RAPPORT

Aanvraag Mijnbouwvergunning pijpleiding op zee

Porthos CO2 transport en opslag

Klant: Porthos Development C.V.

Referentie: BF8260

Status: S0/P01.01

Datum: 18-6-2020

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Inhoud

Bijlagen

1 Inleiding

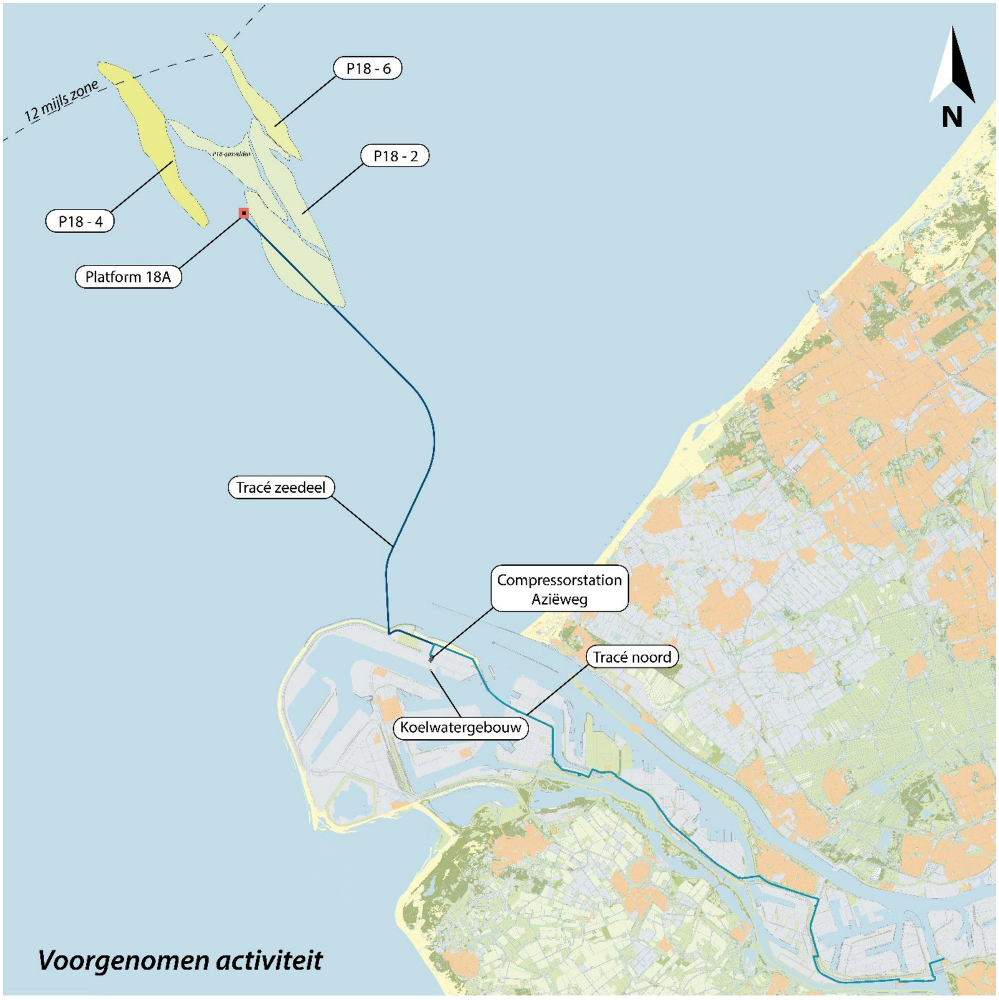
Voor u ligt de aanvraag mijnbouwvergunning van Gasunie N.V. voor de aanleg van de transportleiding voor het transport van koolstofdioxide (CO_2) vanaf de Maasvlakte naar platform P18-A van TAQA Energy B.V.

1.1 Het voornemen: CO_2 opslag in lege P18 gasvelden

Doel

Met het Porthos project wordt vanuit het Rotterdamse havengebied de Carbon Capture and Storage (CCS)-infrastructuur Porthos ontwikkeld om door bedrijven afgevangen CO_2 te transporteren naar platform P18-A en op te slaan in de leeggeproduceerde P18-gasvelden. De infrastructuur bestaat uit:

1. een transportleiding voor CO_2 in het havengebied;
2. een compressor op de Maasvlakte om het CO_2 op hogere druk te brengen;
3. een transportleiding vanaf het compressorstation, deels over land, dan onder de zeewering door en in de zeebodem naar het platform P18-A op circa 20 kilometer van de kust;
4. de putten vanaf dit platform in leeggeproduceerde P18-gasvelden onder de Noordzee.



Figuur 1.1 Schematische weergave Porthos project

Initiatiefnemer
De initiatiefnemer is Gasunie. Gasunie is een netwerkbedrijf voor energie.

Elk van de organisaties brengt haar eigen ervaring en expertise in het CCS-project: Het Havenbedrijf focust zich op de lokale situatie en markt, Gasunie brengt haar ruime kennis en ervaring in op gebied van gasinfrastructuur en -transport, en EBN deelt haar expertise op gebied van de diepe ondergrond en offshore infrastructuur.

Voornemen
In het Klimaatakkoord[1] is uitgewerkt hoe de reductie van CO_2-emissies in Nederland in de komende jaren gerealiseerd wordt. Voor de industrie is daarbij aangegeven dat 1. de overstap gemaakt moet worden naar CO_2-arme brandstoffen en 2. dat de bedrijfsprocessen zodanig worden aangepast dat hierbij minimale hoeveelheden CO_2 vrijkomen. Het aanpassen van bedrijfsprocessen zal voor sommige industrie een dermate ingrijpende aanpassing zijn, dat hiervoor nieuwe technieken nodig zijn. Het ontwikkelen en testen van de nieuwe CO_2-arme technieken en het ombouwen van de installaties zal voor sommige bedrijfstakken een langdurige inspanning vergen. Om een voortgaande uitstoot van CO_2 te voorkomen in deze periode, is in het Klimaatakkoord aangegeven dat het afvangen van CO_2 uit deze bedrijfsprocessen en het ondergronds opslaan onder de zeebodem, een effectieve maatregel is.

Het gebied van de Rotterdamse haven is verantwoordelijk voor de jaarlijks uitstoot van circa 26 Mton CO_2. Dit is circa 16% van de totale landelijke uitstoot. In dit gebied bevindt zich industrie waar de ombouw naar processen met een lage CO_2-uitstoot ontwikkeld moet gaan worden. Door hier een transport infrastructuur aan te leggen, inclusief faciliteiten voor ondergrondse opslag, kan aan de industrie de mogelijkheid worden geboden de komende jaren de CO_2-emissie aanzienlijk te reduceren.

De afgevangen CO_2 wordt via een transportleiding op land naar een compressorstation getransporteerd om vervolgens via een transportleiding landzijdig en in de zeebodem naar het platform P18-A geleid te worden. Vanaf het platform wordt de CO_2 in de leeggeproduceerde P18-gasvelden opgeslagen.

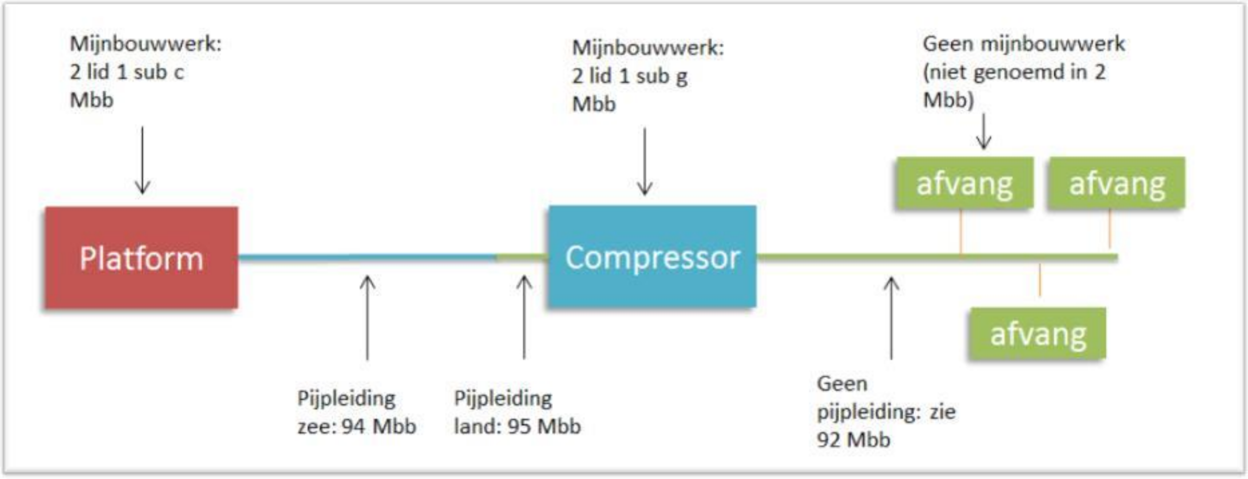
Voor de realisatie van de transportleiding in de zeebodem t.b.v. de Porthos infrastructuur moet aan een aantal verplichtingen worden voldaan. Het betreft de volgende verplichtingen:

- De aanleg van transportleidingen op zee is m.e.r.[2]-plichtig, wat inhoudt dat er een milieueffectrapportage opgesteld moet worden. Voor het verkrijgen van de benodigde vergunningen is ter onderbouwing een gecombineerd plan- en project-MER[3] nodig.
- Waterwetvergunning voor de kruising van de harde zeewering bij de Maasvlakte.
- Vergunning in het kader van de Wet Natuurbescherming (Wnb): De aanleg en de operationele fase van het Porthos project kan negatieve natuureffecten hebben door onder meer vergraving, emissies en depositie en mariene verstoring. Er is een vergunning nodig voor de verschillende onderdelen van het project, waaronder de offshore leiding. Voor de vergunning zijn de effecten op beschermde natuurwaarden (soorten en gebieden) beoordeeld en zijn stikstofdepositieberekeningen uitgevoerd. De vergunningaanvraag is bijgevoegd als bijlage 5[4].
- Vergunning op grond van artikel 94 en artikel 95 Mijnbouwbesluit (Mbb): Volgens het Mbb is het verboden zonder vergunning van Onze Minister (EZK) een pijpleiding in de territoriale zee, op het continentaal plat of in een ander gebied waarvoor op grond van het Besluit milieueffectrapportage het

[1] *Klimaatakkoord (2019)*
[2] *m.e.r. staat voor de milieu effect rapportage (procedure)*
[3] *MER staat voor het Milieu Effect Rapport*
[4] *De vergunningaanvraag Wnb wordt op een later moment opgeleverd en bijgevoegd*

maken van een milieueffectrapport verplicht is aan te leggen. Met deze onderhavige aanvraag, vraagt Gasunie een vergunning aan voor de aanleg van de pijpleiding.

- Een klein deel van de leiding ligt niet in de zeebodem, maar wordt ingegraven op land. Dit deel valt onder het Besluit externe veiligheid buisleidingen (Bevb).



Figuur 1.2 Overzicht artikelen Mijnbouwbesluit met betrekking op onderdelen Porthos

Planning
De levering van CO_2, het compressorstation, het transport naar het platform P18-A en de injectie in de P18-gasvelden zal naar verwachting vanaf 2024 operationeel zijn. Er wordt uitgegaan van een operationele periode van circa 15 jaar. De transportleiding wordt echter ontworpen op een technische levensduur van tenminste 30 jaar en de vergunning wordt dan ook voor onbepaalde tijd aangevraagd.

1.2 Scope van het document

Deze aanvraag is opgesteld in het kader van de besluitvorming over de Mijnbouwvergunning voor de aanleg en ingebruikname van de pijpleiding voor het transport van CO_2 tussen de Maasvlakte en het platform P18-A. De Mijnbouwvergunning wordt aangevraagd bij de Minister van EZK in het kader van de Mijnbouwwet.

1.3 Leeswijzer

Hoofdstuk 2 geeft de algemene gegevens van de aanvrager, de pijpleiding, tijdvak en locatie van de aanvraag. Hoofdstuk 3 gaat in op de details van de vergunningaanvraag, waaronder de aard en sterkte van de pijpleiding, het tracé, de wijze van aanleg, de getransporteerde stoffen, de wijze van kruisen met andere leidingen en kabels, testen en bedrijfsvoering.

2 Algemene gegevens

2.1 Activiteit

Gasunie vraagt een vergunning aan voor de aanleg van één pijpleiding deels in de territoriale zee en deels op land op grond van het Mijnbouwbesluit:

- Gasleiding: 16" (ca. 40 cm) buitendiameter geïsoleerde stalen hogedrukleiding voor het transport van het CO_2 vanaf de Maasvlakte, onder de Maasgeul naar platform P18-A. De pijpleiding kan worden gemonitord met behulp van een ragerinstallatie (pig)..

De leiding loopt vanaf het compressorstation op de Maasvlakte naar de zeewering, wordt onder de zeewering geboord, ingegraven in de bodem van Maasgeul en gaat ten noorden van de Maasgeul in de zeebodem naar het bestaande platform P18-A. De leiding wordt op de zeebodem gelegd en vervolgens ingegraven op een diepte ter verbetering van de isolatie en bescherming tegen *upheaval buckling*, zie hoofdstuk 3.

2.2 Gegevens aanvrager

Gegevens aanvrager

Naam aanvrager:	N.V. Nederlandse Gasunie
Adres:	Concourslaan 17, 9727 KC, Groningen
Contactpersoon:	D. Hiemstra
Functie:	Technisch juridisch adviseur
Telefoonnummer:	+31 6 31 03 73 25
E-mailadres:	LAJteamMilieu@gasunie.nl

Gegevens pijpleiding

Naam:	Offshore CO_2 transportleiding P18-A
Tracé:	Nederlandse territoriale zee, binnen de 12 mijlszone, vanaf land aan de zuidzijde van de Maasmond in de zeebodem naar platform P18-A (geografische positie 52 graden, 07 minuten, 40.201 seconden N.B. en 03 graden, 56 minuten en 21.519 seconden O.L)

Opsteller aanvraag

Naam:	N.V. Nederlandse Gasunie
Adres:	Concourslaan 17, 9727 KC, Groningen
Contactpersoon:	D. Hiemstra
Telefoonnummer:	+31 6 31 03 73 25
Emailadres:	LAJteamMilieu@gasunie.nl

2.3 Tijdvak van de vergunning

Het is gepland dat de leiding in 2022 en 2023 wordt gelegd. Dit duurt naar verwachting in totaal 2 jaar. De pijpleiding wordt mechanisch ontworpen voor een periode van tenminste 30 jaar. De vergunning voor de leiding wordt voor onbepaalde tijd aangevraagd.

2.4 Gebied aanvraag

Deze aanvraag betreft de aanleg van de pijpleiding, voor het grootste deel in de territoriale zee en voor een klein deel op land. Het deel in de territoriale zee bevindt zich nabij de Maasvlakte tot circa 20 km van de kust binnen de 12 mijlszone, zie figuur 1.1. De territoriale zee strekt zich uit op grond van de Wet grenzen Nederlandse territoriale zee vanaf de laaglaagwaterlijn (LAT) tot aan de grens van de 12 mijlszone (zijnde tweeëntwintig kilometer en tweehonderdvierentwintig meter, gemeten zeewaarts vanaf de laagwaterlijn langs de kust). Het deel op land bevindt zich op de Maasvlakte, vanaf het compressorstation aan de Aziëweg tot aan de laagwaterlijn, zie Figuur 3.1.

De aanvraag omvat het tracé vanaf de afsluiters bij het compressorstation tot aan de afsluiter op het platform P18-A bovenaan de riser. Het tracé bestaat uit een landdeel en een zeedeel. Het landdeel van de leiding bestaat uit het gedeelte vanaf “de afsluiter” bij het compressorstation tot de afsluiter bij de ingang van de boring onder de zeewering.. Het zeedeel van de leiding bestaat uit het gedeelte vanaf de afsluiter bij de ingang van de boring onder de zeewering tot aan “de afsluiter ter hoogte van de riser op het platform P18-A.

2.5 Milieueffectrapportage

De voorgenomen activiteit is m.e.r.-plichtig op grond van categorie C8.1 van het Besluit m.e.r.: De aanleg, wijziging of uitbreiding van een buisleiding voor het transport van gas, olie, chemicaliën of voor het transport van kooldioxide (CO_2) stromen ten behoeve van geologische opslag. Het MER dient ter onderbouwing van deze vergunning.

2.6 Wettelijk kader en bevoegd gezag

De relevante wetgeving met betrekking tot pijpleidingen is geregeld in het Mijnbouwbesluit (Mbb) en de Mijnbouwregeling (Mbr). § 6.2 van het Mbb regelt de vergunningplicht van pijpleidingen in de territoriale zee of op het continentaal plat of in een ander gebied waarvoor op grond van het Besluit milieueffectrapportage het maken van een milieueffectrapport verplicht is. §1.7.2 Mbr regelt de inhoud van de vergunningsaanvraag. Hoofdstuk 3 gaat in op de gevraagde punten met betrekking tot de vergunningsplicht. De Minister van Economische Zaken en Klimaat is bevoegd gezag.

Tot slot staan in het Bevb de eisen waaraan de pijpleiding op het gebied van externe veiligheid moet voldoen.

Naast deze aanvraag worden vergunningen aangevraagd in het kader van de Wet natuurbeheer (Wnb) en de Waterwet. De bevoegde gezagen voor deze vergunningen zijn respectievelijk de Gedeputeerde Staten van de Provincie Zuid-Holland (samen met de Minister van Landbouw, Natuur en Visserij) en Rijkswaterstaat.

2.7 Vooroverleg

Porthos heeft met verschillende instanties vooroverleg(gen) gevoerd met betrekking tot het voornemen:

- Ministerie van Economische Zaken en Klimaat: afstemming met betrekking tot het project als geheel inclusief tracé offshore pijpleiding en vergunningen;
- Rijkswaterstaat: afstemming met betrekking tot onderdoor boren zeewering en tracé pijpleiding op zee;
- Havenmeester Rotterdam: afstemming met betrekking tot kruising Maasgeul;
- Staatstoezicht op de Mijnen: afstemming met betrekking tot vergunningen;
- Havenbedrijf Rotterdam: afstemmen intredepunt HDD op Maasvlakte 2;
- Tennet: Ligging van de zeeleiding t.o.v. de kabels Zuid-Hollandse kust zuid;
- Eneco: Ligging van de HDD t.o.v. windmolenpark MV2;
- ONE-DYAS: ligging van de zeeleiding t.o.v. de leiding tussen Q16 en P18-A;
- Havenbedrijf Rotterdam en RWS directie Noordzee: Ligging van de zeeleiding t.o.v. de zandwin- en verspreidingslocaties van baggerspecie op de Noordzee;
- Kustwacht, afstemming over nautische veiligheid;
- Rijksdienst Cultureel Erfgoed: afstemming in het kader van mogelijke verstoring van archeologische waarden.

3 Details vergunningsaanvraag

3.1 Aard en sterkte van de pijpleiding

De leiding komt van het compressorstation op de Maasvlakte, wordt vanaf land onder de zeewering geboord, ingegraven in de Maasgeul bodem en gaat ten noorden van de Maasgeul in de zeebodem naar het bestaande platform P18-A. De leiding transporteert CO_2 naar het platform, van waar het in lege gasvelden wordt opgeslagen. Het rapport van het voorontwerp van de pijpleiding zoals bedoeld in Artikel 1.7.1 lid 1 onder d van de Mbr is in uitgebreidere vorm van FEED studie opgenomen in bijlage 3[5]:

- Gasleiding: 16” hogedrukleiding voor het transport van CO_2:
- Buitendiameter 16” (ongeveer 40 cm), wanddikte 14-18 mm, gelaagde coating (anti-corrosie en isolatie) 20 mm en 80-100 mm betonnen mantel;
- Ontwerpdruk: 140 bar CO_2-mengsel in “dense phase”,
- Ontwerptemperatuur vanuit de compressor is tussen -20°C en 100°C;
- Materiaal: staal met coating en betonmantel;

Insluiten van de leiding
De pijpleiding wordt voorzien van afsluiters om uitstroming in geval van een calamiteit te voorkomen of te beperken:

- Bij de ingang van de boring onder de zeewering wordt een afsluiter aangebracht die wordt aangestuurd vanuit het drukbeveiligingssysteem van het compressorstation en ten doel heeft de pijpleiding en het compressorstation van elkaar te isoleren voor onderhoud of in geval van calamiteiten;
- Op platform P18-A wordt na de riser boven het zeeniveau een afsluiter aangebracht die wordt aangestuurd vanuit het drukbeveiligingssysteem van het platform P18-A en ten doel heeft de pijpleiding en het platform P18-A van elkaar te isoleren voor onderhoud of in geval van calamiteiten.
- Bij een calamiteit kan de leiding van hoge druk worden gehaald. Dit vindt plaats door het afblazen bij het compressorstation en/of leeg laten lopen in de put. In het MER document wordt hier dieper op ingegaan.

CO_2-mengsel condities in de transportleiding naar het platform
De druk en temperatuur van het geïnjecteerde CO_2-mengsel worden geregeld vanaf het compressorstation. De condities in de transportleiding worden zodoende gereguleerd vanuit het compressorstation met als doel onderin de put de juiste omstandigheden te creëren.

Er zijn tevens condities voor de transportleiding zelf, zoals het voorkomen van slug flow. Transport van vloeistofslugs in het gas zorgen voor vibraties en dientengevolge een onvoorspelbaar krachtenspel, met name bij bochten en afsluiters. Dit kan tot schade aan het systeem leiden.

Voor Porthos is door TNO een “flow assurance” onderzoek uitgevoerd, waaruit volgt binnen welke randvoorwaarden en onder welke omstandigheden CO_2 technisch veilig en effectief kan worden getransporteerd en geïnjecteerd. Dit onderzoek is als bijlage 7 toegevoegd.

3.2 Naleven van wettelijke eisen en normen

De pijpleiding voldoet aan de relevante eisen gesteld in de NEN 3650 serie:

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[5] *De definitieve versie van het FEED rapport wordt naar verwachting in juli 2020 opgeleverd en bijgevoegd bij deze aanvraag*

- NEN 3650-1 Eisen voor buisleidingsystemen (generiek)
- NEN 3650-2 Eisen voor stalen buisleidingsystemen
- NEN 3651 Aanvullende eisen voor buisleidingen in of nabij belangrijke waterstaatswerken
- NEN 3654 Wederzijdse beïnvloeding van buisleidingen en hoogspanningssystemen
- NEN 3656 Eisen voor stalen buisleidingsystemen op zee

Er wordt voldaan aan de eisen van artikel 93 Mbb:

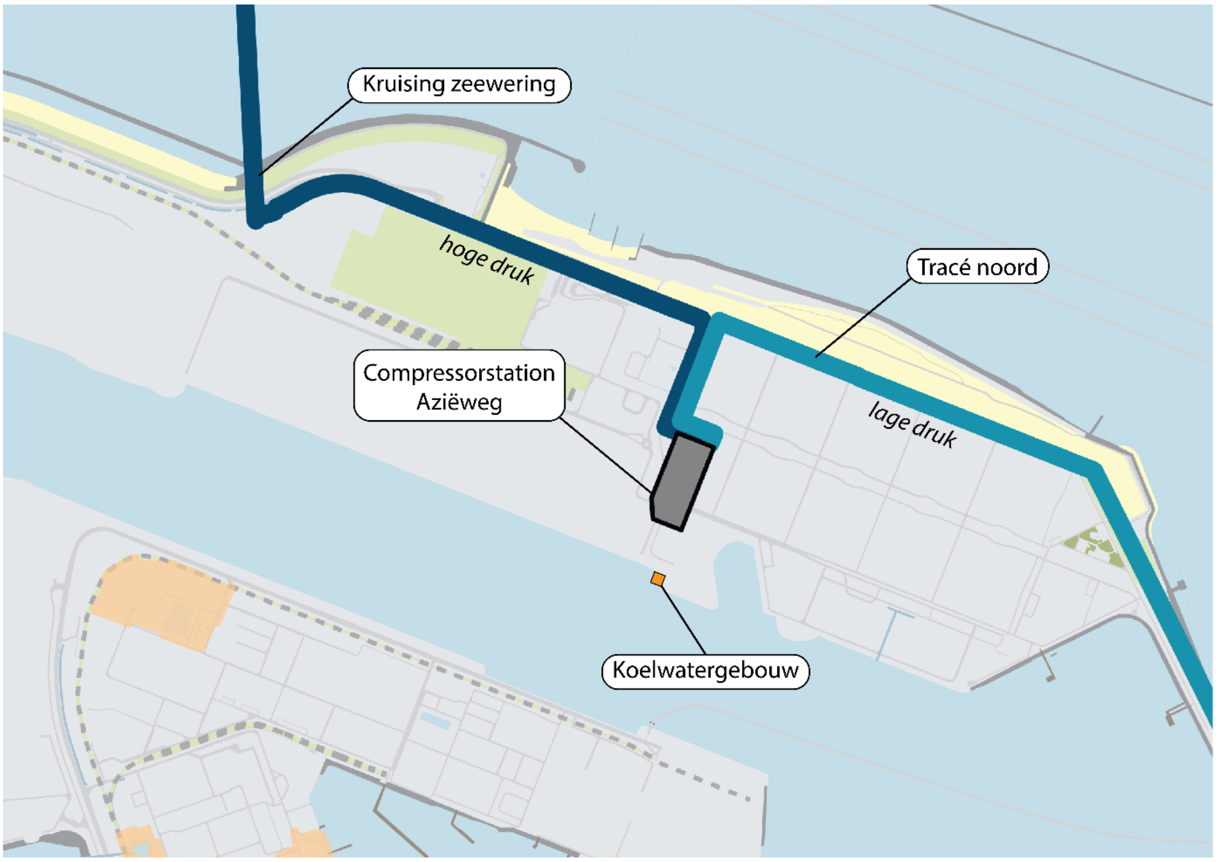
1. Een pijpleiding bestaat uit pijpen die voldoende sterk zijn en op doelmatige wijze met elkaar zijn verbonden. De pijpleiding is tegen corrosie en uitwendige krachten beschermd.
    - De ontwerpdruk van de pijpleiding is gebaseerd op de maximale bedrijfsdruk. Overschrijding van de maximale bedrijfsdruk wordt voorkomen door instrumentele beveiliging indien nodig in combinatie met veiligheidskleppen. Alle leidinglassen worden volledig gecontroleerd, mogelijk met uitzondering van enkele 'gouden lassen' voor het koppelen van lange leidinglengtes. De gehele leiding wordt voor ingebruikname afgeperst;
    - De pijpleiding wordt uitwendig gecoat tegen corrosie;
    - De pijpleiding wordt tegen uitwendig krachten beschermd door ze voldoende diep in het graven volgens NEN3656. De pijpleiding wordt ontworpen om schade, door eventuele ontoelaatbare krachten door thermische uitzetting, te voorkomen.
2. De ligging van de pijpleiding is zodanig dat geen schade wordt veroorzaakt of zoveel mogelijk voorkomen.
    - Het tracé is afgestemd met de Kustwacht, Havenbedrijf Rotterdam, Rijkswaterstaat en SodM;
    - De beheerders van bestaande leidingen en kabels zijn geïnformeerd en details met betrekking tot de ligging nabij bestaande Kabels en Leidingen (K&L) worden met hen afgestemd.
3. De eigenschappen, de aanleg, de ligging en het onderhoud van de pijpleiding voldoen aan bij ministeriële regeling te stellen eisen.
    - De pijpleiding voldoet aan artikel 10.1 Mbr: de leidingen zijn ontworpen conform de relevante bepalingen van de NEN 3650 serie. Met het van kracht worden van NEN 3656 voor deze leiding specifiek de bepalingen van deze norm aangehouden.

3.3 Tracé en de directe omgeving

3.3.1 Beschrijving tracé

Het tracé van deze aanvraag loopt vanaf het compressorstation op de Maasvlakte naar een locatie net westelijk van de Tennet HDD locatie, vanwaar de leiding door een HDD-boring onder de zeewering doorgaat. Ten noorden van de zeewering komt de leiding omhoog. Vanaf dat punt zal de leiding de Maasgeul kruisen in een voorgebaggerde sleuf die na installatie van de pijpleiding weer opgevuld wordt. Hierna volgt de leiding de bestaande 26” TAQA gasleiding in noordelijke richting. Vanaf Q16 buigt de leiding af in noordwestelijke richting om vervolgens aan de zuidkant van de bestaande leidingen vanaf Q16 richting het platform P18-A te gaan (zie Figuur 3.1 en 3.2). In bijlage 2 zijn de tracékaarten toegevoegd in groot formaat.

Het tracé houdt rekening met de aansluitkabels van toekomstige windparken die op de Maasvlakte 2 aanlanden. Het tracé bevindt zich ten westen van de geplande kabels en zal deze niet kruisen.



Figuur 3.1 Overzicht ligging tracé van de transportleiding vanaf het compressorstation tot en met de kruising van de zeewering. Hierin is aangegeven het deel vanaf het compressorstation met een relatief hoge druk (donkerblauw) en relatief lager druk tot aan het compressorstation vanaf tracé noord (lichtblauw).

