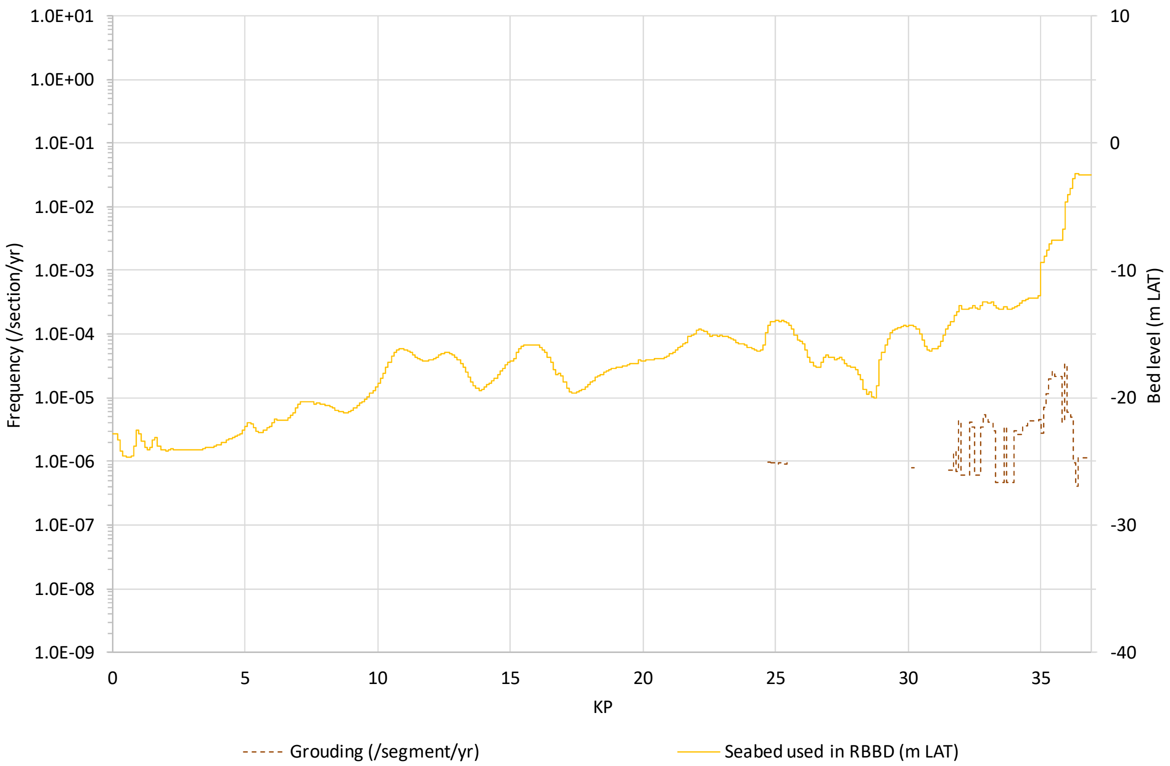


Figure A2.17 *Frequency that critical ship grounding occurs on* ***Hollandse Kust (noord) route alternative 6****.*

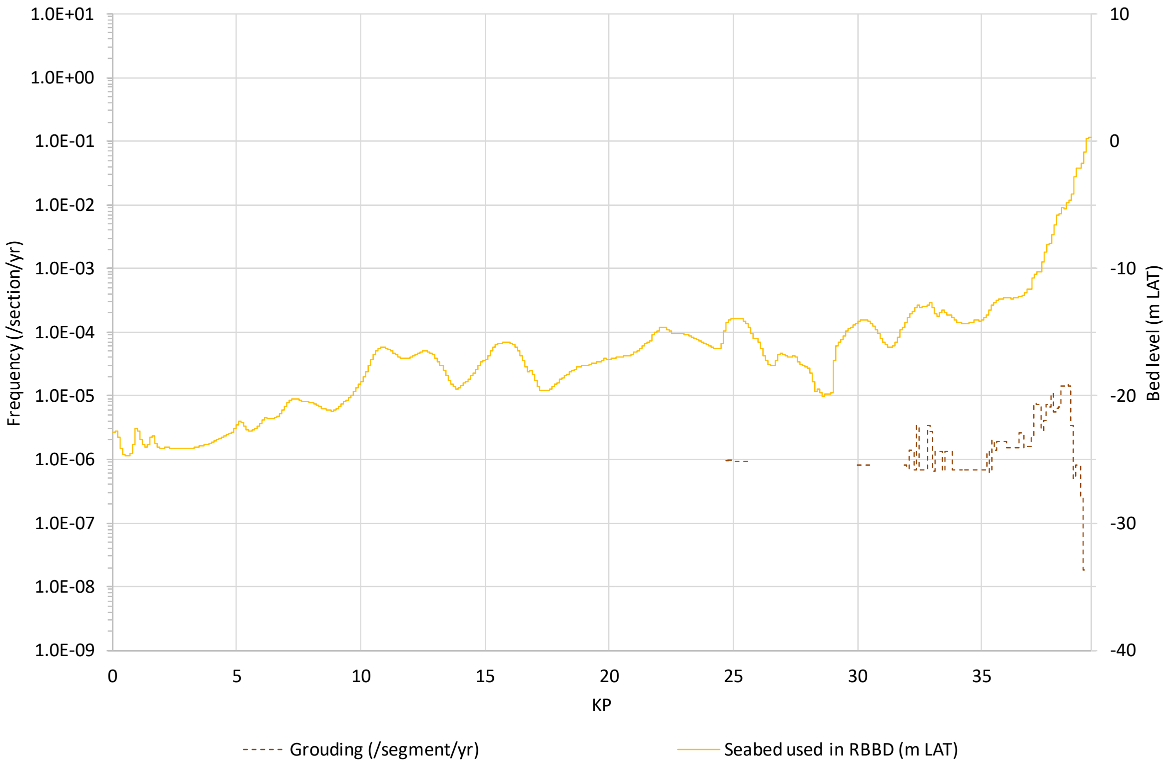


Figure A2.18 *Frequency that critical ship grounding occurs on* ***Hollandse Kust (noord) route alternative 7****.*

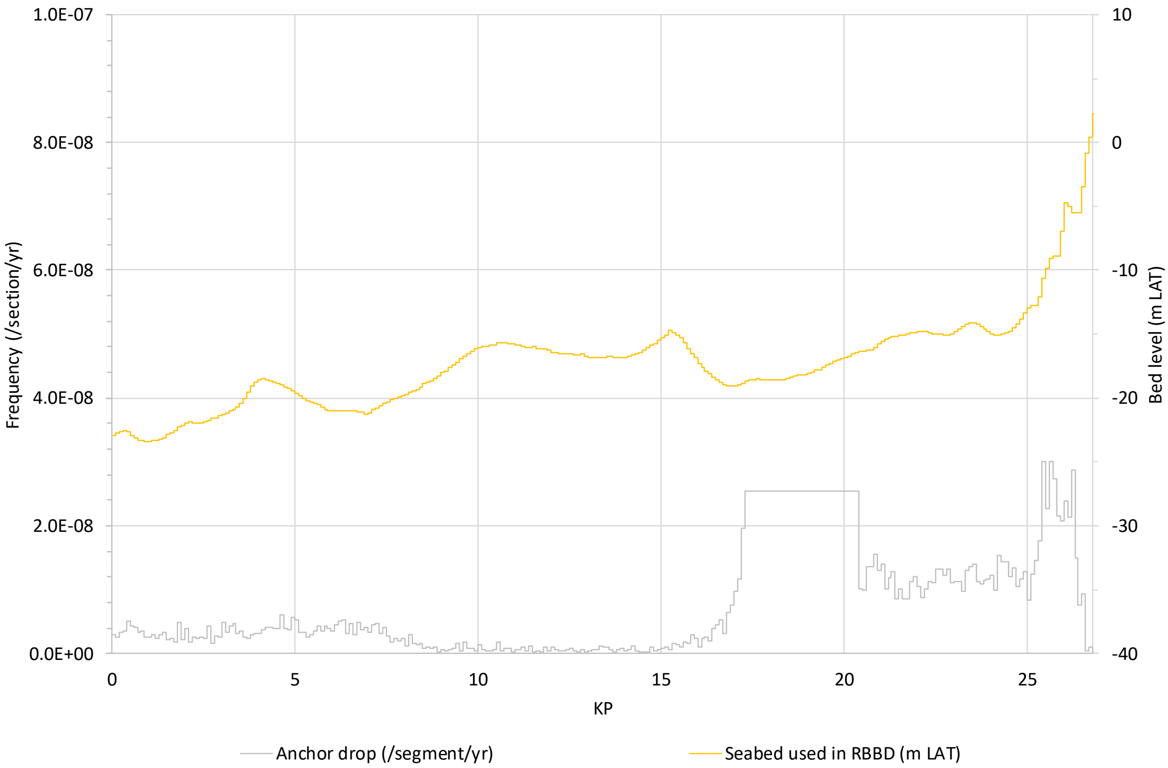


Figure A2.19 *Frequency that critical anchor dropping occurs on* ***Hollandse Kust (noord) route alternative 1****.*

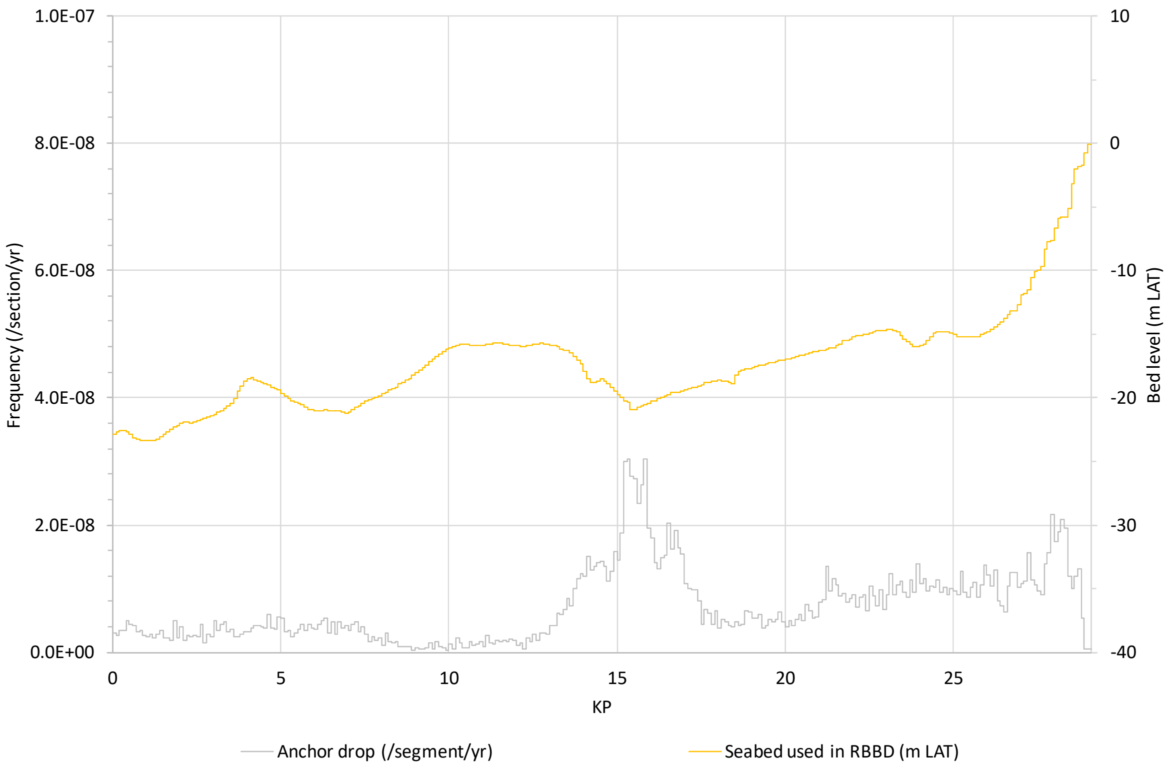


Figure A2.20 *Frequency that critical anchor dropping occurs on* ***Hollandse Kust (noord) route alternative 2****.*

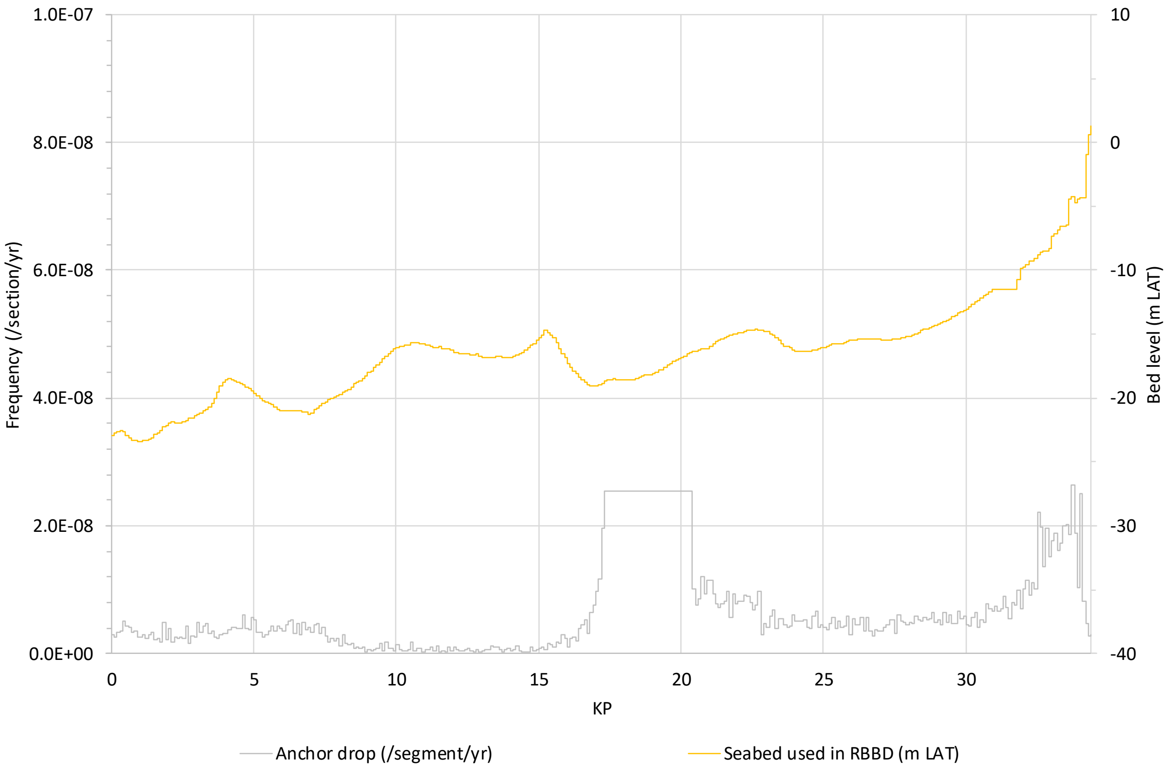


Figure A2.21 *Frequency that critical anchor dropping occurs on **Hollandse Kust (noord) route alternative 3**.*

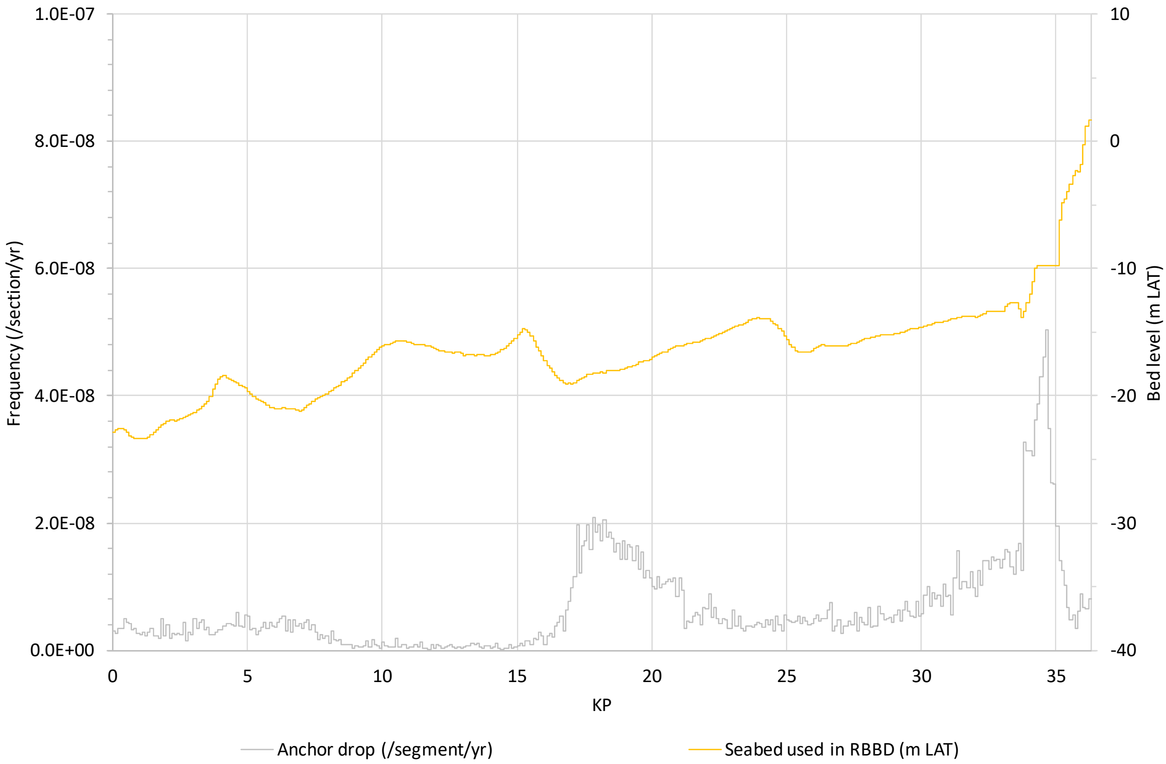


Figure A2.22 *Frequency that critical anchor dropping occurs on **Hollandse Kust (noord) route alternative 4 and 5.***

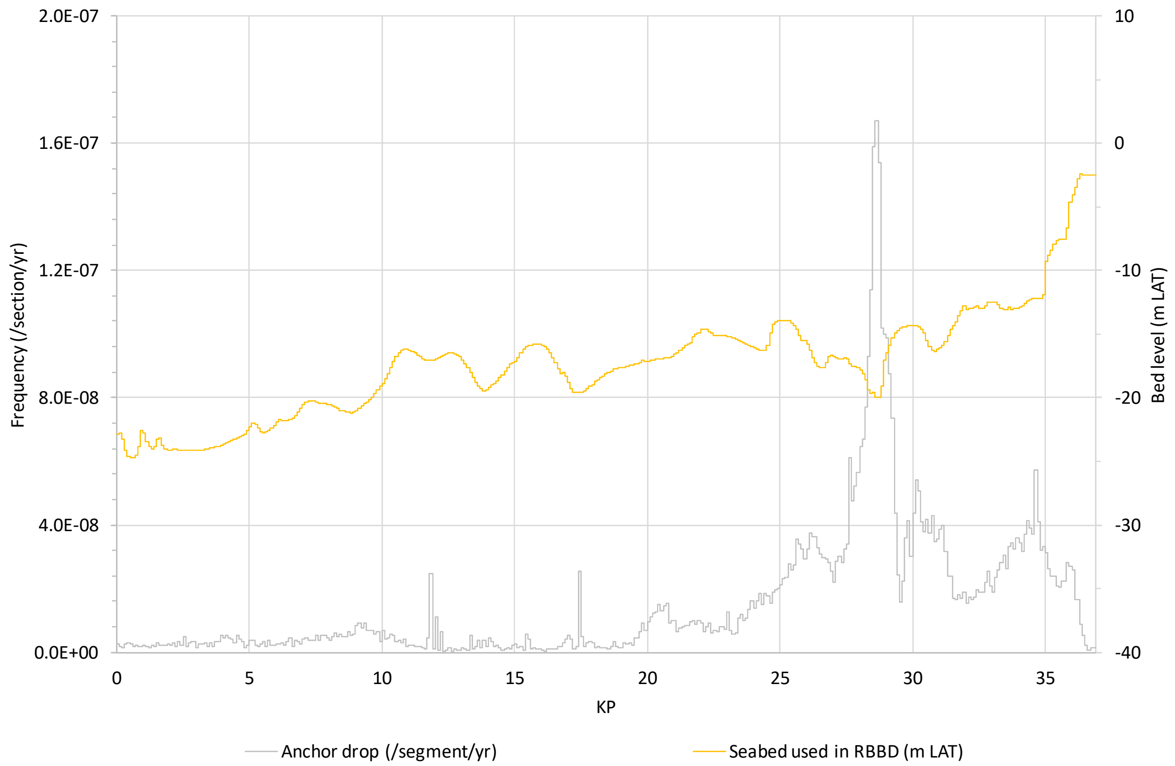


Figure A2.23 *Frequency that critical anchor dropping occurs on **Hollandse Kust (noord) route alternative 6**. <u>Note: The scale of the y-axis is a factor 2 larger compared to routes 1-5.</u>*

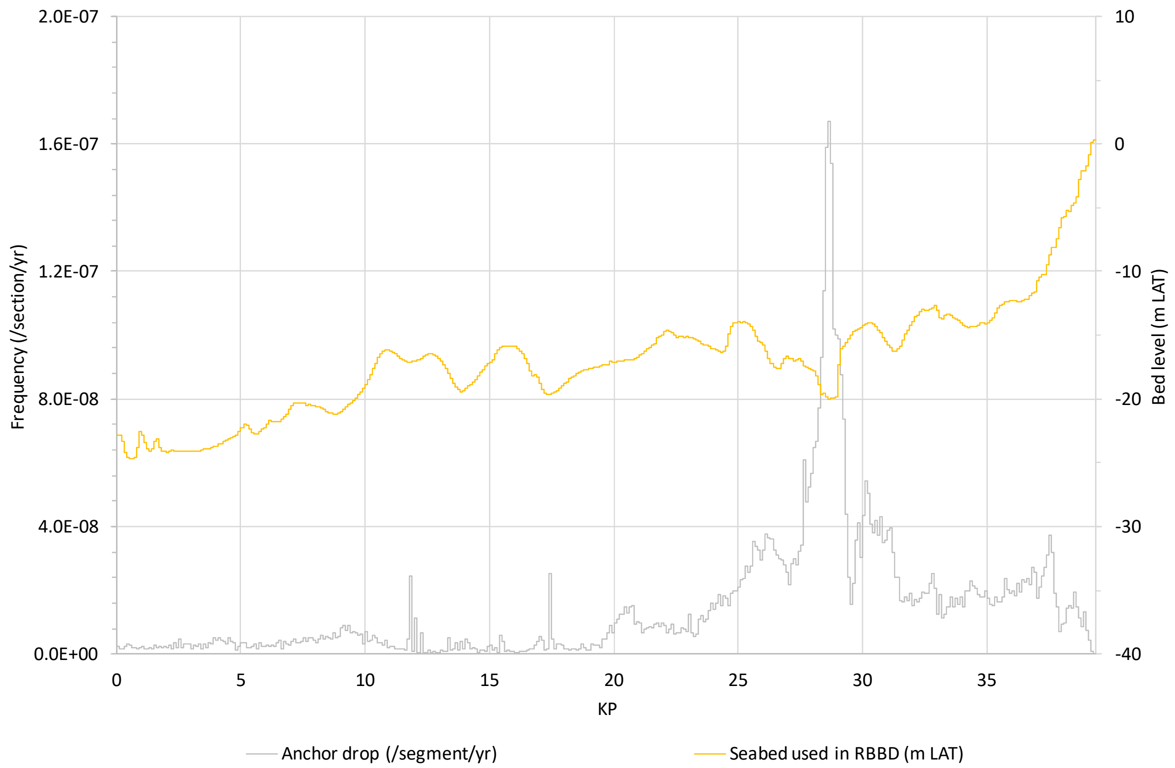


Figure A2.24 *Frequency that critical anchor dropping occurs on **Hollandse Kust (noord) route alternative 7**. <u>Note: The scale of the y-axis is a factor 2 larger compared to routes 1-5.</u>*

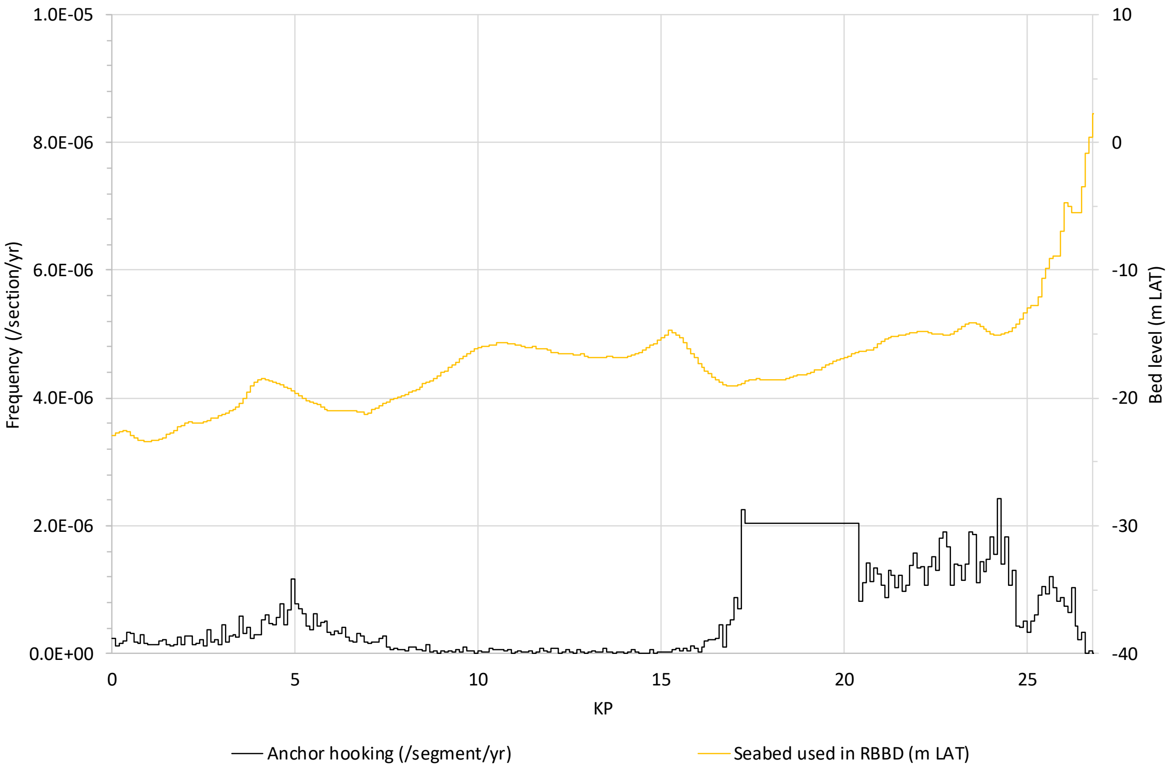


Figure A2.25 *Frequency that critical anchor hooking occurs on* ***Hollandse Kust (noord) route alternative 1****.*

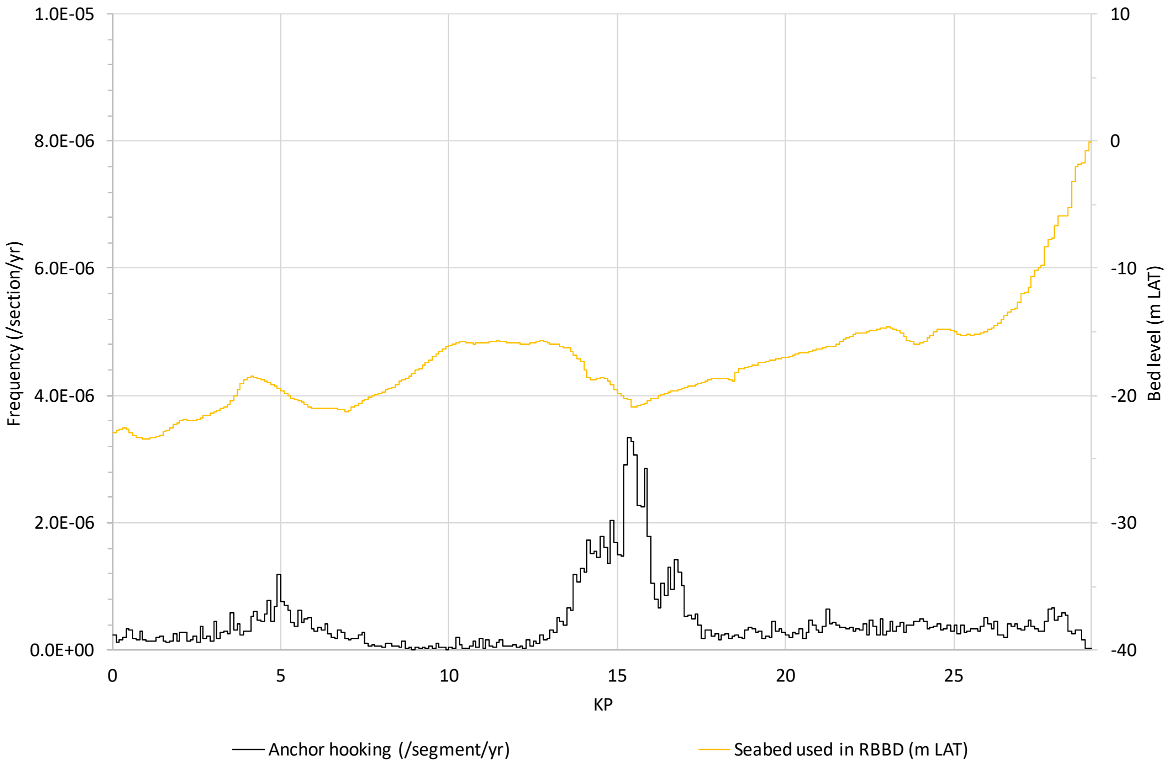


Figure A2.26 *Frequency that critical anchor hooking occurs on* ***Hollandse Kust (noord) route alternative 2****.*

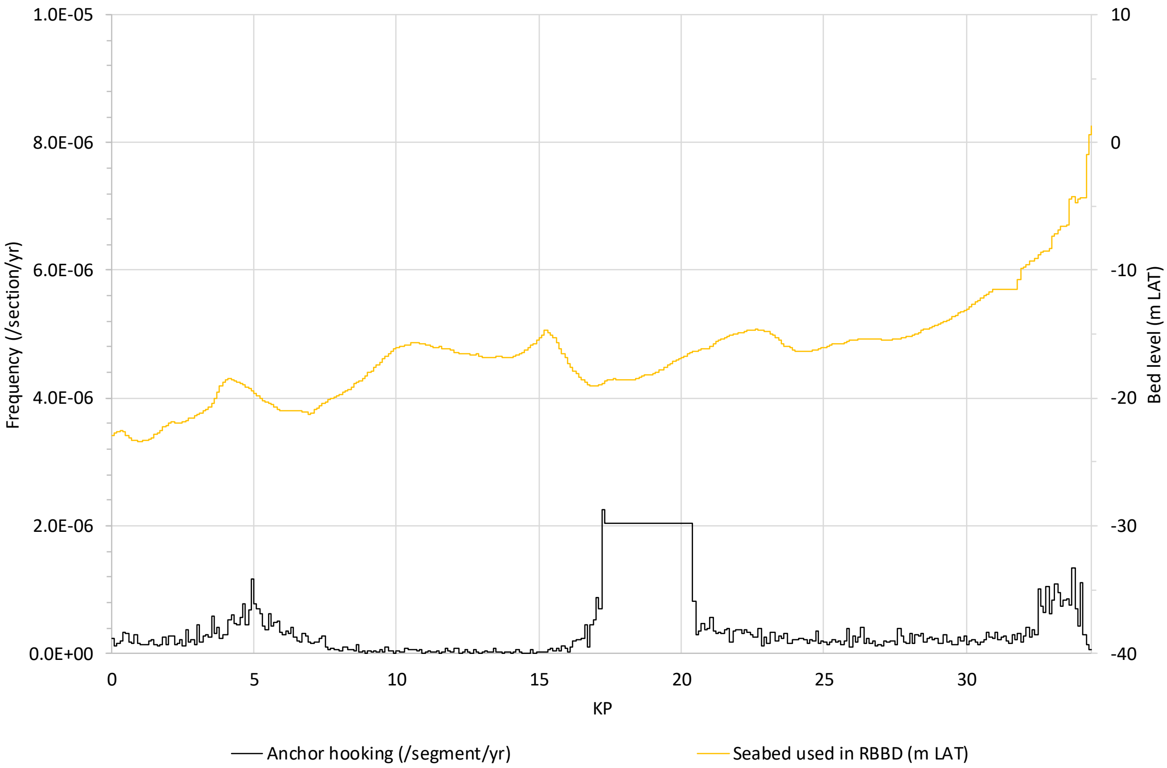


Figure A2.27 *Frequency that critical anchor hooking occurs on **Hollandse Kust (noord) route alternative 3**.*

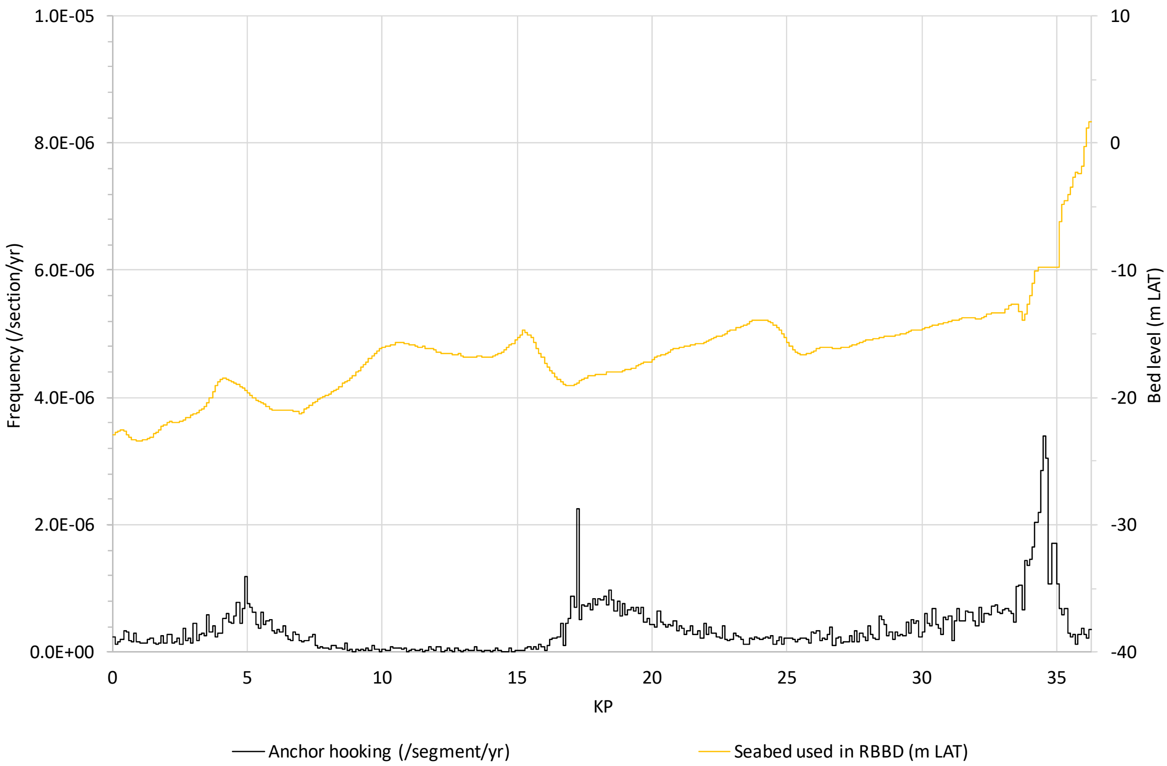


Figure A2.28 *Frequency that critical anchor hooking occurs on **Hollandse Kust (noord) route alternative 4 and 5**.*

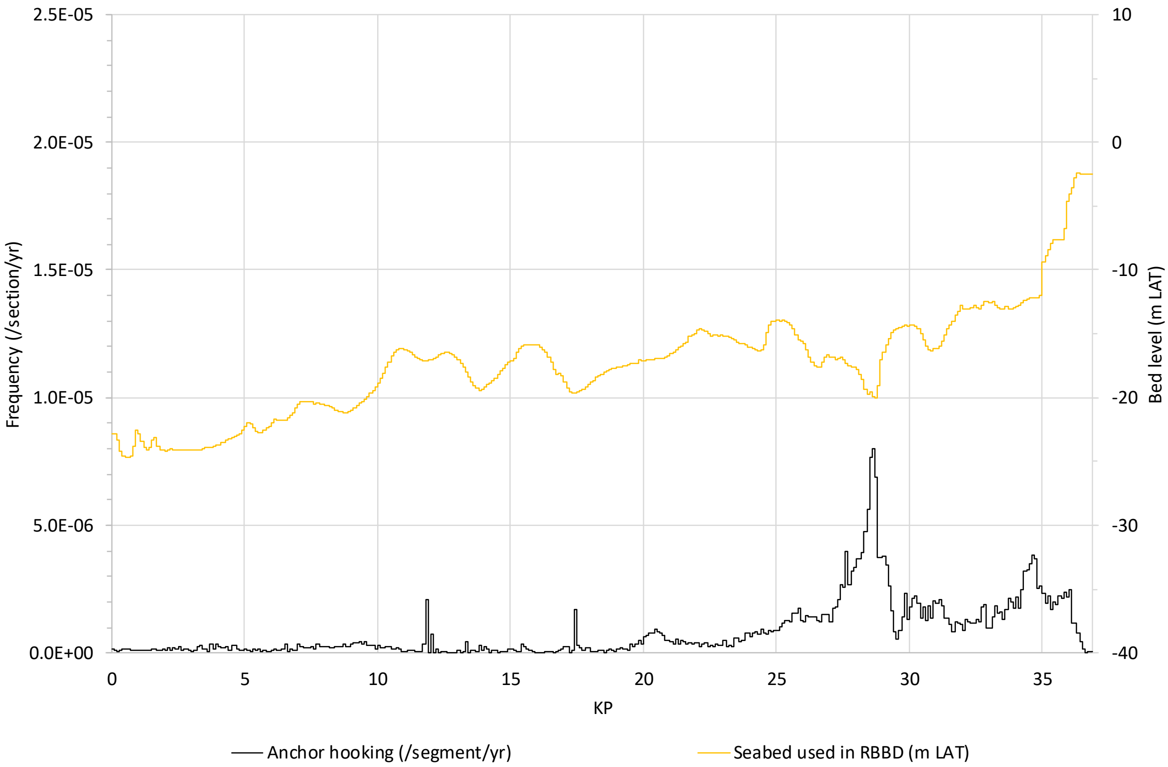


Figure A2.29 *Frequency that critical anchor hooking occurs on* ***Hollandse Kust (noord) route alternative 6****. Note: The scale of the y-axis is a factor 2 larger compared to routes 1-5.*

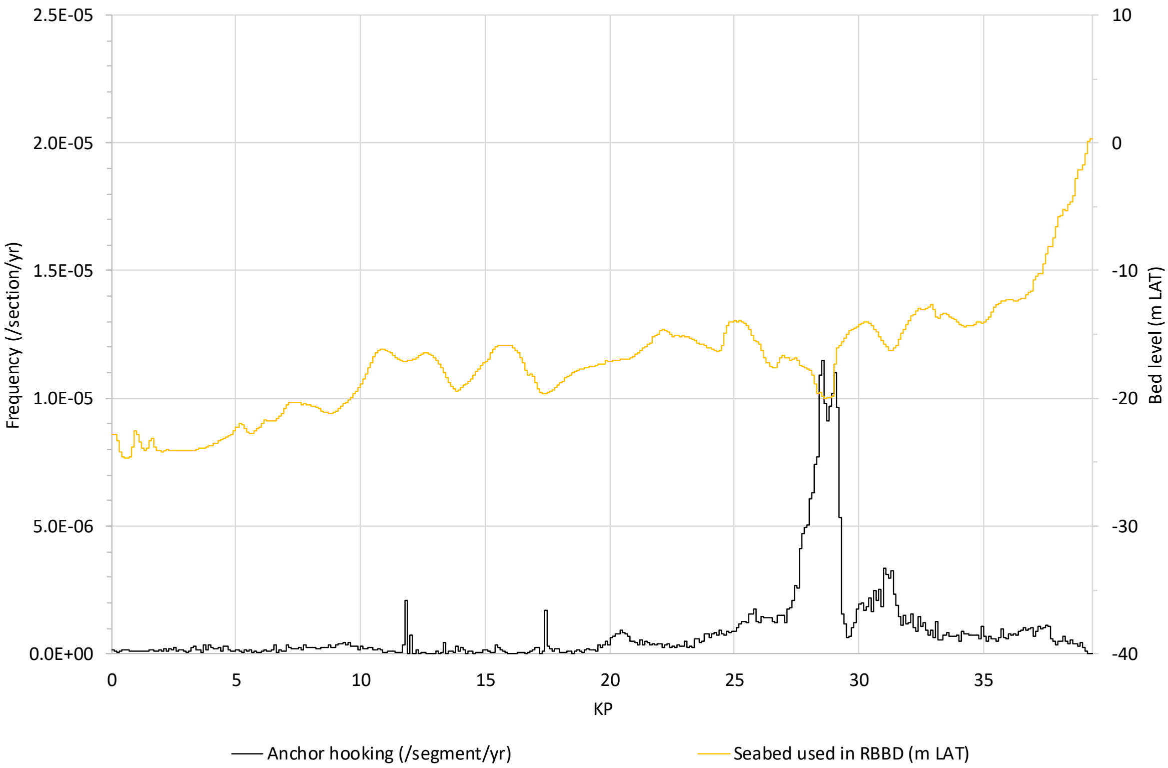


Figure A2.30 *Frequency that critical anchor hooking occurs on* ***Hollandse Kust (noord) route alternative 7****. Note: The scale of the y-axis is a factor 2 larger compared to routes 1-5.*

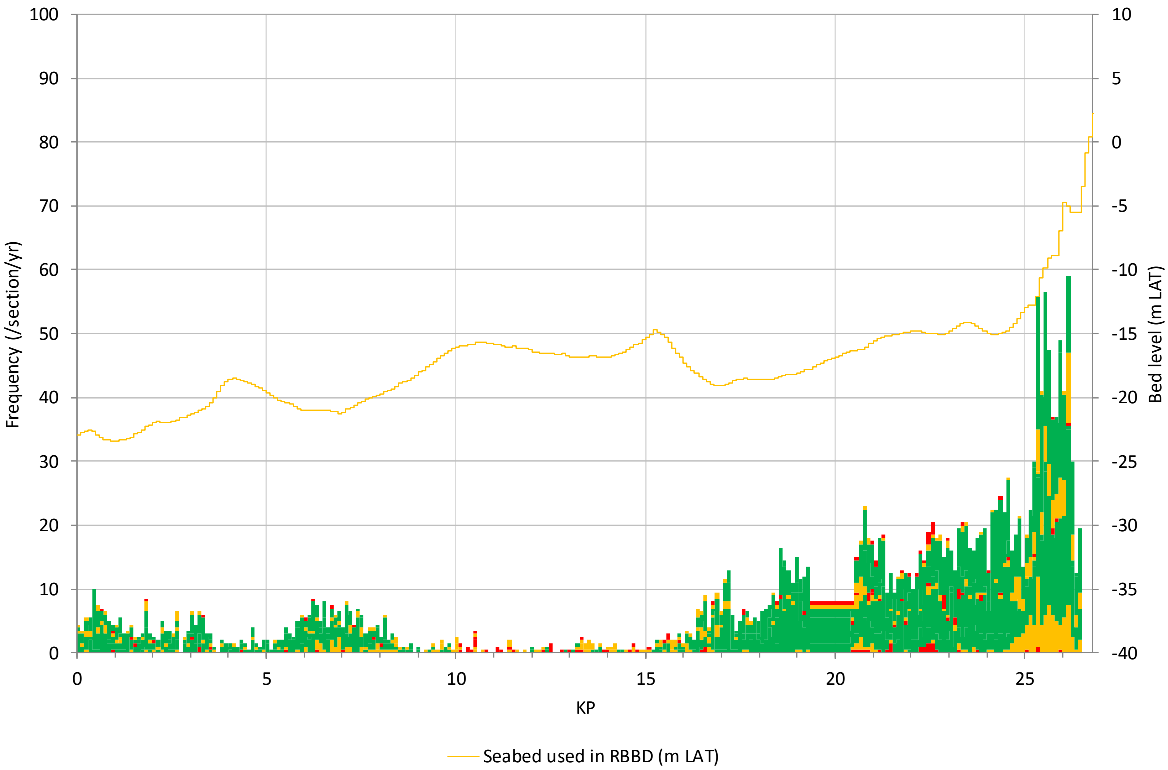


Figure A2.31 *Frequency that fishing activities interacting with **Hollandse Kust (noord) route alternative 1**.*

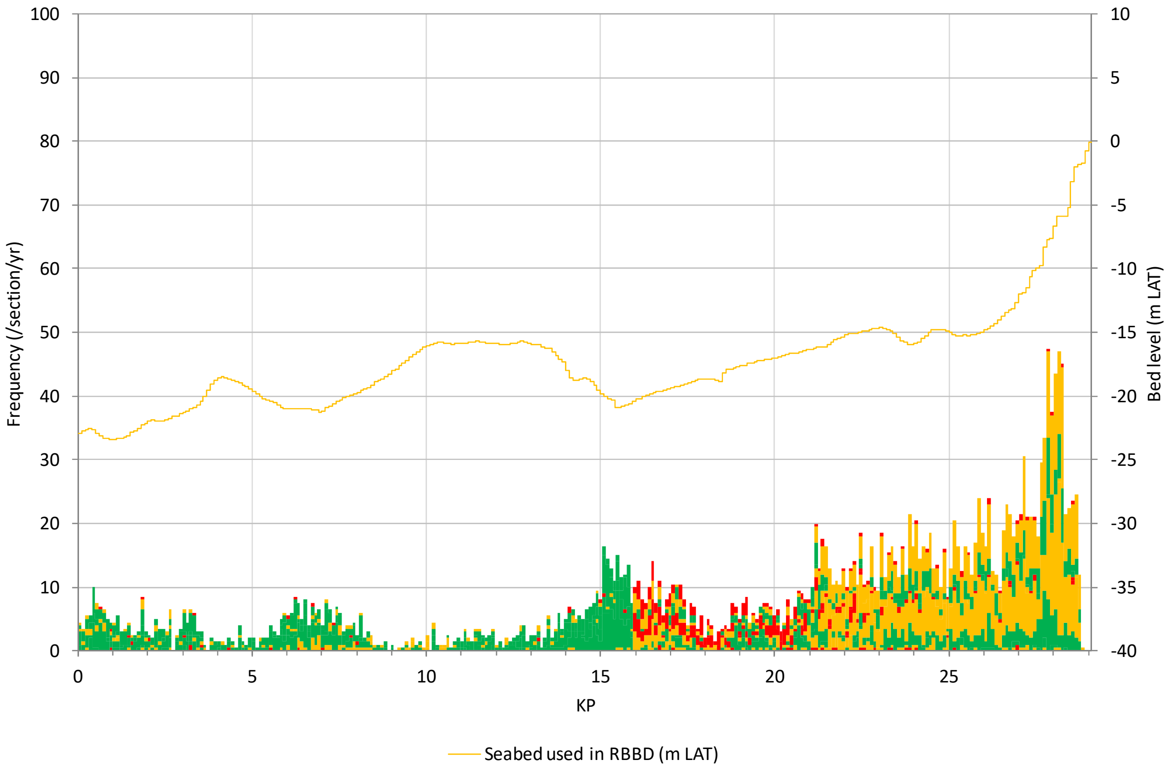


Figure A2.32 *Frequency that fishing activities interacting with **Hollandse Kust (noord) route alternative 2**.*

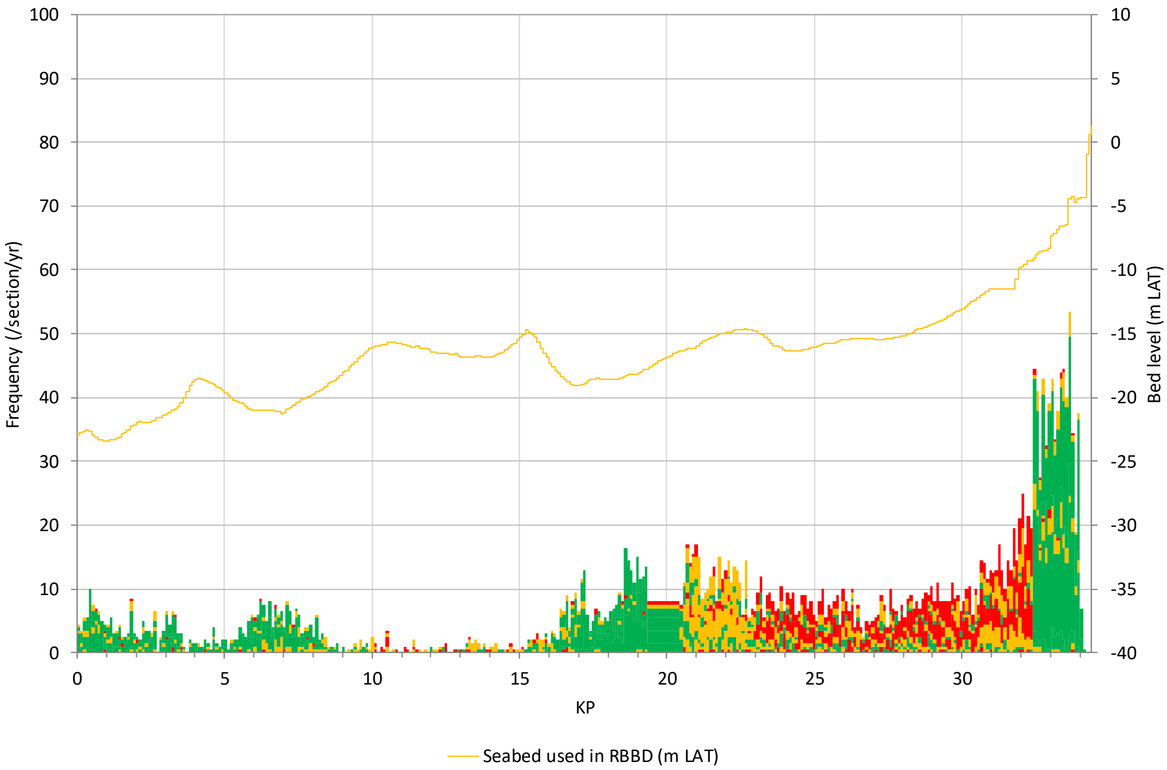


Figure A2.33 *Frequency that fishing activities interacting with* ***Hollandse Kust (noord) route alternative 3****.*

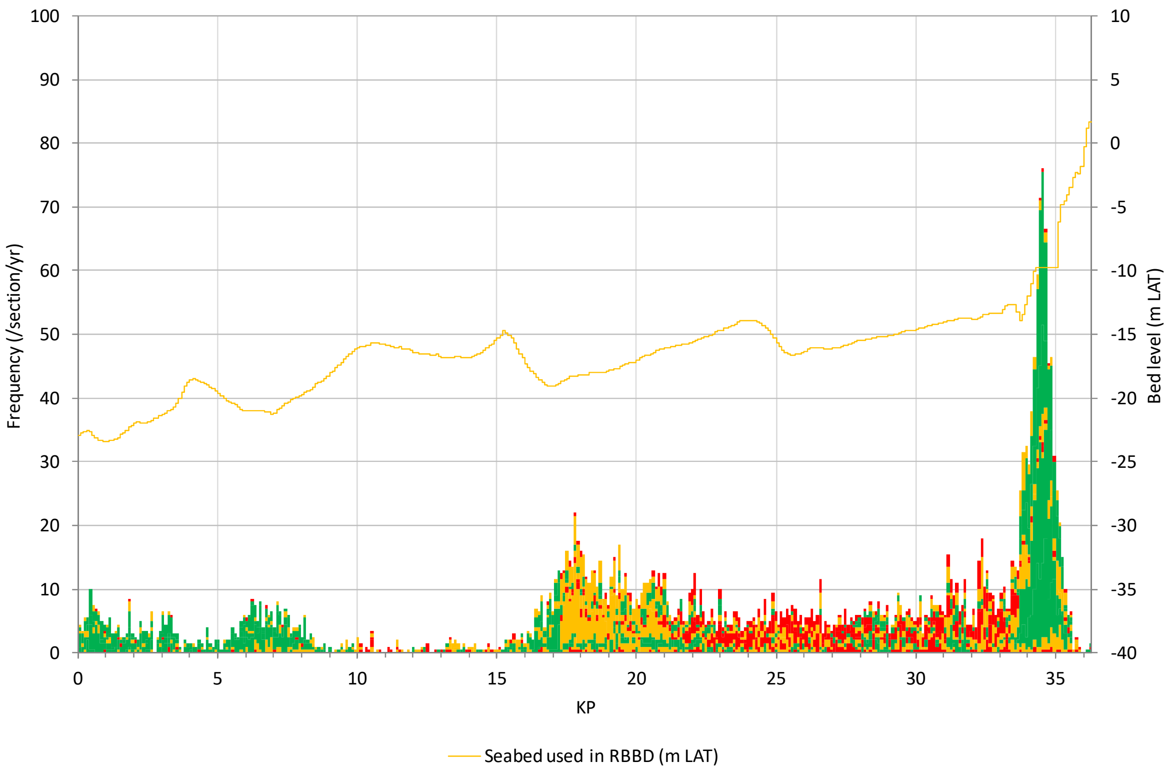


Figure A2.34 *Frequency that fishing activities interacting with* ***Hollandse Kust (noord) route alternative 4 and 5****.*

