Replacing the fibre optic cable between Vlieland and Terschelling

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Abstract

KPN owns and operates several fibre optic cables in the Wadden Sea. The cable from Terschelling to Vlieland is suffering from a malfunction and needs to be replaced. The current cables in the Wadden Sea need constant reburial maintenance because of the dynamic behaviour of the area. The cables are constantly exposed due to the transport of sediment during the tidal cycle. The main goal of this thesis is to come up with a placement plan of the new cable in terms of route, burial depth, burial method and cable type such that the expenditure on maintenance can be minimized through a reasonable investment. Another aspect that poses a challenge is the special environmental protection status of the Wadden Sea. One of the additional requirements is that the cable should have 1 meter of burial at all time.

All islands in the Wadden Sea are connected with two independent cables. This means that each island is connected with its adjacent island or has a double shore connection. Because of this redundancy it is possible to ensure the double connection to Vlieland and Terschelling in another way. Either by connecting them to the islands on the other sides or by allowing them to have a double shore connection. This means that not only replacement of the current cable needs to be researched but also the alternatives.

An important factor when burying a cable are the in situ soil specifications. In order to come up with soil characteristics open source measurements are available. The most important characteristics are the soil uniformity, grain size and soil type. These characteristics vary according to their location on the Wadden Sea. In the inlets the soil is uniform sandy with a mean diameter of around 200 micron. However when going to shore and further away from the inlets uniformity is decreasing along with the mean diameter. Furthermore some silty soil can be expected in this region as well.

Maintenance is mostly caused by the shifting of channels. It is therefore important to look at the morphodynamics of the Vlie inlet and of the western part of the Wadden Sea. The most important event that took place in the western part of the Wadden Sea is the closure of the Zuiderzee in 1932. Only recently the inlets seem to totally have adapted to this new situation. In general there is an inflow of sediment from the outer delta to the inner delta so there is net deposition in the Wadden Sea. Most of this sediment is deposited near the tidal divides so these divides are good locations for new cables.

The Vlie inlet has since the closure of the Zuiderzee changed its orientation from northwest to southeast. The inlets main channel is ebb dominated and the flood inflow from the outer delta is almost radial. This leads to a more stable morphologic environment in the outer delta making it a better position for the new cable. The movement of the secondary channel the Boomkensdiep does pose a challenge for the new cable. The inlets on the other sides of the island do not pose a significant advantage and are therefore not considered viable options for a new cable.

Considering the inputs from the soil and the morphodynamics two route options are further discussed: the one replacing the current cable and one with a double shore connection. In the Vlie the best burial option is jetting since the soil is sandy and water availability is not a problem. Due to soil erosion, burial will have to be 3m to allow for a surfacing chance of 1/100 years on the Vlieland side. On the Terschelling side some maintenance can’t be avoided. The route will cross the north sea

side of the inlet. The route over the tidal divide has more fines and has a problem with water availability. Therefore burial should be done using mechanical trenching supplemented by jetting when crossing channels. Burial should be done at 2 meters to allow for some movement of the tidal divide and because the major length of this route increases the change of surfacing. The cables for both routes can be single armoured cable because of the fishing and anchoring ban near the cables and the general low risk of failure.

Confidential

In order to get an idea behind the needed power, trench size and trencher needed a model was developed. Here the jet trencher is eroding the sand bed in front of it while from behind the sand is allowed to settle over the cable. Some extra depth should be dredged to allow sand to settle before the cable is totally lowered into the trench. This model estimates that for the KPN cable around 500 kW of power is needed to bury it up to 3 meters. With an estimated overdepth of about 0.5 meter for a reasonable burial velocity.

Another important finding is that the cost of maintenance are low compared to the placement of new cables. This means that upgrading cable capacity without using a new cable is less expensive. However if a new cable is needed, findings from this report are not exclusively useful to the cable between Vlieland an Terschelling but could also be used on other cables in the Wadden Sea.

Contents

List of tables

List of figures

Nomenclature

A	Forward trench Area	$[m^2]$
A_{cable}	Cross sectional cable area	$[m^2]$
c	Near bed sand concentration	[-]
c_d	Drive coefficient	[-]
c_f	Flowline coefficient	[-]
c_n	Nozzle coefficient	[-]
c_p	Pump coefficient	[-]
C_u	Soil uniformity coefficient	[-]
d	Grain size	[m]
d_{50}	Median grain size	[m]
$D_{additional}$	Additional trench depth	[m]
D_{target}	Target trench depth	[m]
D_{total}	Total trench depth	[m]
d_x	Largest grain size of x% of smallest particles by mass	[m]
E	Young's Modulus	$[N/m^2]$
E	Erosive flux	$[kg/m^2/s]$
f_0	Fanning's friction factor	[-]
g	Gravitational constant	$[m/s^2]$
I	Area moment of inertia	$[m^4]$
I_j	Jet momentum	$[kgm/s^2]$
k_l	Bed permeability	[m/s]
L	Span length	[m]
M_s	Mass flux eroded sand	[kg/s]
n	Hindered settling coefficient	[n]
n_0	In-situ bed porosity	[-]
n_l	Top bed porosity	[-]
P	Cao's pick-up flux coefficient	[-]
p_j	Jet pressure	[Pa]
P_j	Jet power	[W]
P_t	Total power	[W]
q	Submerged unit weight	[N/m]
Q_j	Jet discharge	$[m^3/s]$
$Q_{j,back}$	Backward jet discharge	$[m^3/s]$
R_p	Reynolds particle number	[-]
S	Sedimentation flux	$[kg/m^2/s]$
T	Lay tension	[N]
t	Trenching time	[s]
u	Depth average flow velocity	[m/s]
u_0	Jet exit velocity	[m/s]
u_1	Flowline velocity	[m/s]
v_{bed}	Bed velocity	[m/s]
v_e	Erosion velocity	[m/s]
v_t	Jet trailing velocity	[m/s]

w_0	Single particle settling velocity	[m/s]
W_b	Trench bottom width	[m]
w_s	Bulk settling velocity	[m/s]
W_t	Trench top width	[m]
x	Distance from start Trench	[m]
x_2	Distance from cable touchdown point	[m]
y	Vertical cable deflection	[m]
α	Jet production parameter	[s/m]
Δ	Specific density	[-]
θ	Dimensionless bed shear stress	[-]
θ_c	Cable departure angle	[°]
θ_{cr}	Critical dimensionless bed shear stress	[-]
ν	Kinematic viscosity	[m^2/s]
ρ_f	Fluid density	[kg/m^3]
ρ_s	Sand density	[kg/m^3]
ρ_w	Water density	[kg/m^3]
ϕ_p	Dimensionless pick-up flux	[-]

1 Introduction

This report is the thesis written in order to attain a master's degree at Delft University of Technology. This degree is attained at the section Offshore and Dredging Engineering with a specialisation in dredging, trenching and deep Sea mining. The assignment was provided by KPN and the research was also conducted at KPN.

1.1 Problem

KPN owns and operates multiple fibre optic communication cables in the Wadden Sea. One of these cables is the cable going from Terschelling to Vlieland. This is an old cable and suffers some transmission problems. Furthermore one of the company goals of KPN is to offer higher speed internet to everyone in the Netherlands. This increase in data rate over the KPN network is needed because the per capita data use is increasing yearly and the future transmission capability needs to able to cope with this. These factors mean that the cable going from Vlieland to Terschelling will have to be replaced in the near future.

Because the Wadden Sea is a dynamic region the infrastructure in the Wadden Sea requires maintenance in order to keep the cable burial depth up to specifications. This maintenance is expensive and it would be best if a new cable could be laid in such a way such that maintenance costs can be kept as low as possible. However these maintenance costs are not the only important cost when placing a new cable since the initial investment should also be taken into account. Furthermore the special environmental status of the Wadden Sea cannot be ignored.

1.2 Objective

The objective of this thesis is to come up with a total placement plan for the new cable going from Vlieland to Terschelling such that total cost are kept to a minimum. This will include routing, burial depth, cable type and burial method. Because the prevention of maintenance is important when placing the new cable, maintenance on other cables owned by KPN is also looked at. This is however secondary to the placement of the new cable between Vlieland and Terschelling.

1.3 Approach

First of all some of the background regarding KPN and the fibre optic cables in the Wadden Sea will be given. Furthermore it is important what kind of maintenance is currently conducted in order to know how this can be prevented. Important is also the Wadden Sea environment itself so a further study is conducted at the in-situ soil conditions and into the morphodynamics in the Wadden Sea. Some alternative routes will also be investigated.

The burial depth, route, cable type and type of burial is then selected and a cost based comparison is made between the different alternatives. The expected yearly maintenance cost are also included in this comparison. Once the new connection between Vlieland and Terschelling has been chosen, the maintenance and possible renewal of the other cables owned by KPN in the Wadden Sea is discussed. To get an idea behind the powers and way of burial a model is written to simulate the burial of the cable. In the last chapter conclusions and recommendations are given.

2 Background

This chapter gives more insight into the context in which the research will to be conducted. First more information is given about the company sponsor of the research. Secondly the Wadden Sea and especially the Vlie inlet is discussed. Thirdly and fourthly an explanation of fibre optic communication and their specific properties within KPN is given. The fifth paragraph of this chapter will discuss some boundary conditions of the research.

2.1 KPN

KPN (Koninklijke PTT Nederland) is the largest IT and oldest telecom provider in the Netherlands. Origination from a state owned company but privatised in 1989 and transformed into a listed firm. It provides both wired and mobile (IT) services to its customers, in total it has about 14,000 employees. These services are offered to both companies and individuals. Because of these wired services KPN owns lots of internet infrastructure in the Netherlands. However also wireless communication will travel mostly through the wired network. This infrastructure includes fibre optic cables going to the Dutch islands in the Wadden Sea.

The infrastructure part of KPN operates separate from the service part of the company. The infrastructure part of KPN is located in Amersfoort and at this department the graduation is conducted. The reason the infrastructure is not integrated with services is to ensure a free market and allow other companies to use the network of KPN and compete with the service part of KPN.

KPN thrives to be the best IT company in the Netherlands. In order to attain this goal the strategy of KPN is formulated in three words: ”*simplify, grow and innovate*”. This expected results of this strategy is a continues simplification of its services, increasing the capacity of the network and the innovation of current products in order to give the customer the best experience possible.

In order to facilitate the growth in bandwidth, investments in the infrastructure are inevitable. For the Wadden Sea this would mean an increase of bandwidth over the current infrastructure or investments in the infrastructure itself.

2.2 Wadden Sea

The Wadden Sea is one of the largest tidal flat areas in the world. It stretches 3 countries (the Netherlands, Germany and Denmark) and is proclaimed an international world heritage site as well as a Dutch Natura 2000 area giving it a special protected status.

It was formed during the last post-glacial period around 7000 years ago. The dynamics of the area are well known with its barrier islands and tidal flats system. During the last century significant human involvement influenced the dynamics of the Wadden Sea. The most well-known example of human involvement is the closure of the Zuiderzee with the Afsluitdijk in 1932 becoming the IJsselmeer and no longer being part of the Wadden Sea. However the recent policy of the Dutch government is that the Wadden Sea should have as much natural behaviour as possible. A map of the Wadden Sea is shown in Figure 2-1.

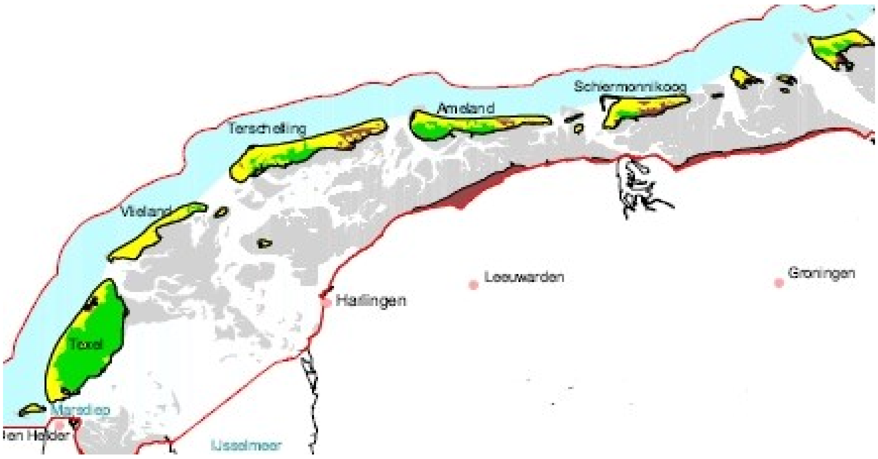

Figure 2-1: Map of the Wadden Area

The Dutch part of the Wadden Sea contains 5 major islands. In order from west to east: Texel, Vlieland, Terschelling, Ameland and Schiermonnikoog. In between the islands and between the islands and the shore are tidal inlets. These are called in order from west to east: Marsdiep inlet, Eierlandse Gat inlet, Vlie inlet, Ameland inlet, Frisian inlet and the Eems-Dollard inlet. The latter being partially in Germany.

2.2.1 Utilities in the Wadden Sea

Because most islands in the Wadden Sea are inhabited utilities are needed. In the Wadden Sea multiple utility connections of different companies are present. These utilities include: power, natural gas, water and data. The location of these utilities is declared a designated pipeline area. In designated pipeline areas it is forbidden to fish and anchor or conduct other bottom penetration activities.

All utilities owners and the government (Rijkswaterstaat) are united in the Steunpunt Waddenzee. This organisation oversees all problems related to utilities in the Wadden Sea and allows for better cooperation.

2.2.2 Vlie inlet

The Vlie inlet consist of the main channel called the Vliestroom [8] with a NW-SE orientation. In the outer delta two smaller channels on the island heads of Vlieland and Terschelling are called the Zuiderstortemelk [7] and the Boomkensdiep [9]. The Boomkensdiep changes into the Schuitengat [11] upon leaving the outer delta. The Schuitengat is separated from the Vliestroom by a shallow sand bank. In the inner delta more channels are formed. All other main channels and sand banks are named and numbered in Figure 2-2.

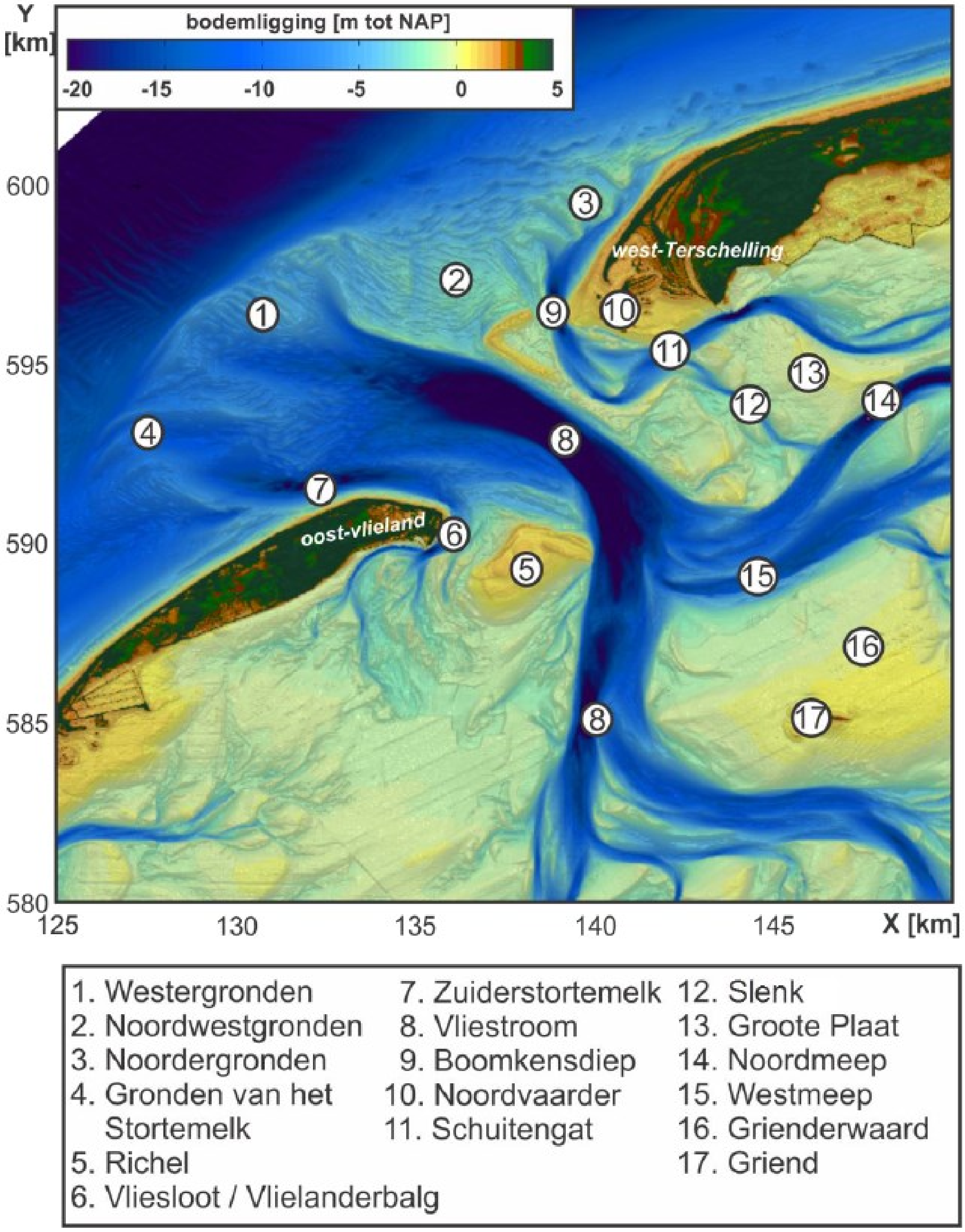

Figure 2-2: The main channels and banks in the Vlie inlet (Elias, et al., 2015)

2.3 Fibre optic transmission cables

An optic fibre contains two layers of glass. Due to the different breaking indices of the two layers of glass internal reflection will occur according to Snell's law (Venghaus & Grote, 2012). A cable can contain any amount of fibres since they are custom made. Within KPN the standard used to be a cable with 6 fibres however nowadays these cables are replaced for cables with 96 fibres (internal communication KPN).

Each fibre can be used for the transmission of data. So the newer cable will be able to transmit more data. Because of better transmission equipment the amount of data that can be transported per fibre has also increased greatly and is expected to continue growing in the future (Venghaus & Grote, 2012). The data rate over a cable is also distance and glass type dependant. So new cables will be able to send more data because of the better glass type and the increased amount of fibres. However newer transmission equipment on fibre optic cables can also increase the data rate without cable renewal.

Cables are normally made continuous; welding of cable is possible. Welds are unwanted because the weld remains a weak point in the cable and causes some additional damping. So welds are avoided as much as possible.

2.3.1 Offshore optic fibre transmission cables

The optic fibres in on-and offshore cables are not different. However cables that are placed in a marine environment will need some water protection. A deep-sea transmission cable which is situated in the pacific would have a diameter of approximately 20mm (ICPC, 2009). In shallow water normally some armament is added to the cable to lessen the risk of failure when getting tangled by fishing nets or anchoring equipment. This will increase the diameter to up to 50mm (ICPC, 2009) depending on the degree armouring (the fibres itself are not thicker). If a cable is longer than 50 km some amplifiers may be needed (internal communication KPN) to compensate for signal damping in the cable.

2.4 KPN transmission cables in the Wadden Sea

This Chapter is confidential

2.4.1 Trajectory of current Vlieland Terschelling cable

The current Vlieland Terschelling cable runs from the village of west-Terschelling through the dunes and under the beach called the Spathoek before it reaches the coast line. The offshore trajectory passes through channels called the Boomkensdiep and the Vliestroom and one shallow area called the Engelschhoek. On Vlieland the cable again crosses the beach and dunes to allow it to enter the village of Oost-Vlieland. The route of the cable along with a bathymetry map is show in Figure 2-3.

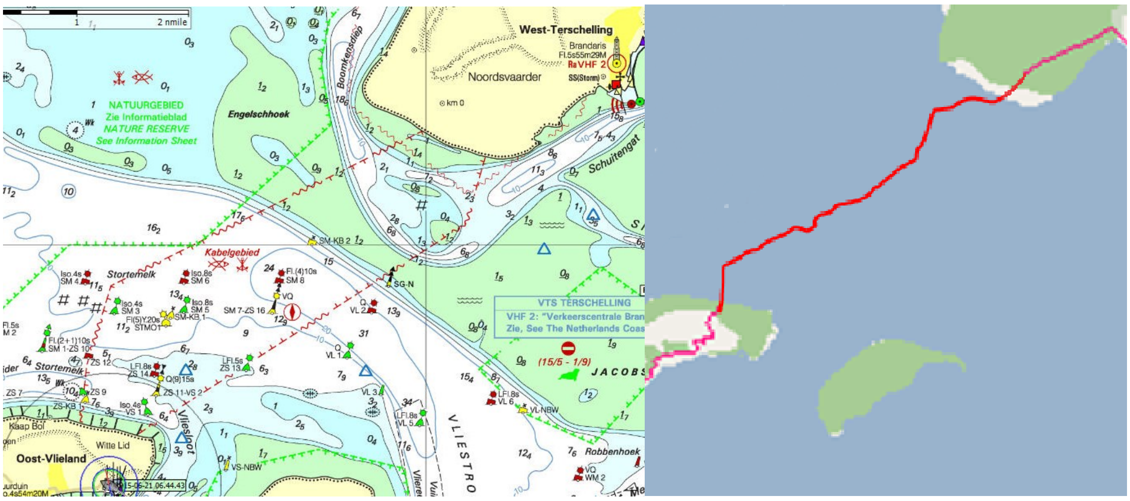

Figure 2-3: Current optic fibre transmission cable

The area between the red dotted lines in the left figure shows the designated cable area. No other utilities are present in the area between Vlieland and Terschelling (Elle Vellema, Liander).

The routing of the cable is known however the depth at which the cable was and is buried is unknown. There is little to no historic data (the exact age of the cable is unknown) of the cable and an offshore cable depth measurement was not conducted. A yearly survey is conducted to measure the bottom profile above the presumed location of the cable. This measurement however does not measure the actual burial depth.

The burial of the cable on the beach on the Terschelling side of the cable is known. Jan Klein (KPN) conducts a biannual measurement of the burial depth of the cable. The reason for this measurement is that the cable has experienced surfacing problems. During the last measurement the cable had an approximate burial of 0.7 m meter on the beach with a slightly less burial near the dunes of about 0.2m (measurement taken 14 December 2016).

This measurement is taken by putting a signal on the cable. The cable needs to be able to conduct electricity for this to work. The cable depth can then be acquired via a measurement device which can detect the signal on the cable. A similar method can and is used offshore.

2.5 Boundary conditions

Since all cables are and will be placed in a protected environment, law is the most important boundary condition. Besides law other users of the Wadden Sea also impose limitation on cable placement options. The last and final boundary condition is safety.

2.5.1 Law

The permit for all utilities in the Wadden Sea is approved by the ministry of Infrastructure and Environment. Their demands are split out in technical, survey and water safety demands below a summary of the demands.

Technical:

- Trenching activities are to be conducted outside the stormy season. Digging is prohibited on the shoals.
- If one would like to conduct works on a cable a working plan will have to be submitted at least 10 days before the start of the works.

- The minimal soil coverage above an utility should be at least 1 meter at all times.
- An old cable that becomes visible should be removed.
- No sediment can be transported to the Wadden Sea without a special permit. If dredging is conducted displaced soil should be released close to the original location.
- At least one month after conducting works an overview of the conducted works should be handed in. This should include the exact work conducted and the placement (X, Y and Z) of the works.

Survey:

- Every year, before the first of July, an inspection report should be handed in. This report should at least include the cable depth and location change of the cable (in practice a depth survey).

Water safety:

- Flood prevention and water quality should not be affected.
- Other users should be able to use the waterway in a safe way.

Besides these demands the government will look at other (economic) activities in the region before allowing the placement of the cable. When a new cable is placed a designated cable and pipeline area will be allocated on the cable route. In this area anchoring and fishing is prohibited.

2.5.2 Other users of the Wadden Sea

Several human activities take place that could interfere with the cable during operation or during the placement/burial of the cable. The three most important being ship wrecks, dredging operations and cockle/mussel extraction. A picture of the exact locations of these activities and a map of all human activities in the Wadden Sea can be found in Appendix B.

Dredging takes place to maintain the Slenk connection for the ferry traveling from Harlingen to Terschelling. About one meter of soil per square meter is dredged per year from this waterway with a total of around 300000 cubic meters (Terwisscha van Scheltinga, 2012). During maintenance the channel is allowed to shift somewhat to make the maintenance easier. In the past when the connection between the Boomkensdiep and the Vlie still existed this route was used by the ferry. Might this connection restore itself the ferry could divert to this route and thus possible dredging could occur on this location. Further information about all dredging activities in the Wadden Sea can be found in a report from Rijkswaterstaat (Arcadis, 2011) and in the environmental management plan from Rijkswaterstaat. The main channel from Harlingen into the Wadden Sea is dredged as well.

The islands itself are maintained by coastal management up to a depth of 20 meters (Elias, et al., 2015). The basis for this maintenance is the base coast line set by Rijkswaterstaat. However some movement of the islands is allowed to let the Wadden Sea to distribute most of the supplied sediment and thus save costs.

Another human activity that needs to be considered is the presence of a military practice ground on the west side of Vlieland. Especially not-detonated explosives could pose a major risk during the trenching of a cable on this island and practice with live rounds could pose a danger to the cable during operation.

2.5.3 Personal Safety

Besides safety of the waterworks personal safety is important as well. Because the works will be carried out by a third party, a safety document will have to be provided by the contractor (in Dutch called VGM). This safety document will make sure that all work is conducted safely and that personal risks are minimised. Furthermore it will have to include some what-if scenarios such that the right steps will be taken in case of an emergency. The current maintenance VGM can be found in Appendix G.

2.5.4 Cable Safety

In the industry some guidelines for the safe burial of cables are available. For this the burial protection index (BPI) was developed by P. Mole (Mole, et al., 1997). A further description of the BPI was given by 1998 by P. G. Allen (Allen, 1998).

The three levels of burial protection are (Mole, et al., 1997):

- **BP= 1** Depth of Burial consistent with protecting a cable against normal fishing gear only. Would be appropriate to water depths greater than say 100m where anchoring of ships is unlikely, or in areas where shipping and anchoring is effectively prohibited.
- **BP = 2** Depth of Burial will provide protection from vessels with anchors up to app. 2 tonnes. This may be adequate for normal fishing activities but would not be suitable for larger ships' anchors.
- **BP = 3** Depth of Burial sufficient to protect from anchors of all but the largest ships. Suitable for anchorages and heavily trafficked shipping channels with adjustments made to suit known ship/anchor sizes.

The burial depth can then be deduced from the following graph developed by P. Mole shown in Figure 2-4. It can be seen from the figure that the burial depth is highly dependent on the soil strength. This seems appropriate since the stronger the soil the lower the change of significant soil displacement.

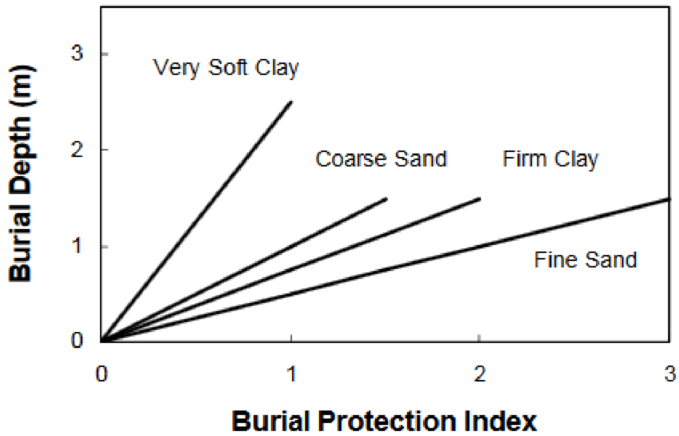

Figure 2-4: Burial protection index

However this method only takes into account human activity that could affect the functioning of the cable. Natural hazards like soil movement and seismic activity are not taken into account. It is assumed that these dangers can be averted through alternative routing or by a risk assessment of their likelihood during the cable life.

3 New cable and Maintenance

This chapter will give insight why the cable between Terschelling and Vlieland will have to be replaced. Furthermore the reasons for maintenance on current cables owned by KPN is explained and how this maintenance could be prevented. Maintenance is also important for current KPN cables which do not need immediate replacement.

3.1 New cable

The current fibre optic transmission cable between the islands Vlieland and Terschelling is suffering from a malfunction in the cable. This malfunction is in a weld which is located close to the beach of Terschelling. The problem with this weld is that some light frequencies are damped more than they should allowing less data transport than technically possible.

Another fact that plays a role in the replacement of the cable is the need for higher data transmission rates. The old cable contains six optic fibres and the new cable will contain 96 fibres. This upgrade will allow this cable to be more future resistant. The first main goal of this research is to find a replacement option for this cable in terms of route, burial depth and burial method. A change in transmission equipment would also be able to increase the data rate over the cable, this is not the scope of the research however.

3.2 Maintenance

This paragraph will give some insight in the maintenance currently conducted on the KPN cables.

3.2.1 Maintenance vessel

The maintenance is currently conducted by the Steeborg 1 owned by J.W. van Stee. It is an overhauled cockle ship with a beam of 12 meters and a length of 42 meters. The ship has a flat bottom which limits its open sea sailing ability but allows it to nicely dry out on the shallows. The draft of the ship is approximately 0.6 meters. This limited draft allows it to sail up to almost low tide. Hereby increasing its intertidal working window.

Positioning of the ship is done in two ways. The ship has two spuds as well as anchors. The anchors are handled by another vessel. A water jet is located on the ship. This jet (Figure 3-1) is mounted in a crane. The spuds are normally not used since the exact location of an utility needs to be known before one can safely lower the spud. There are tracks on the ship which allow the excavator and crane to move and thus continue its maintenance works for another 20 meters when the ship is stranded during low tide.

Figure 3-1: Jetting Tool

The jetting tool is placed over the cable fluidising the soil around the cable. The cable is then pushed down into the fluidised material. The jet apparatus is an inverted u-shaped device with nozzles on both sides to improve its movability. It has jets on two sides to make it able to follow the cable instead of being guided by the crane itself. For utilities which cannot be contacted (gas pipes) a breaching process suction head is used instead. The centrifugal pump which powers the jetting tool is direct diesel driven. If temporarily more power is needed an extra hydraulically powered pump is used with an additional hose in order to aid penetration.

The ship also performs surveys on the cables; this is done with a fork like jet which is placed over the cable. This fork touches the cable and thereby measures the three-dimensional coordinates of the cable.

3.3 Reasons for maintenance

In general four reasons of maintenance exist for the current cables. This does not include breaking of this cable since this is not a regular event and is regarded as an incident. The following reasons for maintenance are described:

- Surfacing of cables due to changes in bathymetry.
- Surfacing of cables due to beach scouring.
- Inappropriate length of cables during reburial.
- Removal of abandoned cables.

Furthermore a description is given of how the maintenance is conducted.

The maintenance of all utility companies is overseen by Liander, itself the owner of power cables to some of the islands. By combining the maintenance of all utilities in the Wadden Sea synergy advantages are achieved and thus costs are lowered. These companies meet two times a year to discuss problems they encounter. If a problem with a utility in the Wadden Sea is encountered it is communicated with Liander which than in turn contacts the owner of the cable. Together they will than make a plan of approach to get the cable back to specifications.

3.3.1 Surfacing of cables due to changes in bathymetry

The Wadden Sea is an area with constant changing bathymetry. During low tide almost the entire basin drains except for some shipping lanes and tidal trenches. Because of this constant movement of water lots of sediment is transported to and from the Wadden Sea. This means that the bathymetry of the Wadden Sea is changing over time. A cable that is lying in the tip of a sandy shoal could be uncovered the next year or even week.

A good example of this type of problem can be found on the western cable going to Schiermonnikoog. Here a sand bank called the Roode Hoofd is moving to the east thereby exposing the transmission cable. Causing the need for reburial of the cable. Another reason for a cable to surface is the maintenance dredging which constantly takes places in the Wadden Sea.

The reburial of the cable is done with the jetting tool available on the maintenance ship. For reburial the cable needs to be slightly longer to be able to follow the new seabed contours. To make sure there is enough length, reburial starts and ends some distance before and after the actual reburial spot. To be able to get enough slack in the cable sometimes several passes will have to be made by the maintenance ship. However due to the short bending radius of the fibre optic cable this is usually not necessary.

3.3.2 Surfacing of cables due to beach scouring

Some of the beaches in the Wadden sea experience significant scouring. As a result of this scouring cables tend to surface on beaches. In a way this is comparable to surfacing of the cables discussed earlier. This problem has been observed for the Vlieland-Terschelling cable on the Terschelling side of the cable.

The reburial is accomplished by digging a trench with a bucket crane next to the cable. The cable is then placed in the trench after which the trench is backfilled. Because this scouring also happens on the water line some works will have to be done in the water as well. Because of the minimal depth near the beach this is usually done by hand. Someone will stand on the cable (pushing it down) while simultaneously fluidising the sand with a water jet.

3.3.3 *Insufficient length of cables*

All cables are laid at a certain specified depth. However as the years pass by and the cable surfaces the constant reburial of the cable will lead to an increase in needed cable length. This problem is closely related to the surfacing and reburial of the cable. This described phenomena can be seen in Figure 3-2.

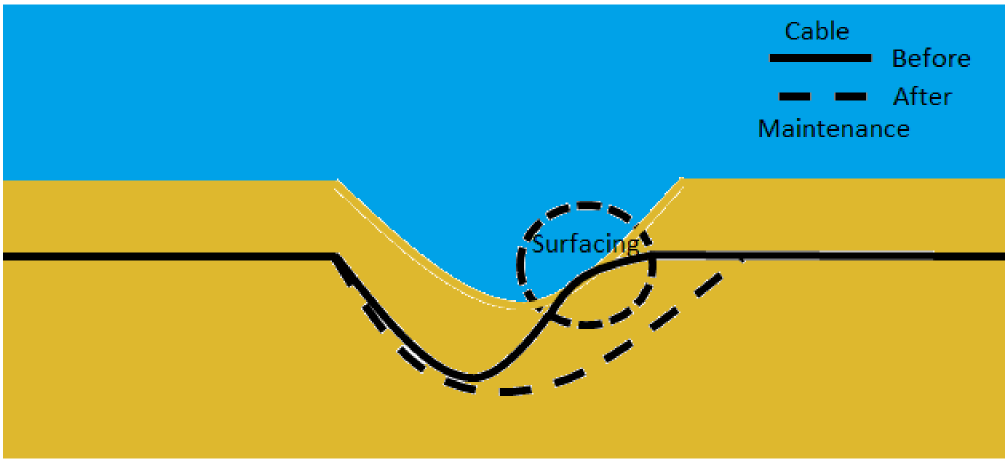

Figure 3-2: Insufficient cable length

The increase in length can be clearly seen in the figure. Might the chanel move more to the right reburial would be needed again leading to an even longer cable. Once all slack is gone from the cable reburial will no longer be possible.