Figuur 3.2 Overzicht ligging tracé van de transportleiding vanaf de kust tot aan het platform P18-A

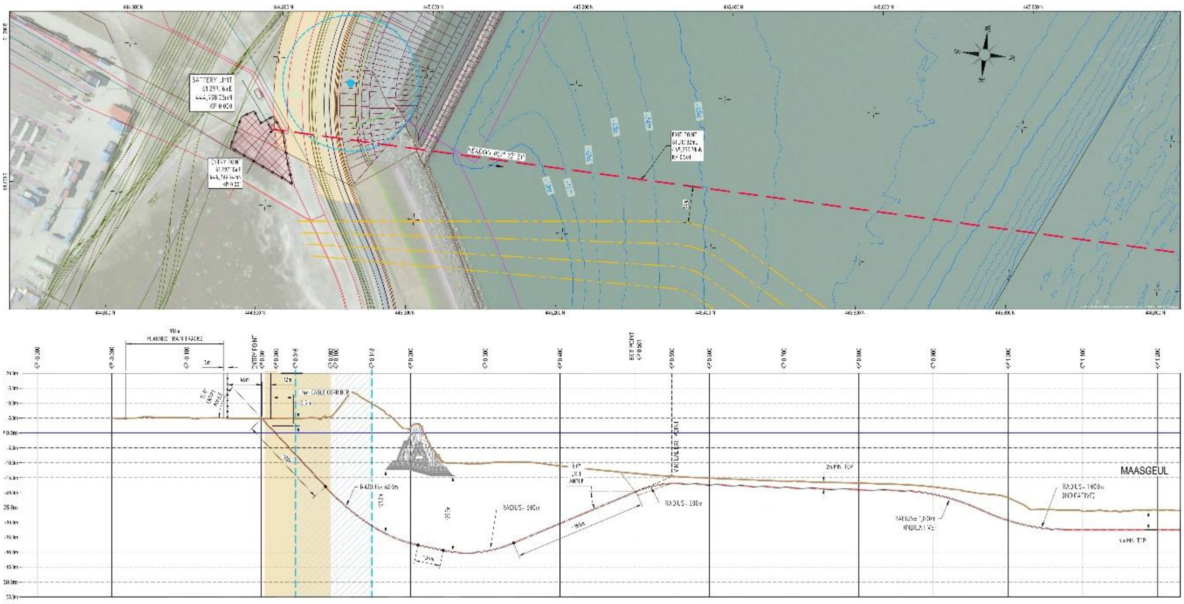
Maasvlakte

De pijpleiding op land vanaf het compressorstation tot de zeewering heeft een lengte van circa 2.500 meter. Vanaf het compressorstation bevindt de leiding zich in de bestaande leidingstrook en volgt deze de Aziëweg naar het noorden. Vervolgens loopt de leiding langs de Maasvlakteweg totdat deze afbuigt richting het afsluiterschema nabij het intredepunt van de boring.

Zeewering KP 0.000 – KP 0.501

De zeewering is weliswaar geen primaire waterkering, maar de leiding zal door Rijkswaterstaat wel volgens voorschriften van een primaire kering beoordeeld worden. De zeewering wordt gekruist door een diepe gestuurde boring (HDD) van circa 500 meter op een diepte van maximaal -40 m NAP onder de zeewering, zie Figuur 3.3.

De boring komt op een diepte van circa twee meter onder de zeebodem uit. Hier is de waterdiepte circa -14 m. Tussen de zeewering en de Maasgeul bevindt de leiding zich op deze diepte voor enkele honderden meters.



Figuur 3.3 Locatie en diepte HDD-boring zeewering (bron Intecsea)

Maasgeul KP 0.501 – KP 2.689

Vanuit het zuiden richting de Maasgeul wordt de zeebodem snel diep, met een gradiënt van 25° gaat de zeebodem van -18 m naar -26 m en lokaal in de Maasgeul enkele meters dieper. Hierna overbrugt de route de zuidelijke helling van de Maasgeul met een gradiënt van maximaal 12°.

Bij de Maasgeul kan de leiding niet zondermeer op de bodem gelegd worden, vanwege de risico's die de drukbevaren route opleveren. Ter plaatse van de kruising heeft de Maasgeul een NGD (Nautisch Gegarandeerde Diepte) van 23,2 m LAT. De vaargeul wordt periodiek uitgebaggerd. De leiding wordt zodanig diep aangelegd dat deze voldoet aan de veiligheidsvoorwaarden van de waterbeheerder van de Maasgeul (RWS) en ontwerpeisen.

De veiligheidsvoorwaarden van de waterbeheerder van de Maasgeul omvatten het volgende:

- *De leiding dient 3 meter dekking te hebben t.o.v. het bodemniveau van de Maasgeul en de Noordberm. Rekening houdend met de Nautisch Gegarandeerde Diepte (NGD) van LAT -23,2 meter en een baggermarge van 1,5 meter, kan worden uitgegaan van een diepste bodemniveau ligging van LAT -24,7 meter. Dit resulteert in een minimale aanlegdiepte van LAT -27,7 meter, bovenkant leiding.*
- *Indien er bij de aanleg een sleuf gebaggerd zou worden waar de leiding gelegd wordt, dan dient die sleuf na het leggen van de leiding aangevuld te worden met zand tot een dekking van 3 meter.*
- *In verband met afschuiving van de oevers van de geul en een eventuele verbreding van het begin van de Maasgeul, dient de aanlegdiepte tenminste gedurende 25 meter in de bermen van de vaargeul (zowel Noord als Zuid) gehandhaafd te blijven.*
- *Afwijkende minimale gronddekking ten behoeve van andere infrastructuur, constructies, te verwachten toekomstige ontwikkelingen, daadwerkelijk optredende ontwikkelingen en natuurlijke obstakels behoeven vooraf schriftelijke goedkeuring van de waterbeheerder.*

Met bovenstaande aanpak voldoet de gronddekking aan de richtlijnen van de laatste versie van NEN3656 (2015) waarbij ook het risico is gekwantificeerd van ankers van zeeschepen of overboord vallende lading op dit traject. Onderliggende berekeningen zijn opgenomen in het FEED-rapport, zie bijlage 3.

Noordzee KP 2.689 – KP 19.269

Na de kruising van de Maasgeul zal de leiding ten westen ervan de bestaande gasleiding van TAQA volgen in noordelijke richting. Vanaf Q16 buigt de leiding af richting het noordwesten. Met een vloeiende bocht zal de leiding de bestaande gasleiding van ONE-DYAS aan de zuidzijde volgen om vervolgens aan de zuidzijde aan te sluiten op het platform.

De zeebodem ligt op een diepte van circa 22 m ter hoogte van het platform, waarbij de diepte over het geplande traject varieert met een minimum en maximum van respectievelijk circa 16 m en circa 23 m. De gemiddelde gradiënt van de zeebodem langs de geplande route is minder dan 1°.

De leiding wordt met een gronddekking van circa 0,6 meter in de zeebodem ingegraven om de volgende redenen:

- Om de stabiliteit te borgen bij het uitzetten en krimp ten gevolge van de temperatuurverschillen van de CO_2; (upheaval buckling)
- Ter verhoogde warmte-isolatie van de leiding.

Hiermee voldoet de gronddekking aan de richtlijnen van de laatste versie van NEN 3656 (2015) wat upheaval buckling en beschadiging door externe oorzaken zoals vistuig van trawlers betreft. Er loopt nog een onderzoek naar de kwantificering van het risico van ankers van zeeschepen of overboord vallende lading voor dit traject waar mogelijk een aanvullende diepte eis uit volgt. Eerste indicaties geven geen noodzaak tot aanvullende diepte eisen. Onderliggende berekeningen zijn opgenomen in het FEED rapport, zie bijlage 3.

Offshore platform P18-A KP 19.269
Het platform P18-A is een bestaand gaswinningsplatform dat deel uit maakt van een complex met het oliewinningsplatform P15-ACD. Het platform ligt circa 22 km uit de kust, binnen de 12-mijlszone. Vanaf de bodem van de zee komt de leiding via een riser aan op het platform, waar deze wordt aangesloten op de putten. Een riser is een type pijpleiding bedoeld voor verticaal transport. Bij de voet van het platform vindt mogelijk installatie van matrassen of afstorting met steen plaats om de leiding te beschermen tegen activiteiten waarbij dropped objects kunnen plaatsvinden, die rondom het platform kunnen plaatsvinden. De leiding wordt verbonden met het platform middels de riser. Aan de bovenkant van de riser komt een pigging station, een vaste pig-receiver, waardoor inspectie van de transportleiding met intelligent pigs mogelijk is.

Beschrijving coördinaten tracé op zee
Het tracé op zee wordt in detail omschreven in de routestudie, Ref. TROF-ENG-PIP-INT-REP-0005, zie bijlage 6.

Beschermde gebieden
Het plangebied ligt ter hoogte van de Maasgeul in beschermd gebied dat als zodanig is aangewezen op grond van de Wet Natuurbescherming, het Natura 2000-gebied Voordelta. De HDD-boring onder de zeewering zal onder dit gebied uitkomen en het tracé zal een klein gedeelte onder het Natura 2000-gebied lopen tot aan de Maasgeul. De leiding wordt in dit deel ingegraven door middel van trenching & backfill.

Het plangebied ligt buiten reserveringsgebied voor zandwinning.

3.3.2 Tracéonderzoek

Geotechnisch onderzoek
§1.7 Mbr vraagt dat de aanvrager bij de aanvraag om een vergunning tot aanleg van een pijpleiding gegevens verstrekt ten aanzien van het geotechnisch onderzoek van tracé en een strook van ongeveer 300 meter ter weerszijden. In bijlage 4 is het geotechnisch onderzoek uitgevoerd naar het leidingtracé

opgenomen[6]. Dit onderzoek dient om informatie te verzamelen over onder meer het zeebed, daar aanwezige objecten en de bodemopbouw van het zeebed.

Voor onontplofte munitie (UXO) is een apart onderzoek opgestart, bestaande uit een bureauonderzoek en mogelijk een sitesurvey, mochten er vanuit het bureau onderzoek locaties zijn die als verdacht worden aangemerkt. Dit onderzoek vindt plaats in het kader van de arbo-wetgeving. Het bureauonderzoek bevat een risicoanalyse op welke explosieven in dit deel van de Noordzee verwacht kan worden (een zogenaamd PRA, project risico analyse). Vervolgens wordt, wanneer er verdachte locaties worden aangemerkt, een survey gericht op UXO uitgevoerd. De verzamelde data zal worden geanalyseerd en mogelijke anomalieën die op UXO lijken, zullen worden geïdentificeerd. Deze anomalieën worden in een volgende fase benaderd vanaf een schip. Wanneer alle anomalieën zijn benaderd en waar UXO daadwerkelijk wordt aangetroffen, deze UXO onschadelijk zijn gemaakt, wordt het gehele gebied middels PVO (Proces verbaal van oplevering) vrijgegeven.

Cultuurhistorisch / archeologisch onderzoek
Voor het deel van de leiding op land geldt dat het maaiveld van het havengebied zich op circa NAP +5 meter bevindt. De bodemopbouw bestaat uit circa 5 meter opgebracht materiaal, afkomstig uit de Noordzee, met daaronder het oorspronkelijk maaiveld of oude geulen. Archeologisch waardevolle afzettingen worden in de ophooglaag niet verwacht, maar mogelijk wel daaronder. De transportleiding wordt tussen 1 en 2 meter onder maaiveld aangelegd, met uitzondering van de boring onder de zeewering. Voor de boringen geldt dat archeologische waarden mogelijk verstoord kunnen worden.

Voor het deel op zee is er een kans dat in het tracé objecten met cultuurhistorische en/of archeologische waarde aanwezig zijn. Voor het bepalen of de aanleg van de buisleiding kan leiden tot aantasting of vernietiging van mogelijk aanwezige archeologische resten is een archeologisch vooronderzoek (bureauonderzoek) uitgevoerd (zie bijlage 8). Na bureauonderzoek wordt inventariserend veldonderzoek uitgevoerd om de archeologische verwachting te toetsen, waaronder een magnetometrisch onderzoek. Deze onderzoeken worden in de komende maanden uitgevoerd.

In het verleden zijn voor vergelijkbare tracés dergelijke archeologische onderzoeken uitgevoerd. Zo heeft Bureau RAAP in 2011 voor het toenmalige CO_2-opslag project ROAD (Rotterdam Opslag en Afvang Demonstratieproject) geconcludeerd dat langs de beoogde kabeltracés scheeps- en vliegtuigwrakken verwacht kunnen worden. Op basis van de uitkomst van het onderzoek adviseerde RAAP om een inventariserend veldonderzoek uit te voeren om de archeologische verwachting te toetsen, waaronder een magnetometrisch onderzoek.

Een dergelijk magnetometrisch onderzoek en een archeologische beoordeling ervan is in opdracht van TenneT uitgevoerd voor de elektriciteitskabels voor de windparken Hollandse Kust zuid en IJmuiden Ver Beta dat grotendeels hetzelfde tracé aanhoudt (Periplus, 2018). In dit onderzoek zijn twee locaties van mogelijke archeologische waarde gevonden waarin magnetische anomalieën zijn aangetroffen. Aanbevolen wordt het tracé lokaal aan te passen op deze locaties.

Mogelijke wijziging definitief tracé
Het definitieve tracé kan nog wijzigen op grond van de onderzoeksresultaten van het UXO- en archeologisch onderzoek. Conform artikel 98 Mbb zal Gasunie binnen vier weken na de aanleg van de pijpleiding de feitelijke ligging van de pijpleiding verstrekken.

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[6] Het opgenomen onderzoek dekt het voorgenomen tracé niet volledig. Op dit moment wordt een survey uitgevoerd naar de ontbrekende delen. Naar verwachting wordt deze aanvulling in juli 2020 opgeleverd en bijgevoegd bij deze aanvraag.

3.4 Wijze van aanleg

3.4.1 Maasvlakte

De leiding wordt in de leidingstrook gelegd conform de NEN 3650-serie, het "Handboek Beheer Ondergrond Rotterdam" en de richtlijnen van Rijkswaterstaat. Dit vindt plaats door middel van open ontgraving. De aanleg van transportleidingen in open ontgraving gebeurt door een sleuf te graven waarin de leiding wordt gelegd. Daarna wordt de sleuf weer aangevuld met de ontgraven grond en wordt het maaiveld zo goed als mogelijk weer hersteld naar de oorspronkelijke situatie.

De transportleiding wordt conform het voorschrift uit het "Handboek Beheer Ondergrond Rotterdam" van de gemeente Rotterdam standaard met een dekking van 1,0 meter gelegd en op een tussenafstand ("dagmaat") van 0,4 meter van bestaande kabels of transportleidingen.

Voor een uitgebreide beschrijving van de wijze van aanleg van de transportleiding op land wordt verwezen naar het MER, deelrapport Technische toelichting.

3.4.2 Kruising zeewering en Maasgeul

De kruising van de zeewering vindt plaats als mantelbuis of mediumvoerende buis die middels een HDD-boring wordt aangebracht, vanaf het landzijdige intredepunt naar het uittredepunt op zee. De boring heeft een lengte van circa 500 meter. Het uittredepunt bevindt zich twee meter onder de zeebodem en wordt verder in noordelijke richting als een geul uitgebaggerd. Hierbij komt naar verwachting circa 180 m^3 grond vrij per uitgebaggerde meter van de geul. Na het plaatsen van de leiding wordt de geul weer aangevuld tot oorspronkelijk niveau.

De kruising van de Maasgeul vindt plaats door middel van trenching & backfill. De leiding dient op minimaal -27,7m LAT onder de vaargeul aangelegd te worden. Ten aanzien van de effecten in de bodem van de Maasgeul zijn de voorwaarden van Rijkswaterstaat richtinggevend.

Bij de aanleg is het van belang dat er minimale verstoring van het scheepsvaartverkeer optreedt. Hierbij zullen de Nautische voorwaarden zoals opgesteld door DHMR richtinggevend zijn.

3.4.3 Pijpleiding zeebodem

Vanaf de kruising Maasgeul wordt de transportleiding op circa 0,6 meter diepte ingegraven in de zeebodem, tot aan de aansluiting met het platform.

Onderstaand wordt ingegaan op de aanlegtechniek, zoals deze toegepast kan worden, aangezien dat bepalend is voor de mogelijke milieueffecten die kunnen optreden.
De aanleg vindt plaats in de volgende stappen:

Uitvoeren van onderzoek en metingen
Langs het tracé zijn onderzoeken uitgevoerd om de bodemgesteldheid vast te stellen. Dit heeft geleid tot de volgende onderliggende documenten bij deze vergunning:

- FEED rapport pijpleiding zeedeel (Intecsea (2020)), bijlage 3
- Geotechnisch onderzoek (Pipeline route survey, Deep BV (2020)), bijlage 4

Controle of tracé vrij is van obstakels
Voordat de buisleiding wordt geïnstalleerd, moet de leidingroute uiteraard vrij zijn van obstakels, zoals buiten gebruik gestelde kabels, leidingen, schroot en van nature voorkomende stenen. Tijdens de voorbehandeling van de route of vlak voor de installatie worden deze obstakels opgezocht (met sonar en een magnetometer) en zo nodig verwijderd.

Leggen van de buisleiding op de zeebodem
Afhankelijk van de hoeveelheid buisleidingdelen die het legschip mee kan nemen wordt er eventueel een additioneel bevoorradingsschip ingezet om het legschip tijdig van buisdelen te voorzien.

Figuur 3.4 Visualisatie leggen van buisleiding op zeebodem

Op het legschip worden de buisleidingdelen opgestapeld. De individuele buizen zijn circa 12 meter lang. Vanaf de achterzijde van het legschip worden de buisdelen aaneengelast en in het water gebracht. Het schip wordt daarbij met geavanceerde plaatsbepalingsapparatuur in positie gehouden, zodat de leiding nauwkeurig op de zeebodem kan worden gelegd. De exacte positionering binnen de vergunde corridor wordt kort voorafgaand aan het feitelijke leggen van de buisleiding bepaald, op grond van de dan aangetroffen omstandigheden.

Voor het manoeuvreren en positioneren van het buisleidingschip worden normaal gesproken geen ankers gebruikt, maar stuwmotoren en schroeven. Een dergelijk schip kan in principe met behulp van GPS-navigatie, binnen een marge van ongeveer twee meter, nauwkeurig in positie worden gehouden. Voor het leggen van leiding is een nauwkeurigheidsmarge van twee meter voldoende.

Alleen als een schip lange tijd op dezelfde plek moet liggen wordt mogelijk gebruik gemaakt van ankers. Het gebruik van ankers houdt het schip voor langere tijd op dezelfde plaats en bespaart brandstof omdat dan niet continue hoeft te worden gewerkt met motoren. Rondom de ankers varen kleine ondersteunende schepen rond om de ankers te kunnen verzetten. Over het algemeen worden er vier ankers gebruikt.

Geul maken en leiding in bodem leggen
De leiding wordt op de zeebodem gelegd. Vervolgens wordt hieronder een geul gemaakt van circa 1 meter diepte d.m.v. een trenching machine. De leiding wordt hierin geplaatst, waarna het zand wordt teruggelegd in de geul.

Rekening houden met expansie van de leiding

Bij de aanleg wordt rekening gehouden met expansie ten gevolge van hogere temperaturen. Zowel bij het intredepunt van de kruising Maasgeul als bij het platform komen expansievoorzieningen. Het feit dat de leiding ingegraven ligt, draagt ook bij aan beperking van de uitzetting.

3.4.4 Overzicht scheepsbewegingen

Scheepsbewegingen
Qua scheepsbewegingen is het erg afhankelijk van de grootte van de schepen, of bijvoorbeeld alle segmenten al op de pijplegger liggen of wordt bevoorraad door een ander schip. Voor het baggerschip is het afhankelijk of die de bagger direct kan lozen of ergens anders moet dumpen.

De ingeschatte snelheid waarmee de buisleiding kan worden aangelegd bedraagt circa 1-3 km/dag. Dit is weersafhankelijk en afhankelijk van het aantal behandelingen die de buisleiding moet ondergaan in het productieproces aan boord van de pijplegger.

Schepen bij de installatieprocedure
Tijdens de installatieprocedure wordt in het basisontwerp gebruik gemaakt van de volgende schepen:

1 Het legschip;

2 Het schip met ingraafmachine;

3 Sleepboot of -boten, voor assistentie en het verzetten van ankers (indien noodzakelijk);

4 Begeleidingsschepen (assistentie, survey, bevoorrading e.d., eveneens indien noodzakelijk);

5 Een bevoorradingsschip dat buisdelen van de wal naar het legschip transporteert (indien nodig).

Mogelijk worden kleine sleepboten ingezet voor assistentie bij het manoeuvreren. De installatieschepen worden tijdens het doorkruizen van de Maasgeul begeleid door tenminste één en mogelijk twee begeleidingsschepen. Deze schepen surveilleren rond de installatieschepen om te vooromen dat andere schepen te dichtbij komen. Buiten de vaarroutes is het basisontwerp dat er zonder deze begeleidingsschepen gewerkt wordt, met als alternatief het wel toepassen van deze schepen.

Werkgebied
Bij het gebruik van twee schepen voor het leggen en het begraven heeft het spreidingsgebied van de werkzaamheden een lengte van maximaal circa 2 kilometer en een breedte van minimaal circa 1 kilometer. Het gaat dan om het gebied waarbinnen een leidinglegschip, het schip met de ingraafmachine en zo nodig de kleine sleepboten voor assistentie gelijktijdig werkzaam zijn. Indien met ankers wordt gewerkt, varen kleine sleepboten rond om de ankers te verzetten. Ook dit vindt plaats binnen het spreidingsgebied van 2 bij 1 kilometer. Rondom de installatieschepen geldt een veiligheidsafstand van 500 meter, in alle richtingen. De begeleidingsschepen zorgen er voor dat andere schepen niet te dichtbij komen.

3.5 Getransporteerde stoffen

De 16” leiding wordt gebruikt voor het transport van CO_2 met de volgende specificaties:

Tabel 3.1 Overzicht Porthos samenstelling gasmengsel

Component	Concentratie*
CO_2	≥ 95%
H_2O	≤ 40 ppmv
Sum [H_2+N_2+Ar+CH_4+CO+O_2]	≤ 4%
H_2	≤ 0.75%
N_2	≤ 2%
Ar	≤ 1%
CH_4	≤ 1%
CO	≤ 750 ppmv
O_2	≤ 40 ppmv
H_2S	≤ 5 ppmv
SO_x	≤ 50 ppmv
NO	≤ 2.5 ppmv
NO_2	≤ 2.5 ppmv
NO_x	≤ 5 ppmv
C2+ (hydrocarbons)	≤ 1200 ppmv
Aromatic hydrocarbons (incl. BTEX**)	≤ 0.1 ppmv
Total volatile organic compounds***	≤ 350 ppmv
Ethylene (Etheen)(C_2H_4)	≤ 1 ppmv
H-cyanide (HCN)	≤ 20 ppmv
Carbonyl Sulfide	≤ 0.1 ppmv
Dimethyl Sulfide	≤ 1.1 ppmv

*Alle percentages zijn mole %: 1% (mole) = 10.000 ppm
**: BTEX = benzene, toluene, ethylbenzene, xylene
***: Total volatile organic compounds = ethanol, acetaldehyde, ethyl acetaat, traces of n-propanol, isobutanol, acetone, dimethyl ether, propanal, 2-butanol, methanol, n-butanol and isoamyl acetaat

Toelichting temperatuurcondities onderin de put

Bij het transport van CO_2 is het van belang dat druk en debiet binnen de vastgestelde bandbreedte blijven, zodat de injectie van CO_2 in de putten kan worden uitgevoerd. Onderin de put zijn de druk en temperatuur afhankelijk van het aangevoerde gasmengsel en van de druk en temperatuur in het reservoir. Oorspronkelijk c.q. bij eerste CO_2-injectie is er een hoge temperatuur en lage druk in het reservoir. Geleidelijk aan zal de druk toenemen en de temperatuur afnemen doordat het geïnjecteerde CO_2 kouder zal zijn dan de reservoir temperatuur. Hierdoor veranderen in de loop van de tijd de condities onderin de put. Indien de druk en temperatuur buiten vooropgestelde marges komen, kan hydraatvorming onderin de put ontstaan, waardoor geen injectie meer mogelijk is.

CO_2-mengsel condities in de transportleiding naar het platform

Onderin de put zijn temperatuur en druk van cruciaal belang voor een goede injectie van het CO_2-mengsel. Door druk en temperatuur van het mengsel in het compressorstation te regelen en de condities in de transportleiding voorspelbaar te maken, kan de injectie vanaf het compressorstation worden beheerst.

Daarnaast is het van belang dat er in de transportleiding geen slug flow stroming optreedt. Indien er vloeistofslugs in het gas ontstaan, kan dit zorgen voor vibraties wat een negatief effect kan hebben bij bochten en afsluiters.

Voor Porthos is door TNO een “flow assurance” onderzoek uitgevoerd, waaruit volgt binnen welke randvoorwaarden en onder welke omstandigheden CO_2 technisch veilig en effectief kan worden getransporteerd en geïnjecteerd. Dit onderzoek is als bijlage 7 toegevoegd.

3.6 Kruisingen met andere leidingen en kabels

Het startpunt van het tracé op zee is ten westen van het aanlandingspunt van de geplande elektriciteitskabels van Tennet. Vervolgens blijft het tracé ten westen van de kabels, alsmede de te volgen TAQA leiding. Na Q16 blijft de leiding ten zuiden van de bestaande leidingen tussen Q16 en platform P18-A. Zodoende worden er geen bestaande leidingen gekruist. Uit de survey van Deep BV (2020) zijn twee onbekende “out of use” kruisingen gekomen. Eén met een kabel waarvan geen historische informatie is. De andere is een lineaire anomalie loodrecht op de leiding tussen Q16 en P18-A. Met de onbekende “out of use” kruisingen wordt rekening gehouden gedurende de aanleg.

3.7 Testen en inspectie transportleiding

Na het voltooien van de aanleg van de leiding en een waterdruk proef ter controle op lekken staat deze nog vol met water. Vanaf het intredepunt op MV2 wordt lucht door de leiding geblazen om het water te verwijderen. Er worden ook foampigs toegepast om de leiding droog te sponzen. Uiteindelijk moeten water en zuurstof uit de leiding verwijderd zijn om corrosie te voorkomen. Hierbij dient de onafhankelijk deskundige aanwezig te zijn die uit eindelijk ook een verklaring afgeeft dat de leiding voldoet aan het ontwerp en is aangelegd zoals vergund. Deze verklaring is noodzakelijk voor de instemming ingebruikname van de Inspecteur Generaal der Mijnen (IGM).

Bescherming van de buisleiding tegen corrosie
Om corrosie van de buisleiding van buitenaf tegen te gaan, wordt voorzien in een bescherming rond de buisleiding in combinatie met opofferingsanodes. De stalen buisleiding wordt beschermd door middel van een PP (polypropeen) beschermlaag. Na het aaneenlassen van de buisdelen wordt over elke las een bescherming aangebracht. De opofferingsanodes worden aangebracht op de stalen buis. Dit zijn anodes op basis van een aluminium legering in de samenstelling zoals deze doorgaans gebruikt worden op de Noordzee. Een voorbeeld van de samenstelling legering kan zijn volgens DNVGL eisen, meestal aangeduid als aluminium-zink-indium anodes waar de laatste componenten in kleine hoeveelheden aanwezig zijn om goed functioneren van de anodes te garanderen.

Door het PP en de betoncoating is de buisleiding geïsoleerd. Wanneer de betonlaag en de PP-bescherming rond de buisleiding beschadigd raken, kan het staal in aanraking komen met zeewater en zou de buisleiding gevoelig worden voor corrosie. Door opofferingsanodes wordt corrosie echter tegengegaan. Door de (lage) spanning op de buisleiding kunnen er geen elektronen uit de buisleiding uittreden en wordt corrosie voorkomen.

3.8 Bedrijfsvoering

Conform het Mbb zal Gasunie uiterlijk twee weken voor de geplande ingebruikname van de transportleiding een verzoek indienen bij het ministerie van EZK (gemandateerd aan de Inspecteur Generaal der Mijnen (IGM). Het verzoek wordt dus ingediend bij SodM voor instemming met de ingebruikname daarvan. Onderdeel van dit verzoek zijn:

a. Een verklaring van een onafhankelijke deskundige, waarin wordt beoordeeld of de eigenschappen en de aanleg van de transportleiding voldoen aan de bij of krachtens artikel 93 gestelde eisen, en

b. Gegevens waaruit blijkt dat de ligging van de transportleiding die is aangelegd in de territoriale zee voldoet aan de bij of krachtens artikel 93 gestelde eisen en, voor zover van toepassing, aan de desbetreffende vergunningvoorschriften.

De bedrijfsvoering van de leidingen wordt gebaseerd op een risicomanagementsysteem (RMS) om een veilige en duurzame bedrijfsvoering voor mens en milieu gedurende de totale levensduur te waarborgen. De bedrijfsvoering kan worden uitgevoerd door Gasunie of door een aan te wijzen exploitant. Het nog op te stellen RMS wordt conform NEN 3656 gebaseerd op gedocumenteerde doelen op het gebied van risicomanagement en niet zozeer op middelen. Het bepalen van de doelstellingen en de manier waarop die doelen moeten worden bereikt is de verantwoordelijkheid van de exploitant.
Een inspectieplan maakt deel uit van het RMS. De inspectie- en onderhoudsfrequentie wordt bepaald op basis van het RMS en de resultaten van eerdere inspecties en van een risico-inventarisatie en -evaluatie. Het RMS is gereed voordat de leiding in gebruik wordt genomen.