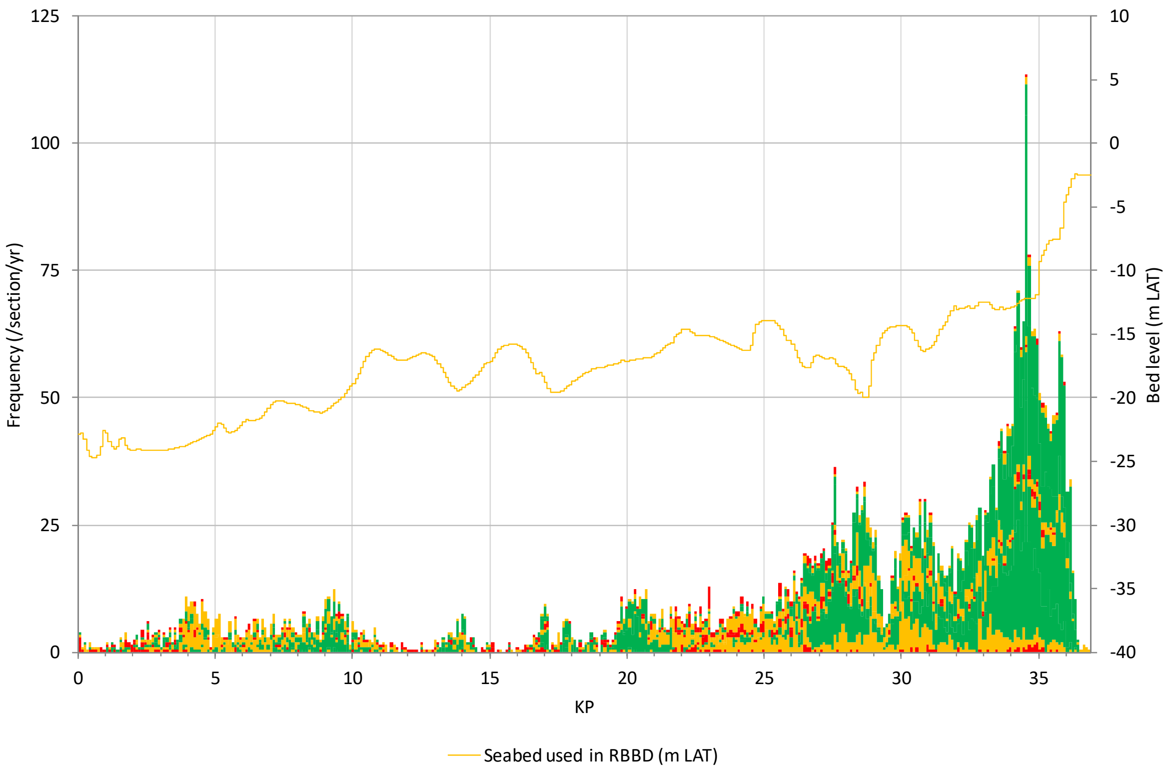


Figure A2.35 *Frequency that fishing activities interacting with **Hollandse Kust (noord) route alternative 6**.*

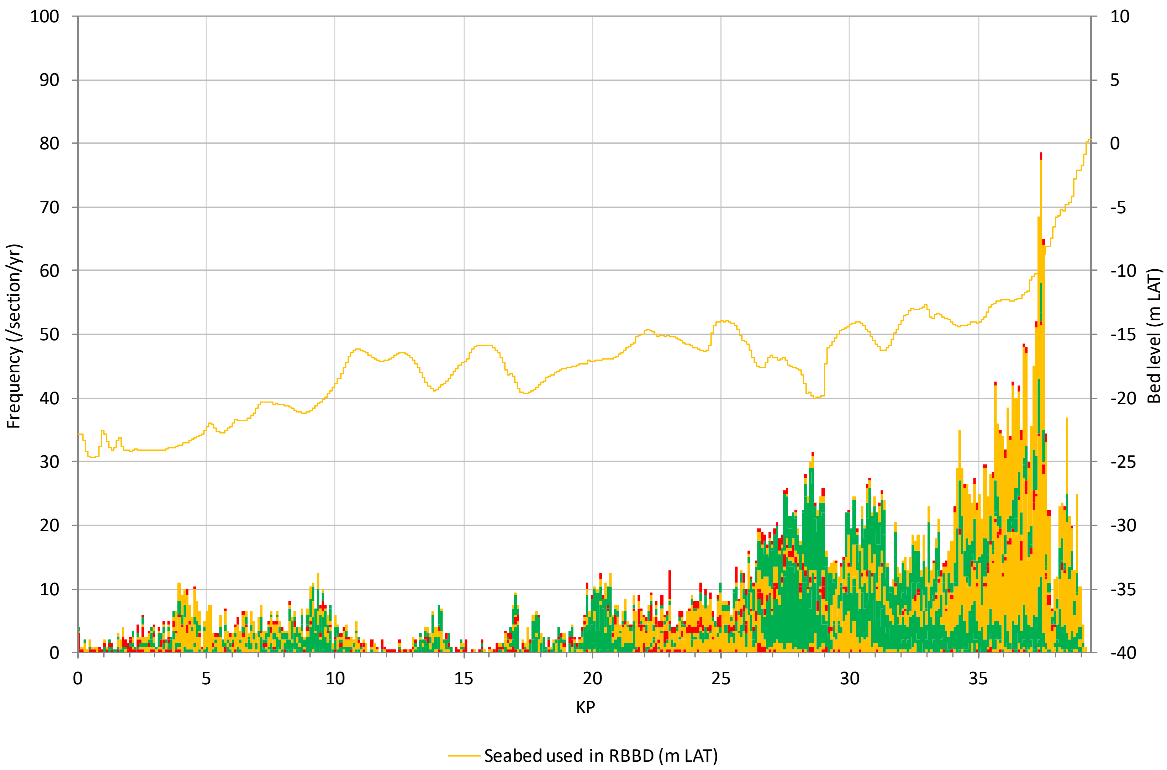
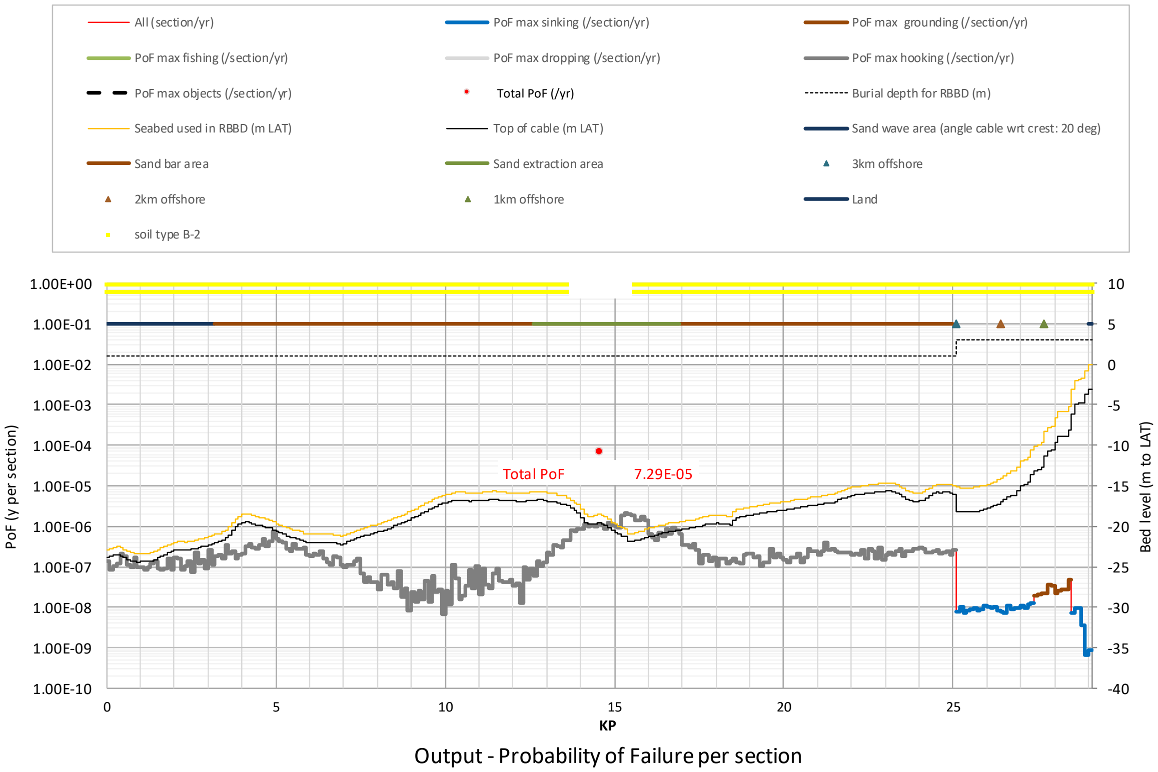


Figure A2.36 *Frequency that fishing activities interacting with **Hollandse Kust (noord) route alternative 7**.*

Figure A2.37 *Probability of Failure (PoF) for **Hollandse Kust (noord) route alternative 1**: Installation scenario = Initial permitting requirements + pre-sweeping, burial depth is 3 m (nearshore, < 3km from shore), 1 m (offshore, > 3km)*



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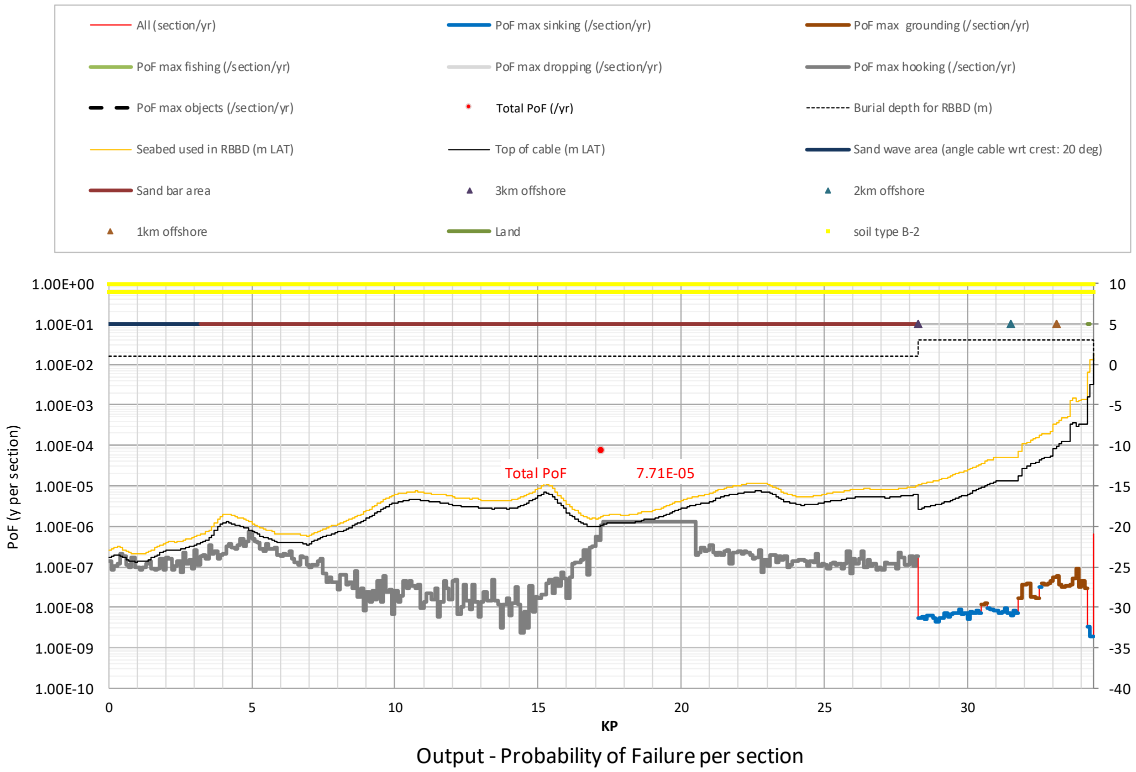


Figure A2.39 *Probability of Failure (PoF) for **Hollandse Kust (noord) route alternative 3**: Installation scenario = Initial permitting requirements + pre-sweeping, burial depth is 3 m (nearshore, < 3km from shore), 1 m (offshore, > 3km)*

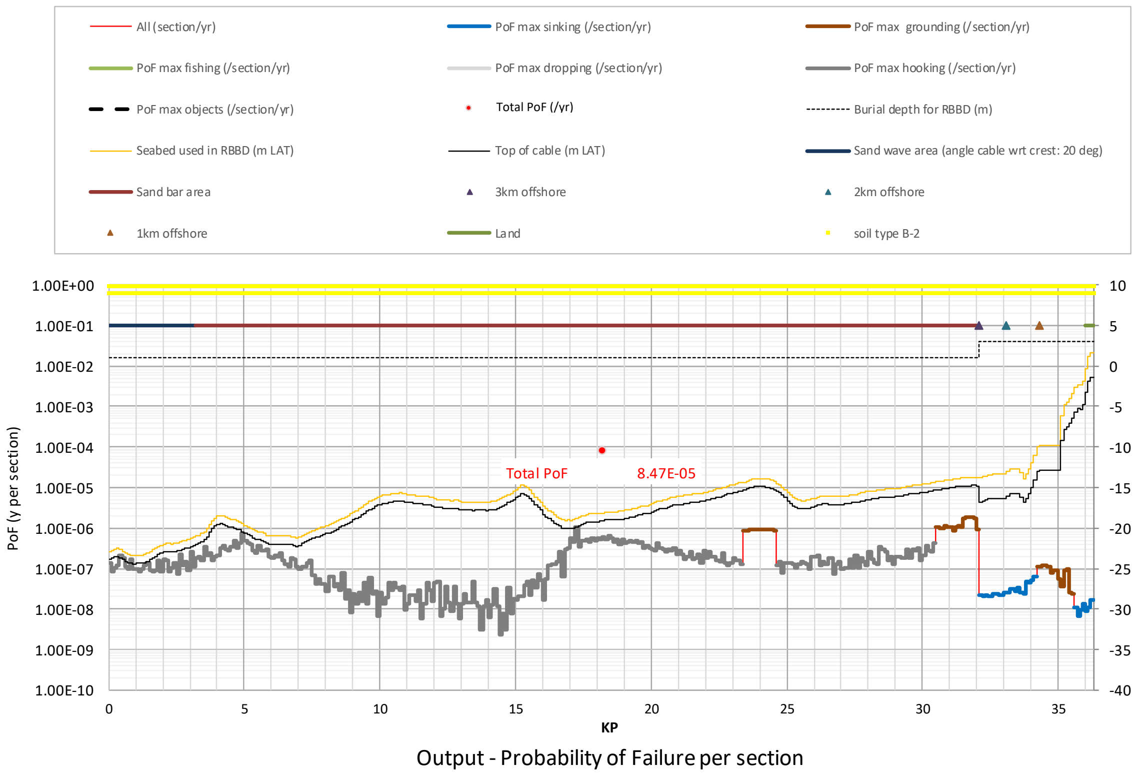


Figure A2.40 *Probability of Failure (PoF) for **Hollandse Kust (noord) route alternative 4 and 5**: Installation scenario = Initial permitting requirements + pre-sweeping, burial depth is 3 m (nearshore, < 3km from shore), 1 m (offshore, > 3km)*

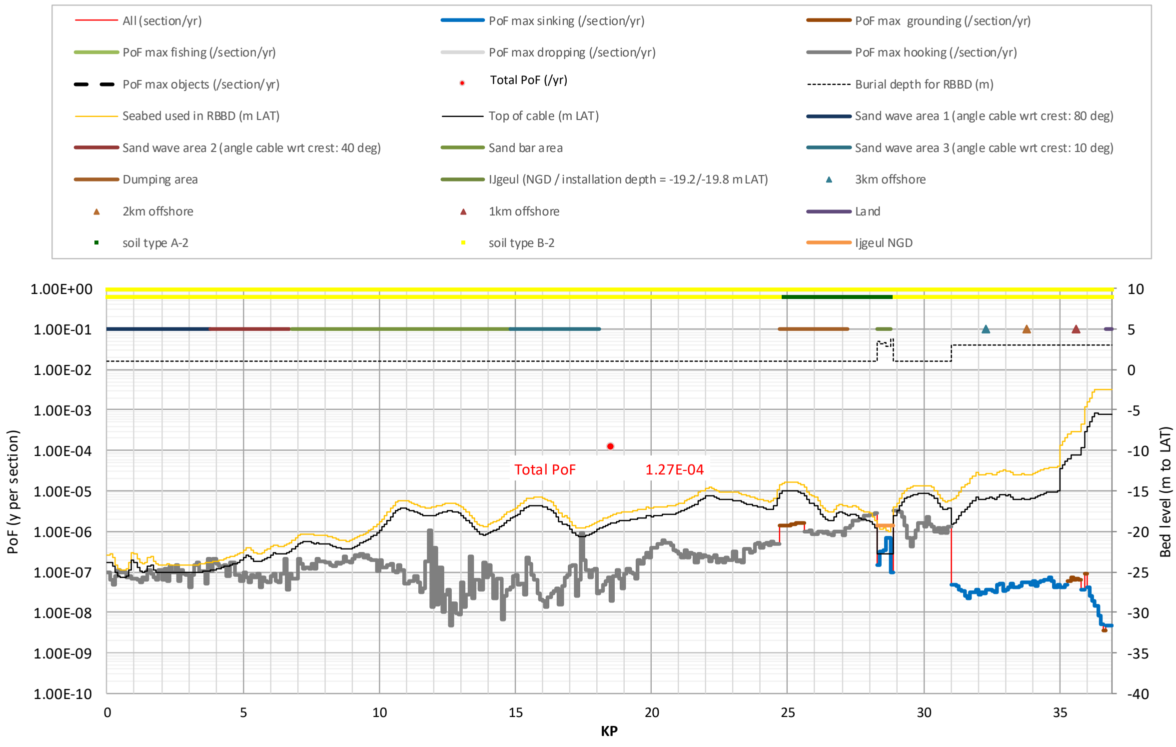


Figure A2.41 *Probability of Failure (PoF) for* ***Hollandse Kust (noord) route alternative 6****: Installation scenario = Initial permitting requirements + pre-sweeping, burial depth is 3 m (nearshore, < 3km from shore), 1 m (offshore, > 3km), burial in IJ-geul is 3m below -19.8 m LAT (= NGD-0.5m)*

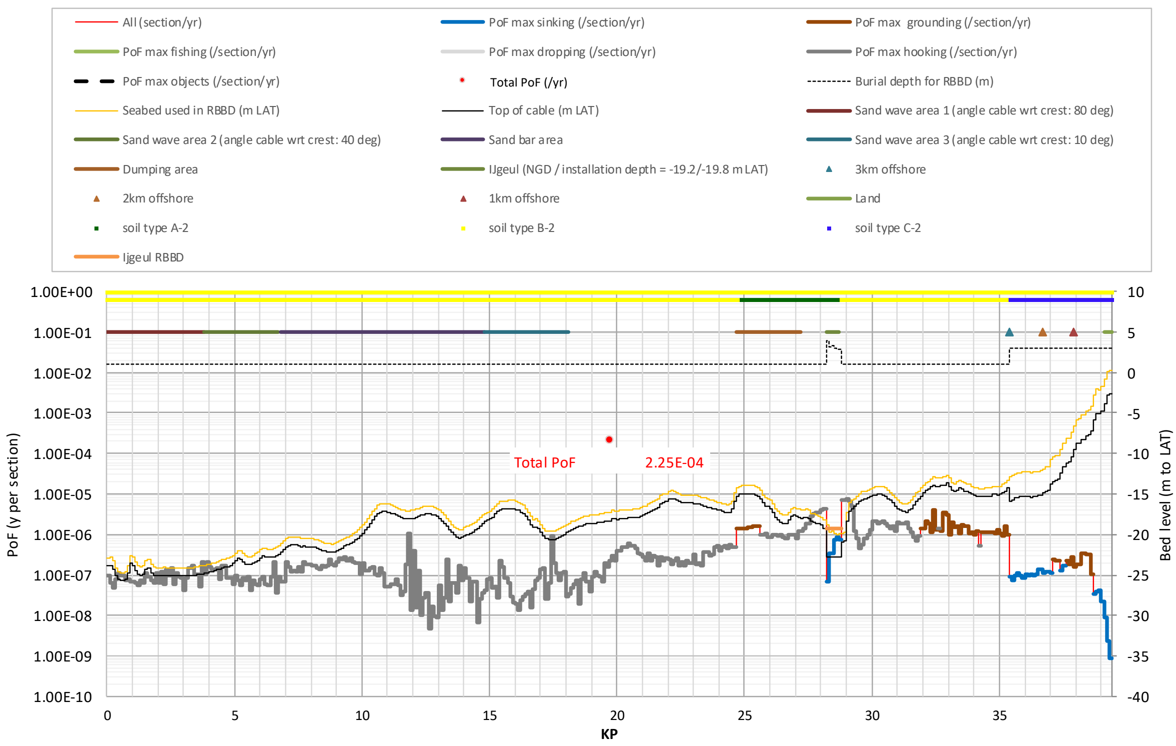


Figure A2.42 *Probability of Failure (PoF) for* ***Hollandse Kust (noord) route alternative 7****: Installation scenario = Initial permitting requirements + pre-sweeping, burial depth is 3 m (nearshore, < 3km from shore), 1 m (offshore, > 3km), , burial in IJ-geul is 3m below -19.8 m LAT (= NGD-0.5m)*

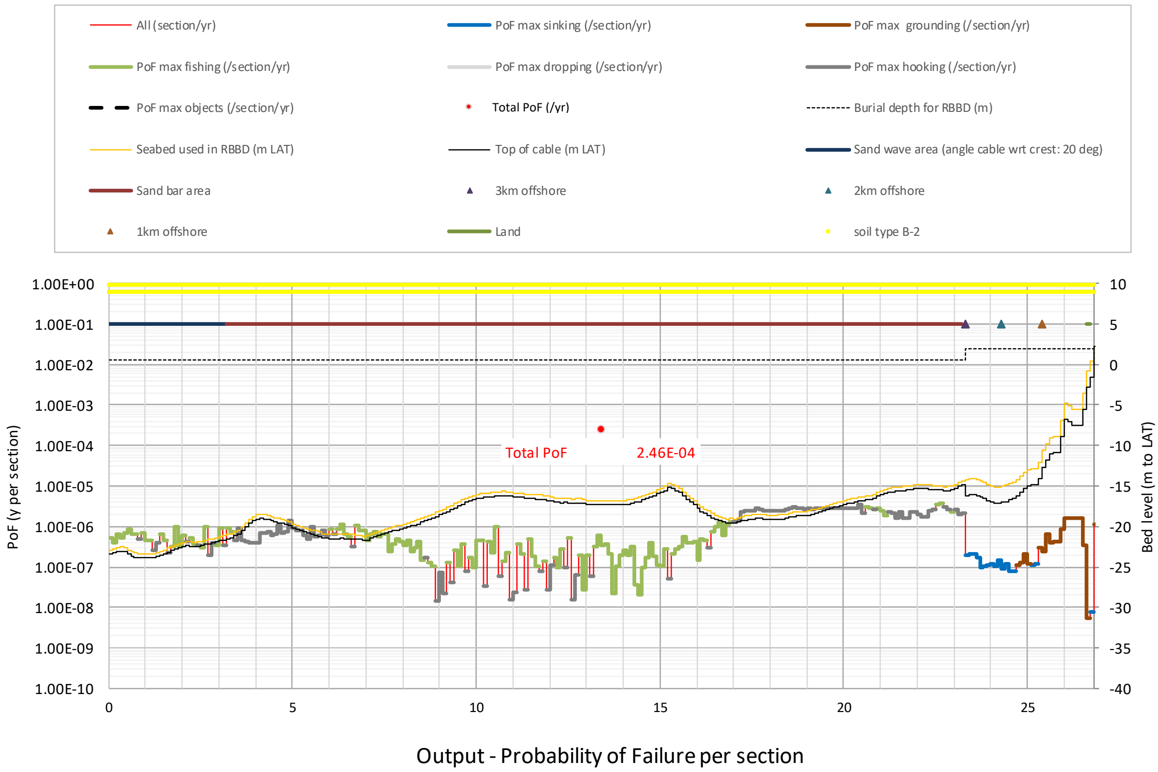


Figure A2.43 *Probability of Failure (PoF) for* ***Hollandse Kust (noord) route alternative 1****: Signal scenario = burial scenario 1 + pre-sweeping, burial depth is 2 m (nearshore, < 3km from shore), 0.5 m (offshore, > 3km)*

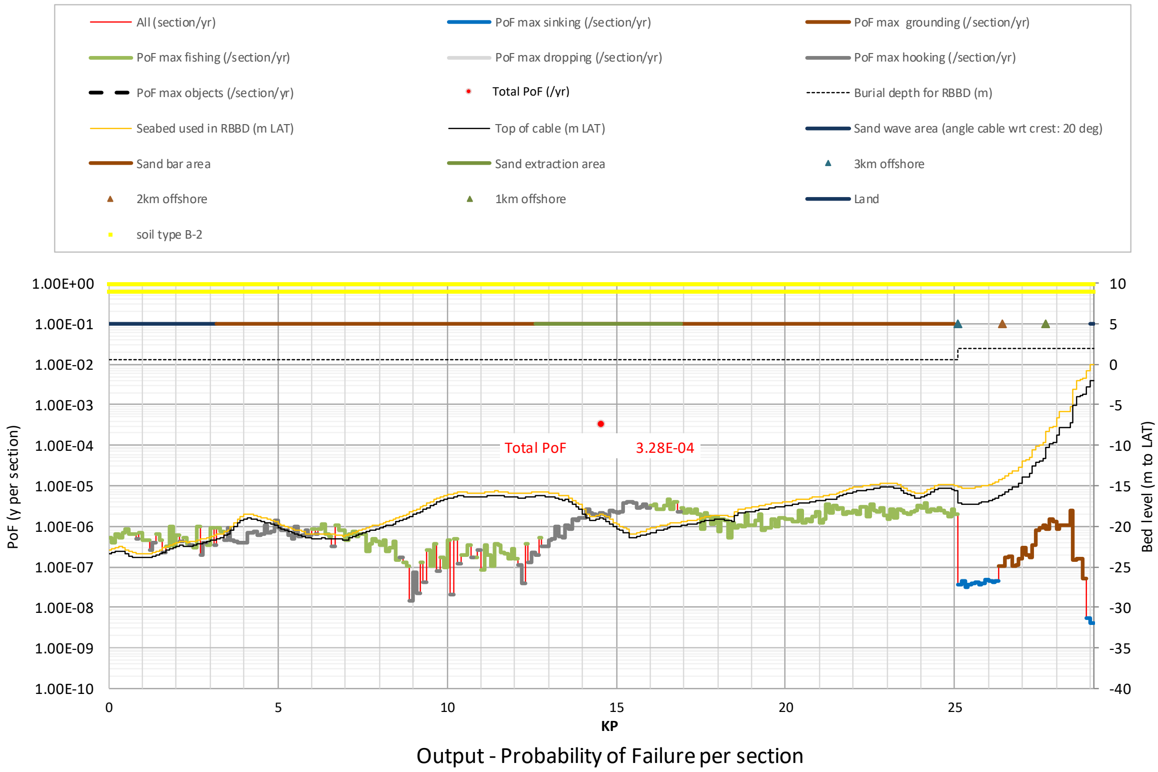
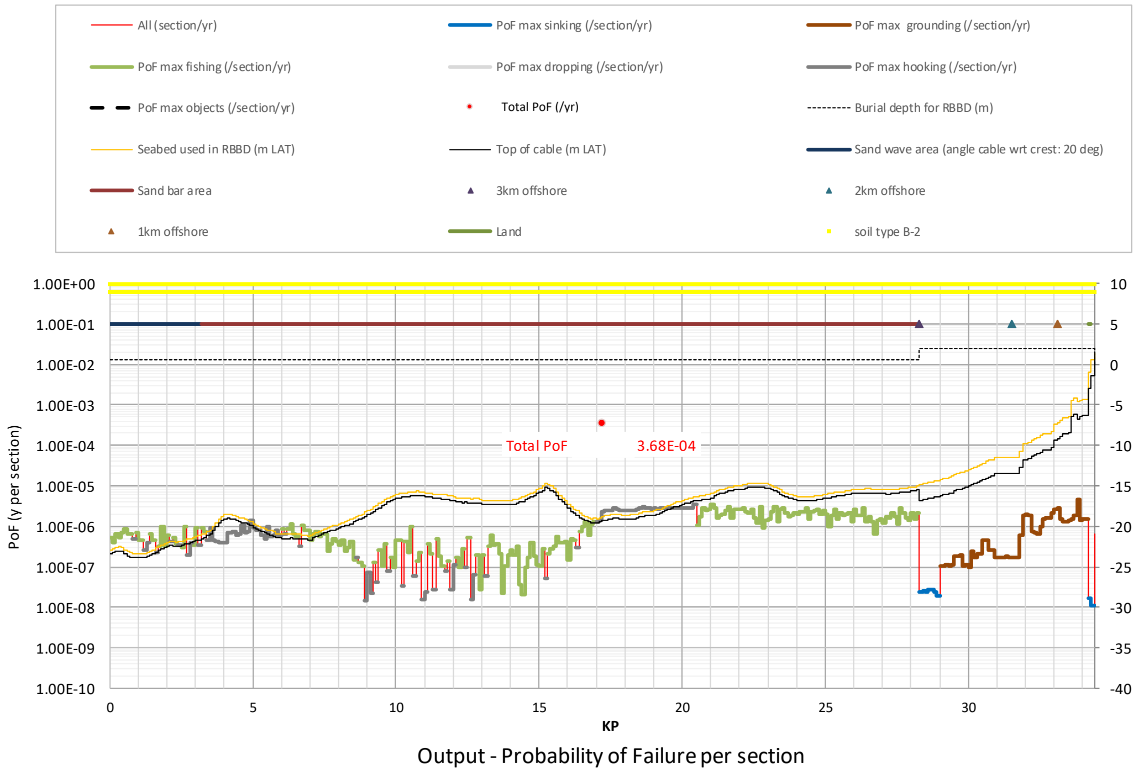


Figure A2.44 *Probability of Failure (PoF) for* ***Hollandse Kust (noord) route alternative 2****: Signal scenario = burial scenario 1 + pre-sweeping, burial depth is 2 m (nearshore, < 3km from shore), 0.5 m (offshore, > 3km)*



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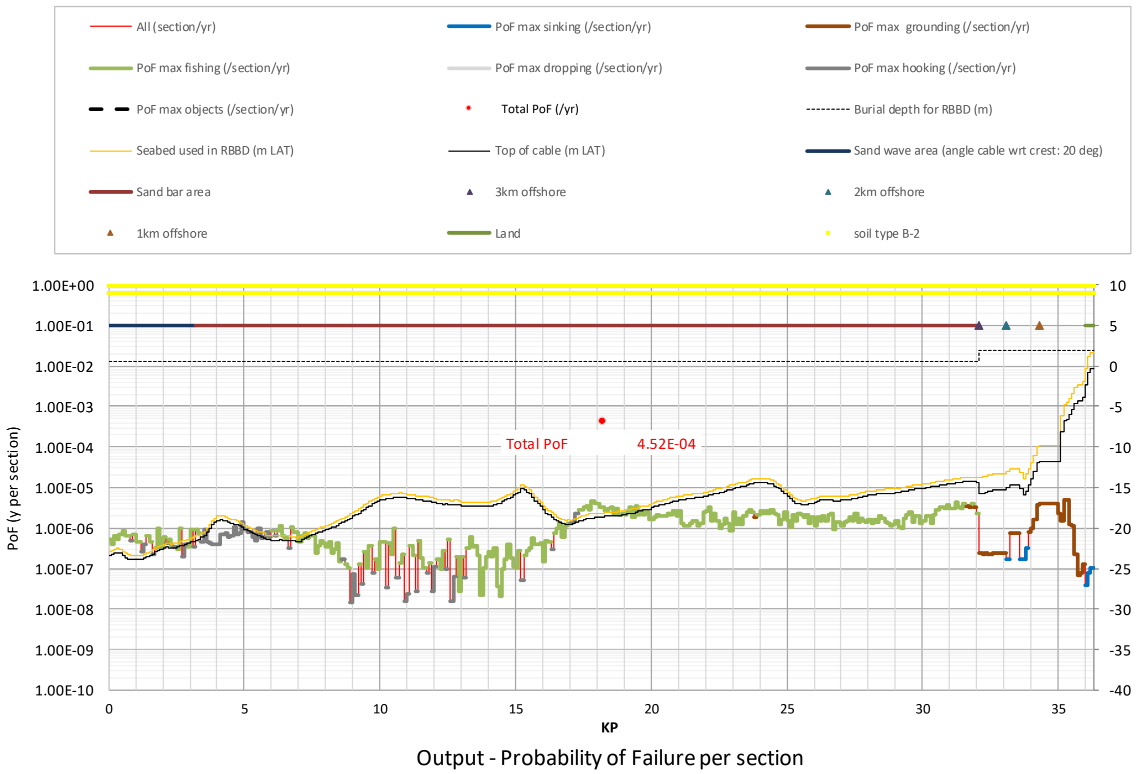
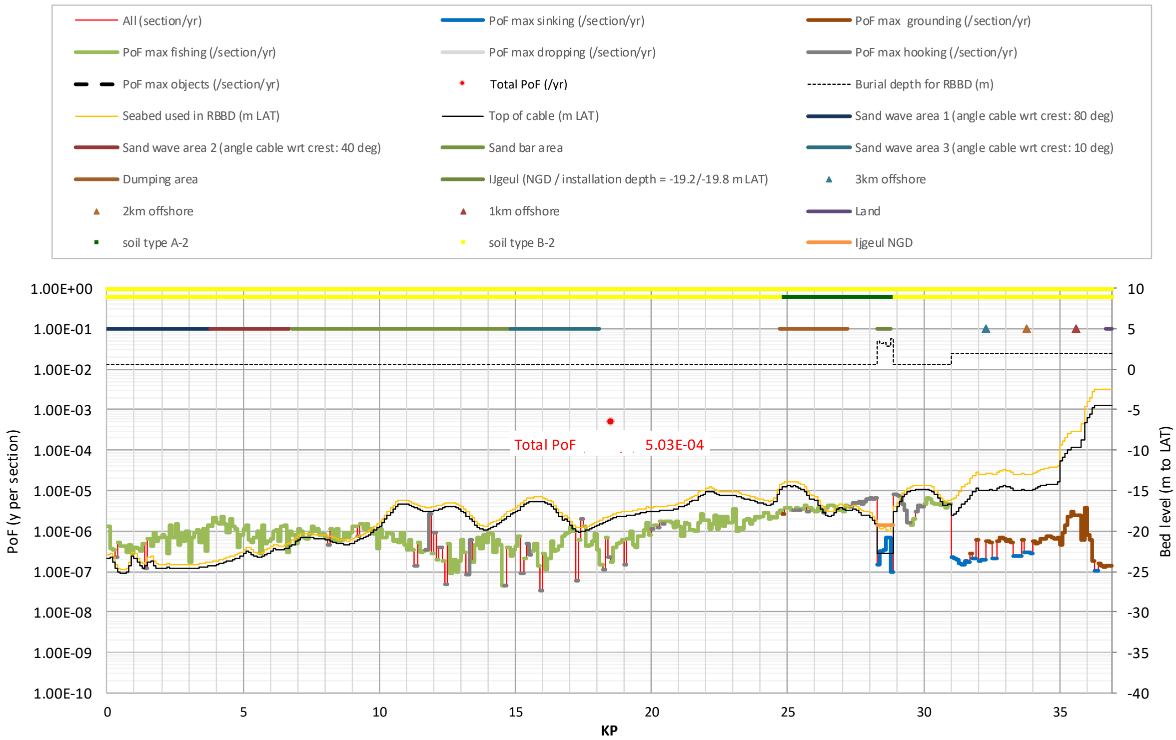
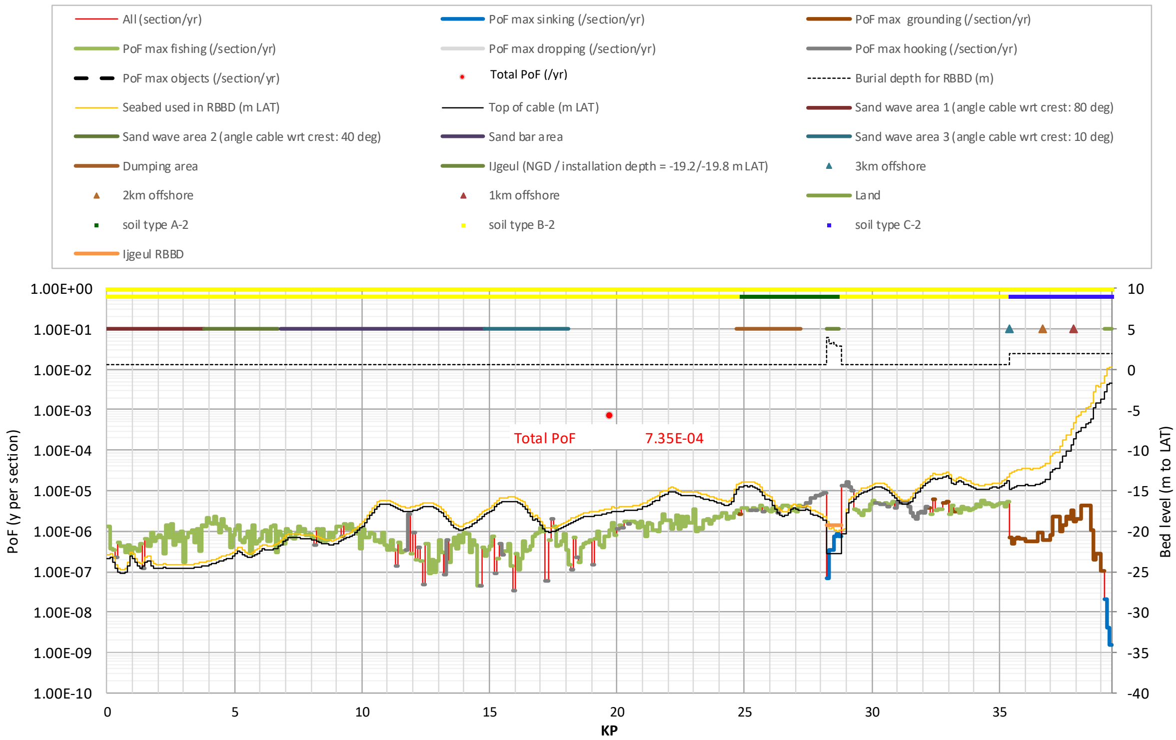


Figure A2.46 *Probability of Failure (PoF) for* ***Hollandse Kust (noord) route alternative 4 and 5****: Signal scenario = burial scenario 1 + pre-sweeping, burial depth is 2 m (nearshore, < 3km from shore), 0.5 m (offshore, > 3km)*



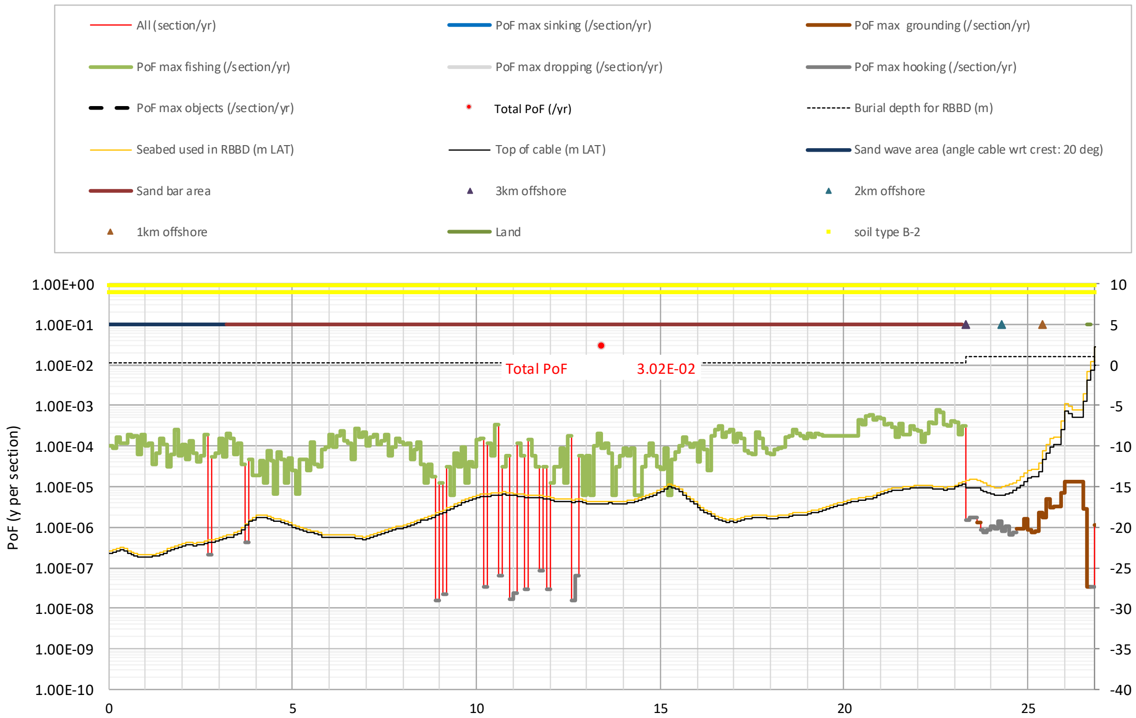
Output - Probability of Failure per section

Figure A2.47 *Probability of Failure (PoF) for **Hollandse Kust (noord) route alternative 6**: Signal scenario = burial scenario 1 + pre-sweeping, burial depth is 2 m (nearshore, < 3km from shore), 0.5 m (offshore, > 3km), burial in IJ-geul is 3m below -19.8 m LAT (= NGD-0.5m)*



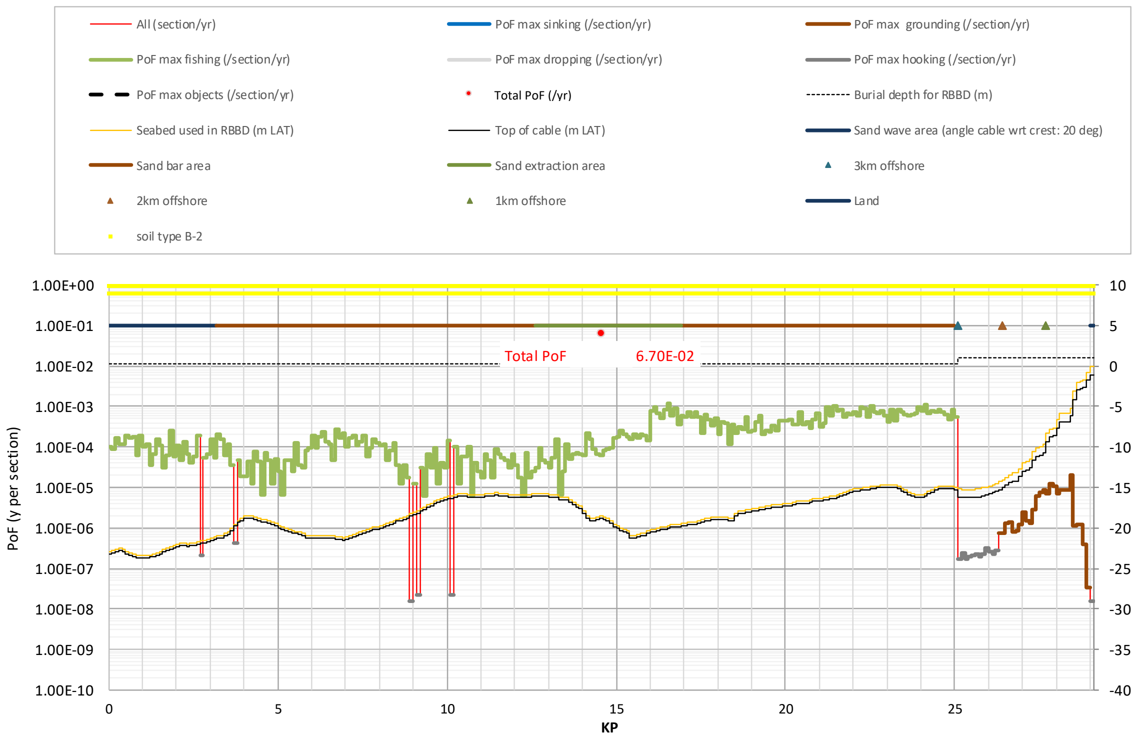
Output - Probability of Failure per section

Figure A2.48 *Probability of Failure (PoF) for **Hollandse Kust (noord) route alternative 7**: Signal scenario = burial scenario 1 + pre-sweeping, burial depth is 2 m (nearshore, < 3km from shore), 0.5 m (offshore, > 3km), burial in IJ-geul is 3m below -19.8 m LAT (= NGD-0.5m)*



Output - Probability of Failure per section

Figure A2.49 *Probability of Failure (PoF) for **Hollandse Kust (noord) route alternative 1**: Minimum scenario = burial scenario 2 + pre-sweeping, burial depth is 1 m (nearshore, < 3km from shore), 0.3 m (offshore, > 3km)*



Output - Probability of Failure per section

Figure A2.50 *Probability of Failure (PoF) for **Hollandse Kust (noord) route alternative 2**: Minimum scenario = burial scenario 2 + pre-sweeping, burial depth is 1 m (nearshore, < 3km from shore), 0.3 m (offshore, > 3km)*

Figure A2.51 *Probability of Failure (PoF) for* ***Hollandse Kust (noord) route alternative 3****: Minimum scenario = burial scenario 2 + pre-sweeping, burial depth is 1 m (nearshore, < 3km from shore), 0.3 m (offshore, > 3km)*

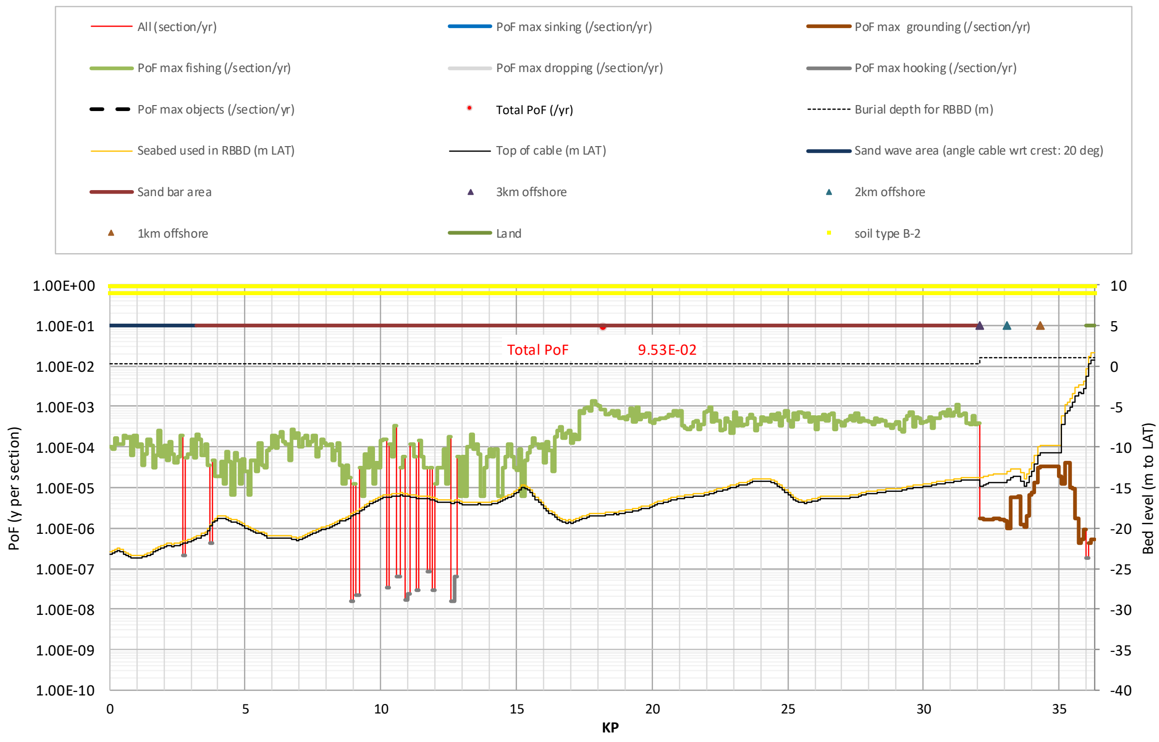


Figure A2.52 *Probability of Failure (PoF) for* ***Hollandse Kust (noord) route alternative 4 and 5****: Minimum scenario = burial scenario 2 + pre-sweeping, burial depth is 1 m (nearshore, < 3km from shore), 0.3 m (offshore, > 3km)*

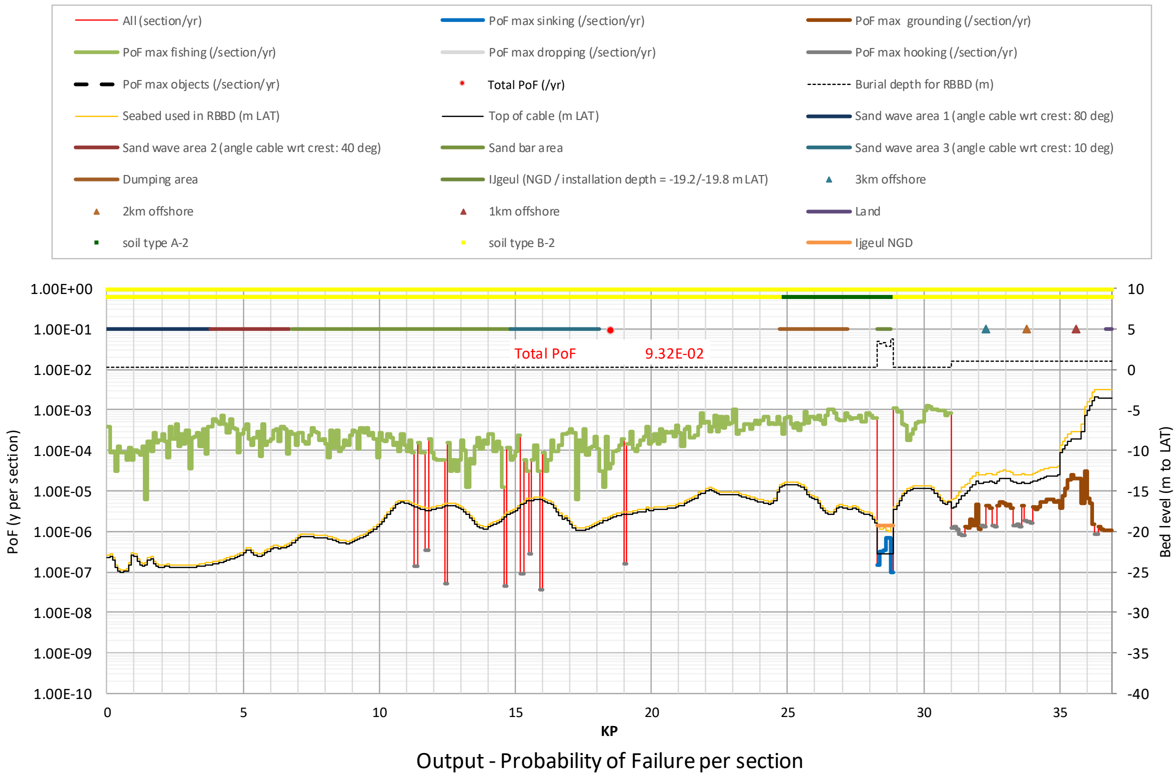
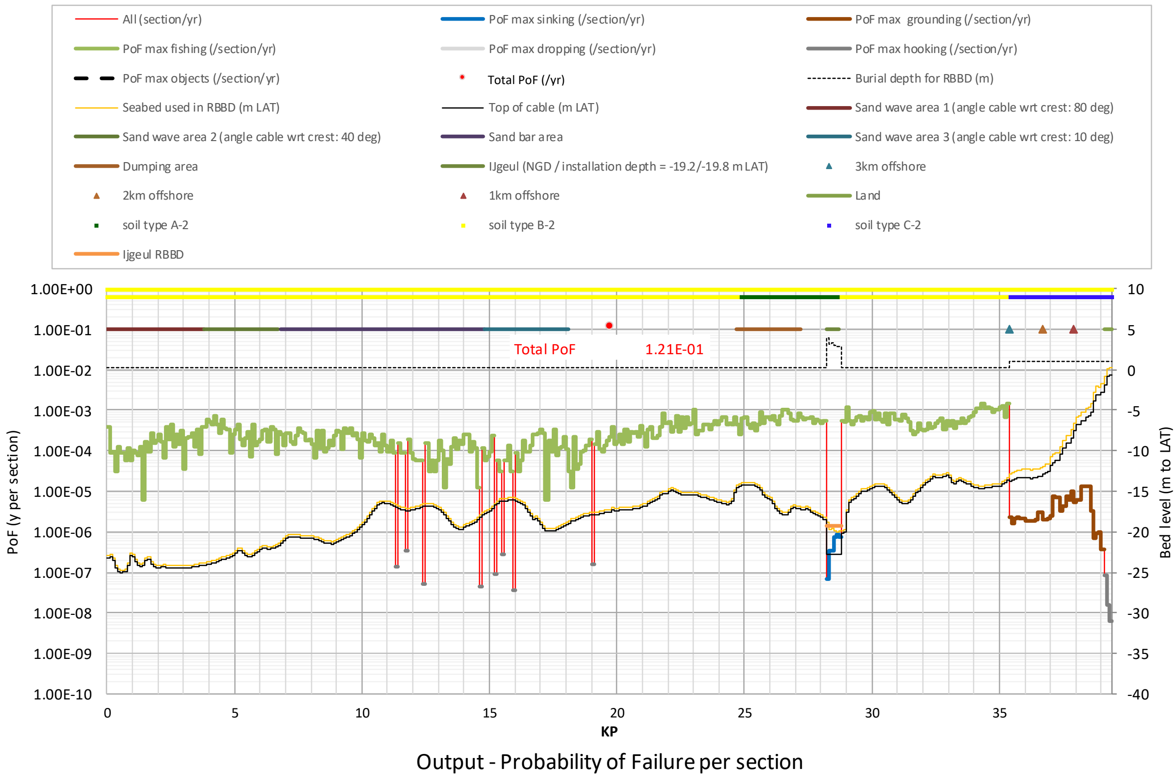


Figure A2.53 *Probability of Failure (PoF) for* ***Hollandse Kust (noord) route alternative 6****: Minimum scenario = burial scenario 2 + pre-sweeping, burial depth is 1 m (nearshore, < 3km from shore), 0.3 m (offshore, > 3km), burial in IJ-geul is 3m below -19.8 m LAT (= NGD-0.5m)*



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Seabed mobility study route comparison Windpark Hollandse Kust (noord)

Final

1901/U17229/C/LdW

17 November 2017

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1 INTRODUCTION

1.1 General

Different wind farms are being developed in the North Sea near the Dutch coast: Borssele, Hollandsche Kust (zuid) and Hollandsche Kust (noord). TenneT has the task to connect these wind farms with the onshore electricity system. TenneT ONL is preparing for the installation of the export cables which are to connect the Hollandse Kust Noord (HKN) wind farm with the electricity grid onshore in 2023. For the selection of a route amongst others a seabed mobility study is required to assess the impact of seabed mobility on the burial depth of the cables over their lifetime.