A solution used in the past was to weld in an extra piece of transmission cable before reburial of the cable. This can be done offshore and onshore however the closer to the beach the easier this can be done.

3.3.4 *Removal of abandoned cables*

When a cable is abandoned it is simply cut at its start and end point. This is common practice both on-and offshore since the beginning of the Wadden sea operations. The oldest cable still (partially) in the Wadden sea is from the 1920’s (J. Klein, personal communication, 8 December 2016). KPN retains the obligation to remove cables when they surface. Pieces of cables are identified during the yearly survey, other maintenance work or by other people using the Wadden Sea (mainly wadlopers). This information is than communicated with KPN through the Steunpunt Waddenzee. In that case Liander will plan the removal of the cable.

The removal of the cable is done by cutting the cable during low tide and attaching a buoy to the cable. The cable is easier to access during low tide because people can walk to the cable. However pulling in the cable during low tide is difficult because the service vessel has no movement capability. So when the tide rises the cable is hoisted on deck in pieces. On the beach this removal is done with an excavator.

3.4 Cost of Maintenance

This Chapter is confidential

4 Alternatives

In this chapter alternatives for the new connection to the islands of Terschelling and Vlieland will be discussed. The main reason for placing a cable with certain specifications is the expected maintenance on the cable. Maintenance can be prevented in two ways:

Route selection:

- If a cable is buried through a stable seabed no maintenance would be needed. A good trajectory for example would be the place were two tidal waves meet (Dutch: wantij), so where the tidal wave from one side of the island meets the tidal wave from the other side of the island (Van der Spek, 1994). Here the divide is maintained by near zero velocities of the currents leading to high deposition rates (Oost & de Boer, 1994).

Burial depth of the cable:

- By selecting a burial deeper than the lowest expected seabed depth all maintenance could also be prevented. The burial depth will have to be based, on the maximum expected seabed change over the lifetime of the cable.

Both measures could prevent all maintenance to the transmission cables of KPN however a combination of the two could also be a solution. The type of cable wouldn't really influence the needed maintenance however it could limit the consequences if the cable would become exposed. Furthermore it will make the cable more strain resistant during a trenching operation. It is more of a failsafe measure than a safety measure. Rock placement (loose rock or mattresses) could also be used to protect the cable but this is not legally allowed in the Wadden Sea.

Route is the first thing that needs to be selected since the route itself will influence the burial depth and cable selection. The burial method will have to be chosen as well. In total the following alternatives regarding the cable will be discussed in this chapter:

- Route
    - Depth of burial
- Trenching method
- Cable
    - Other possible transmission methods

4.1 Route options

The route between the islands of Vlieland and Terschelling is not the only way to ensure a redundant connection. Other possible routes are to be considered as well. The first possible route would be the current route optimised for the current situation in the Vlie inlet. Every alternative would require at least one extra cable compared to the Vlieland-Terschelling route (so two new cables in total). The first alternative would be to give both islands a direct double connection to shore. A schematic overview of this alternative and the second alternative can be found in Figure 2-1.

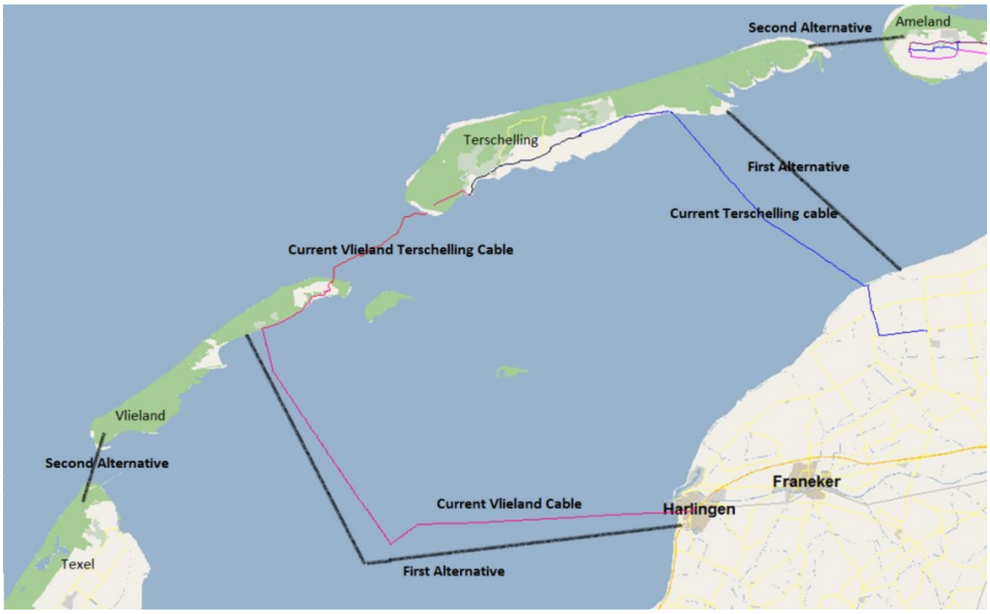

Figure 4-1: Schematic overview of current cable and alternatives

The second alternative would be to connect each island with its adjacent island on the other side. So Vlieland with Texel from the west and Terschelling with Ameland from the east. A combination of both is possible as well by providing one of the islands with an extra shore connection and the other island with a connection to its other adjacent island.

In order to get a first idea about the alternatives the appoximate distances can be seen in Table 4-1 An important note is that the actual cable trajectory will almost never be the shortest route (Intecsea, 2016). Since the most suitable route to place the cable is not always the shortest route.

Table 4-1: Approximate distances between the islands and shore

Route	**Approximate distance** (Maps)**(km)**
Terschelling-Vlieland	7
Texel-Vlieland	2.5
Terschelling-Ameland	4.5
Terschelling-shore	15
Vlieland-shore	33

From the table it can be seen that a double shore connection to each island would mean an increase in total cable length. Whereas a double connection from Vlieland with Texel and from Terschelling with Ameland would only mean a minor increase in length.

The alternative route will only be considered if they can offer a major advantage in terms of cost. This major advantage in cost is needed because the onshore infrastructure will have to be altered as well. This lower cost means there must be an adavantage with a combination of cable length, burial depth and maintenance.

4.1.1 Depth of burial

The burial depth will have to be selected as well. The burial depth depends on the route, soil conditions and possible risks for the cable when it is not sufficiently buried.

4.2 Trenching options

There are different ways to bury a cable in soil. It is not only important how these methods work but particularly how they perform on both tidal flats and deeper parts. Furthermore the moment at which the cable will be buried varies. This could be done before, during or after the placement of the cable. A combination could be used as well. A pre-lay burial would require some backfilling. This is done with naturally or artificially supplied sediment. The pre-lay trench is usually made with a dredging vessel, backfilling is mostly done with the same vessel.

In general there are four burial methods (Beindorf, et al., 2012). Each method can have different types of trenching equipment depending on type of soil and burial depth. These methods are:

- Mass flow excavation: fluidisation of the soil by high flow.
- Water jet cutting.
- Mechanical trenching.
- Ploughing.

Horizontal directional drilling is considered an option for cable burial as well. This is technically not a type of trenching but is able to bury the cable along its route. Some methods can be used together to improve performance in certain kinds of soil. In the past a vibrational blade has also been used on shoals to bury cables. This method is only possible on the shoals and no data about performance is available. So this is not considered a possibility.

4.2.1 Mass flow excavation

The working principle of this method is to create a turbidity current and thereby creating a trench. This means a high mass flow of water with low pressure is blasted at a non-cohesive or weak cohesive soil surface. This is normally done by a tracked vehicle or by pumps suspended just above the working area. Due to the high pump capacity, this method works better in deeper waters (>10 m) because of the required pump head. Smaller excavators can work from a depth of about 5m (Red Penguin, 2012). A major advantage of this method is that it uses low pressure water to remove soil therefore decreasing the risk for the cable.

The burial velocity and depth is dependent on the pump power and readiness of the soil to be picked up by the flow (dependant on permeability, grain size and soil type). Because of the high water flow during this type of burial a significant amount of soil will be moved, leading to a wide trench. This method is mostly used for pipes and not for cables. Because of the wide trench settling will take place so some extra soil will be excavated allowing the pipe which has a large bending radius to lower itself into the soil before all particles have settled. Cables have shorter bending radiuses allowing them to be lower in the seabed more quickly. Thus eliminating the need for the creating of a large trench.

4.2.2 Water jet cutting

This method relies on jet momentum to cut through the soil. This will create a narrow trench in which the cable can be laid down. In the case of soils without sufficient shear strength (sand, soft clays) simultaneous trenching and burial will be done. However the radius of curvature of the cable/pipe will have to be small enough to decent into the trench before collapsing of the trench. The penetration of the jet depends on the jet momentum and the soil characteristics such as permeability.

The jetting nozzles can be placed on a lance to shorten the distance between the soil and the nozzles. These nozzles are usually placed on a remote operated vehicle (ROV) which can be either free floating or tracked.

A lance can be lowered or elevated in order to adjust the actual burial depth. Not a lot of soil is displaced using this kind of trenching because the high pressure jet focuses on cutting instead of soil removal. Water needs to be available in order to feed the pumps, for short distances in shallower water a hose can be used to feed the jet pumps of the jetter. The control of the ROV takes place on the ship which also feeds the power to the ROV. Because of this umbilical connection, it has some independent movement capability.

The maintenance is currently conducted with a manual water jet lance which is able to do the same trick. This would however be a slower method but could be cheaper due to the lack of heavy equipment. This lance can be seen in the chapter about maintenance (page 15). Some adjustment can be made in order to make it more suitable for the placement of a new cable. For example changing the distance between the nozzles or adding pump power.

4.2.3 Mechanical trenching

Mechanical trenchers use a wheel or cutting chain to cut a trench. The cable will then fall or be guided down into the trench. They can cut through almost any kind of soil. They are mostly used in higher strength soils that prevent the use of ploughs or jets (Stuyts, et al., 2015).

Because no water is needed with the mechanical trencher it could be used on shallows where there is limited water available. An examples of trenchers especially made for this purpose is the Moonfish from Jan de Nul or the Nessie equipment from Christoffers (Christoffers, 2017) (especially designed for the German Wadden Sea). Deltares is currently conducting fundamental research regarding chain cutters (Rijksdienst voor Ondernemend Nederland, 2014). This research could prove beneficial the cable burial.

These last two trenchers (Moonfish, Nessie) are especially designed for shore approaches on shallows in sandy soil. The maximum operational water depth of these kind of trenchers is limited which makes them less suited for cutting in channels. The cutting forces needed are depth and permeability dependant. A more thorough explanation of this phenomenon is given in chapter 4.2.4.

4.2.4 Ploughing

An offshore plough resembles a plough normally used in agriculture. It is pulled through the soil (either with a ship or through winches) creating a trench. Due to the shape of the cutting area the plough is also pushed down at the same instance. A typical example of a plough can be seen in Figure 4-2.

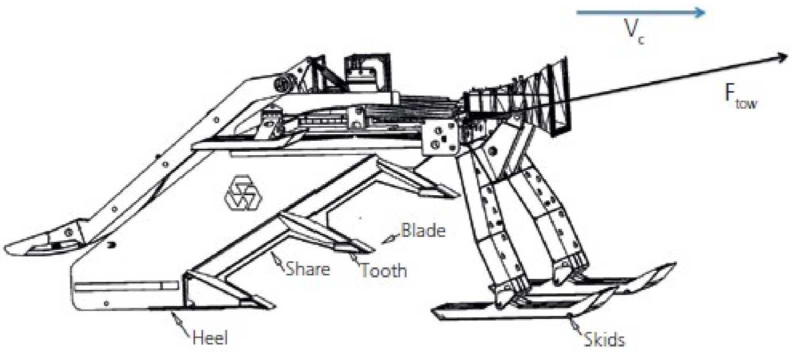

Figure 4-2: Cable Plough (IHC)

Due to the ploughing action high towing forces are needed to pull the plough through the soil since the soil will have to fail passively. This in comparison to the other trenching methods which do not rely on a pulling action to displace the soil. The pulling force also increases with depth because cavitation will occur with a higher pressure difference. Once cavitation is reached in the soil the pulling force no longer increases with increasing velocity. Cavitation will always occur in low permeable soils and in high permeable soils it will occur depending on the velocity of the plough (Miedema, 2014). Intermediate behaviour is also possible. The velocity and direction of the plough are not easy to control since the soil resistance is location and direction dependant and will influence the desired direction of the plough.

If the trench is sufficiently narrow such and will collapse on its own. The ploughing operation is called trenchless ploughing (Beindorf, et al., 2012). Because of this immediate collapse of the adjacent soil the cable is fed through the plough and laid down immediately. This is called simultaneously laying and burial or trenchless burial.

An advantage of the plough is that no water is used during operation. So it can also be used on the beach which makes the beach start-up of the cable easier. A disadvantage is that this is a brute force method which will require a large ship in order to pull the plough through the soil. In the case of cutting sand additional jets on the cutting surface can be used to lower the total needed pulling force. This principle is also used on the cutting teeth of a trailing suction hopper dredger.

4.2.5 Horizontal directional drilling (HDD)

An alternative to trenching could be horizontal directional drilling. Horizontal directional drilling seems particularly interesting because a new tap water connection to Texel was drilled instead of dredged (A. Hak Drillcon, in press). However the distance covered under the Marsdiep is approximately 4 kilometres and this is the longest HDD ever. This connection is operational and is functioning according to specifications. Drilling uses an outer tube so it is possible to upgrade a cable without drilling again ensuring easier future upgrades.

Since the route Terschelling Vlieland is at least 7 km this seems not an option with the current state technique. This could be overcome by drilling the distance in two instances by placing an artificial island in the Vlie inlet. This option is not considered because of the technical challenges and the expected costs. A partial drill of the route could be possible however, so drilling the first possibly most difficult part and dredge the other part of the cable route.

If an alternative route is chosen, drilling could be used in between Texel and Vlieland and in between Terschelling and Ameland since these routes are definitely shorter and drilling would thus be possible.

4.3 Cable options

The selection of cable will mainly involve the amount of armouring needed in order to safely operate in the Wadden Sea. The risk of failure is thus dependant on the other users of the Wadden Sea and governmental restrictions on the use of the area near the cable. Furthermore during the initial burial and maintenance the cable could be subjected to stresses and strains which could induce failure if cable strength is insufficient. The amount of fibres which should be in new cable is fixed at 96 by KPN.

4.3.1 Alternatives for cable replacement

There are two alternatives for wired data transmission. The first one is using satellite data transmissions. The second option is to use radio link data transmission. Both satellite and radio link connections are used in interlocal/international communication.

In the past some radio link masts were connecting the main land with the islands. They were abandoned because the data rate was insufficient. Besides the lack of data rate the availability due to atmospheric influences of this kind of connection is less than that of fibre optic cables. Furthermore the data rate over a cable can be more easily upgraded. Once a cable of sufficient quality is placed capacity can be upgraded easily.

Satellite data transmission is mostly used in remote parts of the world but suffers the same lack of transmission rate as with radio link transmission. So both of these will not offer enough data rate to the islands in the Wadden Sea (internal communication KPN).

Secondly a single connection to each island could be maintained and thus the cable going from Vlieland to Terschelling could be abandoned. This would mean that the redundancy in the system is reduced however it would mean a reduction in maintenance cost since only half the cables will have to be maintained. So this decision is more of policy based decision and not in the scope of this thesis. If a cable has insufficient capacity receiving and sending equipment could be upgraded to increase the capacity of one data transmission line.

4.3.2 Using other infrastructure

Capacity could be rented from other operators. However no other operator owns data infrastructure in the Wadden Sea so this is not an option. It is not expected in the near future that new data infrastructure will be placed to the islands by other companies.

Another option is to place the KPN data cable into a pipeline of another utility company (most likely a gas line). After deliberation with the other utility companies this is not an option because of their concern for an increase in pipeline failure risk. If a new pipe is placed this could be an option.

Onshore it is quite normal when an horizontal directional drilling operation takes place the diameter of the pipeline is increased such that multiple utility operator can use the same pipeline. Thus saving on cost and overhead. This could also be done with dredging but increasing the diameter of a pipeline will lead to a higher stiffness and thus burial and reburial would become more difficult. Thus allowing for a greater chance of succeeding when drilled. Furthermore cost divisions will have to clearly agreed upon.

It is not known if KPN was asked to be involved in the drilled connection to Texel. However companies owning infrastructure in the Wadden Sea have a biannual meeting and should be obliged to tell if they plan to place new infrastructure allowing for cooperation between companies. Even if cables are not placed in the same tube costs can be saved with other engineering cost made for the new utilities. These engineering cost will include pilot drills and route selection.

5 Soil

In this chapter the soil characteristics in the Wadden Sea are discussed. Some more attention is given to the soil characteristics in the Vlie Inlet because that is where the current cable is located. Soil is important since it influences how the cable can be buried. Furthermore soil also protects the cable once it is buried, so stronger soil will provide more protection when a cable is buried at equal depth.

The Wadden Sea contains three areas: tidal flats, channels and the marshes, each with slightly a different soil composition (Van Straaten, 1954). The three areas can be seen in Figure 5-1.

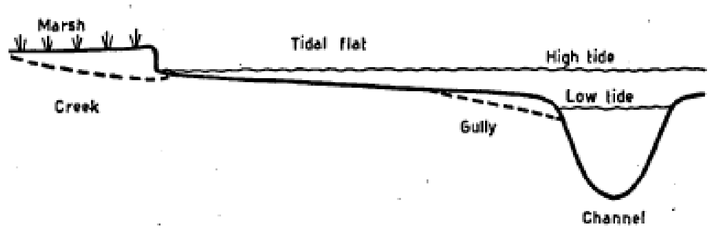

Figure 5-1: Schematic overview of the Wadden Sea

Sand makes up most of the sediment in the channels and the tidal flats. Fine sands make up most of the sediment on the marshes. Of all settling sediment in the Wadden Sea 70-80 % composes of sand. The rest of the material mainly consists of silt (Louters & Gerritsen, 1994).

According to (Van Straaten, 1954) 7 conclusions about the soil in the Wadden Sea can be drawn. These conclusions are:

1. The typical Wadden sands are of relatively fine grain size.
2. The Wadden sand contains usually a certain amount of material finer than 16 micron.
3. The sands of the Wadden Sea show a decrease in coarseness from the tidal inlets inwards.
4. The sand of the outer deltas is finer than those in the inlets.
5. The Wadden Sea sand show, in general, a decrease in coarseness from below upwards (south to north).
6. The material which has mainly been transported in suspension shows remarkably uniform distribution along the whole length of the Dutch coast.
7. The deposits of the tidal flats may show seasonal variation in lutite (clay) content.

Though most of the sands in the Wadden Sea are relatively fine, the sand in the inlets is coarser. There the tidal currents filter the fines from the coarser bottom material. This is also the reason that the amount coarseness increases near the tidal inlets and that most fines are found near the tidal divide (Louters & Gerritsen, 1994).

Besides literature also data is available from the soil in the Wadden Sea. Data is available in two ways. One is through the sedimentatlas (English: sediment catalogue). This is a research conducted by Rijkswaterstaat in the period 1989-1997 which took a large amount of samples from the Wadden Sea. The other way to obtain soil samples is through the Dino Loket. This is a database set up by TNO (Dutch research institute) which collects soil sample data taken in the Netherlands. The data from both of these databases is freely available.

Two characteristics of the soil are important: the uniformity and the grain size. In order to determine the uniformity of the soil the uniformity coefficient is used (Verruijt, 2001).

$$C_u = \frac{d_{60}}{d_{10}} \tag{5-1}$$

The grain size in this formula is characterized by the specific diameters D_{60} and D_{10}. These indices indicate that respectively 60% and 10% of the particles (by weight) have a smaller diameter than this fraction. The higher the uniformity coefficient is the less uniform a soil is. While a value of 1 means that the soil is perfectly uniformly graded, the specific diameters will then be equal. Values around 2 are still regarded as uniformly graded soil (Verruijt, 2001).

The grain size of the soil is usually defined with the d_{50} also called the median grain size. The relevance of this number is however coupled with the uniformity. The less uniform a soil is, the less relevant the median grain size is.

5.1 Soil characteristics in the Vlie inlet

To analyse the soil in the Vlie inlet first the measurements from TNO are analysed. The data points can be seen in Figure 5-2, the wider area of measurements can be found in Appendix A. On the bottom left the island of Vlieland is situated whereas on the top right the island of Terschelling is situated. The sandbank in between the two island can be clearly seen as well.

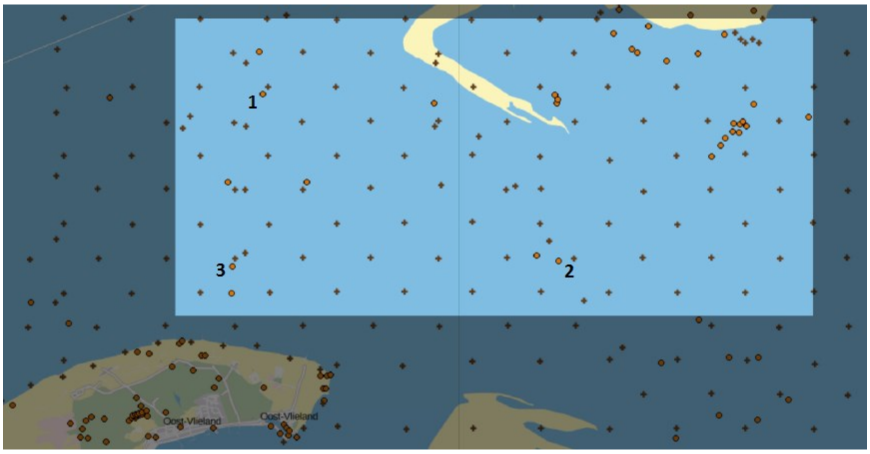

Figure 5-2: Soil Samples

The regular patterns of measurements, are measurements with a soil penetration of about 0.1m. There could be some inaccuracies in the measurement since they were taken over a period of 100 years and two different sieve setups were used. The irregular dots on the map represent measurements taken with drilling equipment. These measurements were taken on different times and with different final depths.

5.1.1 Top surface soil characteristics

First of all the measurements with a soil penetration of 0.1m are analysed. The D_{50} of all samples can be seen in Figure 5-3.

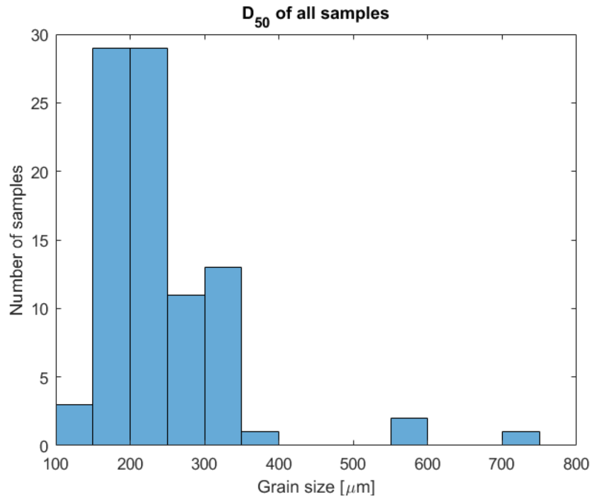

Figure 5-3: D_{50} of all soil samples

The D_{50} seems to be comparable for all soil samples. With a D_{50} mostly lying in between 150-250 micron. This data is confirmed with data taken from the sedimentatlas. Water depth dependency cannot be concluded from these samples since they were taken at different times and depth has changed considerably in this area.

The uniformity coefficients of all samples can be seen in Figure 5-4.

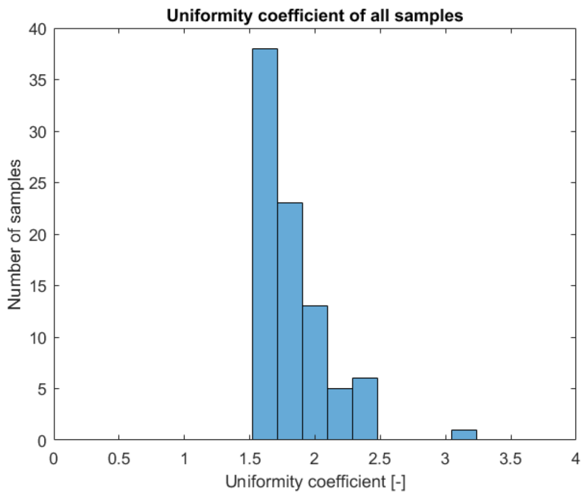

Figure 5-4: Sample uniformity coefficient

The majority of the samples have a uniformity coefficient between 1.5 and 2 which means that the specific diameters are close together and that the soil can be regarded as uniform. This means that it makes sense to compare the different samples of soil by their median grain size (D_{50}).

It is also important to look at the spatial variability of the soil characteristics since there could be some gradient in diameter over the inlet. The Variability of the D_{50} and uniformity coefficient in the entire inlet can be seen in Figure 5-5.

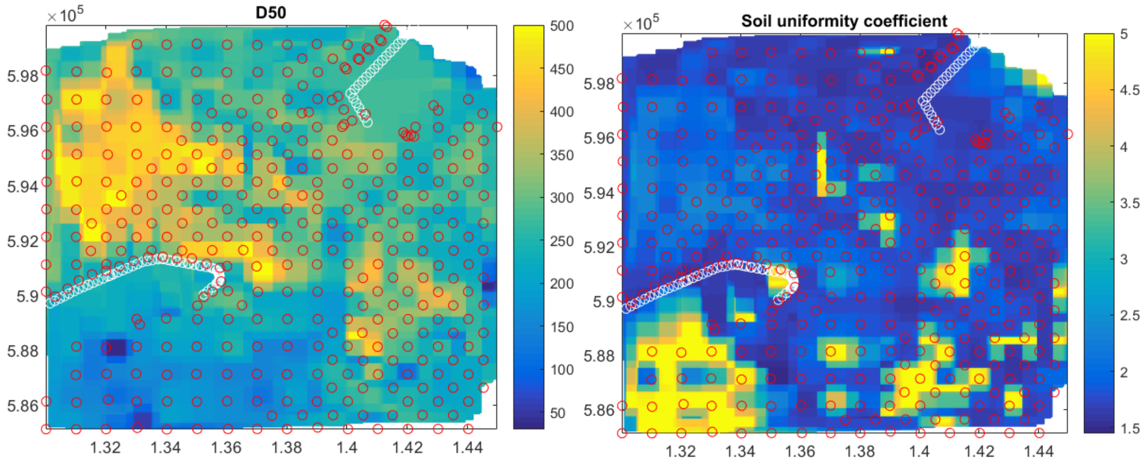

Figure 5-5: Spatial variability of the D_{50} in the Vlie inlet

The red dots in this figure display the actual measurement points. The soil is uniform over the entire inlet furthermore there seems to be little variability in the mean diameter. Further offshore the diameter is increasing and behind the island where lower current velocities are expected the diameter is decreasing. What can be concluded from this figure is that the grain size difference in between the islands is small however further offshore and to the coast the grain size seems to be changing.

5.1.2 Drilled measurement soil characteristics

Besides the soil samples taken up to a final depth of 0.1 meter some drilled measurements are analysed as well. A general conclusion that can be drawn from all measurement is that the soil consists of sand. Three drilled measurement are looked at in greater detail (marked with 1, 2, and 3 in Figure 5-2). Measurements 1 and 2 where chosen because of their location in the main tidal channel and drilling depth. Measurement 3 was chosen because of the availability of sieve data and drilling depth.

Measurement 1 started at 15m below NAP (seafloor depth) and ended 24.20m below NAP. So this measurement can give a good image of the seafloor in the deeper part of the Vlie inlet. Up to a depth of 23.80m only sandy soil was found. Below this depth at least 0.3m of clay was found. This measurement suggests that in the deeper parts of the Vlie inlet some clayey soil can be found. From literature it is expected that this is boulder clay (Haartsen & van Marrewijk, 2001).

The starting water depth of the second measurement is unclear however its total drilled depth is 12m. The soil characteristics that were obtained with these measurements are shown in Table 5-1.

Table 5-1: Drilled sample soil analysis

Lithology Layers						
Topside layer (m below seafloof)	Bottomside layer (m below seafloor)	Colour	Main soil	D50	Silt/gravel/clay	Calk
0.00	3.00	Light brown grey	Sand	170	---	Rich
3.00	7.00	Grey	Sand	220	---	Rich
7.00	12.00	Light yellow brown	Sand	210	---	None

From the table can be seen that all soil is sandy and that the grain size is in the medium/fine range. The difference in D_{50} between the layers is small however a difference in grain size distribution could still be present, these are however not available. Still the median grain sizes found with this drilled measurement are comparable with the large scale measurements.

The starting water depth of the third measurement is unclear, however the total drilled depth is 3.65m. Four different sieve curves were obtained from these measurement, each at a different depth. So this measurement provides some insight about the differences in soil characteristics with water depth. The sieve curves for the different water depth are plotted in Figure 5-6.

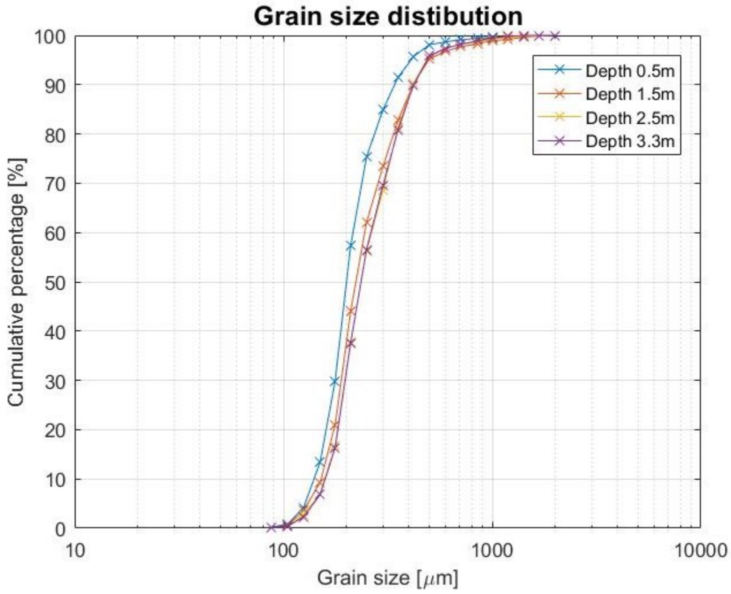

Figure 5-6: Grain size distribution

All samples are composed of sand. The sand is mostly medium grain sized with a D_{50} around 200 micron. There is little depth dependency only the sample which was taken at a water depth of 0.5m seems to be a negligibly finer. Judging from the steep slope of the graph the sand is uniform with most of the grainsizes between 150 and 250 micron as was expected from the large scale measurements.

5.2 Soil characteristics in other parts of the Wadden Sea

In case another route is selected knowledge of the soil in the rest of the Wadden Sea could also be relevant. From literature (Van Straaten, 1954) it is expected that this sand will be less uniform and that the grain size will decrease. The median grain size distribution along with the coastlines of Texel, Vlieland and Terschelling can be found in Figure 5-7.

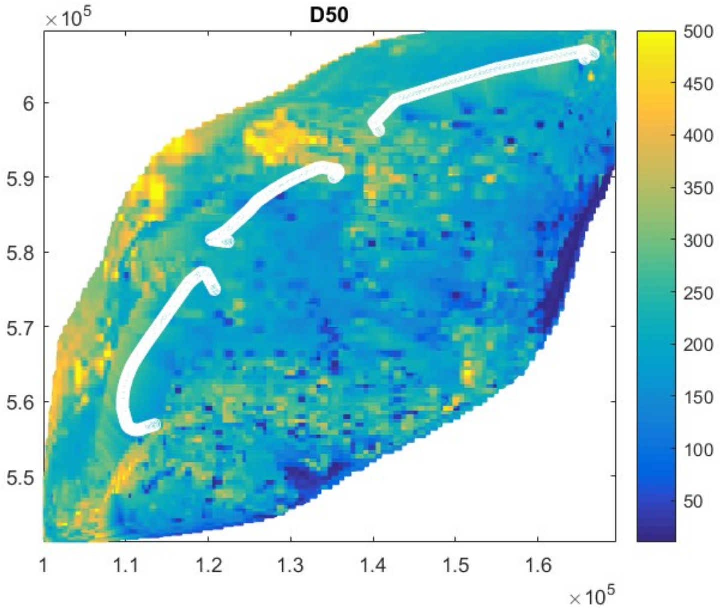

Figure 5-7: Median grain size in the Western Wadden Sea

The grain sizes are clearly decreasing going from inlet to shore. So the coarseness is increasing going from shore to inlets. The main channels going to the inlets also seem to be composed of more coarse particles however due to the resolution of the grid this is hard to see. The soil in the Texel and Vlie basin is coarser than the particles in the Eierlandse Gat inlet. So the expected result from literature is confirmed with the data. The uniformity coefficient from all actual samples is plotted in Figure 5-8.