3.9 Milieu- en veiligheidsaspecten

Milieueffecten
De milieu- en veiligheidsaspecten van de aanleg en operatie van de leiding zijn uitgebreid behandeld in het MER. Uit het MER blijkt dat er effecten op natuur en archeologie optreden. De effecten op natuur worden veroorzaakt door onderwatergeluid en depositie van stikstof. De effecten worden zoveel mogelijk beperkt door het toepassen van mitigerende maatregelen.

Externe veiligheid
Voor de transportleiding op land is in het kader van het MER een kwantitatieve risico analyse (QRA) uitgevoerd. De berekening laat zien dat de langs de leiding de 10^{-6}-contour zich op de leidingstrook bevindt. Voor meer details wordt verwezen naar het MER en de onderliggende QRA-studie.

Monitoring
Gedurende de operationele fase wordt het zeedeel van de transportleiding gemonitord op twee aspecten:

- De ligging van de leiding in de zeebodem door middel van (ROV / MBES) survey;
- De inwendige integriteit van de leiding door middel van ‘intelligent pigs’.

De transportleiding op zee wordt in de zeebodem aangelegd. Om te zorgen dat de leiding daadwerkelijk in de bodem blijft liggen, is het van belang om in eerste instantie jaarlijks na aanleg inspectie uit te voeren. Hiermee wordt gecontroleerd of de aanvankelijke ingraafdiepte voldoende is en of de bodemdynamiek (erosie en sedimentatie) voldoet aan de verwachtingen. Indien de leiding stabiel blijkt te liggen kan na een aantal jaren verzoek worden ingediend voor andere frequentie.

De inspectie van de ligging in de zeebodem in de eerste jaren bestaat uit akoestische metingen langs het leidingtracé, waaruit, door vergelijking met de gegevens die vooraf en tijdens de installatie zijn verkregen, kan worden afgeleid hoe de bodem zich gedraagt.
Daarnaast wordt een inspectieplan voor de buisleiding zelf opgesteld waarin in de eerste jaren een internal baseline survey uitgevoerd wordt. De meting wordt gedaan door een *intelligent pig* door de buis te leiden welke de materiaaltoestand van de buisleiding controleert.

3.10 Buitengebruikstelling en verwijderen van de transportleiding

Na de buitengebruikstelling aan het einde van de levensduur wordt de buisleiding in principe verwijderd. De leiding wordt zonder groot grondverzet verwijderd van locaties waar deze gemakkelijk bereikbaar is. De verwijderde leiding wordt afgevoerd voor eindverwerking (recycling), door daarvoor erkende bedrijven.

Voor het verwijderen van de buisleiding wordt een schip gebruikt dat de leiding omhooghaalt en hem aan boord in stukken snijdt. Volgens het beleid voor de Noordzee in het Integraal Beheerplan Noordzee 2015 (IBN2015) is het verplicht om buiten gebruik gestelde kabels en leiding op ruimen.

Bij het verlenen van een vergunning voor het leggen en behouden (exploiteren) van een kabel of leiding wordt dan ook standaard een opruimplicht als voorschrift opgenomen als de kabel of leiding buiten gebruik wordt gesteld. Ontheffing van deze opruimplicht wordt alleen verleend als de maatschappelijke baten van het laten liggen groter zijn dan de maatschappelijke kosten ervan. Deze afweging maakt het Bevoegd Gezag op basis van door de vergunninghouder aan te leveren informatie.

De eigenaar van de buisleiding zal bovenstaande voorgenomen aanpak voor het verwijderen van de leiding toetsen op het moment dat dit aan de orde is.

Bijlage 1: Onderbouwing tracékeuze en bodemgesteldheid

Het in deze aanvraag beschreven tracé voor de transportleiding vanaf de Maasvlakte, kruising met de Maasgeul naar platform P18-A, is tot stand gekomen op een afwegingsproces van verschillende opties en varianten en de bespreking hiervan met de betrokken partijen. In deze bijlage wordt kort ingegaan op de gemaakte keuzes voor het hele tracé en per tracédeel. In het tweede deel van deze bijlage wordt ingegaan op de bodemgesteldheid langs het tracé.

Tracékeuze

Uitgangspunten

Bij het vaststellen van het leidingtracé voor het landdeel is rekening gehouden met de aanwezigheid van de leidingstrook en daarmee het huidige bestemmingsplan. Voor het zeedeel geldt het bestemmingsplan van de gemeente tot 1 kilometer vanaf de kust. In de huidige situatie is er in de zone vanaf de kust geen bestemming voor een transportleiding, zodat hier niet op kan worden aangesloten.

In de nabijheid bevinden zich de kabeltracés van de TenneT-aansluitkabels voor windparken op zee. Deze zijn deels al bestemd in het gemeentelijk bestemmingsplan. Hiermee wordt rekening gehouden door een minimale afstand van 50 meter tot de TenneT-kabels aan te houden.

Voor de Noordzee geldt dat er ruimtelijke reservering zijn gemaakt voor verschillende functies, zoals voor de olie- en gaswinning met transportleidingen, de te ontwikkelen windparken en ruimte voor zandwinning. Daarnaast zijn gebieden aangewezen als natuurgebieden, gereserveerd voor scheepvaart en visserij en voor militaire doeleinden.

Op de bodem van de Noordzee bevinden zich archeologische waarden, onder meer uit de periode voordat het Noordzeegebied onder water is komen te staan, enkele duizenden jaren geleden (begin van het Holoceen). Er bevinden zich ook scheepswrakken, waarmee rekening gehouden moet worden.

Selectie tracé landdeel

Het tracé op land wordt grotendeels bepaald door de locatie van het compressorstation. Hiervoor zijn drie locaties onderzocht:

1. Locatie Aziëweg, ten oosten van de Euromax terminal en ten westen van de GATE terminal
2. Locatie Edisonbaai, op de kop van de Maasvlakte aan de Maasvlakteweg
3. Locatie Europaweg, op het terrein van Uniper gelegen

Op basis van een multi criteria analyse is gekozen voor de eerste optie, waardoor het tracé op land langs de Aziëweg en Maasvlakteweg voert.

Selectie kruising Maasgeul

Voor de kruising met de Maasgeul waren in overeenstemming met de uitgangspunten twee opties beschikbaar:

1. HDD-boring (circa 1800 m) vanaf land onder de Maasgeul door met een intredepunt oostelijk van de Tennet-aanlanding en een uittredepunt ten westen van de strekdam. Bij deze optie dient een kofferdam op zee te worden aangelegd.
2. HDD-boring (circa 500 m) vanaf land onder de zeewering door met een intredepunt westelijk van de Tennet-aanlanding en een uittredepunt achter de zeewering en voor de Maasgeul. Bij deze optie wordt de Maasgeul gekruist door middel van trenching&backfill.

In overeenstemming met de Havenmeester is gekozen voor de tweede optie. De eerste optie wordt te complex geacht door de meer risicovolle boring.

Selectie tracé zeedeel

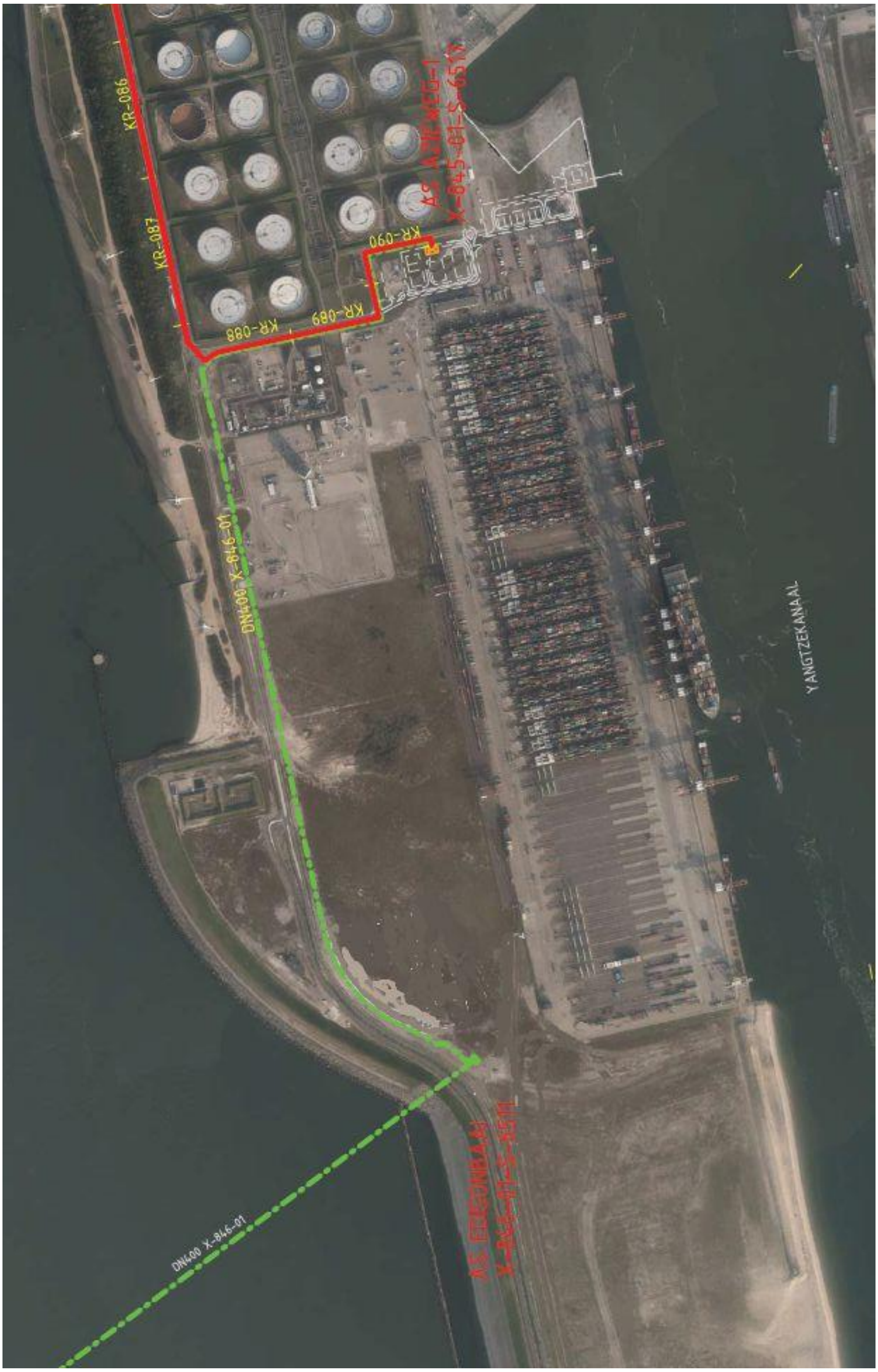
De initiële gedachte om een leiding tracé direct van de kust naar het platform te laten gaan, komt in conflict met een aantal bovenstaand genoemde functies en reserveringen. Het voorgestelde tracé wordt voorzien langs al bestaande leidingen. Daarbij is er de mogelijkheid om respectievelijk ten westen en zuiden van de bestaande leidingen de leiding aan te brengen met een aanlanding bij het platform aan de zuidkant, of ten oosten en noorden van de bestaande leidingen met een aanlanding bij het platform aan de noordkant. De keuze wordt grotendeels bepaald door de locatie van de kruising van de Maasgeul. Omdat voor de westelijke variant is gekozen, is de meest logische route langs het westen en zuiden van de bestaande leidingen. Hiervoor is dan ook gekozen.

Bodemgesteldheid

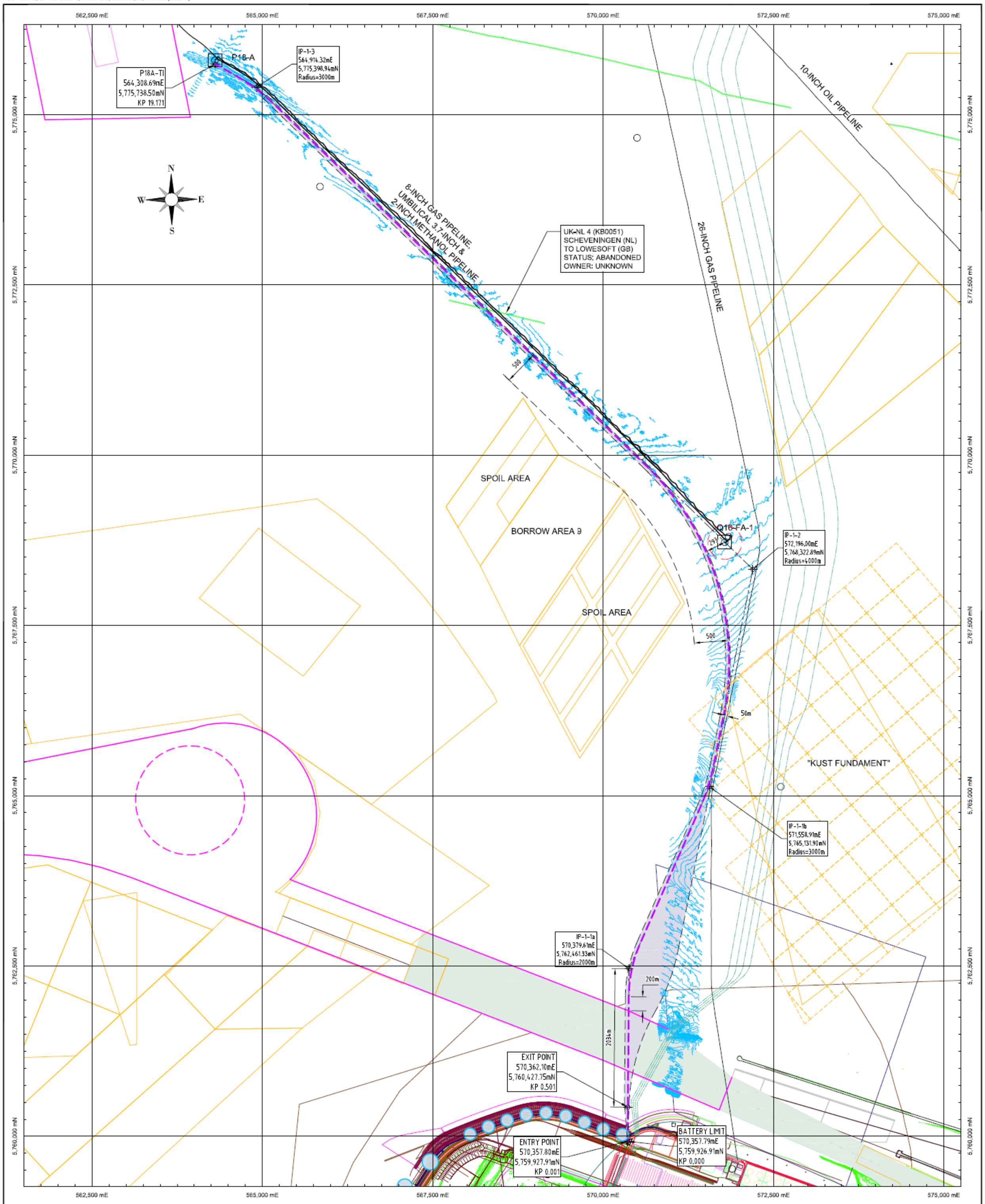
Het voorlopige tracé is vastgesteld op basis van beschikbare gegevens van het zeebed en de daar aanwezige kabels, leidingen en andere obstakels. De zeebodem van dit deel van de Noordzee bestaat voornamelijk uit zand en de waterdiepte is 14 tot 23 meter. In 2020 is een route-survey uitgevoerd voor het vaststellen van het exacte tracé en de bodemgesteldheid. Omdat de bodem van dit deel van de Noordzee al goed in kaart is gebracht, wordt niet verwacht dat dit tot grote wijzigingen van het tracé leidt. Kleine wijzigingen van maximaal enkele honderden meters van het opgegeven tracé worden opgegeven bij het verstrekken van de feitelijke ligging van de pijpleiding.

Royal HaskoningDHV

Bijlage 2: Kaarten met ligging tracé



FILE NAME: Y:\INTECSEA WP\41601000212 PORTHOS\CAD\SU\DWG\TROF-ENG-PIP-INT-DWG-0001\TROF-ENG-PIP-INT-DWG-0001.DWG
PLOT DATE: 27 Feb 2020 8:19 AM BY: VAN KUIJK, FRANK (DELFT)



NOTES & LEGEND

1. Confirmation heading of pipeline awaiting Porthos-TenneT Influence study.
2. Porthos Route ID: Porthos_04_20200221
3. Route coordinates: see TROF-ENG-PEN-INT-REP-0001
4. Pipeline route still pending agreement with third parties, e.g. Rijkswaterstaat
5. Minimum distance to existing offhore infrastructure: 50m
6. Pipeline approach to platform P18A may be further optimized.

Legend:
- Proposed Pipeline Route
- ONE-DYAS assets
- Submarine Cable
- TenneT Power Cable
- Existing Pipeline
- Proposed Pipelines (TBC)
- Boundary of Clearway
- Area of Sand Winning
- Kustfundament
- Dredging Maintenance Area
- Indicative Routing Optimization Envelope
- Planned Wind Turbine Location Radius represents safety zone

0 250 1,250 2,500
METERS

GEODETIC & PROJECTION PARAMETERS

DATUM NAME	:	European Datum 1950
REFERENCE SPHEROID	:	International 1924
PROJECTION		
Projection System	:	Universal Transverse Mercator (UTM)
Zone	:	31 North
Latitude of origin	:	0° (Equator)
Central meridian (CM)	:	3° E
False Easting at origin	:	500 000 m
False Northing at origin	:	0 m
Scale factor at CM	:	0,9996

REV	DATE	DESCRIPTION	DRWN	DSGN	ENGR	APPR
01	27 FEB 2020	RE-ISSUED FOR CLIENT REVIEW	FAK	FAK	OB	FvdL
00	17 DEC 2019	ISSUED FOR CLIENT REVIEW	FAK	FAK	OB	FvdL
B	16 DEC 2019	ISSUED FOR INTERNAL REVIEW	FAK	FAK	OB	
A	09 DEC 2019	ISSUED FOR INFORMATION	FAK	FAK	OB	

Intecsea
Worley Group

PROJECT: Porthos CO2 Pipeline FEED

CLIENT: Port of Rotterdam, gasunie (crossing borders in energy), ebn

TITLE: ROUTE OVERVIEW

DRAWN BY:	DATE:	CHECKED BY:	DATE:	APPROVED BY:	DATE:	SHEET	OF
FAK	26 NOV 2019	OB	25 FEB 2020	FvdL	27 FEB 2020	1	1

SCALE AT 'A1' SIZE	DRAWING NUMBER	REV
1:25,000	TROF-ENG-PIP-INT-DWG-0001	01

Route Points	Coordinates UTM31N-ED50		LL – ED50		Heading	Radius	KP
	Easting [m]	Northing [m]	Longitude [°]	Latitude [°]	[°] to GN	[m]	[km]
Onshore Battery Limit	570357.880m	5759926.917m	E004° 01' 28.13"	N051° 59' 04.11"	355.274	-	0.000
HDD Entry Point	570357.798m	5759927.914m	E004° 01' 28.12"	N051° 59' 04.15"		-	0.001
HDD Exit Point	570316.613m	5760426.064m	E004° 01' 26.33"	N051° 59' 20.29"		-	0.501
TP-1-1a	570177.116m	5762113.272m	E004° 01' 20.26"	N052° 00' 14.95"		-	2.194
IP-1-1	570136.292m	5762607.041m	E004° 01' 18.49"	N052° 00' 30.95"	-	2000	-
TP-1-1b	570330.683m	5763062.767m	E004° 01' 29.02"	N052° 00' 45.61"	23.101	-	3.165
TP-1-2a	571607.555m	5766056.239m	E004° 02' 38.24"	N052° 02' 21.89"		-	6.420
IP-1-2	572426.216m	5767975.491m	E004° 03' 22.66"	N052° 03' 23.61"	-	3000	-
TP-1-2b	570911.727m	5769410.780m	E004° 02' 04.23"	N052° 04' 10.77"	313.462	-	10.066
Preliminary End	564231.748m	5775741.432m	E003° 56' 17.75"	N052° 07' 38.57"		-	19.269

Bijlage 3: FEED rapport van de transportleiding (Intecsea, 2020)

Bijlage 4: Rapport geotechnisch leidingonderzoek (Deep BV, 2020)

Bijlage 5: Aanvraag vergunning Wet Natuurbescherming

Bijlage 6: Route Selection Report (FEED IntecSea 2020)

Bijlage 7: Porthos flow assurance onderzoek (TNO, 2019)

Bijlage 8: Archeologische bureaustudie Porthos pijpleiding (Periplus Archeomare, 2020)

Aan
RCR coördinator Bouke Bussemaker Porthos

Van
Menno Bekker

K.c.
Porthos

Via

Datum
4 september 2020

Onderwerp
Addendum Mijnbouwzeeleding aanvraag Porthos

NOTITIE

Geachte heer Bussemaker,

Hierbij stuur ik u het addendum op de aanvraag van de Mijnbouwzeeleiding voor Porthos ingediend 22 juni 2020.

ETRS89 (projectie zie https://epsg.io/4258)

Reeds aangeleverd in bijlage 6 app A

Table 7-1: Coordinates RD: Route Definition: Porthos_03_20191209

Route Points	Coordinates RD Grid		Heading	Radius	KP
	Easting [m]	Northing [m]	[°] to GN	[m]	[km]
Onshore Battery Limit	61297.16	444798.73	357° 09' 21"	-	0.000
HDD Entry Point	61297.11	444799.73		-	0.001
HDD Exit Point	61272.30	445299.12		-	0.501

ETRS89:

Longitude [°]	Latitude [°]
4,023166	51,983676
4,023165	51,983685
4,022667	51,988168

Reeds aangeleverd in bijlage 6 app A

N.V. Nederlandse Gasunie

Datum: 4 september 2020

Onderwerp: **Fout! Verwijzingsbron niet gevonden.** Addendum Mijnbouwzeeleding aanvraag Porthos

Table 2-2: Coordinates UTM31N-ED50 and Longitude Latitude – ED50. Route Definition: Porthos_03_20191209

Route Points	Coordinates UTM31N-ED50		LL – ED50		Heading	Radius	KP
	Easting [m]	Northing [m]	Longitude [°]	Latitude [°]	[°] to GN	[m]	[km]
Onshore Battery Limit	570357.880m	5759926.917m	E004° 01' 28.13"	N051° 59' 04.11"	355.274	-	0.000
HDD Entry Point	570357.798m	5759927.914m	E004° 01' 28.12"	N051° 59' 04.15"		-	0.001
HDD Exit Point	570316.613m	5760426.064m	E004° 01' 26.33"	N051° 59' 20.29"		-	0.501
TP-1-1a	570177.116m	5762113.272m	E004° 01' 20.26"	N052° 00' 14.95"		-	2.194
IP-1-1	570136.292m	5762607.041m	E004° 01' 18.49"	N052° 00' 30.95"	-	2000	-
TP-1-1b	570330.683m	5763062.767m	E004° 01' 29.02"	N052° 00' 45.61"	23.101	-	3.165
TP-1-2a	571607.555m	5766056.239m	E004° 02' 38.24"	N052° 02' 21.89"		-	6.420
IP-1-2	572426.216m	5767975.491m	E004° 03' 22.66"	N052° 03' 23.61"	-	3000	-
TP-1-2b	570911.727m	5769410.780m	E004° 02' 04.23"	N052° 04' 10.77"	313.462	-	10.066
Preliminary End	564231.748m	5775741.432m	E003° 56' 17.75"	N052° 07' 38.57"		-	19.269

ETRS89

Longitude [°]	Latitude [°]
4,023166	51,983676
4,023165	51,983685
4,022667	51,988168
4,020981	52,003353
4,020487	52,007797
4,023412	52,011869
4,042639	52,038615
4,054979	52,055762
4,033192	52,06886
3,936944	52,126584

Ten aanzien van de bevestiging van de juiste coördinaten van het beginpunt (afsluiter compressorstation) en eindpunt (afsluiter platform P18-A) van de pijpleiding.:
Startpunt bij compressorstation:
KP 0 km North 443818 East 62934
Eindpunt bij platform
ETRS89

Longitude [°]	Latitude [°]
3,936944	52,126584

Bijlage 5 (Wnb-vergunningaanvraag).
De bijlage 5 (Wnb-vergunningaanvraag). maakt geen onderdeel uit van de mijnbouwzeeledingsvergunningaanvraag. De Wnb-vergunningaanvraag valt echter onder dezelfde RCR procedure als deze mijnbouwzeeledingsvergunningaanvraag en ligt gelijktijdig met de Mijnbouwzeeledingaanvraag en de besluiten hierop ter inzage.

Porthos FEED Offshore Pipeline

Offshore Pipeline Design Report

Porthos

CTR No.: LB012, 015, 016, 017, 018, 019, 020
Revision: 0.1
Date: 04-Aug-2020

416010-00212 -TROF-ENG-PIP-INT-REP-0006

Intecsea
Worley Group

Intecsea.com

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416010-00212 -TROF-ENG-PIP-INT-REP-0006 – Porthos FEED Offshore Pipeline: Offshore Pipeline Design Report

Rev	Description	Author	Review	Intecsea approval	Date
0.1	Client Review	EK	OB/FvdL	FvdL	04-08-2020
0.0	Client Review	EK	OB/FvdL	FvdL	15-04-2020
B	Internal Review	EK/ OB	NK/FvdL		25-03-2020

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1 Introduction

1.1 Project General

EBN (Energie Beheer Nederland), Gasunie and Port of Rotterdam, united in the PORTHOS consortium (Port of Rotterdam CO_2 Transport Hub & Offshore Storage) have initiated a plan to collect CO_2 from the industrial area of the port of Rotterdam and transport it to an abandoned gas field offshore for storage.

As part of this CCUS-project (Carbon Capture Utilization and Storage) a concept study was completed in 2018. PORTHOS now proceeds with the FEED phase in 2019 and 2020, which will include the FEED design for the offshore pipeline section which extends from the last onshore weld in the horizontal pipe section connecting to the trenchless shore and Maasgeul crossing, up to the bottom flange of the riser at the P18-A platform.

INTECSEA BV is performing the Front End Engineering & Design (FEED) of the offshore pipeline in between the above mentioned battery limits.

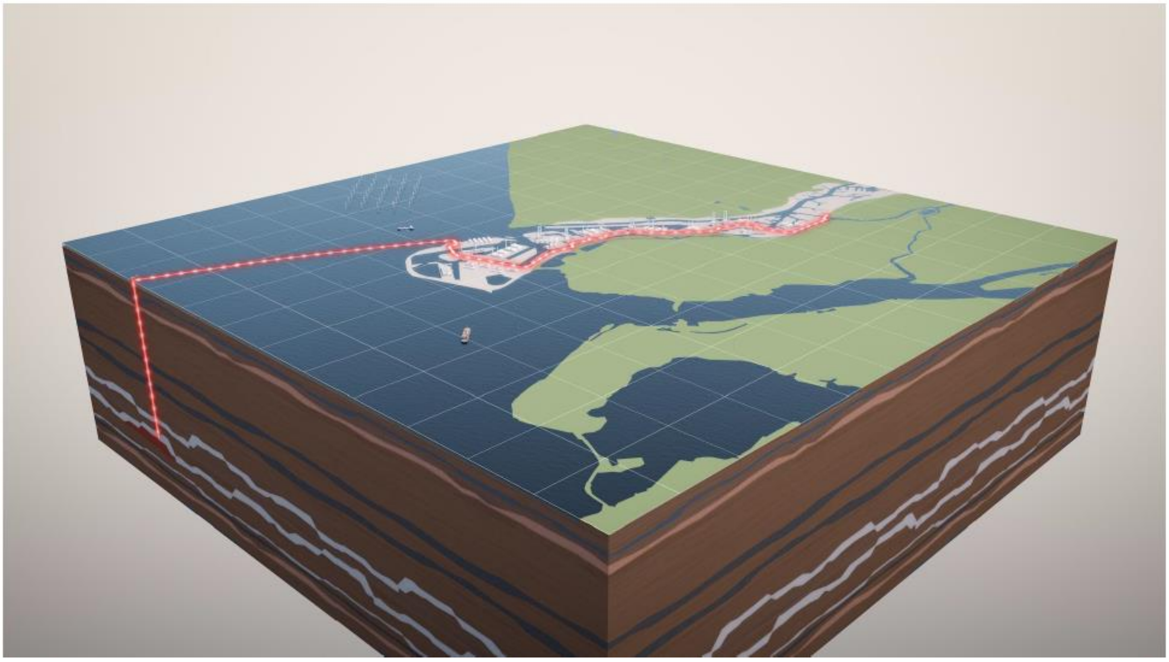


Figure 1-1 PORTHOS overview

1.2 Scope of Document

The purpose of this report is to present the results of the offshore pipeline design. This includes stability, upheaval buckling and cathodic protection design but not wall thickness design which is part of the material selection report Ref. [1]. Note that the document is completed before finalization of the flow assurance assessment and definition of the operating philosophy.

1.3 Definitions

1.3.1 System of Units

All data and results presented shall be expressed in SI (metric) units. In addition, other units may be used where they are universally accepted standards, such as for standard flow rates, temperature (°C), pressure (bar), or pipeline diameters (inch).