This report describes the morphological seabed mobility route comparison for wind farm Hollandsche Kust (noord) (HKN). The 7 different cable export route options for HKN under consideration are shown in Figure 1.1.

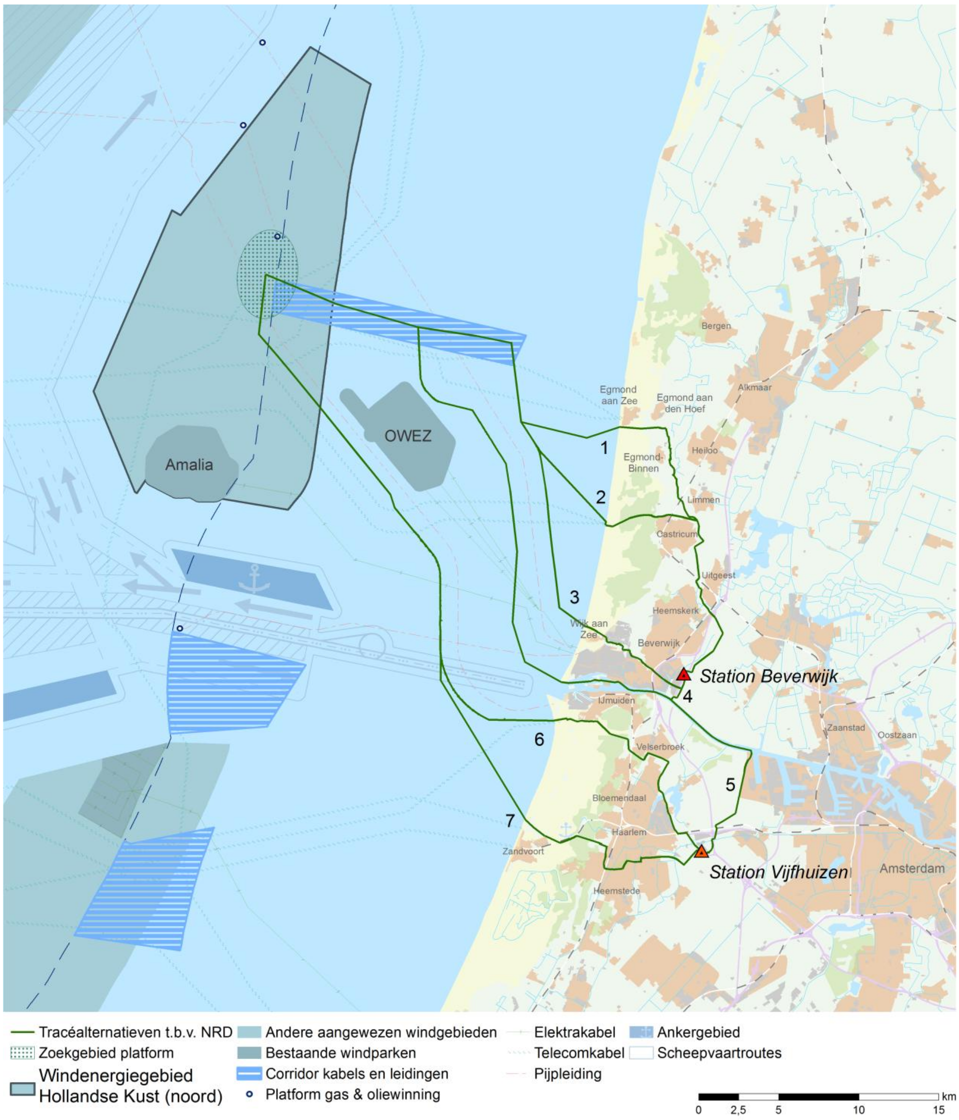

Figure 1.1 Different cable route options windfarm HKN under consideration by TenneT. Source: TenneT TSO B.V.

Export cable route options 1-4 connect wind farm HKN with land Station Beverwijk and export cable rout options 5-7 connect wind farm HKN with land Station Vijfhuizen. Route options 1-3 all three follow the same route eastward out of wind farm HKN, then at approximately 5 km from the shore they split up towards different landfall locations being Egmond aan Zee, near Castricum, and Wijk aan Zee respectively. Cable route options 4-5 also follow the east route out of wind farm HKN and then bend south towards a landfall near IJmuiden north pier. Cable route option 4 subsequently follows the Noordzeekanaal up to Station Beverwijk and cable route option 5 follows the Noordzeekanaal 5 km further and then bends south towards Station Vijfhuizen. Cable route options 6-7 go southeast out of wind farm HKN towards a landfall location near the south pier of IJmuiden for cable route option 6 and just north of Zandvoort for cable rout option 7. Cable route options 6-7 cross the IJgeul approach channel for the IJmuiden/Amsterdam port.

1.2 Study objectives

Goal of this study is to compare the route options with regards to seabed mobility and its impact on the installation and the operation and maintenance of the cables over their lifetime, as input to the VKA (voorkeursalternatief) process.

The cables are to be buried into the seabed for protection against external threats like fishing gear, anchors as well as protection of other users of the sea against interference with the cables. In order to provide sustainable protection to the cable by burial, the seabed mobility is to be taken into account during installation. The objective is to install the cables in such a way that no maintenance on the depth of burial is required over the lifetime of the cable, as previous CAPEX/OPEX comparisons have indicated that deeper burial at installation is significantly less expensive than shallower initial installation followed by maintenance of the Depth of Burial over the lifetime of the cables. In addition to that maintenance on the Depth of Burial adds an operational risk.

The results of this report are a first quantification of the seabed mobility based on already available bathymetry and geological data. The results are intended to be used for supporting the cable route selection process at TenneT. In a following phase an update of this study will be performed based on extra surveys of bathymetry and geology.

1.3 Study approach

For each cable route option for wind farm HKN offshore seabed mobility, landfall seabed mobility and offshore geological conditions are assessed and for route option 4-5 also JJmuiden harbour entry and Noordzeekanaal bed mobility. For this study no new surveys have been undertaken, therefore all analyses are performed based on already available bathymetry and geological data.

Chapter 2 deals with offshore seabed mobility. Historic bathymetry data sources are processed to identify stationary and migrating bed features. Specific attention is paid to the size and migration speed of offshore sand waves by different filtering operations on the bathymetry data. Offshore human influences like sand extraction and crossing of the IJgeul approach channel are analysed.

Chapter 3 deals with landfall seabed mobility. First the historical coastline evolution and nourishments are analysed. The influence of the Dutch coastal maintenance strategy is summarised. For 1 in 100 year design conditions the coastal erosion is modelled.

Chapter 4 continues with bed mobility at the IJmuiden harbour entry and Noordzeekanaal. Historical depth surveys and the maintenance dredging strategy are presented as well as channel design depths at different locations. Possible future developments are mentioned.

In Chapter 5 offshore geological conditions are presented based on boreholes and literature.

Finally the report ends with a synthesis of all findings on seabed mobility for each cable route option in Chapter 6.

2 OFFSHORE SEABED MOBILITY

2.1 Introduction

This chapter describes the offshore seabed mobility for the different cable route options for HKN. Aim is to provide a first assessment of the natural seabed mobility of relevant bedforms and to describe relevant anthropogenic effects.

2.2 Morphological description area

A sandy seabed is almost never completely flat. There exist all types of wave like bed shapes which occur under influence of the interaction of hydrodynamic forces (tides, flow, waves) and the sediment forming the seabed. Table 2.1 mentions the most important bed shapes on a sandy sea bed together with typical dimensions and the potential influence they have on the cable burial depth.

The burial depth of a cable is prescribed as 3m within 3 km from the coast and 1m more offshore. Therefore megaripples and ripples with a typical height of decimetres and centimetres are not critical for the cable burial depth even though they are mobile because the resulting bed level variations are smaller than the burial depth. On other parts of the North Sea, for example along the BritNed cable, there are megaripples of 1-1.5m high which are significant for the burial depth of cables. However, in this part of the North Sea along the cable route options considered for windfarm HKN there are no megaripples of that size. Sand banks can reach heights up to 10s of metres. In estuaries sand banks change height and position over time, but on the North Sea they are stationary relative to the cable lifetime and therefore are no threat for cables. Sand waves are critical for the burial depth of cables because they possess the combination of a height which can be more than the burial depth, a length of hundreds of metres and migration speeds up to 10 m/yr. In the lifetime of a cable of several decades a sand wave can move several hundred metres and an individual location could be crossed by sand wave crests and troughs. Hence, a cable placed in an area with sand waves should anticipate a change in bed level over time which lies in the order of the sand wave height. Because this height is in the same order or more as the burial depth itself this should be taken into account when determining the burial depth and maintenance strategy. Therefore this study pays special attention to sand waves.

Table 2.1 Morphological sandy bed features

	Typical length	Typical height	Mobile?	Influence on burial depth?
Sand banks	Kilometres	10s metres	Stationary	No
Sand waves	100s metres	Metres	Mobile	Yes
Megaripples	10s metres	Decimetres	Mobile	No
Ripples	Centimetres	Centimetres	Mobile	No

A composite bathymetry map has been generated based on bathymetry survey data of the Netherlands Hydrographic Office (NLHO) of the Netherlands Royal Navy. In total 23 different surveys were available for different moments in time in the area around windfarm HKN. The bathymetry data has a x,y resolution of 25x25m. All these 23 different bathymetry maps have been combined for a composite most recent, second most recent and third most recent bathymetry map. It turned out that there was sufficient data to fill a most recent and second most recent bathymetry map, but there was insufficient data available to fill a third most recent bathymetry map covering the complete area. Therefore the analyses of the offshore seabed mobility in this chapter have been conducted based on the most recent and second most recent bathymetry maps.

The most recent bathymetry map is presented in Figure 2.1 and has been surveyed between 2001 and 2016. The two white squares indicate zones where no bathymetry data is available. Windfarm HKN is located at about 20 km from the coast in front of the North Holland coast at a depth of about 25m (LAT). In the zone around windfarm HKN and the different cable route options the depth varies between 0 and 30m (LAT). Anthropogenic features as the IJgeul approach channel to IJmuiden of about 20m depth (LAT) and some sand extraction sites can be recognised with locally deeper bed levels.

The natural morphological system around windfarm HKN can be characterised by areas with sand waves, areas with sand banks, areas with sand waves on top of sand banks and areas without sand banks or sand waves, see Figure 2.1 and Figure 2.2. At the coast the depth increases rapidly within 2km from 0m to 15m (LAT). The sand waves in this area are mainly concentrated south and south east of windfarm HKN, with additional smaller patches of sand waves within windfarm HKN and around different cable route options. The sand waves have a length of several hundred metres and an orientation of 30-40^{o}N. The zone between windfarm HKN and the contour at 2km from the coast has sand banks of about 5m high oriented about 35^{o}N.

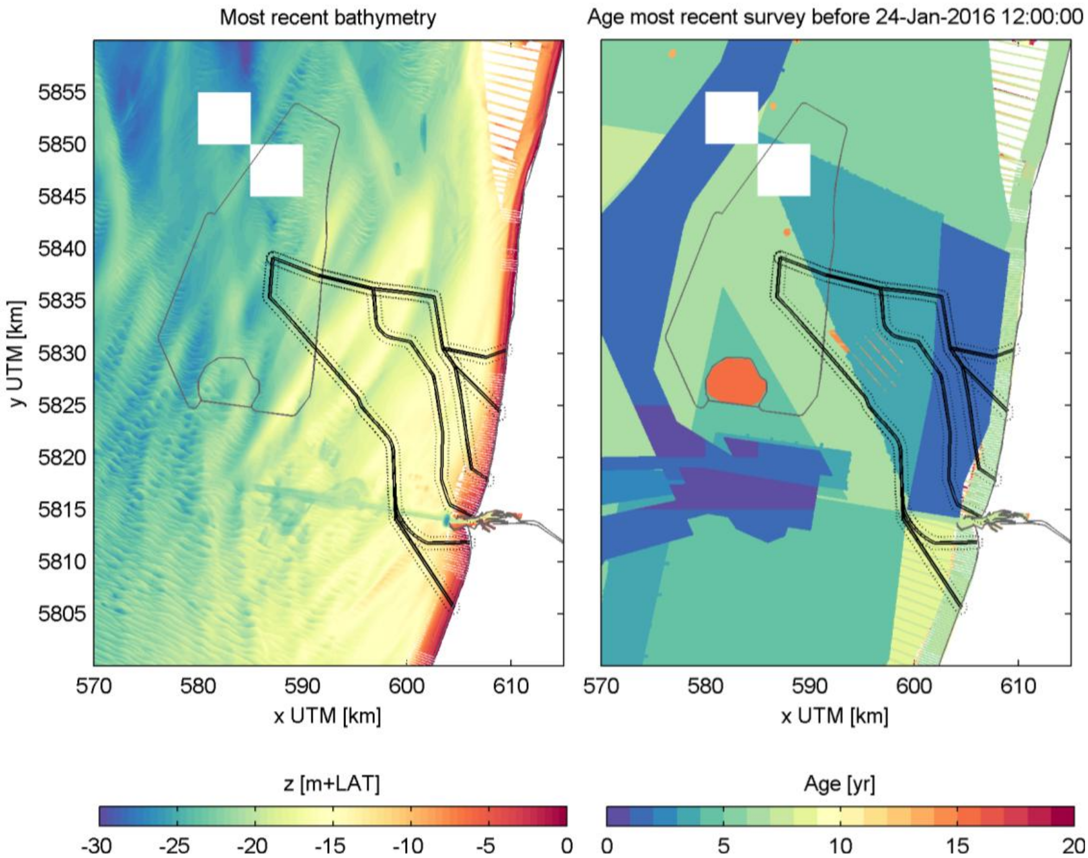

Figure 2.1 Left panel: Most recent bathymetry map. Right panel: Age of composite bathymetry data.

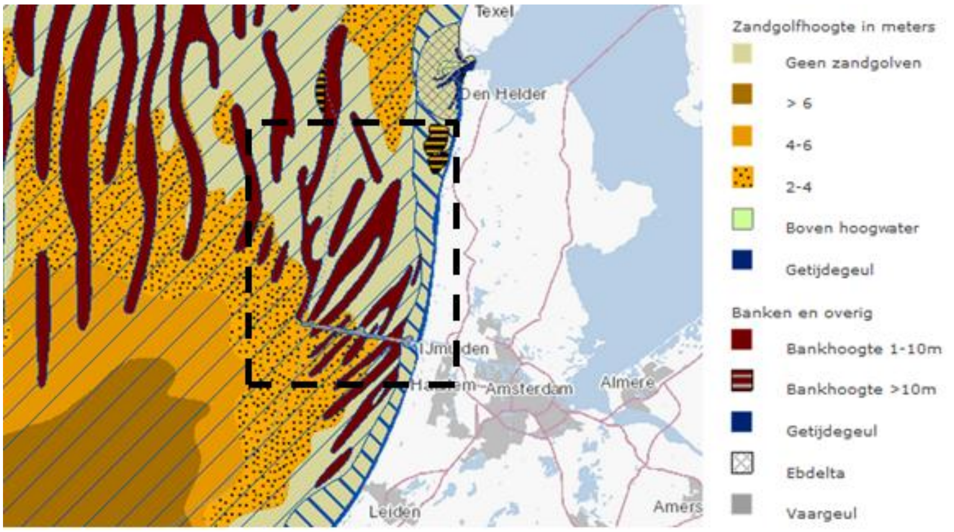

Figure 2.2 Geomorphology map North Sea, black dashed lines indicate area around HKN of Figure 2.1. Source: Noordzeeatlas [https://www.noordzeeloket.nl/Beheer/noordzee-atlas/watersysteem/geomorfologie.aspx (visited 11 August 2017)]

2.3 General seabed mobility

General seabed mobility has been assessed from the most recent and second most recent bathymetry. The second most recent bathymetry map is shown in Figure 2.3 and has been surveyed between 1995 and 2015.

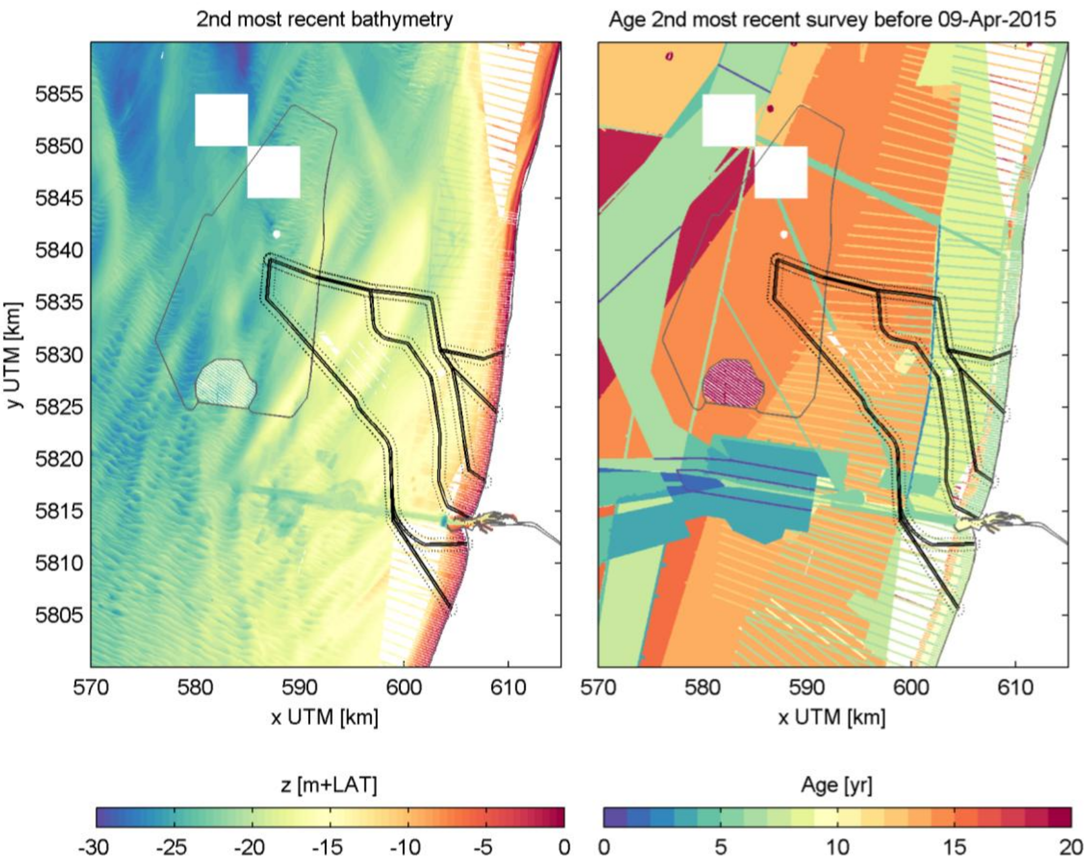

Figure 2.3 Left panel: Second most recent bathymetry map. Right panel: Age of composite bathymetry data

The difference between the most recent and second most recent bathymetry shows the change in bed level over time, see Figure 2.4. A third most recent bathymetry is missing, therefore no trend in dz/dt over time can be calculated. In Figure 2.4 the patches with constant colours are caused by small differences in reference level of individual survey campaigns, but the red-blue lines around the sand waves show the movement of sand waves over time. Also anthropogenic influences as maintenance of the IJmuiden approach channel and some sediment disposal and sand extraction areas are recognisable in Figure 2.4 by substantial bed level changes over time. The red-blue patterns around sand waves indicate that they move from southwest to northeast. Figure 2.4 verifies that the sand banks in this area are stationary as there is no substantial change in bed level visible at the sand bank edges. This further justifies to not study sand banks specifically in this study.

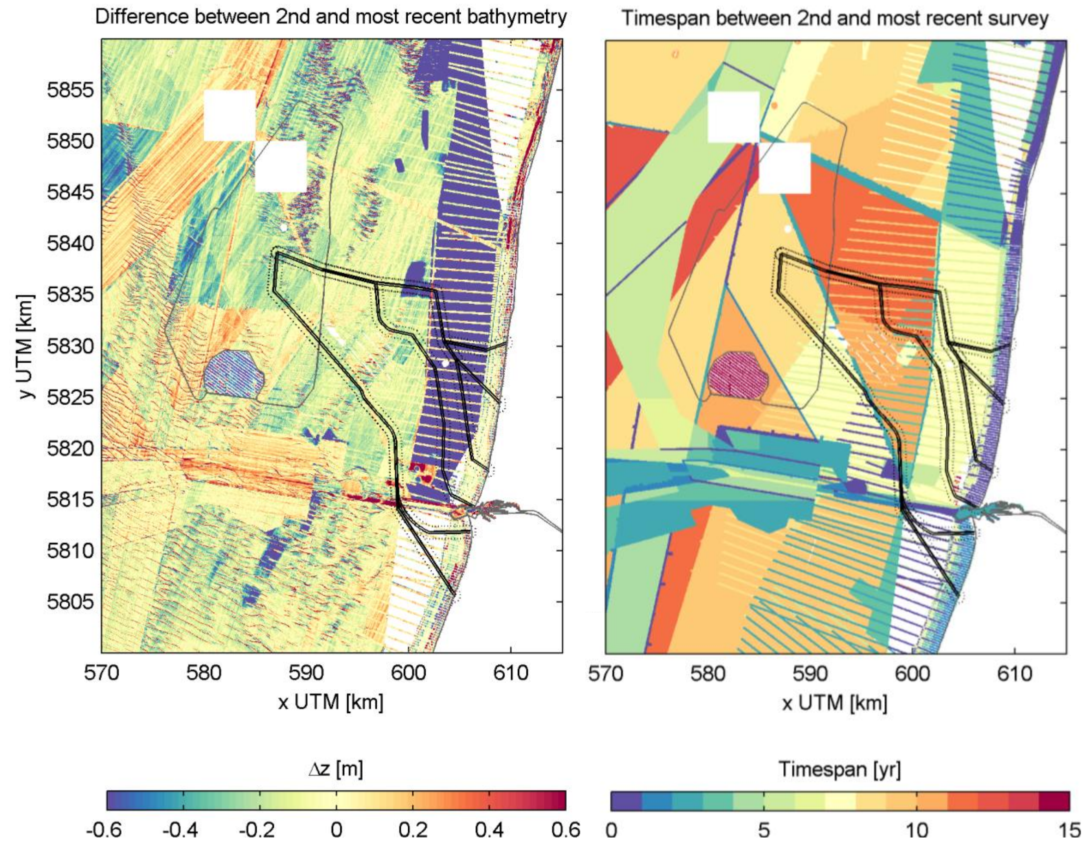

Figure 2.4 Left panel: Difference between most recent and 2nd most recent bathymetry map showing change in bed level over time. Right panel: Time span between most recent and 2nd most recent bathymetry.

The most recent and second most recent bathymetry have been interpolated along the different cable route options to show the sea bed mobility along the different routes in more detail. An example for cable route alternative 1 is given in Figure 2.5. Figures for all cable route alternatives are given in Appendix A. The bathymetry is shown along the complete route as well as along 4 km stretches; the latter showing more detail. The influence of reference level issues of individual survey campaigns is visible by the occasional sudden jumps in the blue line of the second most recent bathymetry.

Both in Figure 2.4 and Figure 2.5 an issue with the vertical reference level of some of the bathymetry data sets contained in the 2nd most recent bathymetry is apparent with a difference in offset of about 1 meter. This error in vertical offset does not influence the analysis of sand waves in this study as the locations with sand waves along the cable route options do show this error in vertical offset.

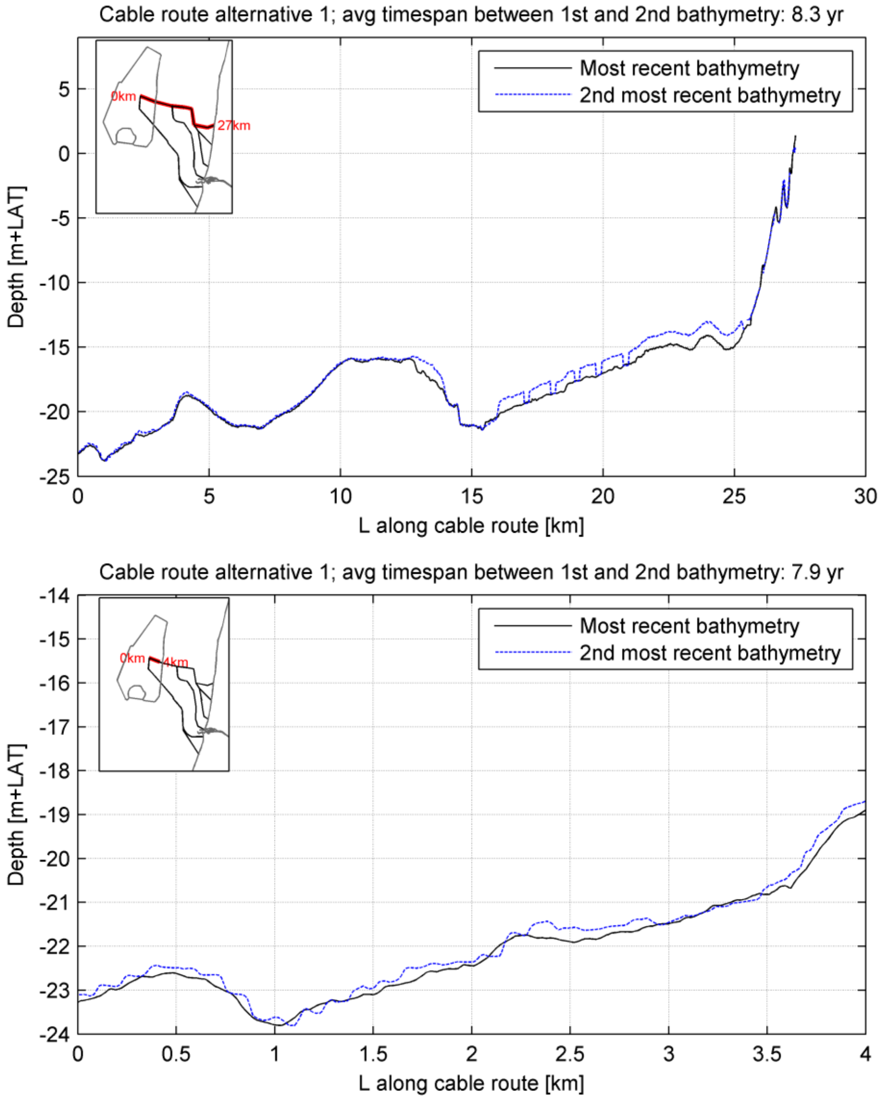

Figure 2.5 Example plot of bathymetry along cable route alternative 1. Top panel: full route, bottom panel: stretch of 4 km.

2.4 Analysis sand waves

2.4.1 Sand wave field

The most recent bathymetry map has been filtered with an ellipse shaped filter of 1500m long, 200m wide with an angle of 36^{o}N (this is the characteristic sand wave angle) to isolate the sand waves. The filter size is chosen to be longer than the characteristic sand wave length in order to eliminate the sand waves from the most recent bathymetry effectively. The resulting sand wave field is shown in Figure 2.6 (left). Sand waves have bed slopes perpendicular to the sand wave crest. The slope behind the crest is gentle and the slope in front of the crest is steep, and sand waves tend to move into the direction of the steepest slope (Deltares 2016b). Therefore, like in previous study (Deltares 2016a), the sand wave direction is determined from the orientation of the steepest bed slope. The bed slope is determined by spatially differentiating the sand wave field, see Figure 2.6 (right). In boxes of 1000x1000m first the steepest bed slope is determined, see Figure 2.7 (left). Subsequently the migration direction of sand waves is determined from the orientation of the steepest bed slopes, see Figure 2.7 (right). Figure 2.7 (left) also gives a clear visualization where the largest sand waves can be found: namely south-southwest of wind farm HKN. The migration direction of the sand waves found in Figure 2.7 (left) are presented in a histogram in Figure 2.8. The majority of the sand waves have a direction 25-45^{o}N with its centre around direction 36 ^{o}N.

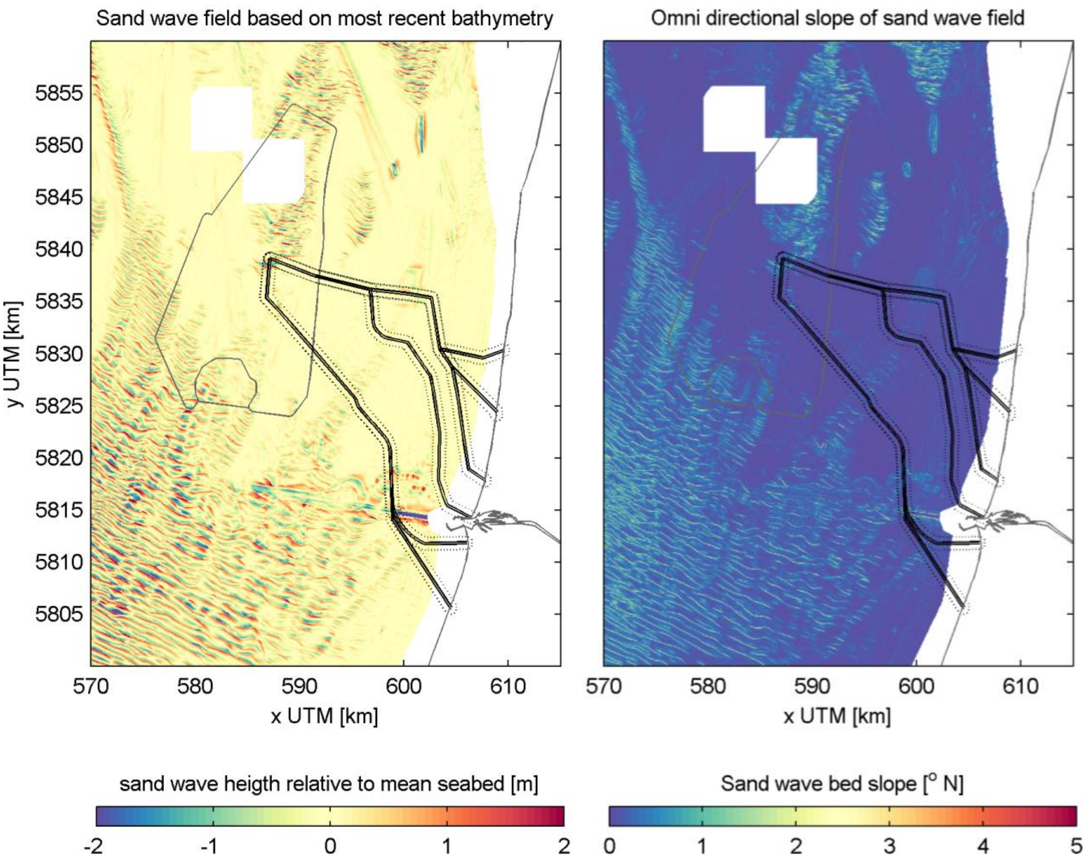

Figure 2.6 Left panel: Sand wave field. Right panel: Bed slopes of sand wave field.

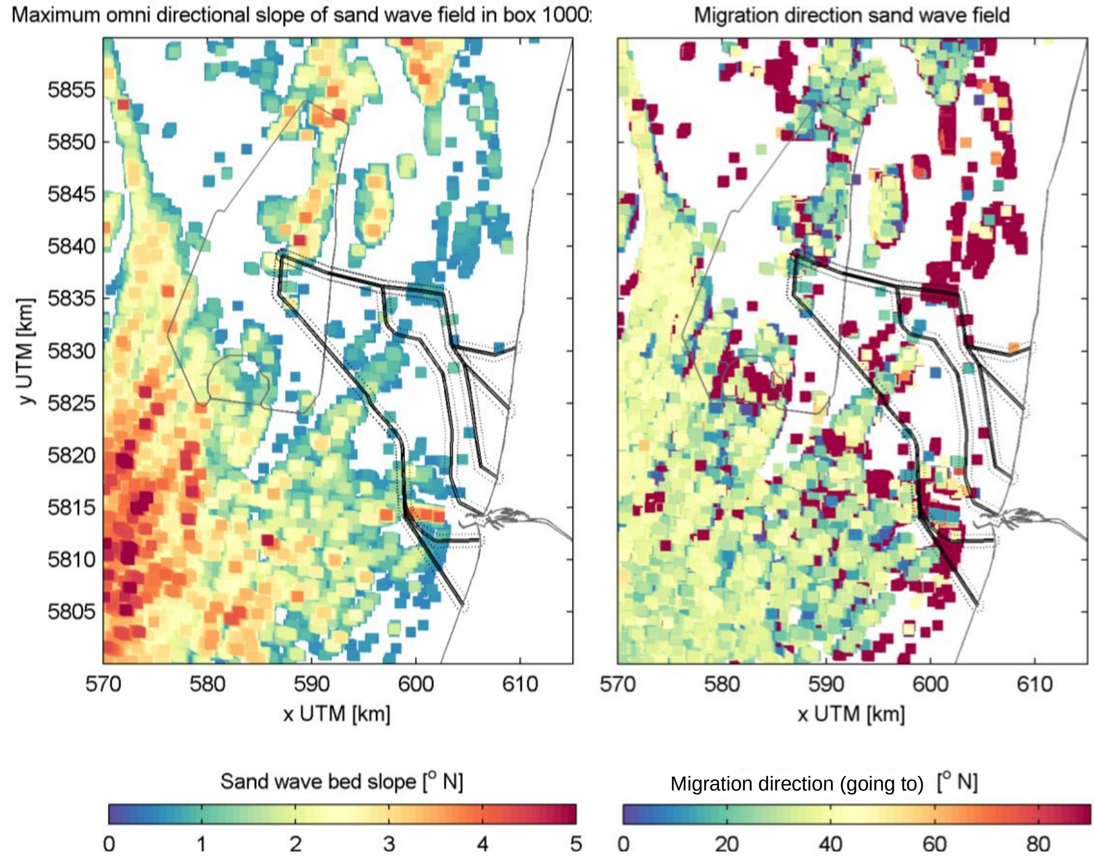

Figure 2.7 Left panel: Steepest bed slope in boxes of 1000x1000m. Right panel: Migration direction sand waves determined from the direction of the steepest bed slope in boxes of 1000x1000m.

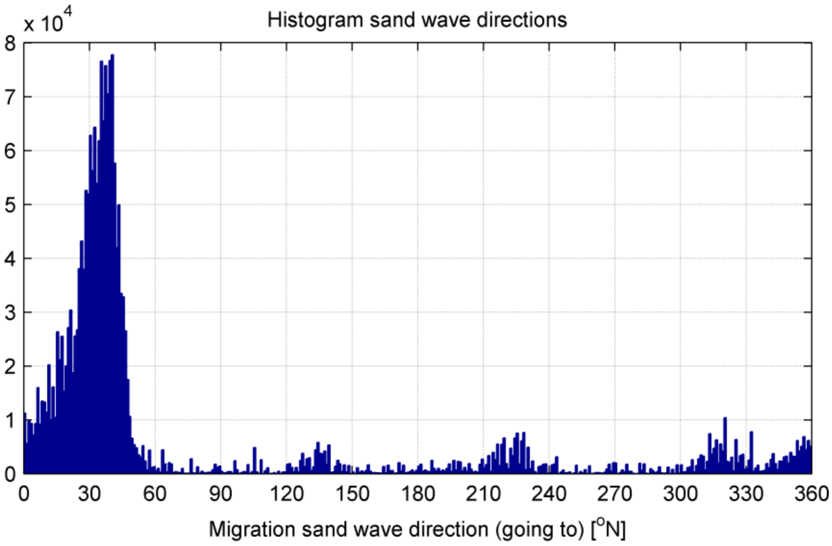

Figure 2.8 Histogram migration direction sand waves.

2.4.2 Sand wave transects

For six locations at the different cable route options where there are sand waves they are analysed in detail by a Fourier analysis along a transect. Figure 2.9 shows the location and direction of the six transects, the direction of the transect is based on the migration direction of the sand waves from Figure 2.7 (right).

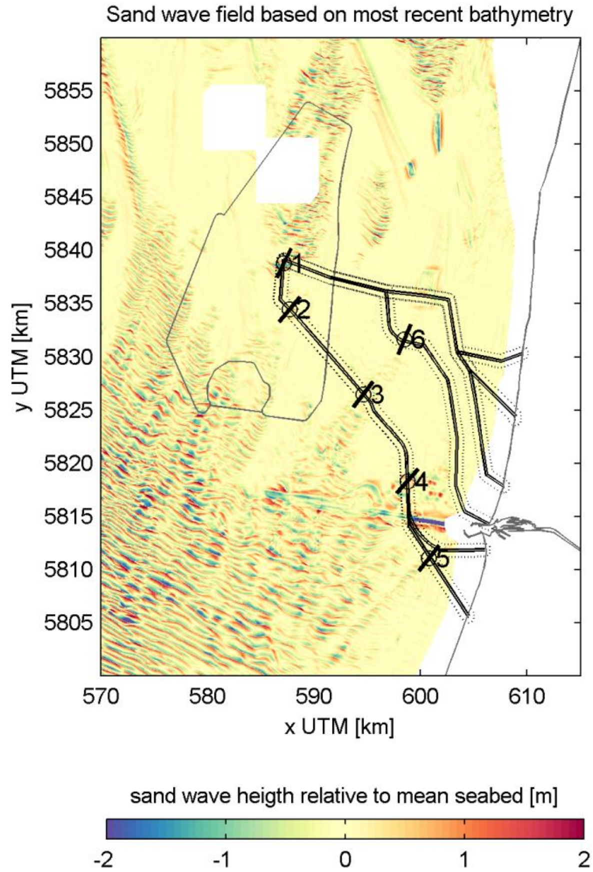

Figure 2.9 Location six transects for sand wave Fourier analysis

The raw sand wave signal along each transect is filtered by a Fourier analysis of which the highest frequencies are removed to eliminate smaller bed features like megaripples. From the Fourier filtered sand wave signal individual crests and troughs are tracked for each of the six transects. This is done for the most recent and second most recent bathymetry. In this manner sand wave height and length can be determined and the change in position over time of the crests and troughs determines the migration speed of the sand waves. See the sand waves along transect 1 as an example in Figure 2.10. For the other five transects similar analyses have been made, see Table 2.2 for the resulting average sand wave characteristics. For transect 5 it was not possible to determine the sand wave migration speed because there is no 2nd recent bathymetry available at this location. The sand waves along the different cable route options have mean heights between 0.6-1.2m, with a mean length between 450-1000m and a mean migration speed of 2.8-9.6 m/yr.

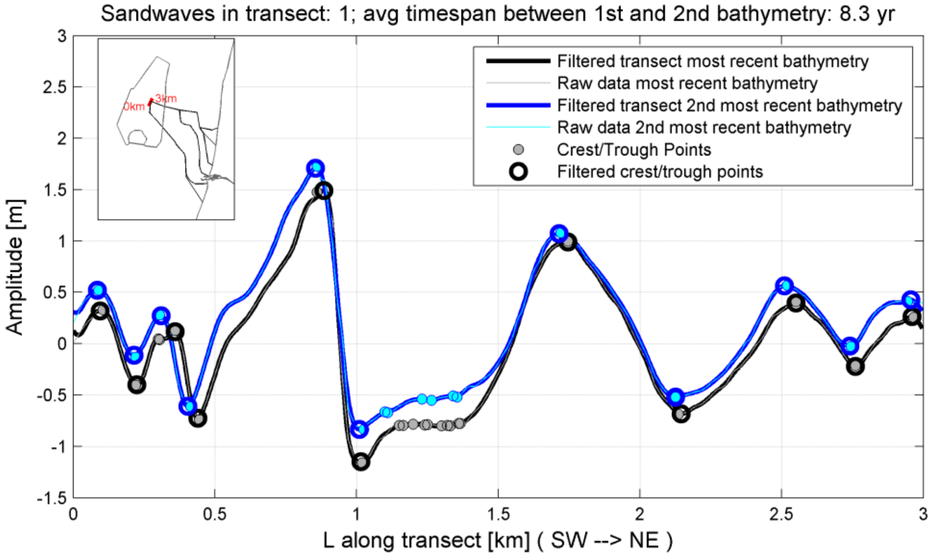

Figure 2.10 Fourier filtered sand waves along transect 1

Table 2.2 Mean sand wave characteristics of the 6 transects

Transect	Along cable route option	Migration speed [m/yr]	Height [m]	Length [m]
1	1-7	2.8	1.2	600
2	6,7	3.7	0.8	660
3	6,7	7.4	0.6	600
4	6,7	3.7	1.2	1000
5	6,7	-	0.7	450
6	4,5	9.6	0.6	720

The sand wave migration speeds, lengths and heights found in this study are in line with previous studies. A study for wind farm Hollandsche Kust Zuid found sand wave lengths of 200-1000m, sand wave heights of 1.1-4m and migration speeds of 0.7-5.2 m/yr with an increasing south to north trend in migration speed (Deltares 2016b). Near Texel an average sand wave length of about 700m, height of about 2m and migration speed of 16-19 m/yr was found (TNO 2004).

2.4.3 Sand wave characteristics for different cable route options

The average sand wave values in Table 2.2 are determined based on 3km long transects containing about 3-5 sand waves, therefore there is an uncertainty bandwidth around these values indicated by the range enveloped by the min and max values of the individual sand waves in each transect. This range of expected sand wave characteristics is shown in Figure 2.11. Along transect 1 and 2 the expected range in sand wave speed is in the order 1-5 m/yr which is not far from the mean values found in Table 2.2. In transects 3,4,6 the fastest sand waves are much faster leading to a range in the order 1-15 m/yr, but even these fastest sand waves are in line with sand wave migration speeds of 16-19 m/yr (TNO 2004) found near Texel. Along transect 3-7 sand wave heights as small as 0.2-0.3 m are found, which is in the range of the typical height of megaripples, but their length is still several hundred meters qualifying them as sand waves and not as megaripples.

Table 2.3 gives the number of sand waves along each cable route option, the length of each cable route option influenced by sand waves and the range of expected sand wave characteristics along each cable route option.

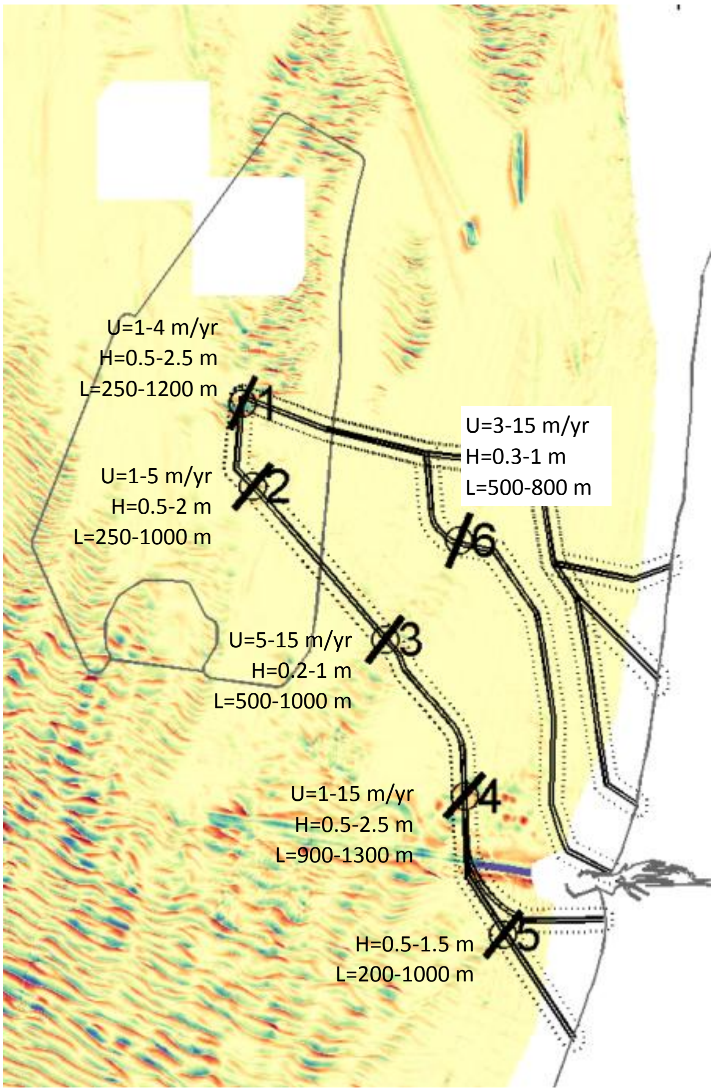

Figure 2.11 Range of sand wave characteristics

Table 2.3 Sand wave characteristics of each cable route option

Cable route option	Migration speed	Height (min-max)	Length (min-max)	Orientation	Number of sand waves along route	Length route influenced by sand waves
1	1-4 m/yr	0.5-2.5 m	250-1200 m	16^oN	3	4 km
2	1-4 m/yr	0.5-2.5 m	250-1200 m	16^oN	3	4 km
3	1-4 m/yr	0.5-2.5 m	250-1200 m	16^oN	3	4 km
4	1-15 m/yr	0.3-2.5 m	250-1200 m	$12\text{-}16^oN$	6	5 km
5	1-15 m/yr	0.3-2.5 m	250-1200 m	$12\text{-}16^oN$	6	5 km
6	1-15 m/yr	0.2-2.5 m	200-1300 m	$16\text{-}32^oN$	15	13 km
7	1-15 m/yr	0.2-2.5 m	200-1300 m	$16\text{-}32^oN$	15	13 km

2.5 Anthropogenic effects

2.5.1 Crossing IJgeul

Cable route option 6 and 7 cross the IJgeul at 5km distance from the pier of IJmuiden. The IJgeul is the approach channel for the Port of Amsterdam and Port of IJmuiden. At the crossing location the IJgeul is 450m wide with a nautical depth of LAT-19.2m/LAT-19.3m and a construction depth of LAT-19.8m. Actual depths in the IJgeul are a bit more with surveyed depths in 2016-2017 at the deepest locations around cable route option 6/7 of LAT-20.5m (west part corridor) to LAT-22.5m (east part corridor). The depth of the first 5km of the IJgeul is surveyed four times per year and the rest is surveyed once a year. The first 5km encounters more sedimentation than the rest and therefore is surveyed more often. After every depth survey it is decided whether maintenance dredging is required. Typically maintenance dredging of the IJgeul takes place once a year and typically only some ridges and locations near the sides need to be deepened[1]. Typical bed level changes between different surveys of the IJgeul are 0-0.2 m.

Note that as a result of the New Sea Lock at IJmuiden, to be finished in 2019, the Port of Amsterdam will attract larger ships. This could lead to an adjustment of the IJgeul, but at the moment there are no specific development plans for the IJgeul[2].

2.5.2 Sediment extraction and placement

In Figure 2.12 four sand extraction sites with depths of 20-25m LAT are indicated where sand has been extracted during the last 5-15 years. Within each sand extraction area a couple of meters of sediment is extracted (see Figure 2.12 right) and the resulting sea bed is a couple of meters deeper than the surrounding sea bed (see Figure 2.12 left). Of these four sand extraction sites only one is near a cable route option; this sand extraction area is indicated with 'A' in Figure 2.12. Sand extraction area 'A' is located right next to cable route options 1-3, has a depth of LAT-20m and is deepened about 3m. However, sand extraction area 'A' stops at the edge of cable route options 1-3. This is confirmed by the sand extraction strategy map of the Noordzeeloket in Figure 2.13 which shows that cable route options 1-3 up to the sharp corner to the south follow a preferred route for cables and pipelines and in this zone there is no permit issued for sand extraction. Within 500m from cables and pipelines sand extraction is not allowed according to Beleidsnota Noordzee 2016-2021 (Ministerie I&M en EZ 2015).

Sand extraction (20 million m^3) for the Hondsbossche en Pettemerzeewering coastal reinforcement project has taken place more to the North of the cable route options of wind farm HKN and sand extraction for the Sand motor (20 million m^3) and Maasvlakte 2 port extension (200 million m^3 plus 40 million m^3 for 2nd phase up to 2033) has taken place more to the south of wind farm HKN. These large sand extraction areas are not close to the cable route options for wind farm HKN.

Near the IJgeul strips with an increase of bed level over time are visible in Figure 2.12 (right) which is caused by the influence of the IJgeul, see Section 2.5.1. Sediment placement area 'Loswal IJmuiden' is shown with the dark gray 'unloading quay allocation' boxes in Figure 2.13 and an approximate translation of these contours to Figure 2.12 shows that the increase of bed level visible in Figure 2.12 (right) is associated with sediment placement within 'Loswal IJmuiden'. Cable route option 4/5 and 6/7 cross 'Loswal IJmuiden' and it is advised to consult Rijkswaterstaat on how they deal with cables

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[1] Pers. Comm. H. Van der Gouwe / N van der Sleen, Rijkswaterstaat Zee en Delta

[2] Pers. Comm. H. Van der Gouwe / N van der Sleen, Rijkswaterstaat Zee en Delta

crossing a sediment placement area in case one of these cable route options would be selected by TenneT. East part of cable route 4/5 corridor is outside 'Loswal IJmuiden', therefore it would be possible to avoid crossing this sediment placement area with cable rout 4/5. To guarantee a minimum burial depth of the cables, sediment placement is positive, but the associated dredging operations might pose a danger for the cables. Moreover, the burial depth should not become more than allowable from a thermal perspective given the thermal resistivity of the disposed sediment is limited. Hence, disposal of sand on top of the cable can be allowed but disposal of silt and clay cannot be allowed.

Summarising, there are no permitted sand extraction areas at the 7 considered cable route options. Next to cable route options 1-3 approximately 3m sand has been extracted up to LAT-20m in the past, however nowadays this part of cable route options 1-3 follows a preferred route for cables and pipelines and no permit is issued for sand extraction, see Figure 2.13. Additionally within 500m from cables and pipelines sand extraction is not allowed (Ministerie I&M en EZ 2015, Beleidsnota Noordzee 2016-2021). Cable route options 4/5 and 6/7 cross sediment placement area 'Loswal IJmuiden' and it is advised to contact Rijkswaterstaat on how they deal with cables crossing a sediment placement area in case one of these cable route options would be selected by TenneT. Within the cable route option 4/5 corridor it is possible to avoid 'Loswal IJmuiden'.

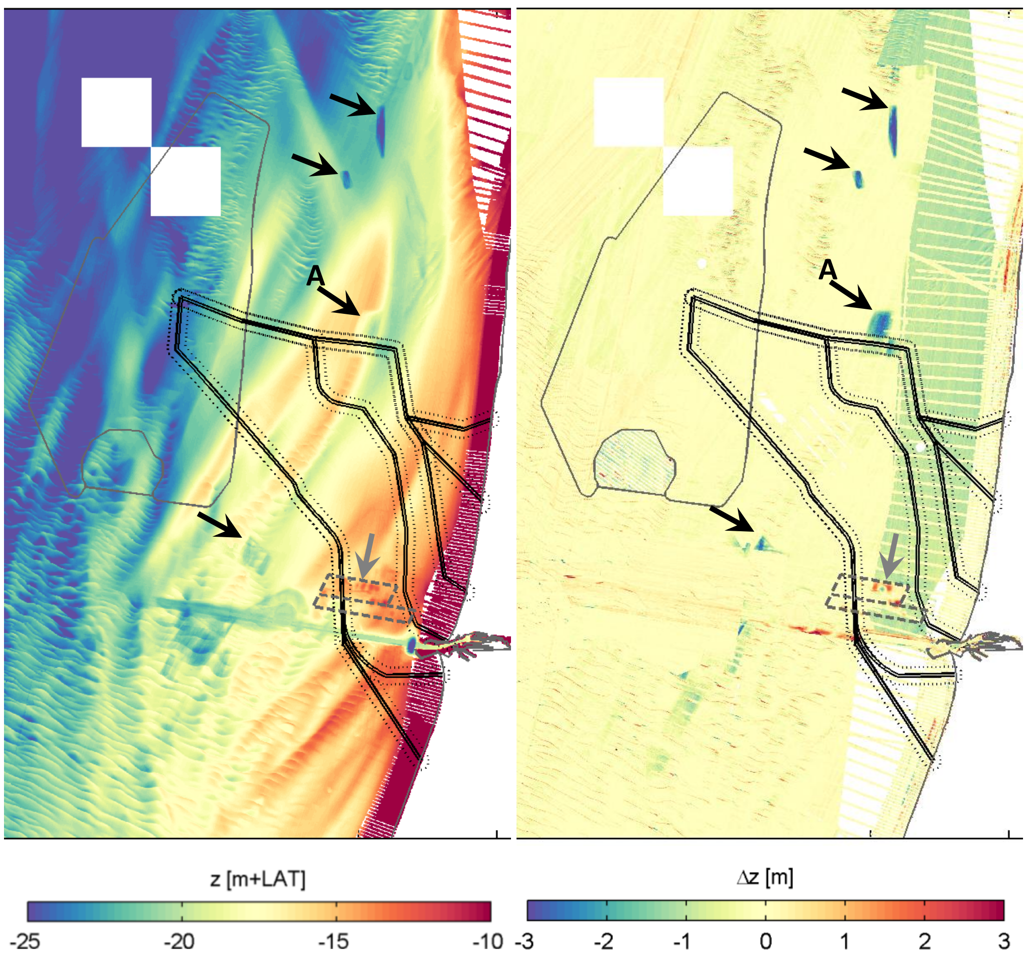

Figure 2.12 Left panel: Location sand extraction areas indicated with black arrows on map of most recent bathymetry, location of sediment placement is indicated with a grey arrow. Approximate location of sand disposal area Loswal IJmuiden is indicated with gray dashed lines. Right panel: Location sand extraction areas indicated with black arrows on map of difference between most recent and 2nd most recent bathymetry map, location of sand placement is indicated with a grey arrow. Approximate location of sand disposal area Loswal IJmuiden is indicated with gray dashed lines.