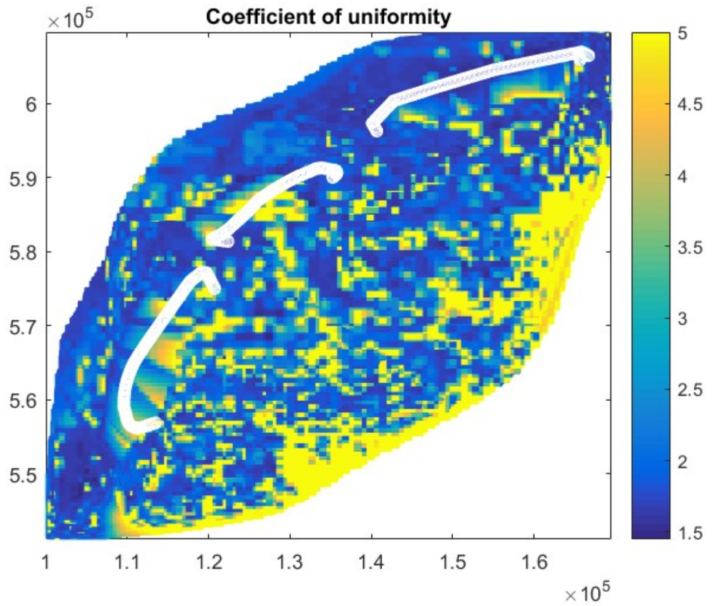

Figure 5-8: Uniformity coefficient in the Western Wadden Sea

As expected the grain uniformity is decreasing further away from the inlets. The uniformity coefficient seems to be decreasing quickly when leaving the coast, so quite near to the coast the soil is already quite uniform. The measurement density near shore is less so the areas depicted in the figure are therefore exaggerated. The soil in all inlets is uniform. Again the expected result from literature is confirmed with the data.

A few deeper soil measurements are available as well. They seem less interesting since sedimentation in the dominant process in this region and the total water depth is way less than in the Vlie inlet. So when placing the cable in this region, the shallow soil samples could be used to describe the soil in the deeper parts as well.

6 Morphodynamics

In order to determine what the optimal route for a cable is, it is important to look at morphodynamics of that area. This chapter looks at all sea and land areas where a cable could be routed. Some literature is available on the morphodynamics of the Vlie inlet, the other inlets in the Wadden Sea and the Wadden Sea in general.

Furthermore Rijkswaterstaat conducts yearly cross-shore single beam measurements from the beach at certain points of the coast. These are called Jarkus (English: yearly coast) raaien and have been conducted since 1965. A measurement is taken every 5 meters and is onshore supplemented with radar measurements. Besides these Jarkus raaien every 6 years since 1926 the entire depth profile of the Wadden Sea is measured single beam. These measurements are called the vaklodingen, the latest vakloding for which the data is available was in 2010. For coastal maintenance reasons the outer delta is measured together with the vakloding but also in between each vakloding, so once every three years.

The x and y measurements in the vaklodingen are measured using Rijksdriehoekscoördinaten (Dutch triangular coordinates). This system couples each point in the Netherlands with a tower in Amersfoort which itself has the coordinates (x=155,000 m and y=463,000 m) giving each place in the European Netherlands a positive coordinate. Newer measurements are taken using GPS however for reasons of simplicity they are also converted to Rijksdriehoekscoördinaten.

In order to get a good view of the morphodynamics of an inlet it is important that data from a long term equilibrium period is available. This equilibrium does not necessarily mean that no changes can take place; it means that the boundary conditions remain unchanged. Dredging for example could influence the morphodynamics of an inlet which is clearly an incidental change in the depth profile of a channel.

6.1 General Morphodynamics

The general morphodynamics of three inlets and the general morphodynamics of an inlet have been studied. The Vlie inlet is the location of the current cable. The other inlets (Eierlandse Gat and Ameland inlet) are studied because they could pose an alternative route for the current connection.

Inlets connect the Wadden Sea with the North Sea in between those inlets is a string of barrier islands. In these inlets water and sediment travels with the tides. The natural behaviour of these islands is to move to the east this movement is prevented by coastal management. The tidal wave travels around those islands and meet each other on the tidal divide or tidal watershed (Dutch: Wantij). The tidal velocities around the tidal divide are zero. The physical processes and an idealized picture of an inlet can be seen in Figure 6-1

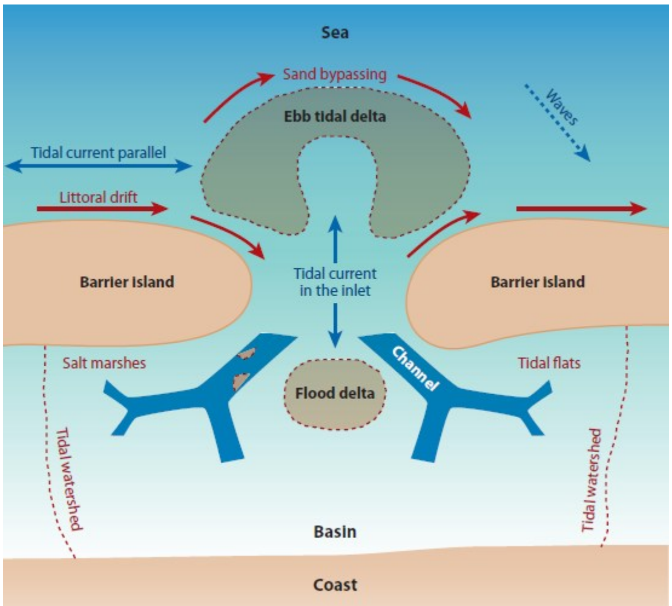

Figure 6-1: Sketch of an idealized tidal inlet system (de Swart & Zimmerman, 2009)

The tidal divide can change position if major changes in the basin or inflow take place. For example the tidal divides in the western part of the Wadden Sea is still adjusting to the Afsluitdijk.

Two types of tidal divides exist (Vroom, 2011): hydraulic tidal divide and the morphological tidal divide. The hydraulic tidal divide is the line splitting the basins of two inlets. The morphological tidal divide is the location of the highest bed levels. In an equilibrium situation both are located on the same line. If something changes the hydraulic tidal divide is quicker to adapt because no sediment will have to settle in order for the hydraulic tidal divide to change. Both tidal divides are influencing each other as well; a higher bed level will influence the flow around it. Currently all tidal divides are increasing in height and show a slight tendency to move to the east. This eastward shift is most likely caused by the preferred eastward movement of the islands (Vroom, 2011). The morphological tidal divides and their position over time can be seen in Figure 6-2.

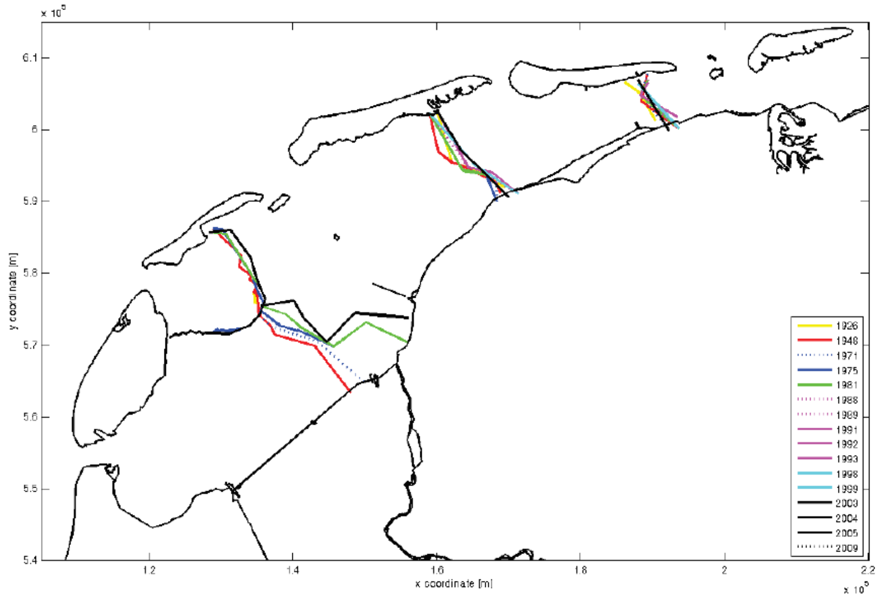

Figure 6-2: Position of the morphological tidal divide over time (Vroom, 2011)

A tidal divide of two inlets doesn't necessarily run all the way to the coast. The inlets of Texel and Vlieland share a divide because the tidal divide of the Eierlandse gat forms an arc around its inlet. This way the Vlie and the Marsdiep share a tidal divide. The Tidal watershed going to Vlieland from shore starts in a north-western direction (starting near Harlingen) on the divide between the Vlie and Marsdiep before reaching the tidal divide of the Eierlandse gat inlet and continuing on a more northerner course. Eventually reaching Vlieland.

On the seaward side of the inlet there is an outer delta. This is in general a shallow region; even parts above mean sea level can exist. The ebb flow behaves as a jet and pushes sediment out to sea. Because of this behaviour the outer delta is folded around the main ebb current. In the inlet the ebb flow is thus dominant over the flood current.

The flood current enters the channel from every direction (radial) (de Swart & Zimmerman, 2009). The floods current is usually strongest at the margin of the outer delta. The flood flow also carries sediment. In the Wadden sea the sediment balance is positive (net deposition on the shoals). The soil going into the Wadden Sea mainly comes from the outer delta. It is expected that this deposition of soil can keep up with the sea level rise. The total amount transported is greater than this deposition (Elias, et al., 2012). So some soil is transported back and forth during tidal cycles.

The outer delta is exposed to wind and tidal wave energy. Here small scale bars are observed that migrate from the inlet to the coast and get attached to the island (Elias & Bruens, 2012). These bars can clearly be observed in the cross-shore measurements.

Each inlet has its own tidal prism. The tidal prism is the amount of water that is exchanged through an inlet during one tidal period. In Table 6-1 the tidal prism of each inlet can be seen.

Table 6-1: Tidal prism from west to east of each Wadden Sea inlet (Louters & Gerritsen, 1994)

Tidal Basins	Average Tidal Prism (10^6 m^3)	Surface area at MHW (km^2)	Surface area tidal flats at MLW (km^2)
A. Texel Inlet	1054	712	121
B. Eierlandse Gat Inlet	207	153	106
C. Vlie Inlet	1078	668	323
D. Ameland Inlet	478	309	165
E. Frisian Inlet	300	195	124
F. Eems-Dollard Inlet	1000	520	214

This table shows that the volume exchange to the Vlie inlet is way higher than through the other inlets at the coasts of Terschelling and Vlieland. Together with the Texel inlet they form the main inlet channels in the western Wadden Sea. The tidal prisms in the western part of the Wadden Sea have increased significantly due to the increased difference between ebb and flood levels since the closure of the Zuiderzee. This also led to adaptations of the inlet channels (Elias, et al., 2012).

6.1.1 Morphodynamics of the Vlie inlet

The morphodynamics of the Vlie inlet since the 1930’s have been dominated by the closure of the Zuiderzee. The construction of the Afsluitdijk resulted in an increase of tidal volume and tidal range (Elias, et al., 2012). Due to this closure the orientation of the Vliestroom changed and a major redistribution of sand in the outer delta took place (Elias & Bruens, 2012). Furthermore the tidal divide between the Vlie inlet and the Texel inlet has shifted to the east with a position now close to Harlingen (Wang, et al., 2012).

Since the closures of the Zuiderzee a large amount of sediments have been carried to the tidal shoals most of it by the Texel and Vlie inlet. Some of this sediment is carried by the Marsdiep and deposits in the Vlie basin. This interaction influences the sediment transport in the Vlie because the Texel inlet is not in equilibrium and could therefore influence the Vlie (Elias & Bruens, 2012).

However the recent dynamics of the Vlie seem to have reached a new equilibrium (Elias & Bruens, 2012) (Terwisscha van Scheltinga, 2012). Because of not being in equilibrium in the past it is difficult to interpret historical data since the most important changes of the Vlie inlet were caused by this major effect and not by natural inlet behaviour. Since the vaklodingen are taken once every six years only the most recent data will have significant relevance.

This equilibrium does not mean that no more changes occur; it is possible that the tidal system will enter a cyclic dynamic state as other inlets in the Wadden Sea with constant formation of new sand banks which will walk to the island shore (Sha, 1990).

Dynamic behaviour is noted in the channel directly along the island head of Terschelling connecting the Schuitengat and the Boomkensdiep. One of two options will occur. The first option is that the channel around the island head will deepen, in this case the channel in the outer bend will fill up with sediment. (Elias, et al., 2015)

Another option for this channel is that a new connection will occur between the Boomkensdiep and the Vlie (This connection existed in the past) which in turn will lead to deposition along Terschelling. Both processes are taking place and can be seen by the large deposition and erosion rates in Figure 6-3 and by the channel profiles in Figure 2-2.

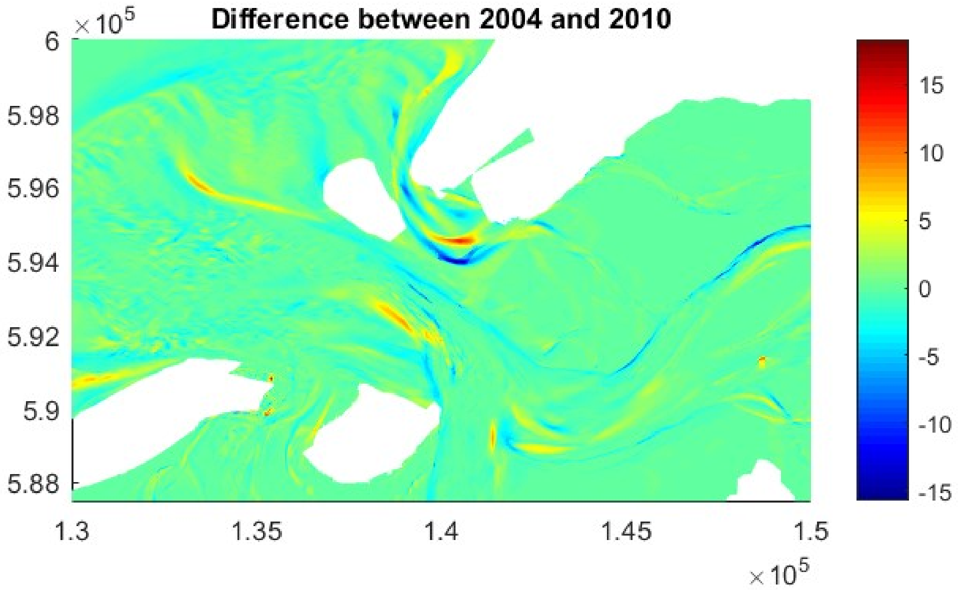

Figure 6-3: Depth difference between 2004 and 2010.

It is unclear which scenario will unfold however large deposition and erosion rates in the centre part of the island as well as near the beaches will be case in either one of them.

Besides this major change there is a small ongoing movement between 5 and 10 meters per year of the Vliestroom in the direction of Terschelling (Terwisscha van Scheltinga, 2012). Because of the steep channel profile a small movement of this main channel can lead to large increase in depth. An decrease or increase of 15m in these channel sections is no exception. This means that cable surfacing in this area is inevitable and that it is wise to avoid the steepest/deepest section of the Vlie.

The sandbank Engelschhoek located between the Boomkensdiep and the Vlie main channel shows a shallowing trend. Because the data about the Engelschhoek is absent in the 2010 vakloding, the data from the outer delta in the years 2007 and 2012 was used. Here a clear shallowing trend can been observed. The Boomkensdiep also shows some movement however this movement is small compared to the movement near the island head of Terschelling and with less depth change since the channel itself is shallower.

The outer delta is in an erosive state however the southern part near the islands has stable behaviour. It is not expected that in the future this behaviour will change (Elias & Bruens, 2012). This region seems well suited for the placement of a buried cable; looking at Figure 6-3 the shore approach at the side of Terschelling could pose a challenge.

6.1.2 Morphodynamics of the Eierlandse Gat

The Eierlandse gat is the inlet between the islands of the Texel and Vlieland. Since this is an inlet in the western part of the Wadden Sea the inlet development cannot be seen apart from the closure of the Zuiderzee. Coastal management also influenced this inlet because of the construction of coast protection and the Eierlandse dam. So on this inlet as well it is hard to draw conclusions about the morphodynamics because of the lack of data and the absence of an equilibrium situation. The major change that took place in this inlet was the formation of two main channels instead of one (Elias & Bruens, 2012). This change itself caused major depth changes over the years.

In order to quantify the difference over the years in this inlet a difference map is created to look at the actual change of depth in the inlet. De depth differential map can be seen in Figure 6-4.

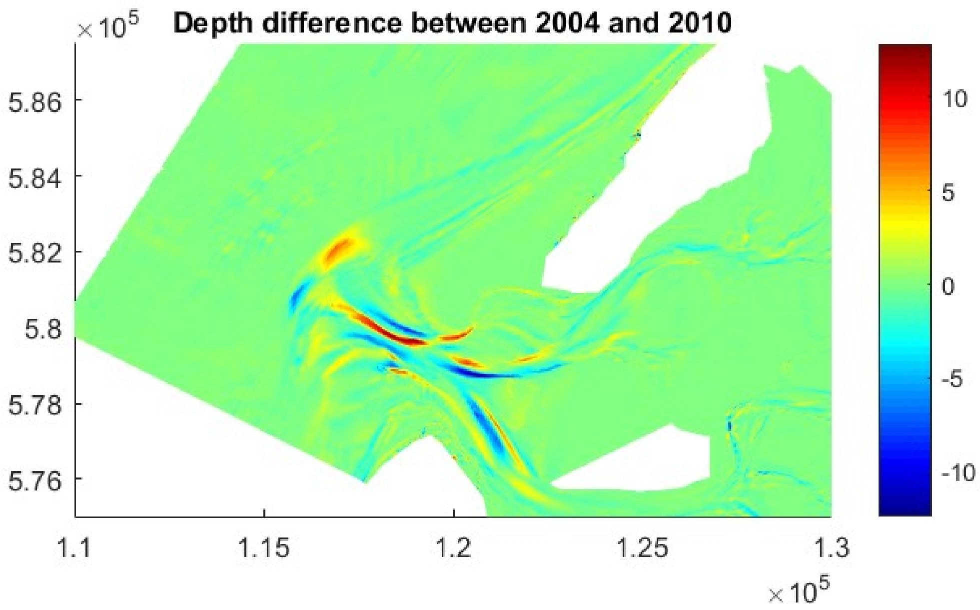

Figure 6-4: Depth difference map of the Eierlandse Gat

What can be seen from this map is that there are not only significant depth changes in the central part of the inlet but in the outer delta as well. Because the depth of this channel is less than the Vlie inlet the depth changes are smaller. Because of this behaviour the burial of a cable will need to be at a significant depth in order to prevent surfacing.

6.1.3 Morphodynamics of the Ameland Inlet

The Ameland inlet is the inlet between the islands of Terschelling and Ameland. It is the fourth inlet from the west in the Wadden Sea. Because of its location to the east the influence of the Afsluitdijk was far less and long term morphological behaviour is known. This inlet is assumed to be in a cyclic state with a period of 50-60 years (Israel & Dunsbergen, 1999). This cyclic behaviour is shown in Figure 6-5.

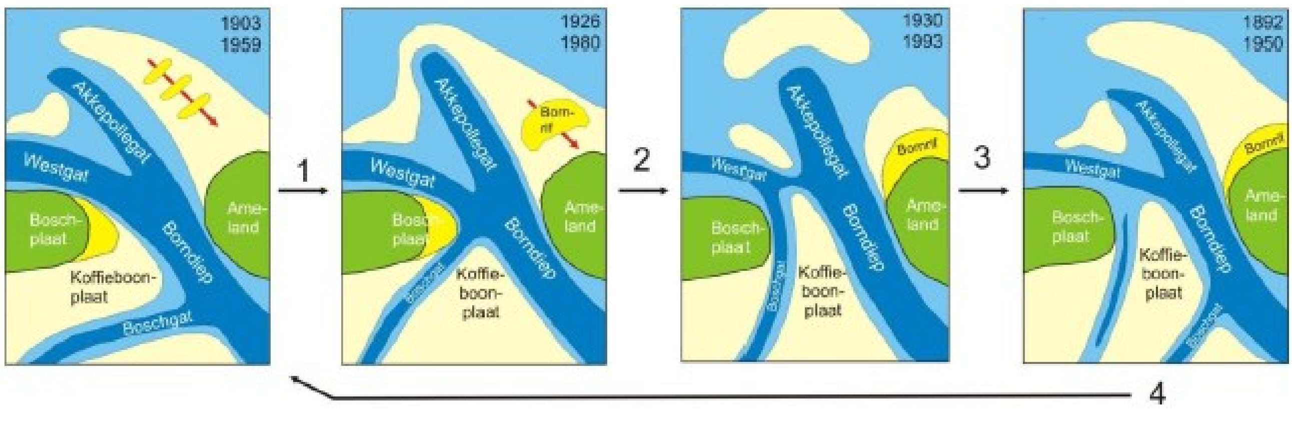

Figure 6-5: Cyclic development of the Ameland inlet (Israel & Dunsbergen, 1999)

The state of the cycle decides where erosion and deposition will take place. Looking at the data the inlet is currently transforming from a two waterway system to a one waterway system, so in between stage three and four. This would mean that in the near future deposition would take place at the coast of Terschelling. The coast of Ameland is reinforced with a stone dam and groin system so no major erosion is expected at the head of this island.

The erosion is limited by the maximum depth of the inlet. Since this depth is less than that of the Vlie the erosion depth will be less. Erosion depths of up to 15 meters could be expected however.

6.1.4 Morphodynamics of the island shore connections

The Morphodynamics of the area between the shore and the two islands is important because of the possible alternatives running through the inner delta of the Wadden Sea. The basin from Terschelling to the coast is nicely divided by the tidal divide of the Vlie and the Ameland inlet. With its position being slightly to the east of the island. The basin behind Vlieland is totally different since it is a shared basin with the three western most inlets.

The inner delta behind Terschelling according to the latest depth profile can be seen in Figure 6-6.

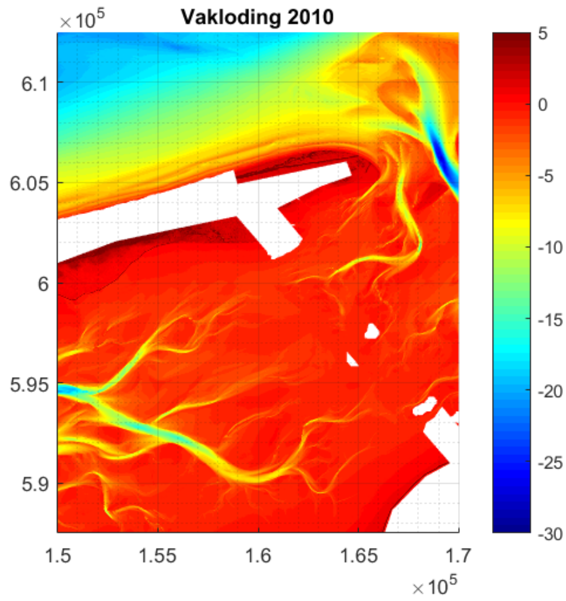

Figure 6-6: Depth profile of the Terschelling inner delta

The tidal watershed can be clearly seen in this figure. This tidal divide is close to the shortest route to the island as well. It is a relatively stable tidal divide with a shallowing trend and with little tendency to move to the east (Vroom, 2011). Since it is both the shortest route and the most ideal location to place a cable it is not necessary to further look into other possible routes to Terschelling.

The inner delta behind Vlieland can be seen in Figure 6-7. To the left is Texel, with to the right of it the Eierlandse Gat. The Vlie and Marsdiep inlets can be clearly seen as well. At the left top corner a small part of Vlieland can be seen.

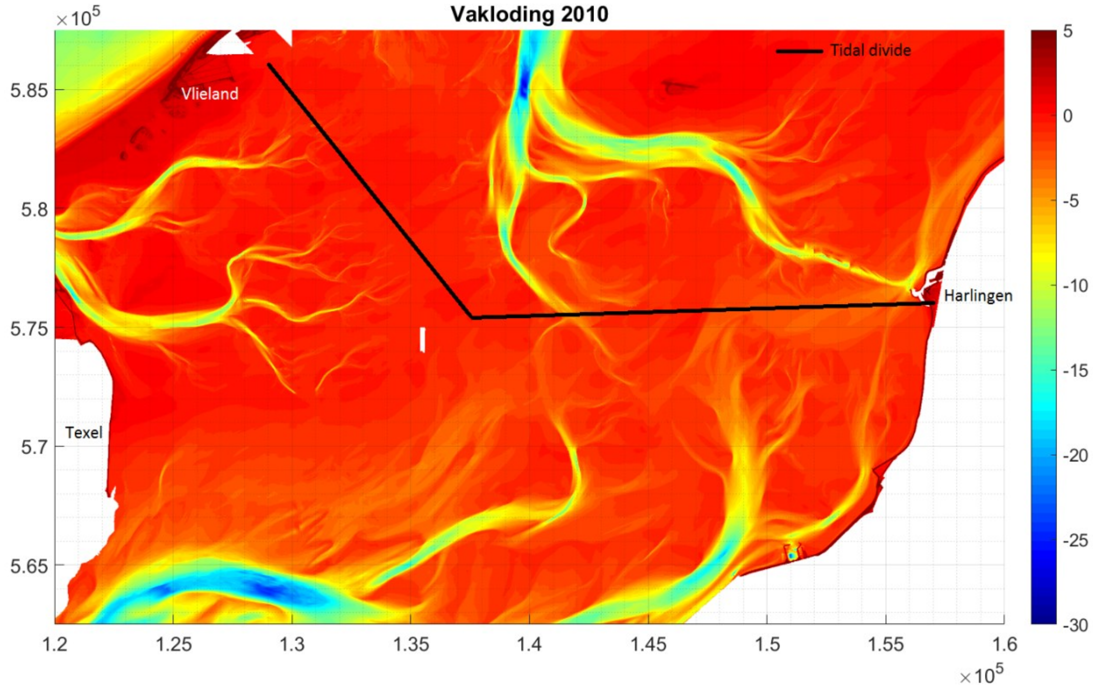

Figure 6-7: The inner delta of Vlieland

Because of the split tidal divide between the three inlets there is not one tidal divide going from the island to shore. The tidal divide to Vlieland first follows the divide between the Vlie and the Marsdiep (north western direction) before continuing on the watershed between the Vlie and the Eierlandse Gat (north). This also means that a shorter route is possible, this route would then not be on the tidal divide (This route however crosses some major dredged channels). Another fact which is quite beneficial is that the channels located near the tidal watershed are shallow (<7m) which would make their possible movement less problematic.

The Harlingen harbour channel is clearly visible because of its straightness. This channel is on the tidal divide (definitely not the natural place for a channel) however it is maintained by dredging operations (up to 1.4 million cubic meters a year).

6.1.5 Conclusion Morphodynamics

Net deposition takes place on the shoals in the Wadden Sea. So all cable routes on or near the tidal divide would not require any maintenance (if buried at the legal depth of 1 meter). There is still movement in the tidal divides in the western part of the Wadden Sea, so some difficulties can be expected. Minimal burial would only be sufficient on the three eastern most islands in the Wadden Sea.

Due to ongoing movement in the central part of the Vlie channel, with erosion rates in the order of meters per year cable burial in this area would be impractical. The departure from Ameland does not seem to be too difficult. On the Terschelling side of the inlet major changes are taking place and the main dredged maintained entry channel to the harbour of west-Terschelling harbour along with some other economic activities is situated there. The dredged depth of the channel is constant however cable upheaval here will lead to immediate failure. The only option here would be to choose a more northern approach. If the processes at the island head of Terschelling play become clear the central route could become an option as well.

The alternative routes through the inlets of the other sides of the island are also dynamic with movements in the order of meters per year. So do not seem a good alternative for the route to through the Vlie (2 new cables will inevitably be more expensive). The Eierlandse gat is sufficiently narrow to allow horizontal directional drilling however the western part of Vlieland is a military practice ground which would pose a major thread to the cable and would make burying difficult because of remaining explosives and acquiring a permit could be difficult as well.

6.2 Jarkus Raaien

The Jarkus depth profiles do not encircle the whole island. These measurements are only conducted where the base coast line (Dutch: basiskustlijn) is defined. This is mainly on the coastal part of the islands. Because the behaviour of the Vlie inlet is important only the measurements in the inlet are selected. The studied measurements can be seen in Figure 6-8.

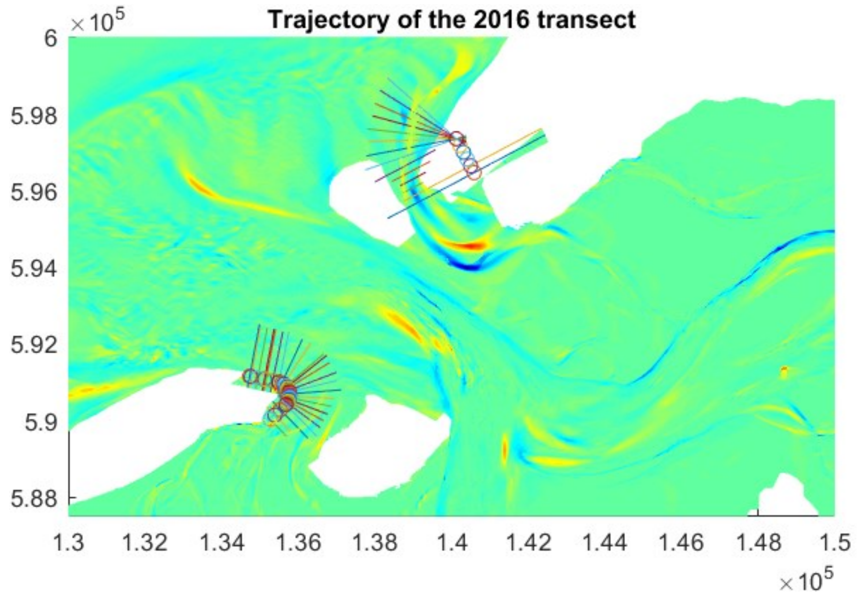

Figure 6-8: Transects on Vlieland and Terschelling

The measurements from the coast of Vlieland cover the entire head of the island, the measurements from Terschelling only cover the Northern part of the island head. The cross-shore distance of the measurement differs but can go up to two kilometres into the sea. The circle near the start of the transect show the beach pole. This is the starting point of the cross-shore distance. Because the Jarkus Raaien are two-dimensional measurements drawing conclusions from one cross-shore measurement is difficult since the processes in the Wadden Sea are clearly three-dimensional. However if multiple adjacent cross-shore measurement show similar behaviour; similar behaviour in the area between the transects can be assumed.

To get an idea of the behaviour of the channel the following parameter/graphs are studied: the maximum depth, the location of the maximum depth, the difference in depth over the last five years and the entire profile. The evolution of these parameters of the first transect can be seen in Figure 6-9.

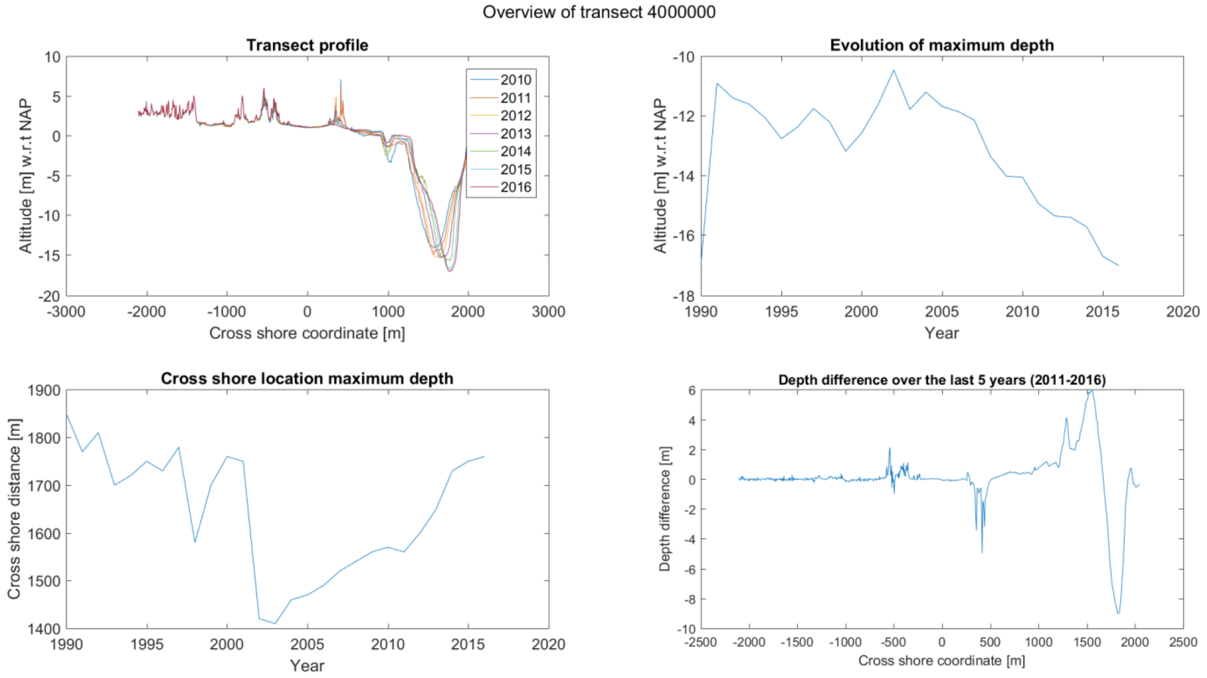

Figure 6-9: Transect 4000000 profile

The transect shown is the first transect on the west side of Terschelling. On the x-axis either time or cross-shore coordinates are shown. On the y-axis depth differences, depths or cross-shore coordinates are shown. The following can be observed from the graphs of the transect. The deepest point of the transect is deepening and moving further offshore. Because of the far inland placement of the beach pole the first section of this transect actually displays the shore of Terschelling in which little height differences occur over the years. In the offshore part depth differences of up to 6 meters in the last five years are seen. The Jarkus figures of the studied transects can be found in 0 and 0.

6.2.1 Jarkus Raaien Terschelling

The first ten raaien (transects) at the coast of Terschelling are interesting since they can give an idea about the development of the Boomkensdiep. The channel starts narrow and ends up widening further to the north. A smaller channel with lead to greater depth differences over shorter length because of the higher gradient. The depth behaviour is location dependant and highly dynamic. Because of deposition on the island head the base coast line is far inshore resulting in measurements which only run a bit into the inlet. The general behaviour of each transect is given in Table 6-2.