1.3.2 Abbreviations

Table 1-1: Abbreviations

Al	Aluminium
BOD	Basis of Design
CA	Corrosion Allowance
CCUS	Carbon Capture Utilization and Storage
CP	Cathodic Protection
CWC	Concrete Weight Coating
DNVGL	Det Norske Veritas and Germanischer Lloyd
E	Young's Modulus
EBN	Energie Beheer Nederland
EN	European Norm
FBE	Fusion Bonded Epoxy (coating)
FEED	Front End Engineering & Design
HDD	Horizontal Directional Drilling
ID	Inside Diameter
NEN	Nederlandse Norm (Nederlands Normalisatie Instituut)
OD	Outside Diameter
PP	Poly Propylene
PORTHOS	Port of Rotterdam CO_2 Transport Hub & Offshore Storage
SI	Système International (d'unités)
SMTS	Specified Minimum Tensile Strength
SMYS	Specified Minimum Yield Stress
WD	Water Depth

1.3.3 Other Definitions

Table 1-2: Definitions

CLIENT	PORTHOS (Cooperation between EBN, Gasunie and Port of Rotterdam)
ENGINEER	INTECSEA B.V. (Worley Group)
PROJECT	PORTHOS pipeline. Scope of work: pipeline between battery limits
Nearshore	Area south of the Maasgeul
Offshore	Maasgeul and area North of Maasgeul towards P18-A
HOLD	Data to be established / determined or to be received

1.4 HOLD Record

Location	Description of HOLD
N/A	NONE

2 Summary

This report presents the results of the offshore pipeline design. This includes, amongst others; stability, upheaval buckling and cathodic protection design but not wall thickness design which is part of the material selection report Ref. [1]. The results and conclusions are not final until completion on the flow assurance assessment and definition of the operating philosophy.

Pipeline design has been performed in accordance with NEN 3656 (Ref. [3]), which is the latest issue of the Dutch offshore pipeline design code, applicable for the Dutch continental blocks of the North Sea. The design life of the pipeline system is 30 years. The design is based on the information contained in the basis of design (Ref. [2]) and material selection report.

Pipeline stability

Pipeline stability design is based on the requirements of DNVGL-RP-F109 (Ref. [6]) because of the lack of detailed and up to date guidance in NEN 3656. For the relative deep water section beyond KP 8.0 a weight coating thickness of 80 mm is proposed. For the shallow water part and Maasgeul up to KP 8.0 two options are given. A weight coating thickness of 110 mm for the entire section up to KP 8.0 provides additional safety against lateral displacements in the critical Maasgeul section but requires a higher installation effort. As an alternative, mainly to limit the pull forces for the HDD and Maasgeul section, a reduction to 80 mm weight coating for the Maasgeul part can be considered (dredged channel depth >28 m, < 1 km length).

For these weight coating thicknesses, the pipeline is stable in flooded condition. In empty condition the maximum displacements under DNVGL-RP-F109 design conditions is less than 10 OD. For the Maasgeul section smaller displacements are predicted for 110 mm weight coating (stable even for winter conditions) than for 80 mm (still acceptable for summer installation period). Selection involves cost and schedule risks, requiring Client decision. All proposed and optional weight coating thicknesses are considered acceptable under the following conditions;

- Installation shall be initiated based on good weather forecast, in the period May to August. If weather forecasts during the installation period predict higher sea states, the pipeline shall be abandoned and flooded.
- The temporary phase between installation and trenching or flooding shall be minimized.
- A detailed study shows that local and seasonal currents in the Maasgeul (high river flow rate) do not exceed values assumed in this study (SP3 data point, located close to Maasgeul)

The empty pipeline with the considered wall thickness of 14.3 mm and proposed weight coating thickness has a specific gravity of 1.9 (for 80 mm CWC) or more (110 mm CWC) in empty condition, which is sufficient for an efficient trenching operation. Only if the pipeline has been flooded, for example for stability reasons, trenching in flooded condition is required.

Upheaval buckling

To limit the risk of upheaval buckling a cover height of 0.2 m (110 mm CWC) or 0.4 m (80 mm CWC) is required over the route length, with an increase in requirement to 0.3 m (HDD side, 110 mm) to 0.6 m

(platform side, 80 mm) for the sections within the high safety zone. A cover height of up to 0.6 m is considered to be well within capabilities of most trenching contractors.

The trenching requirements following from a pipeline safety study (shipping lane crossing) to be performed as part of further design should be considered in the final trench depth specification. Therefore, the final burial requirement will be defined in the offshore route safety study (Ref. [12]).

Cathodic protection

In addition to the anti-corrosion / insulation coating the pipeline will be protected by aluminium based sacrificial anodes. A total net anode mass of 12242 kg is required (conservative estimate for costing). The CP solution for the HDD section will be addressed as part of the HDD design. Separation of CP systems of the various pipeline system parts (if considered needed) has to be affected outside the offshore pipeline scope and is not addressed in this report.

In place stresses and expansion

Pipeline spans are checked based on static stresses (bottom roughness analysis). The pipeline will be trenched after installation on the seabed. The first section will be installed in an HDD and pre-excavated trench with prescribed trenching accuracies. North of the Maasgeul, the natural seabed slope is generally less than 2 degrees with very few locations where the slope is more than 2 but less than 4 degrees. In view of the short duration the pipeline is positioned on the seabed static spans are more relevant than the dynamic behaviour of the spans. Model results show that the pipeline may only see some very minor spans in the temporary on-seabed condition between KP 12 and KP 13. These have a length of less than 10 m and have a maximum span height in the order of 0.1 m. These spans are considered to be negligible for the temporary pipe-on seabed phase. Also, for the current route no crossing of existing infrastructure is required, eliminating the requirement for the design of a crossing lay-out with associated stress check.

Pipeline expansion will occur at the pipeline ends. These will be absorbed by the expansion spools near the platform and at the offshore to onshore interface. To correctly analyse these sections, FE models will have to be made to determine displacements and stresses in pipeline, spools and riser at the platform, see (Ref. [13]) and (Ref. [14]).

Installation assessment

The final installation analysis will be performed by the contractor for the selected installation vessel. A preliminary S-lay analysis has been performed to confirm that S-lay of the project pipeline is feasible. The analysis results (using commercial software Offpipe) show that the required lay tension to limit the pipeline stresses and concrete crushing is in the order of 50 to 100 metric tonnes, depending on the vessel and stinger configuration. This makes the pipeline installable by many of the S-lay vessels available.

An essential aspect of all, or most installation methods is the pull of a pipeline length covering the HDD and Maasgeul section. The length of this section is approximately 2300 m. With the submerged weight of the pipeline and an assumed axial friction factor of 1.0 the required pull force for various scenarios have been calculated (Table 8-1). Some scenarios require weight reduction by means of buoys or reduction of the concrete weight coating for the deep part of the Maasgeul crossing.

The results show that the pull is feasible, but depending on the selected installation scenario measures such as buoys or weight coating optimization may be required, also depending on the use of a dedicated winch or HDD drill rig.

HDD and Maasgeul design (weight coating, CP) and installation (pull forces) have to evaluated considering the interaction between aspects, this also involves cost and schedule risks and requires Porthos final decision.

3 Design Conditions

In this section the design guidelines and operating and design conditions for offshore pipeline design are given, as well as the relevant internal and external environmental conditions. All data is taken from Ref. [2] unless specified otherwise.

3.1 Design Guidelines

Pipeline design will be performed in accordance with NEN 3656 (Ref. [3]), which is the latest issue of the Dutch offshore pipeline design code, applicable for the Dutch continental blocks of the North Sea.

NEN 3656 uses design loads for calculation purposes. These loads are obtained by multiplying the service loads by design factors. The design factor is a measure of the required safety margin between a given load and the associated limit state.

From a safety point of view, NEN 3656 uses different design factors for the 500 m zone near the platform (zone 2) and the main pipeline section away from any areas with human activity (zone 1).

All design factors are given in Table 3 of Ref. [3].

3.2 Design Life

The design life of the pipeline system is 30 years.

3.3 Route Data

The pipeline route corridor (route ID _06_20200625) is defined in Ref. [4] and shown in Figure 3-1, see also (Ref. [15]). The seabed elevation profile is shown in Figure 3-2 (based on DEEP survey, Ref. [16]).

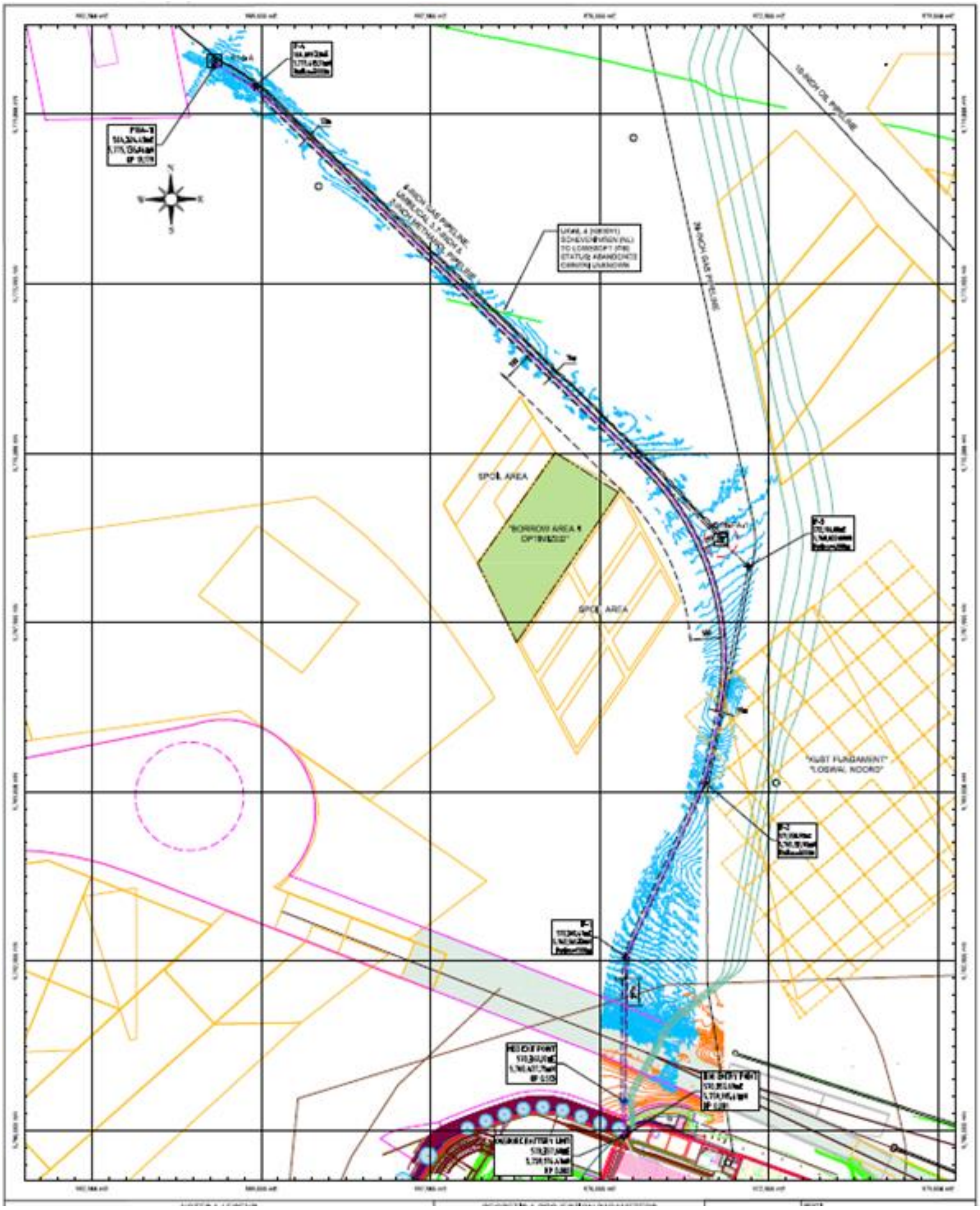


Figure 3-1 PORTHOS pipeline route overview

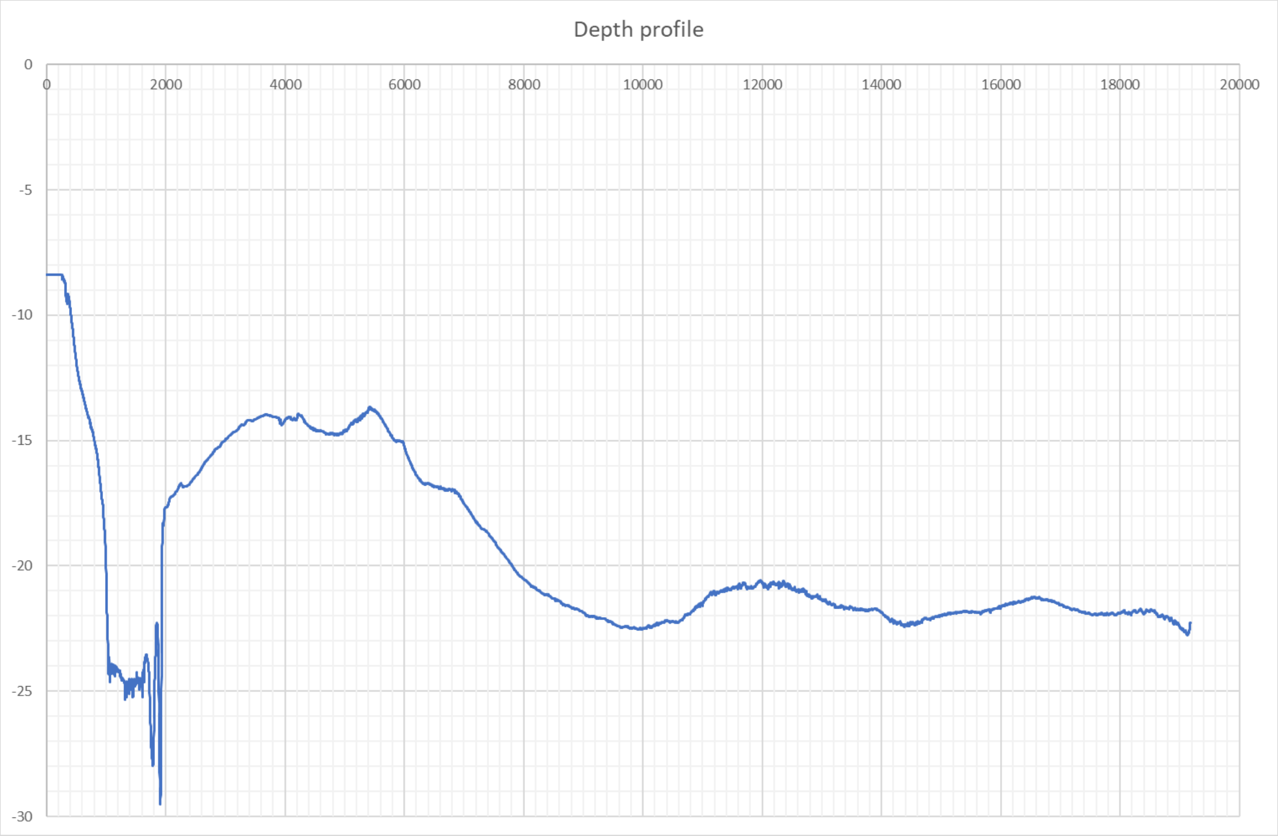


Figure 3-2 PORTHOS pipeline seabed elevation profile

The pipeline will not cross existing pipelines or cables. It is assumed that the abandoned UK-NL 4 telephone cable will be removed should it prevent pipe laying and/or trenching.

The pipeline is crossing a major shipping lane (Buitengaats verkeersscheidingsstelsel Rotterdam - Rijnmond met Eurogeul, route #4 of the verkeersscheidingsysteem Noordzee), see Ref. [5].

3.4 Pipeline Operational Data

Pipeline operational data is collected in Table 3-1.

Table 3-1: Pipeline Operational Design Data

Parameter	Value
Design pressure	140 barg at +5 m rel to NAP
Maximum operating pressure	131 barg at +5 m rel to NAP
Design temperature - maximum - minimum	 90 °C -20 °C
Operating temperature - maximum (compressor outlet) - minimum (minimum seawater temperature)	 80 °C 0 °C

3.5 Pipeline Material Data

The dimensional data and steel properties for the 16-inch OD pipeline are given in Table 3-2.

Table 3-2: Pipeline Material Design Data

Parameter	Value
Pipe nominal outside diameter	16-inch / 406.4 mm
Wall thickness	14.3 mm
Corrosion allowance [1)]	0 mm
Wall thickness tolerance (LSAW or other)	- 0.5 mm

Parameter	**Value**
Carbon steel grade SMYS @ <50 °C SMYS @ 100 °C	L450 450 MPa 402 MPa
Density	7850 kg/m^3
Young's modulus	2.07*10^5 MPa
Poisson ratio	0.3
Coefficient of thermal expansion	11.6*10^{-6} /°C
Notes 1) The transported medium is CO_2 with a water content of < 40 ppmv, and H_2S content of < 5 ppmv. Provided that the target composition is guaranteed by technical measures (measurement of composition and offshore pipeline automated safety valves), no free water will be present in the offshore pipeline. This implies that no electrolyte is present and therefore no internal corrosion will occur, see Section 1.2	

The line pipe will be coated with a 5-layer polypropylene anti-corrosion/ insulation coating and concrete weight coating with the properties shown in Table 3-3.

Table 3-3: Pipeline Coating Data

Parameter	**Value**
Coating type	5LPP [1)]
1st layer; FBE (@ 0.3 W/mK)	0.3 mm @ 1400 kg/m^3
2nd layer; adhesive (@ 0.22 W/mK)	0.3 mm @ 900 kg/m^3
3th layer; solid PP (@ 0.22 W/mK)	5 mm @ 900 kg/m^3

Parameter	**Value**
4th layer; PP foam (@ 0.175 W/mK)	27 mm @ 750 kg/m^3
5th layer; solid PP (@ 0.22 W/mK) with rough coat finish	5 mm @ 900 kg/m^3
Concrete weight coating 2)	3040 kg/m^3
Notes 1) Total anti-corrosion / insulation coating thickness is 37.6 mm with an equivalent density of 790 kg/m^3, this results in combination with 0.6 m burial (TOP) in an U-value of 3.0 W/mK, the build-up of layers to achieve this value will vary per coating contractor 2) The weight coating thickness is determined in the section on-bottom stability (see Section 4.3)	

3.6 Environmental Conditions

The pipeline will be installed in seawater and seabed soils consisting mainly of sand. The environment is not known to contain any unusual components, or to have any unusual characteristics that require consideration in design. Seawater salinity, pH and temperature are normal for North Sea conditions.

Environmental data is taken from Ref. [2], the locations for which data is available are identified as SP 1 to SP3. For the exact locations see Ref. [2], the approximate locations are shown on Figure 3-3.

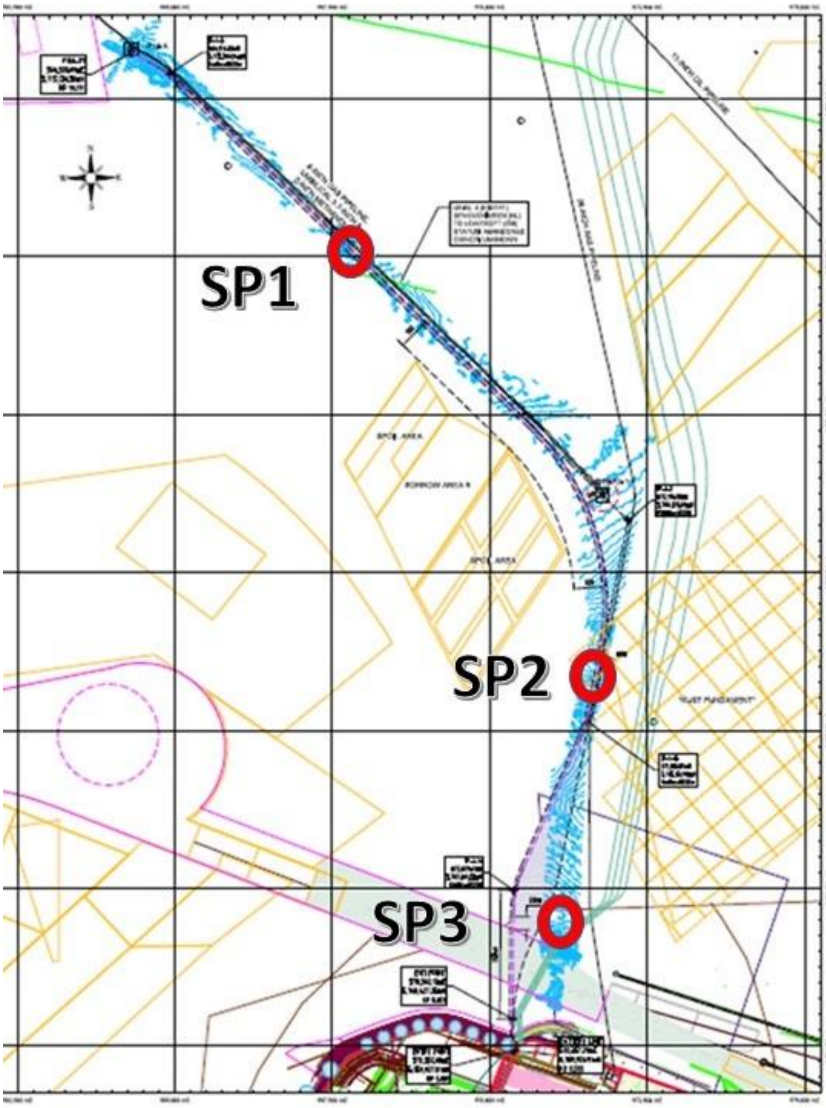


Figure 3-3 Environmental Data Locations SP 1 to SP 3

3.6.1 Water Depth and Seabed Characteristics

The water depth at the HDD exit is approximately -16 m relative to LAT.

The water depth at P18-A is approximately - 22 m relative to LAT.

The depth varies between and -16 m and -23 m between HDD and platform, with exception of the Maasgeul which is kept at a depth of over 25 m, see also Figure 3-2. The seabed is generally flat with only small depth variations and gentle slopes (generally less than 2 degrees slope angle), again with the exception of the Maasgeul. The top layer of the seabed consists generally of (very) loose sand for which the following parameters have been selected for design.

Table 3-4 Soil Parameters

Parameter	**Value**
Submerged soil weight	9.5 – 10 kN/m^3
Angle of internal friction	28-30 degrees

3.6.2 Wave Data

Directional wave data is given in Table 3-5. Given are the values for “all year”, for seasonal data; April to September and May to August, reference is made to Ref. [2]. Given directions are the direction the wave is coming from.

Table 3-5: Directional Wave Data, All Year

Location SP 1									
RP (yr)	Hs (m)								
	Direction (deg N)								
	0	45	90	135	180	225	270	315	Omni-dir
1	4.52	2.02	1.59	1.28	1.54	3.72	4.72	4.99	5.18
10	5.54	2.50	2.05	1.72	1.91	4.36	5.58	5.94	6.07
50	6.18	2.80	2.34	2.02	2.13	4.76	6.11	6.54	6.64
100	6.45	2.92	2.46	2.14	2.23	4.92	6.33	6.78	6.88
Tp (s)									
RP (yr)	Direction (deg N)								
	0	45	90	135	180	225	270	315	Omni-dir
1	9.78	5.67	4.57	4.12	4.77	7.93	8.93	9.76	9.96
10	10.70	5.80	5.08	4.42	4.96	8.62	9.73	10.63	10.90
50	11.27	5.88	5.40	4.62	5.08	9.05	10.22	11.19	11.50
100	11.51	5.91	5.54	4.70	5.13	9.23	10.43	11.41	11.75
Location SP 2									
RP (yr)	Hs (m)								
	Direction (deg N)								
	0	45	90	135	180	225	270	315	Omni-dir
1	3.86	1.62	1.20	0.96	1.14	2.70	4.23	4.98	5.08
10	4.62	2.00	1.54	1.24	1.45	3.28	5.03	5.87	5.96
50	5.09	2.24	1.75	1.42	1.64	3.64	5.53	6.43	6.52
100	5.28	2.34	1.83	1.49	1.71	3.79	5.74	6.65	6.75

Tp (s)									
RP	Direction (deg N)								
(yr)	0	45	90	135	180	225	270	315	Omni-dir
1	9.19	5.56	4.13	3.91	4.56	6.83	8.48	9.75	9.86
10	9.87	5.66	4.51	4.10	4.72	7.46	9.22	10.57	10.78
50	10.29	5.73	4.74	4.22	4.82	7.85	9.68	11.08	11.37
100	10.46	5.76	4.83	4.26	4.86	8.01	9.88	11.29	11.61
Location SP3									
RP	Hs (m)								
	Direction (deg N)								
(yr)	0	45	90	135	180	225	270	315	Omni-dir
1	3.44	1.57	1.11	0.87	1.04	2.55	4.09	5.03	5.03
10	4.20	1.99	1.43	1.19	1.35	3.08	4.87	5.92	5.92
50	4.68	2.26	1.62	1.42	1.53	3.41	5.37	6.47	6.50
100	4.88	2.37	1.70	1.51	1.61	3.54	5.58	6.69	6.74
Tp (s)									
RP	Direction (deg N)								
(yr)	0	45	90	135	180	225	270	315	Omni-dir
1	8.82	5.55	4.03	3.85	4.51	6.67	8.35	9.79	9.81
10	9.50	5.66	4.39	4.06	4.67	7.24	9.07	10.61	10.74
50	9.93	5.74	4.60	4.22	4.76	7.60	9.54	11.12	11.35
100	10.11	5.77	4.69	4.28	4.81	7.74	9.73	11.32	11.60

3.6.3 Current Data

Current data per direction is given in Table 3-6. Given directions are the direction the current is flowing to. The currents mainly flow towards sectors SW and NE.

Table 3-6: Directional Current Data

Location SP 1									
RP	Bottom Current (m/s)								
(yr)	0	45	90	135	180	225	270	315	Omni-dir
1	0.22	0.82	0.22	0.09	0.17	0.62	0.14	0.09	0.82
10	0.25	0.86	0.26	0.10	0.19	0.65	0.17	0.10	0.86
50	0.26	0.87	0.28	0.11	0.21	0.66	0.18	0.10	0.88
100	0.26	0.88	0.29	0.11	0.21	0.66	0.18	0.10	0.89
Location SP 2									
RP	Bottom Current (m/s)								
(yr)	0	45	90	135	180	225	270	315	Omni-dir
1	0.12	0.82	0.19	0.06	0.12	0.60	0.13	0.06	0.82
10	0.14	0.86	0.26	0.09	0.16	0.62	0.15	0.06	0.86
50	0.14	0.87	0.30	0.10	0.19	0.62	0.16	0.06	0.87
100	0.15	0.88	0.31	0.10	0.21	0.62	0.17	0.07	0.88
Location SP 3									
RP	Bottom Current (m/s)								
(yr)	0	45	90	135	180	225	270	315	Omni-dir
1	0.09	0.74	0.21	0.04	0.06	0.50	0.18	0.06	0.74
10	0.10	0.77	0.26	0.06	0.09	0.52	0.21	0.06	0.77
50	0.11	0.79	0.30	0.06	0.11	0.53	0.22	0.06	0.79
100	0.11	0.80	0.31	0.07	0.12	0.53	0.22	0.07	0.80

3.6.4 Seawater Density

In the analysis, a seawater density value of 1,027 kg/m^3 is adopted. This is a common value for the Dutch sector of the North Sea.

4 On-Bottom Stability Design

4.1 Introduction

Given the limited design guidance on lateral stability in NEN 3656, stability of the pipeline system is assessed in accordance with DNVGL Recommended Practice for pipeline stability (Ref. [6]). The aim of the stability analysis is to verify that the submerged weight of the pipeline complies with the relevant stability criteria in vertical and lateral direction.

Since the pipeline will be trenched after installation (for safety, to prevent buckling, to contribute to the pipe insulation and to avoid large weight coating thicknesses in the shallow water part), the pipeline stability analysis is only performed for the installation condition. Some lateral displacements will be allowed during the period on the seabed depending on the proximity of other infrastructure and considering that the pipeline has to be trenched after pipeline installation.

4.2 Methodology

4.2.1 General

Offshore pipelines resting on the seabed are subject to hydrodynamic forces induced by the combined effect of steady currents and waves. The pipeline resting on the seabed, during the temporary phase between installation and trenching must be safeguarded against these destabilizing hydrodynamic forces. The hydrodynamic loads are resisted by the frictional soil resistance generated by the weight of the pipeline; see Figure 4-1.

In shallow waters, where the effect of hydrodynamic forces is considerable, additional pipe weight is normally required to counteract the hydrodynamic loads. Additional weight is commonly provided by concrete weight coating or by an increase of steel pipe wall thickness.

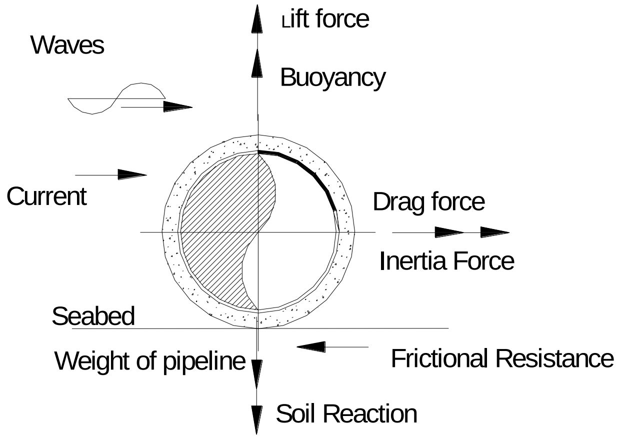


Figure 4-1 - Hydrodynamic Forces acting on Offshore Pipeline resting on Seabed

The analysis of horizontal stability is very much dependent on location specific conditions. These include wave and current conditions, but also wave approach angles, and soil characteristics because they strongly affect the frictional resistance force.