Figure 2.13 Sand extraction strategy map zoomed in on area around wind farm HKN with permitted sand extraction areas indicated in yellow and sand disposal areas indicated in dark blue. Source: https://www.noordzeeloket.nl/en/Images/Sand%20extraction%20strategy_4923.pdf (visited 24 August 2017)

2.6 Synthesis

The offshore seabed mobility of the 7 different cable route options has been addressed in this chapter. Historic bathymetry data sources are processed to identify stationary and migrating bed features. A subdivision is made between natural and man-made influences.

Size and migration speed of offshore sand waves around each cable route option has been determined. A lot of area around the cable route option does not have sand waves and their size and speed varies considerably. Cable route options 1-3 cross only 3 sand waves and just 4 km of the route is influenced by sand waves of 0.5-2.5m high (min-max), 250-1200m long and a migration speed of 1-4 m/yr. Cable route options 4-5 are identical in the offshore region and cross 6 sand waves with 5 km of the route being influenced by sand waves of 0.3-2.5m high (min-max), 250-1200m long and a migration speed of 1-15 m/yr. Cable route options 6-7 come across the largest number of sand waves. Cable route options 6-7 cross 15 sand waves with 13 km of the route being influenced by sand waves of 0.2-2.5m high (min-max), 200-1300m long and a migration speed of 1-15 m/yr.

In the area around the cable route options several anthropogenic features are present, like sand extraction pits, sediment deposition areas and the IJgeul approach channel.

Next to cable route options 1-3 there is an old sand extraction area, however nowadays this part of cable route options 1-3 follows a preferred route for cables and pipelines and no permit is issued for sand extraction. Additionally within 500m from cables and pipelines sand extraction is not allowed (Ministerie I&M en EZ 2015, Beleidsnota Noordzee 2016-2021). Cable route options 4/5 and 6/7 cross sediment placement area ‘Loswal IJmuiden’ and it is advised to contact Rijkswaterstaat on how they deal with cables crossing a sediment placement area in case one of these cable route options would be selected by TenneT. Within the cable route option 4/5 corridor it is possible to avoid ‘Loswal IJmuiden'.

Cable route option 6-7 cross the IJgeul approach channel which has a width of 450m, a nautical depth of LAT-19.2m/LAT-19.3m, a construction depth of LAT-19.8m, and an actual surveyed depth of up to around LAT-20.5m (west part corridor) to LAT-22.5m (east part corridor). Approximately once a year maintenance dredging is carried out to keep the channel at depth, mainly some ridges and locations near the sides need to be deepened.

3 LANDFALL SEABED MOBILITY

3.1 Introduction

This chapter describes the landfall mobility for the different cable route options for HKN. A total of six landfall locations are defined for seven cable route options, see Figure 1.1. To determine the mobility of the landfall area, historical bathymetric data (JarKus) is analysed. Besides, the mobility for 1 in 100 year storm condition is assessed by means of XBeach model computations.

Two of the cable route options for HKN run through the Noordzeekanaal, see Figure 1.1. In the next chapter attention is paid to the seabed mobility of this part of the cable routes.

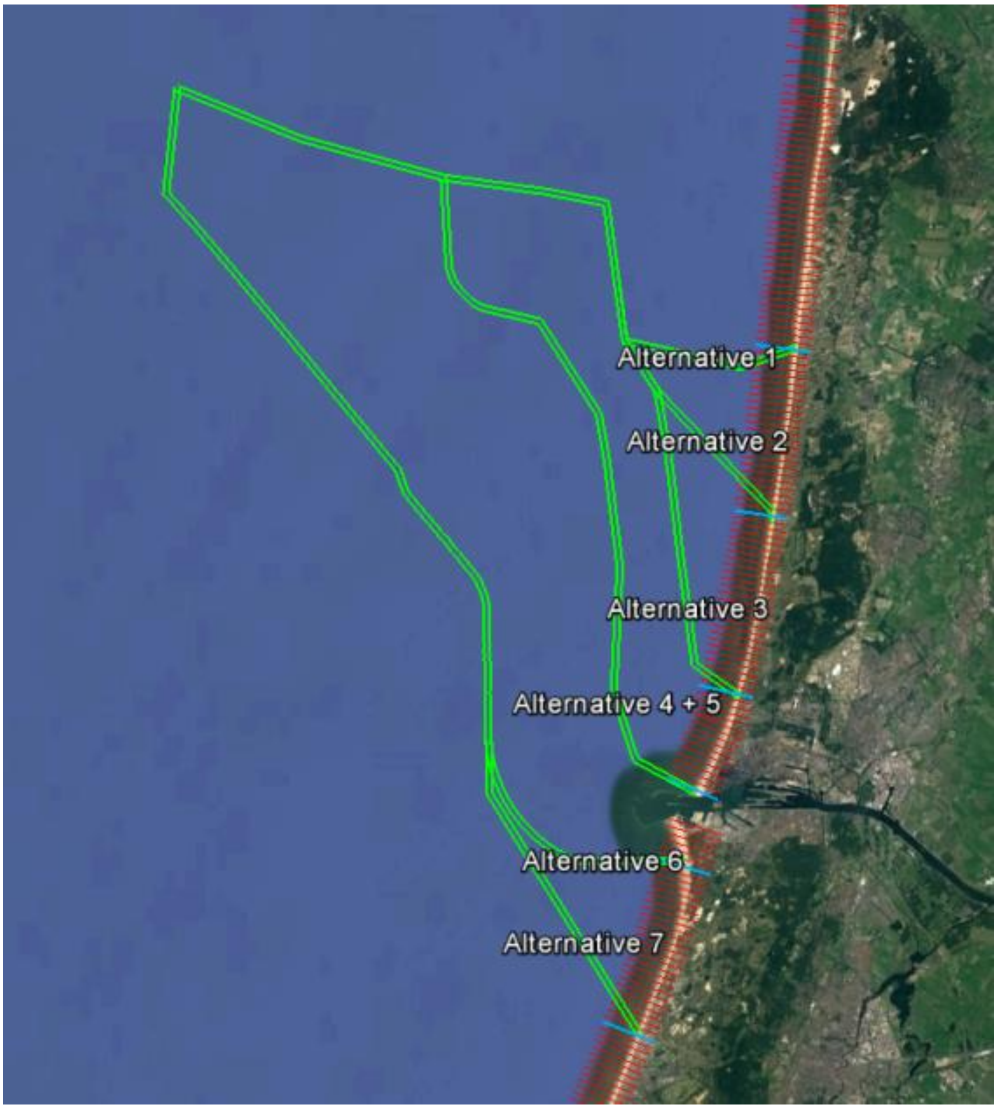

Figure 3.1: Landfall locations for the alternative cable route options (green), JarKus transects (red) and selected JarKus transects (blue) for coastal profile mobility assessment.

3.2 Coastal profile mobility

To determine the coastal profile mobility, historical JarKus data is analysed. For each of the landfall locations the nearest JarKus transect is selected, see Figure 3.1 and Table 3.1. The coast is maintained by means of beach and shoreface nourishments, which are performed roughly every 5 years over the past decades. For each landfall location an overview of the beach and shoreface nourishments in that specific area is provided based on data from the Rijkswaterstaat nourishment database.

Table 3.1: Selected JarKus transects for coastal profile mobility assessment.

Route	Selected JarKus transect nr
1	3875
2	4475
3	5125
4+5	5500
6	5550
7	6400

3.2.1 Route alternative 1

The morphological evolution of the coastal profile at landfall location 1 is shown in Figure 3.2. The minimum and maximum bed level over the past 50 years can also be established from Figure 3.3, being the envelop of all the profiles plotted in Figure 3.2. The most morphological active area is the area between NAP +2 m and NAP -8 m. The bed level varies with over 1 m in het area above mean water level and increase to a bed level variation up to 4 m over time in the deeper areas. The fact that the bed level goes up and down several times in the analysed period while not exceeding the indicated band width described here, shows that the observed bed level variation is a good indication for future bed level variations as well.

Some activity is also visible below NAP -8 m. This activity seems to be related to the executed shoreface nourishments, considering the jumps in bed level at specific moments in time in this area.

This coastal section is maintained by means of the beach and shoreface nourishments, which are performed roughly every 5 years over the past decades. Note that some nourishments can be recognised in Figure 3.2, but not all. JarKus transects are surveyed once a year, so this strongly depends on when nourishments are carried out exactly. An overview of the beach and shoreface nourishments in this area from 1965-2016 is given below:

- Beach nourishment (204 m^3/m) in 1995
- Beach nourishment (123 m^3/m) in 1997
- Beach nourishment (196 m^3/m) in 1998
- Beach nourishment (143 m^3/m) in 1999
- Shoreface nourishment (400 m^3/m) in 1999
- Beach nourishment (207 m^3/m) in 2000
- Shoreface nourishment (450 m^3/m) in 2004
- Beach nourishment (216 m^3/m) in 2005
- Shoreface nourishment (343 m^3/m) in 2010
- Beach nourishment (200 m^3/m) in 2011
- Beach nourishment (216 m^3/m) in 2015
- Shoreface nourishment (278 m^3/m) in 2015

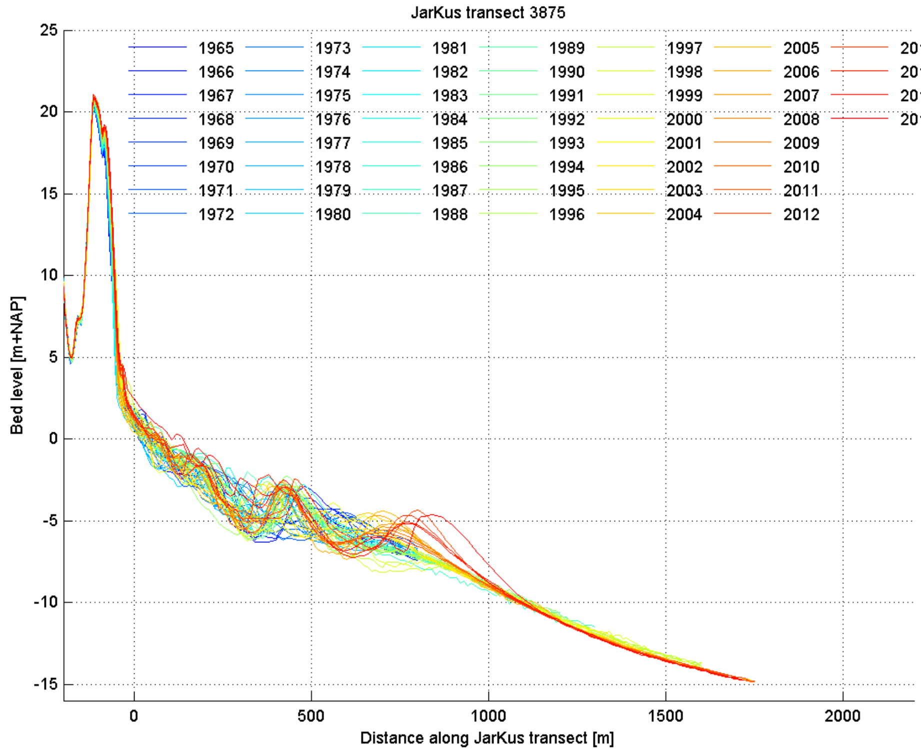

Figure 3.2: Coastal profile at JarKus transect 3875 (route alternative 1) in the period 1965-2016.

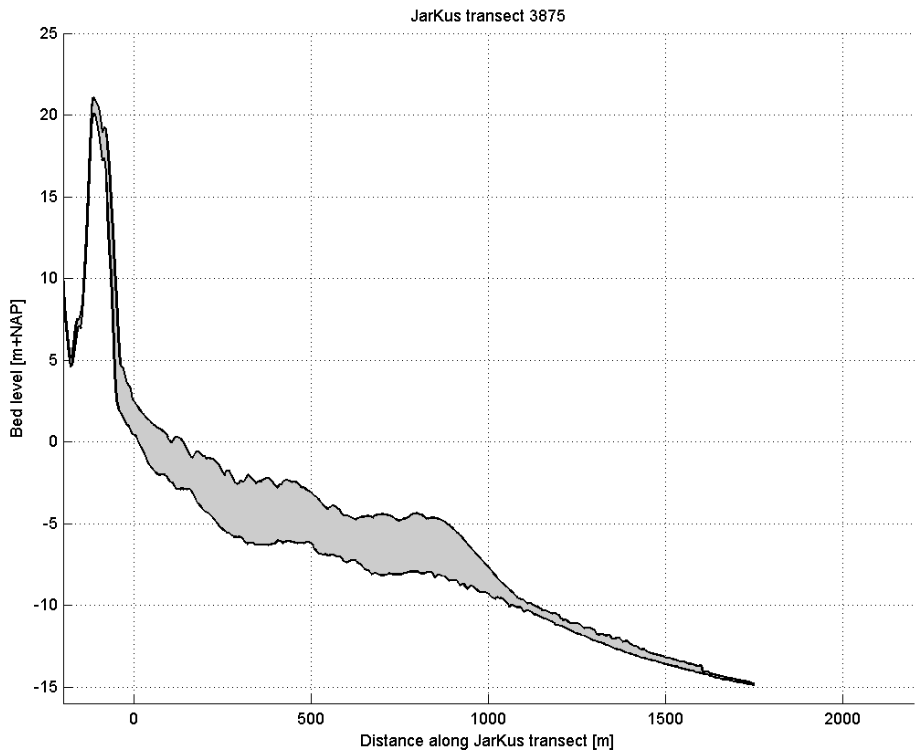

Figure 3.3: Envelop of the coastal profile at JarKus transect 3875 (route alternative 1) in the period 1965-2016

3.2.2 Route alternative 2

The morphological evolution of the coastal profile at landfall location 2 is shown in Figure 3.4. The envelop of the profiles represents the minimum and maximum bed level over the past 50 years in Figure 3.5. Morphological activity is present between NAP +3 m and NAP -7 m and is mainly due to migrating sand banks. The bed level variation is circa 1 m above mean water level and increases up to 4 m in the deeper areas. Some accretion of the beach over time is visible.

Only a single beach nourishment is performed in this area, but very small compared to the regular beach nourishments (100 m^3/m – 300 m^3/m) along the Dutch coast, so it is not likely that the purpose of this nourishment is maintenance.

- Beach nourishment (12 m^3/m) in 2005

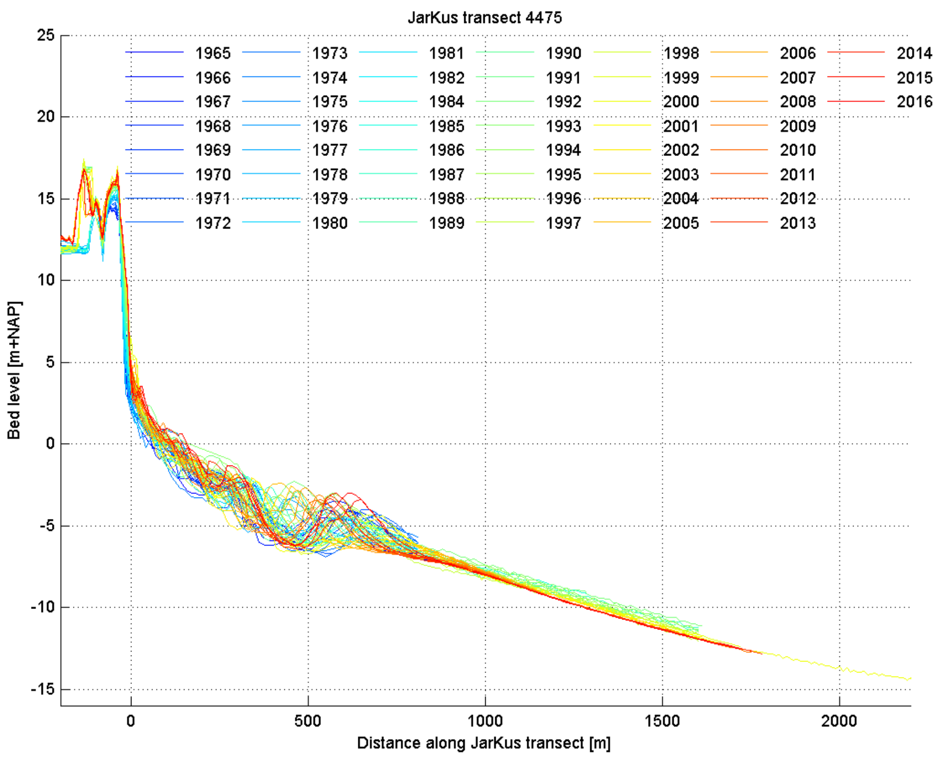

Figure 3.4: Coastal profile at JarKus transect 4475 (route alternative 2) in the period 1965-2016.

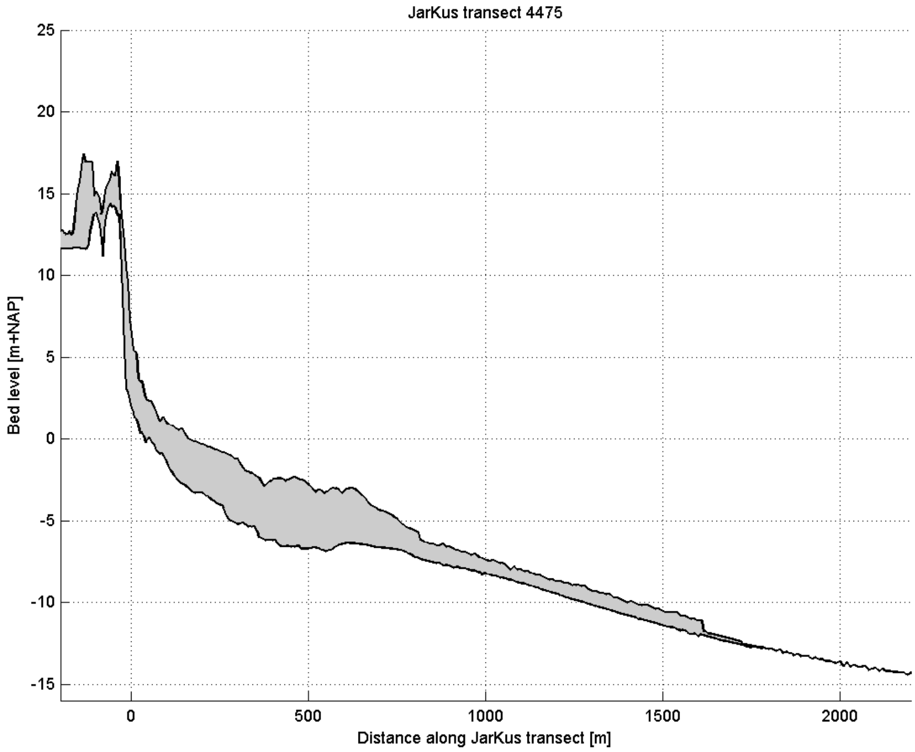

Figure 3.5: Envelop of the coastal profile at JarKus transect 4475 (route alternative 2) in the period 1965-2016.

3.2.3 Route alternative 3

Figure 3.6 shows the morphological evolution of the coastal profile at landfall location 3, with the envelop showing the maximum and minimum bed level over the past 50 years in Figure 3.7. The area is morphological active between NAP +1 m and NAP -7 m. Migration of sand banks is clearly visible in the bed development, leading to depth variation of circa 4 m between NAP -3 m and NAP -7 m. Above NAP -2 m, the depth variation amounts 1 to 2 m. The beach is slightly accretion over time and no maintenance nourishments are carried out in the area.

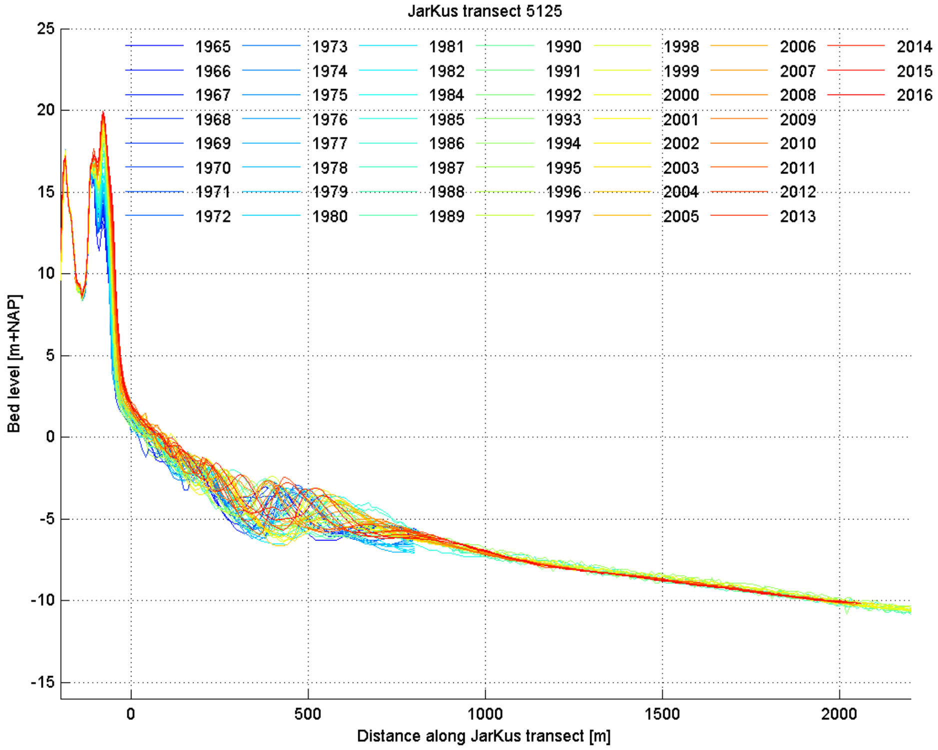

Figure 3.6: Coastal profile at JarKus transect 5125 (route alternative 3) in the period 1965-2016.

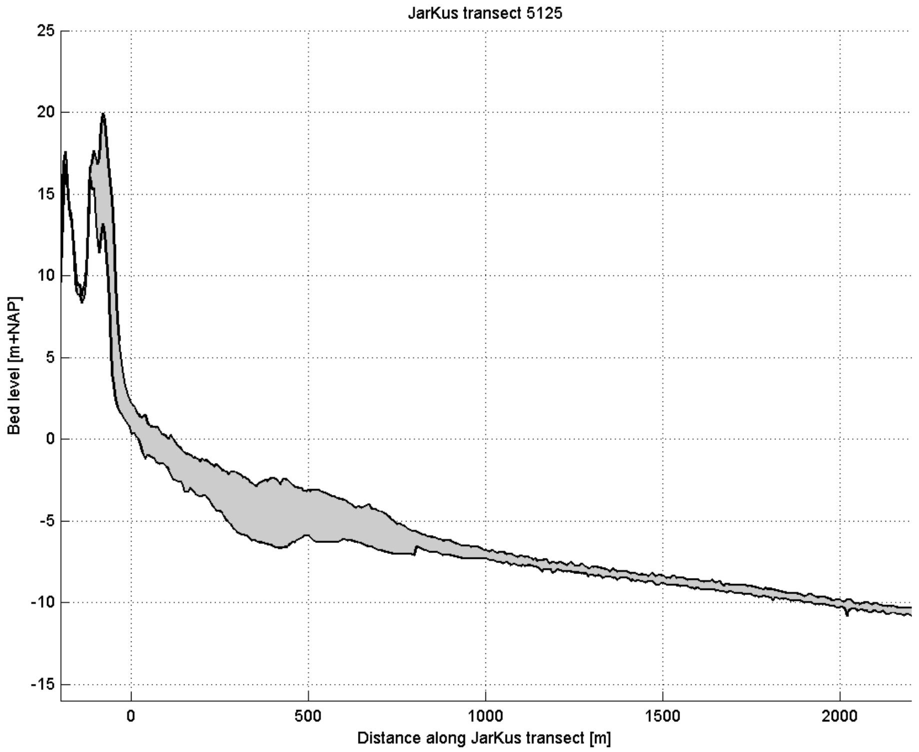

Figure 3.7: Envelop of the coastal profile at JarKus transect 5125 (route alternative 3) in the period 1965-2016.

3.2.4 Route alternative 4+5

The morphological evolution of the coastal profile at landfall location for route alternative 4 and 5 is shown in Figure 3.8. The envelop of the profiles represents the minimum and maximum bed level over the past 50 years in Figure 3.9. The coastal profile has experienced strong accretion under the influence of the Port of IJmuiden and the lee that exists north of the breakwater. The profile is stable below NAP -6 m. In front of the dunes, a plateau, which is constructed as foundation for beach pavilions, is present at circa NAP +5 m.

No maintenance of the beach profile is required, but in the past a ‘nourishment’ is performed once. The aim of this nourishment is not clear, but could be to dispose sediment obtained during the construction of the Averijhaven. This basin came in use in 1967 and is closed off in the early 90’ies.

- 1962-1976: 1.5 Mm3 beach nourishment, 1000 m^3/m

The accretion of the coastal profile seems to have stagnated over the past few decades. To gain more insight in the recent developments of the coastal section, the morphological evolution of the coastal profile in a smaller area is shown in Figure 3.10. The figure shows that accretion was still present in roughly the first 10 years, 1997-2006. The following years, the coastal profile is relatively stable, but in 2015 and 2016 the bed level is circa 1 m lower between NAP +2 m and NAP -4 m. In the area above NAP +2 m, accretion is ongoing for the full period.

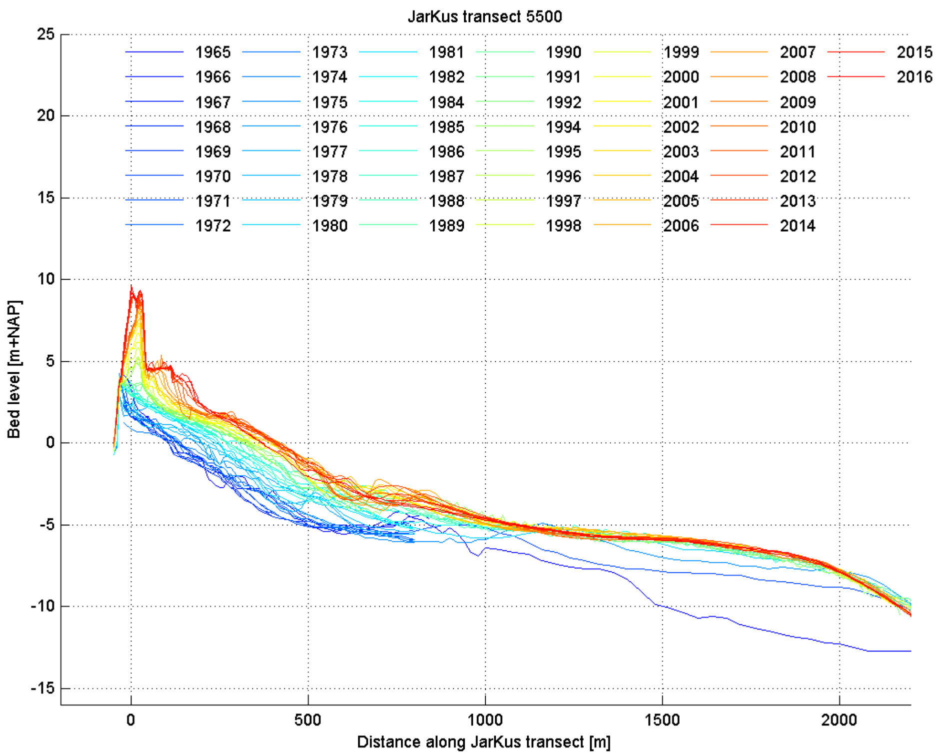

Figure 3.8: Coastal profile at JarKus transect 5500 (route alternative 4 + 5) in the period 1965-2016.

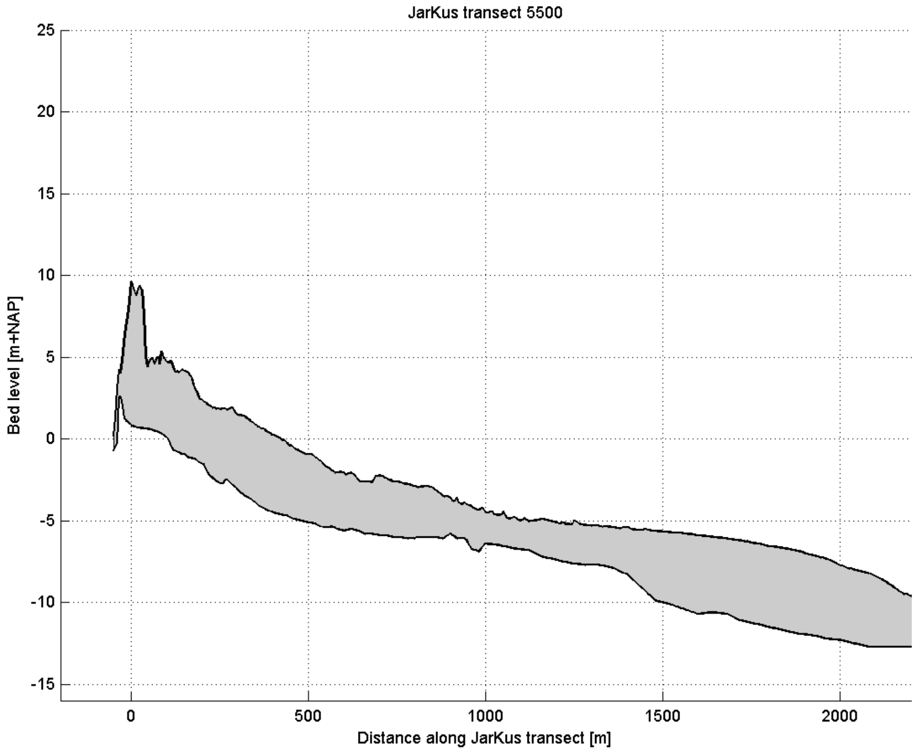

Figure 3.9: Envelop of the coastal profile at JarKus transect 5500 (route alternative 4 + 5) in the period 1965-2016.

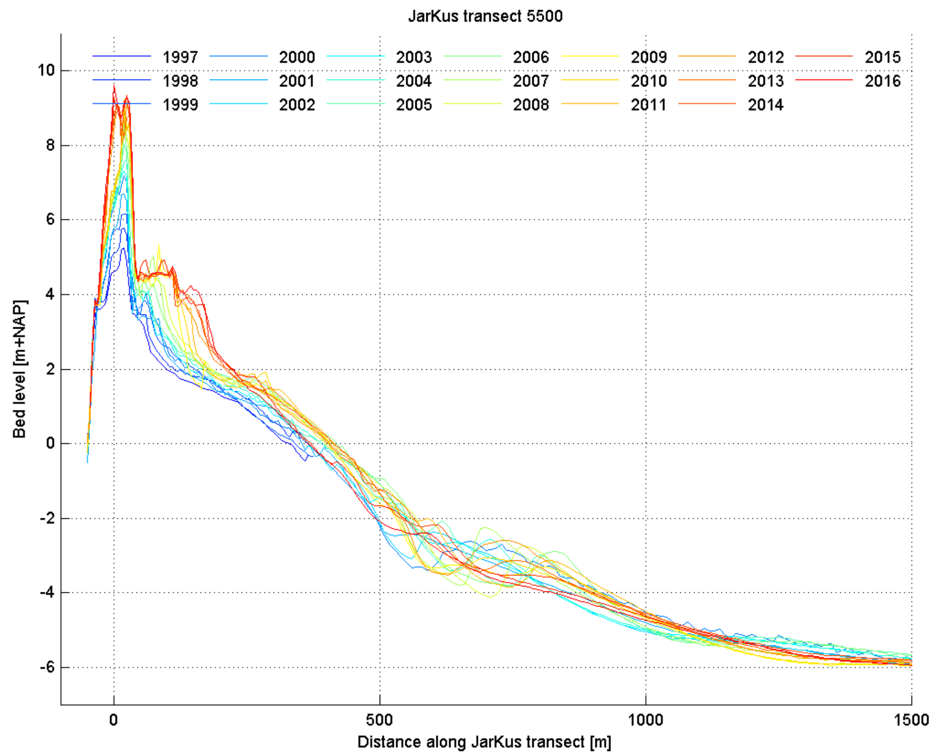

Figure 3.10: Coastal profile at JarKus transect 5500 (route alternative 4 + 5) in the period 1997-2016, zoomed in.

3.2.5 Route alternative 6

Figure 3.11 shows the morphological evolution of the coastal profile at landfall location 6, with the envelop showing the maximum and minimum bed level over the past 50 years in Figure 3.12. The figure shows that the coastal profile is stable below NAP -5 m. Between NAP -2 m and NAP -5 m, migration sand banks are visible, leading to a depth variation of circa 2 m over time. In general, the coastal profile above NAP -2 m is accreting under the influence of the Port of IJmuiden and new dunes arise in front of the existing dunes. Accretion is also visible between NAP -2 m and NAP -5 m, but the accretion rate is lower in this part of the profile.

No nourishments are carried out in this landfall area.

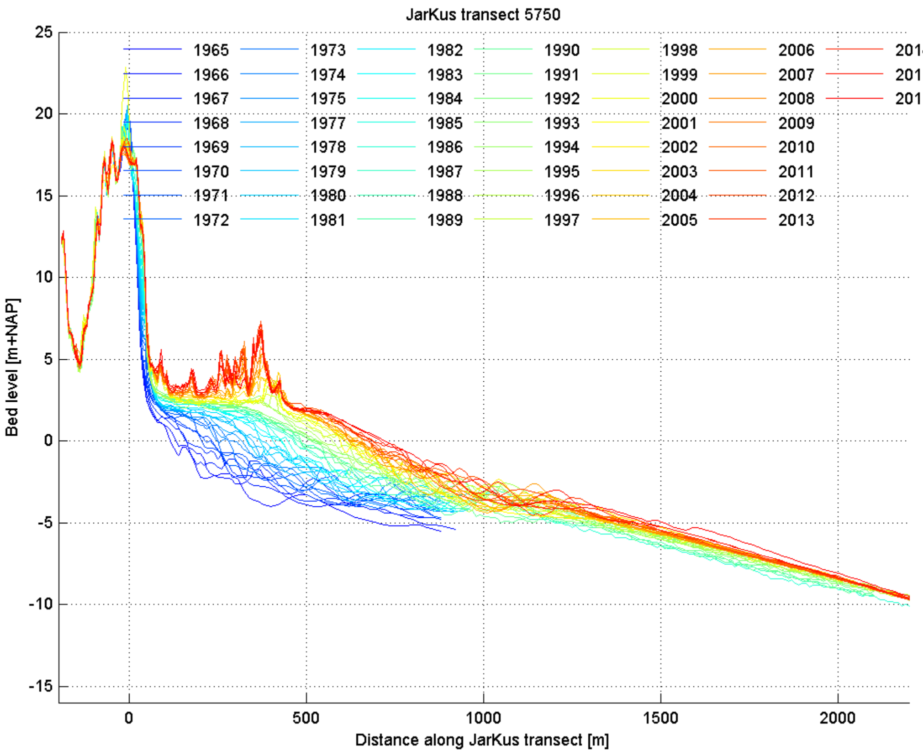

Figure 3.11: Coastal profile at JarKus transect 5750 (route alternative 6) in the period 1965-2016.

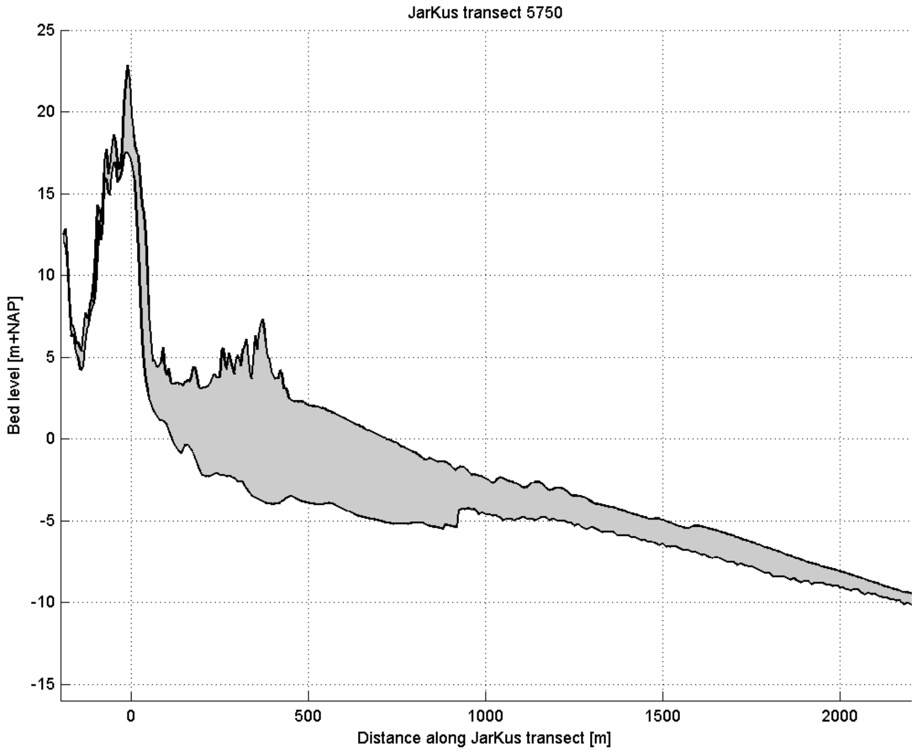

Figure 3.12: Envelop of the coastal profile at JarKus transect 5750 (route alternative 6) in the period 1965-2016.

3.2.6 Route alternative 7

The morphological evolution of the coastal profile at landfall location 7 is shown in Figure 3.13. The envelop of the profiles represents the minimum and maximum bed level over the past 50 years in Figure 3.14. Morphological activity is present between NAP +1 m and NAP -6 m and is mainly due to migrating sand banks. The bed level variation is circa 1 m above mean water level and increases up to 3 m in the deeper areas. Some accretion of the beach over time is visible.

Maintenance of this coastal section is carried out several times in the past, but cannot be considered intensive. An overview of the beach and shoreface nourishments in this are from 1965-2016 is given below:

- Beach nourishment (201 m^3/m) in 2001
- Shoreface nourishment (401 m^3/m) in 2004
- Shoreface nourishment (320 m^3/m) in 2016

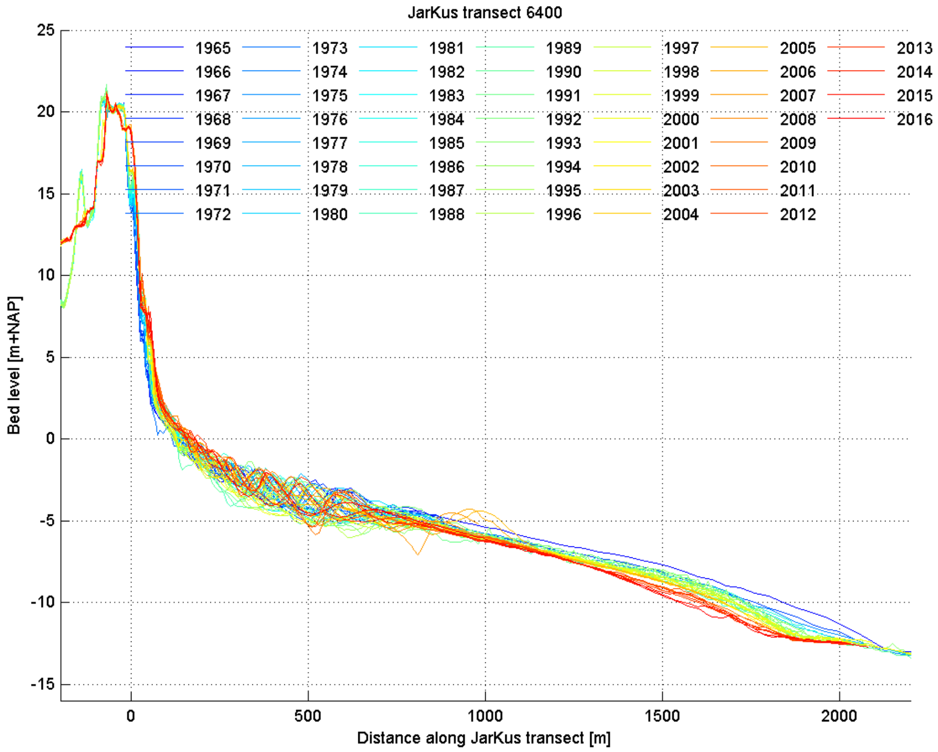

Figure 3.13: Coastal profile at JarKus transect 6400 (route alternative 7) in the period 1965-2016.

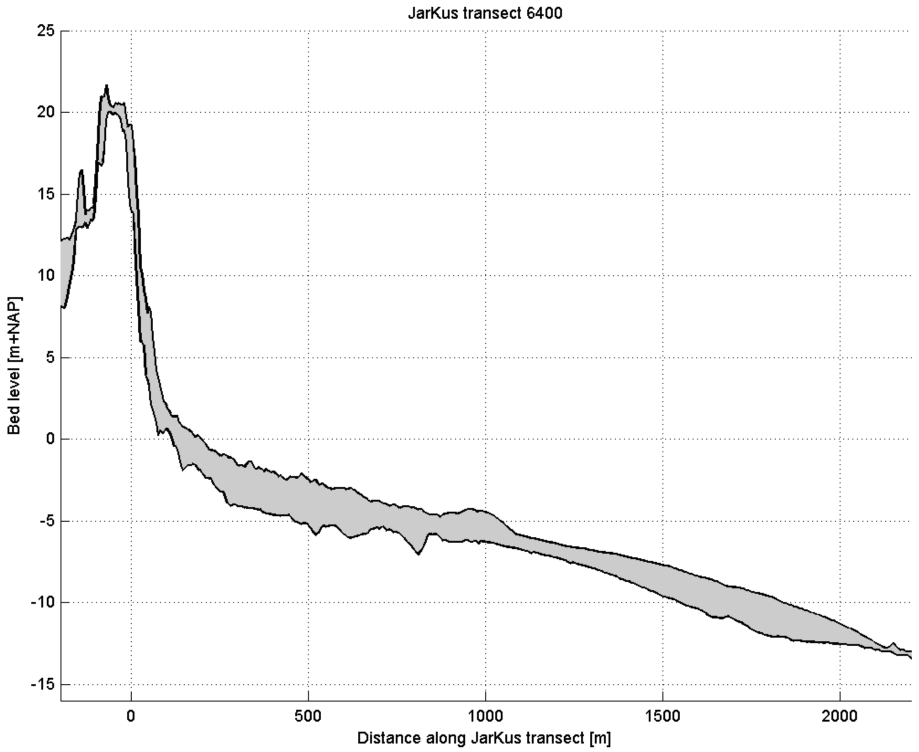

Figure 3.14: Envelop of the coastal profile at JarKus transect 6400 (route alternative 7) in the period 1965-2016.

3.2.7 Impact of rip tides

Breaking waves generate a wave-driven current towards the coast. At several locations along the coastline, a return current arises, a so-called rip current, see Figure 3.15. This return current is located at the deeper areas along the coast, i.e. between sand banks instead of over sand banks. This causes a depth variation in longshore direction, and passing rip currents can therefore impact the cable coverage.

In the previous sections, for each landfall location over 50 years of JarKus profiles are used for the seabed mobility analysis. It is therefore likely that at each landfall location at least one or more rips are present in the data. At the sand engine high resolution nearshore bathymetry data is available and ribs typically have a depth of approximately 2m below surrounding seabed. The depth variation caused by rips is thus in the same order of magnitude as the natural depth variation caused by passing sand bars and they are at least partly covered in the Jarkus depth profiles. However, it is possible that incidental a passing rip might occur at a different location than in previous 50 years covered in the Jarkus profiles and the non-mobile bed level will be 2m below the envelop of the bed levels of the Jarkus profiles for the zone where sand banks are apparent.

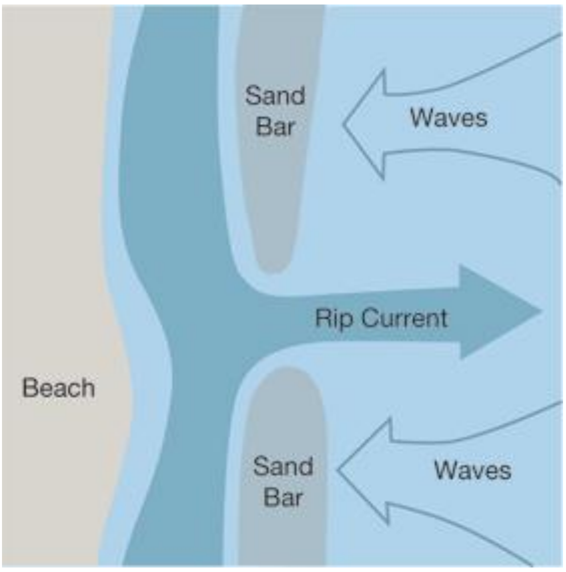

Figure 3.15: Rip currents occur between two sand banks. Locally, the seabed is lower than its surroundings.

3.3 Mobility for 1/100 year design conditions

Storms can lead to significant changes in the cross profile in a short time. To determine the mobility of the coastal profile under such conditions, XBeach computations are performed for each of the landfall location for 1/100 year storm conditions.

3.3.1 Model set up

XBeach is a process based numerical model, developed by UNESCO-IHE, Deltares, TUDelft and Miami University. The model is designed mainly to compute dune erosion during storm events. In this study, XBeach is applied in 1D surfbeat mode, simulating the so-called ‘infra gravity waves', which are responsible for most of the cross shore erosion along a sandy coast. XBeach revision 4567 (King's day release) has been used for this study.

For each of the landfall locations (6 in total), the cross shore profile is constructed based on the same JarKus profiles used for the historical analysis in the section above. An exception to this is the selected JarKus transect for route alternative 6. Here, a JarKus transect further south (no. 5775) is chosen because this transect consists of a further developed new dune and this will lead to more realistic erosion rates.

For each of the 6 XBeach computations 1/100 year storm boundary conditions are applied. These boundary conditions are extracted from HydraNL for location IJmuiden, which leads to representative conditions for all landfall locations. The applied water level set up is 3.6 m, the significant wave height is 5.5 m and the wave period 12.6 s. These conditions are based a so-called 'storm surge hydrograph', see Steetzel (1993), translated to a storm duration of 48 hours. The waves are defined as a JONSWAP spectrum. The resulting time series for 1/100 year storm conditions are shown in Figure 3.16.

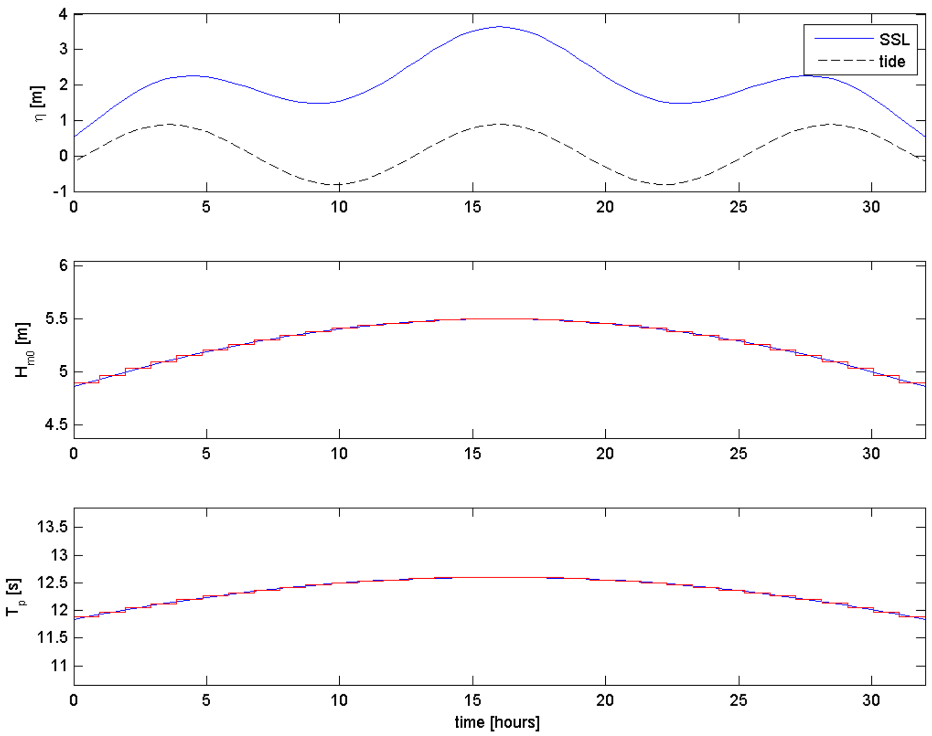

Figure 3.16: Time series 1/100 year storm conditions.

3.3.2 Results

The results of the performed XBeach computations for 1/100 year storm conditions are shown in Figure 3.17 up to Figure 3.22. Each figure shows the coastal profile at the beginning of the computation, the profile at the end of the computation and the storm surge level. Note that uncertainties in model results are in the order of 1 m.

The results show that in each profile dune and beach erosion takes place during storm and that the profile is smoothened. The steeper profiles with higher dunes (landfall 1, 2, 3 and 7) experience more erosion (220 m^3/m to 260 m^3/m) than the flatter profiles (landfall 4+5, 6; 190 m^3/m).

Most of the sediment eroded in the upper part of the profile (dunes and beach) is deposited in the lower part of the profile (shoreface). As long as the long shore sediment transport is not too high, this sediment remains in the direct environment and will be transported back to the beach and dunes during calmer conditions. This is the case for the HKN landfall locations. The landfall locations directly north and south of the Port of IJmuiden can only be subject to strong wave attack when the incoming wave is directed into the 'armpit' of the breakwater, making sure the longshore transport is directed towards the breakwater and the sediment cannot escape the profile. The other landfall locations are at a straight coastline with limited variations in longshore sediment transport rates. Note that the time scale in which this restoration process takes place is much longer than the time scale of erosion during storm.

The 1/100 year storm results in bed level changes between 1 and 2 m up or down, so a total band width of 3-4 m exists. This band width is similar for each of the landfall locations. At the beach and dunes the storm impact is not equal for all landfall locations. The landfall locations can roughly be divided in two types of profiles:

- Stable or stable by means of maintenance coastal sections (landfall 1, 2, 3 and 7);
- Accreting coastal sections (landfall 4+5 and 6).

At the stable coastal sections, dune erosion is clearly visible. At the dune foot, the bed level change is far more than 1-2 m, and it is better to speak of retreat of the coastline here. For the investigated sections, the coastline retreat amounts circa 30 m at landfall 1, 15 m at landfall 2, 30 m at landfall 3 and 50 m at landfall 7. At the beach, the erosion rates are still in the order of 1-2 m.

At the accreting coastal sections, a wide beach is present. During storm events, the beach is most impacted while erosion of the dunes is hardly present. At landfall 4+5, the plateau around NAP +5 m has eroded by over 2 m in vertical direction, whereas at landfall 6 the wide beach around NAP +2 m has eroded by over 1 m in vertical direction.

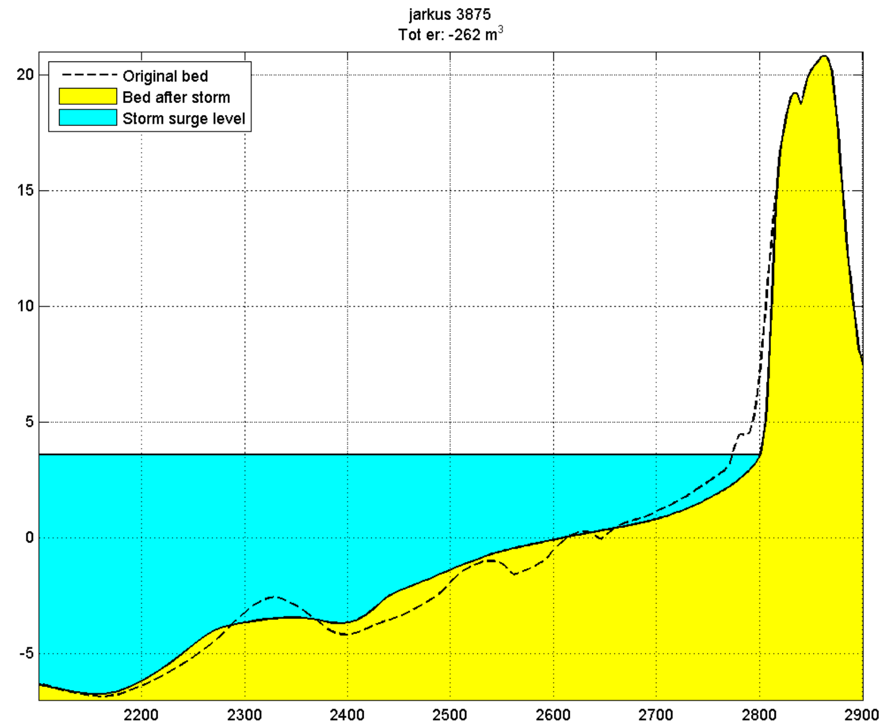

Figure 3.17: Model results of the impact of a 1/100 years storm condition on the most recent recorded coastal profile at landfall location 1.