Table 6-2: Behaviour of Vlieland transects

Transect	**Behaviour**
4000000,4000020	Deepening and offshore movement (beach widening).
4000040	Shallowing and widening
4000060,4000080	Constant depth for the last 10 years, some widening. Significant beach erosion.
4000100,400101	Shallowing and widening
4000102	Shallowing and widening, offshore highly dynamic
4000103	Shallowing and widening
4000104,4000105,4000106,4000107	Shallowing movement of channel to shore
4000108	No trend

All the transects show deepening and shallowing behaviour in some part of the transect. Which makes it more difficult to place a cable there. However once a cable is placed an estimate can be made over where maintenance is needed. Actual prediction of the depth changes over time are impossible since there is lack of equilibrium data. The information from these transects further show that major changes in the Boomkensdiep are taking place. Thus making sufficient cable burial difficult.

6.2.2 Jarkus Raaien Vlieland

The Jarkus Raaien (between 5005212 – 5005267 and between 5005360 – 500371) from the coast of Vlieland shows no low frequency dynamic behaviour only some high frequency dynamic behaviour in the deeper sections. All Jarkus raaien show clear equilibrium behaviour since 1990. An example of one of these transects can be seen in Figure 6-10.

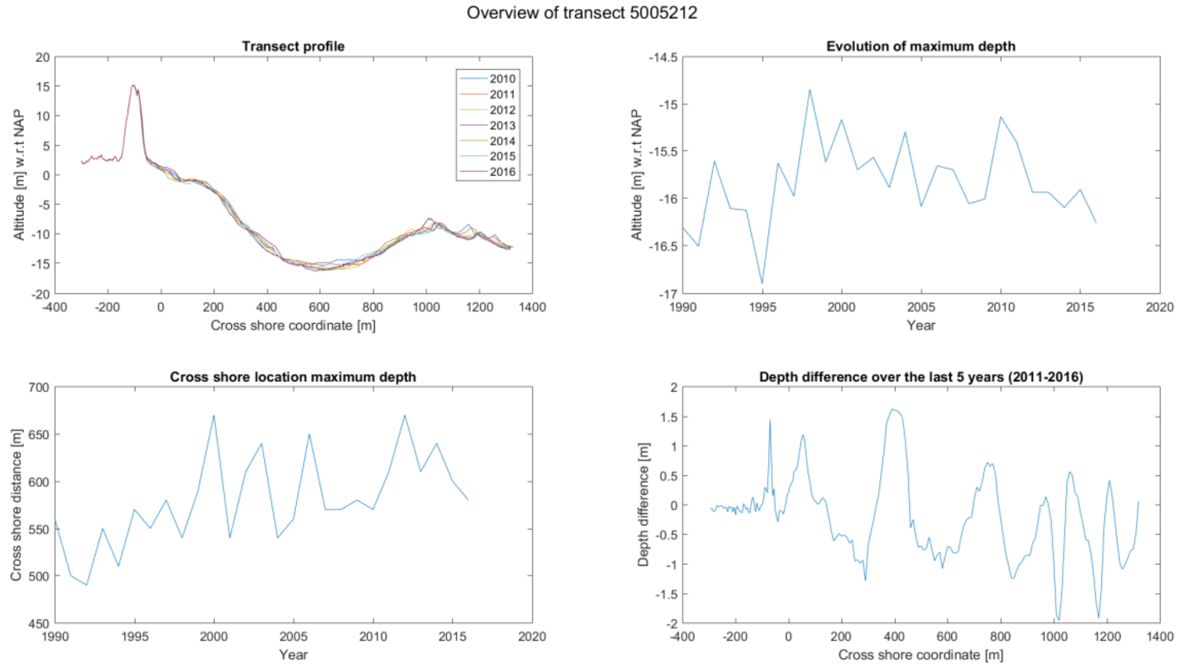

Figure 6-10: Typical Vlieland Jarkus transect

Another thing that can be seen from these transects is the gradual slope of the depth profile which is beneficial for the placement of a cable. There are some depth differences over time with a magnitude of about 1 meter. However looking at the bottom right figure these differences again seems to show some periodic behaviour around an equilibrium. This behaviour and the shape of the profile in the deeper parts of the transects (top left figure) make it likely that this behaviour is caused by sand waves.

The first group of stable transects is located on the north eastern tip of Vlieland and the second group is located on the eastern tip of Vlieland. The location of these transects is shown in Figure 6-11.

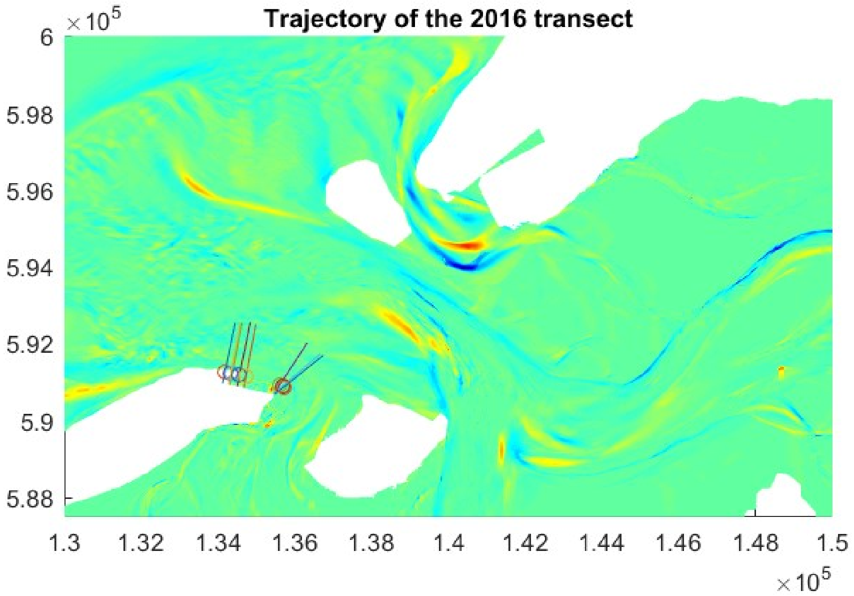

Figure 6-11: Vlieland transects

Notice the gap in between the measurements. The measurements also show equilibrium behaviour. However the deviations here are larger which makes them less suitable. Also some of the raaien have insufficient data to draw conclusions about their behaviour. The cable could be placed on the other locations as well but this would result in deeper burial. The economics of these decisions will be calculated later.

7 Selection

In this chapter the final route, cable, burial depth and burial method selection is made. After all selections have been made the cost of the new cable can be estimated in order to be able to make the final decision regarding the new route of the cable.

7.1 Route

7.1.1 Route Vlieland Terschelling

The input for this chapter mostly comes from the morphology of the Vlie channel. The best route of the cable connecting Vlieland and Terschelling can be seen Figure 7-1. The bend will occur at (138360,596186) after approximately 1.2 km from the Terschelling beach pole and 5.9 km from the Vlieland beach pole. So the total length will be not adjusted for depth profile about 7.1 km.

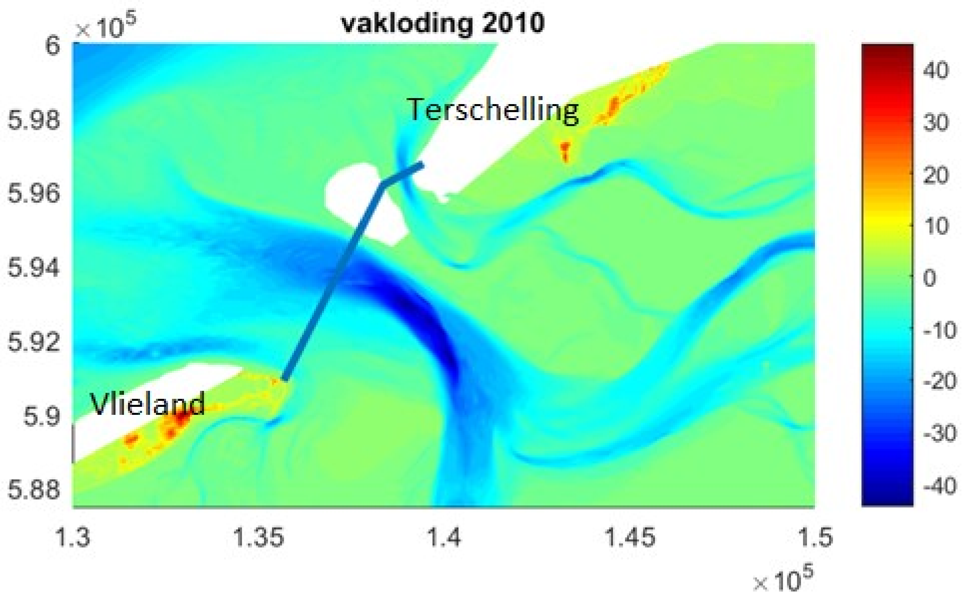

Figure 7-1: Cable route through the Vlie

The shore departure at the side of Vlieland is at one of the stable transects namely at transect 5005367. Another transect could have been chosen however the distance to this beach pole of this transect is shorter and it is closer to the current cable which could make the onshore works easier. It runs through the relatively stable part up until the sandbank called the Engelschhoek. The cable will here cross the Boomkensdiep. A crossing further south-east would have resulted in more maintenance because of the lower morphologic stability in this part of the Wadden Sea.

Another advantage of this route is that only two main channels will be crossed, resulting in less area where erosion can take place; because erosion usually takes place on the edges of channels. The depth profile of the cable can be seen in Figure 7-2. The dynamic areas can be seen from the vaklodingen data. As expected the Terschelling side will be the most dynamic part. Because the depth is scaled differently than the distance, the depth differences are exaggerated.

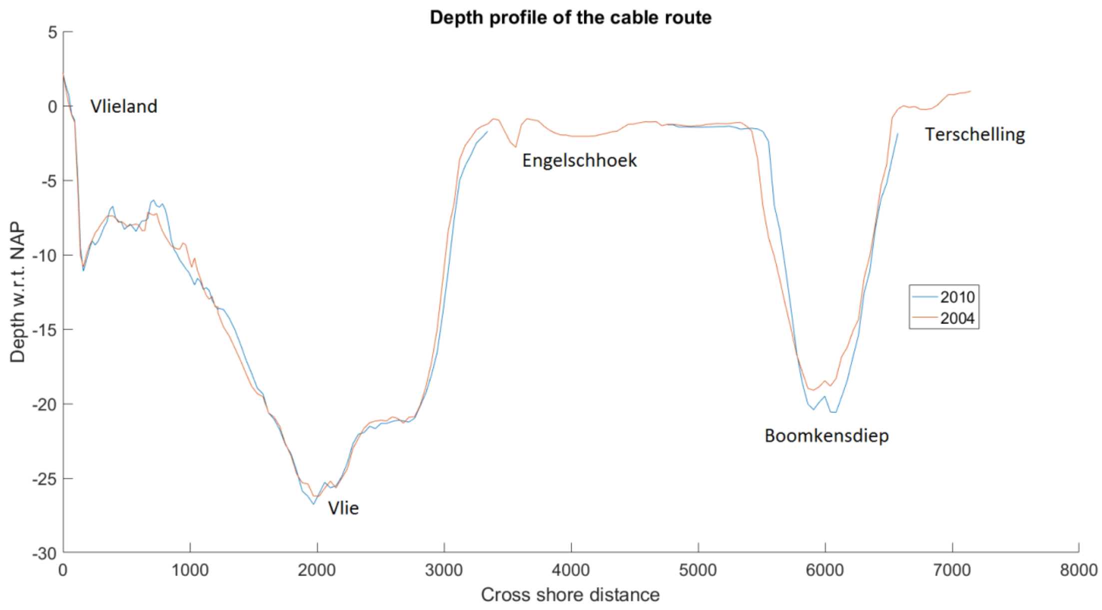

Figure 7-2: Cable depth profile

The deepening of the Boomkensdiep which can be seen in this figure is no longer present in the Boomkensdiep at the location of the crossing so this is not considered a threat. The beach landing at the Vlieland side will be at the beach pole of the 4000080 transect which is a stable transect.

At the edges of the Engelschhoek and on the beach some extra slack must be allowed in the cable since maintenance can be expected in these areas. This will prevent some of the cable shortage during maintenance. The route cannot be so straight as can be seen on the map. During the burial of a cable slight changes in depth are possible so the cable should have some extra length as well. The total length of the route from beach pole to beach pole is 7150 meters. This includes the meters made to follow the depth contours of the trajectory. Burial depth does not influence this too much, since it will still follow the contours of the bottom.

7.1.2 Tidal Divide route

Because this route encompasses two new cables, two separate routes will have to be selected. An important notion is that enough distance (~100m) between the new and the old cable will have to be maintained in order to ensure redundancy. The Terschelling route is easiest since there is ample space on the eastern side of the current cable. This is exactly the place where currently the tidal divide is located so no difficulties are expected in terms of location for this route.

The Vlieland route is more difficult because starting at the east of the current location is difficult. This would mean crossing the main dredged channel leaving Harlingen. This is however the place best suited for the burial of the cable since the tidal divide is located to the eastern side of the current cable. This means that this route should only be used if significant cost advantages are present since crossing a main channel will be an increase in damage risk and preferably avoided. Burying on the west side of the main channel is not an option since redundancy cannot be guaranteed or massive amount of maintenance will be needed.

7.2 Cable selection

For the cable selection it is important to know what the risks are when the cable surfaces. Furthermore the stresses which are expected during the burial of the cable are important. The stresses introduced by the water jet burial or mechanical trenching are low. This means that no double armour is needed during the burial of the cable. Single armouring would be needed however since some stresses and strains both during lay and handling can be expected.

The chance of something hitting the cable when surfaced is low. The current Vlieland Terschelling cable was not buried and was never damaged. No failure occurred at all other cables due to external influences as well. One reason for this is the anchor and fishing ban near the cables. The major risk for shallow water deep sea cables is fishing equipment of large trawlers (internal communication with KPN International). The risk of these ships fishing near the cable is negligible. Since these large vessels are not allowed to fish in the entire Wadden Sea the risk of them entangling a cable is negligible. Dredging and other maintenance works are not performed in the area of the chosen route.

The risk of damage to the cable when surfaced is little, so a single armoured cable will be sufficient. This is also cost efficient since a single armoured cable is at least half as expensive than a double armoured cable. The cable should be one piece, since welds in a cable will increase optic dampening. In 0 an example of a 96 fibre single armoured shallow sea cable can be found. All other properties of the cable can be found in this appendix.

7.3 Burial method

Drilling is not considered an alternative on the approach of Terschelling because seepage of drilling fluid will be inevitable. This seepage is not allowed because of the environmental situation in the Wadden Sea.

Only two types of trenching in deeper parts are possible with the soil characteristics and cable specifications. Mass flow excavation is possible however it would require the displacement of a lot of soil with is not necessary for such a small cable in combination with the short radius of curvature of the cable. Mechanical trenching is also not needed for the low strength soil in the Wadden Sea. However because no water is needed for this kind of trenching, it is most certainly an option on the shallows.

Ploughing of cables requires high forces which will result in the use of a large vessel (typical vessel used in the North Sea: Ndurance of Boskalis). The larger the vessel the higher the cost will be plus most likely an increase in draft. A large vessel is not needed for the carriage capacity of the fibre optic cable since these cables are lightweight compared to normally trenched power cables and the distances in which they will be used are short (typical weight ~1 kg/m for single armoured cable, internal communication KPN). So ploughing is also not an ideal solution. Furthermore the steering of a cable plough is more difficult than with the other trenching methods.

A jet trencher vessel requires a crane which can lower the ROV (Remote Operated Vehicle) overboard and some additional containers in which additional power and control units can be stored. So a cheaper and smaller vessel (with possible a lower draft) or even a cable pontoon can be used when using a jet trencher. Another advantage is the ability to better control the routing of the cable. The shore approach could be more difficult in terms of water availability. Some of this can probably be solved by using a hose. If the ROV option would still be too expensive, the method currently used for maintenance could be used as well. It is clear this method will work and the vessel employing the jetting lance has a small draft ideal for using it on shallow locations. The fact that smaller equipment can be used is critical for the selection of burial method since large shallows can be expected on the route connecting the two islands and the island shore connection is one shallow. So burial of the cable by jetting seems best, however either an ROV or the manual method can be used.

On large tidal flats where water availability could be an issue a mechanical trenching method should be used. This method does not need any water but most of the equipment specialised in this kind of burial has water depth limit it can be used at. So it could be used on a large tidal flats or sandbanks. This can be overcome by using jetting equipment when crossing channels. The combined use of jetting and mechanical trenching seems most applicable when using a route over the tidal divide because this is basically one tidal flat.

7.4 Burial depth

First of all the minimal burial for cables in the Wadden Sea is 1 meter. Because this is the minimum ground coverage given in the cable permit.

To attain a burial depth for the Vlieland side the 100 year depth is calculated from the transect from 1990 onward. This assumes that the depth is Gaussian distributed and can only be done because no deepening or shallowing trend is present. The lifetime of the cables in the Wadden Sea is expected to be at least 30 years so the 100 year depth seems an appropriate choice. This will make it unlikely that a cable will surface during the lifetime of a cable. So burial at a depth which is unlikely to ever occur seems advisory. The average depth over the last 25 years and the appropriate 100 year burial can be seen in Figure 7-3.

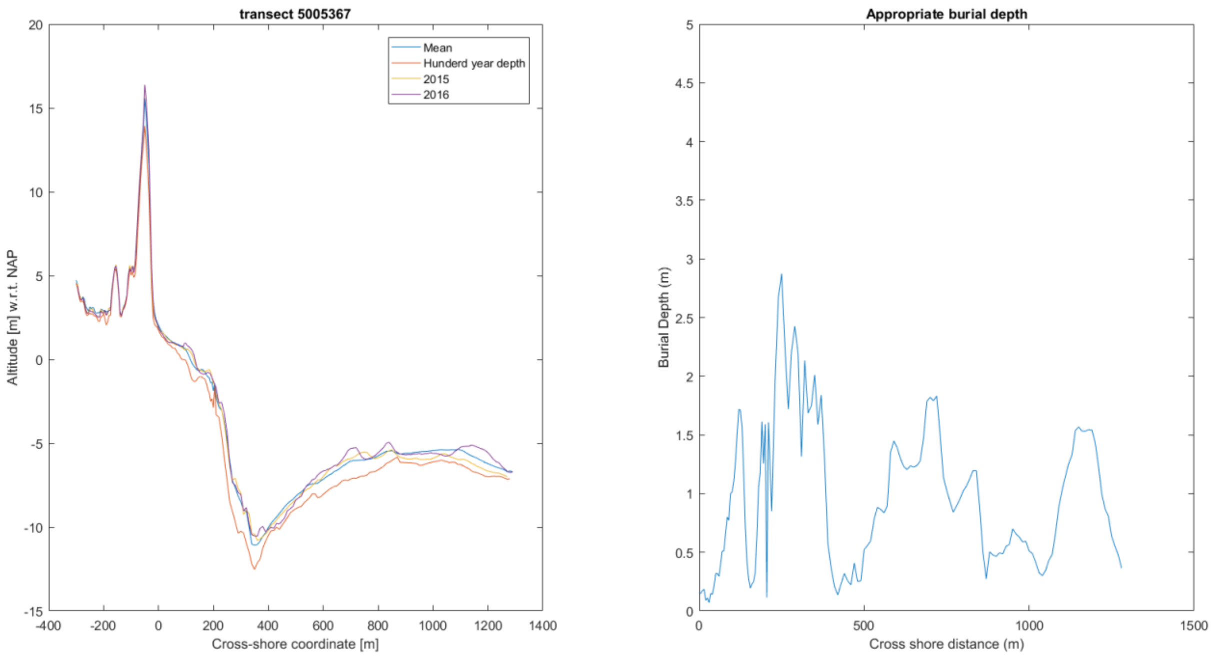

Figure 7-3: Hundred Year Depth

By subtracting the 100 year depth from the 2016 profile depth the actual burial depth can be calculated. Besides this theoretical burial depth the minimal coverage of 1 meter should be taken into account. From the figure it can be seen that burial of approximately 3 meter would be needed for the first 500 meters from the beach (just after the location of the channel in front of the coast of Ameland). Further off shore the depth profile seems to be calmer and a burial of 2 meters would be sufficient, this behaviour is assumed to be similar up until the Engelschhoek. The chance of reaching the minimum burial of 1 m is shown in Figure 7-4 for both 2 and 3 meters of burial.

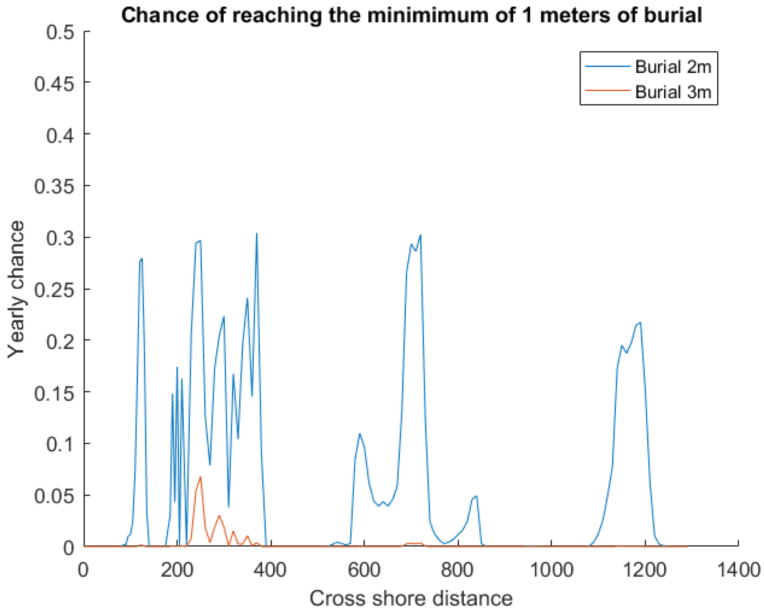

Figure 7-4: Chance of reaching the minimal burial

This gives clearer idea if a burial of less than 3 meters would suffice. From this figure it can be clearly seen that this is not the case. In case of a 2 meter burial the chance of maintenance would be once every three years in several locations. The actual chance of surfacing on most of these spots even with 2 meter of burial is still beneath 0.01. So in order to make sure the minimum burial will not be met a burial of 3 meter is needed.

This method can be used for the beach landing at Ameland but not for the beach landing at Terschelling. Here a different approach will have to be used. However the required burial depth which is acquired at the Ameland side could be used as well. This would mean some maintenance is required. Looking at the data of the landing transect 400080 in 0. A burial of three meter would at least solve the need for maintenance for some time. An exact prediction cannot be made because of the lack of data and highly dynamic behaviour. However maintenance can be expected near the beach and on the edges of the Engelschhoek, this maintenance is hard to prevent since no good prediction about the development of the Boomkensdiep can be done.

The only region where no depth has been decided is the Engelschhoek itself; this is a stable region with a shallowing trend so a burial of 2 meter would suffice. This is only a small part of the route therefore it would be better to also bury the cable here up to a depth of 3 meters.

If a route on the tidal divide would be chosen, minimal burial would suffice. Tidal divides are shallowing. Movement of the tidal watersheds themselves is limited so a minimal burial could suffice. The tidal divide to Terschelling is especially stable and so a burial of 1m could suffice for the entire lifetime of the cable. To allow for some depth variation in burial and or during the lifetime of the cable some safety margin should be included. Especially since large scale movements are possible and if minimal burial would be chosen, maintenance could be needed immediately. So 2 meters of burial should be used to allow some large scale movement before affecting the cable.

The route over the tidal divide to Vlieland is more difficult since it is a shared tidal divide. Moreover big changes in the morphology have taken place. Currently there is a cable running to the island over the tidal divide as well. This cable experiences some maintenance issues on the part where the Vlie, Marsdiep and Eierlandse Gat inlet meet. Furthermore this tidal divide is more dynamic than that of Terschelling. So some maintenance can be expected, the exact location is however hard to predict, so some safety margin will have to be included to allow for some bottom movement before maintenance is needed. If large scale movements occur a large part of the cable will have to be reburied. An extra meter of coverage would make the cable more safe for large scale movements.

Looking at cable failure possibilities of the cables and the burial protection index. On all cable trajectories in the Wadden Sea an anchoring and fishing prohibition is maintained by the government. Furthermore it seems unlikely that a ship will anchor in a busy shipping lane with high flow velocities as the Vlie. Burial is by law required to be at least 1 meter and the soil in the Vlie or on the alternative routes is in between coarse and fine sand, burial seems sufficient for other hazards present in the area.

7.5 Other requirements

Beside the technical details some other activities should be conducted and some agreements will have to be made. Safety is an important factor in these decisions as well as the certainty that the cable will be placed in the right location and depth. These requirements are listed below:

- Prey lay survey
  - Mainly looking at other objects near the cable route.
  - Waves, wind and their season dependency.
    - Cable burial should be done outside the stormy season. The stormy season is between December and April (Hordijk, 2004)
- Post-lay survey
  - In order to make sure the work is done according to specifications. As well as measuring the actual location of the cable. The location of the cable can also be measuring during lay.
- Determining the cut off conditions of the cable
  - This needs to be done beforehand to prevent confusion about the cut off condition during the burial and placement of the cable. End responsibility will be with the captain of the vessel, he will need to have some guidelines to work with however.
- Cable needs some electric conducting part, this is also a requirement for the onshore part.
  - This will make locating the cable easier. Possibly the armouring can be used in the offshore part.
- Safety document
  - The VGM (see Appendix G) for the maintenance operation could be used as source. Additional agreements will have to be made.

8 Cost

This Chapter is confidential

9 Jet trenching model

In order to get a better idea about the power needed and the working principles behind a jet trencher, a model is made. The power will influence the type of trencher needed and therefore the size of the ship needed for the trenching operation. First some theory used in the model is described. Secondly the model itself is described. Whereas the last chapter give some more insight in the slack of a cable.

9.1 Theoretical input for model

While jetting a trench, five physical processes take place: erosion, entrainment, deposition, breaching and overspill. These processes can be schematically seen in Figure 9-1. The forward facing erosion nozzles are not clearly displayed in this figure but the forward erosion is displayed.

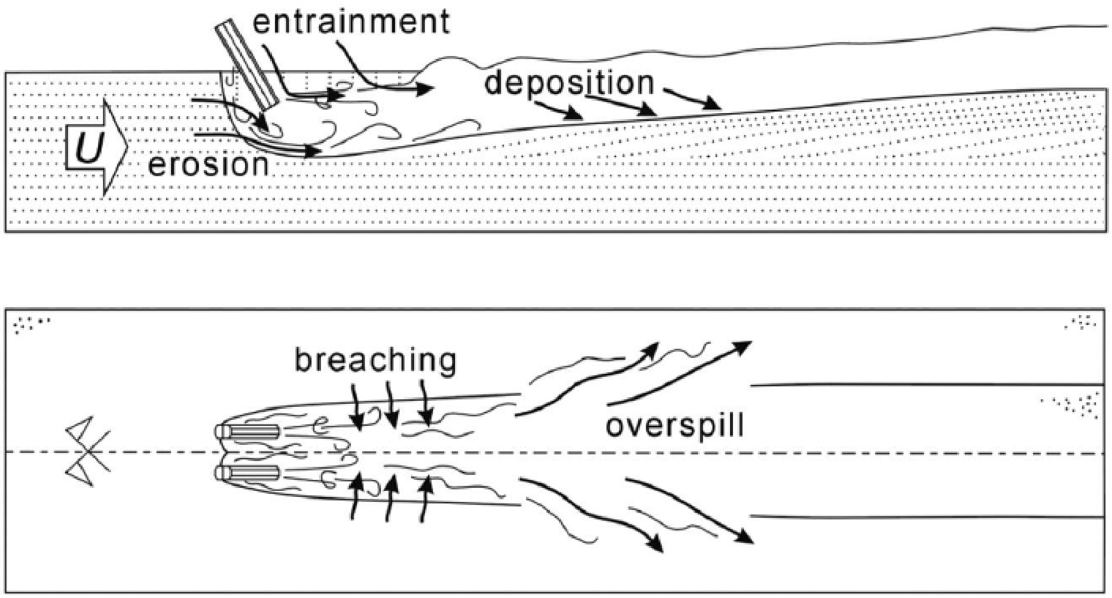

Figure 9-1: Physical processes during jet trenching (Vanden Berghe, et al., 2011)

The nozzles (high pressure, low discharge) in front of the lance will erode the soil after which it will flow down and become entrained in the flow of the backward facing nozzles. These are low pressure high discharge nozzles creating a density current. After the initial trench has been made the soil will deposit into the newly made trench. There will be some overspill losses because not all soil will settle in the trench and because the porosity will probably increase after settling. Because the soil has been removed some breaching of the side wall of the soil will take place.

9.1.1 Production of front jets

The sediment in front of the lance will be hydraulically excavated. To estimate the production of the jets in sand, the formula of Vlasblom is used. The research and origins behind this formula are classified. It couples the jet momentum to the jet sand production [kg/s].

$$M_s = \alpha I_j = \alpha\rho_w Q_j u_0 = \alpha\rho_w Q_j\sqrt{\frac{2p_j}{\rho_w}} \tag{9-1}$$

With α [s/m] being an empirical parameter, p_j = jet pressure, M_s = mass flux of the eroded sand, I_j = jet momentum, Q_j = jet discharge, u_o = jet exit velocity.

This formula only holds if multiple jets are used to fluidize the soil. Since the outflow of a jet has a circular shape (thus width and length are coupled) and the required trench is deeper than it is wide multiple jets will have to be used. This formula also implies that there is no depth dependency on the cutting power needed. Furthermore an increase in trailing velocity will lead to an increase in needed power because more sand will have to be produced. The value of α will have to be found from experiments as it is influenced by environmental influences, however a typical value found in literature is about 0.1.

The jet pressure is assumed to be the same in all forward facing nozzles. This can be done because the pressure drop over the pipe is much lower than the pressure drop over the nozzles itself. The pressure drop is dependent on the difference between the nozzle and flowline velocity.

$$\Delta p = \frac{1}{2}\rho_w(u_0 - u_1) \tag{9-2}$$

Where u_1 = flowline velocity. This is the Bernoulli equation for the nozzle. Normally the flowline velocity is much smaller than the nozzle velocity and is therefore neglected.

In theory this would mean that the pressure drop over the backward facing jet is the same as well. However because this is a larger nozzle the velocity increase is not as large as the forward facing nozzle so here the velocity in the pipe can no longer be neglected. This can be accounted for by giving this nozzle a fictitious lower pressure.

The required production of the jet can be written as:

$$M_s = \rho_s(1 - n_0)Av_t \tag{9-3}$$

Where A = trench cross sectional area, n_0 = the in-situ porosity and ρ_s = sand density. This formula basically describes the amount of sand that will have to be excavated for the trencher to move forward, so the amount of sand in front of the trencher with taking into account the in-situ porosity.

The cross sectional area is dependent on the trench bottom and top width.

$$A = \frac{1}{2}(W_t + W_b)\cdot D_{total} \tag{9-4}$$

Where D_{total} = Total trench depth, W_t = Trench top width and W_b = Trench bottom width. So the trench cross sectional area is the total depth multiplied with the average width of the Trench.

9.1.2 Jet Power

The power of the jet is dependent on the jet pressure and the jet discharge

$$P_j = Q_j \cdot p_j \tag{9-5}$$

The total pump power is dependent on the frictional losses inside the pipes going to the nozzle, the losses inside the nozzle and the losses in the pump. The nozzle losses are a combination of contraction losses and other losses. If the right shape of the nozzle is chosen no contraction losses will take place. Another loss will be the loss inside the drive of the pump this is dependent on which type of drive is chosen (direct diesel or diesel electric).

$$P_t = \frac{1}{c_n \cdot c_p \cdot c_f \cdot c_d} \cdot \sum P_j \tag{9-6}$$

Where c_n = nozzle coefficient, c_p = pump coefficient, c_f = flowlines pressure loss coefficient, c_d = drive coefficient and P_t = total power needed. The total power will thus always be higher than the required jet power.

9.1.3 Cable deflection in trench

To calculate the deflection of the cable in a trench the model of (Vanden Berghe, et al., 2011) could be used. This model assumes that a cable sagging into a trench is equivalent to a hyperstatic cantilever beam uniformly loaded. With one side of the beam being fully constraint (with horizontal alignment) while the other side of the beam is only rotationally constrained (flat on the bottom of the trench). The final cable depth is the point where the cable will reach the first newly settled sediment.

In total the analytical cable deflection in a trench is given as:

$$y(x) = -\left[\frac{qL}{T}\cdot\sqrt{\frac{EI}{T}}\cdot\frac{\cosh\left(\sqrt{\frac{T}{EI}}\cdot L\right)}{\sinh\left(\sqrt{\frac{T}{EI}}\cdot L\right)}\cdot\left[\cosh\left(\sqrt{\frac{T}{EI}}\cdot x\right)-\tanh\left(\sqrt{\frac{T}{EI}}\cdot L\right)\cdot\sinh\left(\sqrt{\frac{T}{EI}}\cdot x\right)-1\right]-\frac{q}{2T}\cdot x^2 + \frac{qL}{T}\cdot x\right] \tag{9-7}$$

Where y = cable deflection in downward direction, L = span length, T = Lay tension, E = Young's modulus, I = area moment of inertia and x = distance from start trench. The cable sag relation also implies that there is a minimum trench length for which a certain depth can be reached.

The submerged unit weight [N/m], q is given as:

$$q = g(\rho_{cable} - \rho_{fluid})A_{cable} \tag{9-8}$$

Where ρ_{cable} = cable density, ρ_{fluid} = density of surrounding fluid, A_{cable} = cable area and g = gravitational constant. The fluid density is influenced by the sand concentration inside the trench. An example of cable profile can be seen in Figure 9-2.