The pipeline on-bottom stability analysis is performed using an in-house calculation tool based on the requirements stipulated in DNVGL-RP-F109. The aim of the stability analysis is to verify that the submerged weight of the pipeline complies with the stability criteria stipulated in the design code DNVGL-RP-F109, which considers:

- vertical stability in water (flotation) and in soil (buried or unburied)
- lateral stability under environmental loads

4.2.2 Vertical Stability Calculation

4.2.2.1 Vertical Stability in Water

The pipeline shall have a submerged weight so that it will meet the following requirement:

$$\gamma_w \cdot \frac{B}{W_s + B} = \frac{\gamma_w}{s_g} \leq 1.00$$

Where,

W_s = Submerged weight per unit length

B = Buoyancy per unit length

γ_w = Safety factor

s_g = Pipe specific density

As per DNVGL-RP-F109, the safety factor can be taken equal to 1.1 if a sufficiently low probability of negative buoyancy is not documented. This safety factor covers for potential weight differences between pipe joints. Applying a value of 1.1 provides a 10 % margin to ensure that even the lightest pipe joint (negative fabrication tolerance on steel, coating and concrete) is still negatively buoyant.

4.2.2.2 Vertical Stability in Soil

Vertical stability in soil is to be verified based on the design procedure stipulated in DNVGL-RP-F109 Section 3.3. When the pipeline must stay buried at all conditions, soil liquefaction and potential up-floating of the pipeline must be considered. Since most of the pipeline trench is in loose sand and sand can potentially liquefy this phenomenon should be considered.

Since there is no significant seismic activity, and wave action at approximately 20 m water depth is normally insufficient to liquefy soil to the target depth of the pipeline, liquefaction is unlikely. In addition, no cases of liquefaction and pipeline flotation are known to have occurred in this part of the North Sea. Nevertheless, the potential for liquefaction will be considered in the vertical stability assessment, see Section 4.3.

4.2.3 Lateral Stability Calculation

DNVGL-RP-F109 presents two methods of calculating the lateral displacement of a pipeline subjected to a hydrodynamic load. The two methods are:

- Absolute lateral static stability method (DNVGL RP-F109 Section 3.6)
- Generalized lateral stability method (DNVGL RP-F109 Section 3.5)

The absolute static stability method allows no lateral movement of the pipeline under the design extreme single wave cycle, while the generalized method allows lateral movement from 0.5 times up to 10 times the pipe diameter under the design current and significant wave induced particle velocity.

The pipeline is not shielded by a pre-excavated trench wall during installation, therefore no force reduction factor as a result of trenching has been considered in the calculation. Pipeline sections installed in pre-dredged channels will not experience a shielding effect from the side slopes due to the width of the dredged channel and shallow side slopes. Only the effect of depth increase can be included in the analysis.

4.2.3.1 Generalized Lateral Stability Method

The generalised lateral stability method specifies the requirements for a virtually stable pipe and for displacement of 0.5 to 10 pipe diameters. This method is subject to the resistance force from the soil, which consists of a pure Coulomb friction factor and a passive resistance, depending on the pipe burial depth into the soil. When the pipe is over penetrated, i.e. the initial penetration (due to forces during installation) of the pipe is larger than the penetration due to its self-weight; the pipe embedment will decrease when it moves laterally.

Stability is verified by the following equation given in Section 3.5 of DNVGL-RP-F109:

$$\frac{Y(L, K, M, N, \tau, G_s)}{Y_{al.}} \leq 1.00$$

Where,

Y	Dimensionless lateral pipe displacement
$Y_{al.}$	Allowed lateral displacement scaled to pipe diameter, for both temporary and operating conditions limited to 10 pipe diameters
L	Significant weight parameter
K	Significant Keulegan-Carpenter number
M	Steady to oscillatory velocity ratio for design spectrum
N	Spectral acceleration factor
τ	Number of oscillations in the design bottom velocity spectrum
G_s	Soil (sand) density parameter

Since there are a relatively limited number of input parameters, the on-bottom stability problem is well suited for establishing databases in which the pipe displacement is given for its set of input parameters. The design code DNVGL-RP-F109 provides design curves for an on-bottom stability design with an allowed lateral displacement in the range from less than half a pipe diameter up to a displacement of 10 diameters during the given sea state. These curves are obtained from a large number of one-dimensional dynamic analysis.

4.2.3.2 Absolute Lateral Static Stability Method

The absolute lateral static stability method provides an absolute static requirement for pipelines based on static lateral forces. Application of this method ensures that the resistance of the pipe against motion is sufficient to withstand maximum hydrodynamic loads during a sea state, i.e. the pipe will not break out of its initial embedment.

A pipeline can be considered to satisfy the absolute static stability requirement if:

$$\gamma_{SC} \cdot \frac{F_Y^* + \mu \cdot F_Z^*}{\mu \cdot W_s + F_R} \leq 1.00$$

and

$$\gamma_{SC} \cdot \frac{F_Z^*}{W_s} \leq 1.00$$

Where:

γ_{SC}	Safety factor

F_Y^*	Maximum horizontal hydrodynamic load during sea state, N/m
F_Z^*	Maximum vertical hydrodynamic load during sea state, N/m
F_R	Passive soil resistance, N/m
μ	Coefficient of friction
W_s	Submerged weight per unit length, N/m

4.2.4 Design Load Conditions

The offshore pipeline will only be exposed to hydrodynamic loads during installation, therefore in accordance with Section 2.1 of DNVGL-RP-F109; the wave-current combination for a temporary phase (installation condition) with duration less than 12 months but more than three days shall be used. That is; a combination of 1- and 10-year return period conditions, either 10 year wave and 1 year current (wave dominant) or 1 year wave and 10 year current (current dominant) whichever is governing. Since the difference between 1, 10 and 100-year currents are small on this project, wave dominant is always governing over current dominant. In principle all year conditions will be considered unless results require consideration of summer conditions (March-September or May-August).

Since the concrete weight coating is applied only for the short period between installation on the seabed and trenching, and more concrete will negatively affect installation, the weight coating thickness will have to be optimized as much as possible. Alternative means to temporarily ensure stability can be considered for the installation conditions, these are:

- Install pipeline in flooded condition or flood immediately after installation.
- Install pipeline in empty condition but define operational limits (i.e. installation period or maximum sea state) for the period between installation and trenching (or flooding) of the pipeline. This approach will require pipeline abandonment and flooding to ensure lateral stability when the operational limits are exceeded.

Figure 4-2 shows the depth profile of the pipeline and the two main design depths considered in stability design. For the section beyond KP 8.0 the design water depth is taken as 20.5 m, the pipeline has a generally South-East to North-West direction. Between HDD exit and KP 8.0 the pipeline has a generally North-North-East heading. The water depth reaches a minimum of approximately 13.7 m in a shallow water section between KP 3.0 and 6.0. The water depth in the Maasgeul reaches water depths of 25 m or more. The design water depth for this section is initially kept at 20.5 m since the length of the crossing is only about 1 km and it is not desirable to introduce an additional weight coating thickness change for the deepest parts of the Maasgeul crossing. Depending on the results and the resulting pull force required to pull the pipeline into the HDD, the aspect of multiple weight coating thicknesses in the pulled section can be re-assessed (see Section 8.2). Note that the HDD exit is at a natural water depth of approximately 14 m, the actual depth at the bottom of the pre-dredged trench during installation will be approximately 16 to 17 m (making 13.7 m design depth a conservative value). Directional wave and current data is used to account for the heading of the pipeline section relative to the highest waves and strongest currents.

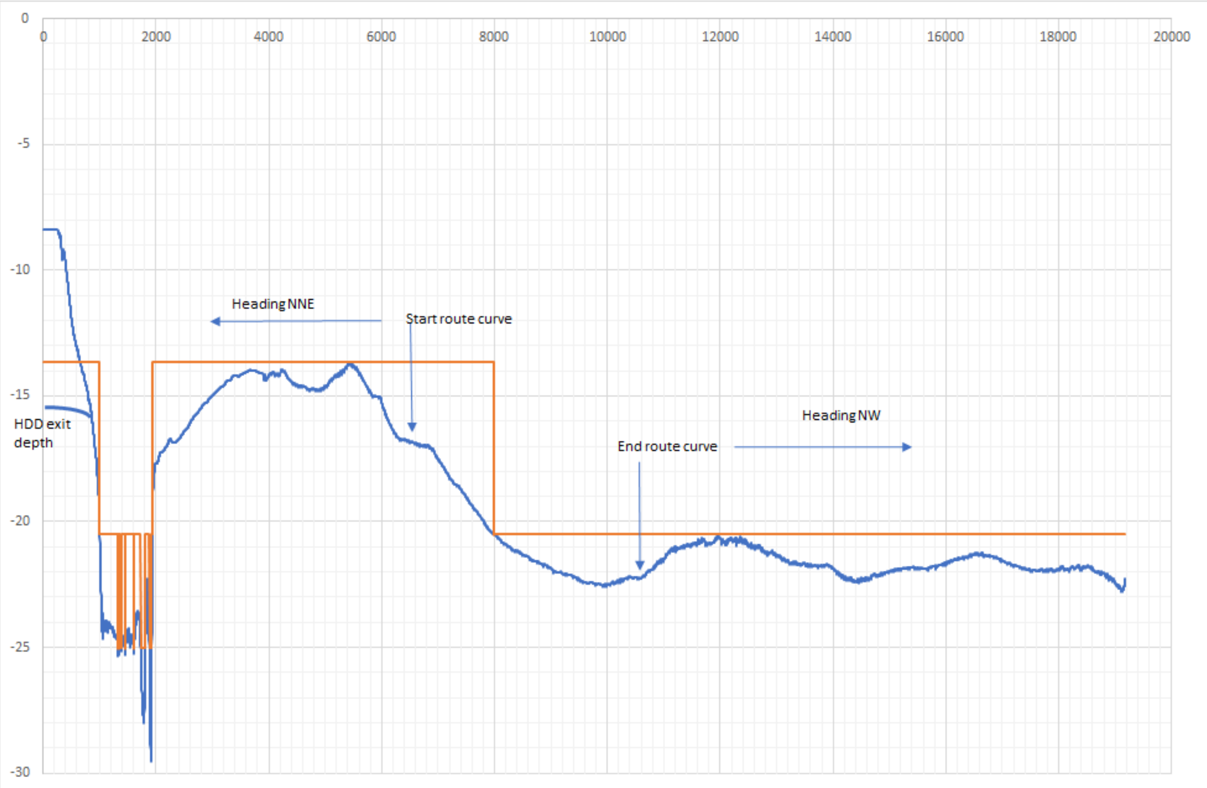


Figure 4-2 Design Depths for Pipeline Stability Design

4.3 On-Bottom Stability Results

The stability analysis is carried out using an in-house developed stability calculation sheet in compliance with the requirements as stipulated in DNVGL-RP-F109. In this calculation sheet, the hydrodynamic forces are computed and iterated to find the minimum submerged weight requirement to provide lateral stability.

The results for vertical stability for a pipeline wall thickness of 14.3 mm and the combined anti-corrosion and insulation coating as defined in Section 3 are presented in Table 4-1 for two proposed concrete weight coating thicknesses.

Table 4-1 - Vertical Stability Results

Case	Submerged weight (N/m)	Specific Gravity
Installation (Empty) - 80 mm CWC - 110 mm CWC	 2718 3968	 1.83 2.02
Flooded - 80 mm CWC - 110 mm CWC	 3845 5095	 2.18 2.31

The results demonstrate that the pipeline is vertically stable on the seabed. Both empty and flooded specific gravity are sufficient to promote pipeline lowering during trenching. The specific gravity is also sufficient to avoid floating of the pipeline in case of liquefaction of the soil (sg pipe > sg of liquefied soil, which can be estimated at about 1.8).

The results for lateral pipeline stability are presented in Table 4-2. The results are presented as expected lateral displacements (as number of pipeline OD's or as no displacement in case of absolute stability) for two selected weight coating thicknesses of 80 mm and 110 mm.

For the relative deep water section beyond KP 8.0 a weight coating thickness of 80 mm is proposed. For the shallow water part and Maasgeul up to KP 8.0 two options are given. A weight coating thickness of 110 mm for the entire section avoids application of different weight coating thicknesses in the section to be pulled and provides an increased level of safety for the pipeline section in the Maasgeul crossing. It provides additional safety against lateral displacements in the critical Maasgeul section but requires a higher installation effort due to the larger weight. As an alternative, mainly to limit the pull forces for the HDD and Maasgeul section, a reduction to 80 mm weight coating for the Maasgeul part can be considered (dredged channel depth >28 m, < 1 km length). The 110 mm weight coating for the relatively deep Maasgeul avoids application of different weight coating thicknesses in the section to be pulled and an increased level of safety for the pipeline section in the Maasgeul crossing.Results for the actual water depth (conservatively taken as 28 m) in the Maasgeul and a weight coating thickness of 80 mm are also provided in the results table for comparison. These further optimized stability results can be considered to reduce the pull loads for the pull in of the HDD and Maasgeul section, see Section 8.2.

Results are given for environmental conditions corresponding to "all year" conditions, these are significant wave height and current for 1- and 10-year return periods considering all months of the year. This would be applicable if installation could take place in the winter. The 1- or 10-year return period significant wave for the period April to September is lower than the all year value since high waves tend to occur more frequent in the winter period. When the period is further limited to only the summer period (May-August) the design waves are even lower and the resulting expected displacements under the design conditions smaller. When the results of the May-August period are considered, this means that the contractor has to install the pipeline in this period including trenching (only flooding instead of trenching may be sufficient to improve stability). Installation shall only be initiated when weather predictions are favourable.

Table 4-2 - Lateral Stability Results

Section [1]	Weight coating [mm]	Scenario [2]	Expected displacement per installation period (envir cond) [3]		
			All year	Apr-Sep	May – Aug
KP 0.5 – 8.0 : WD_{design} 13.7 m [4]	110	Installation (Empty)	>10 OD	10 OD	7 OD
		Flooded	>10 OD	3 OD	2 OD
Maasgeul crossing : WD_{design} 20.5 m	110	Installation (Empty)	4 OD	No sign. displacement	No sign. displacement
		Flooded	1.5 OD	No sign. displacement	No sign. displacement
Maasgeul crossing : WD_{design} 28.0 m	80	Installation (Empty)	10 OD	3 OD	1.5 OD
		Flooded	2 OD	0.6 OD	No sign displacement
KP 8.0 – END : WD_{design} 20.5 m	80	Installation (Empty)	>10 OD	6 OD	3 OD
		Flooded	9 OD	1.5 OD	0.6 OD

Notes:
1) For KP 0.5 – 8.0 SP2 data is used, for the Maasgeul section SP3 data and for KP 8.0 to the platform SP 1 data, see Sections 3.6.2 and 3.6.3.
2) For all empty or flooded scenarios and all installation periods; 10-year return period wave and 1-year return period current are applied (wave dominant).
3) Only from KP 3 to KP 6 the water depth is less than 15 m. For a water depth of 15 m or more the expected displacement in May-Aug is 5 OD and flooded about 1.5 OD.
4) Note that even for the May-Aug installation period the design wave is in the order of 3.5 to 4 m significant wave height. This is well in excess of the operational limits of the installation vessels. If these design waves are expected during installation, the pipe has to be abandoned on the seabed and can be flooded to stabilize it.

Absolute stability is considered convenient if achievable. No lateral displacement facilitates trenching and tie-in to the riser. To make the pipeline absolute stable in empty pipe condition would require a significant amount of concrete, even in excess of what can practically be applied and installed. This would mean a considerable additional investment in material and installation for the short period between installation on the seabed and trenching or flooding.

Lateral displacements can be accepted for subject pipeline under certain conditions. A displacement of 8 to 10 OD corresponds to about 5 to 6 m for subject pipeline. It is noted that the pipeline will not be installed in an exact straight line at the center of the survey corridor. Lateral displacements of several meters are within the lay tolerance of the average installation vessel, assumed to be +/- 5m.

- The section from KP 0.5 to KP 8.0, and the shallow water part between KP 3.0 and 6.0 with 110 mm weight coating, requires installation in the period May to August to limit the lateral displacement to acceptable values (< 10 OD). In flooded condition the pipeline is stable with displacements up to 2 OD (or 3 OD for Apr-Sep). From the results for the Maasgeul crossing (depth 20.5 m instead of 13.7 m and acceptable displacements for "all year" conditions) it can be seen than stability quickly improves with water depth. In this respect it is relevant to note that the HDD exit is at a water depth of approximately 16 to 17 m. The critical part for this section is between KP 3.0 and KP 6.0 where the water depth is less than 15 m. Slightly larger lateral displacement in this section are acceptable since there are no tie-ins to be made or crossings with other infrastructure.
- With a weight coating of 110 mm, the Maasgeul section shows acceptable displacements in empty conditions even for winter installation conditions ("all year"). In flooded condition the displacements are very small and for summer installation (as required for the shallow water section) the pipeline can be considered virtually stable.
- With a weight coating of 80 mm, the Maasgeul section shows acceptable displacements in empty conditions for the period April to September but marginal stability for all year conditions. In flooded condition the displacements are very small and for summer installation (as required for the shallow water section) the pipeline can be considered virtually stable. It can be concluded that, compared to the case with 110 mm weight coating, the displacements are acceptable for a summer installation, however the pipe with 110 mm weight coating is even stable under winter conditions (higher safety level, lower displacements expected)
- The deep water part with a weight coating thickness of 80 mm, from KP 8.0 onwards, shows acceptable lateral displacements of up to 6 OD for installation in the period April to September. For an installation in the period (May to August) as required for the shallow water section the pipeline section can be considered stable with displacement of less than 3 OD, especially when flooded.

Also note that the maximum wave height under which pipeline installation can take place is probably less than the 4.0 m significant wave height considered in the analysis (wave of 4.0 m is above safe installation condition for most installation vessels). This means that pipeline installation has to be abandoned well before the critical wave height for lateral pipeline stability occurs.

After installation of the critical section around KP 6, completion of the installation (section from KP 6 to P18-A) will take place in about a week, after which flooding can be considered for stabilisation. Based on above assessment of expected lateral displacements and considering the short duration of the temporary condition (empty on seabed) the proposed weight coating thicknesses are considered acceptable.

For a weight coating thickness of 80 and 110 mm as described above, the pipeline is stable in flooded condition. In empty condition the maximum displacements under DNVGL-RP-F109 design conditions is less than 10 OD. For the Maasgeul section smaller displacements are predicted for 110 mm weight coating (stable even for winter conditions) than for 80 mm (still acceptable for summer installation period). Selection involves cost and schedule risks, requiring Client decision. All proposed and optional weight coating thicknesses are considered acceptable under the following conditions;

- Installation shall be initiated based on good weather forecast, in the period May to August. If weather forecasts during the installation period predict higher sea states, the pipeline shall be abandoned and flooded.

- The temporary phase between installation and trenching or flooding shall be minimized.
- A detailed study shows that local and seasonal currents in the Maasgeul (high river flow rate) do not exceed values assumed in this study (SP3 data point, located close to Maasgeul)

The as-installed survey may show higher actual penetration of the pipeline into the seabed than considered in the analysis (especially in the pulled section), improving pipeline stability. If required, the as installed condition can be checked based on actual seabed penetration. Also, allowable environmental loads during the temporary phase can be defined.

It is therefore recommended to consider a weight coating thickness of 80 and 110 mm as described in Table 4-2, minimize the temporary phase between installation and trenching or flooding, and installation in the summer period; May to August.

5 Upheaval Buckling

5.1 General

Buried offshore pipelines, when subject to high compressive axial forces induced by operational pressure and temperature are prone to upheaval buckling. The initiation may occur at vertical imperfections, usually produced during the trenching process. At these vertical imperfections or out-of-straightness locations, the compressive effective axial force induced by the pressure and temperature will have a significant vertical component. When the vertical upward force exceeds the pipe weight plus the resistance of the soil cover, the buckle is initiated. Sufficient soil cover height is therefore required to guarantee that the pipeline, for a typical installation out of straightness, does not upheaval buckle.

DNVGL-RP-F110 (Ref. [7]) is used to determine the required soil cover. The present analysis is focused on determining the required cover to prevent upheaval buckling. In a final design it shall also be ensured that the pipeline stresses remain below acceptable levels. The procedure followed in the FEED design follows the recommended practice DNVGL-RP-F110 (Section 8) and DNVGL-OS-F101 (Ref. [8]) for pre-installation design phase. In this report the minimum cover design, part of the upheaval buckling design as per Section 8.4 of DNVGL-RP-F110 is addressed using the analytical methodology in Reference 7 of DNVGL-RP-F110.

The specific cover design (Section 8.3 of DNVGL-RP-F110) and specification of cover (Section 8.5 of DNVGL-RP-F110) shall be confirmed after on-bottom roughness analysis accounting for the post trench pipe profile with the specification of cover as presented in this report. The actual cover height shall always respect the minimum specified cover height. If specified minimum cover is not achieved, mitigation will be required. The final upheaval buckling prevention requirements will be defined based on the as-installed pipeline profile.

5.2 Methodology

5.2.1 Pipeline Profile and Loads

The analysis is performed based on a worst-case prop shape. A prop shape is the configuration of the pipeline given by the relevant self-weight and pipe stiffness when lifted from a horizontal plane a certain height δ. The selected $\delta_{imperfection}$ is 0.15 m.

This 0.15 m imperfection is the maximum code recommended typical standard deviation of survey accuracy. It is unlikely that an imperfection of 0.15 m is present in the pipeline, after installation, and even more unlikely to be undetected in the post trenching survey. DNVGL-RP-F110 recommends using a prop shape with a height of one standard deviation of the survey accuracy as stated in Section 8.4 of DNVGL-RP-F110.

In Section 5.4.2.2 of DNVGL-RP-F110 is stated that the value of $\delta_{imperfection}$ is typically between 0.05 m and 0.15 m. Also, the cover detection survey will have similar accuracy, δ_{cover} (one standard deviation on the pipeline cover depth measurement accuracy), and typically 0.10 m to 0.15 m as recommended by DNVGL-RP-F110 (Section 5.4.2.2).

The selected imperfection height of 0.15 m, accounts for some conservatism based on survey uncertainty for the imperfection and cover detection.

A typical pipeline profile along an imperfection is presented in Figure 5-1. The figure is only a typical profile sketch and not to scale.

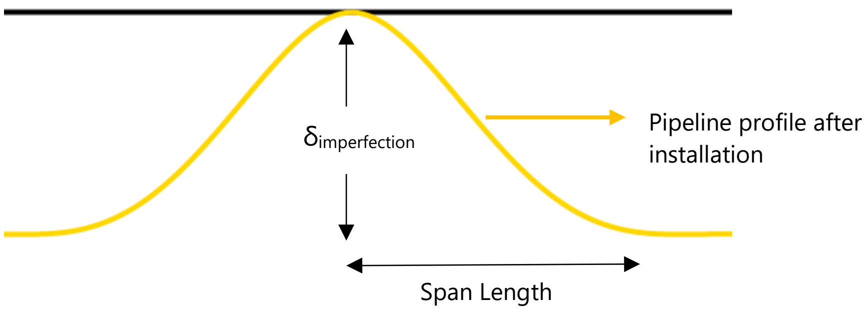


Figure 5-1 - Typical pipeline profile for an imperfection

The larger the imperfection selected, the earlier in pressure and temperature built-up, upheaval buckling occurs for a specific cover height.

For this reason, the imperfection height selected is considered adequate for this pre-installation design of the cover height requirements. This is to prevent specifying a cover height at this stage that after pipeline installation could prove to be inadequate.

In case the pipeline is flooded during installation, its weight is higher, therefore the imperfection in terms of curvature is larger.

5.2.2 Load and Resistance Factors

The material resistance factors and the design load factors used in the analysis are determined in accordance with DNVGL-OS-F101 (Ref. [8]Ref. [6]) and DNVGL RP-F110 (Ref. [7]) with safety class medium for location class 1 and with safety class high for location class 2.

5.2.3 Expansion Driving Force

The fully restrained effective axial force S_{eff} is calculated based on DNVGL-ST-F101 (Section 4.7.4):

$$S_{eff} = H - \Delta p_i \cdot A_i \cdot (1 - 2 \cdot \nu) - A_s \cdot E \cdot \alpha \cdot \Delta T$$

Where:

H is the effective residual lay tension (assumed 0)

Δp_i is the internal pressure difference relative to as laid

A_i and A_s is the Internal area of the pipe and steel cross section area (nominal)

α is the thermal linear expansion coefficient

ΔT is the temperature difference relative to as laid.

In accordance with the DNVGL-RP-F110 the axial load is maximized by a load effect factor of γ_{UF} :

$$\gamma_{UF} = \begin{cases} 1.00 \text{ for Safety Class Low} \\ 1.15 \text{ for Safety Class Normal} \\ 1.30 \text{ for Safety Class High} \end{cases}$$

5.2.4 Upwards soil Resistance

The uplift resistance is calculated as a function of the soil properties, pipeline dimensions and the soil cover height as per equation B.3 of DNVGL RP F110:

$$R_{max} = (1 + f \cdot \frac{H}{D})(\gamma' \cdot H \cdot D_{Full})$$

where *f* is the uplift resistance factor given in Table 5-1.

Table 5-1 - Uplift Coefficient

Sand Type	Uplift Coefficient 1)	
	LB	UB
Loose	0.1	0.3
Medium	0.4	0.5
Dense	0.5	0.6
Notes: 1) Values taken from Table B-2 of DNVGL-RP-F110		

5.3 Upheaval Buckling Results

The results of the upheaval buckling analysis are presented in Table 5-2. Results are presented for the cases; “pipeline trenched empty” and “trenched flooded”.

Table 5-2 – Upheaval Buckling Results

Criteria	Scenario	Design Temp. [°C]	Internal Pressure [barg]3)	Safety Class	Required Cover Height [m]	Specified Cover Heigth [m]
For 80 mm CWC section						
Inside high safety zone	Operation (Buried Empty)1)	90	140	High	0.50	0.6
	Operation (Buried Flooded)2)	90	140	High	0.55	
Outside high safety zone	Operation (Buried Empty)1)	90	140	Medium	0.35	0.4
	Operation (Buried Flooded)2)	90	140	Medium	0.40	
For 110 mm CWC section						
Inside high safety zone	Operation (Buried Empty)1)	90	140	High	0.25	0.3
	Operation (Buried Flooded)2)	90	140	High	0.25	
Outside high safety zone	Operation (Buried Empty)1)	90	140	Medium	0.20	0.2
	Operation (Buried Flooded)2)	90	140	Medium	0.20	

Notes: 1) Scenario where pipe is post trenched in empty condition (lesser imperfection)
2) Scenario where pipe is post trenched in flooded condition (larger imperfection)
3) Based on a local incidental pressure condition (1.15*Pd)

A flooded pipe, with its larger weight will improve trenching efficiency, however, the added weight results in sharper imperfections which require a larger cover height. The empty pipeline with the considered wall thickness of 14.3 mm has a specific gravity of 1.8 (for 80 mm CWC) or more (110 mm CWC) in empty condition, which is sufficient for an efficient trenching operation. Only if the pipeline has been flooded, for example for stability reasons, trenching in flooded condition may be required.

A cover height of 0.2 m (110 mm CWC) or 0.4 m (80 mm CWC) is required over the route length, with an increase in requirement to 0.6 m for the sections within the high safety zone. A cover height of up to 0.6 m is considered to be well within capabilities of most trenching contractors.

The trenching requirements following from a pipeline safety study (shipping lane crossing) should be considered in the final trench depth specification. Therefore, the final burial requirement will be defined in the offshore route safety study (Ref. [12]).

6 Cathodic Protection Design

6.1 Introduction

This section addresses the cathodic protection design for the pipeline. The pipeline will be made from carbon steel. Internal corrosion will be controlled by monitoring and limiting the amount of H_20 in the CO_2 stream. The outer flowline surface will be protected by a high-quality FBE/PP based coating, supplemented by a standard CP design with aluminium half shelf bracelet anodes placed at regular intervals along the pipeline.

6.2 Input Data

The main reference for cathodic protection design is, according to NEN 3656; ISO 15589-2. In offshore pipeline design DNVGL-RP-F103 (Ref. [9]) is a common design guideline which generally complies with the requirements of ISO 15589-2.

The primary corrosion protection for the pipeline system will be by external anti-corrosion coating with an associated field joint coating. The anodes will be designed for the maximum operating temperature of 80 °C for the first section with 110 mm weight coating and 70 °C for the downstream section with 80 mm weight coating. This is conservative for various reasons; at a fluid temperature of 80 °C the anode temperature will be approximately 60 °C, and most of the pipeline length will operate at lower temperatures for at least part of the design life. See also Section 1.2.

The cathodic protection input parameters are presented in Table 6-1.

Table 6-1 Cathodic Protection – Input Parameters

Parameter	Unit	Value
Anode type	-	Half shell bracelet
Anode composition	-	Al based alloy
Anode gap between bracelets	mm	75
Electrochemical capacity in sediment -At 30 °C -At 60 °C -At 80 °C	A·h/kg	1500 680 320
Closed circuit anode potential in sediment	V	-1.000
Utilization factor	-	0.8
Initial coating breakdown factor for 5LPP	%	0.03
Average yearly increase coating breakdown	%	0.001
Design current density (mean and final) buried @ 80°C	A/m2	0.04
Design protective potential	V	-0.80
Environmental resistivity	Ω m	1.5
Maximum allowable anode spacing	m	300

6.3 Methodology

For CP design, the following procedure is being used:

- Select the anode material and general shape,
- Calculate the combined coating breakdown factors for the pipeline coating,
- Calculate the mean and final current demands,
- Calculate the minimum total required net anode mass,
- Select the anode length and thickness, and calculate the individual anode mass,
- Calculate the required minimum total number of anodes, considering the maximum allowable anode spacing and final current demand.