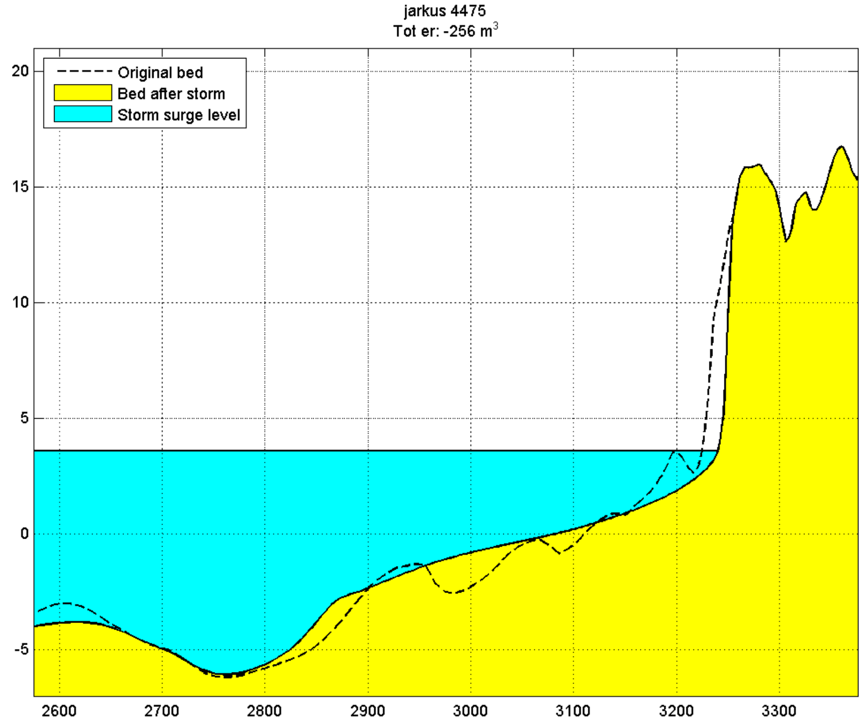

Figure 3.18: Model results of the impact of a 1/100 years storm condition on the most recent recorded coastal profile at landfall location 2.

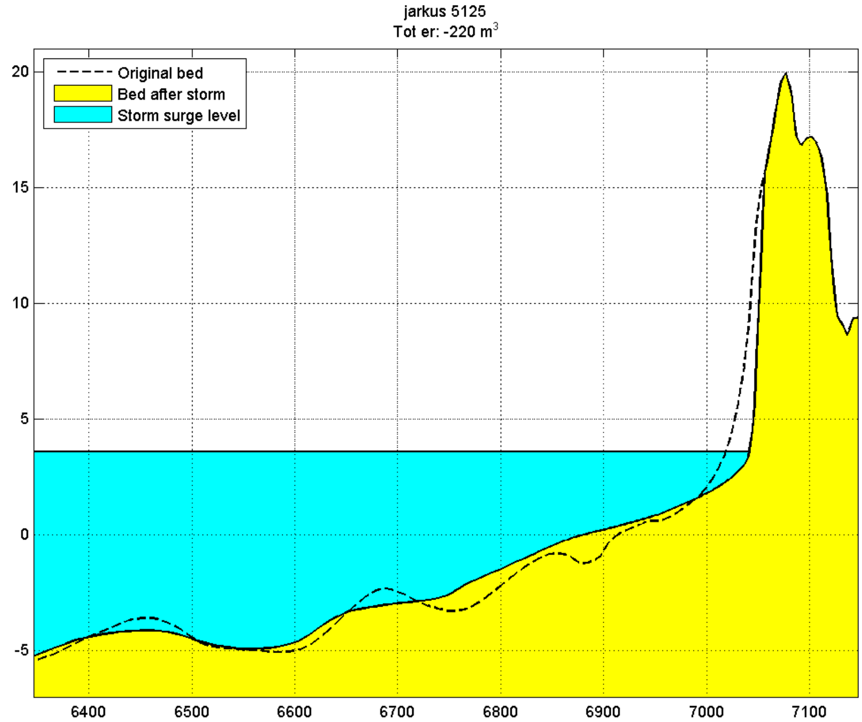

Figure 3.19: Model results of the impact of a 1/100 years storm condition on the most recent recorded coastal profile at landfall location 3.

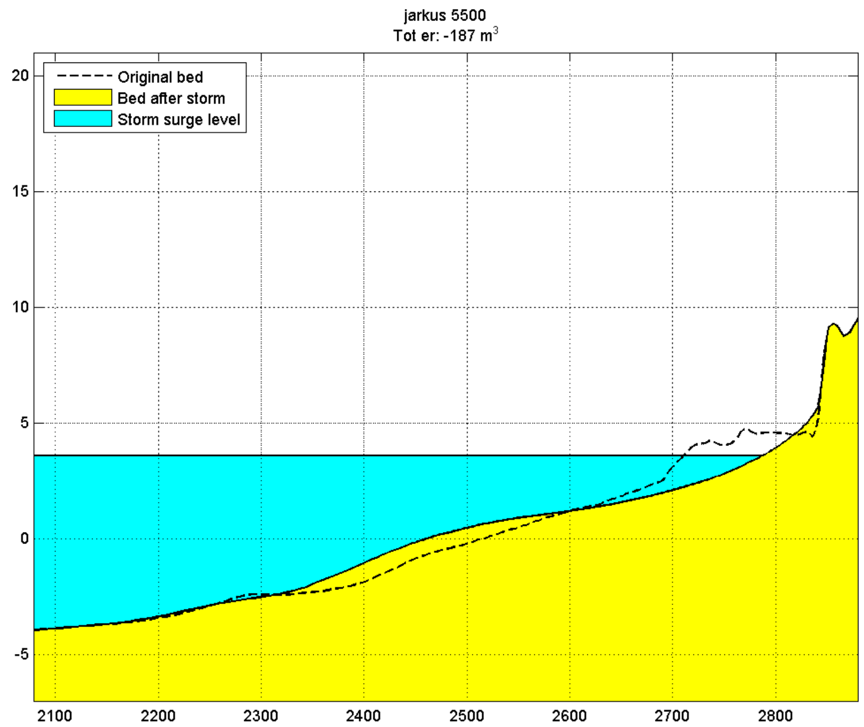

Figure 3.20: Model results of the impact of a 1/100 years storm condition on the most recent recorded coastal profile at landfall location 4+5.

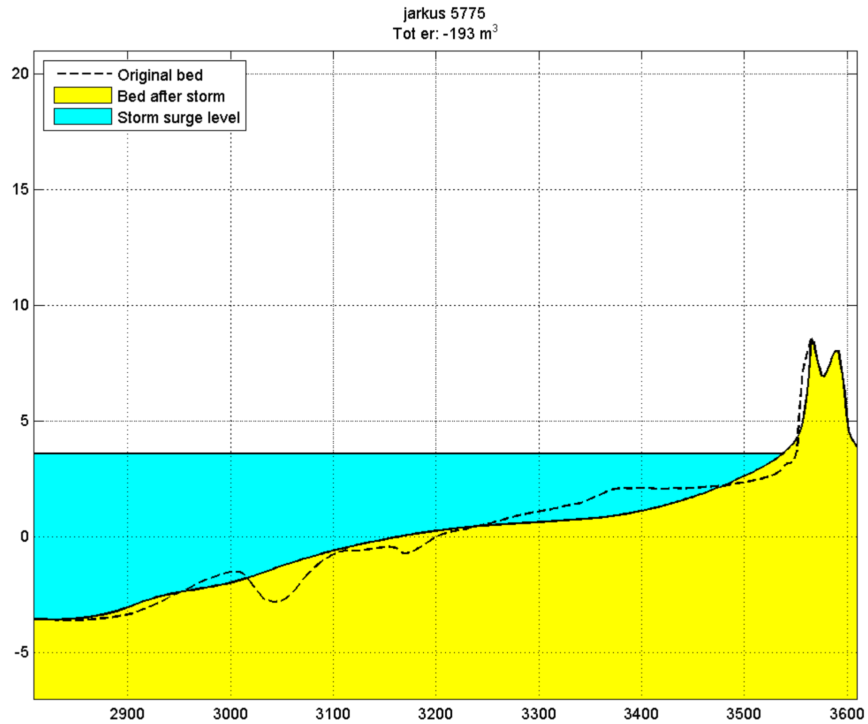

Figure 3.21: Model results of the impact of a 1/100 years storm condition on the most recent recorded coastal profile at landfall location 6.

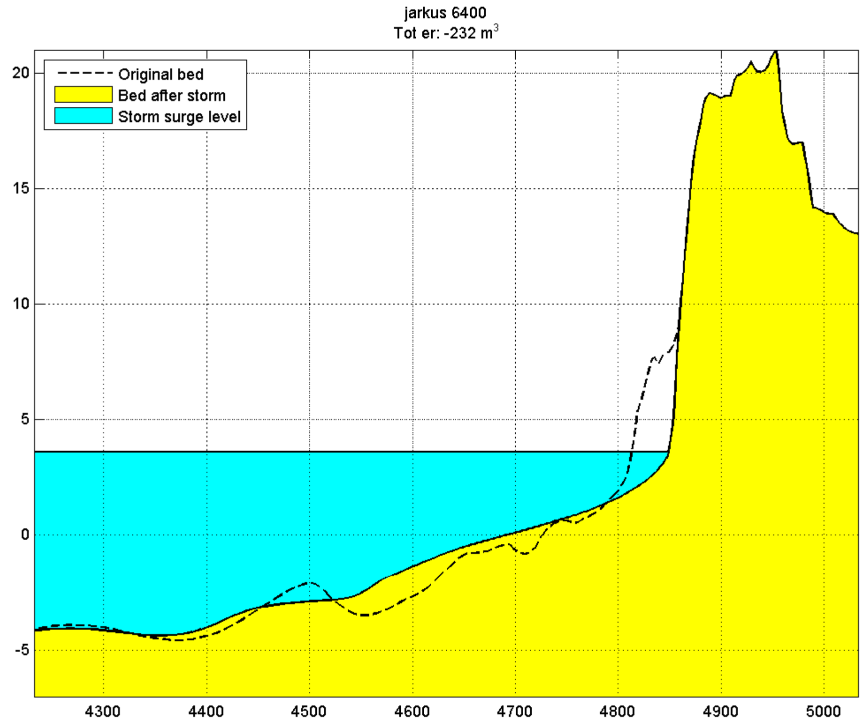

Figure 3.22: Model results of the impact of a 1/100 years storm condition on the most recent recorded coastal profile at landfall location 7.

3.3.3 Impact of climate change

Climate change will result in sea level rise. According to the most recent sea level change scenarios, sea level rise up to 40 cm can be expected around 2050 and up to 80 cm around 2085 (KNMI 2015). At the end of the expected 40 years lifetime of the cable, the expected sea level rise is 60 cm.

When the Dutch government keeps present coastline maintenance nourishment strategy then the beach will grow along with sea level rise by additional nourishments and cable burial depth at landfall will increase. Another impact of climate change may be increasingly extreme storms (more frequent and more severe) which leads to extra beach/dune erosion during storms. However, in order to guarantee the coastline safety the government should strengthen the beach and dune systems to be able to cope with these changing extreme hydraulic conditions which probably means even more nourishments.

Hence, the expectation is that climate change will result in extra cable coverage around landfall and not less.

3.4 Impact of nourishments

In order to maintain the coastline and stop structural coastal erosion, the Dutch government carries out regular nourishments. Whenever the trend in the Momentary Coast Line (MKL) is about to cross the Basal Coast Line (BKL), nourishment of the area in question is carried out. The average annual nourishment volume of the Dutch coast amounts 12 Mm^3. Nourishments make eroding beaches stable and eliminate structural decreasing of beach volume and in this manner also eliminate structural decreasing of cable coverage.

Note that to account for sea level rise, the beach height needs to grow accordingly leading to extra cable coverage, and that the annual nourishment volume will probably rise to be able to maintain the Basal Coast Line (BKL) for its current position. Whether this will be the case depends on how the nourishment policy of the Dutch government is implemented.

Only two of the landfall locations considered in this study are maintained by nourishments and thus influenced by nourishments, see Table 3.2 and previous sections. Both beach nourishments and shoreface nourishments are carried out in the two sections, of which the shoreface nourishment can clearly be distinguished as new sand banks in the evolution of the coastal profile, see Figure 3.2 and Figure 3.13. The depth variation induced by shoreface nourishments is in the order of 3-4 m and similar to the natural depth variation in the shoreface area.

The beach nourishments are not clearly distinguishable in the evolution of the coastal profile but nevertheless impact the profile bathymetry. The depth variation caused by beach nourishments can also be considered in the same order of magnitude as the natural depth variation of the beach profile.

Nourishments are performed to maintain the coastal profile and prevent structural erosion at landfall location 1 and 7. It can be concluded that the depth variation in the coastal profile caused by nourishments is in the same order of magnitude as the natural depth variations in the profile. The other landfall locations are not influenced by nourishments.

Table 3.2: Overview of the total nourishments at the landfall locations during the period 1965-2016.

	Maintenance nourishments		
Location	Beach	Shoreface	Total
Landfall 1	1505 m^3/m	1471 m^3/m	2976 m^3/m
Landfall 2	12 m^3/m	0 m^3/m	12 m^3/m
Landfall 3	0 m^3/m	0 m^3/m	0 m^3/m
Landfall 4+5*	0 m^3/m*	0 m^3/m	0 m^3/m
Landfall 6	0 m^3/m	0 m^3/m	0 m^3/m
Landfall 7	201 m^3/m	721 m^3/m	932 m^3/m

** A nourishment of 1000 m3/m is carried out in 1962-1967 but it is likely this was not for maintenance purposes.*

3.5 Synthesis

In the above sections the mobility of the bed at the landfall locations is assessed. Mobility of the bed has several causes, e.g. cross shore sediment transport under daily conditions, resulting in for instance bank migration, cross shore sediment transport during storm events, leading to dune erosion, and non-natural sediment transport such as beach and shoreface nourishment for maintenance of the coastline. Besides distinction by cause, distinction in seabed mobility can also be made for different zones, such as shoreface, beach and dunes. The seabed mobility for each of the landfall locations is summarised in Table 3.3. In the table a subdivision is made by cause and location in the profile. The length of the cable affected by several processes is indicated in Table 3.4.

In the landfall locations, two types of coastal profiles can roughly be distinguished: stable or stable by means of nourishment profiles and accreting profiles. The two profile types each show characteristic bed developments.

The ‘stable’ profiles show migrating banks in the shoreface, with corresponding depth variations of circa 4 m. The impact of passing rip tides is approximately 2m and falls within these depth variations.

Depth variations at the beach are typically 1-2 m. During a 1/100 year storm, the profile is smoothened leading to both erosion and sedimentation in the shoreface in the order of 1-2 m. At the beach generally the 1/100 year storm erosion takes place in the same order of magnitude. At the dunefoot, the 1/100 year storm erosion rates are higher and it is better to speak of coastal retreat, which is between 15 m and 50 m for the analysed profiles. Sea level rise might lead to some extra coastline retreat.

The accreting profiles also show bank migration, but on a smaller stretch of the shoreface and with depth variations in the order of 2 m. At the beach, depth variations of circa 1 m are visible, and although both erosion and sedimentation take place, the trend is accretion. When a cable is buried here, this means that the sand layer on top of the cable is expected to increase over the years. During a 1/100 year storm, the profile is smoothened leading to both erosion and sedimentation in the shoreface in the order of 1-2 m, similar to the stable profiles. 1/100 year storm dune erosion is very limited at the accreting profiles, but 1/100 year storm erosion in the order of 2 m in vertical direction of the wide, relatively high beach takes place.

Nourishments are performed to maintain the coastal profile and prevent structural erosion at landfall location 1 and 7 only. The depth variation in the coastal profile caused by nourishments is in the same order of magnitude as the natural depth variations in the profile. The other landfall locations are not influenced by nourishments.

Table 3.3: Seabed mobility of the optional landfall locations.

	Historical mobility analysis – long term			Short term	
Location	Shoreface	Beach	Trend	Storm event	Nourishment
Landfall 1	NAP -8m – NAP -2m: 4 m due bank migration	NAP -2m – NAP +2m: 1-2 m	Eroding (stable by maintenance)	1-2 m er. or sed , 30 m retreat	Shoreface: 4 m sand bank, beach: 1-2 m
Landfall 2	NAP -7m – NAP -2m: 4 m due bank migration	NAP -2m – NAP +3m: 1-2 m	Stable	1-2 m er. or sed., 15 m retreat	Does not apply
Landfall 3	NAP -7m – NAP -3m: 4 m due bank migration	NAP -3m – NAP +1m: 1-2 m	Stable	1-2 m er. or sed., 30 m retreat	Does not apply
Landfall 4+5	NAP -6m – NAP -2m: 2 m due bank migration	NAP -2m – NAP +3m: 1 m	Accreting, more stable in recent years	1-2 m er. or sed., beach erosion	Does not apply
Landfall 6	NAP -5m – NAP -2m: 2 m due bank migration	NAP -2m – NAP +3m: 1 m	Accreting	1-2 m er. or sed., beach erosion	Does not apply
Landfall 7	NAP -6m – NAP -2m: 4 m due bank migration	NAP -2m – NAP +1m: 1-2 m	Eroding (stable by maintenance)	1-2 m er. or sed , 50 m retreat	Shoreface: 4 m sand bank, beach: 1-2 m

Table 3.4: Length of cable affected by seabed mobility processes.

Location	Shoreface	Beach
Landfall 1	1 km	0.5 km
Landfall 2	1 km	0.5 km
Landfall 3	1 km	0.5 km
Landfall 4+5	1.5 km	0.5 km
Landfall 6	1 km	1 km
Landfall 7	1 km	0.5 km

The results of the assessed seabed mobility at the landfall locations for each of the processes can be combined to assess a non-mobile bed. At the shoreface banks will always be present above the lower bounds of the enveloped JarKus profiles. During storm, the profile flattens. With banks on top of the lower envelop bound and the depth variations at the shoreface during storm being less than depth variations due to bank migration, the bed will not come below this level. It is possible that incidental a passing rip might occur at a different location than in previous 50 years covered in the Jarkus profiles used in this study and the non-mobile bed will be 2m below the envelop of the bed levels of the Jarkus profiles for the zone where sand banks are apparent. Hence, 2m below the lower bound of the envelop is a good measure for the non-mobile bed at the shoreface.

At the beach, the non-mobile bed is advised as 2m below the lower bound of the enveloped JarKus profiles as well. Namely, during storms 1-2m extra erosion can be expected and such storm can happen just before a beach nourishment is required.

Dune erosion during storm is much higher in terms of depth variations and it is better to speak of coastal retreat, which is between 15 m and 50 m for the analysed profiles. The non-mobile bed can here be defined as the lower bound of the enveloped JarKus profiles, but shifted towards the coast by 15 m to 50 m, depending on the landfall locations. For accreting landfall locations no dune erosion takes place, but erosion of the present plateaus to beach level can occur and this level forms the non-mobile bed.

4 IJMUIDEN HARBOUR ENTRY AND NOORDZEEKANAAL MOBILITY

4.1 Introduction

Two of the proposed cable routes, alternative 4 and 5, continue in the Port of IJmuiden and the Noordzeekanaal after passing landfall location 4+5 and before reaching one of the 380 kV transformation stations. The seabed mobility of this part of the cable route is discussed in this chapter. Besides historical seabed developments, future seabed developments are of significant importance as well, for instance considering alterations as a result of the development of the new sea lock at IJmuiden.

A sketch of cable route 5 is shown in Figure 4.1 and Figure 4.2. Cable route 4 follows the same route up to approximately the Wijkertunnel, where alternative 4 heads north to station Beverwijk. The depth along the cable route is for both the northern and southern boundary of the cable route zone shown in Figure 4.3. At locations where a large difference in depth for the northern and southern boundary exists, the cable is placed in the slope of the channel. Note that the cable route in Figure 4.1 and Figure 4.2 is preliminary and that the final design of the exact position of the cable within the channel cross section may deviate.

The seabed mobility of this part of route alternative 5 is discussed in two parts in the next sections: IJmijden Port and Noordzeekanaal. The development of the IJmuiden locks is discussed where relevant in each of the sections.

Figure 4.1: Cable route alternative 5 in IJmuiden Port and the Noordzeekanaal (magenta). Alternative 4 follows the same route up to approximately the Wijkertunnel before heading north and reaching land.

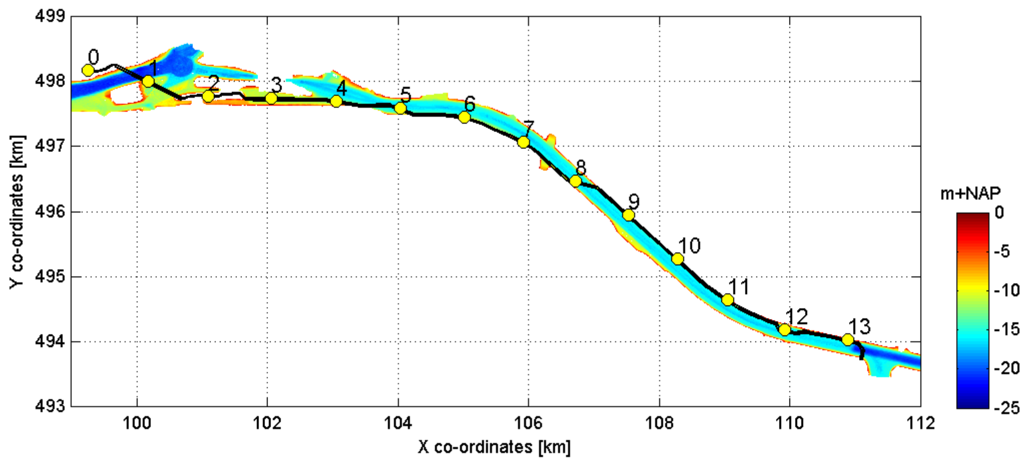

Figure 4.2: Bed level (2017) of IJmuiden Port and the Noordzeekanaal with the cable route alternative 5 (black) and KP's. Alternative 4 follows the same route up to approximately the Wijkertunnel before heading north and reaching land.

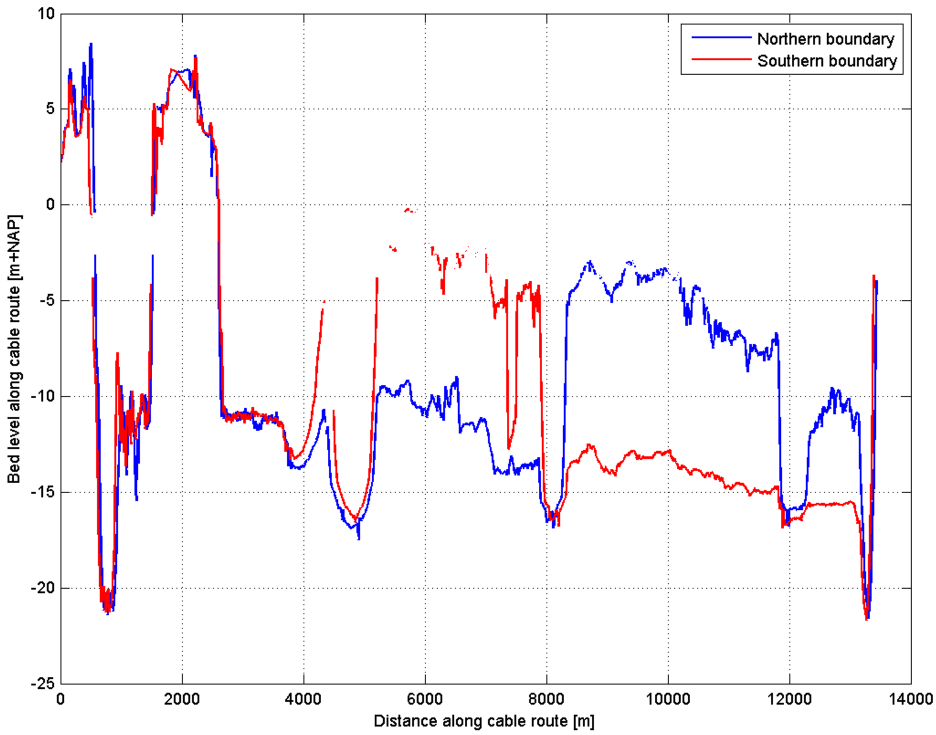

Figure 4.3: Depth (bed level 2017) along cable route alternative 5 in IJmuiden Port and the Noordzeekanaal.

4.2 IJmuiden Port

To determine the mobility of the bed level of IJmuiden Port, several surveys of the area and information on the maintenance dredging policy and guaranteed depths in the area is used.

IJmuiden Port and the IJmuiden locks serve as entrance to the Noordzeekanaal and subsequently the Port of Amsterdam. Because of the open connecting with the sea, significant amounts of sediment are transported into IJmuiden port resulting in a dynamic area. To keep the busy traffic lanes at their guaranteed depth, the area is surveyed every 4 weeks to check whether maintenance is required or not. If so, maintenance is performed. Analysis of several of these surveys shows that the bed level changes in the area between the breakwaters up to the lock complex mainly consist of sedimentation and is in the order of decimetres per month, being strongest closer to the North Sea. Close to the breakwater tips some extra mobility can be expected due to scour.

Route alternative 4 and 5 cross several of the navigation channels of IJmuiden Port. The locations of the traffic lanes crossed by route alternative 4 and 5 are shown in Figure 4.4 up to Figure 4.7. The guaranteed depth and the minimum and maximum depth according to the dredging contract are presented in Table 4.1. The depths indicated in Table 4.1 also show the depth variation (minimum and maximum bed level) that can be found in this area. Note that as a result of the New Sea Lock at IJmuiden, to be finished in 2019, the Port of Amsterdam will attract larger ships. This could result in deeper and/or wider channels on the seaward side of the locks, although there are no specific development plans yet.

At KP 1, see yellow dot in Figure 4.4, route alternative 4 and 5 cross the IJmuidense Fortput, a sand re-handling location. Sea-going vessel dispose sand here, were it subsequently is re-handled by a suction dredger into inland navigation vessels. This is a very dynamic area.

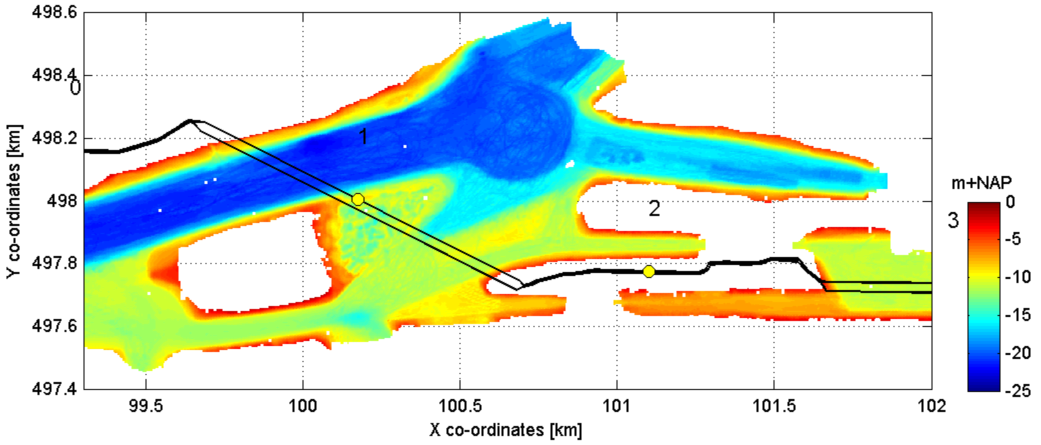

Figure 4.4: Bed level (2017) of IJmuiden Port with the cable route alternative 4 and 5 (black) and KP's.

Table 4.1: Depth of several sections of IJmuiden Port, crossed by route alternative 4 and 5. (Waterboekje, Rijkswaterstaat)

		Dredging contract	
Location	Guaranteed depth	Minimum depth	Maximum depth
Noorderbuitenkanaal	NAP -19.6 m	NAP -19.9 m	NAP -21.4 m
Noorderbuitenkanaal – turning basin	Turning basin is not formalised, but an extra polygon is defined in the dredging contract and maintained at NAP -18.6 m.		
Verbindingskanaal*	NAP -10.5 m	NAP -10.5 m	NAP -11.2 m
Middenbuitentoeleidingskanaal	NAP -10.5 m	NAP -10.5 m	NAP -11.2 m

**Configuration of channel will change as a result of the New Sea Lock. The new lay-out is not determined yet.*

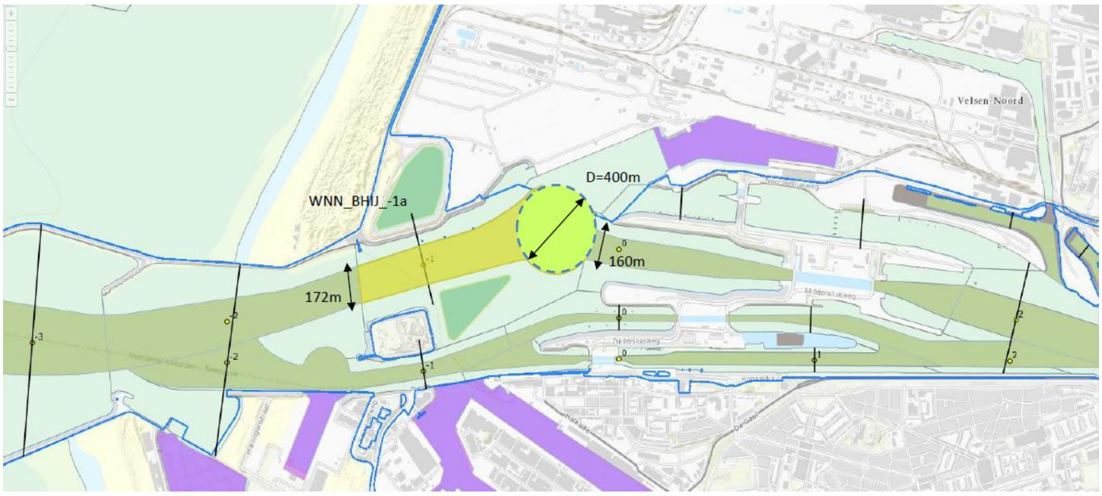

Figure 4.5: Location of Noorderbuitenkanaal, which is crossed by cable route alternative 4 and 5. (Waterboekje, Rijkswaterstaat)

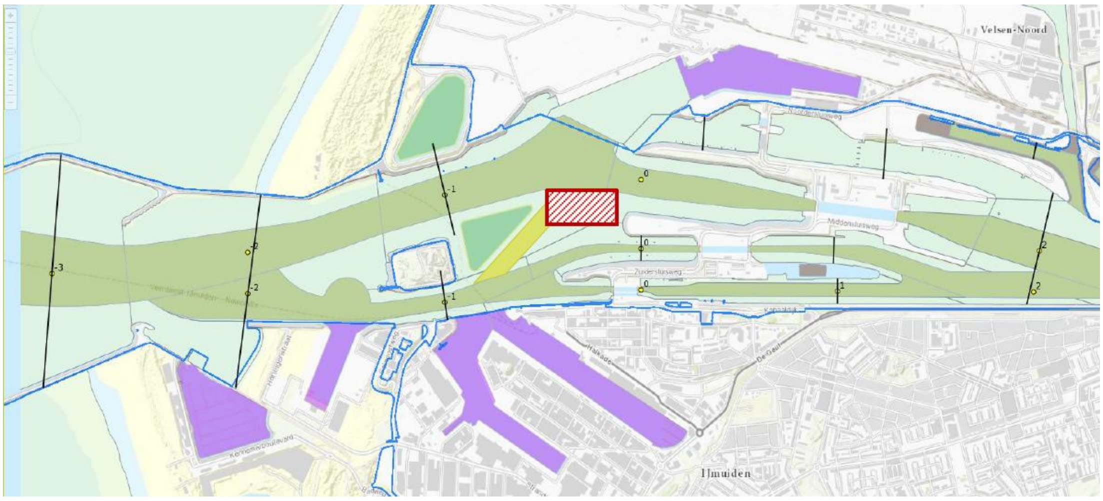

Figure 4.6: Location of Verbindingskanaal, which is crossed by cable route alternative 4 and 5.The configuration of this channel will be changed as a result of the New Sea Lock, but how is not determined yet. (Waterboekje, Rijkswaterstaat)

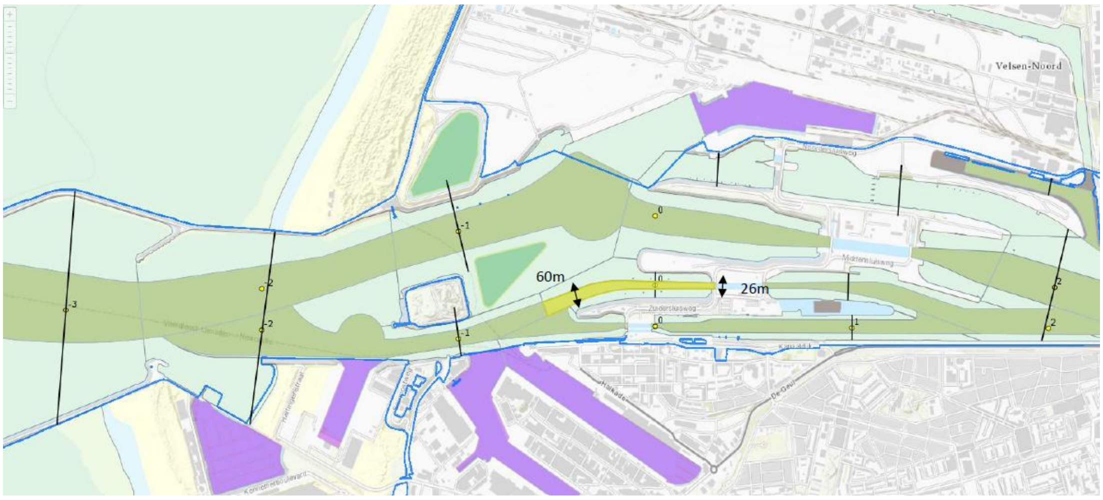

Figure 4.7: Location of Middenbuitentoeleidingskanaal, which is crossed by cable route alternative 4 and 5. (Waterboekje, Rijkswaterstaat)

4.3 Noordzeekanaal

To determine the mobility of the bed level of the Noordzeekanaal, several surveys of the area and information on the maintenance dredging policy and guaranteed depths in the area is used.

The Noordzeekanaal does not have an open connection with the sea and is therefore not very sensitive to sedimentation. Surveys are performed once a year and maintenance dredging is only performed occasionally: the last maintenance dredging has been in 2009, but new dredging works are being scheduled. To indicate the order of magnitude of sedimentation in the Noordzeekanaal, the bed level difference between 2009 and 2017 is shown in Figure 4.8. The red areas in the middle of the channel represent sedimentation and are less than 1 m over 8 years. On the sides, erosion is visible. This can either be scour caused by shipping, or a deliberate change of the channel profile.

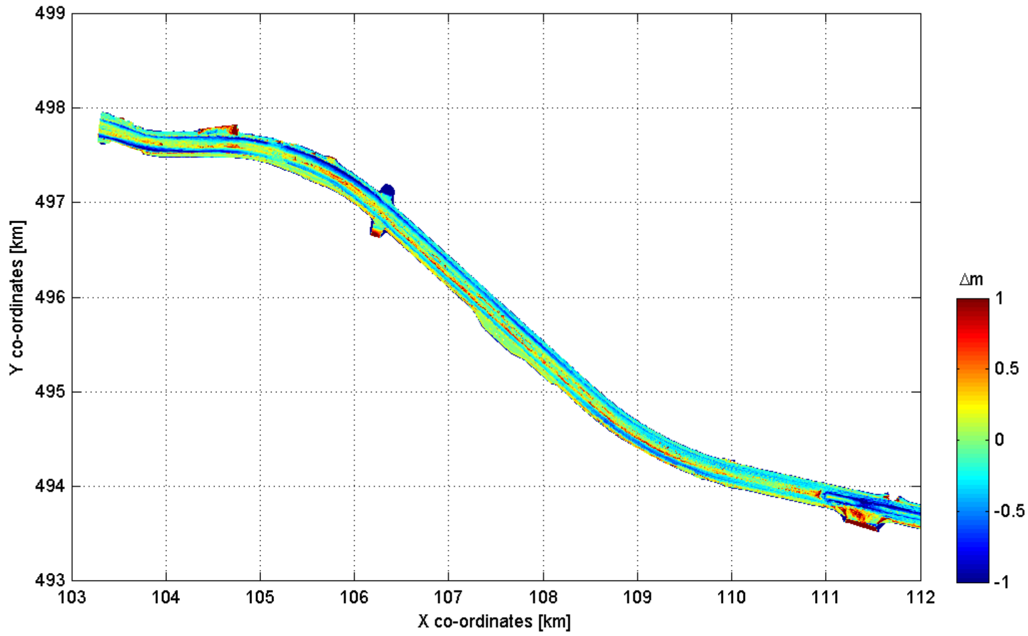

Figure 4.8: Bed level difference in Noordzeekanaal between 2009 and 2017.

Besides the Noordzeekanaal itself, route alternative 4 and 5 cross several of the navigation channels near the sluices, see Figure 4.9 up to Figure 4.11. The guaranteed depth and the minimum and maximum depth according to the dredging contract for these channels and the Noordzeekanaal itself are presented in Table 4.2. The depths indicated in this table also show the depth variation (minimum and maximum bed level) that can be found in this area.

Note that as a result of the New Sea Lock at IJmuiden, to be finished in 2019, the situation for the Middenbinnentoeleidingskanaal has already changed, because the New Sea Lock is situated between the northern and middle lock. It is not clear what the impact of this on the depth of the Middenbinnentoeleidingskanaal is and whether the cable route is impacted by the changed situation at all.

Although the Port of Amsterdam will attract larger ships because of the construction of the New Sea Lock, this will not directly lead to deepening of the Noordzeekanaal. The presence of several tunnels underneath the channel, such as the Velsertunnel and Wijkertunnel, does not allow this. If in the future it is decided to deepen the Noordzeekanaal, these tunnels need to be located deeper below the surface which is a very large effort. Widening of the Noordzeekanaal is also an intervention not without difficulties. Although the option is investigated, no concrete plans to do so are known.

Table 4.2: *Depth of several sections of IJmuiden Port, crossed by route alternative 4 and 5. (Waterboekje, Rijkswaterstaat)*

		Dredging contract	
Location	Guaranteed depth	Minimum depth	Maximum depth
Noordzeekanaal	NAP -15.5 m	NAP -15.5 m	NAP -16.0 m
Middenbinnentoeleidingskanaal*	NAP -10.5 m	NAP -10.5 m	NAP -11.2 m

**Configuration of channel is changed as a result of the New Sea Lock, but not present in the most recent documentation yet.*

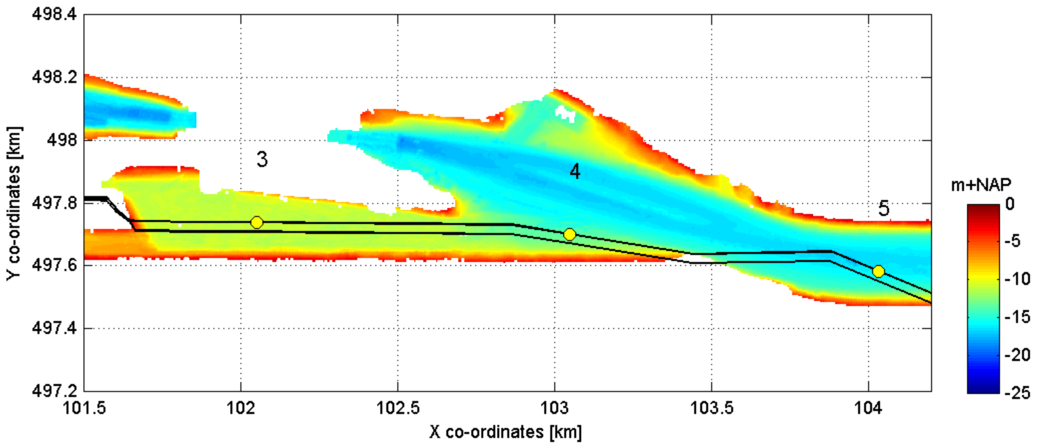

Figure 4.9: Bed level (2017) of IJmuiden locks and Noordzeekanaal with the cable route alternative 4 and 5 (black) and KP's.

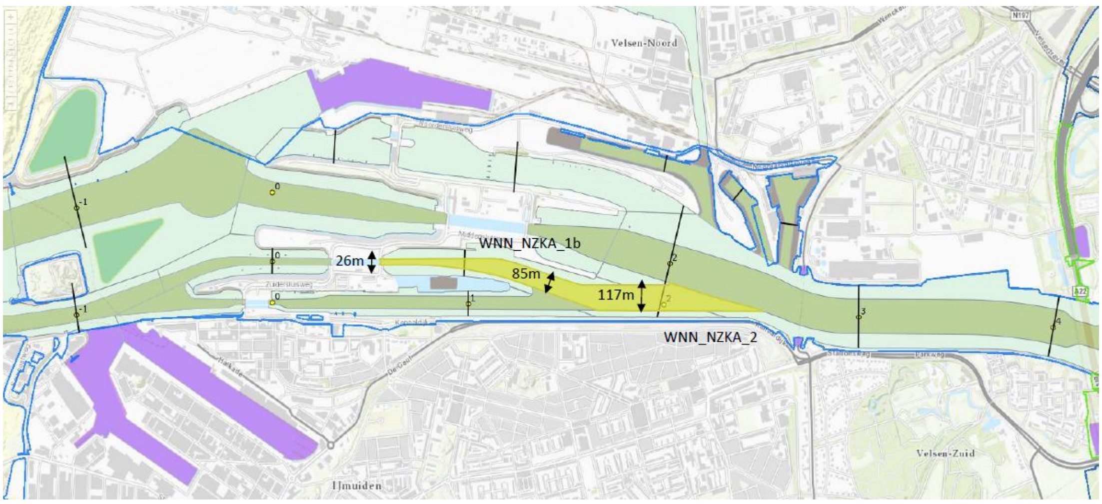

Figure 4.10: Location of Middenbinnentoeleidingskanaal, which is crossed by cable route alternative 4 and 5. The configuration is changed as a result of the New Sea Lock, but not present in the documentation yet. (Waterboekje, Rijkswaterstaat)

Figure 4.11: Noordzeekanaal navigation channel. (Waterboekje, Rijkswaterstaat)

4.4 Synthesis

The construction of the New Sea Lock in IJmuiden results in uncertainties with respect to the future seabed in mainly the IJmuiden Port area. In the near future, guidance channels are relocated and channel depths adjusted, although the exact new configuration is not readily available in documentation yet. Route alternative 4 and 5 also cross sand re-handling location IJmuidense Fortput, which is a very dynamic area due to the sand re-handling activities. Besides, as a result of the New Sea Lock it is expected that the Port of Amsterdam will attract larger ships, leading to deepening of the entrance channel in IJmuiden Port. It is however not known when and to what extent such deepening will take place, and no concrete plans to do so are present yet. This makes it difficult to determine the optimal burial depth of a cable along this part of route alternative 4 and 5, although it is expected that the new lay-out of the IJmuiden Lock complex and its guidance channels will become clear in the near future.

The bed level of the Noordzeekanaal is very constant in the present situation. In the future, deepening of the channel may be desirable, but requires a large effort because of the presence of tunnels that limit the channel depth to its present depth. Widening of the Noordzeekanaal is also an intervention not without difficulties. Although the option is investigated, no concrete plans to do so are known. These two scenarios need to be taken into consideration when deciding on the location of the cable in the Noordzeekanaal. Placing a cable below the navigation channel is preferred when widening of the channel is expected; placing the cable in the channel slopes can be more favourable when deepening of the channel is considered.

5 OFFSHORE GEOLOGICAL CONDITIONS

5.1 Introduction

This chapter gives geological information regarding the upper 10 - 30 m of subsurface of the offshore area around the different cable route options for wind farm HKN. The information in this chapter is based on borehole and model data from TNO and literature.

Stratigraphy and general conditions of the geological formations present in the area of interest are described in paragraph 5.2. Borehole data along the cable route alternatives are given in section 5.3.

5.2 Overall geological condition North Sea

5.2.1 Stratigraphic architecture

The area is dominated by the Upper North Sea group of formations. This group comprises basically the post-Oligocene sediments in the Netherlands. The makeup of this group in this particular area is described qualitatively below.

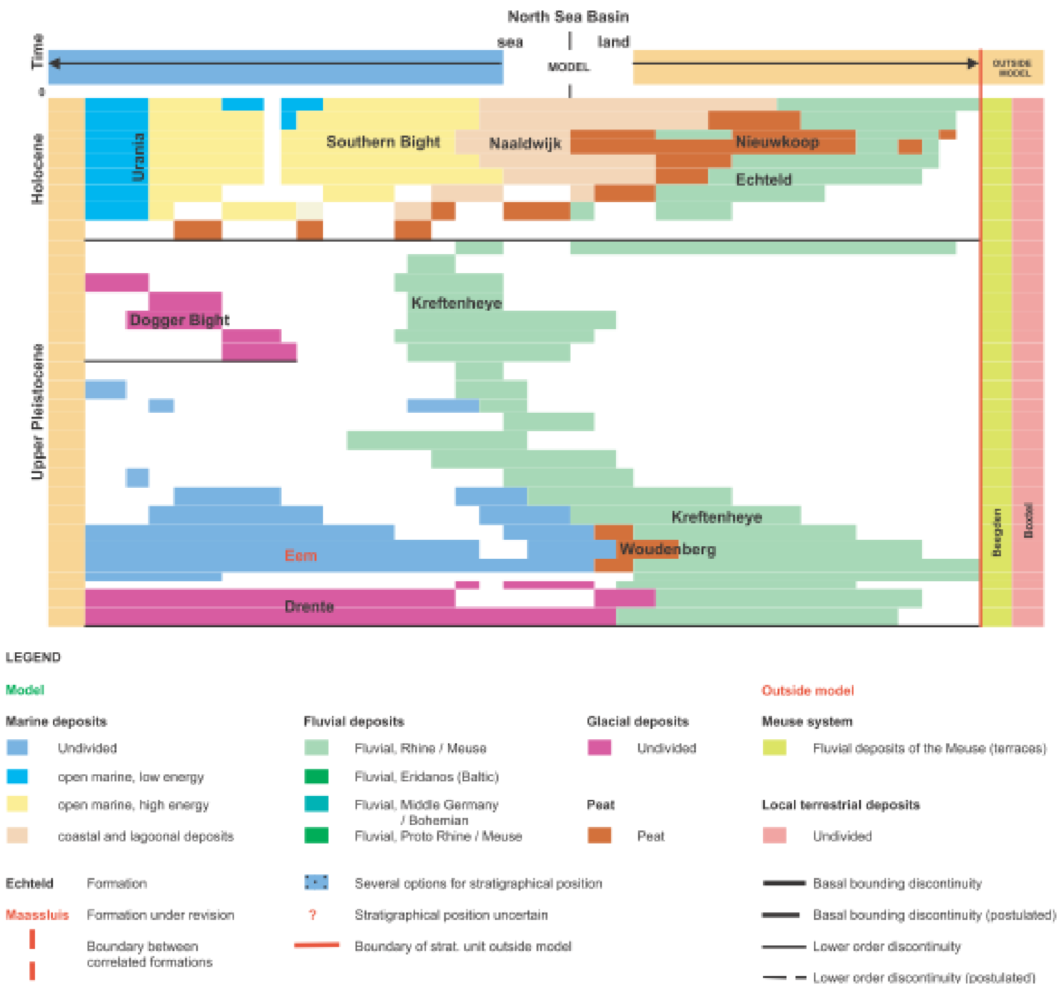

Figure 5.1: Upper part of an integrated stratigraphic model of the North Sea Basin, adapted from Rijsdijk et al. *(2005)*

Figure 5.1 gives a conceptual view of geological stratigraphy of the Dutch coastal zone and North Sea Basin, which has been compiled by Rijsdijk et al. (2005). Figure 5.2 shows the geological stratigraphy along a North-South line close to the Dutch coastline, based on GeoTOP v1.3 data.

Seabed sediments (below roughly the 15 m depth contour) belong to the Southern Bight Formation. Offshore these sands cover Pleistocene fluvial deposits of the Kreftenheye formation which in turn overlie the Eem formation (estuarine deposits).

Approaching shore the Southern Blight Formation turns into the Naaldwijk Formation of tidal depositis of alternating sands and clays. Also in the area close to shore isolated patches of the Nieuwkoop Formation (peat) and Boxtel Formation (aeolian, see Figure 5.2) can be found.

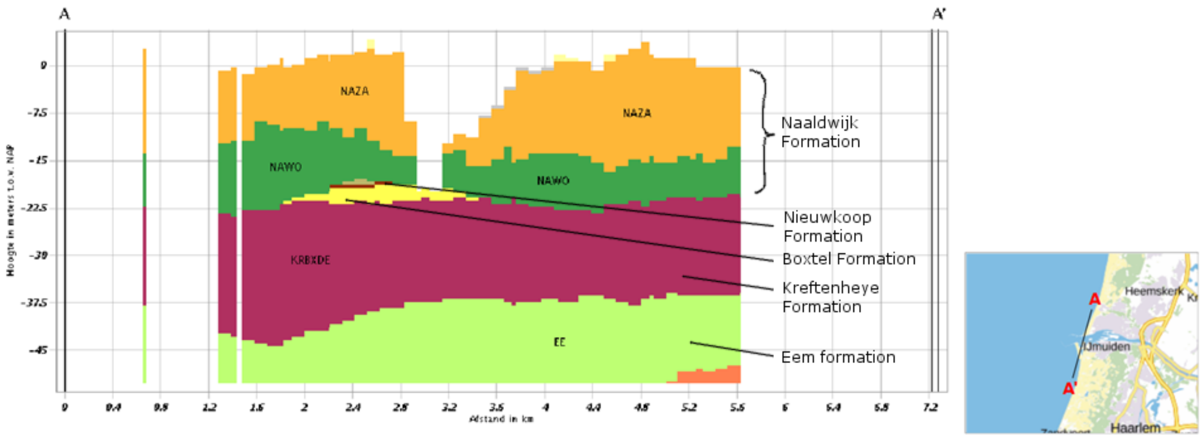

Figure 5.2: Extend of formation along a crosssection over the IJmuiden port Area based of GeoTOP v1.3 accessed via DINO loket[3].

5.2.2 Geological formations

Characteristics of geological formations as presented in the previous paragraph are listed below which are cited (with some adaptation)[4] from Deltares (2016a), which in turn is based on the nomenclator of the DINO Loket (see TNO Geologische Dienst Nederland, 2017) and the Quaternary Geology map Flemisch Bight (1984).:

Southern Bight Formation
At the surface of the seafloor the *Southern Bight Formation* is found (*light yellow layer in Figure 5.1*). This layer is present in the entire study area, the largest thickness, ca. 5 to 6 m, is found at the crests of the sand waves. The formation consists of brown-yellow, medium coarse sand with a D_{50} grain size of 210 to 350 µm. This sand is medium to little sorted, contains CaCO3 and shells (0 – 20%). Sporadically clay and mud laminae can occur. The formation locally contains up to 1 – 2% fine gravel (D_{50} grain size of 2 – 4 mm). The age is Late Holocene.

Naaldwijk Formation
The deposits (*salmon color in Figure 5.1*) consist of 25 – 30% blue-grey clays (with and without shell traces), 5 – 10% peat and 60 – 65% fine sand layers with a D_{50} grain size of 105

[3] Please note that GeoTOP only covers land and a thin strip of the coastal zone, figures as Figure 5.2 can thus not be made for the more offshore located route alternatives.

[4] Italic parts have been added by the author.

– 175 µm. The sand layers often contain intercalated clay layers, in the order of centimeters to about 20 cm thickness; they contain dispersed mud (on average 6%) and are well sorted. The deposits are tidal and deltaic. The age is Early to Late Holocene.

In this area part of the Naaldwijk Formation is the 'Layer of Velsen' which is part of the first clastic deposits of the Holocene. The layer consists of medium to heavy clay which can be peaty (Biewinga et al.*, 1991).*

Nieuwkoop Formation (Basal Peat Bed)
The Basal Peat Bed is a brown (*colored as such in Figure 5.1*) peat layer with a maximum thickness of a few decimetres. The age is Early Holocene. It is strongly compacted.

Boxtel Formation
These wind-blown deposits comprise inland isolated dune complexes and sheets of coversand (Wierden and Delwijnen Layers). The dune sand is yellowish-grey, very fine to medium coarse (D_{50} of 105-300 µm) with a podzolic palaeosol at their top. The age is Late Pleistocene to early Holocene.