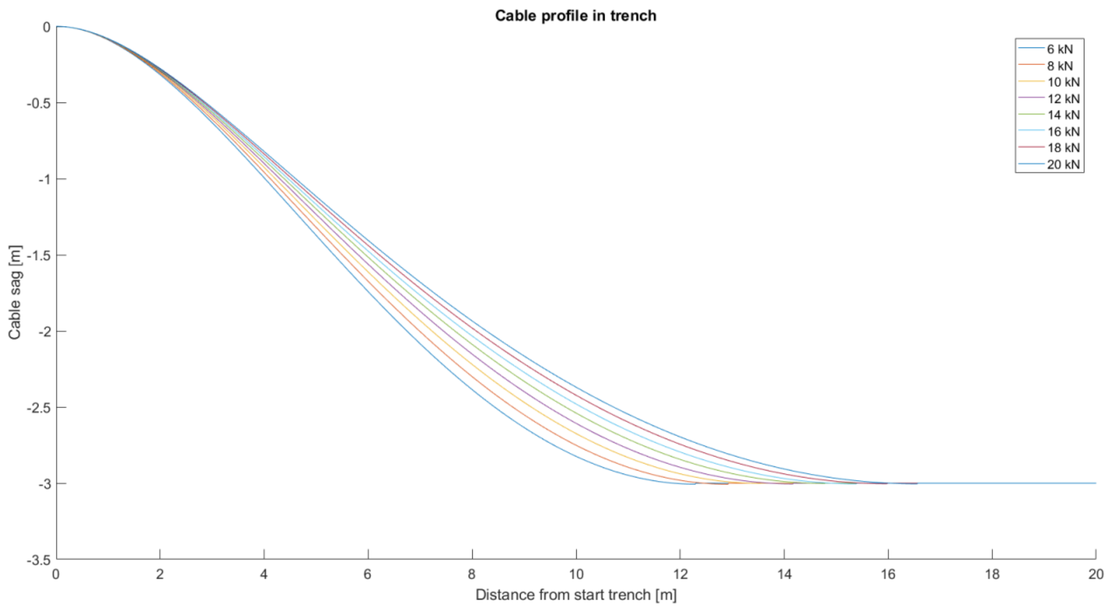

Figure 9-2: Cable sag in a the trench

Where EI = 100000 [m^4] and q = 600 [N/m]. The influence of the cable tension can be clearly seen in the figure. The cable cross sectional area is small. This will lead to a low unit weight and therefore slow sagging into the trench. If realistic value are filled in this formula the trench length can easily become larger than 10 meter. This does not seem correct. This means that the departure angle must not be horizontal or that cable will have be forced down into the trench.

In order to model the angle of the cable catenary theory could be used. If the cable can be given an angle prior to departure the cable sag can be shorten significantly. The catenary cable sag is given as (Jensen, 2010):

$$y(x) = \frac{T \cdot \cos\ \theta_c}{q}\left(\cosh\left(\frac{q}{T \cdot \cos\ \ \theta_c} \cdot x_2\right) - 1\right) \tag{9-9}$$

Where θ_c = departure angle compared to the horizontal and x_2 = distance from cable touchdown point. Where a 0° angle would mean horizontal departure and a 90° degree would mean vertical departure of the cable. This formula does not take into account the bending stiffness of the cable which seems a well enough approximation for such a small cable. The cable sag in a 5 meter long trench with the same numbers used as in Figure 9-2 can be seen in Figure 9-3.

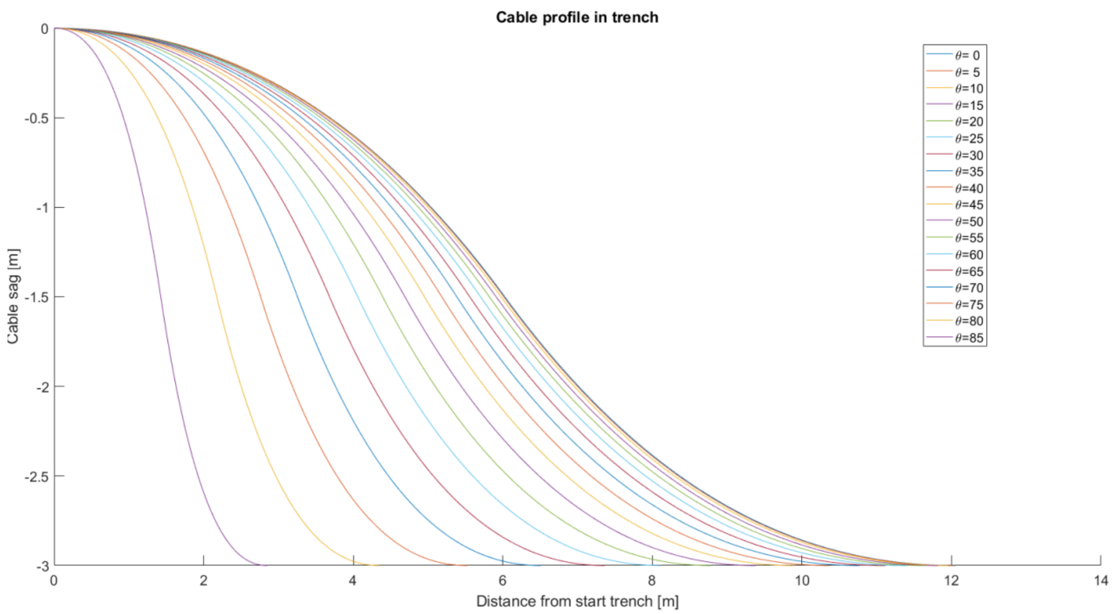

Figure 9-3: Cable sag according to catenary theory

The influence of the departure angle can be seen in the figure. The profile of the cable does not seem correct. What however can be concluded from this graph is that the angle of departure has a significant influence on the cable profile and that the hyperstatic cantilever beam underestimates the deflection of the cable in the trench. In order to model this more accurately the cable sag length is chosen as an input instead of using a calculation to calculate the cable sag length.

9.1.4 Sedimentation in trench

The density current behind jetting lance will have a tendency to settle on the newly created bottom. Because the velocity of this settling is important for the total depth required (in settled sand no cable can be buried) this velocity is calculated.

The sedimentation velocity in the trench is given as:

$$v_{bed} = \frac{S-E}{\rho_s(1-n_0-c)} = \frac{S}{\rho_s(1-n_0-c)} - \frac{E}{\rho_s(1-n_0-c)} \qquad (9\text{-}10)$$

Where E = the erosive flux and c = near bed solid concentration, n_0 = porosity of the sand bed, v_{bed} = the upward velocity of the bed and S = sedimentation flux. The total sedimentation is thus a superposition of two processes. Namely settling and erosion of particles at the same time. The one that dominates will determine whether the sediment will settle or erode.

The sedimentation flux S is stated as:

$$S = \rho_s w_s c = \rho_s w_0 c(1-c)^n \qquad (9\text{-}11)$$

With w_s = bulk settling velocity, w_o = individual particle settling velocity and n = hindered settling coefficient. The settling velocity of a particle is it's terminal velocity, when a group of particles fall together the upwards created stream from every particle will influence the other particles. To compensate for this the hindered settling velocity is used. The single particle settling velocity for natural sand is given as (Ferguson & Church, 2004):

$$w_0 = \frac{\Delta g d^2}{18v + \sqrt{0.75\Delta g d^3}} \qquad (9\text{-}12)$$

Where v = kinematic viscosity, d = grain size and Δ = specific density given with the following formula:

$$\Delta = \frac{\rho_s - \rho_w}{\rho_w} \qquad (9\text{-}13)$$

The hindered settling coefficient is an empirical constant. A common representation of this coefficient is (Richardson & Zaki, 1954):

$$n = \frac{4.7 + 0.41{Re_p}^{0.75}}{1 + 0.175{Re_p}^{0.75}} \qquad (9\text{-}14)$$

With Re_p the particle Reynolds number as given in:

$$Re_p = \frac{w_0 d}{v} \qquad (9\text{-}15)$$

Settling using this approach will only calculated the hindered settling for one grain size fraction. The grain size distribution off the sand in the Wadden Sea is narrow so using the median grain size seems a good approach for all sediment in the studied region.

The pick-up flux is usually calculated using the dimensionless pick-up ϕ_p:

$$\varphi_p = \frac{E}{\rho_s\sqrt{g\Delta d}} \qquad (9\text{-}16)$$

To calculate this dimensionless pick-up for low speed erosion multiple pick-up function exist. For this model the pick-up function of (Cao, 1997) is used:

$$\varphi_p = P d^{1.5}\left(\frac{\theta - \theta_{cr}}{\theta_{cr}}\right)\theta \qquad (9\text{-}17)$$

Where θ = dimensionless bed shear stress, θ_{cr} = critical dimensionless bed shear stress. So when $\theta>\theta_{cr}$ pick-up of particles will occur. The dimensionless bed shear stress is also called the Shields parameter after the first publisher of this concept. P in this equation being:

$$P = 0.02\frac{(1-n_0)\sqrt{\Delta g}}{100\nu} \tag{9-18}$$

The Shields parameter can be estimated using the depth average flow velocity:

$$\theta = \frac{f_0\bar{u}^2}{8\Delta g d} \tag{9-19}$$

Where f_0 = friction factor. This is the Fanning friction factor which is four times lower than the Darcy-Weisbach friction factor. This friction factor will have to be reduced from experiments, however in literature a factor of 0.02 is being used.

The critical bed shear stress can be calculated using (Brownlie, 1981):

$$\theta_{cr} = 0.22{R_p}^{-0.6} + 0.06e^{-17.77({R_p}^{-0.6})} \tag{9-20}$$

Where R_p = particle Reynolds number but not with the single particle settling velocity as velocity scaling factor. This particle Reynolds number is defined as:

$$R_p = \frac{d\sqrt{\Delta g d}}{\nu} \tag{9-21}$$

The Shields parameter in the previous section does not take into account high speed erosion. Therefore it overestimates pickup at high speeds by not taking under pressures created by permeability effects into accounts. The research of (Van Rhee, 2010) adapted this critical shields parameter to also take into account high speed erosion and erosion on slopes:

$$\theta_{cr}^1 = \theta_{cr}\left(\frac{\sin(\varphi-\beta)}{\sin\varphi} + \frac{v_e}{k_l}\cdot\frac{n_l-n_0}{1-n_l}\cdot\frac{1}{1-n_0}\cdot\frac{1}{\Delta}\right) \tag{9-22}$$

Where n_l = porosity of top layer, k_l = bed permeability, ϕ = friction angle of sand, v_e=erosion velocity and β = actual bed angle.

The part with the porosity in it basically describes the effective volume increase which is caused by the shearing of the sand. This volume increase will then create under pressures leading to the inflow of water.

If the bed angle is chosen to be zero and the velocity is sufficiently low the second part of the equation will become 1 and so the normal shields criterion will again surface. Another major advantage of this method is that all other relations will remain valid so using this adapted pick-up the erosive flux can directly be calculated. However due to the fact that the erosion velocity itself is now a function of the erosion velocity it will now have to be calculated implicitly.

Using the described formulas before the erosion velocity can be plotted against the mean velocity. This is done in Figure 9-4 using a mean diameter of 250 micron and a D_{10} of 125 micron. The smaller percentile diameter mainly influences the permeability of the sand bed. A lower permeability will make the influence of the erosion velocity on erosion larger (the second term in between the brackets in equation (9-22).

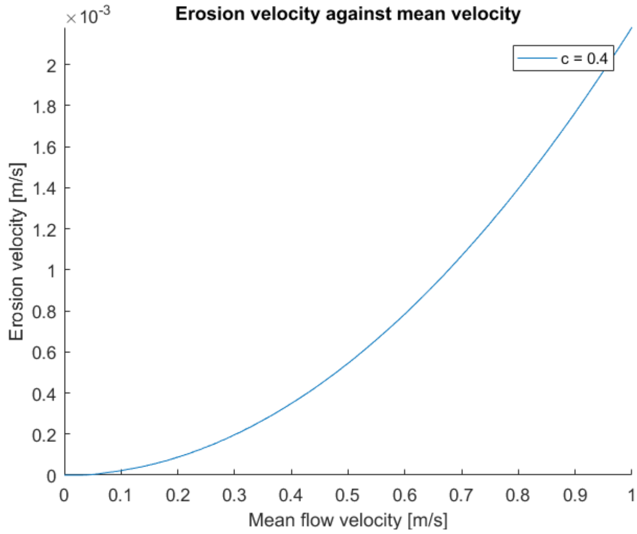

Figure 9-4: Erosion velocity as a function of mean velocity

This figure clearly shows that an increase in mean flow will lead to more than linear increase in erosion velocity. So the effect of an increased flow velocity is stronger than the inhibitive effect of the dilatancy for the chosen soil.

This is not the bed velocity but only the erosion velocity. This erosion velocity always has a positive value this means that the total bed velocity is the sedimentation velocity minus the erosion velocity. So that the total bed velocity can still become negative (net deposition).

The hydraulic conductivity can be found using Hazen's equation (Hazen, 1892):

$$k_l = 6 \cdot 10^{-4} \cdot \frac{g}{\nu}\big(1 + 10(n - 0.26)\big) \cdot d_{10}^2 \tag{9-23}$$

This equation is only applicable if the grain size is in the range between 0.1 and 3 mm with a uniformity coefficient of less than 5. Which is the case in the Vlie inlet and also in a large part of the rest of the Wadden Sea.

9.1.5 Flow velocity in the trench.

Because the erosive flus is dependent on the flow velocity the flow velocity of the backward facing jet will have to calculated. The depth average flow velocity in the trench behind the jet is calculated using continuity, this does not take into account extra entrainment of water and will not satisfy the momentum balance. It is more of an estimation:

$$u_m = \frac{A_t \cdot v_t + Q_j + Q_{j,back}}{A_t} \tag{9-24}$$

Where u_m= depth averaged flow velocity.

This approach will overestimate the settling at the start since the jet will not have fully developed and start at the bottom of the trench where even some additional erosion may take place. This effect in partly moderated by averaging the bed velocity over the length.

The model will probably still overestimate the overdepth because of the large velocity gradient inside the trench. However this overestimation seems at least reasonable according to the outcomes.

Since sediment will settle in the trench additional depth will have to be acquired to allow the cable to settle at the certified depth. This additional depth is specified in the following way:

$$D_{total} = D_{target} + D_{additional} \tag{9-25}$$

Where D_{target} = desired cable depth and $D_{additional}$ = the overdepth. The overdepth can be calculated using the following formula:

$$D_{additional} = v_{bed} * t \qquad (9\text{-}26)$$

Where t = trenching time, which can be obtained using:

$$t = \frac{L}{v_t} \qquad (9\text{-}27)$$

This means that quicker trenching will lead to shorter trenching time which in term will lead to a smaller overdepth which can be beneficial for cable burial.

9.2 Model

A sketch of the general characteristics the model along with some important parameters can be seen Figure 9-5.

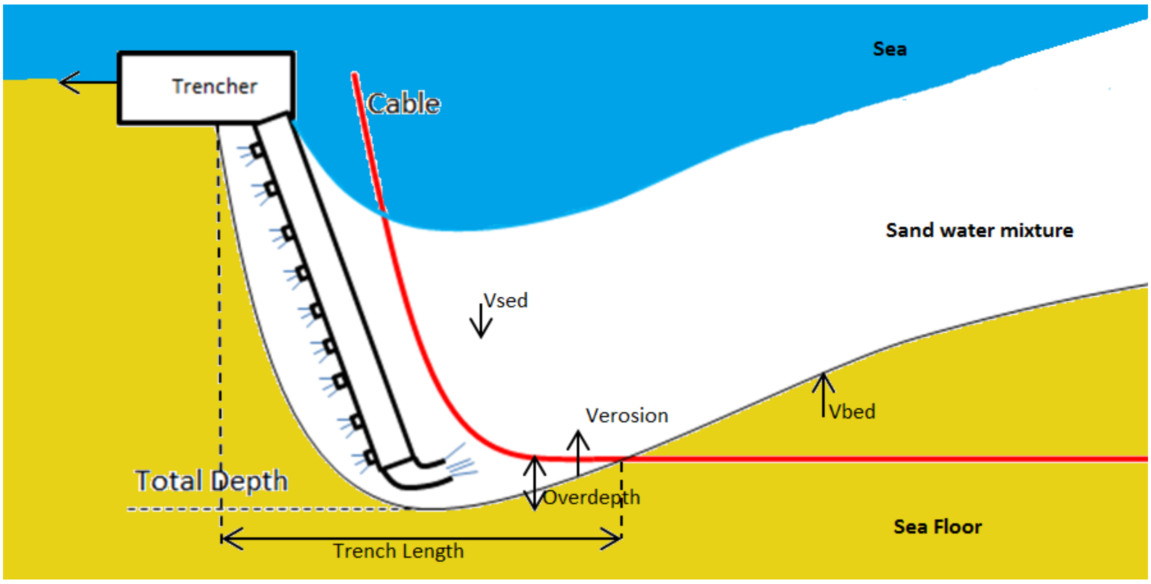

Figure 9-5: Model Sketch

The model does not include overspill and breaching calculations. These physical phenomena are modelled using the sand concentration in the trench.

The way the forward jet power is calculated can be seen in Figure 9-6

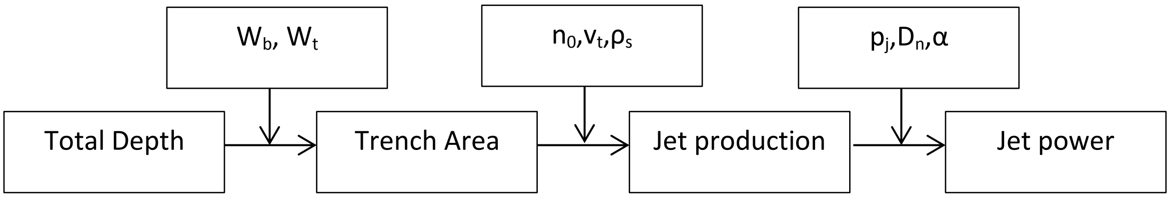

Figure 9-6: Forward Jet power

The trailing velocity here influences the required jet production since for a larger speed more sand will have to excavated by the forward facing jets. Because the total depth is dependent on the required overdepth the total depth will have to be calculated first. The calculation for the total depth can be seen in Figure 9-7.

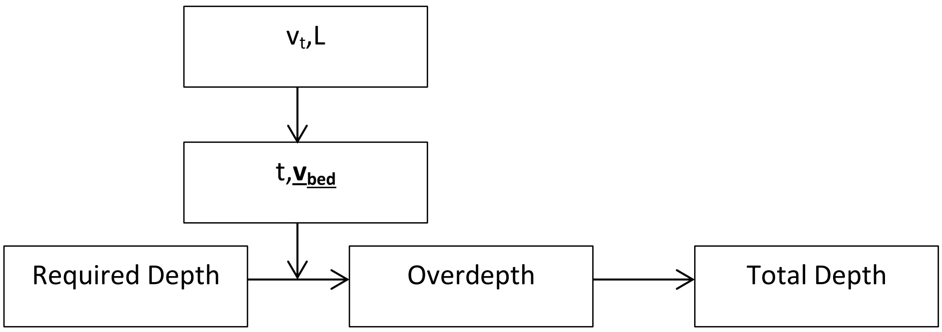

Figure 9-7: Total Depth

This part of the model starts with the required bed. By calculating the time it takes for the cable to travel the distance in the trench and the bed velocity the total overdepth can be calculated. This is the total amount of sand that settling on the bed before the cable reaches the bottom of the trench. The only unknown in this equation is the velocity of the bed. To calculate the bed velocity two velocities will have to be calculated, the erosion velocity and the sedimentation velocity. The sum of these two velocities is the total bed velocity. First the erosion velocity is calculated, this is schematically shown in Figure 9-8.

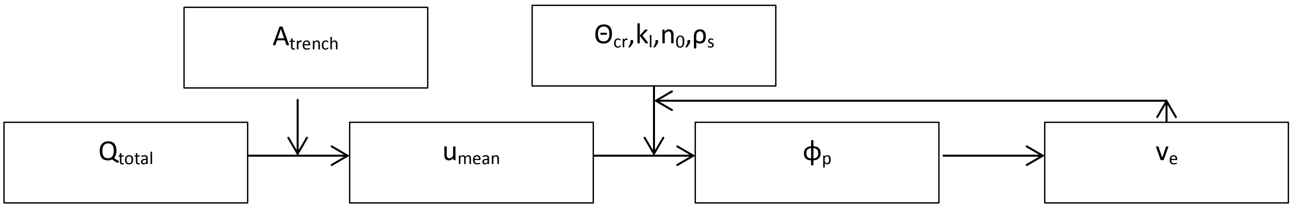

Figure 9-8: Erosion Velocity

The feedback loop in this figure is in place because the erosion velocity itself influences the pickup of particles and therefore the erosion velocity. The trench area is also influenced by the erosion velocity, the feedback is done however over the total iteration. The calculation of the sedimentation velocity and the total bed velocity can be seen in Figure 9-9

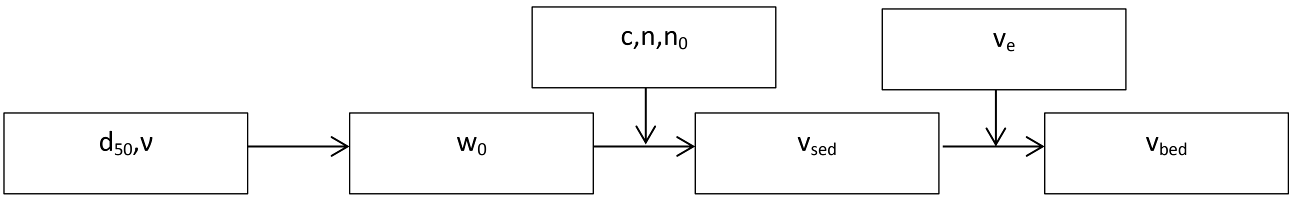

Figure 9-9: Bed velocity

To calculate the sedimentation velocity the hindered settling velocity is used. The velocities are added and not the individual fluxes is to make the model able to handle both positive and negative bed velocities. Since both velocities are independent of each other.

9.2.1 Example of model

To study the performance of the model some typical inputs are used. The inputs can be seen in Table 9-1.

Table 9-1: Inputs for model

Parameter	Value	Unit
c	0.4	[-]
c_{total}	0.8	[-]
D_{10}	125	[μm]
D_{50}	250	[μm]
D_{target}	3	[m]
L	3	[-]
n_0	0.4	[-]
$p_{j,back}$	400	[kPa]
$p_{j,forward}$	1000	[kPa]
ut	100	[m/hour]
W_b	0.5	[m]

W_t	0.8	[m]
α	0.1	[s/m]
ρ_s	2650	[kg/m^3]
ρ_w	1000	[kg/m$^{3]}$

The soil diameters in this table is soil found in the Vlie inlet.

9.2.2 Output

The output is calculated for two velocities in order to show the way the model works. These outputs can be found in Table 9-2.

Table 9-2: Outputs of model

	100 m/hour		200 m/hour	
Output	Value	Unit	Value	Unit
$P_{j,forward}$	21	[kW]	41	[kW]
$P_{j,back}$	342	[kW]	342	[kW]
P_{total}	444	[kW]	479	[kW]
D_{add}	0.5	[m]	0.2	[m]

As can be seen from the output the value of the backward jet is not adapted for the increased speed. Some lower power consumption can be expected however because of the reduced flow over the backwards nozzle. Furthermore the total additional depth clearly decreases because the influence in velocity. This influence is mostly because of the dominant deposition over erosion of the this model. The bottom profile in the trench during cable installation and the possible cable profile can be seen in Figure 9-10.

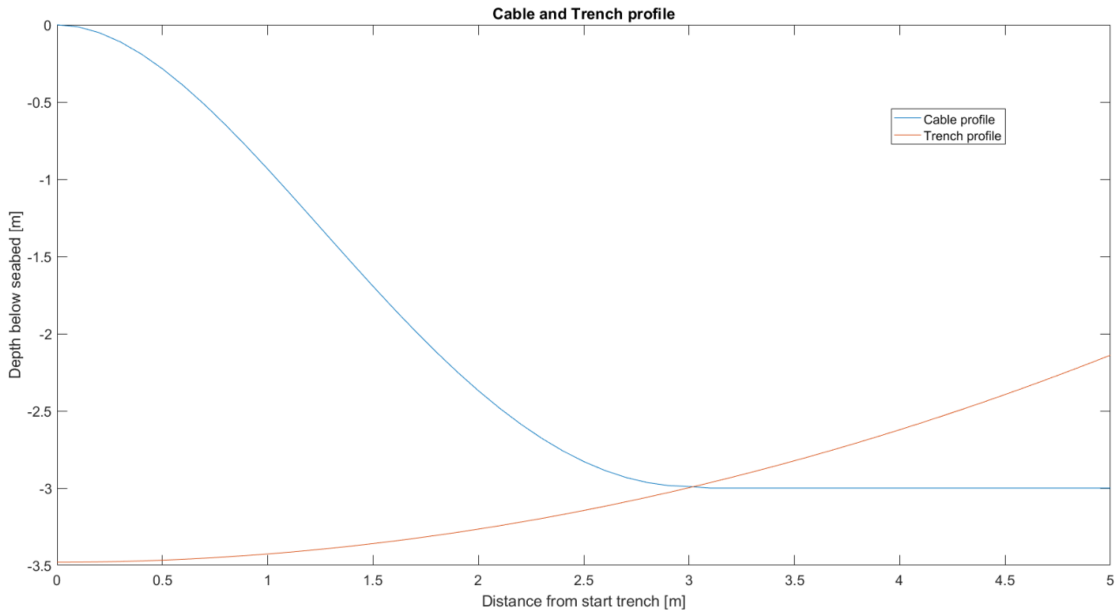

Figure 9-10: Trench profile during installation

The main reason for the shape of this profile is that the deposition was assumed to be increasing linearly. Furthermore the time the soil has to settle is also increasing linearly because the total amount the sediment has been settling increases over the length of the trench. With the particles and the final end of the trench will have the total settling time of the trench length over the trailing velocity. The cable profile in this figure is mainly to illustrate how the cable will be placed into the seabed. As can be seen the cable will no longer sag in to the trench once it reaches the settled sediment.

9.2.3 Influence of depth increase

An increase in depth will lead to a minimal increase in power. Most of the power goes to the backward facing nozzles. In the region behind the jetter settling dominates over erosion. Because settling dominates behind the water jet the erosion of the water jet is not that important. When increasing the water depth the power going to the forward facing nozzles will increase linearly with the depth increase. However the power going to the forward facing nozzles is way less than the power going to the backward facing nozzles.

The most important influence of depth increase is the increase in total length. This length increase is caused by the slower sag of the cable because of the greater sag depth. This means that the soil will have to remain in solution for longer and further behind the jet.

Because the concentration behind jet can't be calculated correctly by the model makes difficult to model the total effects of the depth increase. Therefore the cost increase of deeper burial can't be well estimated using this model.

9.2.4 Influence in velocity increase

The velocity of the burial procedure is mainly governed by the design of the lance. The power going into the lance is divided between the forward facing nozzles and the backward facing nozzle. The division between these nozzles is thus dependant on the design of the lance. If the burial velocity is increased the gross of the power could then go to the backward facing instead of the forward facing nozzles. This means that the lance will be unable to erode enough soil in front of the lance.

Therefore the lance will have to be designed for the maximum depth and maximum velocity allowing for greater velocities at shallower depths by closing some nozzles and therefore increasing the pressure and flow (momentum) over the forward nozzles leading to further erosion.

9.3 Slack in cable

To allow for maintenance to happen the cable will have to have some slack. Some slack can always be expected in a cable (especially in one as flexible as a fibre optic cable). This slack is needed to be able to rebury the cable in a new cable trajectory. Slack can be accounted for in the horizontal plane (x,y) and in the vertical plane (z).

Slack in z direction seems difficult since a normal jetting lance will be made for one depth. Some slack will always be present in this direction because of the different sand characteristics during installation. The only practical way to introduce slack in the z direction will be to vary the cable tension overtime, which seems unpractical.

Slack in the horizontal plane will be different however. Some extra distance can be covered near a place where maintenance can be expected in the future. This can be done by allowing the trencher to differ its x and y velocity. This will only have to be done near sites where maintenance can be expected. On other places longer cables will increase the maintenance probability because of the longer length.

10 Conclusions and recommendations

10.1 Conclusions

- On the offshore part of the current cable between Vlieland and Terschelling no maintenance has been conducted (only maintenance on the beach of Terschelling was needed). It is however certain that this cable has surfaced in the past. With the new cable the chance of surfacing is still present. Because of the possibility of surfacing the cable will have to be armoured, reducing the risk of failure whilst surfaced. Besides this armouring the cable needs to be pingable in order to make it easier to exactly locate the cable when buried.
- Depth information and other data about the Wadden Sea is freely available over long periods of time. However due to its limited spatial and temporal resolution the certainty of conclusions about the future morphological development should be taken with care. This has gone wrong with the east cable of Schiermonnikoog. Change of surfacing for was estimated 1/100 year in 2002. The data to support this conclusion is non-existent. As a result the conclusion for placement of this cable was wrong.
- The inlets are morphological less stable than the inner delta. This stability makes cable placement in the inner delta easier and predictions about surfacing more reliable. The further a cable is morphological from an inlet the less the depth variation is. With the ideal place being on the tidal divide.
- Soil characteristics in the Wadden Sea differ according their location and are mostly related to flow velocities. Near the inlets the soil variability is lower and grain size is large (200 micron). However going to the mainland shore and to the tidal divide, the grain size is becoming smaller and becomes less uniform.
- The way burial needs to be done in the Wadden Sea differs depending on location. In the deeper parts jetting is the preferred method. Where on the tidal divides mechanical trenching would be best. So jetting is the preferred method for the Cable between Vlieland and Terschelling.
- Cable replacement is relatively expensive in comparison with the maintenance on the current cables. So upgrading a cable to keep it online longer is almost always better than replacement.
- A model was made to predict the power and overdepth needed to bury a cable up to a depth of 3 meters. Most power goes to keeping the trench open to allow the cable to sag into the trench and not to the erosion of the soil in front of the trench. The needed power is estimated to be around 500 kW of pump shaft power.

10.2 Recommendations

- All islands are for redundancy purposes connected with two independent cables. This redundancy is expensive both for new cables as for current cables. The capacity of one (new) cable would be more than sufficient to ensure an high enough data rate to each island. Given the limited amount of population on the islands a single connection should be considered as an alternative. Especially given the low risk failure risk of the cables.

- International cables (some of which are partially owned by KPN) going through the Atlantic have only around 10 fibres but are able to get a high data rate. This is because the transmission equipment is more sophisticated. If this upgrade can be done to the current cables, the data rate can be upgraded without the need of a new cable.
- The cooperation with other utility owners in the Wadden Sea is running smoothly for the maintenance of the current cables in the Wadden Sea. However for new cable cooperation could be stepped up a notch to allow for shared burial cost for new connections.
- In order to be able to come up with better cost approximations more information is needed. This information is however not available in the public domain.
- The model can predict the power needed for burial of the cable however to come up with better predictions the model should be supplemented with experimental results. These experiments should be focused on the forward jet erosion parameters and concentration in the trench behind the jet. Other relations for the hindered settling and jet erosion exist as well. These experiments could show whether the chosen relations are a well enough approximation or that some other relation should be used.