The mean and final coating breakdown factors are defined as (Ref. [9]):

$$f_{cm} = f_i + 0.5 \cdot \Delta f \cdot t_{dl}$$
$$f_{cf} = f_i + \Delta f \cdot t_{dl}$$

Where:

f_i	initial coating breakdown factor
Δf	average yearly increase coating breakdown factor
t_{dl}	design life in years
f_{cm}	mean coating breakdown factor
f_{cf}	final coating breakdown factor

The coating breakdown factors for the combination of corrosion coating and field joint coating are calculated as:

$$f_{cm}' = f_{cm}(linepipe) + r.f_{cm}(FJC)$$
$$f_{cf}' = f_{cf}(linepipe) + r.f_{cf}(FJC)$$

Where

f_{cm}'	combined mean coating breakdown factor
f_{cf}'	combined final coating breakdown factor
r	ratio of the field joint coated surface to total pipeline surface, equal to 0.033 for assumed cut back length of 200 mm

The mean and final current demands are determined as follows:

$$I_{cm} = A_c \cdot f_{cm} \cdot i_c$$

$$I_{cf} = A_c \cdot f_{cf} \cdot i_c$$

Where:

A_c	pipeline surface area
i_c	current density
I_{cm}	mean current demand
I_{cf}	final current demand

The minimum total required net anode mass is calculated using below equation:

$$M = \frac{I_{cm}\ t_{dl}\ 8760}{u\ \varepsilon}$$

Where:

M	minimum total net anode mass (kg)
r	anode utilisation factor
ε	anode electrochemical capacity (A·h/kg)

The minimum required number of anodes is calculated by dividing the minimum total required net anode mass by the individual anode mass.

$$N = \frac{M}{m}$$

Where:

N	number of anodes
m	individual anode mass

The number of anodes should also be checked against the recommended maximum allowable anode spacing of 300 m.

The final anode current output is defined as:

$$I_{af} = \frac{E_c - E_a}{R_{af}}$$

Where:

I_{af}	final anode current output
E_a	design closed circuit potential
E_c	design protection potential
R_{af}	final anode resistance

The final anode resistance of bracelet anodes is defined as:

$$R_{af} = 0.315 \frac{\rho}{\sqrt{A_{ea}}}$$

Where:

ρ	environmental resistivity
A_{ea}	end of life anode surface area

The final anode current output should be higher than final current demand:

$$I_{af} > I_{cf}$$

The total net anode mass and required number of anodes is selected based on the following assumptions:

- Since the pipeline is concrete coated, the anodes will have to be made flush with the weight coating thickness or slightly thinner to avoid damage during installation.
- For practical reasons, all anodes on the pipeline will be of the same size and weight and only adjusted for a variation in weight coating thickness
- Additional bracelet anodes will be placed on pipeline ends and at pipeline crossings (if any).

6.4 CP Results

The results of the CP design are presented in **Error! Reference source not found.**. The actual total mass and number of anodes is governed by the concrete coating thickness, minimum anode length and maximum anode spacing.

Parameter	**Value**
80 mm CWC section (12 km)	
Anode spacing (maximum spacing allowed; 300 m)	292 m (24 joints)
Net mass per anode (minimum mass determined by weight coating thickness) Indicative dimensions: ID= 482 mm, h x l=75 x 500 mm	148.4 kg
Number of anodes (based on length / spacing) [1)]	41
Total net anode mass	6083 kg
110 mm CWC section (8 km)	
Anode spacing (maximum spacing allowed; 300 m)	292 (24 joints)
Net mass per anode (minimum mass determined by weight coating thickness) Indicative dimensions: ID= 482 mm, h x l=105 x 500 mm	220.0 kg
Number of anodes (based on length / spacing) [1)]	28
Total net anode mass	6159 kg
80 and 110 mm CWC combined	

Total net anode mass	12242 kg
Note 1) The final number of anodes has to be determined based on the CP solution for the HDD section and weight coating thickness selected for the Maasgeul section, see Section 4.3 and 8.2. The presented numbers assume 110 mm weight coating over the full first 8 km. This results in a conservative cost estimate.	

The CP solution for the HDD section will be addressed as part of the HDD design. Separation of CP systems of the various pipeline system parts (if considered needed) has to be affected outside the offshore pipeline scope and is not addressed in this report.

7 On-Bottom Stress and Expansion

In this section pipeline spans are checked based on static stresses (bottom roughness analysis) and pipeline expansions are calculated. The results are provided for reference and use in more detailed analysis.

The pipeline will be trenched after installation on the seabed. The first section will be installed in an HDD and pre-excavated trench with prescribed trenching accuracies. North of the Maasgeul, the natural seabed slope is generally less than 2 degrees with very few locations where the slope is more than 2 but still less than 4 degrees. In view of the short duration that the pipeline is positioned on the seabed, static spans are more relevant than the dynamic behaviour of the spans. Considering the mild slopes, no critical pipeline spans are expected to occur during the installation period. Also, for the current route no crossing of existing infrastructure is required, eliminating the requirement for the design of a crossing lay-out with associated stress check.

Pipeline expansion at the pipeline ends will be absorbed by the expansion spools near the platform and at the offshore to onshore interface. To correctly analyse these sections, FE models will have to be made to determine displacements and stresses in pipeline, spools and riser at the platform, see (Ref. [13]) and (Ref. [14]).

7.1 On-Bottom Roughness and Pipeline Spans

7.1.1 Analysis Method

For pipelines that are buried in the operational phase, pipeline spanning is only relevant during the installation phase. The integrity of a spanning pipeline must be checked under static and dynamic design loads. In case the period between pipeline installation on the seabed and burial is short the dynamic design case is less relevant. Therefore, a basic bottom roughness analysis has been performed to identify any locations where static stresses may exceed the allowable values. If spans of a significant length are identified the requirement for a dynamic check can be assessed.

The bottom roughness and pipeline stress analysis has been carried out to determine for each design case:

- free span lengths and span heights
- pipe stress and strain along the pipeline route

The analysis has been carried out using SP3D software version 3.0 (by Fugro GeoConsulting). This is an explicit dynamic Finite Element Analysis (FEA) program that has been developed specifically to perform bottom roughness stress analysis.

SP3D simulates the pipeline by discretizing it into sections of finite length, bounded at either end by nodes. The mass and forces acting on the elements is lumped in the node and therefore forms a chain of point masses linked by massless elements, which is a classical method used in FE software.

The motion of these structures is solved using a pseudo-transient dynamic explicit integration kernel. The integration algorithm uses Newton's law as the basis for computing the motion of the nodes at every time step.

The software can either use a full Digital Terrain Model (DTM), an Easting Northing Elevation model (ENE) or a simple KP-Elevation line model (KPE) to simulate the seabed topography along a linear pipeline route. The DTM and ENE model require DTM data as input. The DTM for the PORTHOS route is not yet complete. Therefore, a KPE model has been used, which interpolates seabed elevation data at sections which are not covered by a DTM.

Soil springs are used to model the soil pipe interaction in three directions. Various soil models can be used to define the soil springs.

Each sequential step is run until an equilibrium is achieved along the whole pipeline section. This is reached by controlling the system total kinetic energy so that a static equilibrium is achieved. Each calculation time step is set small enough to ensure unconditional stability of the results.

The empty laydown analysis is generated from a feeder point running along the target route at a low elevation above the seabed with a constant feeding angle of 3° to generate the initial pipeline configuration on seabed. This process involves a limited number of pipe elements only. The as-laid case analysis complements this process to obtain the final pipeline configuration along its full length after dissipation of any excess energy acquired during the installation process and thereby allowing the pipeline to settle along the route.

Model input is provided Table 7-1.

Table 7-1 Bottom Roughness Model Input

Description	**Model Input**
Model type	KPE
KPE seabed step size	0.5 m
Pipe Element length	2 m
Pipe condition	Temporary- on seabed condition
Porthos Route	Porthos_04_20200221 (results valid for route ID _06_20200625)
Lay tension input	500 kN, constant along route

Description	Model Input
Surface Soil	Typical medium dense sand (conservative for OBR assessment), constant along route Used to define the axial, lateral and vertical soil springs and the friction factors.
Pipe content	Empty as-laid and water filled
Delta temperature input	0 °C
Pressure profile input	Not defined for empty and water filled condition. Hydrostatic pressure profile relative to LAT is solved by SAGE
Presented KP range	2.212 – 19.170

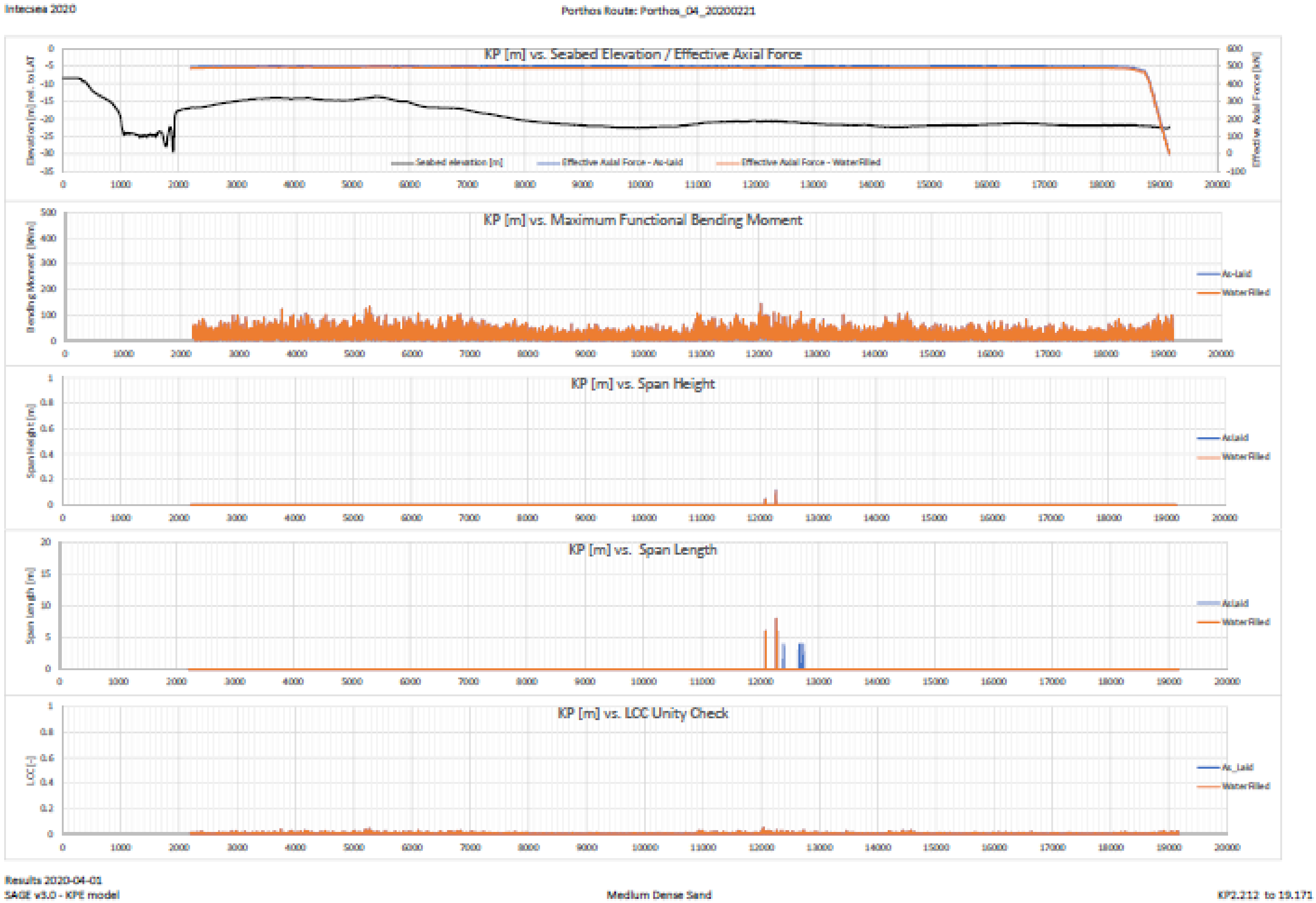
7.1.2 On-bottom Roughness Results

Model results show that the pipeline may only see some very minor spans in the temporary on-seabed condition between KP 12 and KP 13. These have a length of less than 10 m and have a maximum span height in the order of 0.1 m. These spans are considered to be negligible for the temporary pipe-on seabed phase. As expected, spans reduce in size for the water filled condition. Note, these spans may even be smaller in reality in case the surface soil proves locally to be looser. The associated unity check also does not exceed 0.1. No additional fatigue assessment is deemed necessary for the pipe on seabed condition.

A detailed FEA analysis is deemed required for the final buried pipe condition, combined with operational pressure and temperature input. This model also has to cover the final vertical alignment of the section upstream of KP 2.2, that is; from the onshore battery limit to north side of the Maasgeul.

A plot containing result charts are presented in Figure 7-1.

Figure 7-1 Bottom Roughness Results



7.2 Pipeline Expansion

Due to internal pipeline temperature and pressure differential with the surrounding environment, the pipeline will expand. The pipeline expansion has to be determined and accounted for in the design of the pipeline at the interface with adjacent structures or pipe sections. The pipeline expansion is determined at the platform and at the entrance point of the HDD (interface onshore). The pipeline end at the platform is free to move and expand. To avoid large forces on, or deflections of the riser structure, the connection between pipeline and riser will be made through a spool that can absorb the expansion. At the onshore to offshore interface, similarly an expansion spool will be used to make the connection (part of onshore pipeline scope).

7.2.1 Methodology

Longitudinal expansion in a pipeline during hydrostatic testing and operation is dependent on the temperature and pressure differentials, and the resisting frictional force between pipeline and surrounding soil. At some distance from both ends of the pipeline (usually a hot and a cold end) where the forces producing the expansion are balanced with the cumulative effects of the soil frictional force, the pipeline is virtually anchored and from this point on no significant further axial displacement will occur.

Conservative assumptions are made in the pipeline expansion analyses as summarized below:

- The resistance offered by the spool connecting the pipe end to the riser or onshore pipeline is not considered
- The pipeline is assumed to be straight without lateral or vertical curvature (buckling is separately analysed, see Section 5)
- The pipeline installation temperature is taken equal to the minimum seawater temperature during the installation season (April – September)

In addition, NEN 3656 (Ref. [3]) specifies the following requirements:

- An uncertainty factor of 1.4 on the soil friction is considered
- The angle of friction between pipe and soil is limited to 20˚

The method of analysis used in estimating the pipeline end expansion is based on the first principle of stress-strain relation. The stresses acting in the pipeline wall resulting from the operating loads and friction resistance depend on whether the pipeline is unrestrained, partially restrained or fully restrained.

The net longitudinal strain in the pipeline between the free end and the virtual anchor point is given by the following formula:

$$\sigma_L = E \cdot \varepsilon_{NET}$$

$$\varepsilon_{NET} = \varepsilon_E + \varepsilon_\upsilon + \varepsilon_T - \varepsilon_f$$

while ignoring the strain contribution due the water column since it has no impact on the final strain differential distribution

Where,

ε_E	is strain due to end cap effect; $\varepsilon_e = f_{d\,;\,p} \cdot \frac{P_i \cdot A_i}{A_S \cdot E}$
ε_υ	is strain due to Poisson effect; $\varepsilon_v = -f_{d\,;\,p} \cdot \upsilon \cdot \left[P_i \cdot \left(\frac{D_o - t}{2 \cdot t \cdot E}\right)\right]$
ε_T	is strain due to thermal effect; $\varepsilon_v = f_{d\,;\,t} \cdot \alpha \cdot \Delta T$
ε_f	is strain due to mobilization of friction; $\varepsilon_f = \frac{\mu \cdot W_S}{\gamma \cdot A_S \cdot E} \cdot x$

Where,

$f_{d\,;\,p}$, $f_{d\,;\,t}$	are design factors for internal pressure and thermal loads; see Ref. [3]
γ	uncertainty factor as per NEN 3656 equal to 1.4
P_i	internal pressure, conservatively selected equal to design pressure
A_i	internal cross-sectional area of pipeline
A_s	steel cross sectional area of pipeline
D_o	total outside diameter of pipeline
t	wall thickness
W_s	submerged weight of pipe
υ	Poisson's ratio
α	steel coefficient of thermal expansion
E	Young's modulus
ΔT	difference between maximum operating temperature and installation temperature
μ	longitudinal friction coefficient between pipe and surrounded soil
x	distance of pipeline from free end

The active length of the pipeline is derived by solving the following equation:

$$\varepsilon_{NET} = 0$$

To calculate the end expansion the following formula is used:

$$u = \int_0^{L_{AC}} (\varepsilon_E + \varepsilon_v + \varepsilon_T - \varepsilon_f) dx$$

Where,

L_{AC} active length of the pipeline

7.2.2 Thermal Expansion Results

The results presented in Table 7-2 and Table 7-3 are based on the following assumptions:

- The design inlet temperature is 90 °C and the maximum normal operational temperature is 80 °C, the corresponding outlet temperatures are taken as 50 °C and 40 °C (see Section 1.2).
- The pipeline system will be trenched and backfilled prior to the hydrostatic test.
- The pipeline system will be buried with a TOP cover based on the results of the predictive upheaval buckling assessment, see Section 5.3.

Table 7-2 Design Results – hot end (110 mm CWC)

Parameter	Expansion	Anchor length
Hydrotest	65 mm	400 m
Operation - Design conditions - Operating conditions	 1350 mm 895 mm	 1915 m 1565 m

Table 7-3 Design Results – cold end (80 mm CWC)

Parameter	Expansion	Anchor length
Hydrotest	45 mm	370 m
Operation - Design conditions - Operating conditions	 540 mm 360 mm	 1405 m 1140 m

The calculated expansion values at each pipe end are theoretical, worst case values that can be used to estimate the required spool piece dimensions. They can form the basis for the finite element (FE) model that needs to be created and to evaluate the results from the FE model. An FE model for the nearshore end shall include a section of onshore pipeline, the expansion / tie-in spool, the HDD section and a section of offshore pipeline. At the platform end the model shall include a section of pipeline, the expansion / tie-in spool and the riser up to a fixed point (clamp) at deck level or include a section of platform piping (in case no fixed clamp is present). The adequacy of the tie-in spools follows from the FE models when displacements and stresses in spool and riser are acceptable according to the applicable design code, see Ref. [13] and Ref. [14].

8 Pipeline Installation

This section addresses the installation feasibility of the 16-inch pipeline. The preliminary installation evaluation is performed for S-lay operations. Reel-lay is briefly discussed as less likely installation method. Also, the feasibility of the pipeline pull-in is addressed. Final installation analysis will be performed by the installation contractor for the selected vessel and HDD installation method.

8.1 Pipeline Installation Main Offshore Section (Maasgeul to platform)

8.1.1 S-lay pipeline installation

S-lay pipeline installation is the most commonly used method to install offshore rigid pipelines. The method can be used in a wide range of water depths and for most common pipe diameters. During S-lay operations, the pipeline is assembled on board of the pipe lay vessel or barge. Most vessel facilities allow for 24 hours continuous pipe-lay activities; therefore, the S-lay installation method is best suited for installing large lengths of pipe. The average lay rate for a smaller S-lay pipe-lay vessel or barge suitable for the installation of subject pipeline is around 3 to 4 km / day for normal pipe-lay after a period of start-up.

8.1.2 Reel-lay installation method

Reel-lay pipeline installation is a technique where the pipe joints are welded together to form long pipe strings on a so-called onshore spool base. The pipe strings are then wound onto the reel of the pipelay vessel.

During offshore pipeline installation, the pipe string is uncoiled and guided into a J-lay tower. During reel-lay, high installation speeds can be achieved. The lay rate of a reel-lay vessel is typically in the order of 0.5 km / hr up to 1 km / hr. Although high installation rates can be achieved, per trip only a limited amount of length or weight of pipeline can be carried to the field on board of the vessel's reel and this aspect is usually determining the actual average lay rate for longer pipelines. This makes reel-lay suitable for small to medium lengths of pipe, with diameters less than 16-inch.

8.1.3 Selected installation method

There is a large track record for S-lay installation of 16-inch pipe with a wall thickness of 14.3 mm. Reel-lay installation is feasible for 16-inch pipe as well but is considered to be at the upper limit of the applicability range of the method. Reel-lay usually requires a somewhat larger pipe wall thickness than what would be required from a pressure containment perspective (North Sea installation conditions). Also, concrete weight coating cannot be applied for a pipeline installed by Reel-lay and there are limitations on insulation coating (crushing of concrete and compression of insulation). The absence of weight coating is usually compensated by additional steel wall thickness. For smaller diameter (10 to 12-inch) pipelines that will be trenched after installation in water depths of 30 to 40 meter this is often an economical solution. Especially for pipeline lengths of approximately 10 km as installed in considerable numbers in the North Sea. For subject 16-inch pipeline, partly installed in water depths of less than 15 m, the method is considered unpractical and not economically competitive with S-lay. Due to the shallow water depth and larger diameter the required weight coating for the temporary condition between installation and trenching is 80 to 110 mm. Compensation of this weight by additional steel will result in a wall thickness (> 1-inch) that makes the method unsuitable and uneconomic. S-lay is therefore considered the most suitable installation method for subject pipeline.

8.1.4 Results preliminary lay-analysis

The final installation analysis will be performed by the contractor for the selected installation vessel. A preliminary S-lay analysis has been performed to confirm that S-lay of the project pipeline is feasible.

The analysis results (using commercial software Offpipe) show that the required lay tension to limit the pipeline stresses and concrete crushing is in the order of 50 to 100 metric tonnes, depending on the vessel and stinger configuration. This makes the pipeline installable by many of the S-lay vessels available, including; Allseas Lorelay or Audacia, van Oord Stingray, Saipem various vessels, Subsea 7 Antares or Champion.

8.2 Pipeline pull-in

The installation of the landfall section can be performed in several ways. The method will differ from one contractor to another depending on available equipment and experience. The installation will be based on an HDD crossing of the sea defence and an open trench crossing of the Maasgeul (Ref. [11]).

An essential aspect of all or most installation methods is the pull of a pipeline length covering the HDD and Maasgeul section. The length of this section is approximately 2300 m. With the submerged weight of the pipeline as specified in Section 4.3 and an assumed axial friction factor of 1.0 the required pull force can be determined. Various scenarios can be considered to determine the adequacy of available equipment (dedicated winches or HDD equipment pull/push force capacity). Some scenarios are presented in Table 8-1.

Table 8-1 Design Scenarios Pull-in HDD String

Cases	Sections with their length				
	HDD (-) 600 m	On south bank (-) 400 m	Maasgeul (-) 1200 m	On north bank (-) 100 m	Total force (tonnes) 2300 m
Reference case	110 mm concrete				930
With buoyancy	110 mm concrete / 1500 N/m buoyancy				579
Base case	PP	110 mm concrete			690

<table>
<tr><td rowspan="2">Cases</td><td colspan="5">Sections with their length</td></tr>
<tr><td>HDD
(-)
600 m</td><td>On south bank
(-)
400 m</td><td>Maasgeul
(-)
1200 m</td><td>On north bank
(-)
100 m</td><td>Total force
(tonnes)
2300 m</td></tr>
<tr><td>Base case with buoyancy</td><td>PP</td><td colspan="3">110 mm concrete / 1100 N/m buoyancy</td><td>500</td></tr>
<tr><td>Minimized without buoys</td><td>PP</td><td>110 mm</td><td>80 mm</td><td>110 mm</td><td>537</td></tr>
<tr><td>Option with anodes in HDD</td><td>80 mm</td><td>110 mm</td><td>80 mm</td><td>110 mm</td><td>634</td></tr>
<tr><td colspan="6">Input for cases:

- Pipe with 110 mm weight coating: 3968 N/m
- Pipe with 80 mm weight coating: 2718 N/m
- Conservative friction factor concrete – soil: 1 (measured values usually 0.7 – 0.9)
- Reduced friction factor in HDD (rollers, PP – HDPE): 0.6</td></tr>
</table>

The most conservative (full length of 110 mm coated pipe with high friction, no conduit pipe) exceeds the capacity of the largest pull winches available (800 tonnes Bezemer winch). This implies that weight reduction by means of buoys or other measures will be required during pipe pull. For some cases a lift of 1100 to 1500 N/m has been considered to reduce the pull force. This amount of uplift can be achieved with one buoy per pipe joint.

Also, a reduction of the concrete weight coating for the deep part of the Maasgeul crossing can be considered as shown in the table, consequences of reduced weight coating on pipeline stability are presented in Section 4.3.

The results show that the pull is feasible, but depending on the selected installation scenario measures such as buoys or weight coating optimization may be required, also depending on the use of a dedicated winch or HDD drill rig.

HDD and Maasgeul design (weight coating, CP) and installation (pull forces) have to evaluated considering the interaction between aspects, this also involves cost and schedule risks and requires Porthos final decision.

9 References

Ref. [1] INTECSEA, Material Selection Report, TROF-ENG-PEN-INT-REP-0004

Ref. [2] INTECSEA, Design Basis Report, TROF-ENG-PEN-INT-REP-0002

Ref. [3] Nederlands Normalisatie-instituut, Eisen Voor Stalen Buisleiding Systemen Op Zee, NEN 3656, dated December 2015

Ref. [4] INTECSEA, Route Selection, TROF-ENG-PIP-INT-REP-0005

Ref. [5] Integraal Beheerplan Noordzee 2015

Ref. [6] DNVGL, On-Bottom Stability, Recommended Practise RP-F109

Ref. [7] DNVGL, Global Buckling of Submarine Pipelines, Recommended Practise RP-F110

Ref. [8] DNVGL, Submarine Pipeline Systems, Standard F-101

Ref. [9] DNVGL, Cathocid Protection of Submarine Pipelines, Recommended Practise RP-F103

Ref. [10] Porthos, Technical Specification, TRGE-ENG-PEN-NGU-SPEC-0001, rev 2.2, 02-09-2019

Ref. [11] INTECSEA, Landfall and Maasgeul crossing, Doc.No. 416010-00212-EM-001

Ref. [12] INTECSEA, Offshore Route Safety Study, Doc. No. TROF-ENG-RIS-INT-REP-0001

Ref. [13] INTECSEA, Stress Analysis - Maasgeul crossing (covering entry and exit locations), Doc. No. TROF-ENG-PEN-INT-REP-0007

Ref. [14] INTECSEA, Tie-in spool analysis, Doc. No. TROF-ENG-PEN-INT-REP-0008

Ref. [15] INTECSEA, Route Overview, Doc. No. TROF-ENG-PIP-INT-DWG-0001

Ref. [16] DEEP, Porthos pipeline route survey, Doc. No. P3600_SURV_REP_R00, 10-10-2019

deep offshore

CO_2 REDUCTION PROJECT
PIPELINE ROUTE SURVEY
EXTENDED AREAS

SURVEY REPORT

PORTHOS

Port of Rotterdam

gasunie

ebn

DOCUMENT: P3711_SURV_REP_R00

AUTHORISATION

Document title	Porthos pipeline route survey_Extended Areas
Deep Doc-ID	P3711_SURV_REP_R00
Project No (Deep)	P3711
CONTRACTOR details	Deep BV Johan van Hasseltweg 39D 2012 KN Amsterdam The Netherlands +31 20 634 36 76
EMPLOYER details	P/A Port of Rotterdam Wilhelminakade 909 3072 AP Rotterdam The Netherlands
Project No (Porthos)	TROF-ENG-PIL
Execution period	August - September 2019

Revision	Date	Purpose of issue	Author	Review
R00	22-06-2020	For Client approval	RMO	SPI

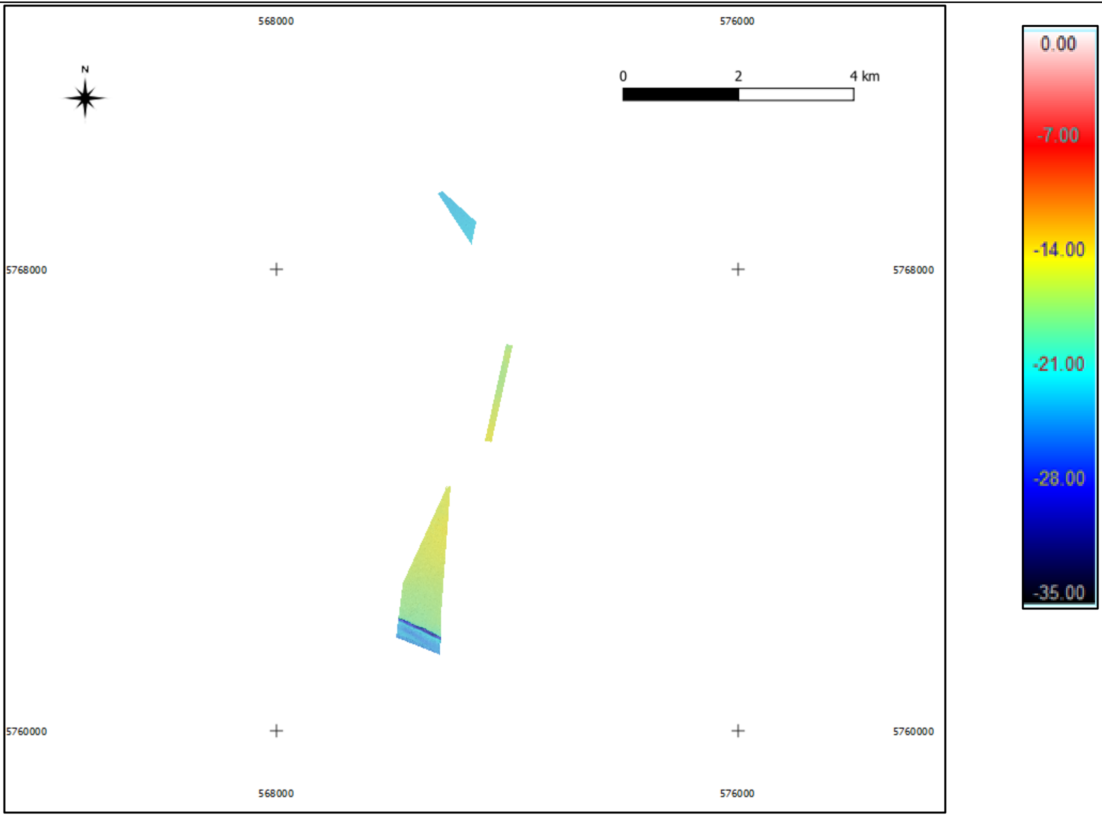
	Name	Date	Signature
Approved PORTHOS			

EXECUTIVE SUMMARY

Deep BV was contracted by the PORTHOS consortium to conduct (part of) the offshore surveys, comprising a MBES, SSS, MAG and SBP route survey. The main part of the route was surveyed in August 2019. The principal requirements of the survey are to map seabed and sub-bottom features considered for detailed pipeline routing. Acquisition and interpretation of high quality geophysical and hydrographic data were performed to provide accurate information on the shallow geology, ferromagnetic objects, seabed characteristics and local topography. All survey work and reporting were performed by Deep BV.