Kreftenheye Formation

If no Boxtel Formation is present, the Kreftenheye Formation (*green in Figure 5.1*) forms the top of the Pleistocene sediments in the area (green layer in Figure 3.2). The Formation can be up to 15 m thick, but the thickness is in general between 5 and 10 m. The fluvial Kreftenheye Formation deposits consist mainly of grey medium to very coarse sands (D_{50} of 180 - 800 µm) and contain gravel and shells. These are braided fluvial deposits. Typically the sand is poorly sorted and has a D_{50} grain size of 650 µm. The gravel content is very variable and ranges from a trace to 25% and is in general between 1 and 10%. The gravel is mainly fine to medium coarse (2 – 16 mm), well rounded and mainly made up of sandstone, quartz and quartzite. The formation can also contain wood fragments and hard clay pebbles. The age is Late Pleistocene.

Eem Formation
The formation (*light blue in Figure 5.1*) has a thickness of ca. 10 – 15 m and consists of fine to medium coarse sand with a D_{50} grain size of 250 µm. About 5% of the sands contain few to many shells, the rest usually contains traces of shells (0 – 1%). There are traces of gravel in the sands and locally ca. 5% gravel can be present. About 10% of the sands contain mud, on average 5%. The age is Late Pleistocene.

5.2.3 Heterogenity in the subsurface

Formations as discussed in the preceding sections have a varying lateral extent, such variations are important because geological properties change with the formations:

- Naaldwijk formation and especially the clayey Layer of Velsen also nearer to shore are heterogenic.
- Patchy extend and varying thickness of Nieuwkoop Formation (peat beds), see peat occurrence in nearer to shore bore holes (paragraph 5.3). Often below Layer of Velsen, see previous bullet.
- Human intervention: especially related to dredging of the IJmuiden access channel. In the port itself the Naaldwijk formation has been dug away revealing the underlying Boxtel and Kreftenheye formations (see Figure 5.2). At medium distances from shore the upper sandy part of the Naaldwijk formation has been dredged revealing clay from the Layer of Velsen, which can be seen in the boreholes of routes 6 and 7 in paragraph 5.3.

5.3 Borehole data and depth map along alternative cable route

Six geological cross sections (option 4 and 5 are the same offshore) of the bathymetry and relevant boreholes from TNO (DINO loket) are made. Figure 5.3 gives an overview of all available boreholes in the area, for each cross section boreholes within 1 km of the route centerline have been selected (colored red in the figure).

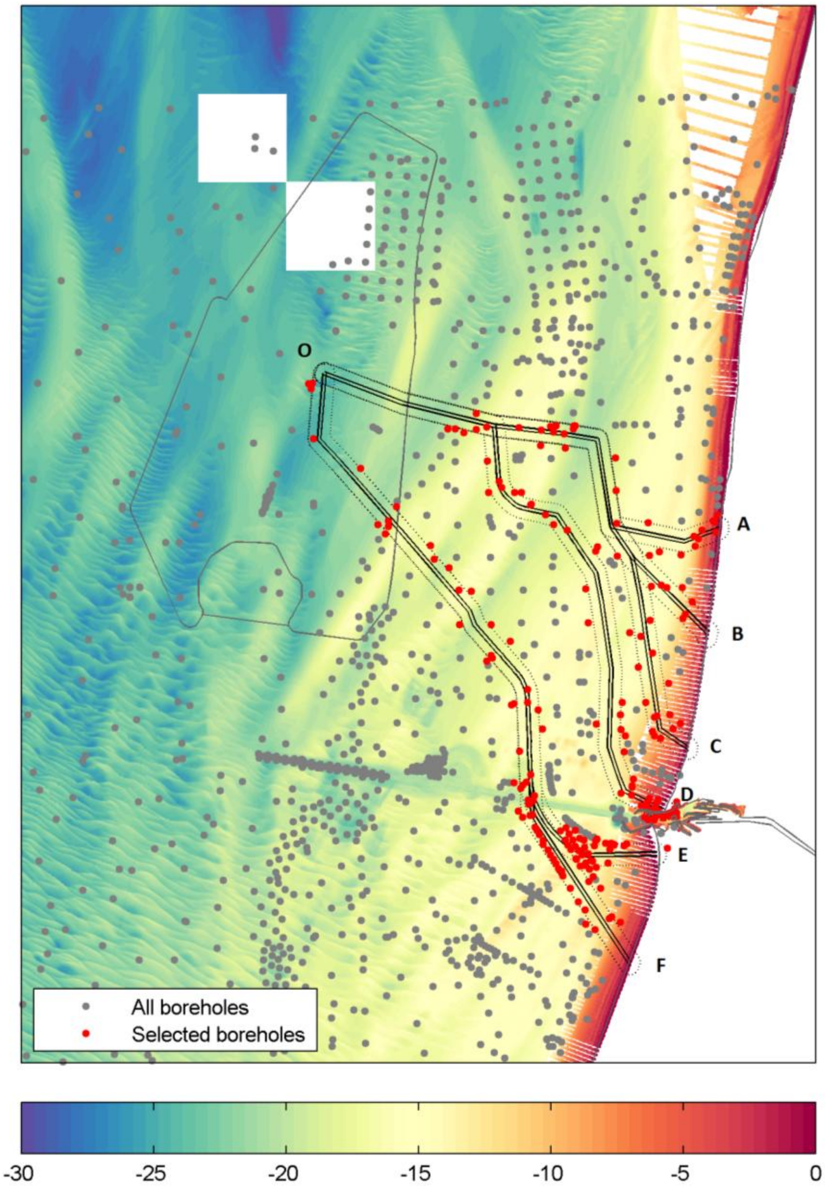

Figure 5.3: Borehole locations (DINO loket) against bathymetry and route alternatives.

Table 5.1 gives an overview of the bathymetry and borehole cross-sections as defined above in relation to cable route options and resulting figures in the remainder of this chapter.

Table 5.1: Overview of cross sections as depicted in Figure 5.3.

Geological transect (Figure 5.3)	Cable route option	Borehole cross-section
O-A	1	Figure 5.4

O-B	2	Figure 5.5
O-C	3	Figure 5.6
O-D	4 and 5	Figure 5.7
O-E	6	Figure 5.8
O-F	7	Figure 5.9

Each figures below shows the bathymetric cross sections based on the Most Recent Bathymetry (see Chapter 2). All boreholes within 1km are plotted to the closest section of the transect.

All soil types (sand, clay, peat, loam, shells) correspond to those supplied by DINO loket. Sands are further subdivided based on median grain size following NEN5104: medium fine and smaller ($D_{50} <$ 210 µm), medium coarse (210 $\leq D_{50} <$ 300 µm) and coarse and larger $D_{50} \geq$ 300 µm). Sand without grain size information is listed as 'sand (unknown size)'.

Description of the transects and references to the different geological formations is made in the figures captions.

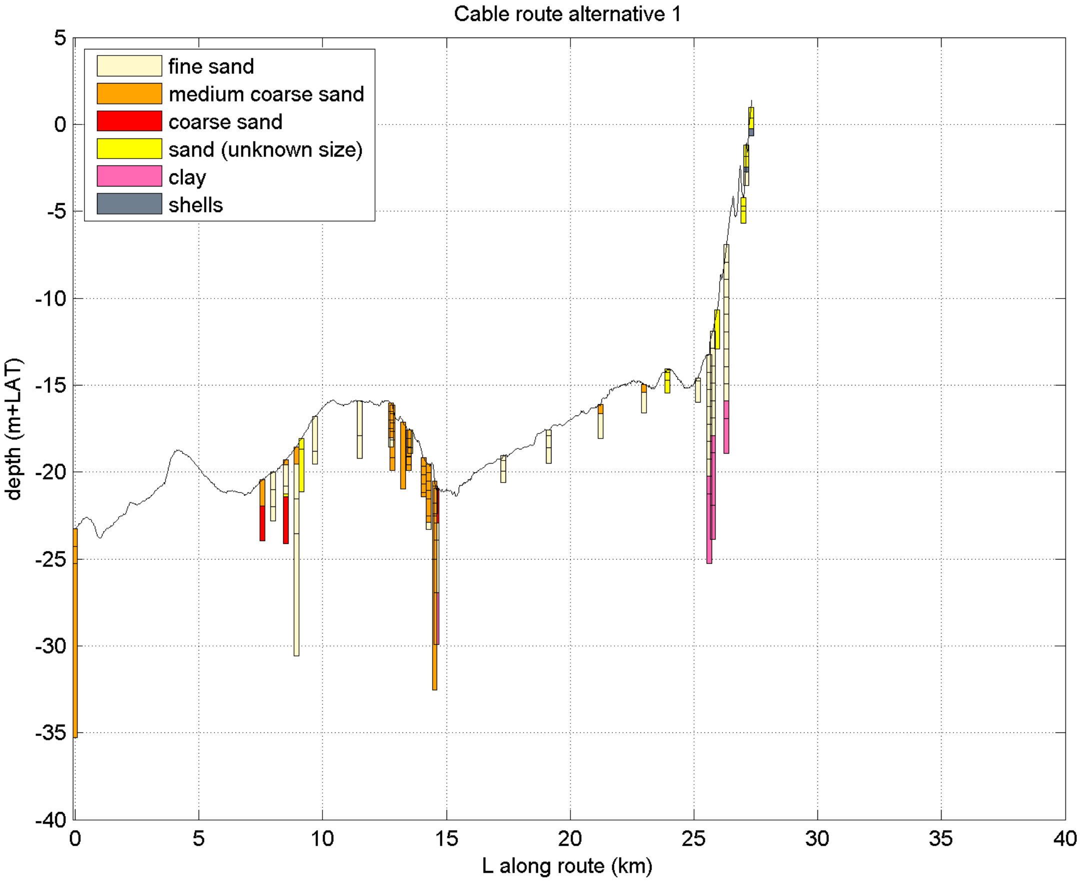

Figure 5.4: Bathymetric and borehole cross-section from O-A, showing mainly fine and medium sand at the surface and some coarser sand at 2 m depth. Near shore clay formation of the Layer of Velsen (part of the Naaldwijk formation) is apparent at 8m depth.

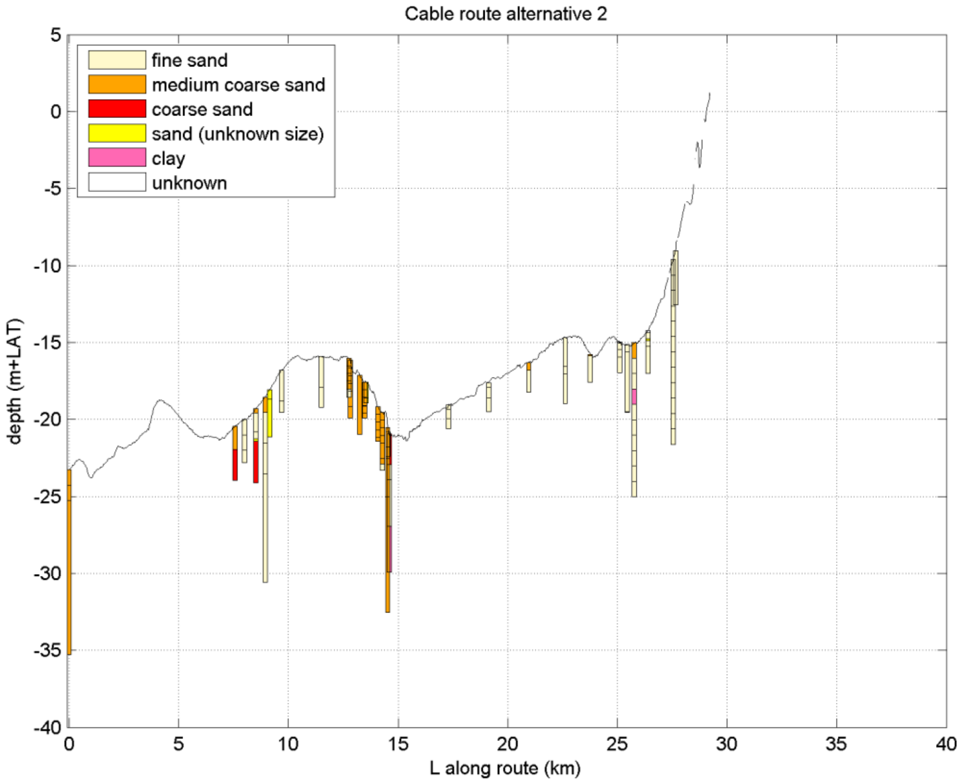

Figure 5.5: Bathymetric and borehole cross-section from O-B, showing mainly medium sand at the surface and some coarser sand at 2 m depth. Near shore some small patches of clay of the Layer of Velsen (part of the Naaldwijk formation) is apparent at 4 m depth.

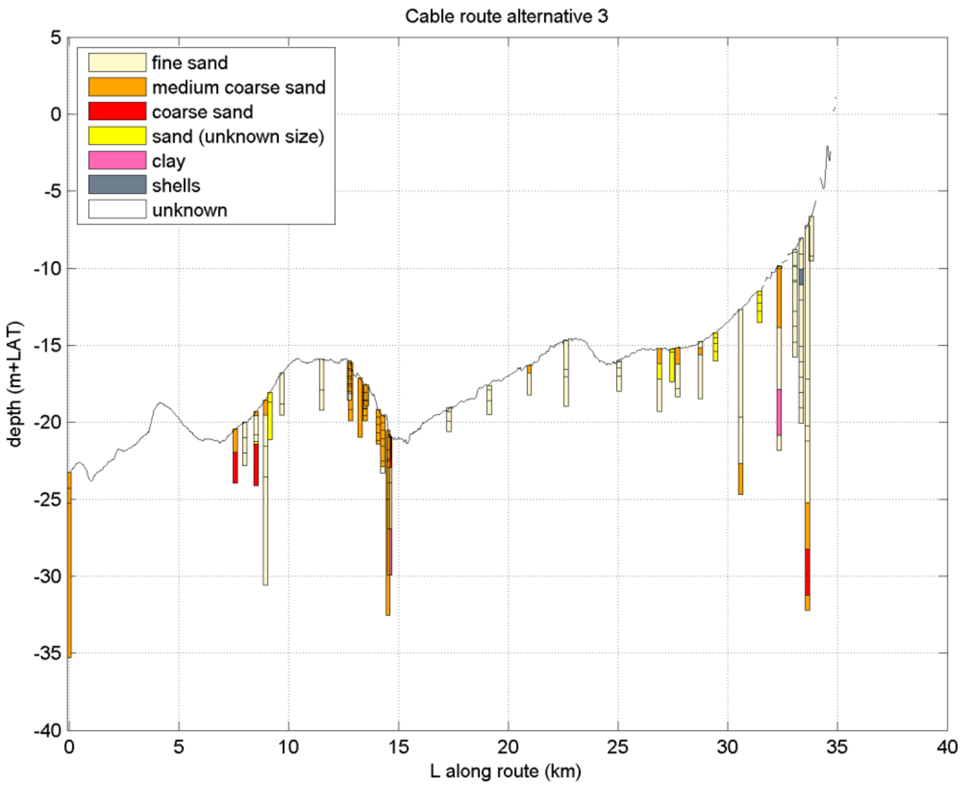

Figure 5.6: Bathymetric and borehole cross-section from O-C, showing mainly medium sand at the surface. Near shore some small patches of clay of the Layer of Velsen (part of the Naaldwijk formation) is apparent at 8 m depth.

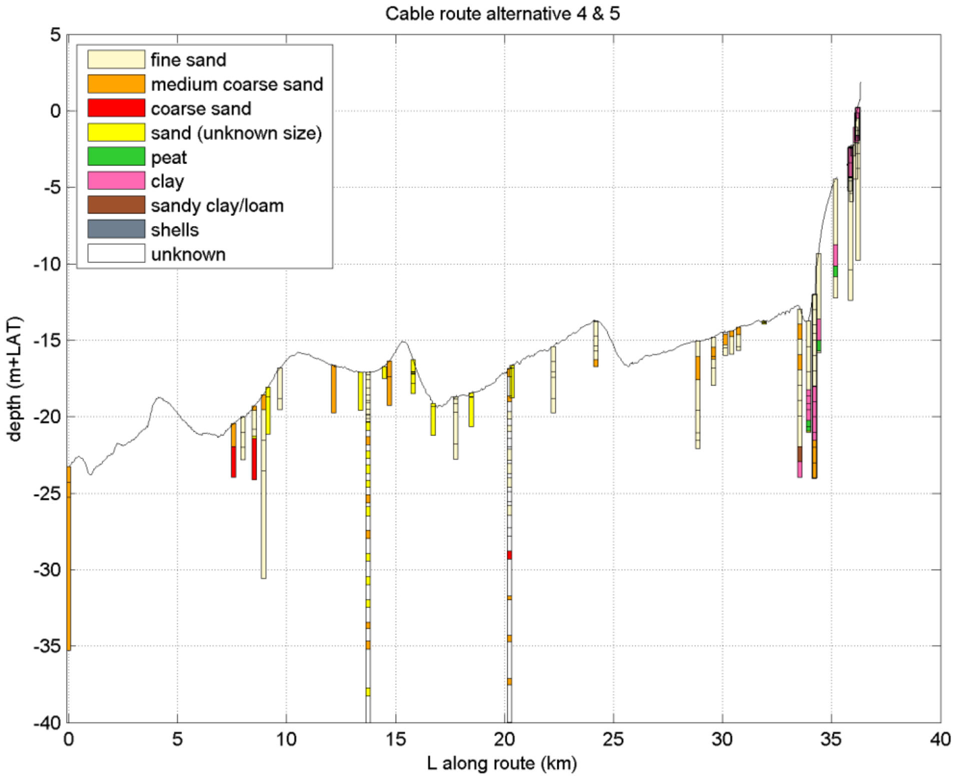

Figure 5.7: Bathymetric and borehole cross-section from O-C, showing mainly medium sand at the surface. Near shore coarse sand at the surface and clay of the Layer of Velsen (part of the Naaldwijk formation) is apparent at the surface and at 8m depth, covering peat beds from the Nieuwkoop formation.

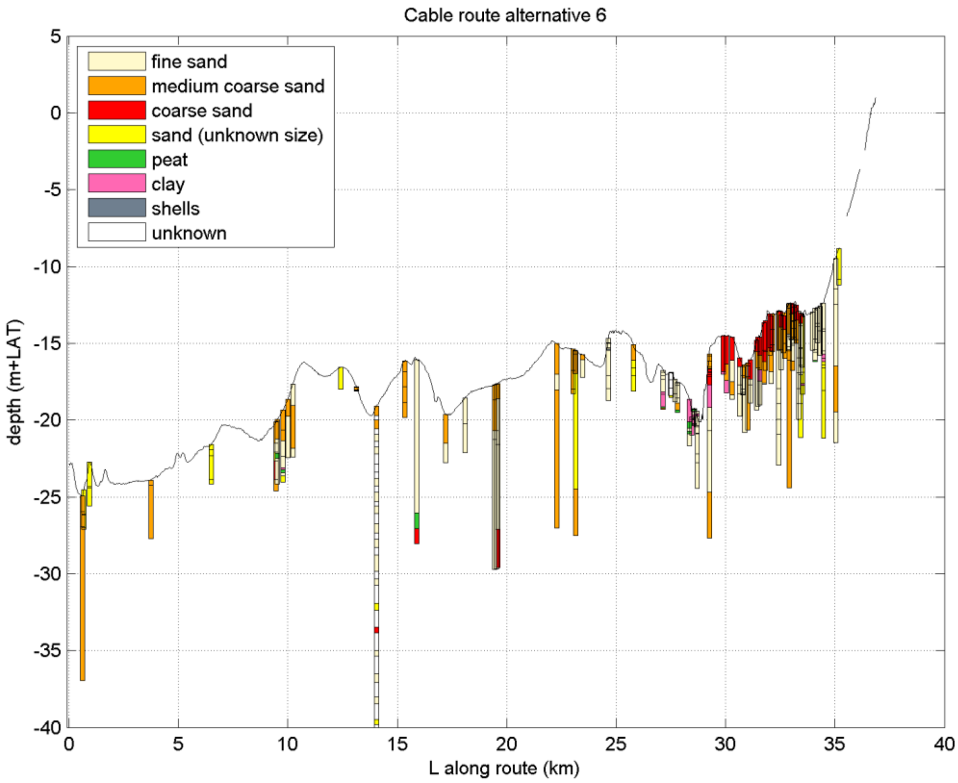

Figure 5.8: Bathymetric and borehole cross-section from O-E, showing mainly medium sand at the surface offshore and coarser sands closer to the coast. IJmuiden shipping channel is visible around km 29, with deposits of clay belonging to the Layer of Velsen (part of the Naaldwijk formation) which have become exposed due to dredging activities. Below the clay, remnants of peat from the Nieuwkoop formation can be seen.

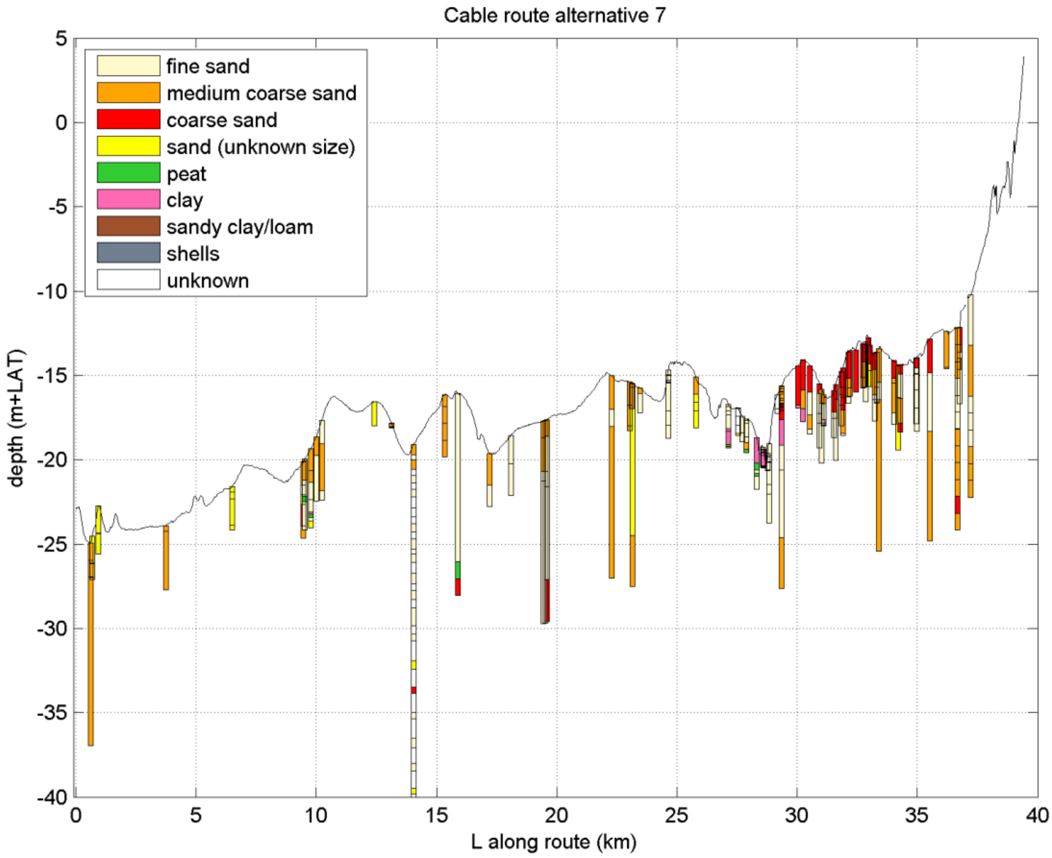

Figure 5.9: Bathymetric and borehole cross-section from O-F, showing mainly medium sand at the surface offshore and coarser sands closer to the coast. IJmuiden shipping channel is visible around km 29, with deposits of clay belonging to the Layer of Velsen (part of the Naaldwijk formation) which have become exposed due to dredging activities. Below the clay, remnants of peat from the Nieuwkoop formation can be seen.

The characteristic sediment types and formations of each cable route option are summarized in

Table 5.2. Please note that this characterisation is based on a limited number of boreholes available and for some cable route options the distance between different available boreholes can be several kilometres. In the gaps there might be different sediment layers, but this remains unknown from the data. Therefore some of the differences in characterisation in

Table 5.2 between the different cable route options might be attributed to lacking borehole information. For example along route option 4/5 clay layers are found at the surface near shore and for route option 1 only sand is found at the surface in the near shore zone, but for route options 2,3,6,7 no bore holes are available in the near shore zone and it remains unknown whether there is clay at the surface near shore or not along those route options.

Not only sand, but also clay is found along the different route options. For cable placement the shear strength of clay can be an issue when such clay layer has significant thickness. For example an indication of the application range of a jet trencher is: <70 kPa applicable; 70-125 kPa possibly applicable and > 125 kPa not applicable. Clay shear stress is strongly dependent on local conditions like sediment packing and must therefore be determined with laboratory shear tests on in-situ soil samples supplemented with CPT's (cone penetration tests). NEN 6740 gives the following representative undrained shear strength values for clay in the Netherlands in case no laboratory tests are available: loose clay 25-50 kPa, moderate clay 50-100 kPa, dense clay 100-200 kPa. The clay layers found along the different cable route options probably are not loose, but are estimated to consist of moderate and dense clay which gives an indicative range of undrained shear strength of 50-200 kPa. Hence, jet trenching might be possible but probably not at all locations.

In order to be certain about the applicability of a jet trencher or comparable cable placement method laboratory shear tests supplemented with CPT's are necessary as well as extra boreholes to fill the gaps between the different available boreholes along the cable route options to assess whether more clay layers are present.

Table 5.2 Characteristic sediment type/size and formations of each cable route option

Cable route option	Geology
1	Mainly Southern Bight formation fine (D_{50} < 210 µm) and medium sand (D_{50} =210-350 µm) at the surface and some coarse sand (D_{50} ≥ 300 µm). Near shore some shell patches at 2m below surface and clay formation of the Layer of Velsen (part of the Naaldwijk formation) at about 8m below surface. First 4m from surface contains fine (D_{50} < 210 µm), medium (D_{50} =210-350 µm) and unknown size sand with incidental coarse sand (D_{50} ≥ 300 µm) and shell patches at 2m below surface.
2	Mainly Southern Bight formation medium sand (D_{50} =210-350 µm) at the surface and some coarse sand (D_{50} ≥ 300 µm). Near shore some small patches of clay of the Layer of Velsen (part of the Naaldwijk formation) at 4 m below surface. First 4m from surface contains fine (D_{50} < 210 µm), medium (D_{50} =210-350 µm) and unknown size sand with incidental coarse sand (D_{50} ≥ 300 µm) as well as clay patches at 3-4m below surface. Unknown sediment type first 4m from surface near shore L=28-30km due to lacking borehole data.
3	Mainly Southern Bight formation medium sand (D_{50} =210-350 µm) offshore and coarse sand (D_{50} ≥ 300 µm) closer to shore. Near shore some small patches of clay of the Layer of Velsen (part of the Naaldwijk formation) at 8 m below surface. First 4m from surface contains fine (D_{50} < 210 µm), medium (D_{50} =210-350 µm) and unknown size sand with incidental coarse sand (D_{50} ≥ 300 µm) as well as shell patches at 2-3m below surface. Unknown sediment type first 4m from surface near shore L=34-35km due to lacking borehole data.
4&5	Mainly Southern Bight formation medium sand (D_{50} =210-350 µm). Near shore approximately 1-2m clay of the Layer of Velsen (part of the Naaldwijk formation) at the surface and at 8m below surface, covering peat beds from the Nieuwkoop formation. First 4m from surface contain fine (D_{50} < 210 µm), medium (D_{50} =210-350 µm) and unknown size sand with incidental coarse sand (D_{50} ≥ 300 µm) as well as unknown type sediment and 1-2m clay at surface along about 2km near shore.
6	Mainly Southern Bight formation medium sand (D_{50} =210-350 µm) offshore and coarse sand (D_{50} ≥ 300 µm) closer to shore. At the IJgeul deposits of clay belonging to the Layer of Velsen (part of the Naaldwijk formation) are at the surface due to dredging activities. Below the clay, remnants of peat from the Nieuwkoop formation can be seen. First 4m from surface contains fine (D_{50} < 210 µm), medium (D_{50} =210-350 µm) and unknown size sand with coarse sand (D_{50} ≥ 300 µm) for L=30-35km as well as clay patches at the surface and at 2-3m below surface for L=27-32km near the IJgeul. Unknown sediment type first 4m from surface near shore L=36-37km due to lacking borehole data.
7	Mainly Southern Bight formation medium sand (D_{50} =210-350 µm) offshore and coarse sand (D_{50} ≥ 300 µm) closer to shore. At the IJgeul deposits of clay belonging to the Layer of Velsen (part of the Naaldwijk formation) are at the surface due to dredging activities. Below the clay, remnants of peat from the Nieuwkoop formation can be seen. First 4m from surface contains fine (D_{50} < 210 µm), medium (D_{50} =210-350 µm) and unknown size sand with coarse sand (D_{50} ≥ 300 µm) for L=30-37km as well as clay patches at the surface and at 2-3m below surface for L=27-32km near the IJgeul. Unknown sediment type first 4m from surface near shore L=37-40km due to lacking borehole data.

5.4 Recommendations

A first order quantification of the offshore geological conditions, based on available open data sources, has been provided in this chapter to support the selection of a cable route option. It is recommended to conduct further field surveys of the selected cable route before commencing burial of the cable. This field survey should provide more detailed information about the subsurface along the full route like details on different soil types, soil strength and location of pipes and cables. This can be achieved by detailed geophysical surveys: bathymetry surveying (multi- and single beam echo sounder), seabed surface (side scan sonar), subsurface profiling (sub-bottom profiler and sparker), magnetometer, boreholes, laboratory shear tests on in-situ soil samples, cone penetration tests (including friction ratio and pore water pressure).

6 MAIN FINDINGS AND RECOMMENDATIONS

6.1 Main findings

This report describes the morphological seabed mobility route comparison for wind farm Hollandsche Kust (noord) (HKN). Seven different cable export route options for HKN are considered. Goal of this study is to compare the route options with regards to seabed mobility and its impact on the installation and the operation and maintenance of the cables over their lifetime, as input to the VKA (voorkeursalternatief) process.

For each cable route option for wind farm HKN an assessment is provided for the offshore seabed mobility (Chapter 2), landfall seabed mobility (Chapter 3), offshore geological conditions (Chapter 5) and for route options 4-5 IJmuiden harbour entry and Noordzeekanaal bed mobility (Chapter 4). For this study no new surveys have been undertaken, therefore all analyses are performed based on already available bathymetry and geological data. In a following phase an update of this study will be made based on extra surveys of bathymetry and geology.

A brief summary of the findings is given in

Table 6.1, but see the relevant chapters of this report for more information, analyses and advice. Please note that some of the differences in geological characterisation in

Table 6.1 between the different cable route options might be attributed to lacking borehole information along some route options.

A ranking of the different cable route options from a seabed mobility perspective is given as follows. Cable route options 1 is most preferable because it crosses the lowest number of sand waves and does not show clay patches in the first 4m from the surface. Next come route options 2-3 which cross the same low number of sand waves, but they have an unknown sediment type in the last 2 km nearshore and like route option 4-5 there is a risk there is clay in this zone. Route option 4-5 cross more sand waves and have clay near the surface in the last 2 kilometers near shore. Least preferable are route options 6-7 which have the largest number of sand waves, cross the IJgeul, have clay patches near the surface for 5 km around the IJgeul (due to dredging of the IJgeul) and an unknown sediment type in the last 2-3 km nearshore and like route option 4-5 there is a risk of clay in this zone. Landfall mobility does not show significant differences between the different route options as the bathymetry variations are similar, eroding coastline sections (route option 1,7) are maintained by nourishments,coastline sections for route option 4,5,6 are slowly accreting and the other coastline sections (route option 2,3) are stable.

Table 6.1 Main findings summarised for each cable route option

Cable route option	Offshore seabed mobility	Landfall/inland bed mobility	Offshore geological conditions
1	3 sand waves along route 4 km of route influenced by sand waves Sandwave height 0.5; 1.5; 2.5m, Length 250-1200m and migration speed 1-4 m/yr Cable route option 1 is next to an old sand extraction area at 400m distance.	Eroding coastline Maintained by shoreface and beach nourishments, 1m -4 m depth variation 4m depth variation in shoreface 1m-2m depth variation at beach 1m-2m depth variation shoreface during storm, 30 m dunefoot retreat Shoreface: 1 km route influenced. Beach: 0.5 km route influenced	Mainly Southern Bight formation fine (D_{50} < 210 µm) and medium sand (D_{50} =210-350 µm) at the surface and some coarse sand (D_{50} ≥ 300 µm). Near shore some shell patches at 2m below surface and clay formation of the Layer of Velsen (part of the Naaldwijk formation) at about 8m below surface. First 4m from surface contains fine (D_{50} < 210 µm), medium (D_{50} =210-350 µm) and unknown size sand with incidental coarse sand (D_{50} ≥ 300 µm) and shell patches at 2m below surface.
2	3 sand waves along route 4 km of route influenced by sand waves Sandwave height 0.5; 1.5; 2.5m, Length 250-1200m and migration speed 1-4 m/yr Cable route option 2 is next to an old sand extraction area at 400m distance.	Stable coastline, no maintenance 4m depth variation in shoreface 1m-2m depth variation at beach 1m-2m depth variation shoreface during storm, 15 m dunefoot retreat Shoreface: 1 km route influenced. Beach: 0.5 km route influenced	Mainly Southern Bight formation medium sand (D_{50} =210-350 µm) at the surface and some coarse sand (D_{50} ≥ 300 µm). Near shore some small patches of clay of the Layer of Velsen (part of the Naaldwijk formation) at 4 m below surface. First 4m from surface contains fine (D_{50} < 210 µm), medium (D_{50} =210-350 µm) and unknown size sand with incidental coarse sand (D_{50} ≥ 300 µm) as well as clay patches at 3-4m below surface. Unknown sediment type first 4m from surface near shore L=28-30km due to lacking borehole data.
3	3 sand waves along route 4 km of route influenced by sand waves Sandwave height 0.5; 1.5; 2.5m, Length 250-1200m and migration speed 1-4 m/yr Cable route option 3 is next to an old sand extraction area at 400m distance.	Stable coastline, no maintenance 4m depth variation in shoreface 1m-2m depth variation at beach 1m-2m depth variation shoreface during storm, 30 m dunefoot retreat Shoreface: 1 km route influenced. Beach: 0.5 km route influenced	Mainly Southern Bight formation medium sand (D_{50} =210-350 µm) offshore and coarse sand (D_{50} ≥ 300 µm) closer to shore. Near shore some small patches of clay of the Layer of Velsen (part of the Naaldwijk formation) at 8 m below surface. First 4m from surface contains fine (D_{50} < 210 µm), medium (D_{50} =210-350 µm) and unknown size sand with incidental coarse sand (D_{50} ≥ 300 µm) as well as shell patches at 2-3m below surface. Unknown sediment type first 4m from surface near shore L=34-35km due to lacking borehole data.
4	6 sand waves along route 5 km of route influenced by sand waves Sandwave height 0.3-2.5m, Length 250-1200m and migration speed 1-15 m/yr Cable route option 4 crosses sediment placement area 'Loswal IJmuiden', but within corridor it is possible to avoid it.	Accreting coastline, more stable in recent years, no maintenance 2m depth variation in shoreface 1m depth variation at beach 1m-2m depth variation shoreface during storm, erosion of high parts of beach ('plateaus') Depth variation IJmuiden Port and Noordzeekanaal 1m, future developments important Shoreface: 1.5 km route influenced. Beach: 0.5 km route influenced	Mainly Southern Bight formation medium sand (D_{50} =210-350 µm). Near shore approximately 1-2m clay of the Layer of Velsen (part of the Naaldwijk formation) at the surface and at 8m below surface, covering peat beds from the Nieuwkoop formation. First 4m from surface contain fine (D_{50} < 210 µm), medium (D_{50} =210-350 µm) and unknown size sand with incidental coarse sand (D_{50} ≥ 300 µm) as well as unknown type sediment and 1-2m clay at surface along about 2km near shore.

Cable route option	Offshore seabed mobility	Landfall/inland bed mobility	Offshore geological conditions
5	6 sand waves along route 5 km of route influenced by sand waves Sandwave height 0.3-2.5m, Length 250-1200m and migration speed 1-15 m/yr Cable route option 5 crosses sediment placement area 'Loswal IJmuiden', but within corridor it is possible to avoid it.	Accreting coastline, more stable in recent years, no maintenance 2m depth variation in shoreface 1m depth variation at beach 1m-2m depth variation shoreface during storm, erosion of high parts of beach ('plateaus') Depth variation IJmuiden Port and Noordzeekanaal 1m, future developments important Shoreface: 1.5 km route influenced. Beach: 0.5 km route influenced	Mainly Southern Bight formation medium sand (D_{50} =210-350 μm). Near shore approximately 1-2m clay of the Layer of Velsen (part of the Naaldwijk formation) at the surface and at 8m below surface, covering peat beds from the Nieuwkoop formation. First 4m from surface contain fine (D_{50} < 210 μm), medium (D_{50} =210-350 μm) and unknown size sand with incidental coarse sand (D_{50} ≥ 300 μm) as well as unknown type sediment and 1-2m clay at surface along about 2km near shore.
6	15 sand waves along route 13 km of route influenced by sand waves Sandwave height 0.2-2.5m, Length 200-1300m and migration speed 1-15 m/yr Cable route option 6 crosses sediment placement area 'Loswal IJmuiden'. Cable route option 6 crosses the IJgeul with a width of 450m and a depth up to LAT-20.5m to LAT-22.5m (nautical depth LAT-19.3m/LAT-19.2m).	Accreting coastline, no maintenance 2m depth variation in shoreface 1m depth variation at beach 1m-2m depth variation shoreface during storm, erosion of high parts of beach ('plateaus') Shoreface: 1 km route influenced. Beach: 1 km route influenced	Mainly Southern Bight formation medium sand (D_{50} =210-350 μm) offshore and coarse sand (D_{50} ≥ 300 μm) closer to shore. At the IJgeul deposits of clay belonging to the Layer of Velsen (part of the Naaldwijk formation) are at the surface due to dredging activities. Below the clay, remnants of peat from the Nieuwkoop formation can be seen. First 4m from surface contains fine (D_{50} < 210 μm), medium (D_{50} =210-350 μm) and unknown size sand with coarse sand (D_{50} ≥ 300 μm) for L=30-35km as well as clay patches at the surface and at 2-3m below surface for L=27-32km near the IJgeul. Unknown sediment type first 4m from surface near shore L=36-37km due to lacking borehole data.
7	15 sand waves along route 13 km of route influenced by sand waves Sandwave height 0.2-2.5m, Length 200-1300m and migration speed 1-15 m/yr Cable route option 7 crosses sediment placement area 'Loswal IJmuiden'. Cable route option 7 crosses the IJgeul with a width of 450m and a depth up to LAT-20.5m to LAT-22.5m (nautical depth LAT-19.3m/LAT-19.2m).	Eroding coastline Maintained by shoreface and beach nourishments, 1m -4 m depth variation 4m depth variation in shoreface 1m-2m depth variation at beach 1m-2m depth variation shoreface during storm, 50 m dunefoot retreat Shoreface: 1 km route influenced. Beach: 0.5 km route influenced	Mainly Southern Bight formation medium sand (D_{50} =210-350 μm) offshore and coarse sand (D_{50} ≥ 300 μm) closer to shore. At the IJgeul deposits of clay belonging to the Layer of Velsen (part of the Naaldwijk formation) are at the surface due to dredging activities. Below the clay, remnants of peat from the Nieuwkoop formation can be seen. First 4m from surface contains fine (D_{50} < 210 μm), medium (D_{50} =210-350 μm) and unknown size sand with coarse sand (D_{50} ≥ 300 μm) for L=30-37km as well as clay patches at the surface and at 2-3m below surface for L=27-32km near the IJgeul. Unknown sediment type first 4m from surface near shore L=37-40km due to lacking borehole data.

6.2 Recommendations

The results of this report are a first quantification of the seabed mobility based on already available bathymetry and geological data. The results are intended to be used for supporting the cable route selection process at TenneT. In a following phase an update of this study will be performed (awarded to Svašek Hydraulics) and extra extra surveys of bathymetry and geology.

This field survey should provide more detailed information about the most recent seabed with sufficient detail to determine sand waves and megaripples and provide more detailed information about the subsurface along the full route like details on different soil types, soil strength and location of pipes and cables. This can be achieved by detailed geophysical surveys: bathymetry surveying (multi- and single beam echo sounder), seabed surface (side scan sonar), subsurface profiling (sub-bottom profiler and sparker), magnetometer, boreholes, laboratory shear tests on in-situ soil samples, cone penetration tests (including friction ratio and pore water pressure).

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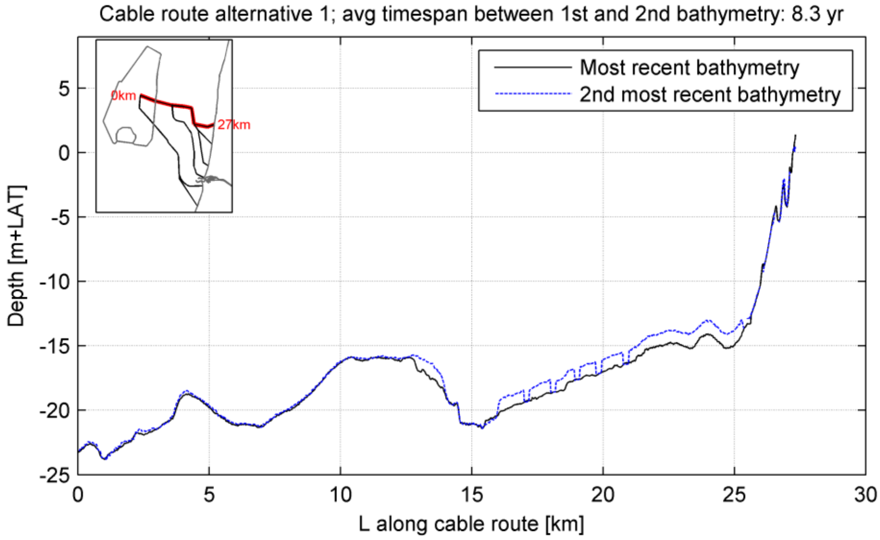
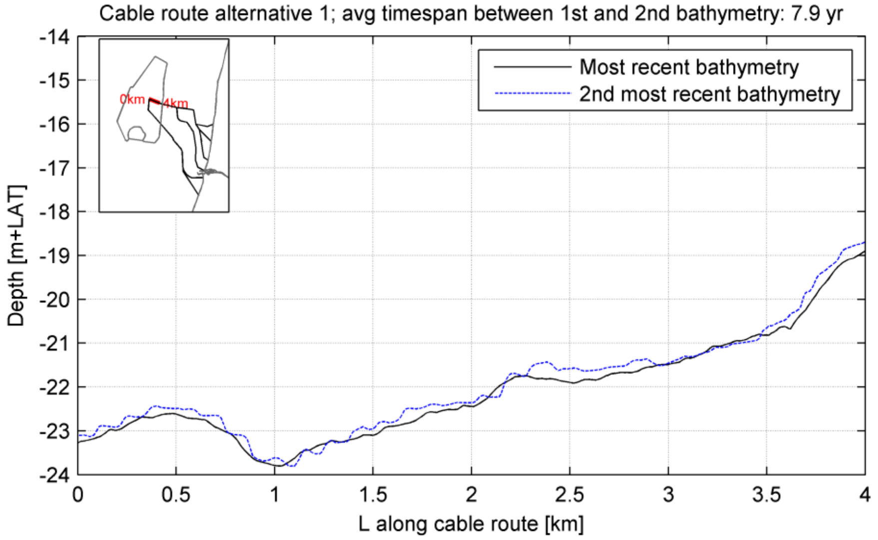
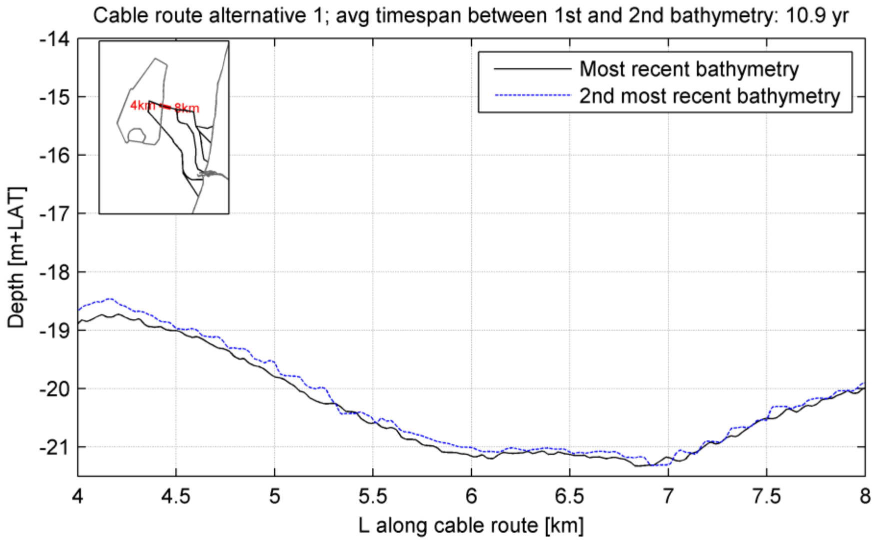
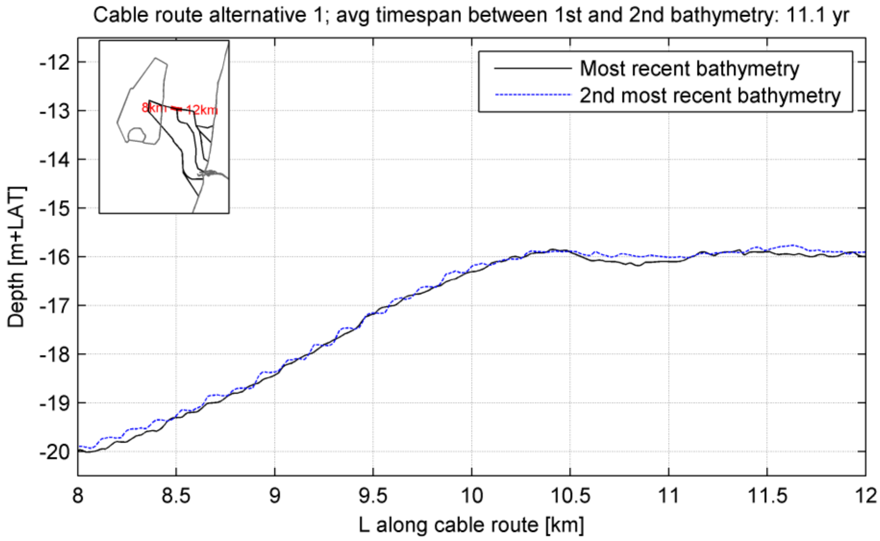
A APPENDIX SEA BED LEVEL ALONG DIFFERENT CABLE ROUTE OPTIONS

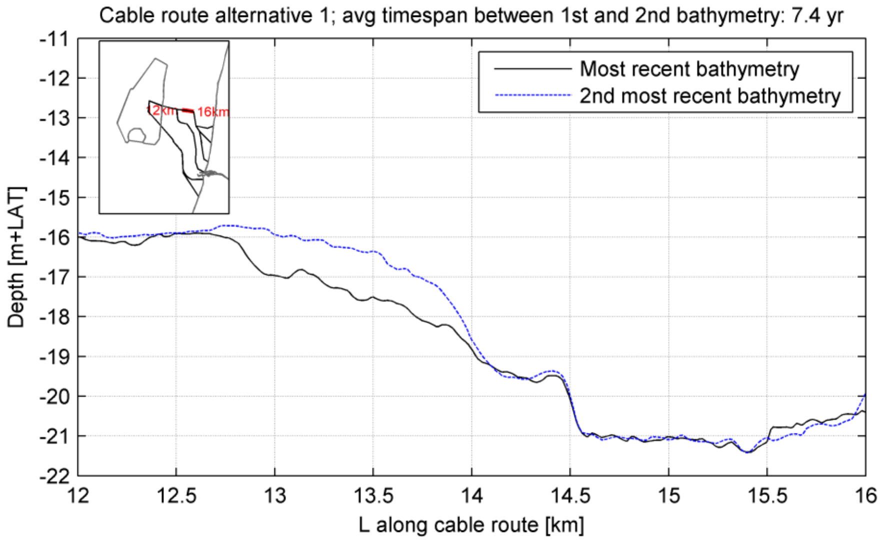
A.1 Sea bed level along cable route option 1

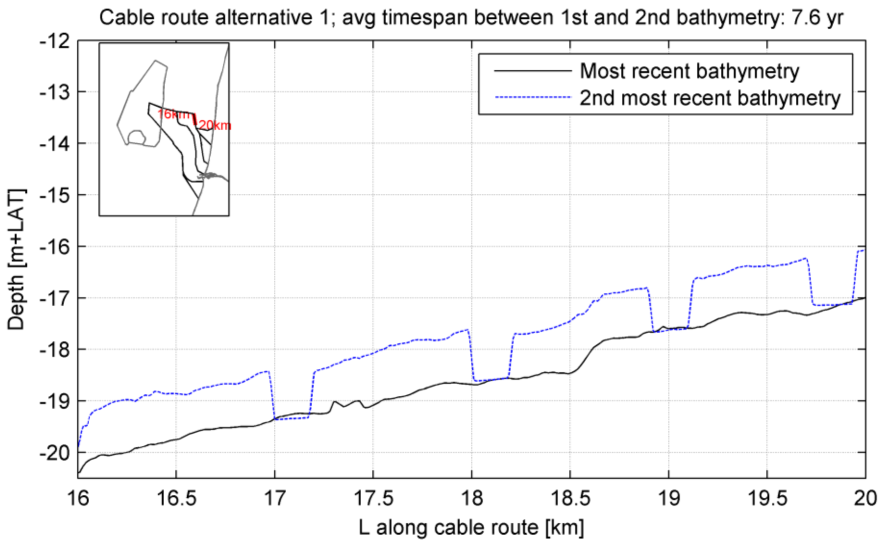


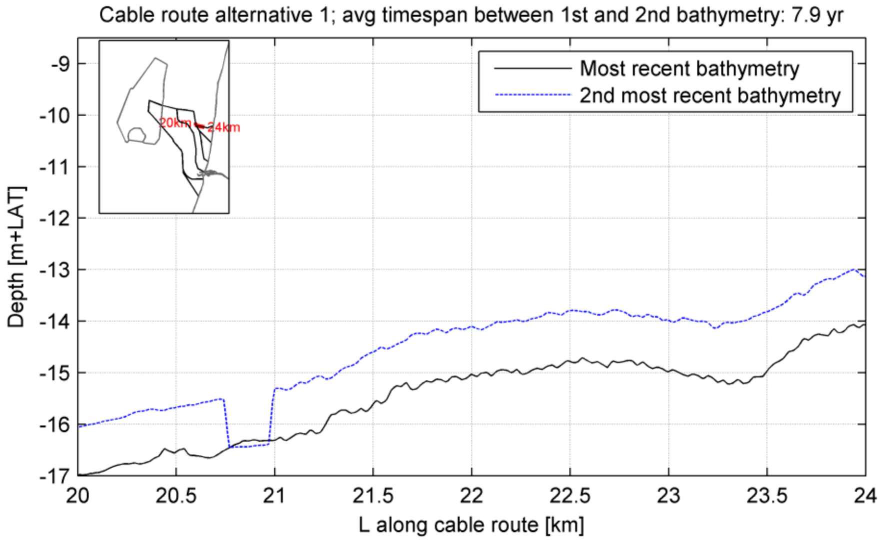


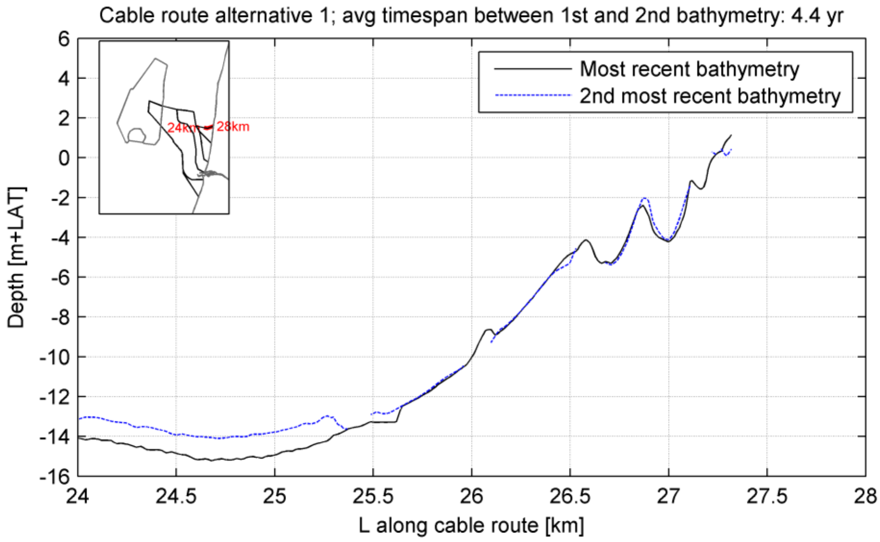



Cable route alternative 1; avg timespan between 1st and 2nd bathymetry: 11.1 yr
Most recent bathymetry
2nd most recent bathymetry
8km
12km
Depth [m+LAT]
L along cable route [km]


Cable route alternative 1; avg timespan between 1st and 2nd bathymetry: 7.4 yr
Most recent bathymetry
2nd most recent bathymetry
12km
16km
Depth [m+LAT]
L along cable route [km]