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Appendix A. LOCATIONS OF SOIL SAMPLES

DINOloket

Datalevering — Data en informatie van de Nederlandse Ondergrond

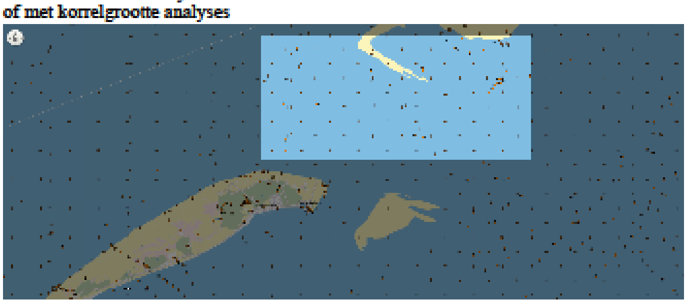
Uw contactgegevens

Naam : BM Noordermeer
Organisatie : TU Delft
E-mail adres : bob.noordermeer@kpn.com

Samenvatting levering

Kenmerk levering :
Datum levering : 13-01-2017
Vorm van levering : zip per url
Samenvatting levering : Inhoud (296 bestanden)
Geologisch booronderzoek:
30 locaties / 159 bestanden
met monsterprofiel
of met monsterfoto(s)
of met boorgatmetingen
of met chemische analyses
of met korrelgrootte analyses
Geologisch waterbodemonderzoek:
94 locaties / 137 bestanden
of met monsterbeschrijving
of met chemische analyses
of met korrelgrootte analyses

Gekozen gebied :



Geleverde bestanden

bericht van levering : bericht van levering.pdf
bericht van levering.xml
Geografie : locatie_levering.kml

Geologisch booronderzoek: 30 locaties

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	B04F0214_01.jpg	Foto	
	B04F0214.gef	Databestand	Boormonsterprofiel_Geologisch booronderzoek
	B04F0214_1.4.xml	Databestand	
	B04F0214_1.3.xml	Databestand	
	B04F0214.txt	Databestand	

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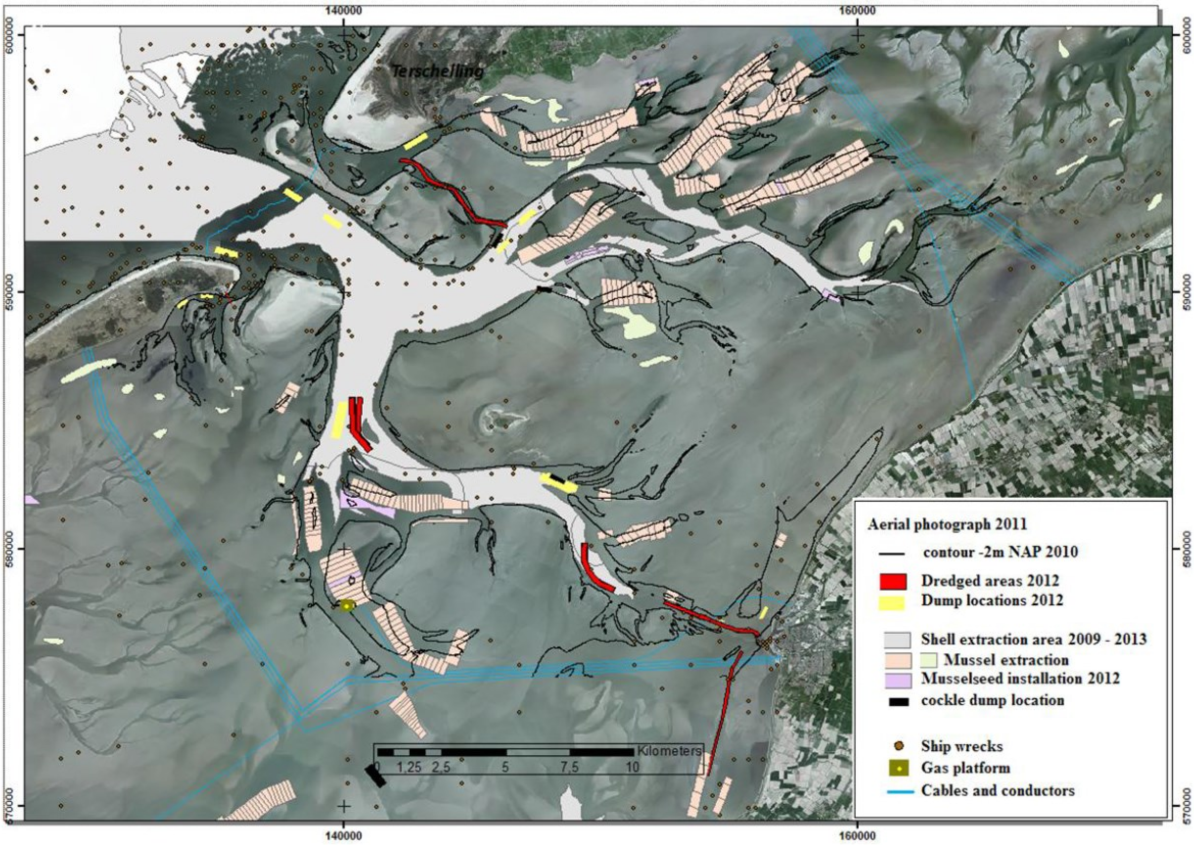
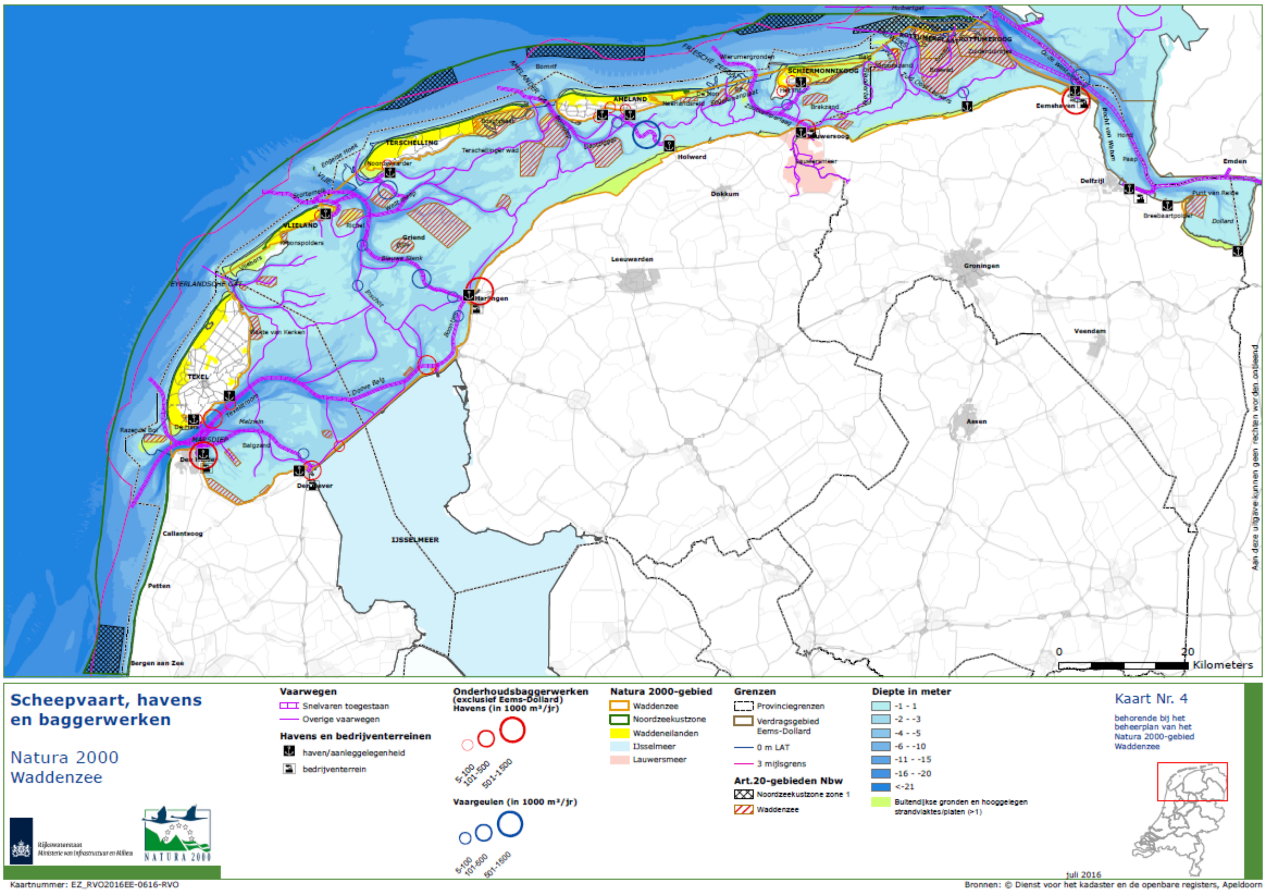
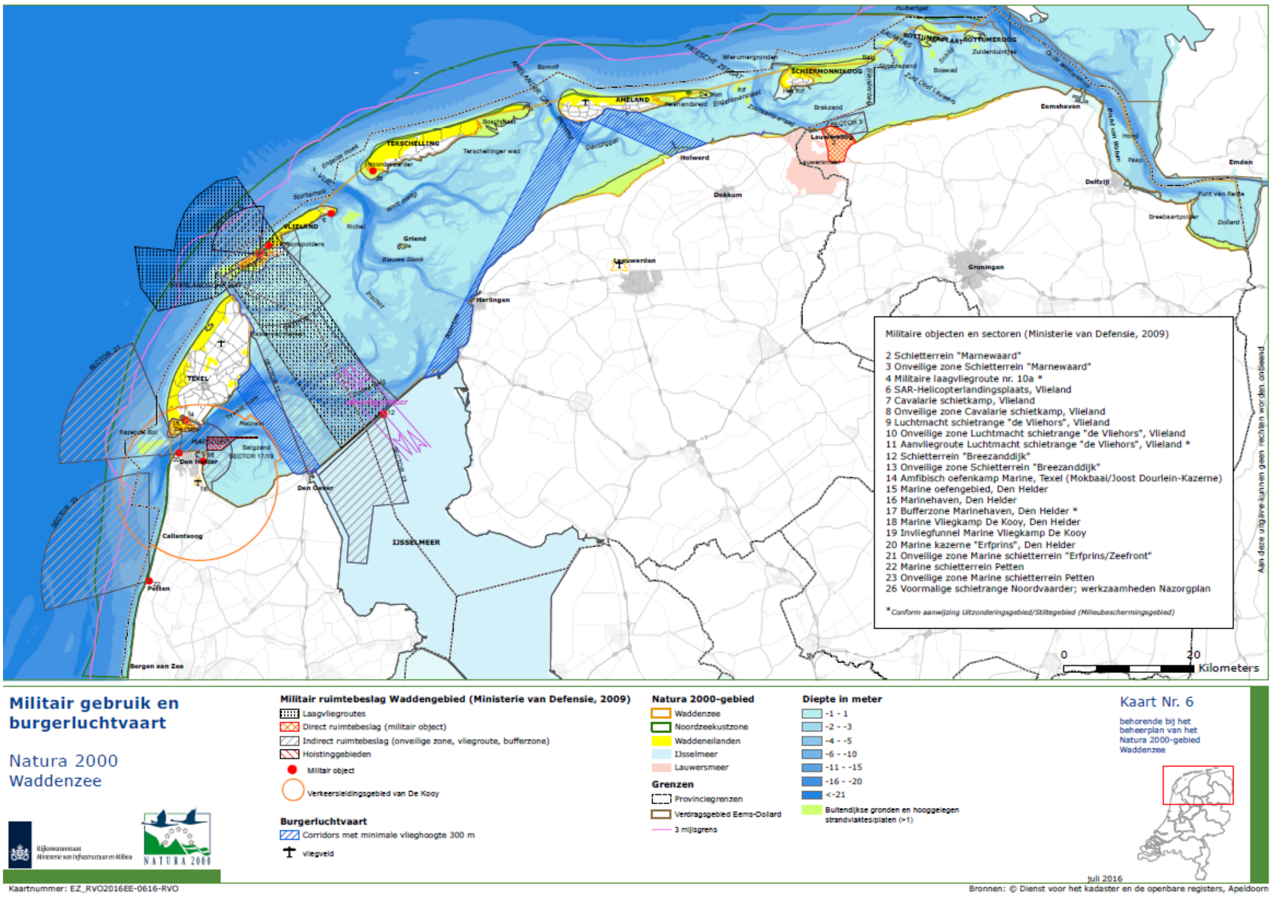
Appendix B. HUMAN ACTIVITIES



Recent economic activities in the Vlie inlet. Source (Rijkswaterstaat NN)


TEXEL
VLIELAND
TERSCHELLING
AMELAND
SCHIERMONNIKOOG
Den Helder
Harlingen
Holwerd
Lauwersoog
Eemshaven
Delfzijl
Emden
Dollard
Leeuwarden
Dokkum
Groningen
Veendam
Assen
IJSSELMEER
Den Oever
Callantsoog
Petten
Bergen aan Zee
MARSDIEP
EYERLANDSCHE GAT
0
20
Kilometers
Aan deze uitgave kunnen geen rechten worden ontleend
Scheepvaart, havens en baggerwerken
Natura 2000 Waddenzee
Vaarwegen
Snelvaren toegestaan
Overige vaarwegen
Havens en bedrijventerreinen
haven/aanleggelegenheid
bedrijventerrein
Onderhoudsbaggerwerken (exclusief Eems-Dollard)
Havens (in 1000 m³/jr)
5-100
101-500
501-1500
Vaargeulen (in 1000 m³/jr)
5-100
101-600
501-1500
Natura 2000-gebied
Waddenzee
Noordzeekustzone
Waddeneilanden
IJsselmeer
Lauwersmeer
Grenzen
Provinciegrenzen
Verdragsgebied Eems-Dollard
0 m LAT
3 mijlsgrens
Art.20-gebieden Nbw
Noordzeekustzone zone 1
Waddenzee
Diepte in meter
-1 - 1
-2 - -3
-4 - -5
-6 - -10
-11 - -15
-16 - -20
<-21
Buitendijkse gronden en hooggelegen strandvlaktes/platen (>1)
Kaart Nr. 4
behorende bij het beheerplan van het Natura 2000-gebied Waddenzee
Rijkswaterstaat
Ministerie van Infrastructuur en Milieu
NATURA 2000
juli 2016
Kaartnummer: EZ_RVO2016EE-0616-RVO
Bronnen: © Dienst voor het kadaster en de openbare registers, Apeldoorn


TEXEL
VLIELAND
TERSCHELLING
AMELAND
SCHIERMONNIKOOG
Den Helder
Callantsoog
Petten
Bergen aan Zee
Den Oever
IJSSELMEER
Harlingen
Leeuwarden
Holwerd
Dokkum
Groningen
Eemshaven
Delfzijl
Emden
Dollard
Breebaartpolder
Militaire objecten en sectoren (Ministerie van Defensie, 2009)
2 Schietterrein "Marnewaard"
3 Onveilige zone Schietterrein "Marnewaard"
4 Militaire laagvliegroute nr. 10a *
6 SAR-Helicopterlandingsplaats, Vlieland
7 Cavalarie schietkamp, Vlieland
8 Onveilige zone Cavalarie schietkamp, Vlieland
9 Luchtmacht schietrange "de Vliehors", Vlieland
10 Onveilige zone Luchtmacht schietrange "de Vliehors", Vlieland
11 Aanvliegroute Luchtmacht schietrange "de Vliehors", Vlieland *
12 Schietterrein "Breezanddijk"
13 Onveilige zone Schietterrein "Breezanddijk"
14 Amfibisch oefenkamp Marine, Texel (Mokbaai/Joost Dourlein-Kazerne)
15 Marine oefengebied, Den Helder
16 Marinehaven, Den Helder
17 Bufferzone Marinehaven, Den Helder *
18 Marine Vliegkamp De Kooy, Den Helder
19 Invliegfunnel Marine Vliegkamp De Kooy
20 Marine kazerne "Erfprins", Den Helder
21 Onveilige zone Marine schietterrein "Erfprins/Zeefront"
22 Marine schietterrein Petten
23 Onveilige zone Marine schietterrein Petten
26 Voormalige schietrange Noordvaarder; werkzaamheden Nazorgplan
*Conform aanwijzing Uitzonderingsgebied/Stiltegebied (Milieubeschermingsgebied)
0
20
Kilometers
Militair gebruik en burgerluchtvaart
Natura 2000 Waddenzee
Rijkswaterstaat
Ministerie van Infrastructuur en Milieu
NATURA 2000
Militair ruimtebeslag Waddengebied (Ministerie van Defensie, 2009)
Laagvliegroutes
Direct ruimtebeslag (militair object)
Indirect ruimtebeslag (onveilige zone, vliegroute, bufferzone)
Hoistinggebieden
Militair object
Verkeersleidingsgebied van De Kooy
Burgerluchtvaart
Corridors met minimale vlieghoogte 300 m
vliegveld
Natura 2000-gebied
Waddenzee
Noordzeekustzone
Waddeneilanden
IJsselmeer
Lauwersmeer
Grenzen
Provinciegrenzen
Verdragsgebied Eems-Dollard
3 mijlsgrens
Diepte in meter
-1 - 1
-2 - -3
-4 - -5
-6 - -10
-11 - -15
-16 - -20
<-21
Buitendijkse gronden en hooggelegen strandvlaktes/platen (>1)
Kaart Nr. 6
behorende bij het beheerplan van het Natura 2000-gebied Waddenzee
juli 2016
Kaartnummer: EZ_RVO2016EE-0616-RVO
Bronnen: © Dienst voor het kadaster en de openbare registers, Apeldoorn

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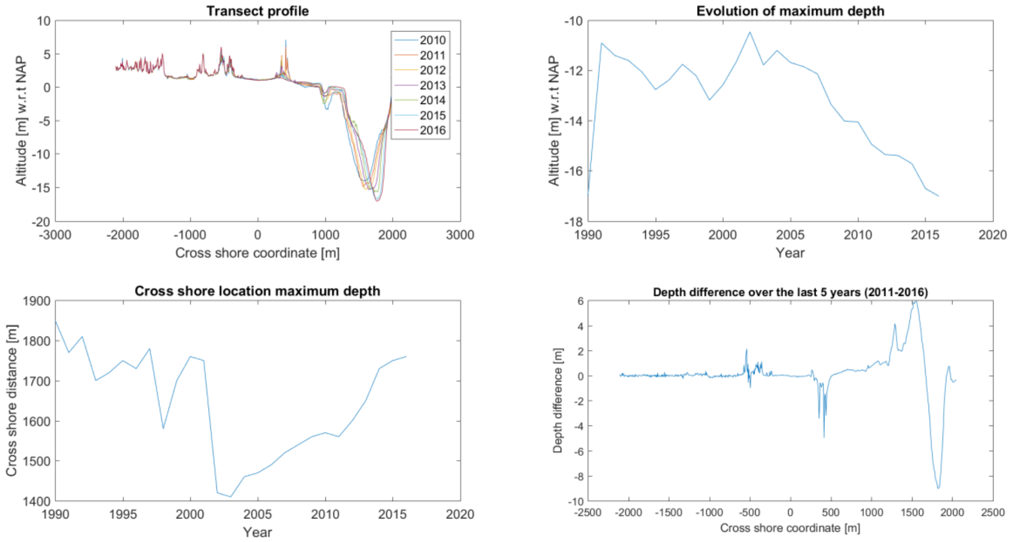
Appendix C. Jarkus Data Terschelling

Overview of transect 4000000



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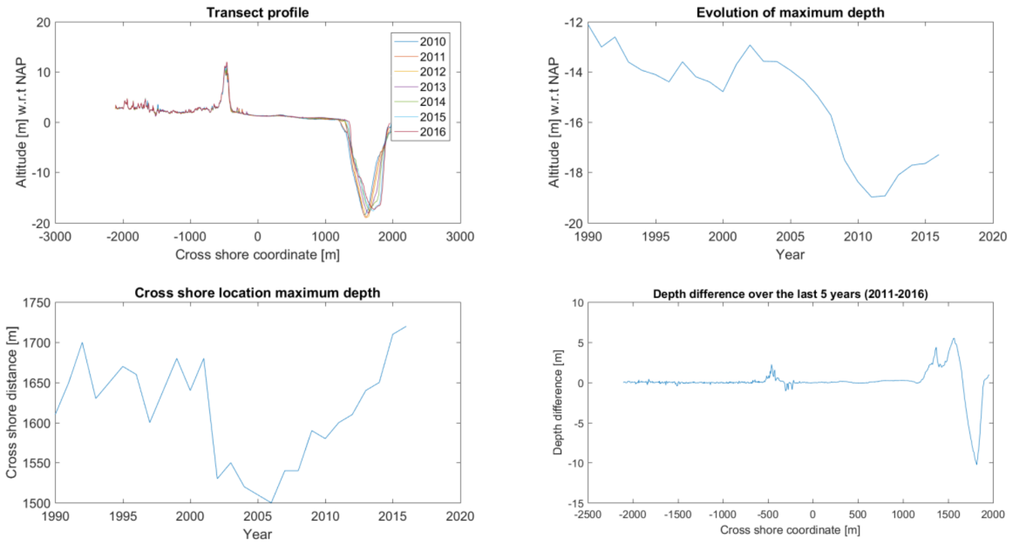
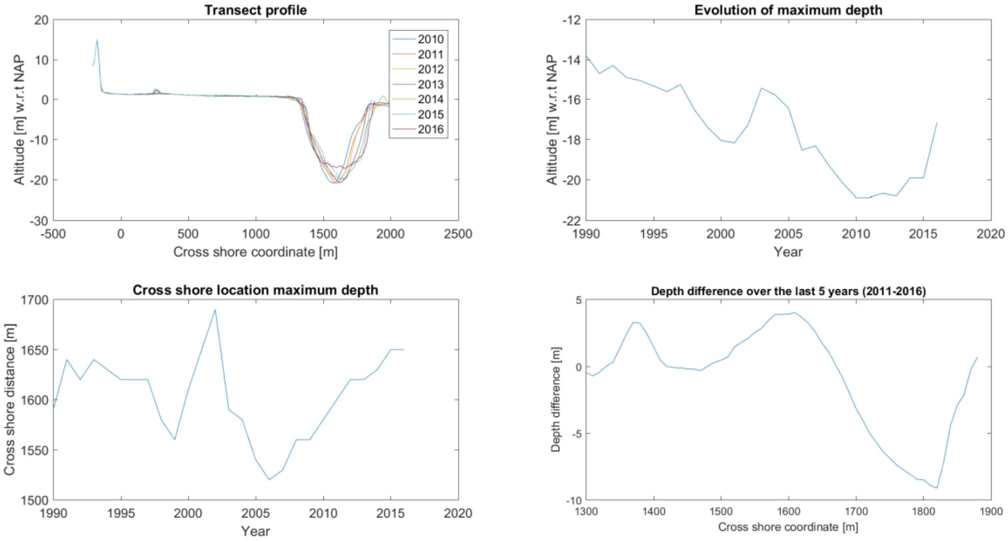
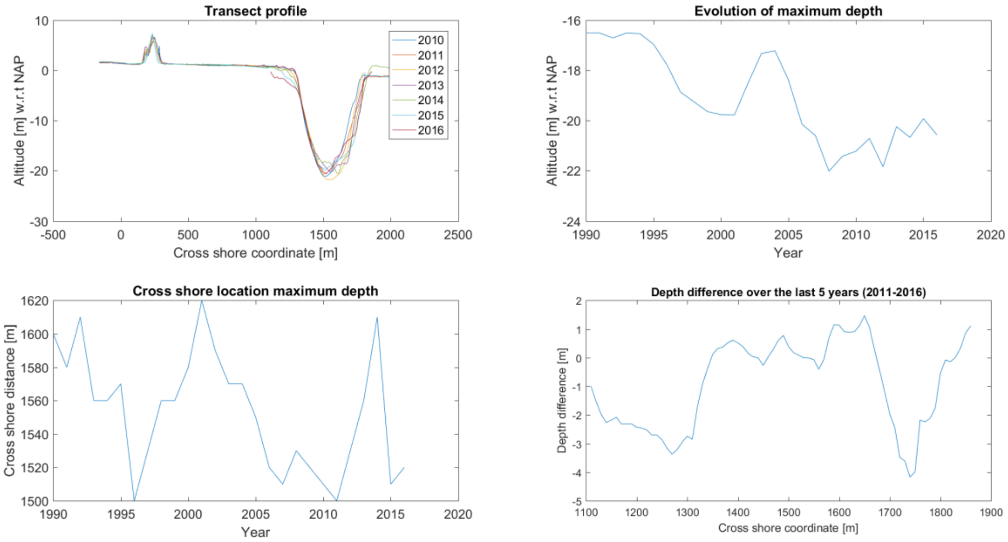


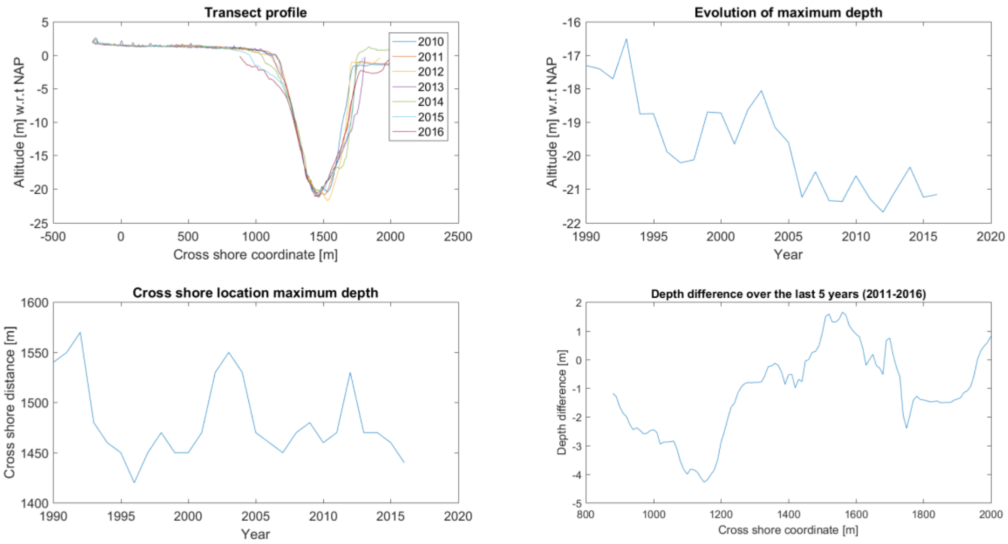
Overview of transect 4000040



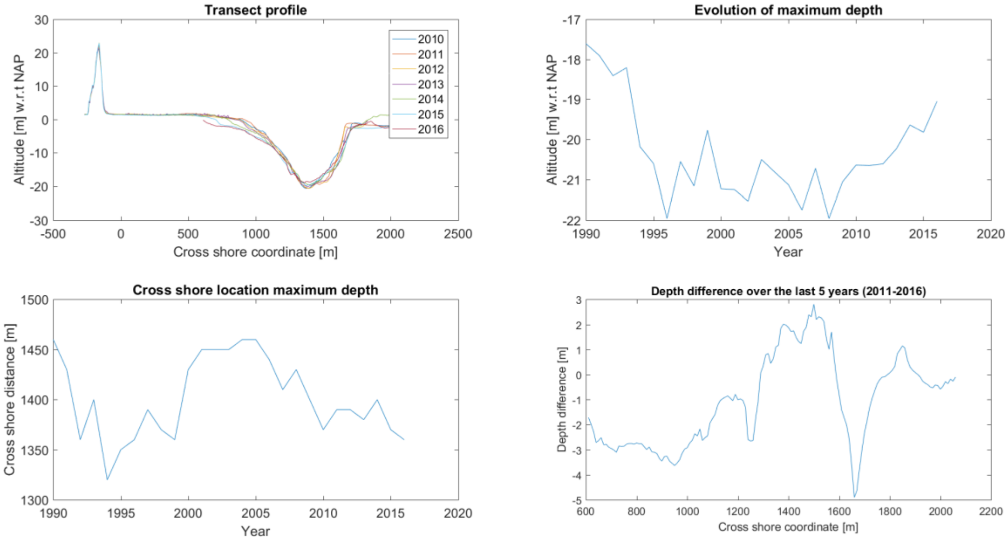
Overview of transect 4000060



Overview of transect 4000080



Overview of transect 4000100



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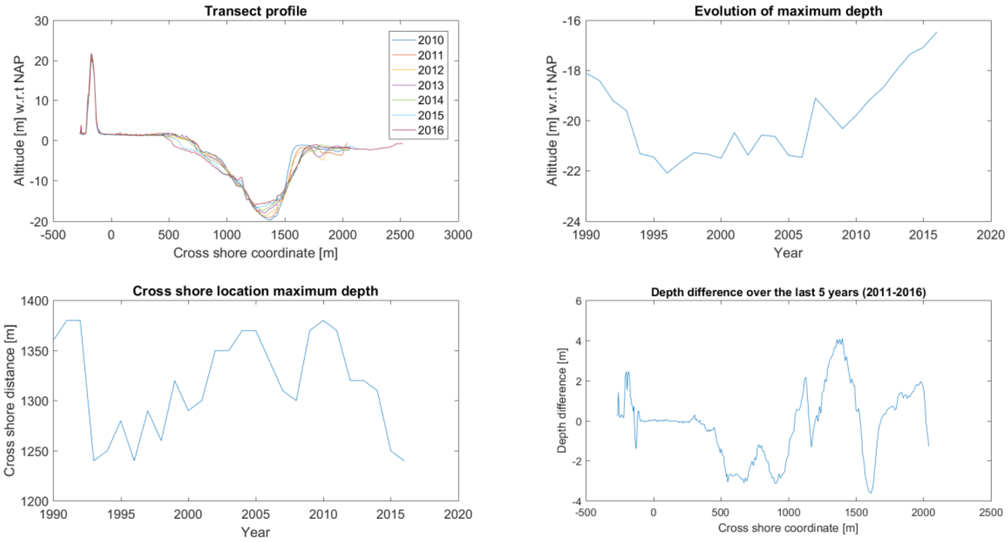

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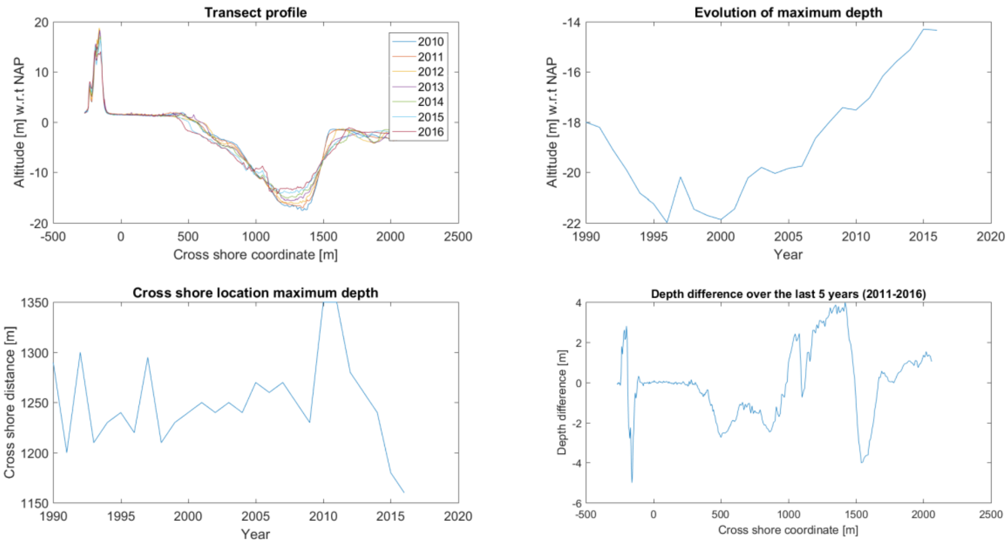
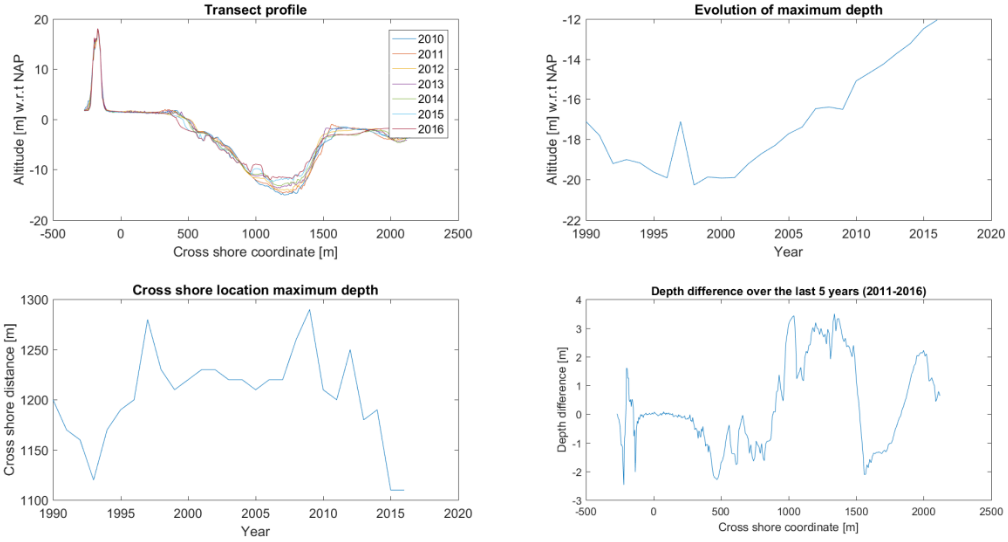


Overview of transect 4000103



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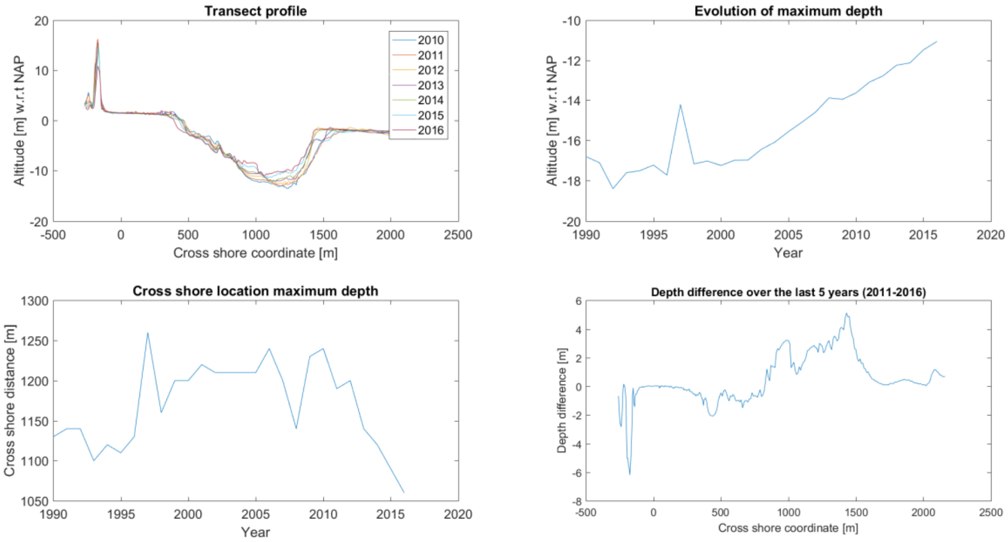
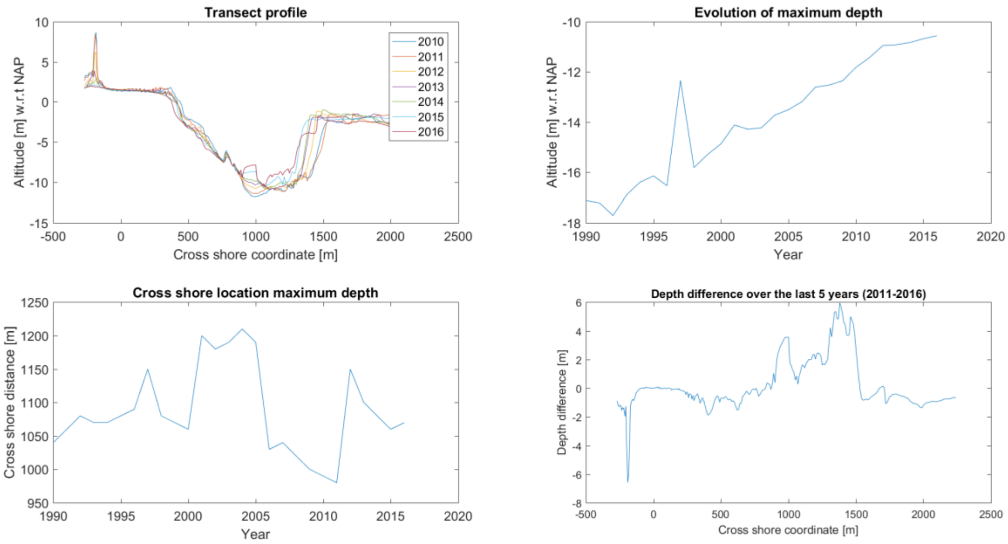
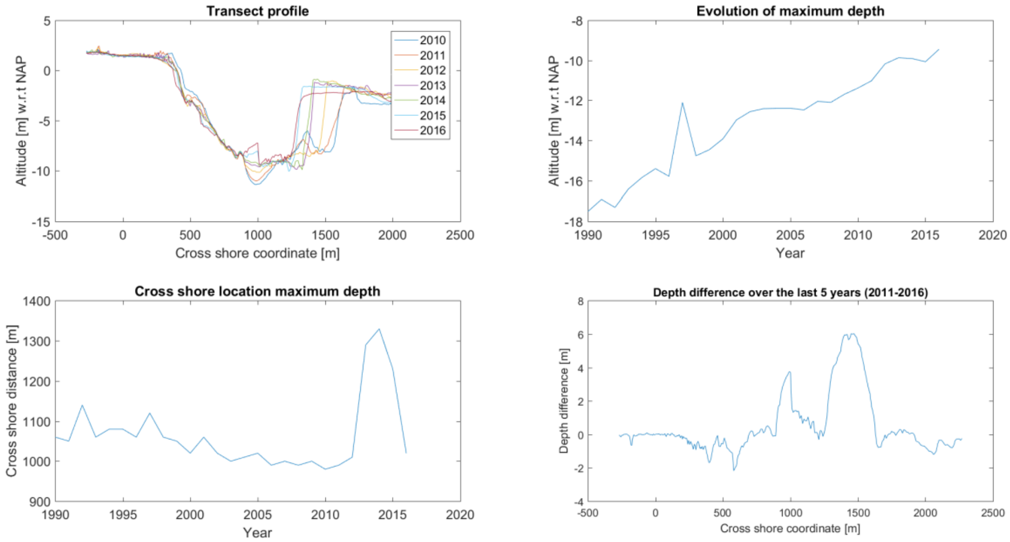