Introduction	
Executing party	Deep BV
Acquisition period	21st June – 31sst June 2020
Scope of work	- project preparations - mobilisation of personnel and equipment to project location - installation, verification and calibration of equipment - multibeam echosounder survey - sidescan sonar survey - seismic survey - sub-bottom profiler survey - magnetometer survey - digital logging of all sensors - online reporting of events and daily logs - demobilisation of equipment and personnel - preparation of report and data
Horizontal and vertical reference	Datum: ED50 Projection: UTM 31 North Vertical reference: LAT (m)
Survey area	3 additional areas (South, Mid and North) adjacent to the main corridor
Vessels	MV Seapal
Equipment	Multibeam echosounder, sidescan sonar, magnetometer, sub-bottom profilers.

Bathymetry
The bathymetry was recorded with a multibeam echosounder, resulting in full data coverage of the survey areas. The data proved to be of good quality. The image below shows the 3 survey areas.



Seabed contacts and ferrous objects	
Contacts on and below the seabed in the areas were detected using sidescan sonar, magnetometer, sub-bottom profiler and multibeam. The results are presented per technique, with correlated contacts from other techniques No archaeological or wreck remains were identified.	
MBES	in total 39 contacts
SSS	in total 59 contacts
MAG	in total 110 contacts of which 5 are existing infrastructure
SBP	in total 12 contacts
Cables and pipelines	
The existing 26'' TAQA pipeline was detected in the MAG data of the mid area.	
Geology within the zone of interest	
For this project the zone of interest is defined as the first 5 meter below the seabed, except for the shipping lane area, here was the aim to reach more penetration due to the planned HDD campaign. Three significant reflectors with lateral continuity have been marked and gridded to isopachs (H1, H2 and H3). H1 is interpreted as a transition line between sandy sediments, H2 marks a clay layer and H3 marks a peat layer.	
Geohazards	
Buried objects	Buried objects were noted in the sub-bottom profiler data. Their position (x, y) and DoB have been picked. No further identification was possible.

No further geohazards have been detected.
Conclusions
The route investigation geophysical survey has been executed to establish the current situation with respect to water depths, shallow geology and seabed features. Additionally information is provided about infrastructure and targets occurrence in the survey area. All objectives were achieved.

CONTENT

FIGURES

TABLES

COMMONLY USED ABBREVIATIONS

AC	Alter Course
ADCP	Acoustic Doppler Current Profiler
AEZ	Archaeological Exclusion Zone
AIS	Automatic Identification System (automatic tracking system)
AHT	Anchor Handling Tug
ARBO	Arbeidsomstandigheden (Dutch regulations for working conditions)
AIS	Automatic Identification System
BGS	British Geological Survey
BOSIET	Basic Offshore Safety Induction and Emergency Training
BV	Besloten Vennootschap (Dutch equivalent to Ltd.)
CD	Chart Datum
CE	Conformité Européenne
CMG	Course Made Good
C-O	Computed-Observed
CoG	Centre of Gravity
CPT	Cone Penetration Test
CRP	Coordinate Reference Point
dGPS	Differential Global Positioning System
DHY	Dienst der Hydrografie (Hydrographical service of the Dutch military)
DoB	Depth of Burial
DoC	Depth of Cover
DP	Dynamic Positioning
DPR	Daily Progress Report
DTM	Digital Terrain Model
DVL	Doppler Velocity Log
EEZ	Economic Exclusive Zone
ENFC	Emergency Notification Flowchart
EPIRB	Emergency Position Indicating Radio Beacon
EPSG	European Petroleum Survey Group Code
ETRS	European Terrestrial Reference System
EVT	Equipment Verification Test
FGDB	File GeoDataBase
FM	Formation (used in a litho-stratigraphic system)
GIS	Geographic Information Systems
GLONASS	(Russian) Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRS	Geodetic Reference System
GPR	Ground Penetrating Radar
HAT	Highest Astronomical Tide
HAZID	Hazard Identification
HAZOP	Hazard and Operability Study
HIRA	Hazard Identification and Risk Analysis
HNM	Height Not Measured
HSE	Health, Safety and Environment
HSEQ	Health, Safety, Environment and Quality
HVDC	High Voltage Direct Current
IMO	International Maritime Organization
IOGP	International association of Oil & Gas Producers
ISO	International Organization for Standardization
ITRF	International Terrestrial Reference Frame
KP	Kilometre Post (Stationing in km)
LAT	Lowest Astronomical Tide
MAG	Magnetometer
MEDIN	Marine Environmental Data & Information Network
MBES	Multibeam Echosounder
MCS	Multi Channel Sparker
MOB	Man Over Board
MRU	Motion Reference Unit
MS	Motorschip (Dutch equivalent to M.V.)
MSDS	Material Safety Data Sheet
MSL	Mean Sea Level
MV	Motor Vessel
MW	Mega Watt
MXD	Map Exchange Document
NCN	Nationaal Contact Nummer (archaeological database number)
NGE	Niet Gesprongen Explosieven (Dutch equivalent for UXO)
NOGEPA	Nederlandse Olie en Gas Exploratie en Productie Associatie
nT	nanoTesla
OCE	Opsporen Conventionele Explosieven (Dutch license compulsory for UXO detection survey in The Netherlands)
OD	Ordnance Datum
OOS	Out Of Service (Cable)
O&M	Operation & Maintenance
OPITO	Offshore Petroleum Industry Training Organization
OSS	Offshore Sub Station
OWF	Offshore Wind Farm
PEP	Project Execution Plan
PLB	Personal Locator Beacon
PPE	Personal Protective Equipment
PPS	Pulse Per Second
PQP	Project Quality Plan
PS	Portside
PTW	Permit To Work
QA	Quality Assurance
QC	Quality Control
QMS	Quality Management System
RAMS	Risk Assessed Method Statement
RCE	Rijksdienst voor Cultureel Erfgoed (Cultural heritage service of the Dutch government)
RFC	Request For Change (in Dutch: aanvraag voor verandering)
RHIB	Rigid-Hulled Inflatable Boat
RMS	Root Mean Square
RPA	Remotely Piloted Aircraft
ROV	Remote Operated Vehicle
ROTV	Remote Operated Towed Vehicle
RPL	Route Position List
RTK	Real Time Kinematic
RWS	Rijkswaterstaat (Dutch governmental agency)
SB	Starboard Side
SBE	Single Beam Echosounder
SBP	Sub-bottom Profiler
SD	Standard Deviation
SCS	Single Channel Sparker
SIMOPS	Simultaneous Operations
SIT	Surrogate Item Trial
SMP	Safety Management Plan
SNR	Signal to Noise Ratio
SoG	Speed Over Ground
SOLAS	Safety Of Life At Sea
SOPEP	Shipboard Oil Pollution Emergency Plans
SRF	Ships Reference Frame
SSDM	Seabed Survey Data Model
SSS	Side Scan Sonar
SVP	Sound Velocity Probe
THU	Total Horizontal Uncertainty
TIFF	Tagged Image File Format
TFW	TIFF World File
TMS	Tug Management System
TSO	Transition System Operator
TSS	Traffic Separation Scheme
TVU	Total Vertical Uncertainty
TW	Territorial Waters
TWTT	Two Way Travel Time
UAV	Unmanned Airborne Vehicle
UHF	Ultra High Frequency
UKHP	United Kingdom Hydrographic Office
USBL	Ultra-Short Baseline underwater positioning
UTM	Universal Transverse Mercator
UXO	UneXploded Ordnance
VCA	Veiligheids Checklist Aannemers (Dutch safety for contractors)
VHF	Very High Frequency
VORF	Vertical Offshore Reference Frame
WFS	Wind Farm Site
WFZ	Wind Farm Zone
WGS	World Geodetic System
WKID	Well Known ID
WoW	Waiting on Weather
WTG	Wind Turbine Generator

1 INTRODUCTION

1.1 General project description

Carbon Capture Usage and Storage (CCUS) is one of the measures to reduce the greenhouse emissions in the Netherlands. CO_2 is captured and reused or stored underground. This is acknowledged by the Dutch government and part of the upcoming climate agreement. That's why the Port of Rotterdam, Gasunie and EBN are jointly preparing a new project in which CO_2 generated by industry in Rotterdam's port area is captured and stored in empty gas fields deep in the North Sea seabed.
The three companies have joined strengths under the project banner Porthos: Port of Rotterdam CO_2 Transport Hub & Offshore Storage and a new CO_2 transport pipeline will be installed from the Port of Rotterdam to the P18-A platform.

Deep BV has been contracted by the PORTHOS consortium for the provision of (part of) the offshore surveys for the marine pipeline section. August 2019, the main part of the route was surveyed. Based upon the results and further engineering some rerouting was advised, resulting in the request for extra data coverage in three areas. This report describes the geophysical survey conducted along the extra areas of the proposed pipeline route corridor, with regard to the water depths, seabed features, shallow geology, and the occurrence of targets.

1.2 Location

The marine section of the pipeline project, including the landfall at Maasvlakte 2, comprises crossing a seawall, crossing the major shipping lane 'Maasgeul' and four Tennet high-voltage power cables, routing past the existing Q16 FA-1 subsea wellhead and towards the existing P18-A platform. The marine pipeline route length is estimated in the order of 19km, water depths ranging approximately from 25 m LAT at the 'Maasgeul' crossing to 16 m directly north of the Maasgeul, 22 m LAT at Q16 and and P18-A. The additional survey areas (South, Mid and North) are depicted in red below.

Figure 1-1: Location of the Porthos pipeline route extra investigation areas.

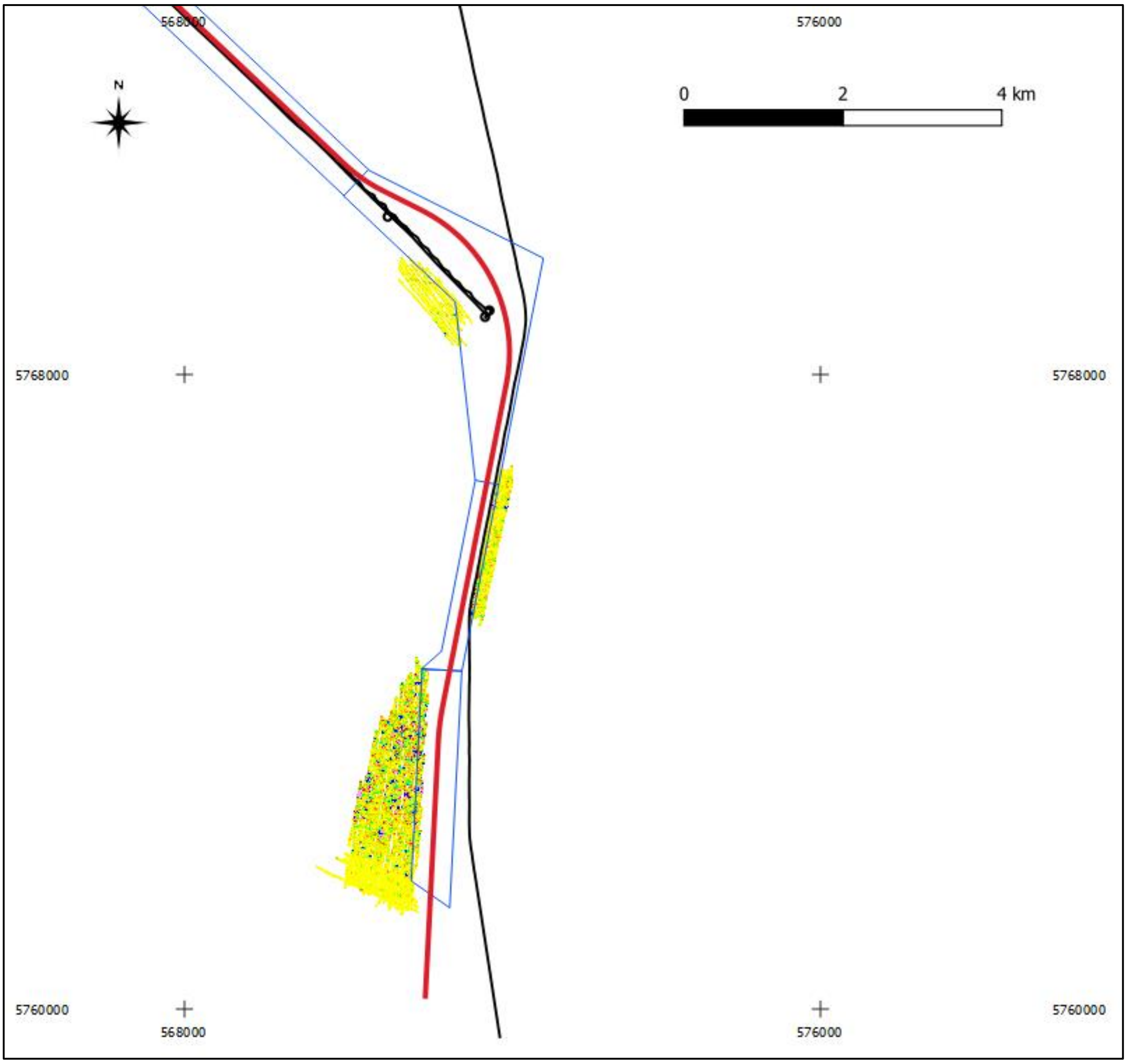


Figure 1-2: Detailed location overview with MAG data coverage.

In red: Location of the proposed Porthos original pipeline route.
In black: Existing infrastructure.
In blue: Main survey corridor.

1.3 Reference Documents

Document	*Description*
Q2019_KVI_DOC_6621	*Deep quotation*
Deep HSE manual v11	*Deep company HSE manual*
Deep BMS 4.1	*Deep Business Management System*
RFQ Porthos Survey Package 2 v3	*Porthos survey requirements*
TROF-ENG-GEO-FUG-REP-0001	*Third party geotechnical report*
www.dinoloket.nl	*General geology*
Netherlands Journal of Geoscience	*General geology*
P3600_DEL_LIST_R00	*Deep deliverable list*
P3600_OPS_MAG_SSS_COVERAGE	*Deep survey parameters*
P3600_OPS_PAR_R00	*Deep survey parameters*
P3600_SURV_REP_R01	*Deep survey report main area*

Table 1: Reference documents.

2 PROJECT DEFINITION

2.1 Objectives

A geophysical investigation survey was required for the designed Porthos pipeline route. The total distance of the routing came to approximately 18 kilometres. The objectives of the investigation survey are defined as followed:

- Obtain high-resolution bathymetry, shallow subsoil stratigraphy and seabed imagery along the designed pipeline route;
- Find surface debris and (if possible) shallow buried objects (down to 3 meters below seabed) that may cause a hindrance to pipeline laying and trenching;
- Detect ferromagnetic objects;
- Determine shallow depth soil stratification down to 5 meter below seabed. Data to be cross referenced with existing geotechnical soil data;
- Identify existing subsea infrastructure (e.g. pipelines, cables, wellheads etc.).

2.2 Scope of work

The scope of work, as defined in the contractual documents, are summarised as follows:

- Project preparations and compilation of survey procedures;
- Mobilisation of personnel and equipment to project location;
- Installation, verification and calibration of equipment;
- Pre-lay geophysical survey;
- Demobilisation of personnel and equipment;
- Preparation of report and data deliverables.

During survey operations the following techniques were used:

- Multibeam echosounder to accurately map the bathymetry covering a 300–500 metre corridor along the preferred pipeline route. Besides measuring the water depth, multibeam data was used to detect objects on the seabed.
- Sidescan sonar was used for the detection of objects on the seabed, and for seabed and features. Scanning range was set to 75 m per channel and line spacing was 40 m. Lines were sailed with sufficient overlap to cover the sonar nadir and achieve a full 300% coverage.
- A magnetometer was deployed for the detection of (large) ferromagnetic objects, and for determining the position of buried pipelines. Survey lines were sailed every 40 metres along the pipeline route. A realistic towfish height (magnetometer piggy backed on sidescan sonar) of 5m above seabed results in a ferro mass detection of approximately 700kg. For details of the detection capabilities see reference pdf document *P3600_OPS_MAG_SSS_COVERAGE*.
- A parametric sub-bottom profiler was used for the mapping of shallow geological layers and for the detection of buried objects, amongst which existing pipelines. Survey lines were sailed every 40 metres along the pipeline route and every 750 m across the preferred route.
- A sparker seismic reflection system was used for the mapping of shallow geological layers near the shipping lane. Survey lines were sailed every 40 metres along the pipeline route and every 750 m across the preferred route.

Nr.	Scope	Survey technique	Line spacing
1	bathymetry along planned proposed pipeline route	• multibeam	full coverage
2	surface debris, seabed features	• multibeam • sidescan sonar	full coverage (300% for SSS)
3	sub-surface debris and shallow geology	• sub-bottom profiler • sparker	40m and 750m cross lines
4	surface and sub-surface debris (large ferrous objects)	• magnetometer	40m

Table 2: Scope of work and used survey techniques.

2.3 Execution of survey

Project preparations and mobilisation started on the 20th of June 2020 in IJmuiden and the survey finished on the 31st of August.

2.4 Quality requirements

The geophysical work is subject to quality requirements specified in the survey parameters from both the Client and the survey operator (see Table 1: *Reference documents*). Table 3 describes if, and which requirements are stated per type of survey.

Nr.	Type of survey	Required work	Required quality
1	MBES	All survey systems shall meet the NORM 20.01 guidelines	NORM 20.01 guidelines
4	MBES	100 % coverage of scoped area	Max 0.5m bin size
5	MBES	Final processed data	Grid of 1m x 1m and 20 soundings/m^2 (after validation minimum of 5 validated hits/m^2
7	SSS	SSS-images of the scoped area	0.5 meters/pixel
8	SSS	Identify objects that may cause a hindrance	Contacts ≥ 50cm
10	SBP	Shallow soil stratification down to 5m below seabed	**no specified requirements*
11	SBP	Identify shallow buried objects that may cause a hindrance	Significant contacts (showing large clear hyperbolas)
13	MAG	Identify objects that may cause a hindrance	Mimimum ferro mass detection of approximately 700kg

Table 3: Specified quality requirements per survey type.

2.5 Deliverables

Table 4 below shows the deliverables related to the project. These include processed bathymetric data, sidescan data, magnetometer data as well as sub-bottom and seismic data. Derived geological data and detailed contact lists are also included.

Part	Technique	Type	Specification	Description	Format
Preparation	Calibrations	Offshore checks	MBES/SSS position health checks	On existing structures	pdf
	Line plan	Direction and interval			dxf
Survey	General	DPR			pdf
		HSE and toolbox meting reports			pdf
	MBES	Bathymetry XYZ	1m gridded data	Mean cell value of 5 validated points	ASCII X,Y,Z [ED50 Common Offshore, UTM31N, LAT]
		Standard deviation	1m gridded data		ASCII X,Y,sd [95% Norm 20.01]
		Interpretation	Contacts ≥50cm (any direction)	Only contacts that may hamper the pipe lay	According to table 4-2 Porthos survey package 2, V3, 04-07-2019
		Raw data files	Upon request		
	SSS	Interpretation	Contacts ≥50cm (any direction)	Only contacts that may hamper the pipe lay	List According to table 4-2 Porthos survey package 2, V3, 04-07-2019 and in dxf/shape
		Interpretation	Contact images 20cm resolution		Color coded geotiffs
		Mosaics	50cm resolution		Color coded geotiffs
		Raw data files			Uncorrected xtf and/or sdf
	MAG	Contacts	No UXO/≥700kg ferro mass		List with Unique ID, coordinates, field value, fish altitude remarks and in dxf/shape
		3rd party cable/pipe crossings	Listing		Unique ID, coordinates, type, owner
	SBP	Interpretation	Relevant reflectors	Cross referenced with geotech info	ASCII X,Y,DBB
		Interpretation	Gridded reflectors (isopach)	Main reflectors only	ASCII X,Y,DBB and color coded geotiffs
		Significant contacts			List according to table 4-4 Porthos survey package 2, V3, 04-07-2019 and in dxf/shape
		3rd party cable/pipe crossings	Listing		Unique ID, coordinates, dbb, type, owner
	Sparker	Interpretation	Relevant reflectors	Cross referenced with geotech info	ASCII X,Y,DBB
		Interpretation	Gridded reflectors (isopach)	Main reflectors only	ASCII X,Y,DBB and color coded geotiffs
Reporting	Reporting	Interpretive report	Description of results and method		pdf
		Correlated contact listing	MBES,SSS,MAG,SBP correlated contact listing		xlsx and shp

Table 4: List of deliverables.

3 RESULTS AND INTERPRETATION

3.1 Disclaimer

In the processing and interpretation of the geophysical data, Deep BV employees have relied on experience and have exercised their best judgment. However, all interpretations are opinions based on inferences from acoustical and/or other measurements. Features that do not produce measurable geophysical anomalies or are hidden by other features may remain undetected. Geophysical surveys may compliment invasive/destructive methods and provide a tool for investigating the subsurface; they do not produce data that can be taken to represent all of the ground conditions found within the surveyed area. Areas that have not been surveyed due to obstructed access or any other reason are excluded from the interpretation.

Deep BV cannot and does not guarantee the accuracy or correctness of any interpretation. Deep BV cannot be held liable for any loss, damages or expenses resulting from reliance on such interpretation.

3.2 Listings and results

The survey results described in this chapter can all be found in the accompanying listings and deliverables. These files and listings aim to provide a clear and quick overview of the survey data along the proposed pipeline route.

Contacts in and on the seabed have been detected by means of the following techniques: magnetometer, sidescan sonar, sub-bottom profiler, and multibeam. The contacts detected by each technique have had technique specific duplicates removed (due to survey overlap) and are presented in four listings showing correlation with other techniques. Separate geotiffs and mosaics were created for each of the three main survey areas. All other data is processed in concordance with *Table 4*.

3.3 Quality requirements/meeting criteria

All the required (see Table 3), and subsequent achieved quality criteria of the deliverables are presented in *Table 5* and the following paragraphs (3.3.1 – 3.3.4).

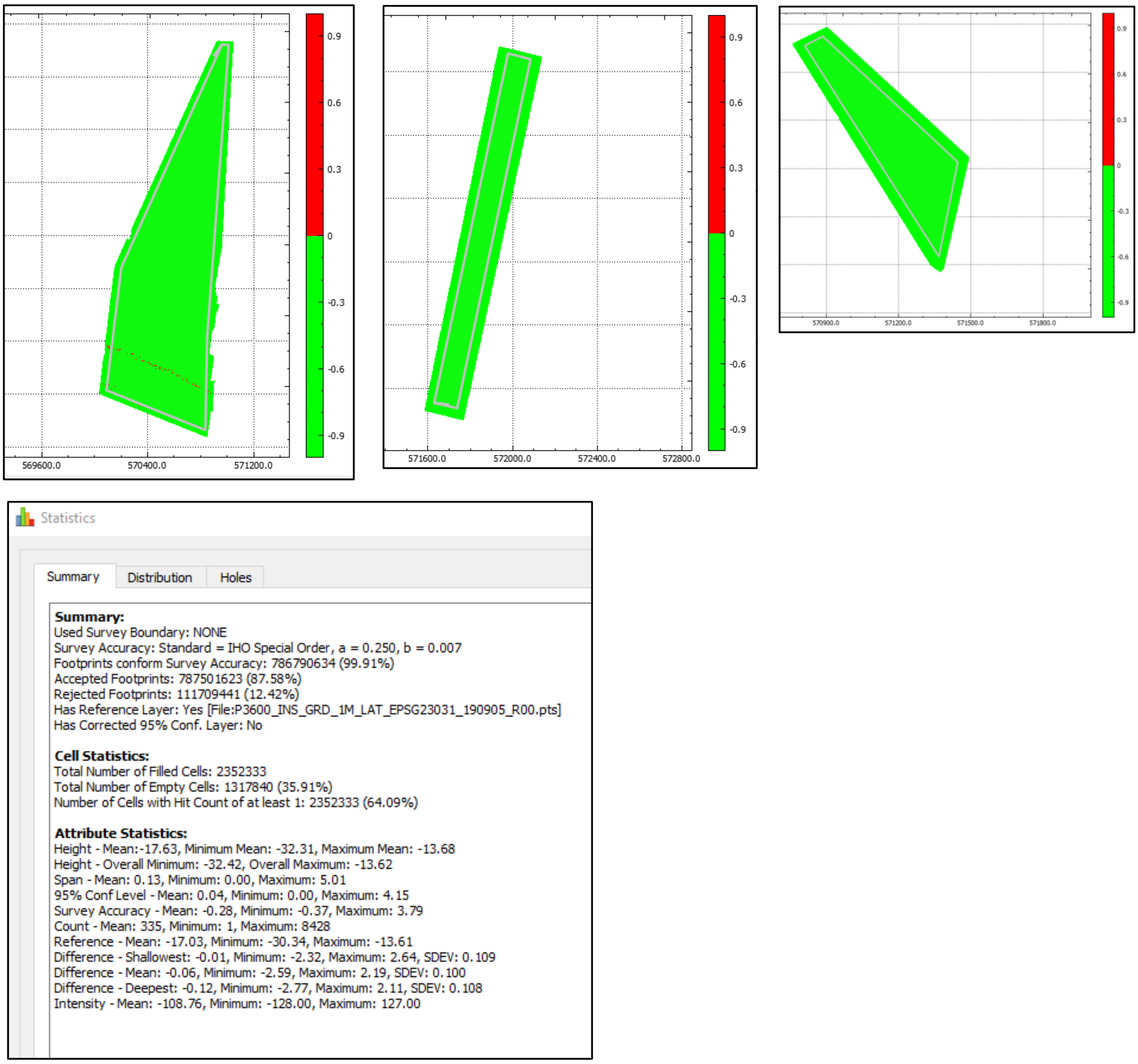
Nr	Type of survey	Required work	Required quality	Reference	Achieved
1	MBES	All survey systems shall meet the NORM 20.01 guidelines Applies only for MBES	NORM 20.01 guidelines	See §3.3.1,§ 3.3.2 and §3.3.3.	YES
4	MBES	100 % coverage of scoped area	Max 0.5m binsize	See§ 3.3.2	YES
5	MBES	Final processed data	Grid of 1m x 1m and 20 soundings/m^2 (after validation minimum of 5 validated hits/m^2	See §3.3.3	YES
7	SSS	SSS-images of the scoped area	0.5 meters/pixel	See deliverables	YES
8	SSS	Identify objects that may cause a hindrance	Contacts ≥ 50cm	See deliverables	YES
10	SBP	Shallow soil stratification down to 5m below seabed	**no specified requirements*		YES
11	SBP	Identify shallow buried objects that may cause a hindrance	Significant contacts (showing large clear hyperbolas)	See deliverables	YES
13	MAG	Identify objects that may cause a hindrance	Mimimum ferro mass detection of approximately 700kg	§3.3.4	YES

Table 5: Required and achieved data quality.

3.3.1 Meeting NORM 2.01 guideline for MBES system

The MBES data meets the Port of Rotterdam provided NORM 2.01 guideline, which is shown in the following images. The requirement of paragraph 3.3.2 and 3.3.3 are also part of this guideline.

All MBES data meet the IHO special order standard, which is depicted below.