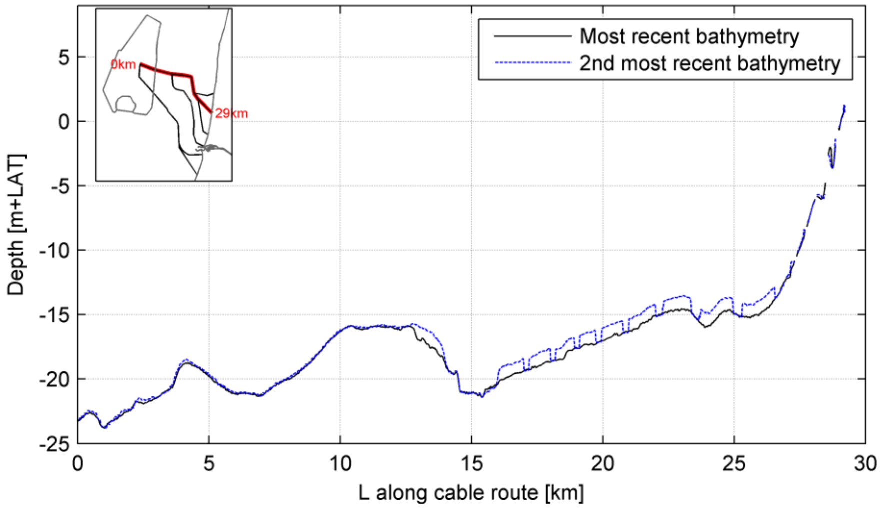

Cable route alternative 1; avg timespan between 1st and 2nd bathymetry: 7.6 yr
Most recent bathymetry
2nd most recent bathymetry
16km
20km
Depth [m+LAT]
L along cable route [km]


Cable route alternative 1; avg timespan between 1st and 2nd bathymetry: 7.9 yr
Most recent bathymetry
2nd most recent bathymetry
20km
24km
Depth [m+LAT]
L along cable route [km]

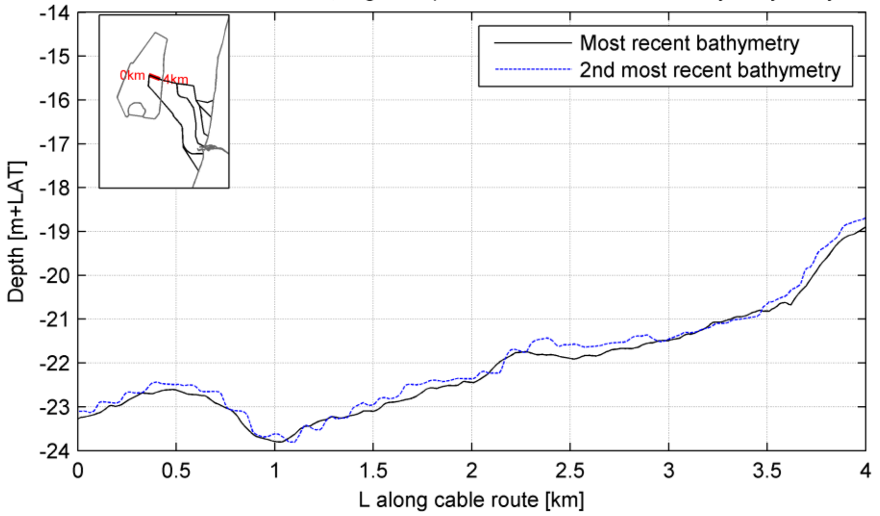

Cable route alternative 1; avg timespan between 1st and 2nd bathymetry: 4.4 yr
Most recent bathymetry
2nd most recent bathymetry
24km
28km
Depth [m+LAT]
L along cable route [km]

A.2 Sea bed level along cable route option 2

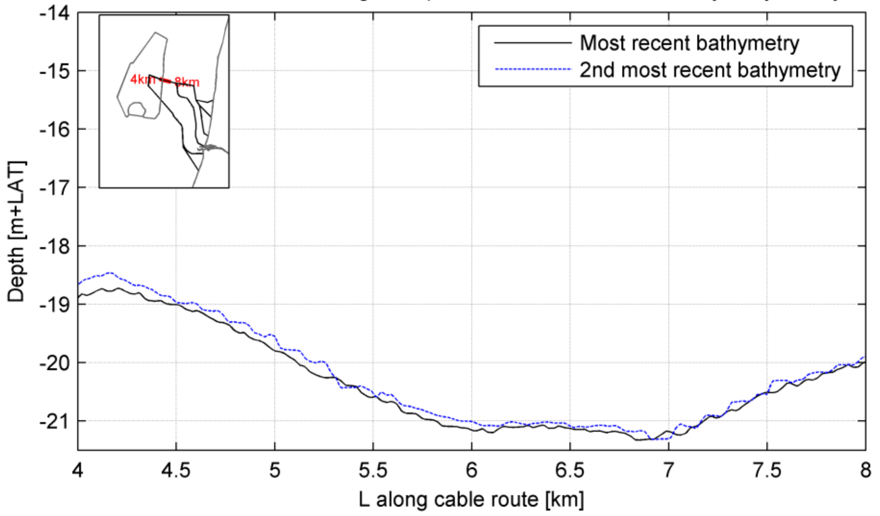
Cable route alternative 2; avg timespan between 1st and 2nd bathymetry: 8.2 yr



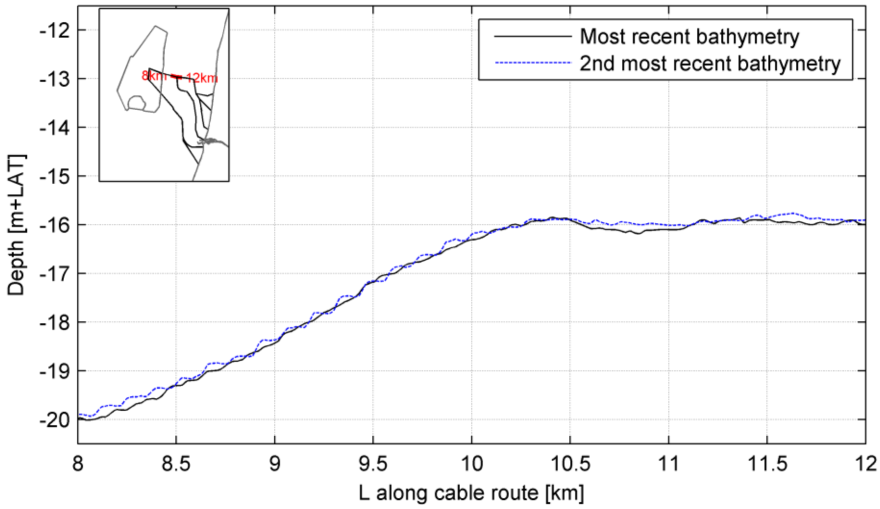
Cable route alternative 2; avg timespan between 1st and 2nd bathymetry: 7.9 yr



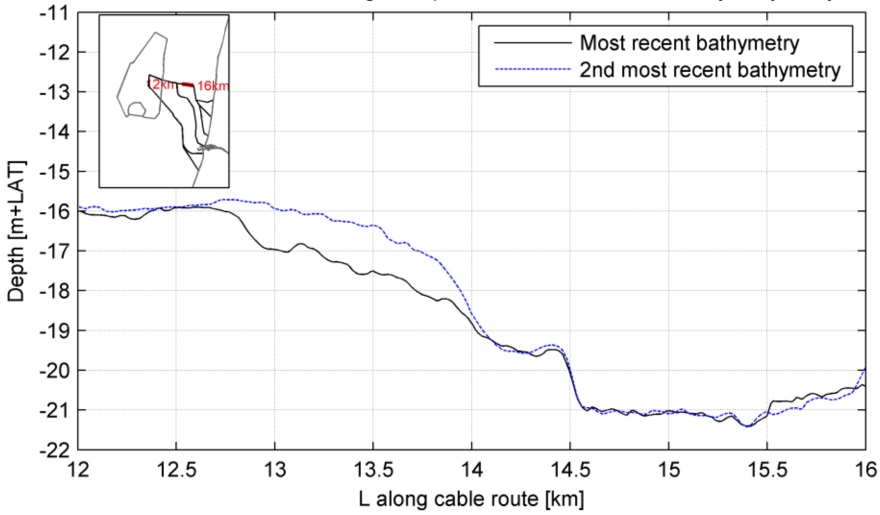
Cable route alternative 2; avg timespan between 1st and 2nd bathymetry: 10.9 yr



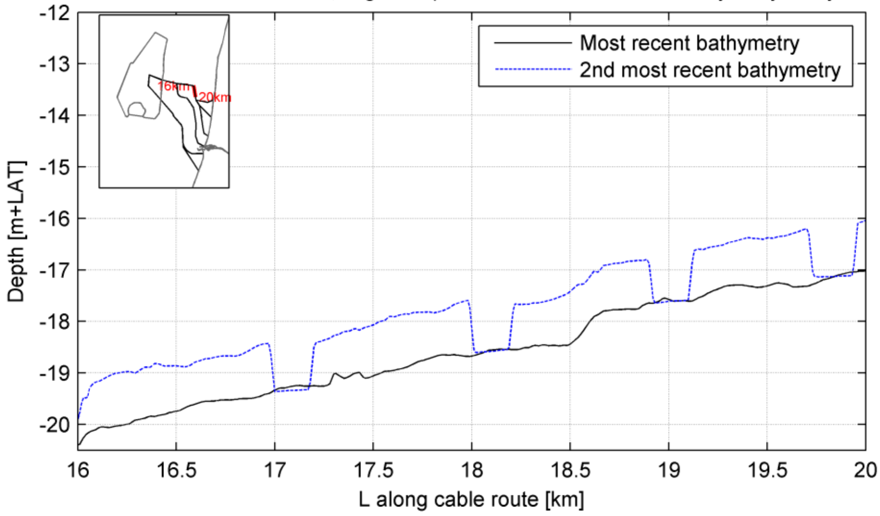
Cable route alternative 2; avg timespan between 1st and 2nd bathymetry: 11.1 yr

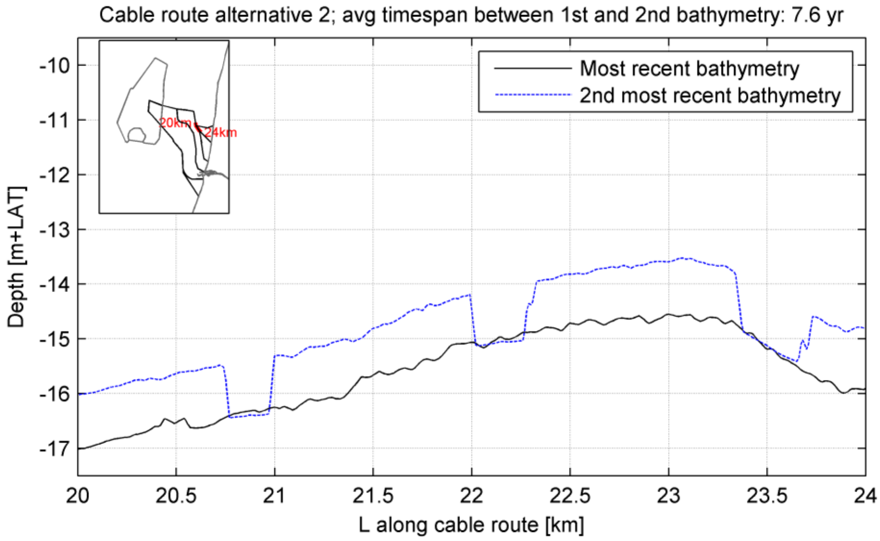


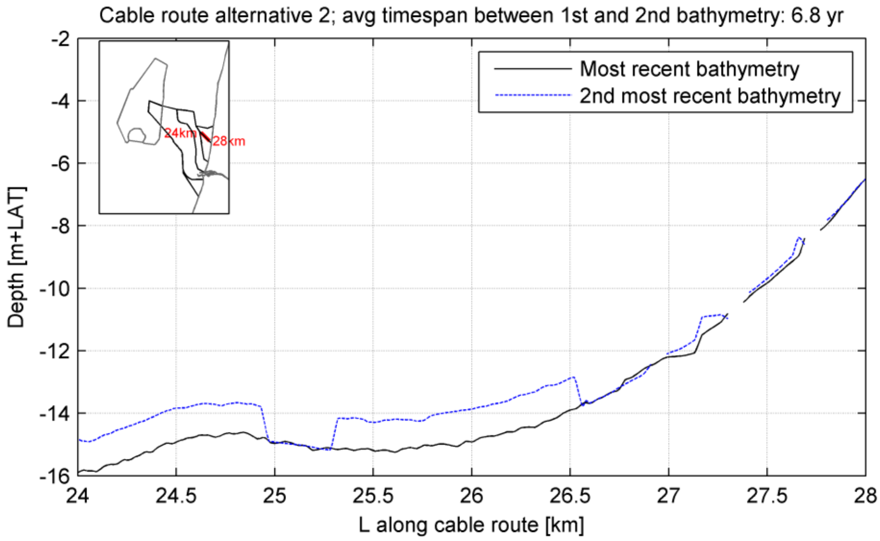
Cable route alternative 2; avg timespan between 1st and 2nd bathymetry: 7.4 yr

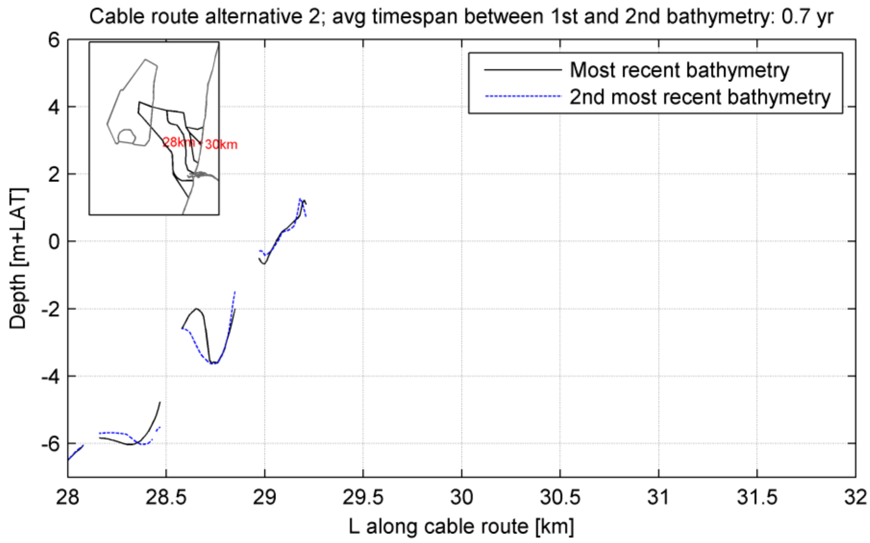


Cable route alternative 2; avg timespan between 1st and 2nd bathymetry: 7.6 yr

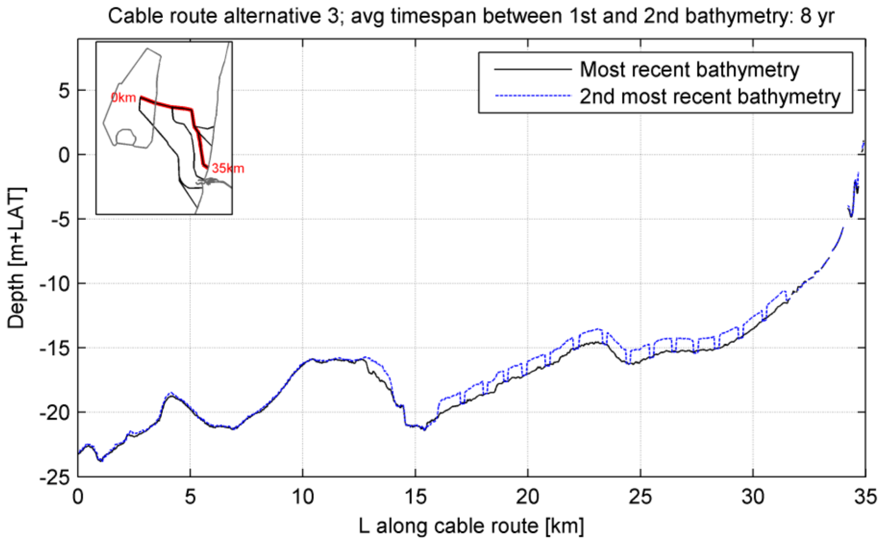


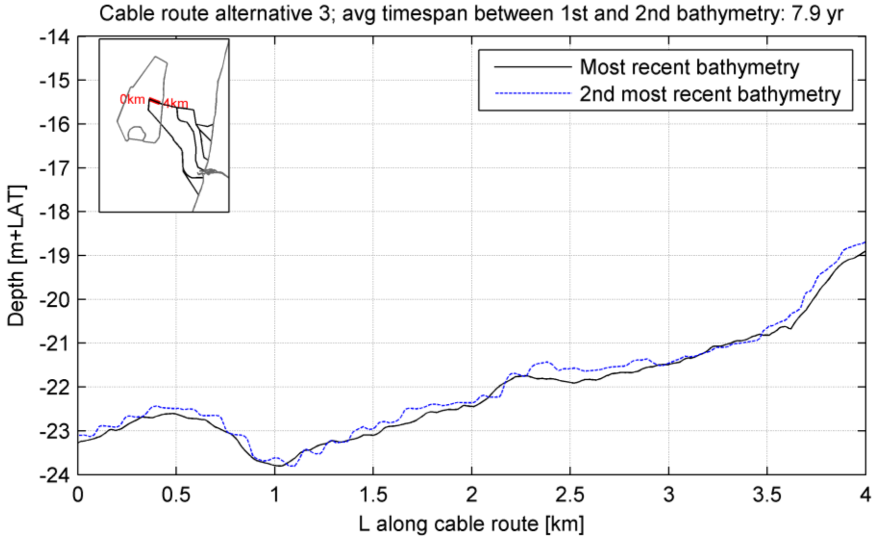

Cable route alternative 2; avg timespan between 1st and 2nd bathymetry: 7.6 yr
Most recent bathymetry
2nd most recent bathymetry
20km
24km
Depth [m+LAT]
L along cable route [km]
-10
-11
-12
-13
-14
-15
-16
-17
20
20.5
21
21.5
22
22.5
23
23.5
24

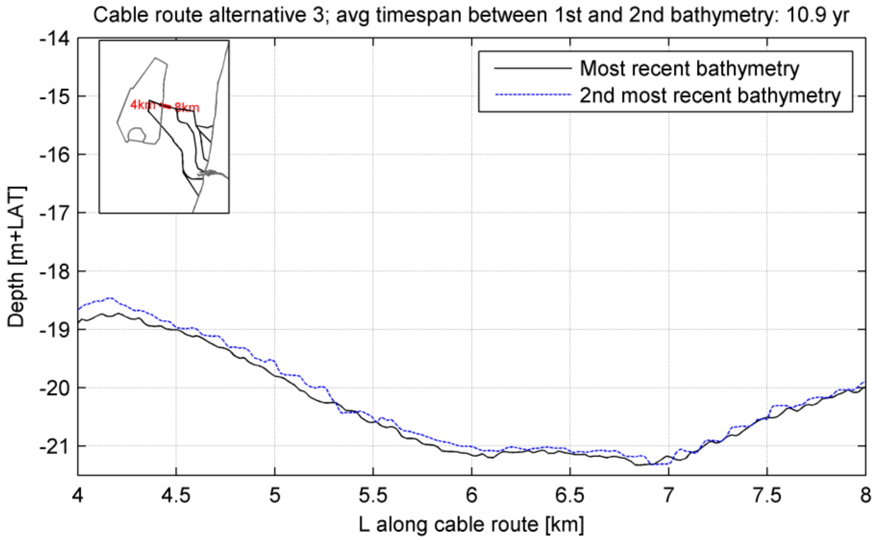

Cable route alternative 2; avg timespan between 1st and 2nd bathymetry: 6.8 yr
Most recent bathymetry
2nd most recent bathymetry
24km
28km
Depth [m+LAT]
L along cable route [km]
-2
-4
-6
-8
-10
-12
-14
-16
24
24.5
25
25.5
26
26.5
27
27.5
28

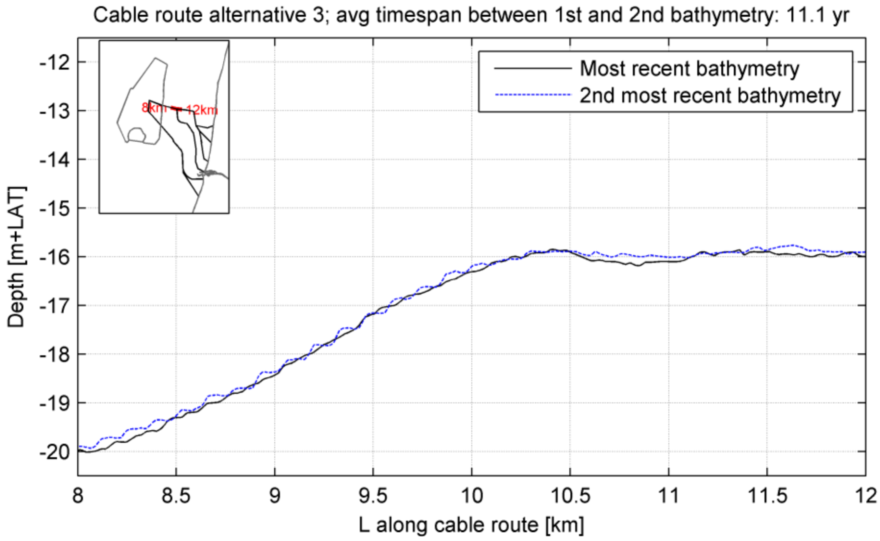

Cable route alternative 2; avg timespan between 1st and 2nd bathymetry: 0.7 yr
Most recent bathymetry
2nd most recent bathymetry
28km
30km
Depth [m+LAT]
L along cable route [km]
6
4
2
0
-2
-4
-6
28
28.5
29
29.5
30
30.5
31
31.5
32

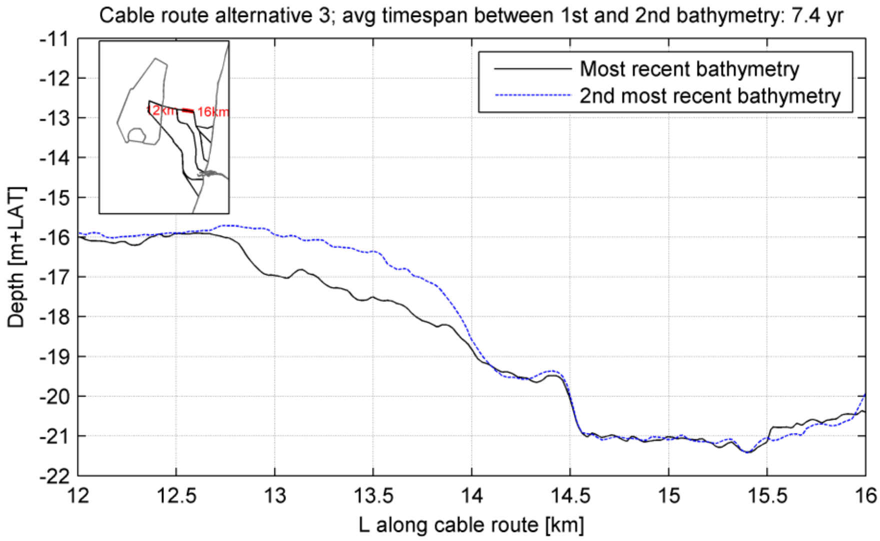
A.3 Sea bed level along cable route option 3

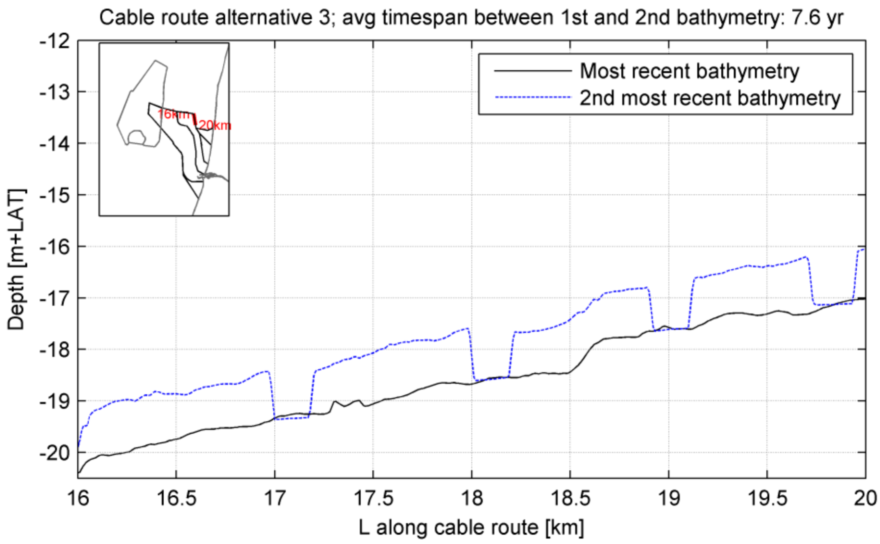


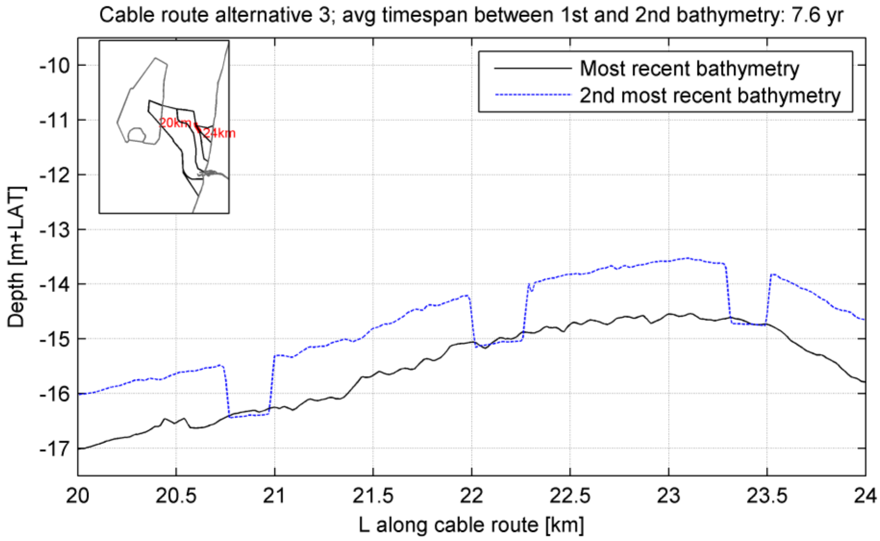


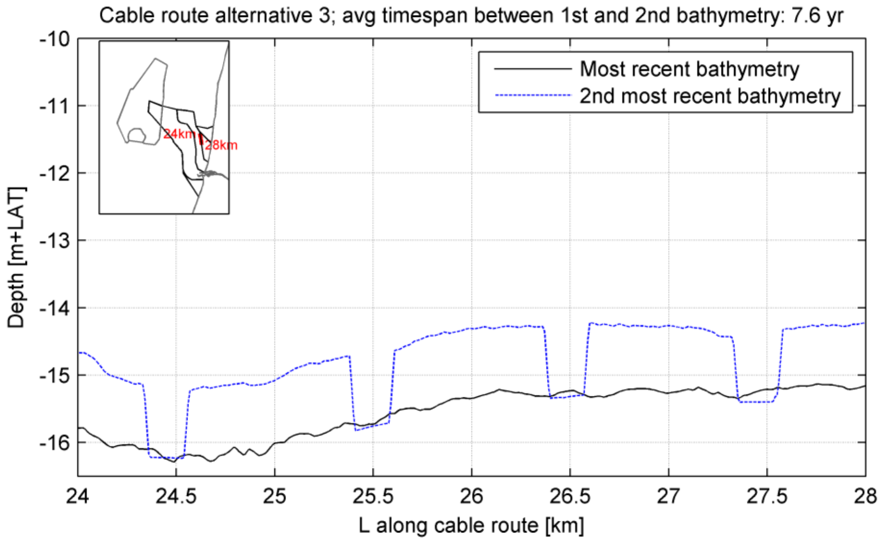


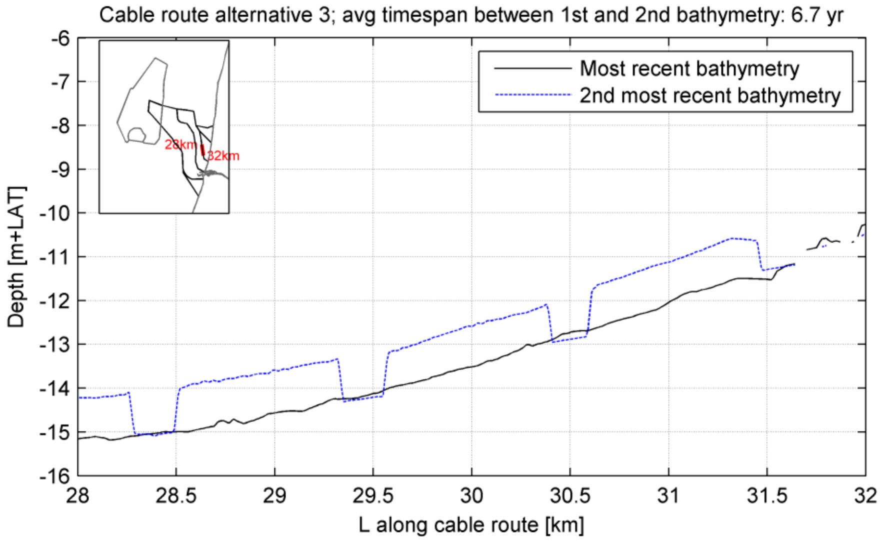

Cable route alternative 3; avg timespan between 1st and 2nd bathymetry: 11.1 yr
Most recent bathymetry
2nd most recent bathymetry
8km
12km
Depth [m+LAT]
L along cable route [km]


Cable route alternative 3; avg timespan between 1st and 2nd bathymetry: 7.4 yr
Most recent bathymetry
2nd most recent bathymetry
12km
16km
Depth [m+LAT]
L along cable route [km]

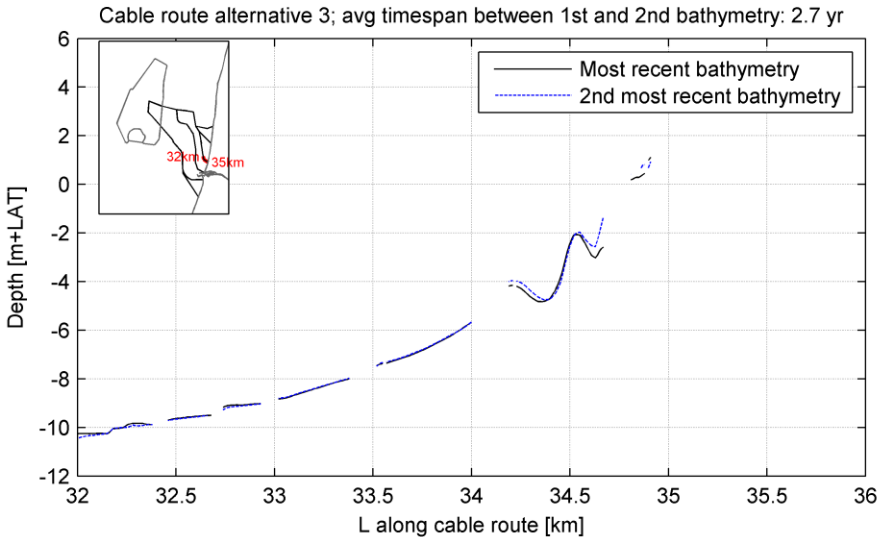

Cable route alternative 3; avg timespan between 1st and 2nd bathymetry: 7.6 yr
Most recent bathymetry
2nd most recent bathymetry
16km
20km
Depth [m+LAT]
L along cable route [km]


Cable route alternative 3; avg timespan between 1st and 2nd bathymetry: 7.6 yr
Most recent bathymetry
2nd most recent bathymetry
20km
24km
Depth [m+LAT]
-10
-11
-12
-13
-14
-15
-16
-17
20
20.5
21
21.5
22
22.5
23
23.5
24
L along cable route [km]


Cable route alternative 3; avg timespan between 1st and 2nd bathymetry: 7.6 yr
Most recent bathymetry
2nd most recent bathymetry
24km
28km
Depth [m+LAT]
-10
-11
-12
-13
-14
-15
-16
24
24.5
25
25.5
26
26.5
27
27.5
28
L along cable route [km]

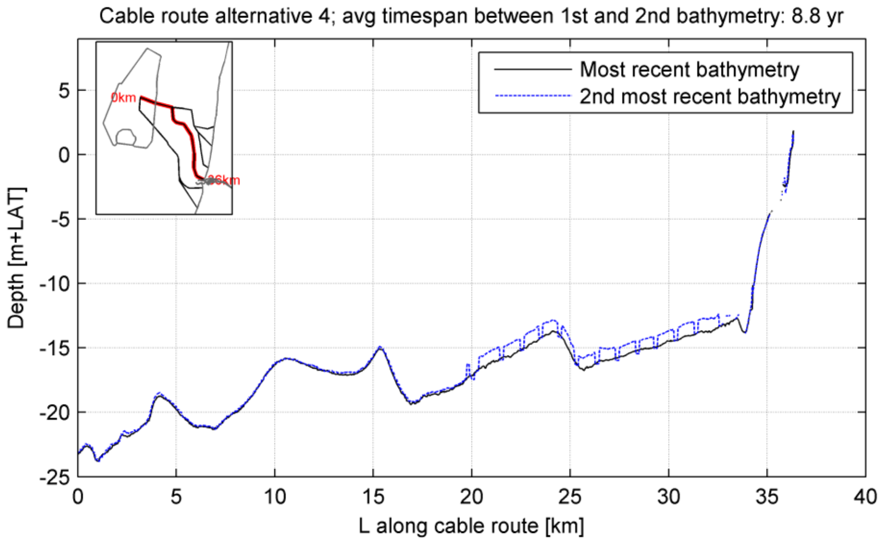


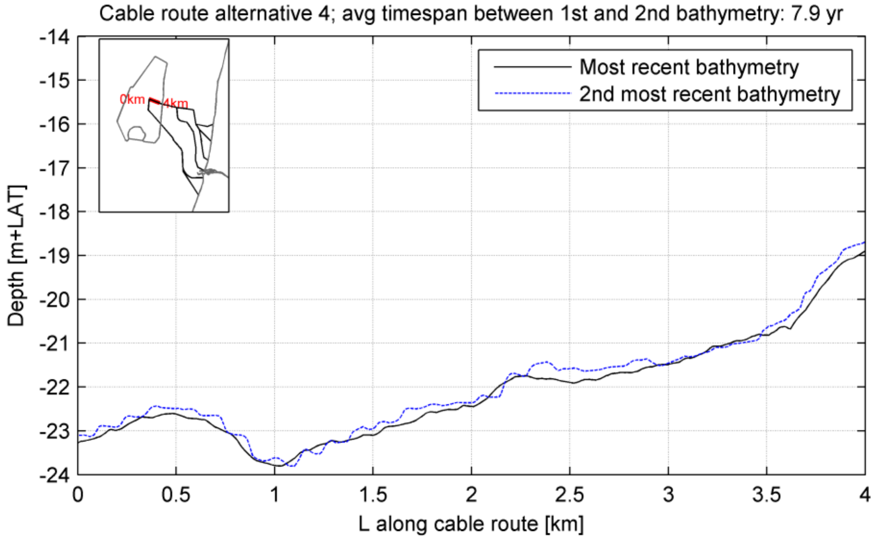
Cable route alternative 3; avg timespan between 1st and 2nd bathymetry: 6.7 yr
Most recent bathymetry
2nd most recent bathymetry
28km
32km
Depth [m+LAT]
L along cable route [km]

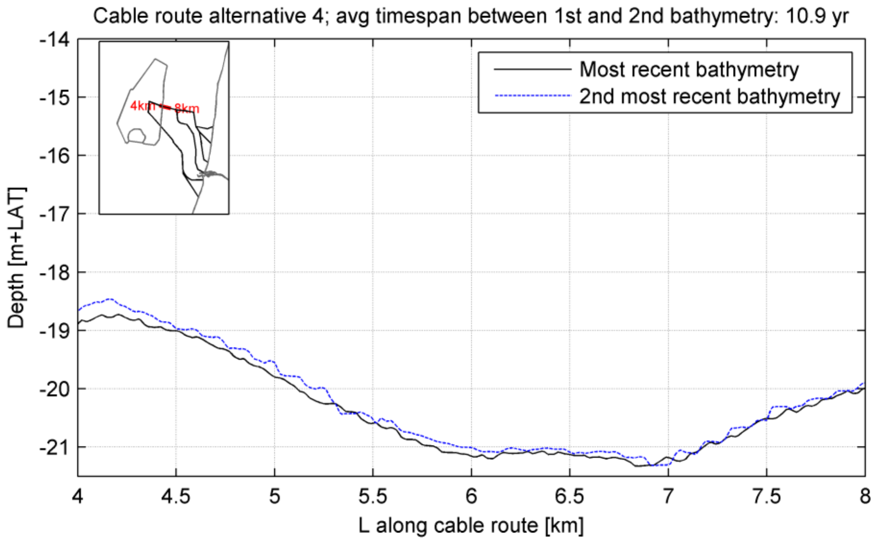


Cable route alternative 3; avg timespan between 1st and 2nd bathymetry: 2.7 yr
Most recent bathymetry
2nd most recent bathymetry
32km
35km
Depth [m+LAT]
L along cable route [km]

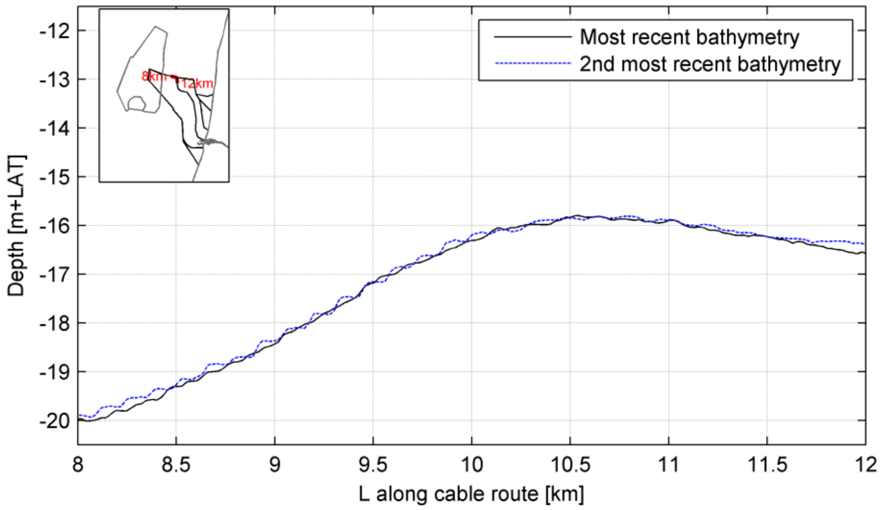
A.4 Sea bed level along cable route option 4



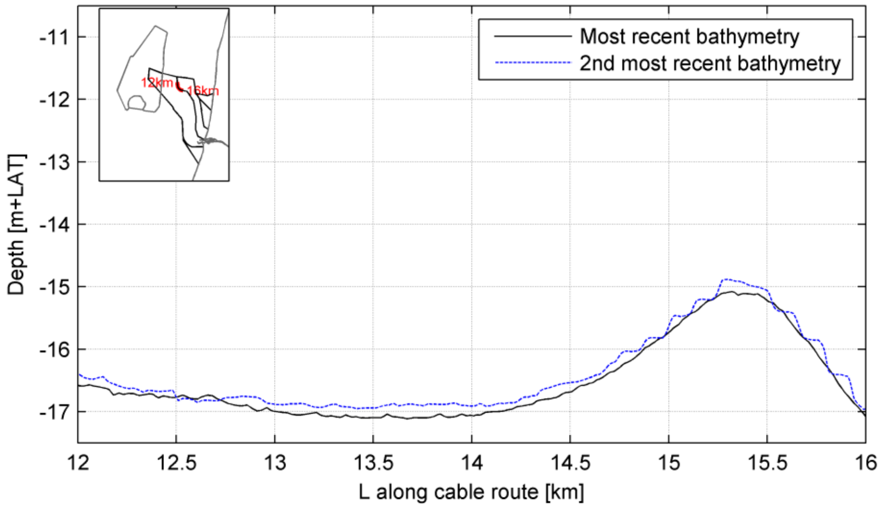




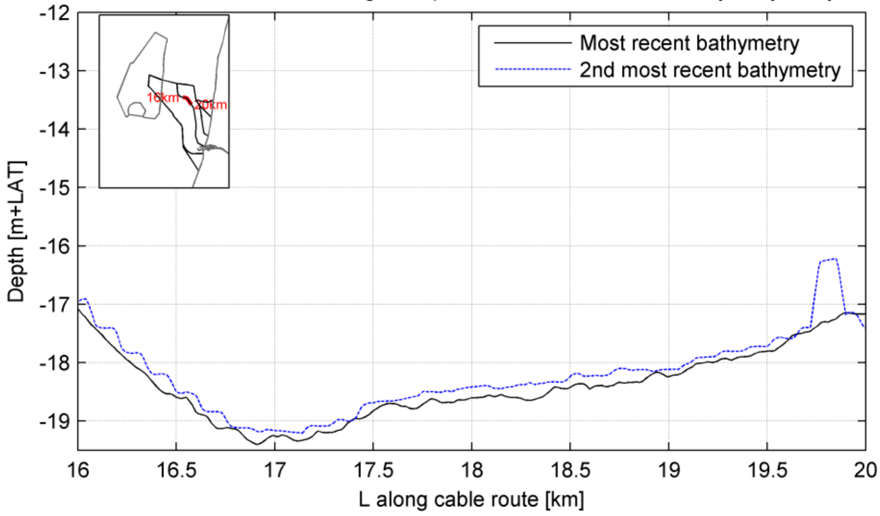
Cable route alternative 4; avg timespan between 1st and 2nd bathymetry: 11 yr

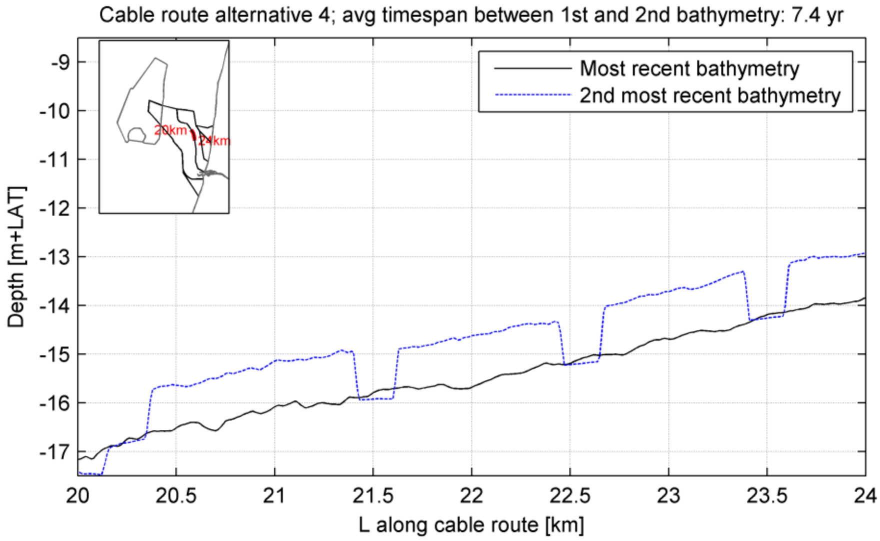


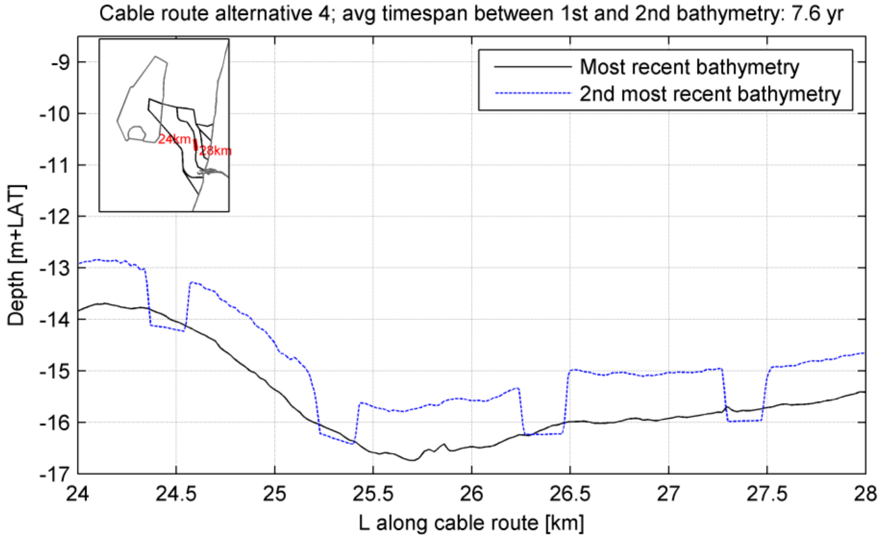
Cable route alternative 4; avg timespan between 1st and 2nd bathymetry: 10.8 yr

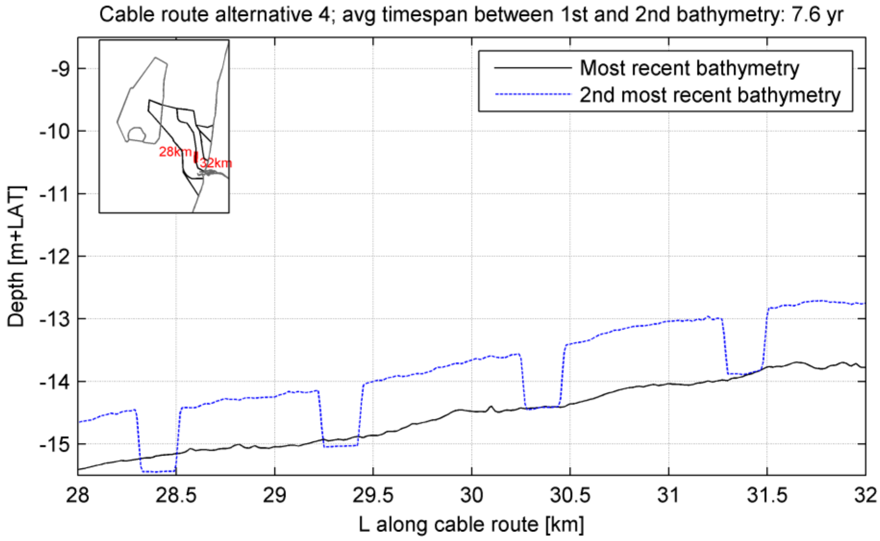


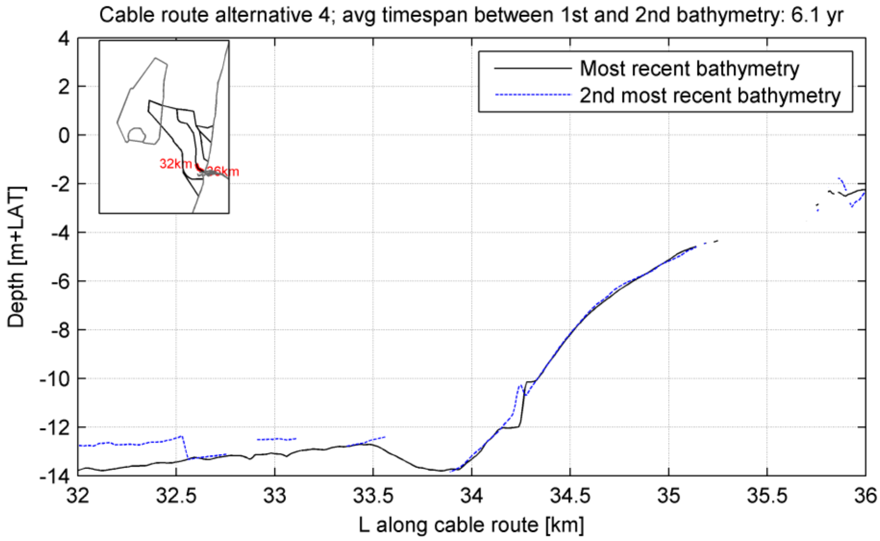
Cable route alternative 4; avg timespan between 1st and 2nd bathymetry: 9.6 yr

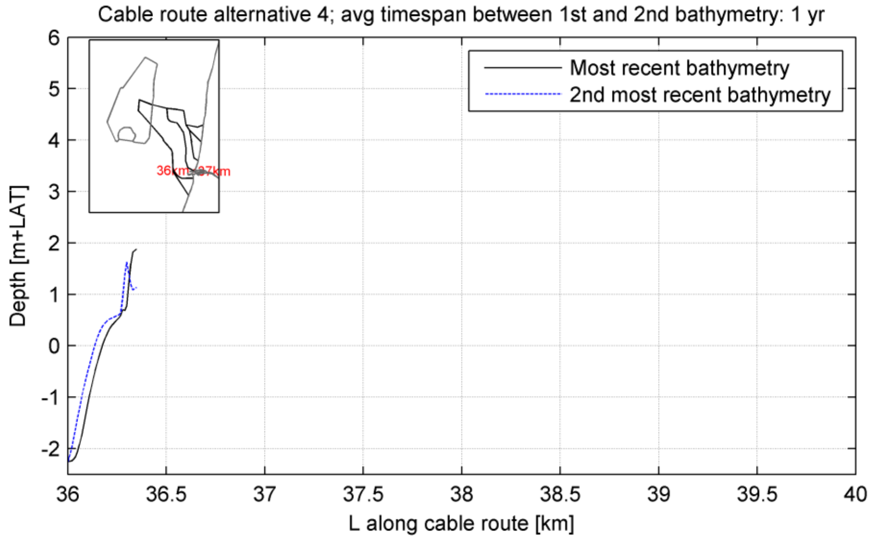



Cable route alternative 4; avg timespan between 1st and 2nd bathymetry: 7.4 yr
Most recent bathymetry
2nd most recent bathymetry
20km
24km
Depth [m+LAT]
L along cable route [km]

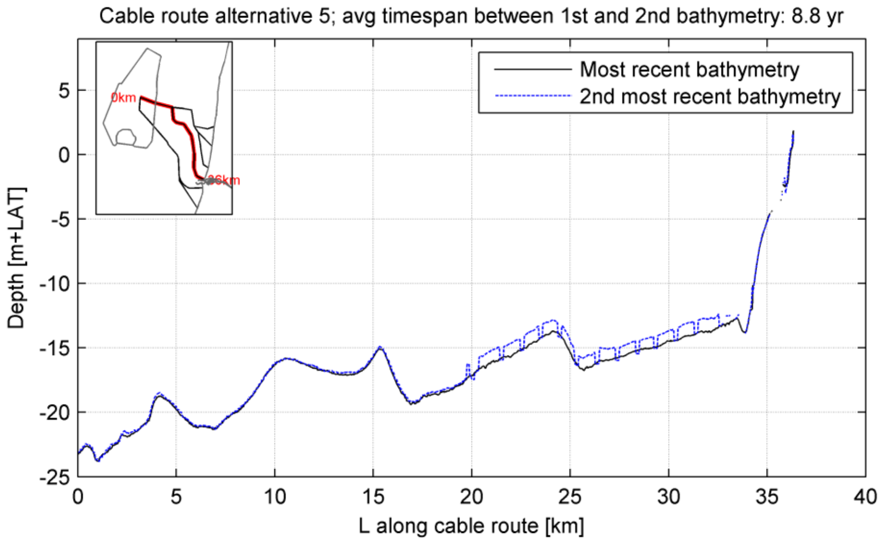

Cable route alternative 4; avg timespan between 1st and 2nd bathymetry: 7.6 yr
Most recent bathymetry
2nd most recent bathymetry
24km
28km
Depth [m+LAT]
L along cable route [km]

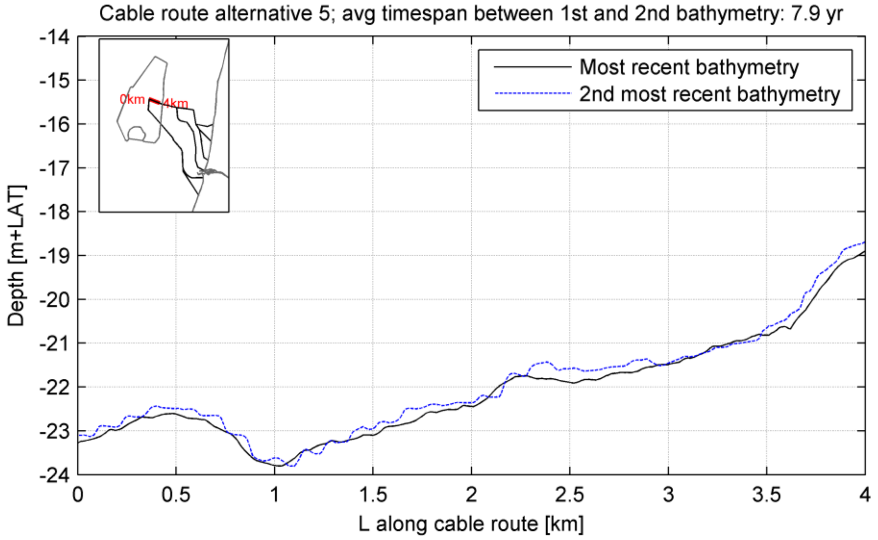

Cable route alternative 4; avg timespan between 1st and 2nd bathymetry: 7.6 yr
Most recent bathymetry
2nd most recent bathymetry
28km
32km
Depth [m+LAT]
L along cable route [km]