Overview of transect 4000105



Overview of transect 4000106



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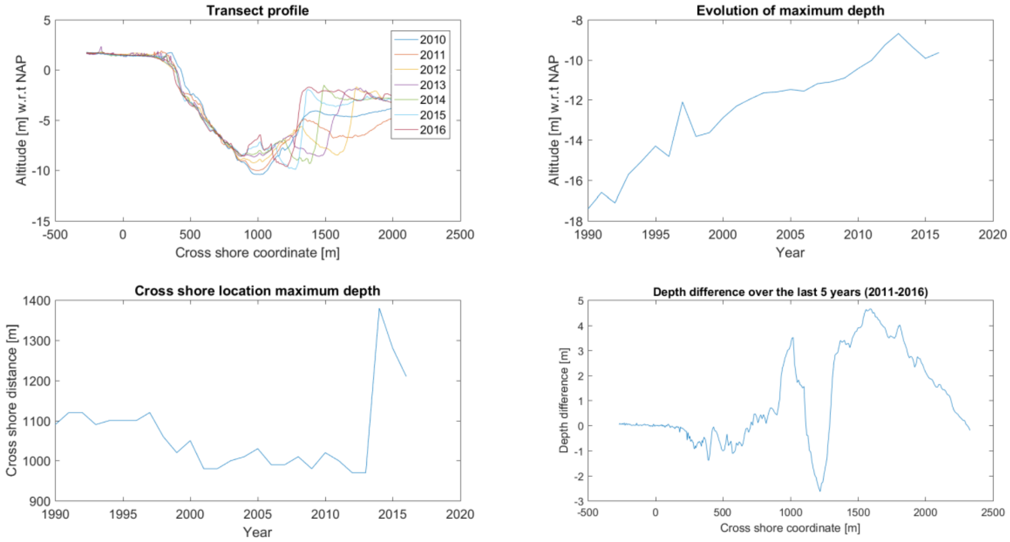

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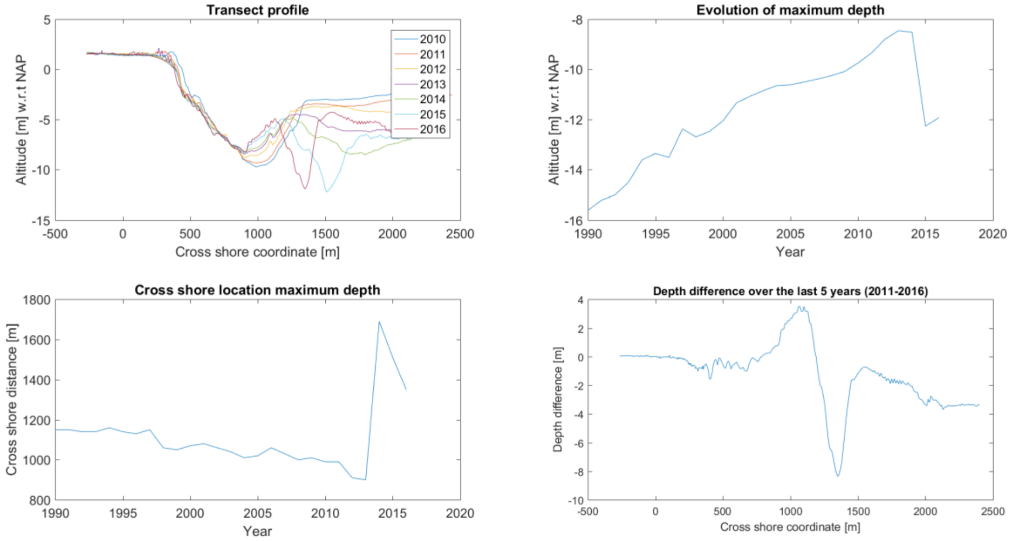

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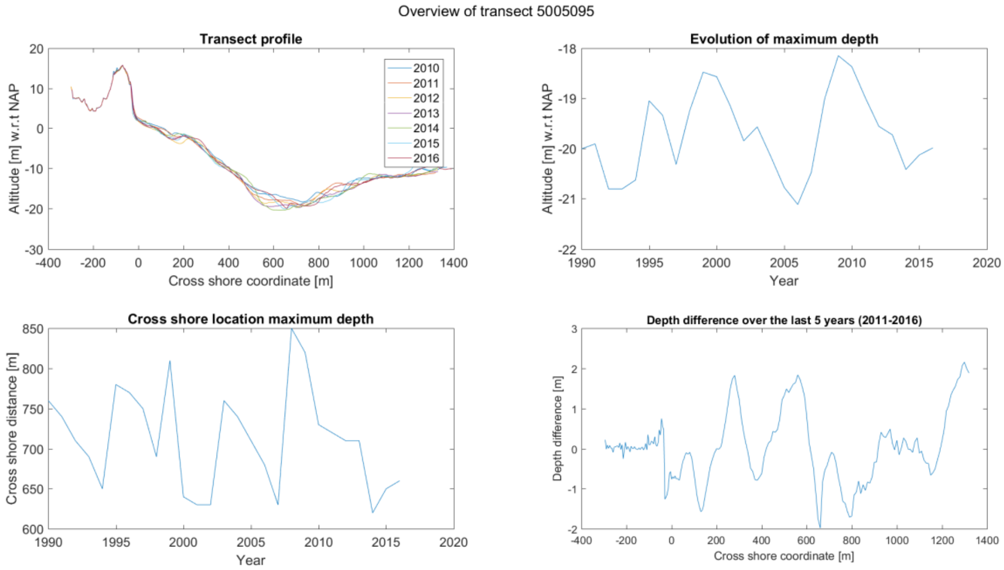
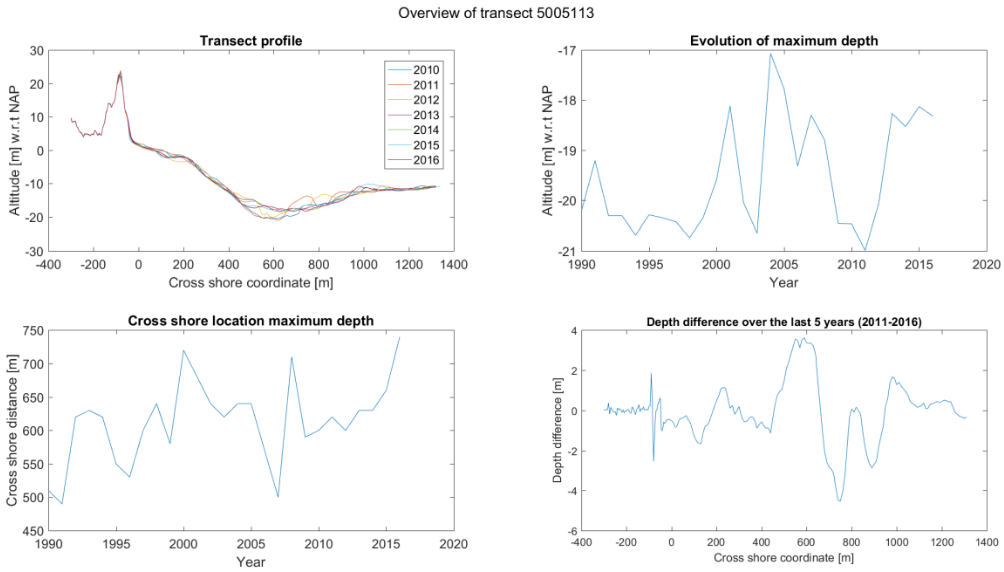
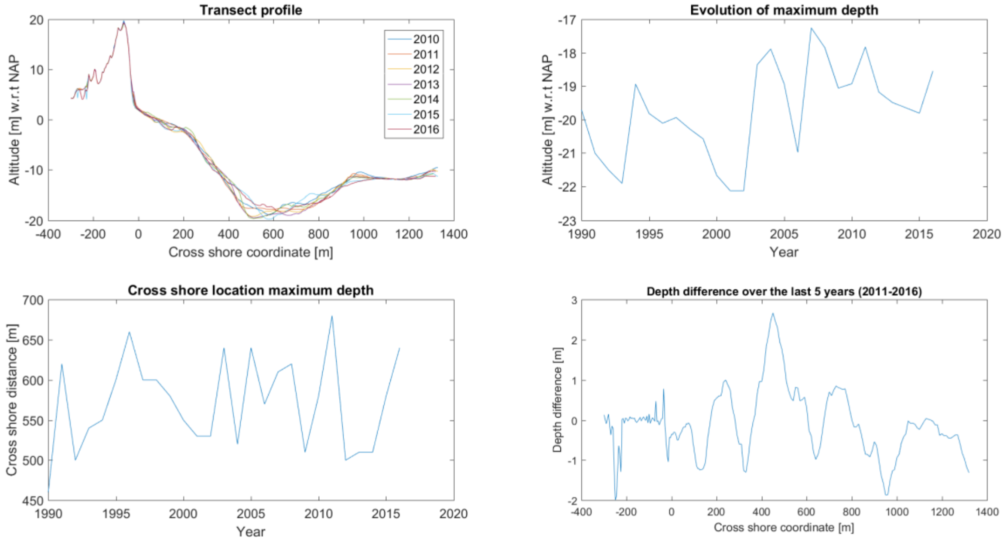
Appendix D. JARKUS DATA VLIELAND

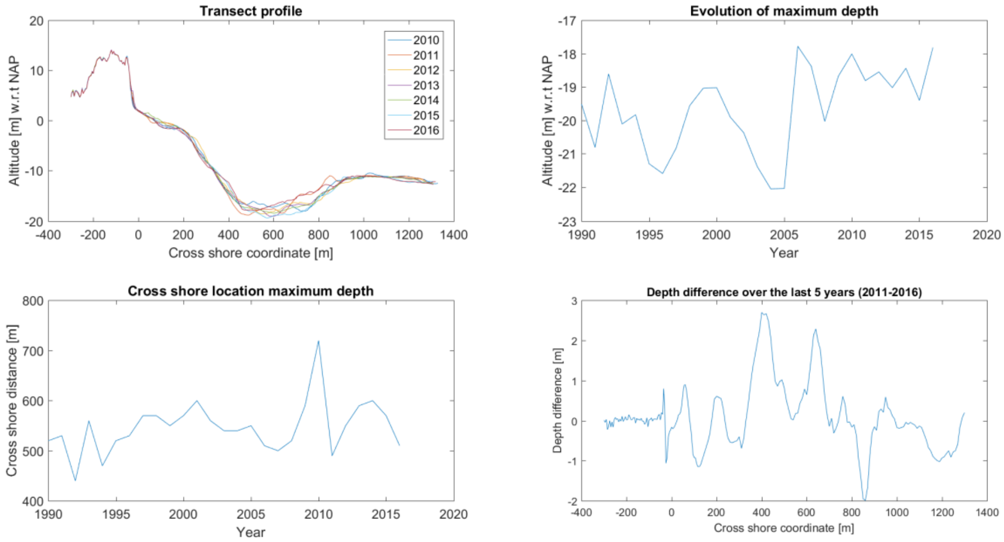




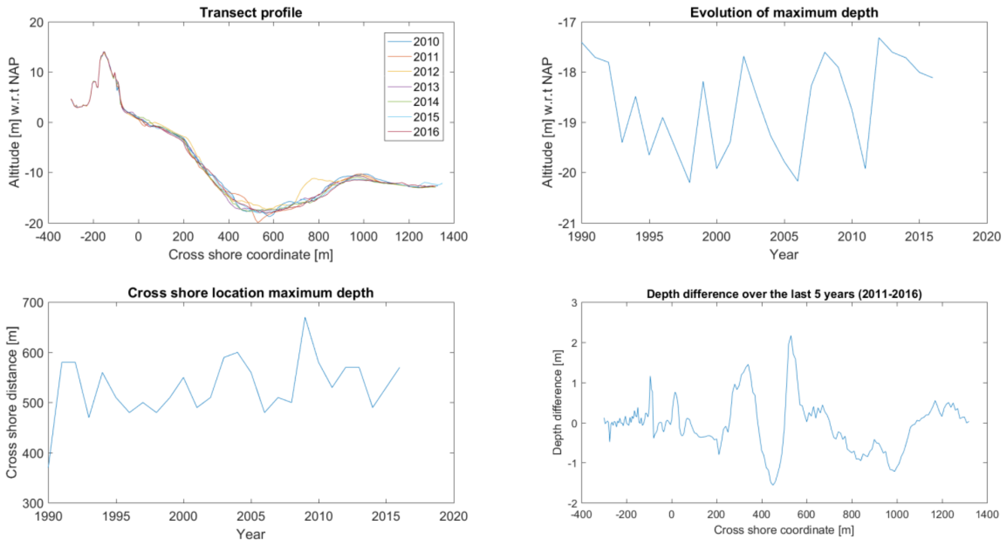
Overview of transect 5005129

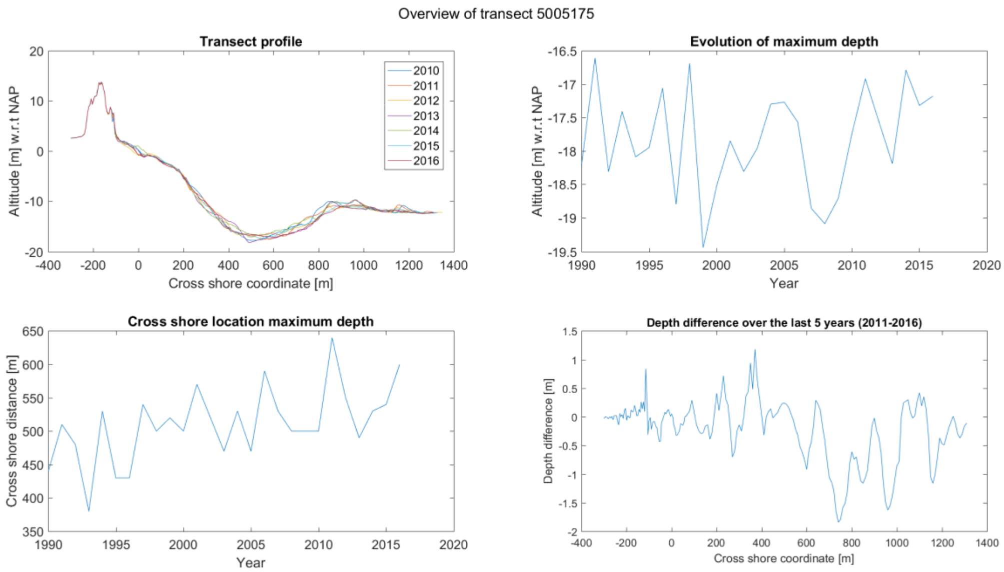


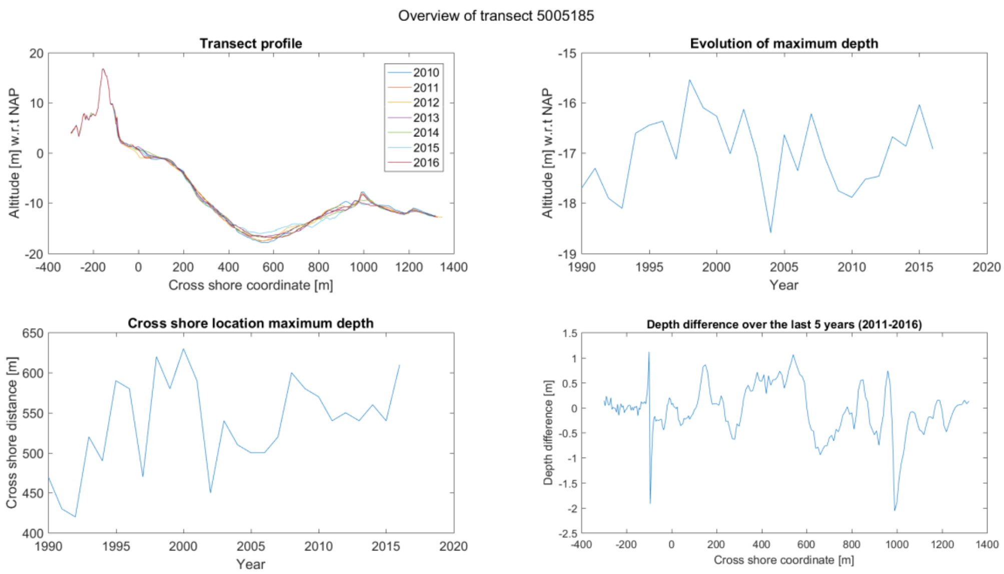
Overview of transect 5005146

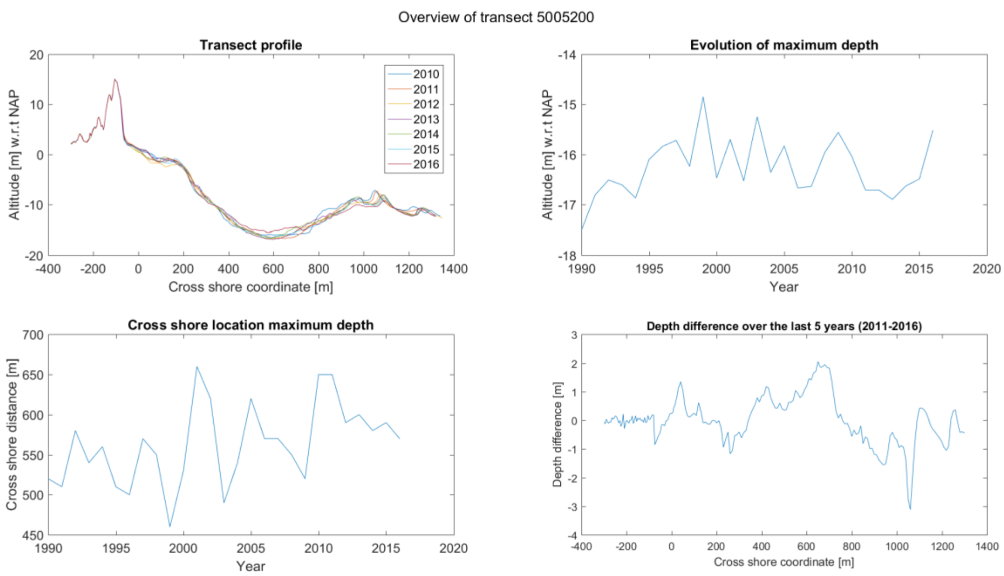


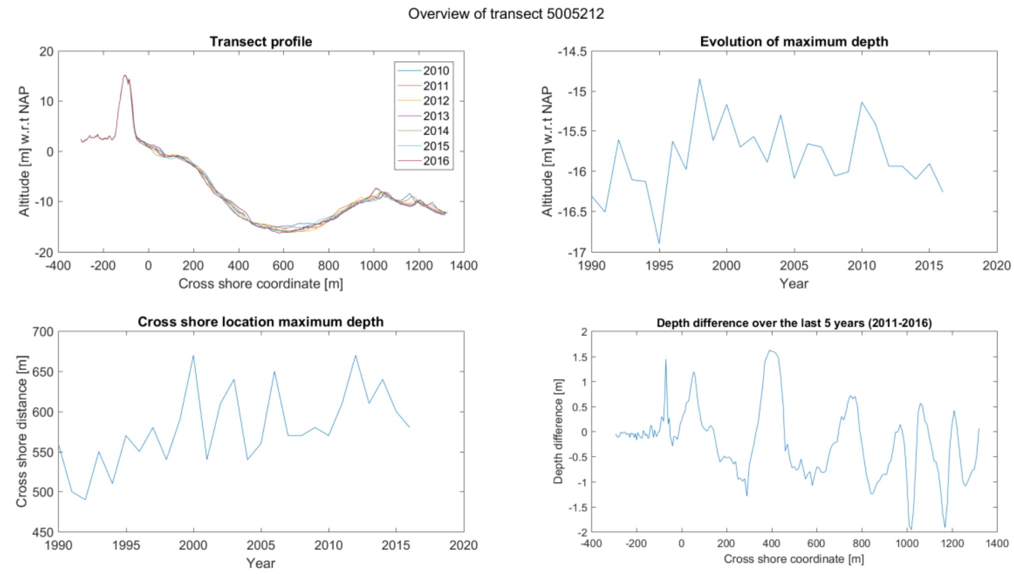
Overview of transect 5005165

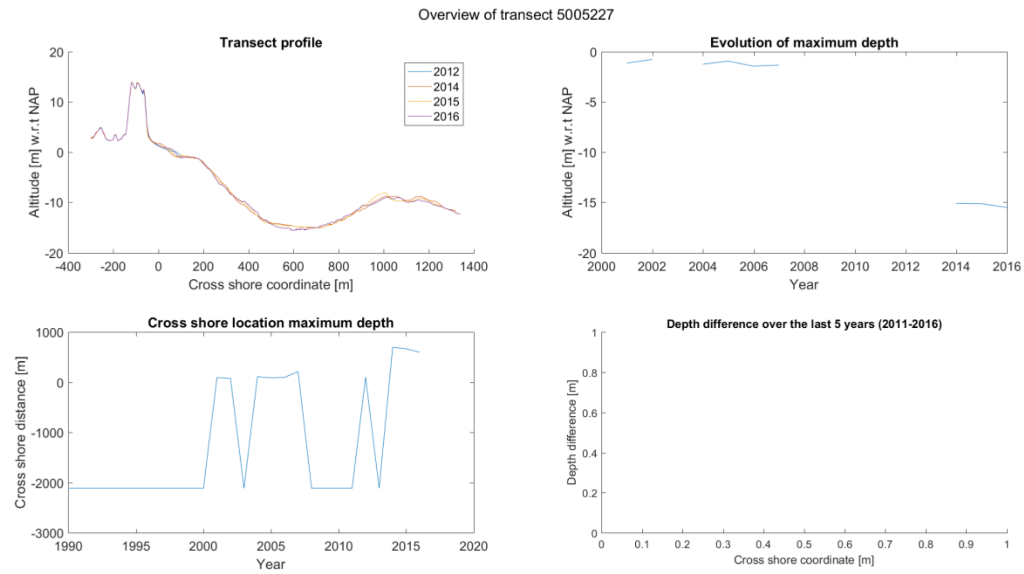


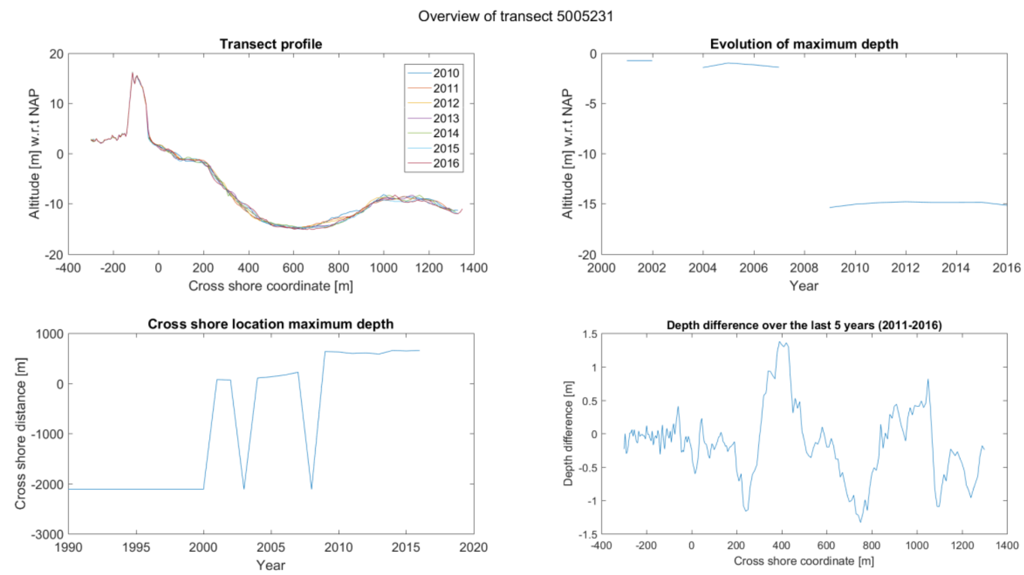

Overview of transect 5005175
Transect profile
Altitude [m] w.r.t NAP
Cross shore coordinate [m]
2010
2011
2012
2013
2014
2015
2016
Evolution of maximum depth
Altitude [m] w.r.t NAP
Year
Cross shore location maximum depth
Cross shore distance [m]
Year
Depth difference over the last 5 years (2011-2016)
Depth difference [m]
Cross shore coordinate [m]


Overview of transect 5005185
Transect profile
Altitude [m] w.r.t NAP
Cross shore coordinate [m]
2010
2011
2012
2013
2014
2015
2016
Evolution of maximum depth
Altitude [m] w.r.t NAP
Year
Cross shore location maximum depth
Cross shore distance [m]
Year
Depth difference over the last 5 years (2011-2016)
Depth difference [m]
Cross shore coordinate [m]

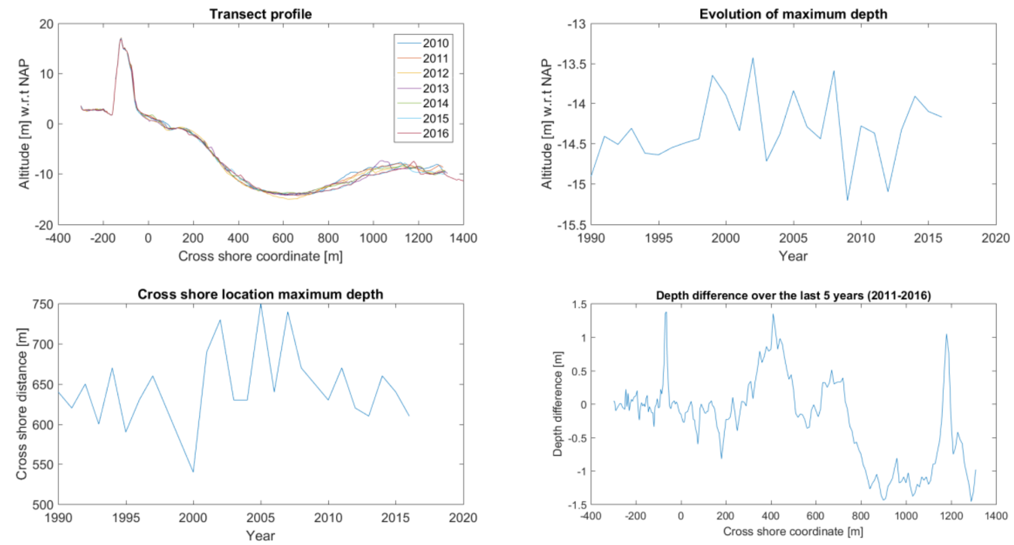

Overview of transect 5005200
Transect profile
Altitude [m] w.r.t NAP
Cross shore coordinate [m]
2010
2011
2012
2013
2014
2015
2016
Evolution of maximum depth
Altitude [m] w.r.t NAP
Year
Cross shore location maximum depth
Cross shore distance [m]
Year
Depth difference over the last 5 years (2011-2016)
Depth difference [m]
Cross shore coordinate [m]


Overview of transect 5005212
Transect profile
Altitude [m] w.r.t NAP
Cross shore coordinate [m]
2010
2011
2012
2013
2014
2015
2016
Evolution of maximum depth
Altitude [m] w.r.t NAP
Year
Cross shore location maximum depth
Cross shore distance [m]
Year
Depth difference over the last 5 years (2011-2016)
Depth difference [m]
Cross shore coordinate [m]

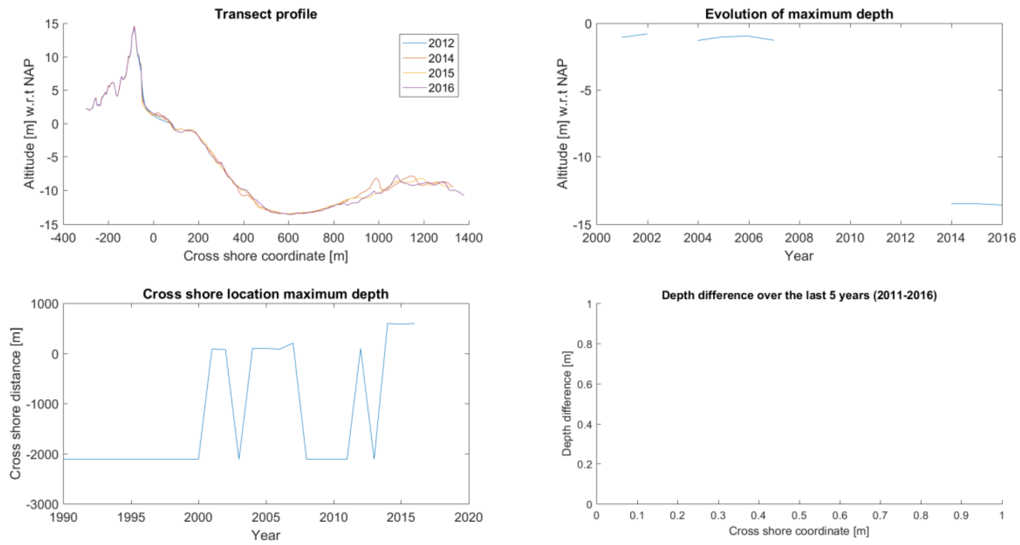

Overview of transect 5005227
Transect profile
Altitude [m] w.r.t NAP
Cross shore coordinate [m]
2012
2014
2015
2016
Evolution of maximum depth
Altitude [m] w.r.t NAP
Year
Cross shore location maximum depth
Cross shore distance [m]
Year
Depth difference over the last 5 years (2011-2016)
Depth difference [m]
Cross shore coordinate [m]


Overview of transect 5005231
Transect profile
Altitude [m] w.r.t NAP
Cross shore coordinate [m]
2010
2011
2012
2013
2014
2015
2016
Evolution of maximum depth
Altitude [m] w.r.t NAP
Year
Cross shore location maximum depth
Cross shore distance [m]
Year
Depth difference over the last 5 years (2011-2016)
Depth difference [m]
Cross shore coordinate [m]

Overview of transect 5005250



Overview of transect 5005267



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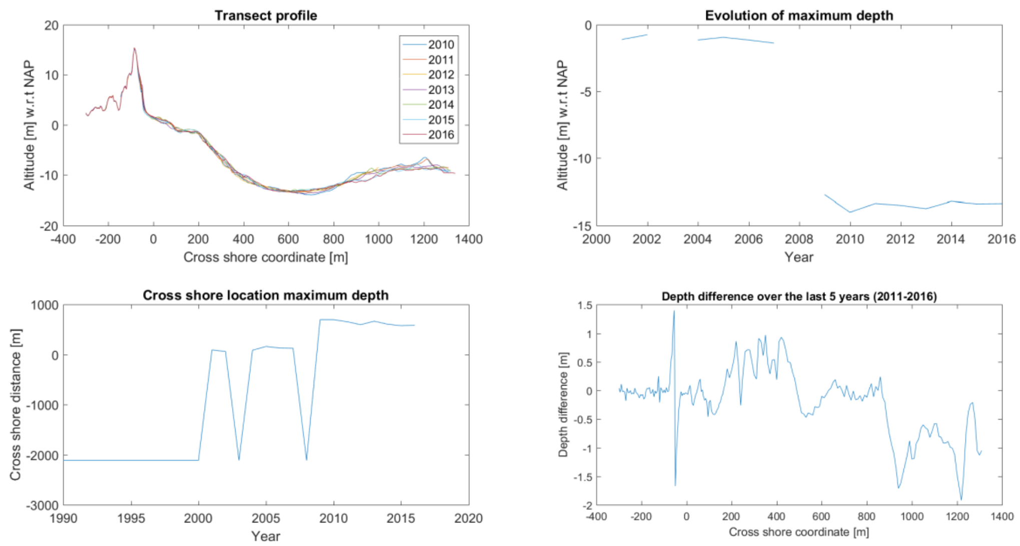

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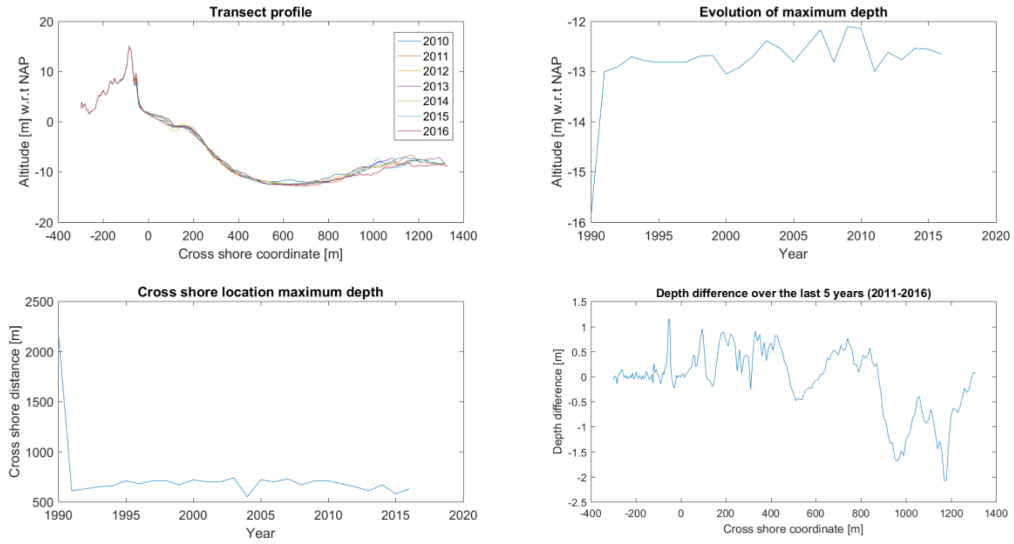