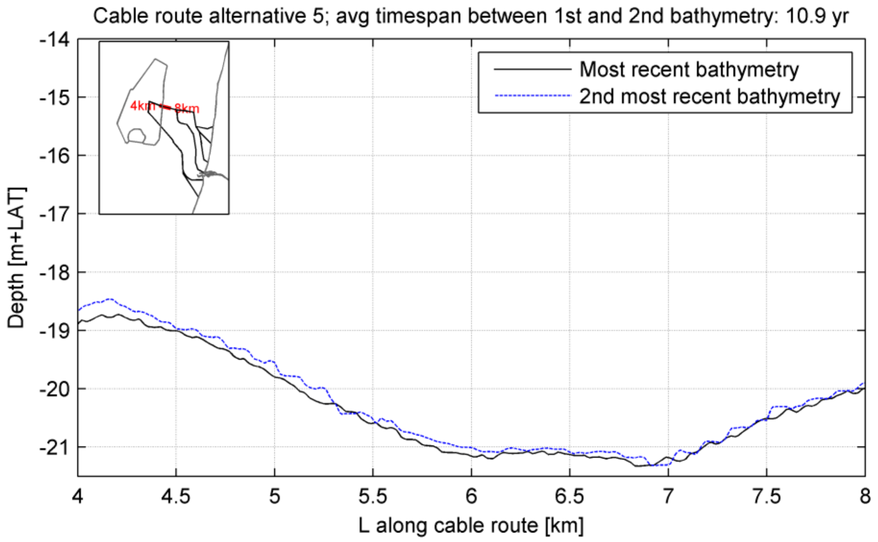

Cable route alternative 4; avg timespan between 1st and 2nd bathymetry: 6.1 yr
Most recent bathymetry
2nd most recent bathymetry
32km
36km
Depth [m+LAT]
L along cable route [km]
4
2
0
-2
-4
-6
-8
-10
-12
-14
32
32.5
33
33.5
34
34.5
35
35.5
36

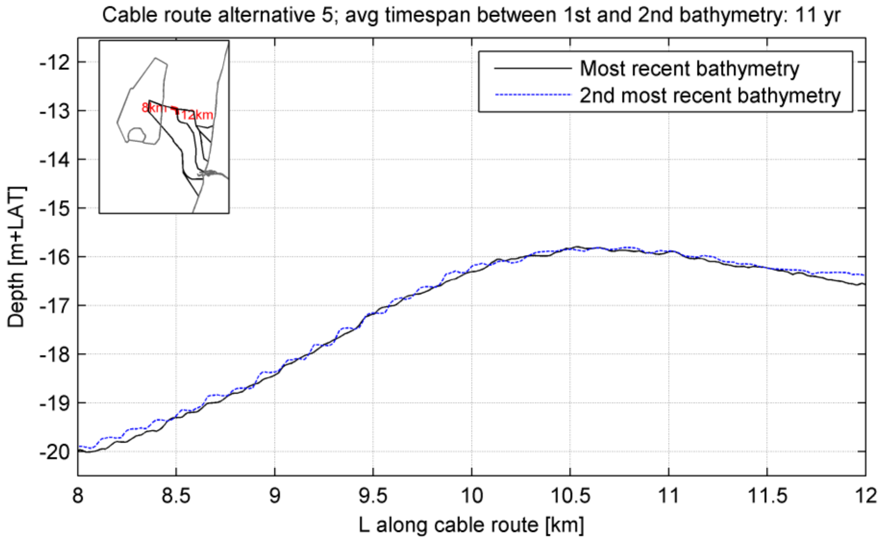

Cable route alternative 4; avg timespan between 1st and 2nd bathymetry: 1 yr
Most recent bathymetry
2nd most recent bathymetry
36km
37km
Depth [m+LAT]
L along cable route [km]
6
5
4
3
2
1
0
-1
-2
36
36.5
37
37.5
38
38.5
39
39.5
40

A.5 Sea bed level along cable route option 5

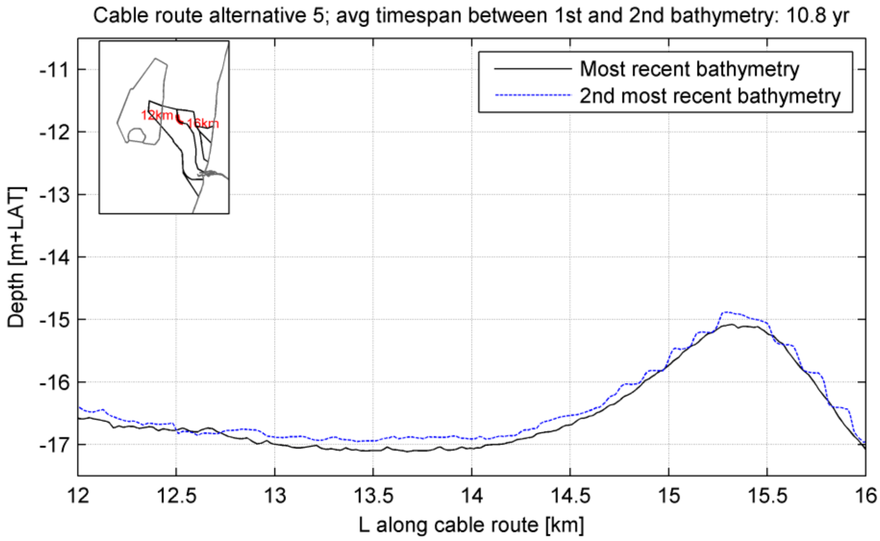




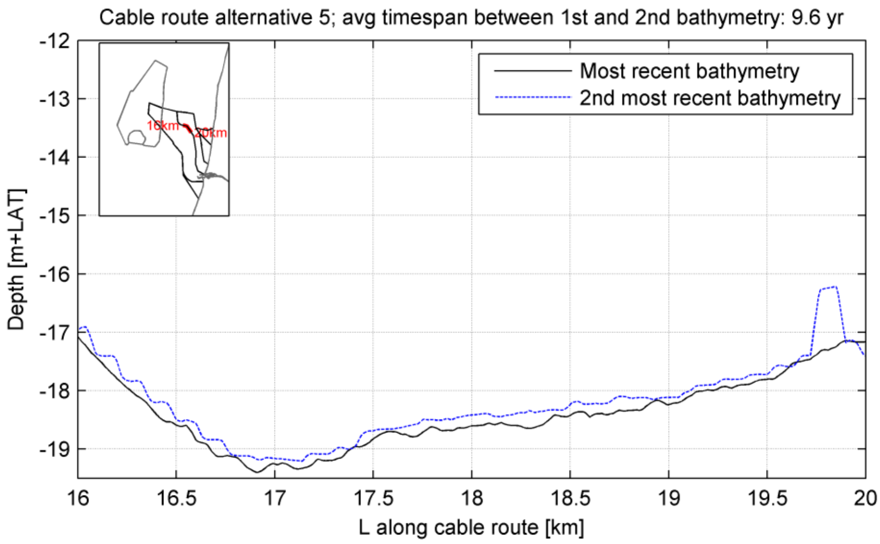




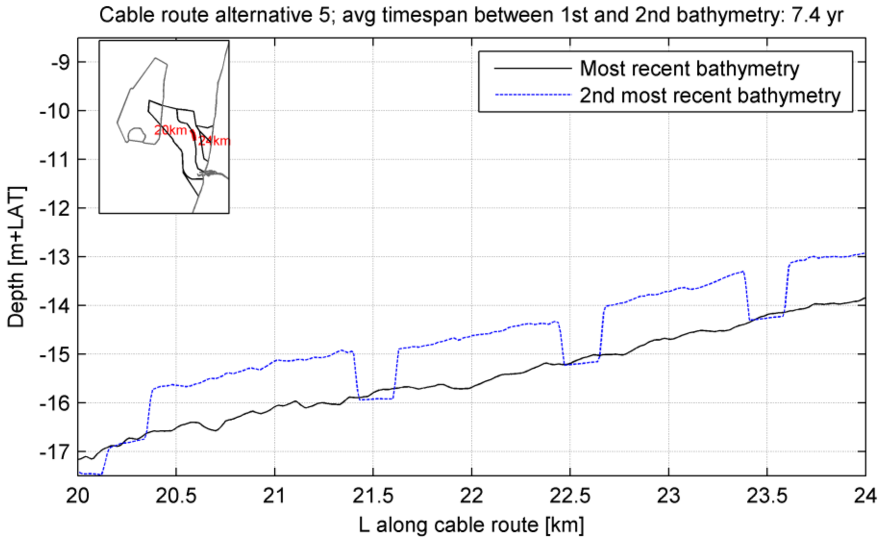
Cable route alternative 5; avg timespan between 1st and 2nd bathymetry: 11 yr
Most recent bathymetry
2nd most recent bathymetry
Depth [m+LAT]
L along cable route [km]
8km
12km



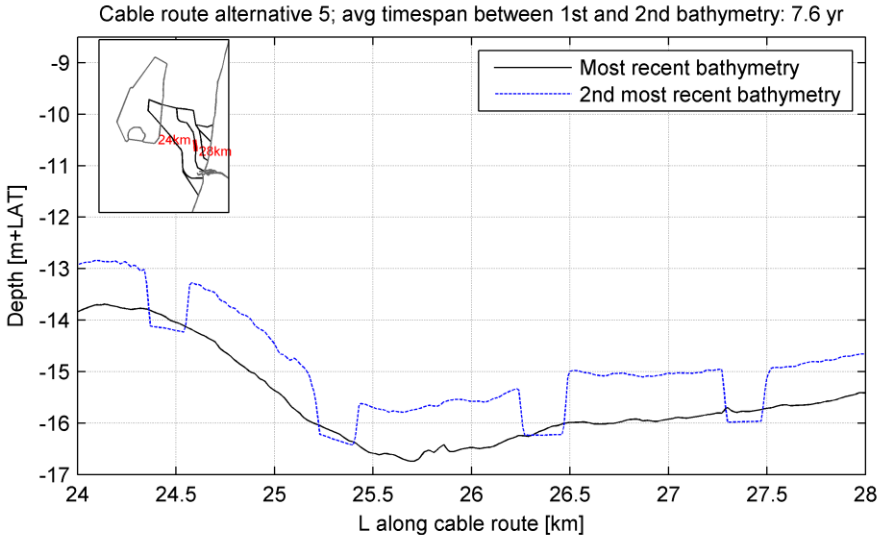
Cable route alternative 5; avg timespan between 1st and 2nd bathymetry: 10.8 yr
Most recent bathymetry
2nd most recent bathymetry
Depth [m+LAT]
L along cable route [km]
12km
16km



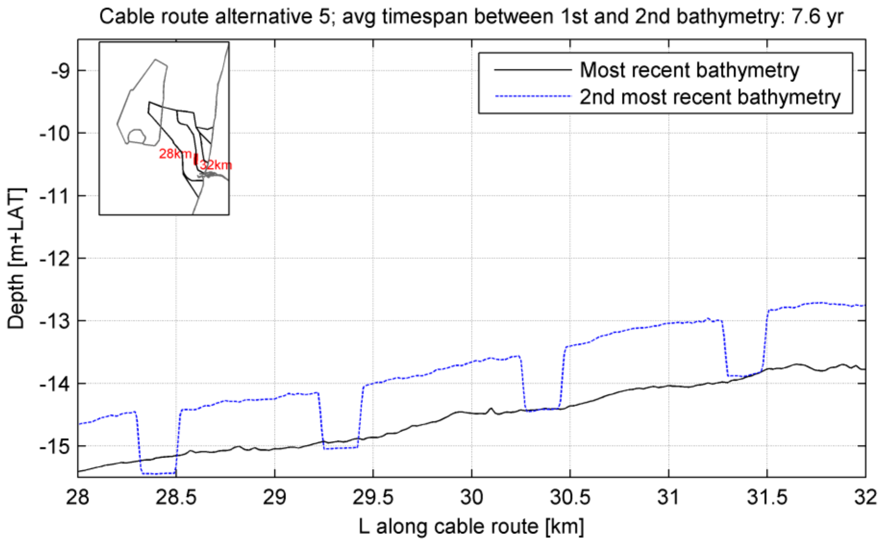
Cable route alternative 5; avg timespan between 1st and 2nd bathymetry: 9.6 yr
Most recent bathymetry
2nd most recent bathymetry
Depth [m+LAT]
L along cable route [km]
16km
20km



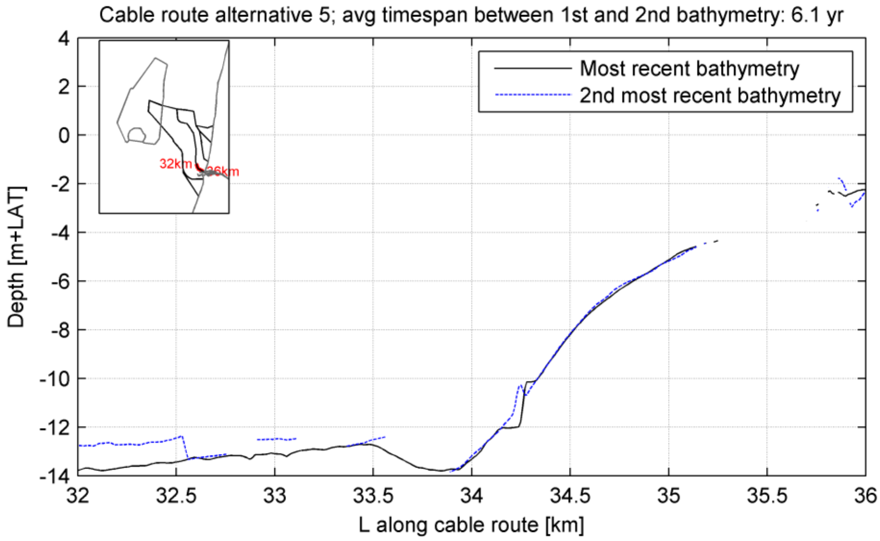
Cable route alternative 5; avg timespan between 1st and 2nd bathymetry: 7.4 yr
Most recent bathymetry
2nd most recent bathymetry
20km
24km
Depth [m+LAT]
L along cable route [km]

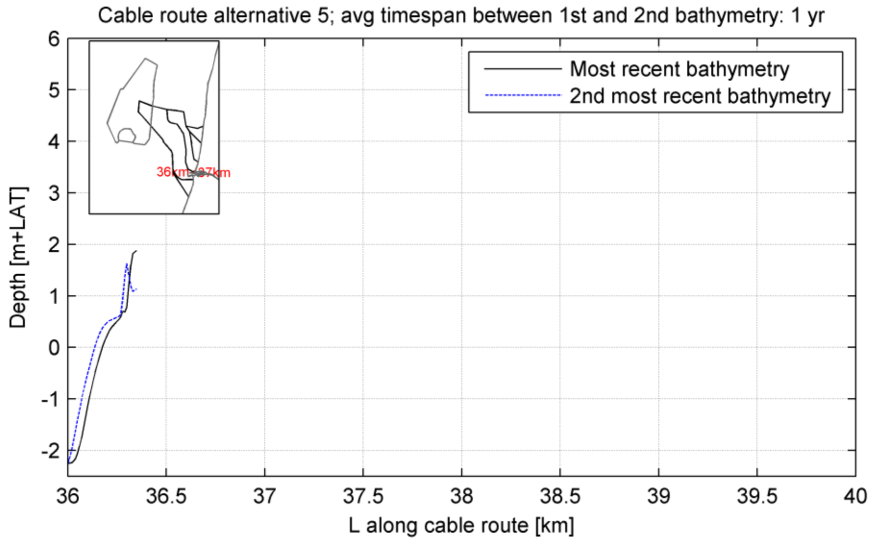


Cable route alternative 5; avg timespan between 1st and 2nd bathymetry: 7.6 yr
Most recent bathymetry
2nd most recent bathymetry
24km
28km
Depth [m+LAT]
L along cable route [km]

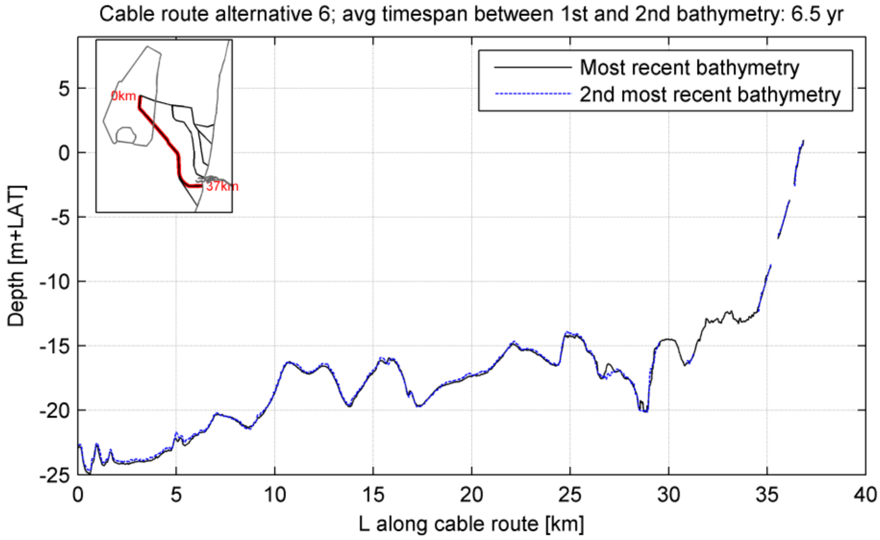


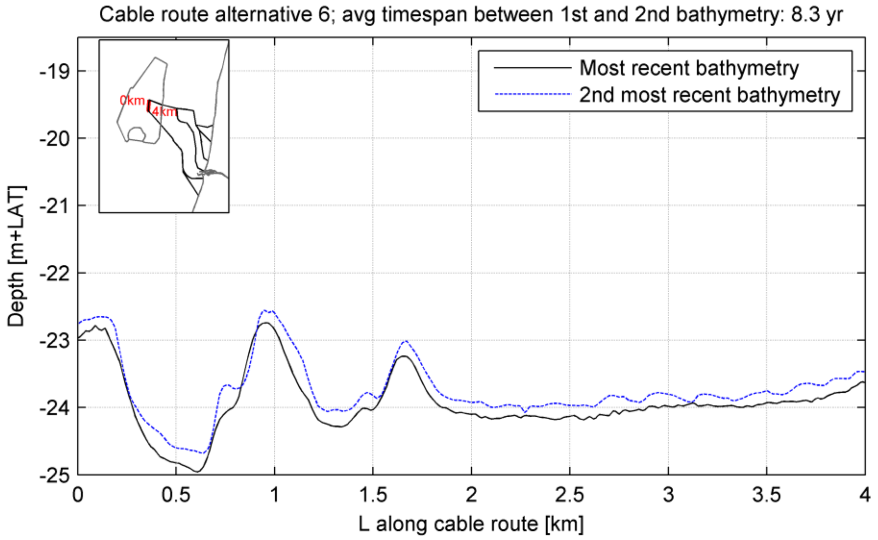
Cable route alternative 5; avg timespan between 1st and 2nd bathymetry: 7.6 yr
Most recent bathymetry
2nd most recent bathymetry
28km
32km
Depth [m+LAT]
L along cable route [km]

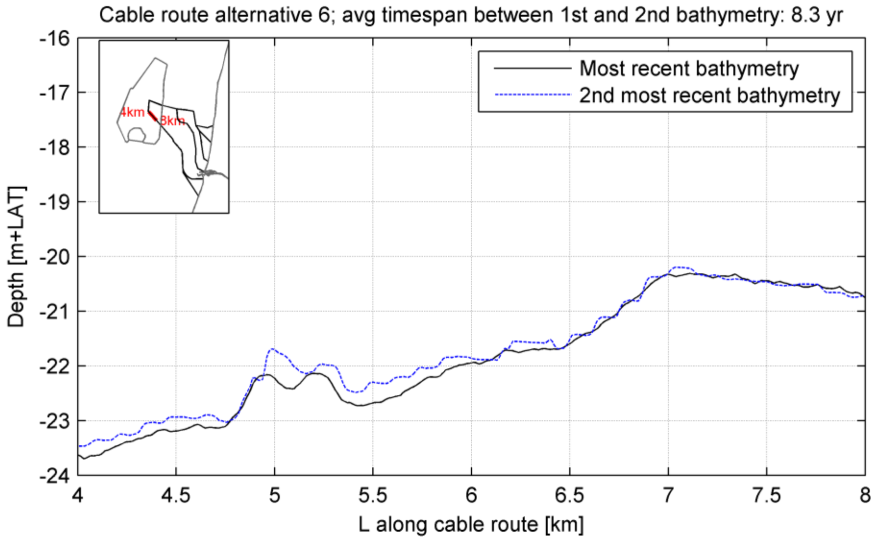

Cable route alternative 5; avg timespan between 1st and 2nd bathymetry: 6.1 yr
Most recent bathymetry
2nd most recent bathymetry
32km
36km
Depth [m+LAT]
L along cable route [km]


Cable route alternative 5; avg timespan between 1st and 2nd bathymetry: 1 yr
Most recent bathymetry
2nd most recent bathymetry
36km
37km
Depth [m+LAT]
L along cable route [km]

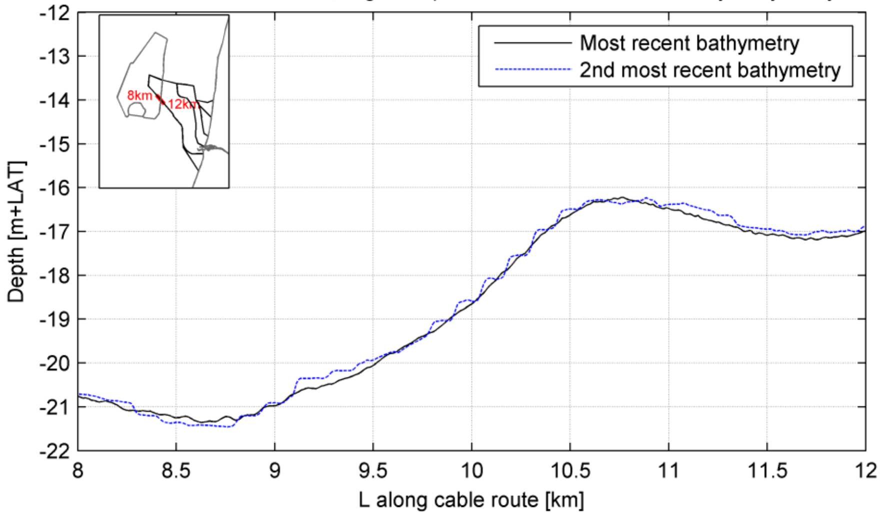
A.6 Sea bed level along cable route option 6



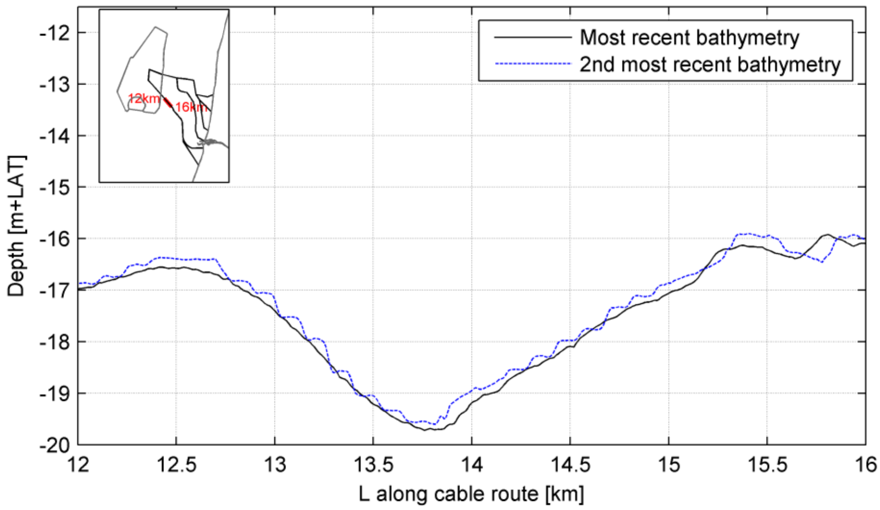




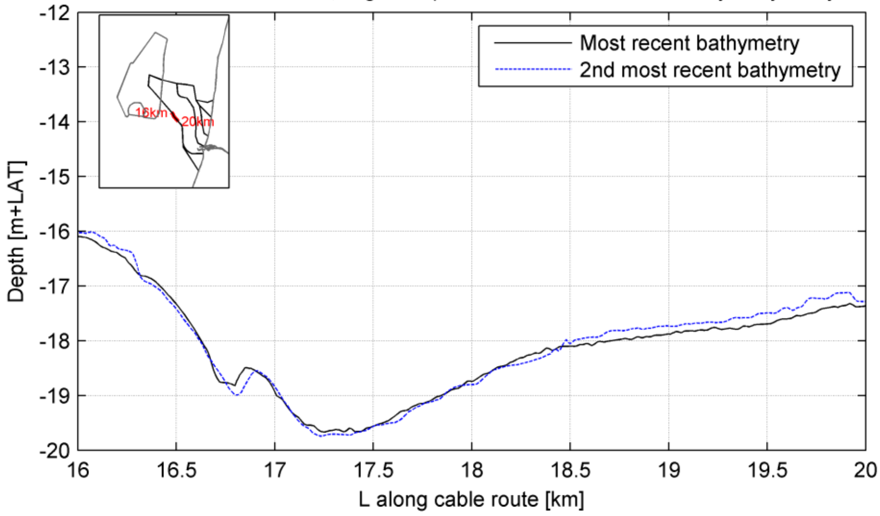
Cable route alternative 6; avg timespan between 1st and 2nd bathymetry: 7.7 yr

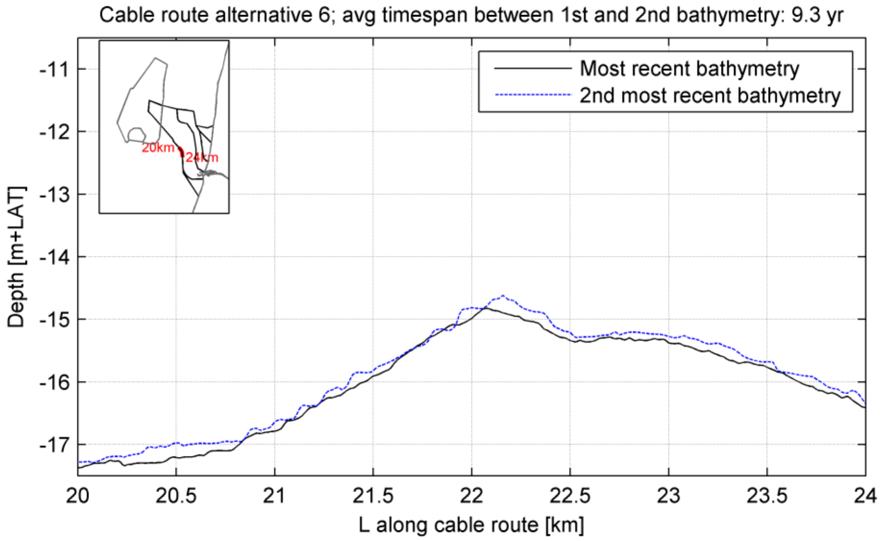


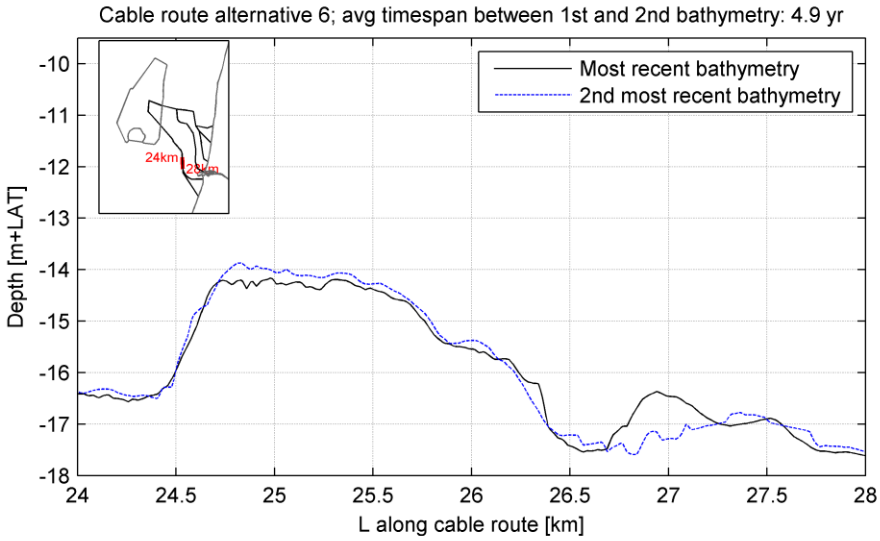
Cable route alternative 6; avg timespan between 1st and 2nd bathymetry: 7.6 yr

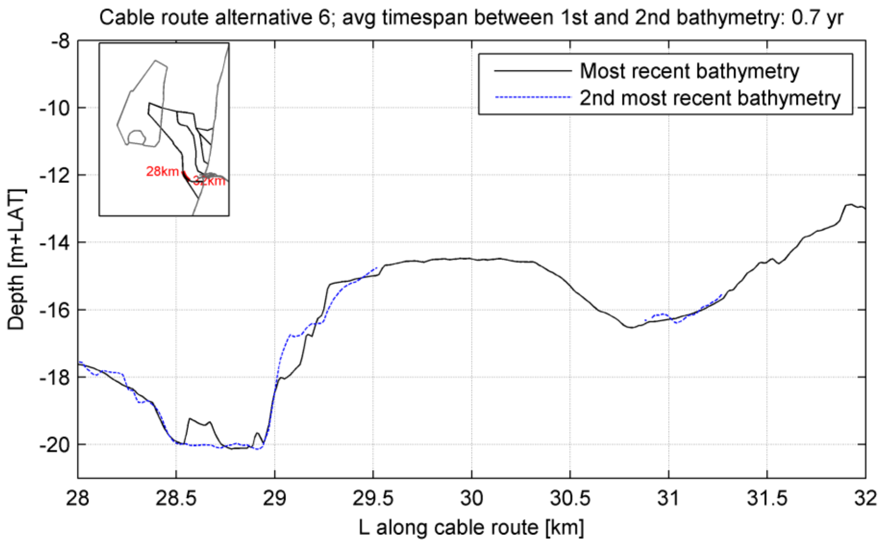


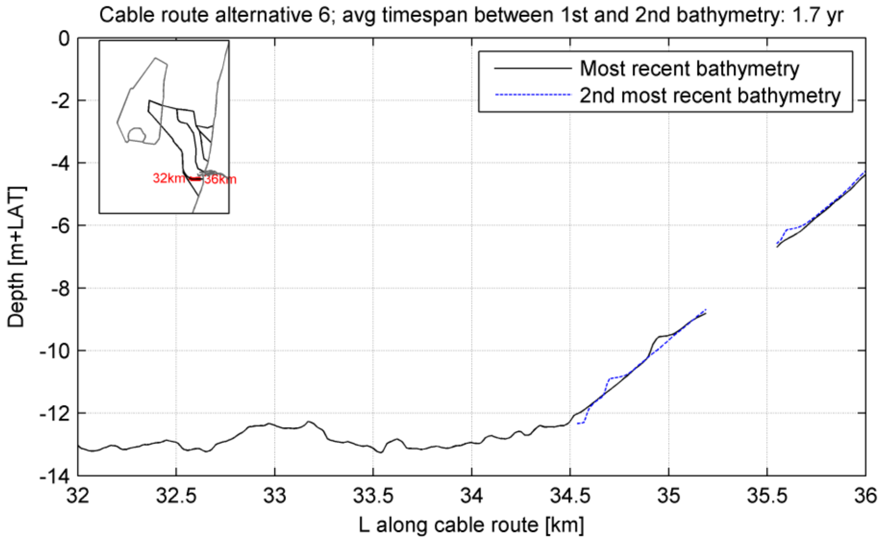
Cable route alternative 6; avg timespan between 1st and 2nd bathymetry: 5.9 yr

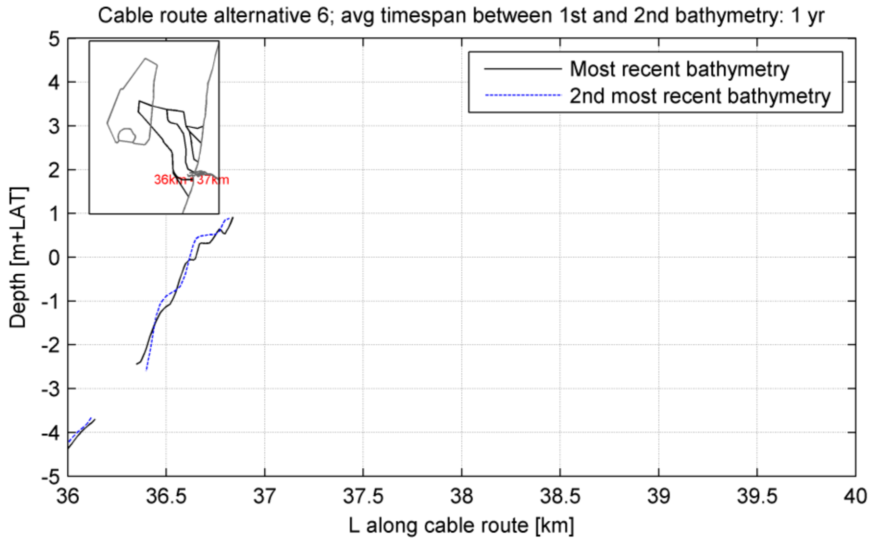



Cable route alternative 6; avg timespan between 1st and 2nd bathymetry: 9.3 yr
Most recent bathymetry
2nd most recent bathymetry
20km
24km
Depth [m+LAT]
L along cable route [km]

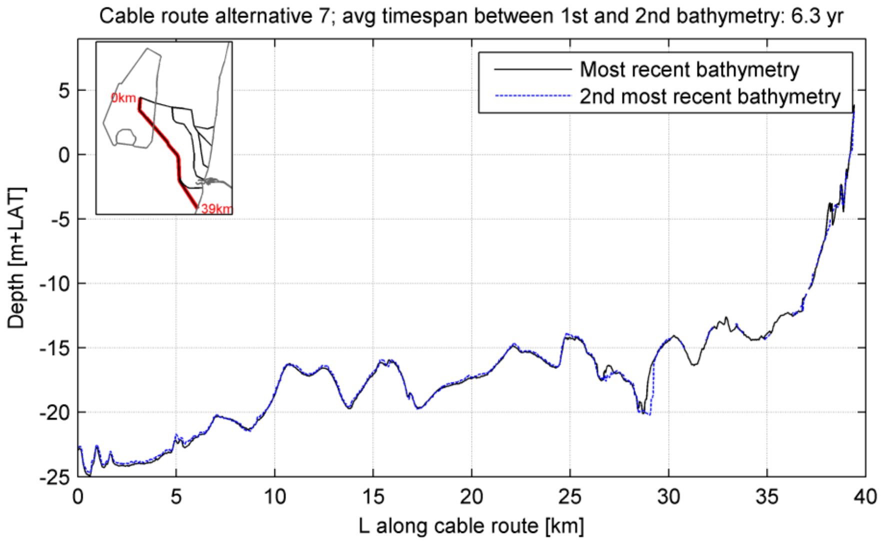

Cable route alternative 6; avg timespan between 1st and 2nd bathymetry: 4.9 yr
Most recent bathymetry
2nd most recent bathymetry
24km
28km
Depth [m+LAT]
L along cable route [km]

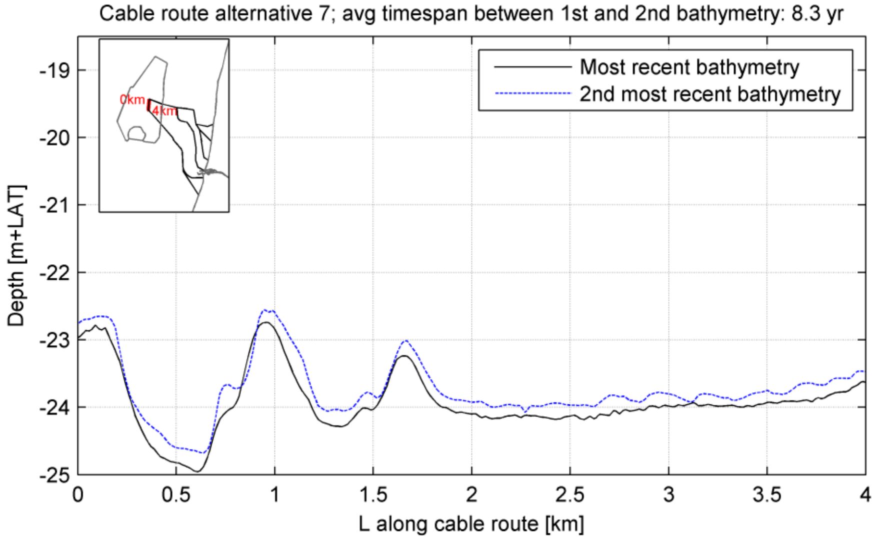

Cable route alternative 6; avg timespan between 1st and 2nd bathymetry: 0.7 yr
Most recent bathymetry
2nd most recent bathymetry
28km
32km
Depth [m+LAT]
L along cable route [km]

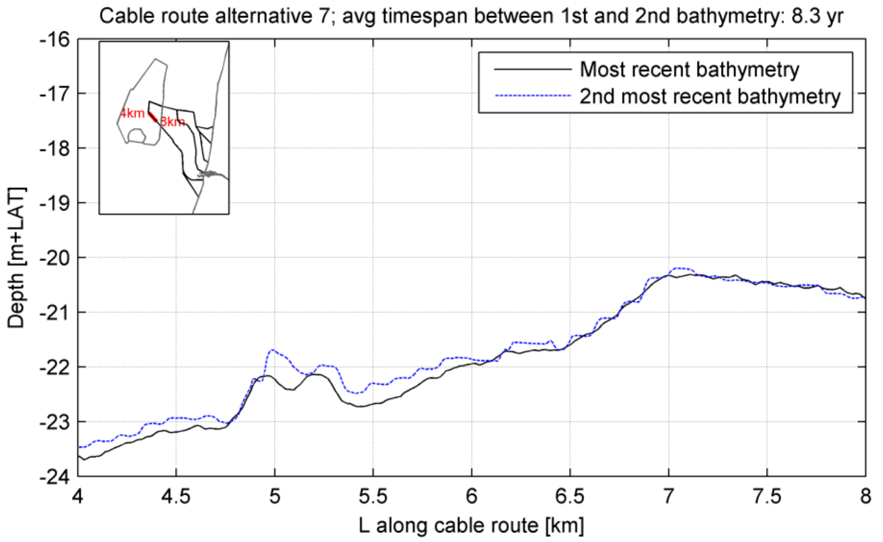

Cable route alternative 6; avg timespan between 1st and 2nd bathymetry: 1.7 yr
Most recent bathymetry
2nd most recent bathymetry
32km
36km
Depth [m+LAT]
L along cable route [km]
0
-2
-4
-6
-8
-10
-12
-14
32
32.5
33
33.5
34
34.5
35
35.5
36

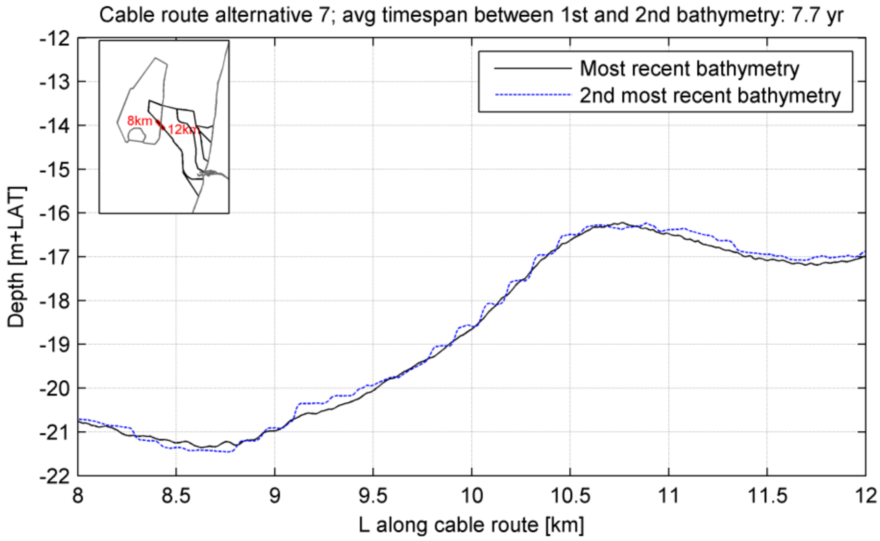

Cable route alternative 6; avg timespan between 1st and 2nd bathymetry: 1 yr
Most recent bathymetry
2nd most recent bathymetry
36km
37km
Depth [m+LAT]
L along cable route [km]
5
4
3
2
1
0
-1
-2
-3
-4
-5
36
36.5
37
37.5
38
38.5
39
39.5
40

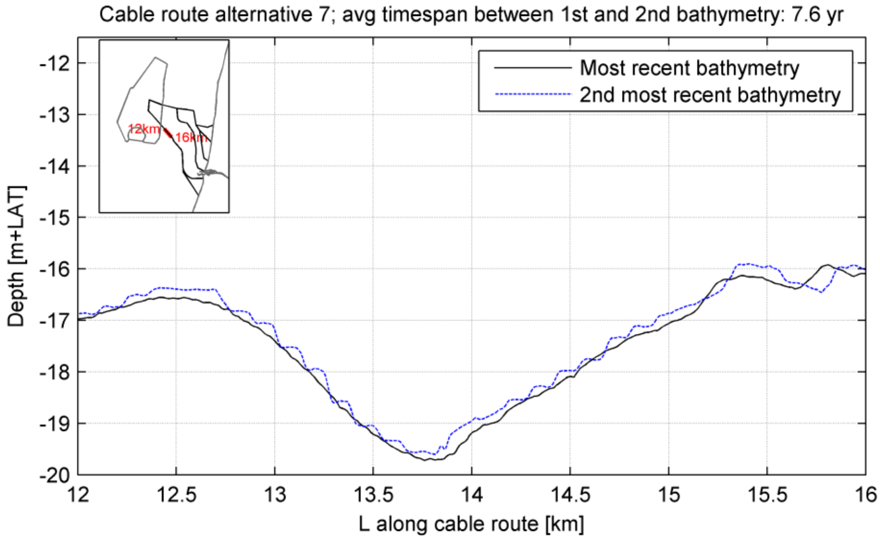
A.7 Sea bed level along cable route option 7

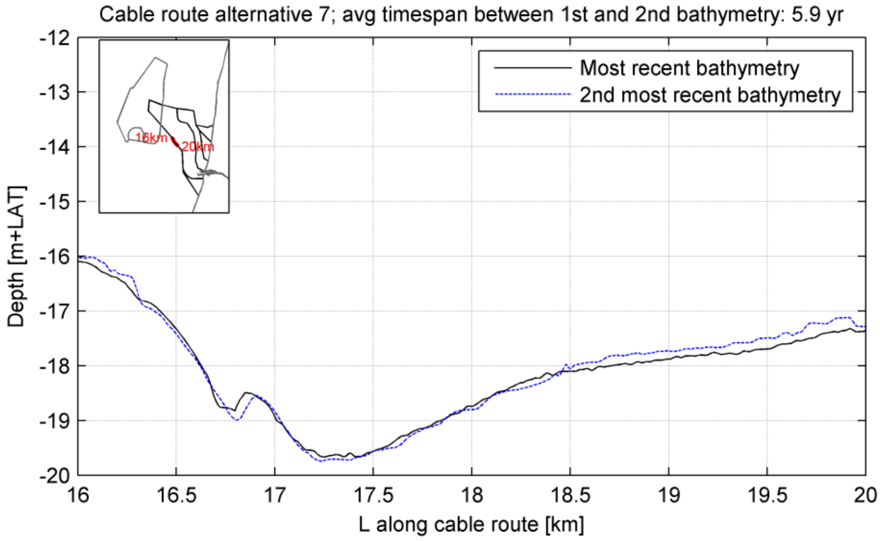


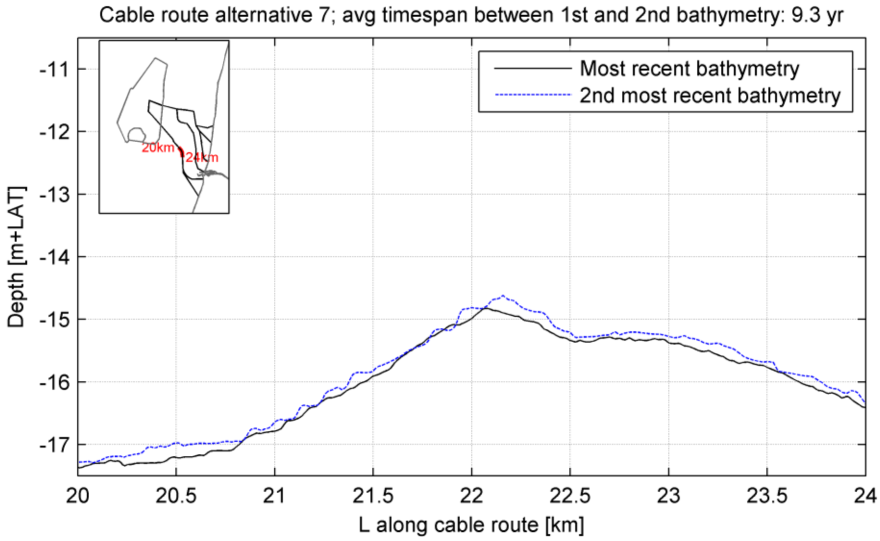


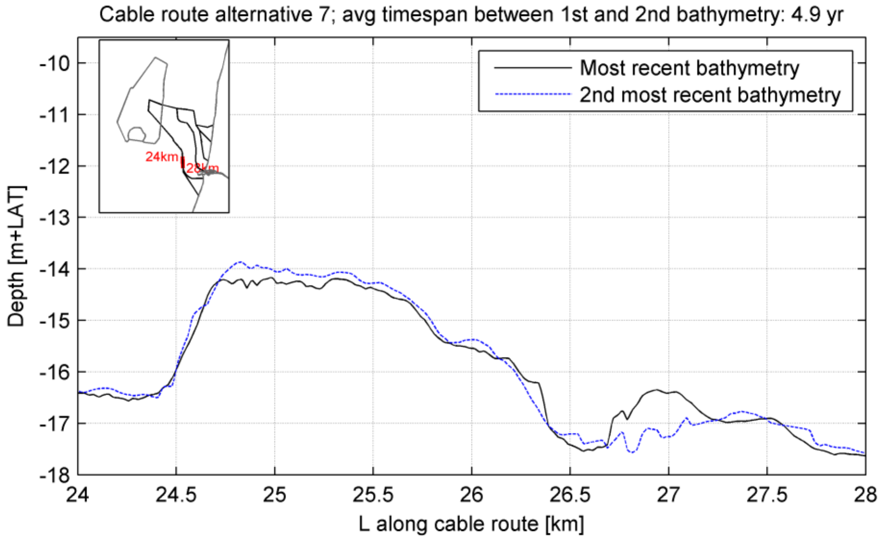


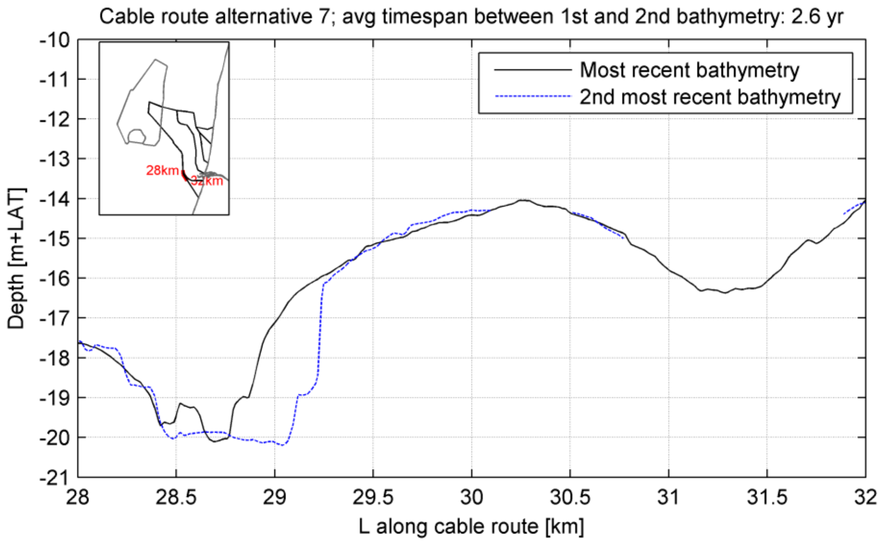

Cable route alternative 7; avg timespan between 1st and 2nd bathymetry: 7.7 yr
Most recent bathymetry
2nd most recent bathymetry
8km
12km
Depth [m+LAT]
L along cable route [km]

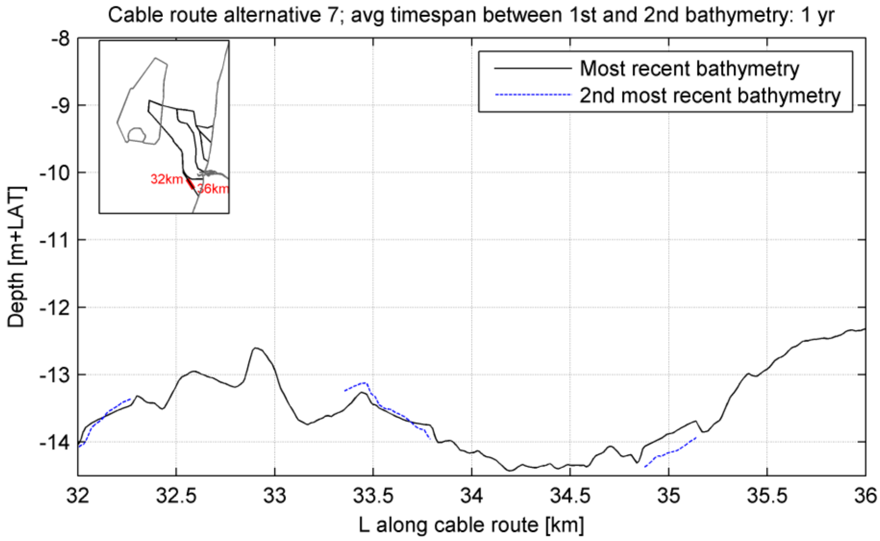

Cable route alternative 7; avg timespan between 1st and 2nd bathymetry: 7.6 yr
Most recent bathymetry
2nd most recent bathymetry
12km
16km
Depth [m+LAT]
L along cable route [km]

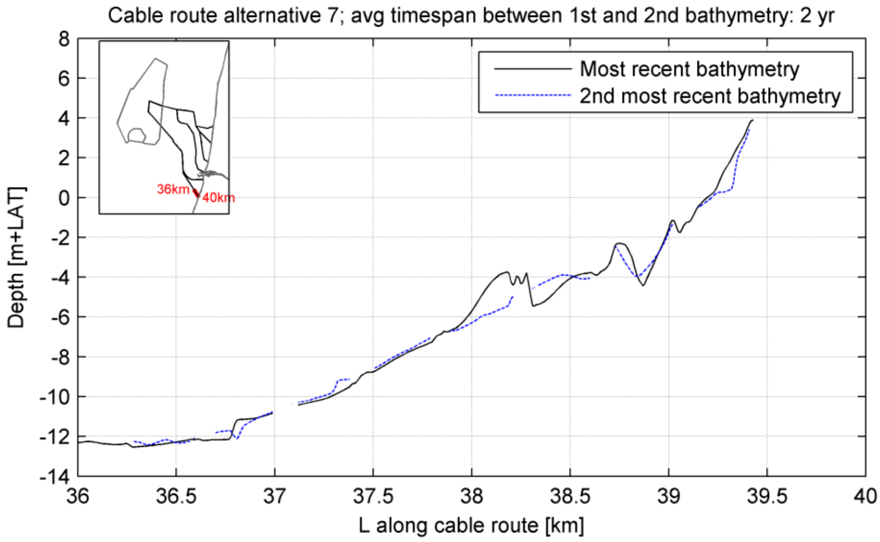

Cable route alternative 7; avg timespan between 1st and 2nd bathymetry: 5.9 yr
Most recent bathymetry
2nd most recent bathymetry
16km
20km
Depth [m+LAT]
L along cable route [km]


Cable route alternative 7; avg timespan between 1st and 2nd bathymetry: 9.3 yr
Most recent bathymetry
2nd most recent bathymetry
20km
24km
Depth [m+LAT]
-11
-12
-13
-14
-15
-16
-17
20
20.5
21
21.5
22
22.5
23
23.5
24
L along cable route [km]


Cable route alternative 7; avg timespan between 1st and 2nd bathymetry: 4.9 yr
Most recent bathymetry
2nd most recent bathymetry
24km
28km
Depth [m+LAT]
-10
-11
-12
-13
-14
-15
-16
-17
-18
24
24.5
25
25.5
26
26.5
27
27.5
28
L along cable route [km]


Cable route alternative 7; avg timespan between 1st and 2nd bathymetry: 2.6 yr
Most recent bathymetry
2nd most recent bathymetry
28km
32km
Depth [m+LAT]
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-20
-21
28
28.5
29
29.5
30
30.5
31
31.5
32
L along cable route [km]


Cable route alternative 7; avg timespan between 1st and 2nd bathymetry: 1 yr
Most recent bathymetry
2nd most recent bathymetry
32km
36km
Depth [m+LAT]
L along cable route [km]
-8
-9
-10
-11
-12
-13
-14
32
32.5
33
33.5
34
34.5
35
35.5
36


Cable route alternative 7; avg timespan between 1st and 2nd bathymetry: 2 yr
Most recent bathymetry
2nd most recent bathymetry
36km
40km
Depth [m+LAT]
L along cable route [km]
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
36
36.5
37
37.5
38
38.5
39
39.5
40

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