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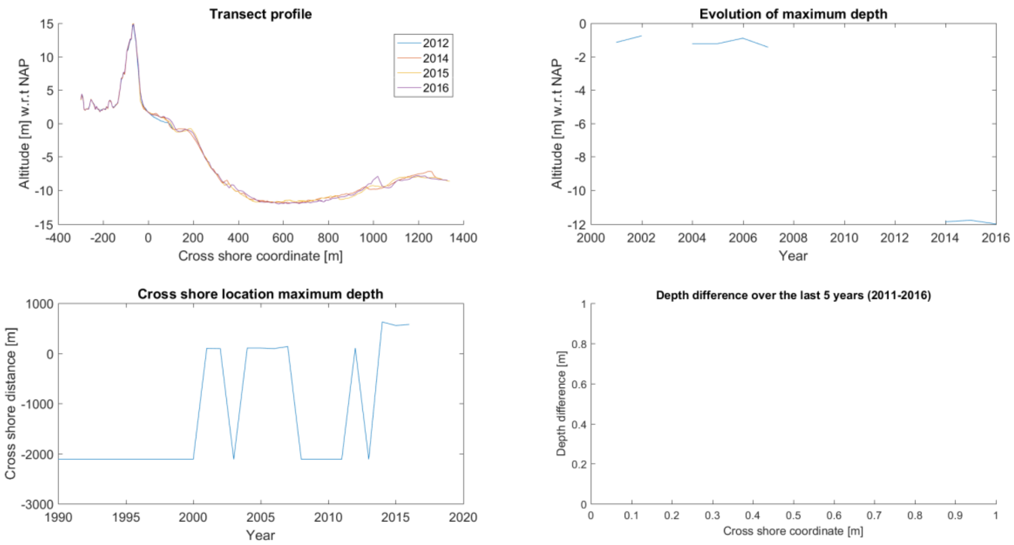

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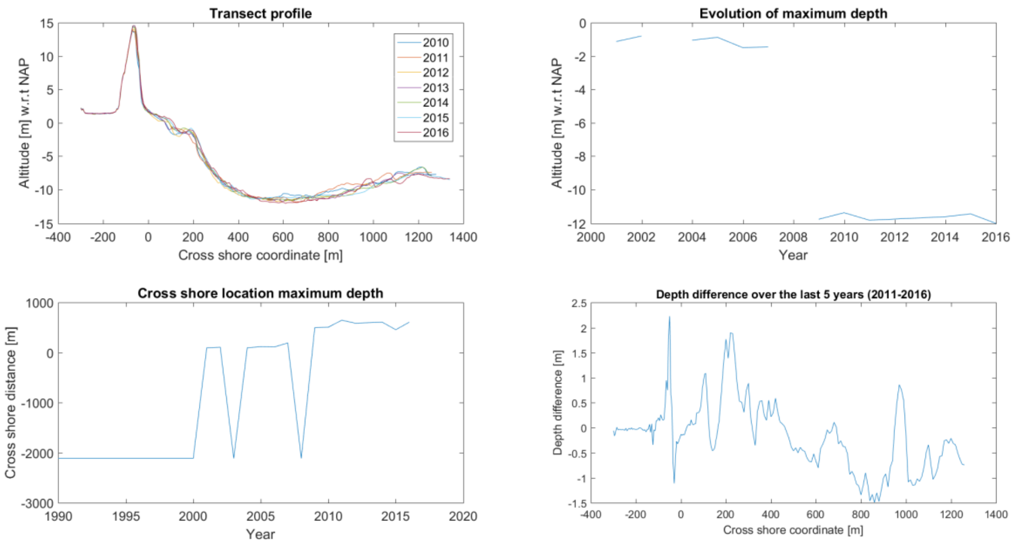
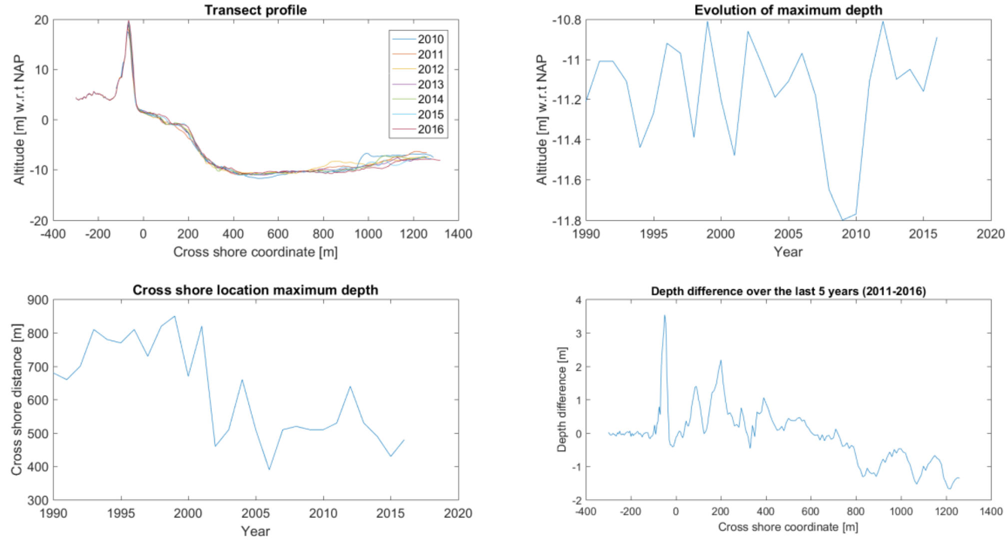
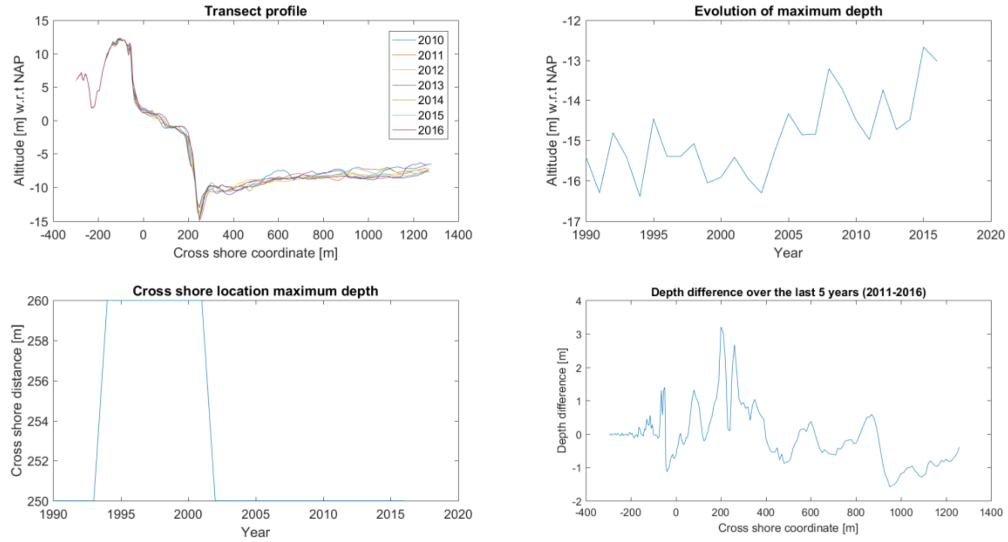


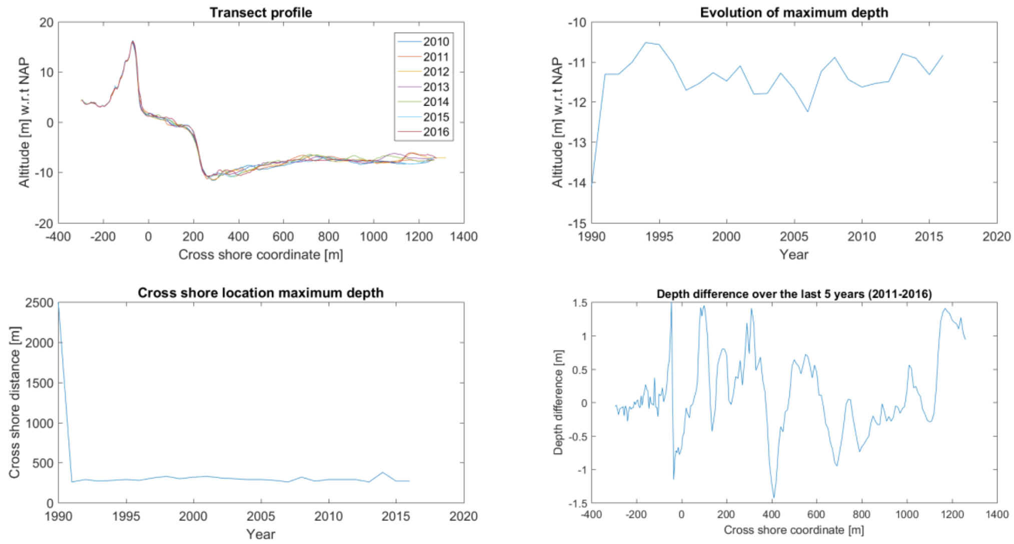
Overview of transect 5005329



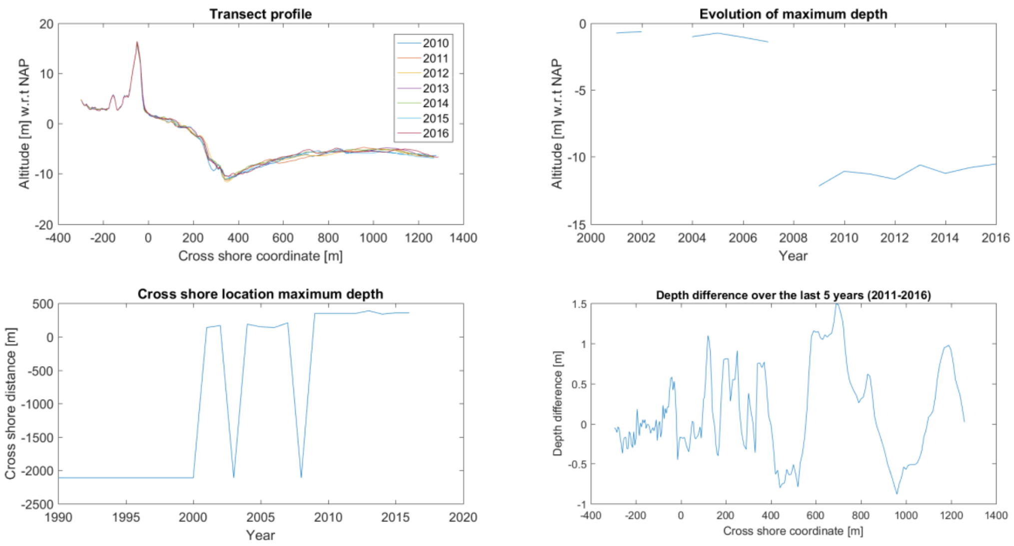
Overview of transect 5005353



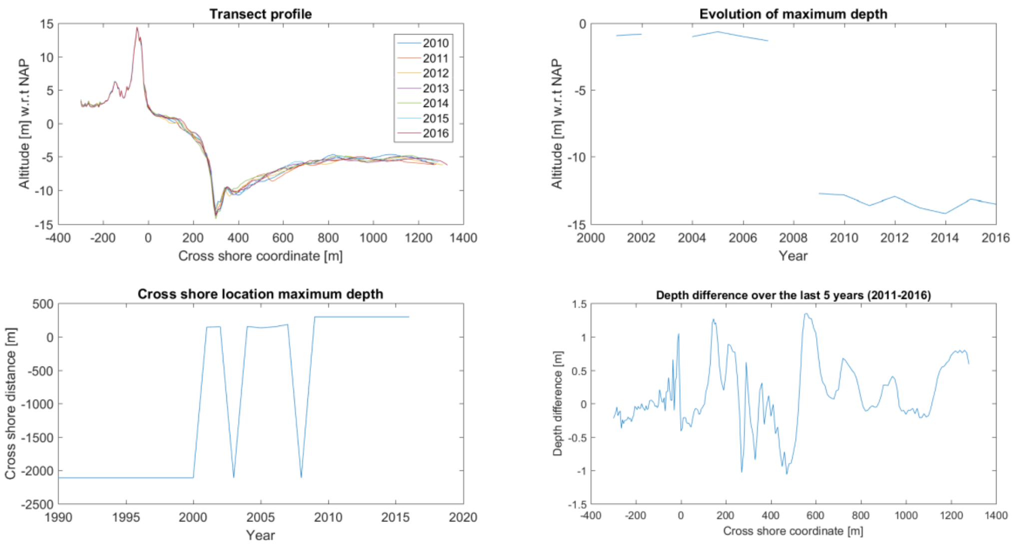
Overview of transect 5005360



Overview of transect 5005367



Overview of transect 5005371



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Appendix E. Example of a Cable

TKF CONNECTIVITY SOLUTIONS

LTC JF MT SWA

Article number: 78177 Date: 31-03-2017

LTC JF MT SWA
96x SM G.657.A1 (8x12)

Product characteristics

Cable type	LTC
Fibre type	Single mode 9/125
Optical fibre standard	ITU-T G.657.A1
Number of fibers	96
Number of fibers per optical element	12
Number of cores	8
Optical element	Loose tube, gel filled
Cable metal free	No
Number of layers	1 Layer
Strain relief	Yes
Type of strain relief	Steel wire
Armouring	Yes
Armouring/reinforcement	Steel wire
Diameter over armouring (nom.)	17,1 mm
Marking	ACE - TKF LTC JF MT SWA 96x SM G.657.A1 A-DF(ZN)(L)2Y(SWA)2Y 78177 {Year} {Batch} {Length}
Material inner sheath	HDPE
Inner sheath thickness	1,3 mm
Diameter over inner sheath (nom.)	13,3 mm
Material outer sheath	HDPE

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Colour outer sheath	Black
Outer sheath thickness	2,0 mm
Outer diameter approx.	21,1 mm
Weight (kg)	0.880

Application

Test procedures	EN IEC 60794-1-2
Maximum water depth	250 m
Application	Outside

Mechanical specification

Tensile load short term (Tm)	20000 N
Tensile load Long Term (Tl)	6000 N
Bending radius during installation	530 mm
Bending radius after installation	320 mm
Crush resistance E3A short (1min)	8000 N/dm
Crush resistance E3A long	4000 N/dm
Crush load E3A long application time	10 min
Crush resistance E3B short term (1min)	3000 N/dm
Crush resistance E3B long term	1000 N/dm
Crush load E3B long application time	10 min
Mandrel diameter by Crush meth. E3B	25 mm
Impact strength	50 J
Striking surface radius	10 mm
Torsion resistance	180 °/m

Optical specification

Category according to EN 50173	OS2
Attenuation @ 1310 nm	0.35 dB/km
Attenuation @ 1550 nm	0,22 dB/km
Attenuation @ 1625 nm	0,25 dB/km

Colour outer sheath	Black
Outer sheath thickness	2,0 mm
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Weight (kg)	0.880

Application

Test procedures	EN IEC 60794-1-2
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Crush resistance E3B long term	1000 N/dm
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Crush load E3A long application time	10 min
Crush resistance E3B short term (1min)	3000 N/dm
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Torsion resistance	180 °/m

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Attenuation @ 1310 nm	0.35 dB/km
Attenuation @ 1550 nm	0,22 dB/km
Attenuation @ 1625 nm	0,25 dB/km

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Appendix F. COST PRICE CALCULATION FOR DREDGING VESSELS (IJSEBAERT, 2010)

Rough costprice calculation of TSHD's and CSD's

1 Introduction

The weekly cost of a TSHD is the sum of:

1. DI: Depreciation And Interest
2. Maintenance and Repairs
3. Insurance
4. Crew
5. Fuel and Lubricants
6. Wear and Tear

The actual cost price of a piece of dredging equipment is depending on a large number of parameters. The capital cost form a large part of these costs and it was recognized that a standard method was needed to establish these costs. A method is described in CIRIA 2005. With this method Depreciation and Interest and Maintenance and repairs can be determined.

2 The hopper dredger

2.1 Computation of D+I and M&R

The value of these components can be established in case the following information is known:

W: Lightweight ship [ton]
P_t : Power dredgpumps during suction [kW]
J_t : Power jetpumps during suction
S: Free sailing power

SH: Service hours per week
Discharge method : dumping or pumping/rainbowing

The fist step is the calculation of the Computation of Value:

$$V = 4400W + 894000W^{0.35} - 4766000 + 1400P_t + 580J_t + 670S \quad [€]$$

2.2 Computation of D+I

When the 'value' of the vessel is known the depreciation and interest can be computed. Several methods are used. One of the methods is based on annuity.

The weekly costs for D+I follows in that case from the following equation:

$$DI = A \cdot V$$

$$A = \frac{i}{p^n - 1}\frac{1}{u}\left(p^n - z\right)$$

Where:

i	interest rate	[-]
n	Service life	[yr]
p	1 + i	[-]
u	utilization	[week/year]
z	residual value at rest of service life as a fraction of V	[-]

example:
i=0.07, n =18 years, u = 33 weeks per year and z = 0.1 (10% restvalue):

DI = 0.00292V [€/week]

2.3 Computation of MR

The amount for maintenance and repair is also related to the value V of the vessel. A certain percentage per week is given in the table below:

V [€]	% per week
7,840,000	0.23
9,480,000	0.225
11,300,000	0.219
13,000,000	0.213
14,600,000	0.206
17,800,000	0.185
20,000,000	0.17
24,700,000	0.151
30,100,000	0.133
36,900,000	0.123
42,800,000	0.114
50,500,000	0.107
59,100,000	0.103
66,000,000	0.101
71,900,000	0.1
94,200,000	0.099
104,000,000	0.099
116,000,000	0.098
135,000,000	0.098
156,000,000	0.098

The value per week is divided by a fixed and a variable (as function of the working hours) part. The discharge method has an influence on the M+R costs. Rainbowing and pumping will lead to more M+R because these discharge methods will create a lrager workload for the dredging installation.

Step 1: Compute M1 which is the percentage of the value V from the table above. For values of V in between given values use linear interpolation.

In case the discharge method is rainbowing or pumping ashore increase the value of M1 by 15 %.

M1T=1.15 *M1

Now split this cost in a fixed part of 30 % and variable past of 70 %. The variable part must be adjusted in case the number of service hours is not equal to 84 h per week with the following formula:

M1var=0.7*M1T*((SH – 84)/84+1)

Hence the total MR per week is:

M1tot=0.7*M1T*((SH – 84)/84+1) +0.3 * M1T

Example:

Suppose the value V = 71,900,000 €. The discharge method is rainbowing. Number of service hours per week is 168 Then:

M1T=1.15*0.1*0.01*71,900,000 = 82,685 €./wk.

Variable part of M&R = 0.7*82,685*(168-84)/84+1)=115,759 €./wk
Fixed part of M&R =0.3*82,685=24806 €./wk

Total M&R per week:
M1tot=115,759 €./wk+24806 €./wk=140,565 €./wk

2.4 *Insurance*

A first guess for the insurance cost per week is 0.03 % of the Value V.

2.5 *Crew*

The total cost for crew depends on the number of working hours per week, the size of the ship and where the vessel is working, since local regulations might dictate the number and origin of the crew. (for instance in Australia, due to Union regulations only local crew is permitted).

The crew cost is the sum of the expat and local crew.

For the exercise the following table can be used. Here we relate the costs to the length of theship.:

Expat crew:

L [m] from	to	cost [euro /wk]
	< 65	21,000
65	80	24,500
80	90	28,000
90	110	42,000
110	135	52,500
	> 135	64,750

Local crew:
Cost = 100*L-3660 €./wk

L is the length of the ship.

2.6 Fuel and Lubricants

2.6.1 Fuel Costs

The fuel cost per week is equal to the fuel consumption per week [ton/wk] times the unit price for fuel. The fuel unit price is expressed in US $ per ton and can be found on the internet. For the fuel consumption a specific consumption can be used:

For IFO 380 : consumption = 0.19 litre /(hour * kW)
For MDO : consumption = 0.26 litre (hour * kW)

Example :

Propulsion power installed : 25,000 kW
Diesel load during sailing: 95 %.
Fuel : IFO 380:

Fuel consumption : 0.95*25,000*0.19 = 4512 litre/hour.

2.6.2 Lubricants

Take 10 % of the fuel cost as costs for lubricants.

2.7 Wear and Tear

Depending on the abrasiveness of the dredged material extra costs must be taken into account for replacement of worn pipelines, pumps etc. on board. These costs are related to the production of the dredger and are expressed in euro's per m^3 dredged. The amount is related to the grain size of the material and can vary from 0.05 €/m^3 for silt (fine grained sediment) up to several €/m^3 for very coarse sediments. For this exercise 0.25 €/m^3 can be taken into account.

3 The cutter suction dredge

The method is comparable with the procedure described for the TSHD.
For the value of V two formula's are used. One for a self-propelled and the other for a non propelled CSD.

Self Propelled:

$$V = 3300C + 1000(P + J) + 6000W + 100000W^{0.35} + 650S$$

Not propelled:

$$V = 3300C + 1000(P + J) + 6400W + 10000W^{0.35}$$

Where:

C	Cutter power	[kW]
P	Power dredge pumps	[kW]
J	Power jet pumps	[kW]
W	Lightweight	[ton]

3.1 *Depreciation and interest*

Calculated with the same method as for the hopper

3.2 *Maintenance and Repairs*

This is a factor times the Value V per week, based on 84 hr/week. For different hours see section 2.3.

3.3 *Insurance*

See section 2.4

3.4 *Crew*

The following table can be used . The cost for expat and local crew based on 168 service hrs per week

Large CSD	cutter power > 2500 kW	45,000 €./wk
Medium size CSD	cutterpower between 250 – 2500 kW	36,000 €./wk
Small CSD	cutterpower < 250 kW	23,000 €./wk

3.5 Fuel

The same method is applied as in section 2.6

3.6 Wear and Tear

For wear and tear an amount per m^3 is reserved as was the case for the hopper. Apart from that an extra amount must be taken into account for wear of pick points and adapters used on the cutter head. These costs as well are strongly dependent on the soil conditions encountered.

The order of magnitude for teeth consumption :
Sand : 2000 – 4000 m3 / tooth
Rock: 200 – 300 m3/tooth

Price per tooth: 100 €
Price per adapter 400 €

Appendix G. SAFETY DOCUMENT FOR CURRENT MAINTENANCE VESSEL

Liander

Veiligheid, gezondheid en Milieuplan

Digitaal Inmeten op het water

KLANT TECHNIEK

Ontwerpstatus	definitief
Auteur(s)	Liander Veiligheid & Milieu (Han Verhagen) Klant & Techniek (Daniël Albers)
Opdrachtgever	Liander Klant & Techniek
Contactpersoon	Elle Vellema

Versielog Document

Versie	Datum	Auteur	Opmerking
0.1	22-10-2014	Wil Zaaijer	[Concept]
0.2	12-11-2014	Hedwig Hoes, Daniel Albers	[Review]
0.3	24-12-2014	Hedwig Hoes, Daniel Albers	[Review]
0.4	6-2-2015	Daniel Albers	[Review]
0.5	27-8-2015	Hedwig Hoes, Han Verhagen	Nieuw concept
0.6	02-10-2015	Hedwig Hoes, Han Verhagen	Nieuw concept, toegevoegd rie werkboten en Risk assesment taken steeborg
0.7	16-10-2015	Han Verhagen	Opm K&T en Gasunie verwerkt
0.8	23-11-2015	Daniël Albers	Opmerkingen Gasunie verwerkt.
0.9	03-06-2016	Daniël Albers	Opmerkingen verwerkt n.a.v. het werkbezoek op de Steeborg samen met Gasunie op 27-mei-2016.
1.0	01-07-2016	Daniël Albers	[Geaccordeerd definitief]

Versielog Bijlagen

Bijlage	Versie	Datum	Auteur	Opmerking
A: Werkopdracht inclusief aanwijzing kaptein	1	30-12-2014	Daniël Albers (Liander)	Aangemaakt en vanaf 2015 in gebruik genomen
B: RI&E van Stee Steeborg 1	1.2	17-7-2015	Jean Barbier (JW van Stee)	Na overleg met Liander en Gasunie vastgesteld
B: Risk assessment taken Steeborg 1	1a	17-7-2015	Jean Barbier (JW van Stee)	Concept versie
B: Risk assessment taken Steeborg 1	1b	7-10-2015	Jean Barbier (JW van Stee)	Na overleg met Liander en Gasunie aangepast.
C: RI&E Liander kleine werkboten	0.1	30-12-2014	Daniël Albers (Liander)	Concept versie
C: RI&E Liander kleine werkboten	0.2	07-10-2015	Han Verhagen (Liander)	Aangepaste versie n.a.v. werkbezoek
D: V&G-plan Gasunie	0.1	24-04-2015	Robert Hoekstra (Gasunie)	
E: Instructie bezoekers	-	15-11-2015	Jean Barbier (JW van Stee)	
F: Ongevallen en calamiteiten	2	16-10-2015	Rindert Procee (Liander)	Gecontroleerd en bijgewerkt door Rindert Procee
G: V&G-plan Aquatech	Rev. 1	1-6-23016	Aquatech Diving	163088.RI&E
H: V&G-plan Deep	2.3	09-03-2016	V. Riekerk (Deep) Manager HSEQ	

Toelichting

Dit document is het veiligheids- en gezondheidsplan (V&G-plan) voor de werkzaamheden bij het digitaal inmeten en het dieper leggen van kabels en leidingen in wateren. Dit V&G-plan beschrijft de werkzaamheden en de organisatie hiervan, de risico's van de werkzaamheden en de maatregelen die genomen dienen te worden. In de bijlagen zijn de Risico- inventarisaties en evaluaties van de opdrachtgevers en de uitvoerende partijen bijgevoegd.

Inhoud

1 Werkzaamheden

1.1 Omschrijving van de werkzaamheden

De uit te voeren werkzaamheden bestaan uit de volgende activiteiten:

- Het uitvoeren van metingen aan kabels en leidingen (juiste diepteligging etc.) in wateren om X,Y en Z coördinaten te bepalen.
- Het dieper leggen (d.m.v. zuigen of spuiten).
- Het **herstel van dekkingsmanco's met het aanbrengen van zand** (back fill sleuf) of andere materialen.
- Het repareren van kabels en leidingen.
- Het nieuw leggen van kabels en leidingen.
- Opruimwerkzaamheden (kabels, leidingen andere objecten).
- Het uitvoeren van metingen aan kabels en leidingen in wateren om storingen te lokaliseren (incidenteel).

1.2 Projectlocaties

- Binnenwateren
  - Rivieren, kanalen en meren die voor binnenvaartschepen bevaarbaar zijn (meestal aangeduid als vaarweg);
  - Alle maritieme wateren achter de basislijn: baaien, mondingen en zeehavens.
  - De Waddenzee valt onder binnenwater.

- Buitenwater is volgens de Waterwet water van de grote rivieren (Rijn, Maas, IJssel), het IJsselmeer, het Markermeer en de zee. Deze wateren kennen zo'n groot debiet dat dit bij extreme situaties (storm, hoge rivierafvoer) niet beheerst kan worden.

2 Organisatie

Diverse partijen geven opdracht voor de werkzaamheden. Liander is opdrachtnemer.

1. Indien werkzaamheden met eigen bootjes kunnen worden uitgevoerd doet Liander dit zelf.
2. Werkzaamheden die niet met eigen materiaal en middelen kunnen worden uitgevoerd worden door de onderaannemer uitgevoerd in regie van Liander.

2.1 Betrokken partijen

De vaste opdrachtgevers zijn:

1. Liander (Netwerkbeheerder Elektra en gas)
2. Liandon (Netwerkbeheerder hoogspanning)
3. Gasunie (Netbeheerder hoge druk gas)
4. Vitens (Waterleidingbedrijf)
5. KPN (telecom)
6. Stedin (Netwerkbeheerder Elektra en gas)
7. Vermillion (Aardgas producent)

De door Liander gecontracteerde aannemers voor de uitvoering van de werkzaamheden zijn:

1. J.W. van Stee
2. DEEP survey
3. AquaTech Diving

2.2 V&G coördinatie

De V&G coördinatie in de ontwerpfase is bij Liander belegd (door Liander aangewezen projectleider).
De V&G coördinatie in de uitvoeringsfase is belegd bij de uitvoerende partijen:

Bij werkzaamheden op de Steeborg1, Steeborg 1a (ankerboot) en Breehorn (tenderboot) is de kapitein verantwoordelijk voor de veiligheid van de opvarenden.

Bij werkzaamheden op de kleinere boten van Liander wordt een ploegleider (kapitein) aangewezen die verantwoordelijk is voor veiligheid. Zie bijlage A werkopdracht.

In geval van een calamiteit wordt er door de uitvoerende partij samen met de betreffende netbeheerder een Taak Risico Analyse gemaakt met aanvullende beheersmaatregelen en bepaald wie welke verantwoordelijkheid heeft.

V&G coördinatie die door Liander verzorgt wordt ziet er als volgt uit:
- Startwerkvergaderingen (zie hfst. 6)
- Periodieke werkplekinspecties
- Periodiek veiligheidsoverleg als onderdeel regulier overleg

3 Opleidingen en oefeningen Liander (boten)

Opleiding	Voor
Basic Safety Training	Alle vaste medewerkers aan boord
Vaarbewijs 1 en 2	Voor iedereen die een boot bestuurd conform regelgeving
Radarcursus	Optioneel voor iedereen die een boot bestuurd
Marifoon	Voor iedereen die een boot bestuurd
Levensreddende Eerste Handelingen (LEH)	Alle vaste medewerkers aan boord
VCA	Alle vaste medewerkers aan boord
Oefeningen (bijvoorbeeld met KNRM of andere partijen)	Alle vaste medewerkers aan boord

Opleidingen en oefeningen andere uitvoerende partijen worden bepaald door uitvoerende partij zelf, minimaal conform wet- en regelgeving.

4 Risico - Inventarisatie en Evaluatie (RI&E)

Werkzaamheden die niet met eigen materiaal en middelen kunnen worden uitgevoerd worden door een andere partij uitgevoerd in regie van Liander of Gasunie.
Van Stee heeft een RI&E aangeleverd voor deze werkzaamheden aan boord van de Steeborg 1 en Steeborg 1a en Breehorn (tenderboot) (zie bijlage B).
Indien opdrachtgevers een RI&E hebben aangeleverd voor de werkzaamheden die zij zelf uitvoeren zijn deze als bijlage aan dit V&G-plan toegevoegd. (RI&E werkboten Liander bijlage C, V&G-plan en RI&E Gasunie bijlage D)

5 LMRA (last minute risico analyse)

Voor aanvang van alle werkzaamheden wordt een LMRA gedaan.
Bijzondere aandachtspunten:

- Bestaande kabels en leidingen derden
- Weercondities en - voorspellingen
- Veiligheid aan boord
- Algemene orde en netheid aan boord

6 Start werkvergadering

Het is van belang dat informatie bij de start van ieder nieuw project bij elke partij bekend en beschikbaar is. Direct voor aanvang van een nieuw project wordt door Liander een startwerkvergadering met betrokken partijen georganiseerd. Er wordt een presentielijst van de bespreking bijgehouden.

Te behandelen VGM-aspecten bij de startwerkvergaderingen:
- RI&E in V&G plan
- Specifieke eisen per kabel- of leiding-eigenaar zullen worden besproken en worden vastgelegd
- Orde en netheid op de werkplek
- Het dragen van de voorgeschreven persoonlijke beschermingsmiddelen
- Het gebruiken van uitsluitend in goede staat verkerende en (indien van toepassing) gekeurde gereedschappen, machines, elektrisch materiaal, gecertificeerde hijsbanden en -stroppen e.d.;
- Het gebruiken van de aangebrachte beveiligingen op machines en gereedschappen
- De te nemen maatregelen bij ongevallen en calamiteiten
- Het melden van onveilige situaties/handelingen en risico's **aan de direct leidinggevende**
- Brandpreventie, blusmiddelen en het juiste gebruik hiervan
- Instructie bezoekers (zie checklist bijlage E).

7 Ongevallen en calamiteiten

7.1 Telefoonnummers en marifoonkanalen bij calamiteiten

Zie bijlage F

8 Milieuzorg

Het beleid van Liander is er op gericht, verontreiniging van milieu en overlast voor de omgeving ten gevolge van haar werkzaamheden te voorkomen, dan wel tot een minimum te beperken. De kapitein ziet er op toe dat:

- (water)Bodem, en oppervlaktewater niet verontreinigd worden.
- Voorzieningen zijn getroffen om een mogelijke verontreiniging tijdens de werkzaamheden te voorkomen.
- Benzine- en diesel aangedreven motoren, apparatuur en machines zo min mogelijk stank en lawaai veroorzaken, alsmede geen lekkage vertonen van brandstof en olie en geen overmatig olieverbruik (blauwe rook) vertoont.
- Lekbakken aanwezig zijn.
- Afval in de daarvoor bestemde afvalbakken/containers gedeponeerd wordt.
- Afvalwater wordt afgevoerd/ afgegeven volgens de geldende wet- en regelgeving.

9 Persoonlijke bescherming

Onderstaande **persoonlijke beschermingsmiddelen** (PBM's) **worden standaard gedragen**:
- Goede beschermende kleding
- Veiligheidsschoenen/laarzen
- Werkhandschoenen
- Werkzwemvest
- Veiligheidshelm

Bij specifieke werkzaamheden worden eventueel andere PBM's verplicht gesteld
- Overlevingspakken

Voor bezoekers en toezichthouders gelden de volgende regels m.b.t. **PBM's**:
- Werkzwemvest bij overstappen en aanwezigheid aan dek;
- Veiligheidsschoenen;
- Veiligheidshelm;
- Gehoorbescherming in de gemarkeerde gebieden en ruimtes.

10 Bijlagen

Weet dat in dit hoofdstuk ervoor gekozen is om grote documenten alleen een print screen zichtbaar te maken, voor het delen van dit V&G plan zullen deze (grote) documenten los worden toegevoegd.