Summary:
Used Survey Boundary: NONE
Survey Accuracy: Standard = IHO Special Order, a = 0.250, b = 0.007
Footprints conform Survey Accuracy: 786790634 (99.91%)
Accepted Footprints: 787501623 (87.58%)
Rejected Footprints: 111709441 (12.42%)
Has Reference Layer: Yes [File:P3600_INS_GRD_1M_LAT_EPSG23031_190905_R00.pts]
Has Corrected 95% Conf. Layer: No

Cell Statistics:
Total Number of Filled Cells: 2352333
Total Number of Empty Cells: 1317840 (35.91%)
Number of Cells with Hit Count of at least 1: 2352333 (64.09%)

Attribute Statistics:
Height - Mean:-17.63, Minimum Mean: -32.31, Maximum Mean: -13.68
Height - Overall Minimum: -32.42, Overall Maximum: -13.62
Span - Mean: 0.13, Minimum: 0.00, Maximum: 5.01
95% Conf Level - Mean: 0.04, Minimum: 0.00, Maximum: 4.15
Survey Accuracy - Mean: -0.28, Minimum: -0.37, Maximum: 3.79
Count - Mean: 335, Minimum: 1, Maximum: 8428
Reference - Mean: -17.03, Minimum: -30.34, Maximum: -13.61
Difference - Shallowest: -0.01, Minimum: -2.32, Maximum: 2.64, SDEV: 0.109
Difference - Mean: -0.06, Minimum: -2.59, Maximum: 2.19, SDEV: 0.100
Difference - Deepest: -0.12, Minimum: -2.77, Maximum: 2.11, SDEV: 0.108
Intensity - Mean: -108.76, Minimum: -128.00, Maximum: 127.00

Figure 3-1: Percentage MBES data (South (l), Mid, North (r)) meeting IHO special order requirement

The 95% confident level is smaller than 0.10m

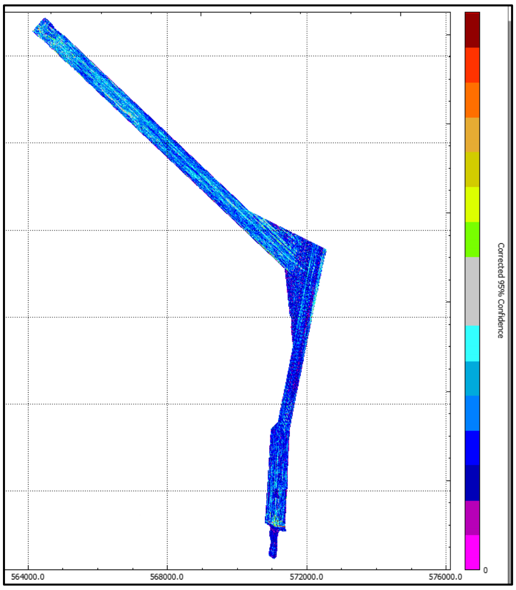


Figure 3-2: The mean 95% confident level is 0.05m

3.3.2 Hit count acquiring 100% MBES coverage at 1m grid level

The following image shows the hit count of the validated bathymetry data at 1m grid size level. No gaps occur.

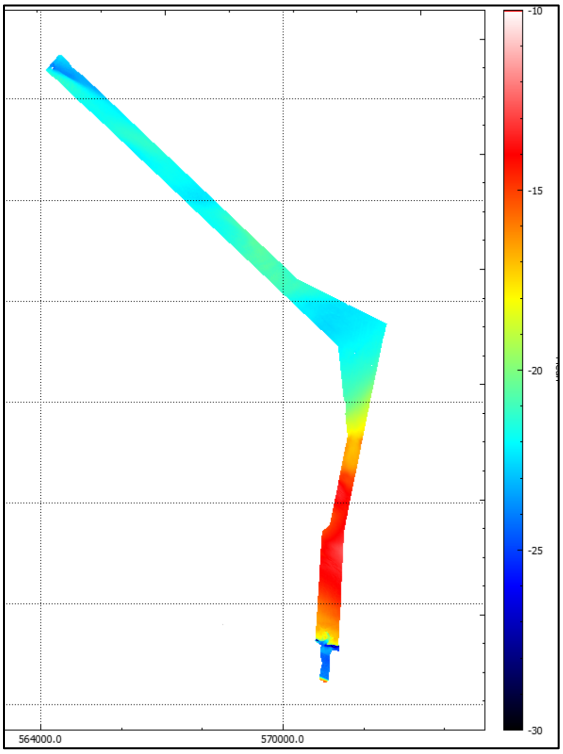


Figure 3-3: Multibeam data in 1m grid

3.3.3 Acquiring 5 validated MBES soundings per m^2

The following images show the amount of MBES soundings per m^2 after validation. The scale of the images does not allow for much detail but the five (5) hits per m^2 were acquired everywhere in the survey boundary.

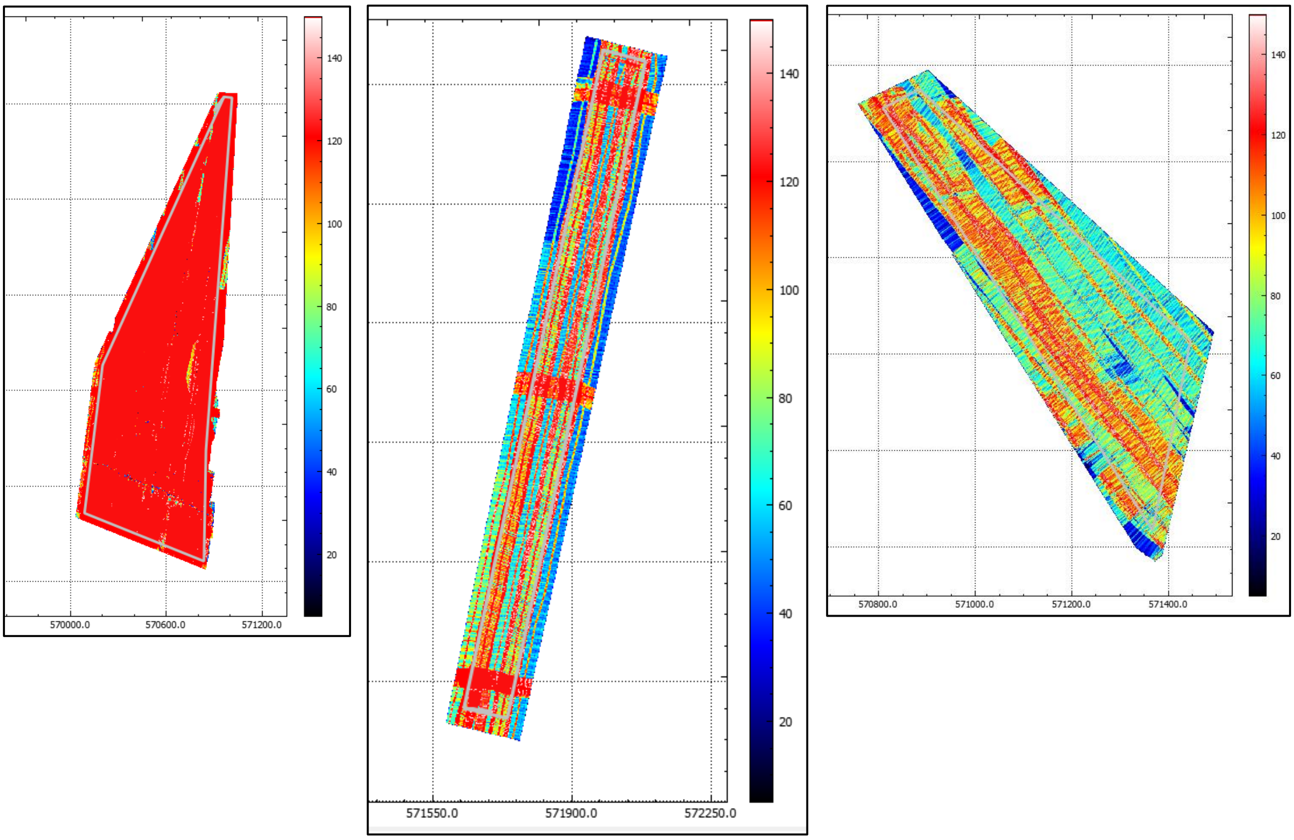


Figure 3-4: Multibeam soundings per m^2

3.3.4 Achieving a magnetometer detection threshold of 700kg

Without a surrogate item trial (not part of this scope and usually only performed prior to an UXO magnetometer survey) it is difficult to prove if the survey detection threshold was achieved. And even if with the execution of a SIT it should be noted that the density, shape, orientation and position of an item very strongly determine the size of the magnetic anomaly.
However, the following facts indicate that the 700kg ferro mass detection threshold has been met:

- Collected data was of good quality
- The noise level is below 2.5nT, see *Figure 3-5*.

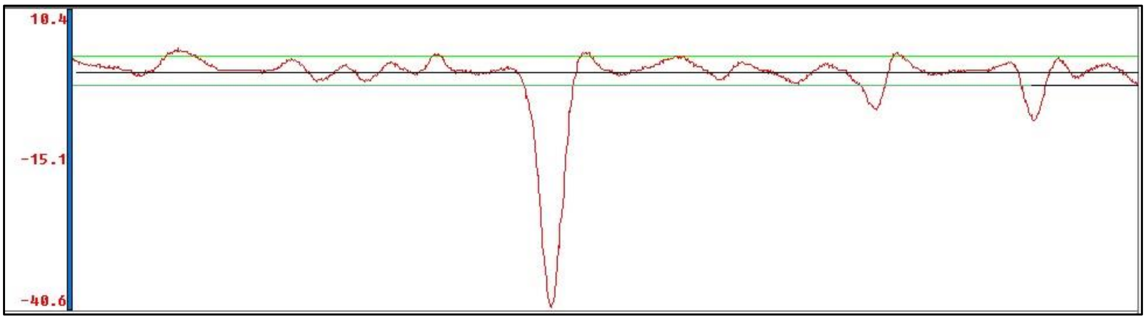


Figure 3-5: Magnetometer noise level
Green lines are +/- 2.5nT.

- Rejected areas were surveyed again, maintaining the high data quality.
  Data with a towfish altitude larger than 5 meters above seabed was rejected.
  Data with absolute sensor quality values less than 300 was rejected.
  Track lines offset more than 20% of survey line spacing (40m) were rejected.
- A 90.5 nT object, calculated directly under the towfish, which is (theoretically and without modelling) less than 700kg ferro mass is also visible in other survey lines. In parallel lines at 33.7m (14.2nT) and 42m (14.5nT) distance. See *Figure 3-6*; the black cross is the contact of 90.5nT. The grey cross represents 14.2nT and brown cross 14.5nT.
  The detection of less than 700kg at a distance more than 20m supports the fact that the criteria of 700kg ferro mass objects detection was met.

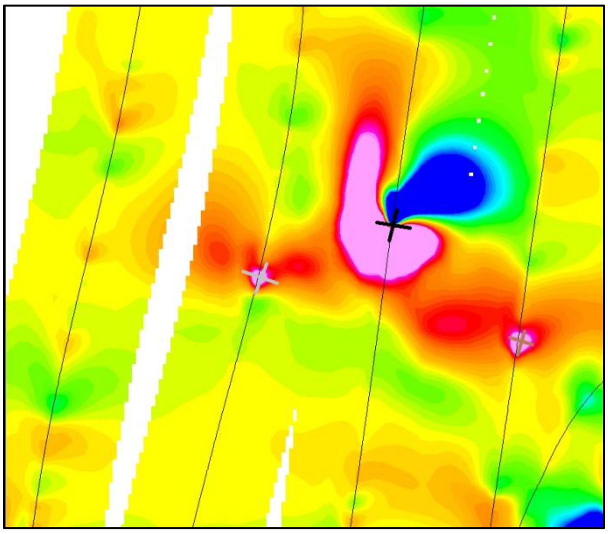


Figure 3-6: Magnetometer contact visible in different survey lines
Black cross; 90.5nT, grey cross 14.2nT and blue cross 14.5nT.

3.4 Multibeam echosounder

The multibeam survey has resulted in a full coverage of the additional areas. The bathymetrical data was validated, using BeamworX Autoclean software and exported to a grid with a cell size of 1mx1m. All water depths are presented in meters relative to LAT.

During the main survey was established that the bathymetry of the Porthos investigation area can be divided in two segments, from north to south and from north-west to south-east. Both segments are generally dipping towards their curve intersection around the Q16FA-1 subsea well area. The NW-SE section is also dipping northerly of the P16-A platform. The N–S section shows a characteristic bathymetric slide to the south close to shore and is adjacent to a morphological escarpment (see *Figure 3-7*).
The additional South area shows similar features, although a lot less dramatic and without slide (see *Figure 3-8*).
MBES data shows similar seabed features as observed in the sidescan sonar records (chapter 3.5). In total 39 contacts are observed in the data set, 36 of them can be correlated with SSS and are therefore dimensioned in the SSS contact list.

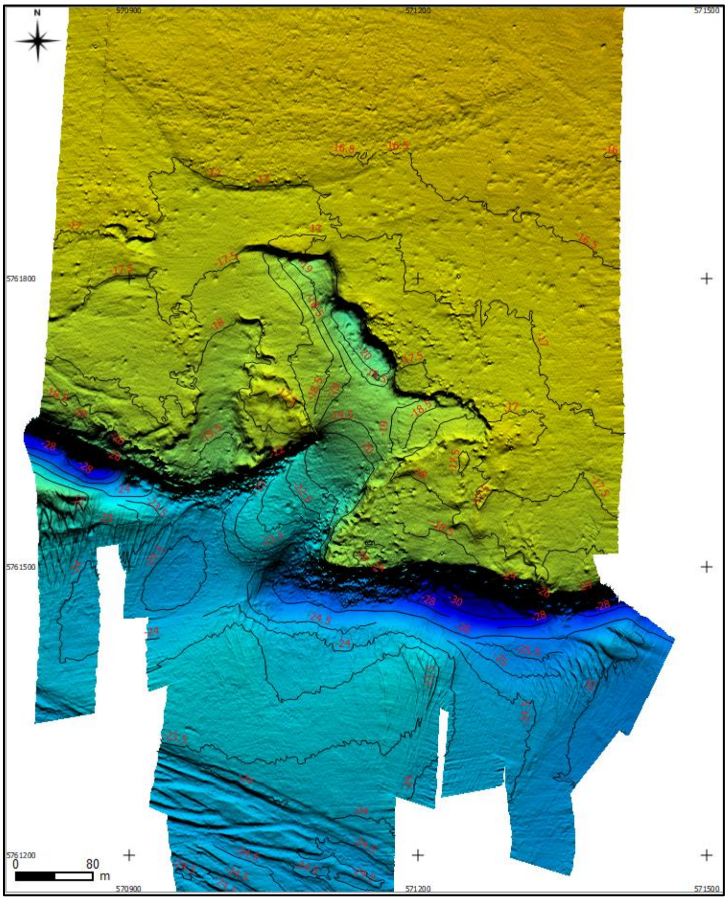


Figure 3-7: Multibeam data example
Nearshore survey section showing a morphological slide with adjacent steep bathymetric slopes.

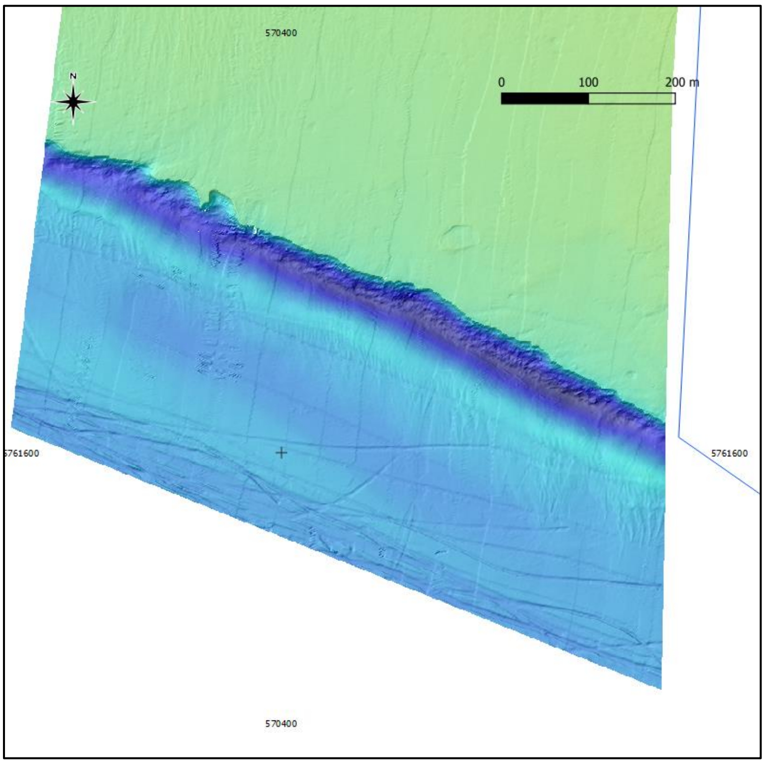


Figure 3-8: Multibeam data example additional South area
Nearshore survey section showing steep bathymetric slope.

3.5 Sidescan sonar

The sidescan sonar survey has resulted in a full coverage of the additional areas. The SSS was primary used for target detection and features analysis.
All targets larger than 0.5 X 0.5 X 0.5 metres have been picked in a waterfall display (which gives the highest possible resolution), resulting in 59 contacts. It was possible to correlate 17 contacts with magnetometer and 36 with multibeam contacts.
A number of features, such as trawl marks and (dredge) scars are delivered as separate shape files.

Listed sidescan sonar contacts include the following data:

- geo-referenced XY position;
- image (snap shot);
- dimensions (width, length and when possible also height);
- short description of contact type;

The estimated height of the contacts should be regarded as an indication only.

The majority of the identified sidescan sonar contacts has been classified as debris, especially when they are correlated to magnetometer targets or show increased reflectivity and/or irregular shape and size. The rest of the SSS targets have been primary classified as boulder with many of them seen also in the multibeam data.

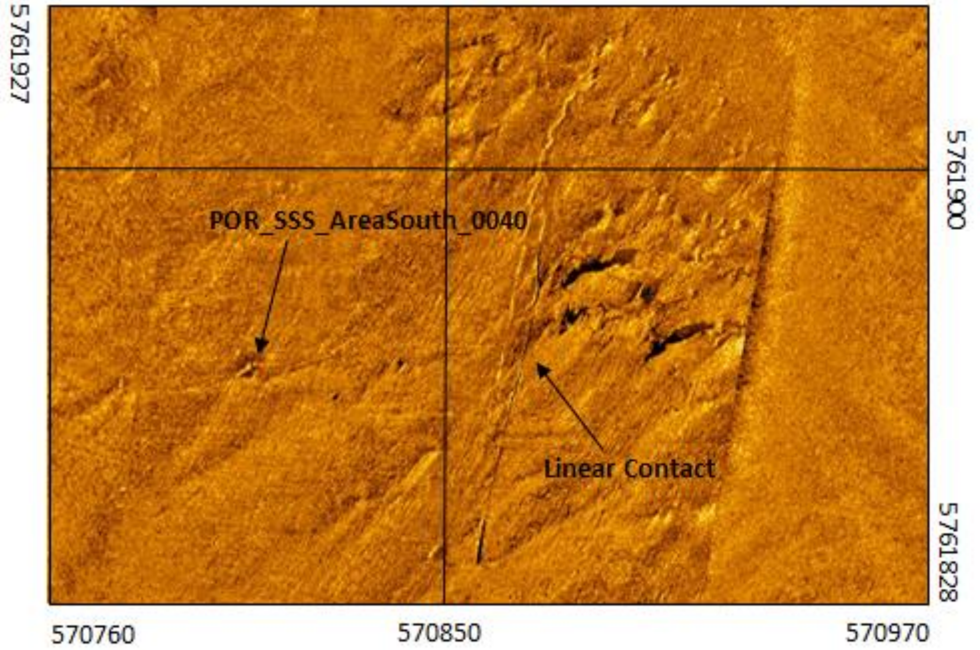


Figure 3-9: Sidescan sonar data example
Debris and Linear contact in Area South.

3.6 Magnetometer

Interpretation of magnetometer data resulted in 110 targets. Six contacts in the North area line up and are delivered as separate shape.

Most of the magnetometer targets represent individual ferrous objects within a wide range of residual values. The large number of targets is primary due to numerous anomalies found across the Maasgeul shipping lane. Many of these anomalies are likely due to regional geology.

A minimum threshold of 5 nT (p2p) was used for target picking.

Subsequently, a total field residual grid was produced based on processed magnetometer data. The grid was used for correlation of magnetic anomalies and to remove duplicate targets.

It has to be noted that due to the relatively large line spacing the magnetometer survey is **NOT** suitable for UXO detection.

Figures below show gridded residual data.

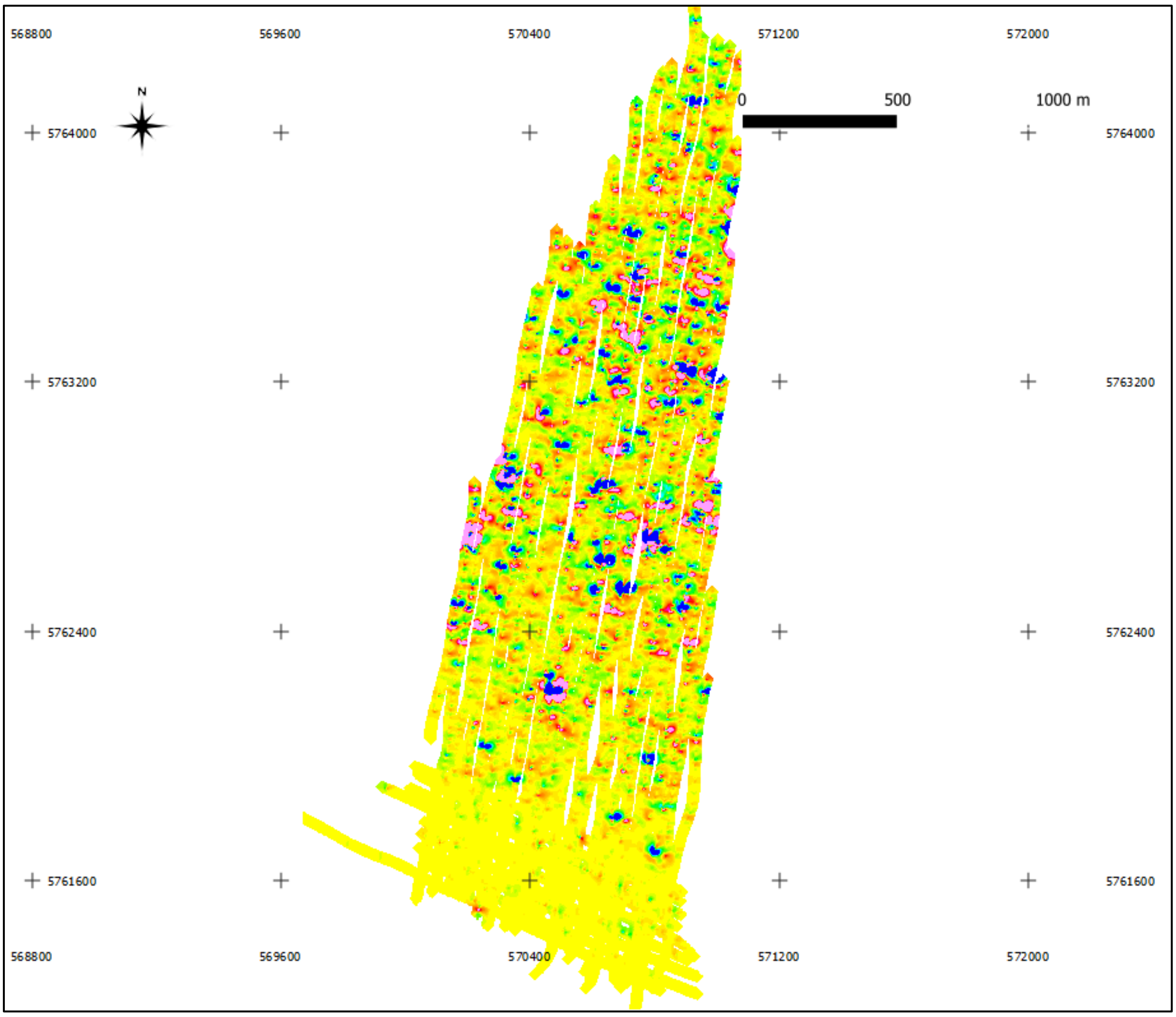


Figure 3-10: Residual grid South Area

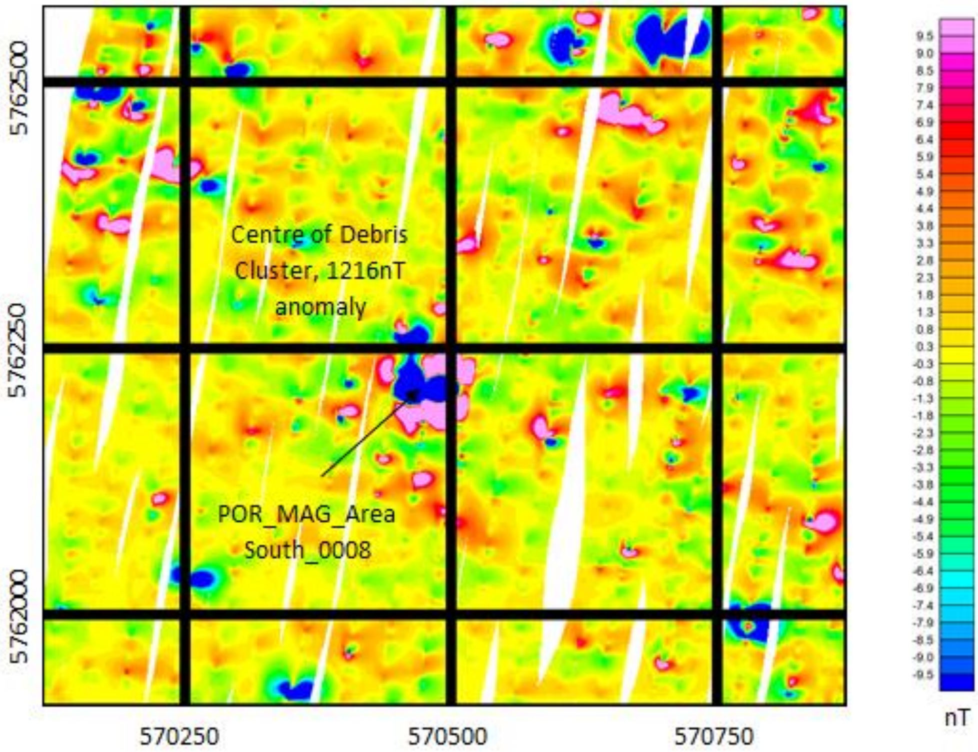


Figure 3-11: Detail of Residual grid
Debris

3.7 Sub-bottom profiler

The geology of the extended areas coincides perfectly with the previous (2019) data and the reporting is therefore virtually identical

Three significant lateral continuous horizons have been identified, H1, H2 and H3 and were exported to isopachs.

A total of 12 sub-bottom contacts was picked and listed with their XY positions and depth of burial.

Due to the purpose of this survey, a zone of interest was determined by the Client. The zone is that part of the subsurface that will be significant to pipeline installation and burial, for this survey a depth of 5 meters below seabed was specified.

General geology
The shallow subsurface of the coastal area of the Dutch North Sea basin is mainly defined by the Naaldwijk Formation, in the offshore environment also named Southern Bight Formation. The Naaldwijk Formation comprises all Holocene sandy and clayey coastal plain deposits from coarse sand to silty clay and lies discordant, mainly with a sharp transition to the underlying deposits of the Nieuwkoop, Echteld or Kreftenheye Formation. The thickness varies from 1 to more than 75 meters.
A basal peat layer that lies at the base of Holocene strata has a basin-wide stratigraphic significance and is assigned to the Nieuwkoop Formation. It characteristics are sandy peat deposits with medium fine sands or very fine to coarse sands with clay layers and clay laminae. The thickness varies from almost zero to more than eight meters.
The internal inhomogeneous lithology is a characteristic of the Echteld Formation. The FE comprises the mixed clay and sand deposits of the Rhine and Meusel that were deposited during Holocene sea level rise. At the coastal region often partly covered by deposits of Naaldwijk and Nieuwkoop Formation.

Local geology
The interpretation of the sub-bottom data focused on finding relevant reflectors of the shallow geology of the planned pipeline route. Therefore, it was chosen not to define stratigraphic units but to interpret main seismic reflectors to get information of the lithological settings of the area of interest. However, due to some clear differences in lithological characteristics in the formations, we can state that at least two formations, Naaldwijk and Nieuwkoop, are presented in the survey area.
The presentation of the sub-bottom data results is geographically divided in three sections (based upon the previous survey), the northern part, the bend area and the southern part. The description starts from the north.

In the northern part the data shows homogenous sediments with a weak discontinuous reflector at mainly two to three meters below seabed. The reflector probably indicates a transition from fine medium sand to medium sand. Another explanation could be a shell layer in this area, indicated by a high amount of shell fragments in the samples and as a characteristic of the Naaldwijk Formation.
An isopach gives the depth of the reflector below seabed, with an interpolation between the sailed survey lines. In this case the isopach shows some gaps, where the reflector was not visible which could be the result of variable grain sizes and density in the sediments as well the different level of shell fragments through the area.
An isopach gives the depth of the reflector below seabed, with an interpolation between the sailed survey lines. In this case the isopach shows some gaps, where the reflector was not visible which could be the result of variable grain sizes and density in the sediments as well the different level of shell fragments through the area.

At the north side of the bend the discontinuous reflector vanishes completely. The whole bend area shows some sporadic reflectors with no clear correlation, therefore no isopach was created for this area. The geotechnical data shows mainly sandy sediments from fine to coarse grainsizes with a thin layer of silty clayey sand on top.

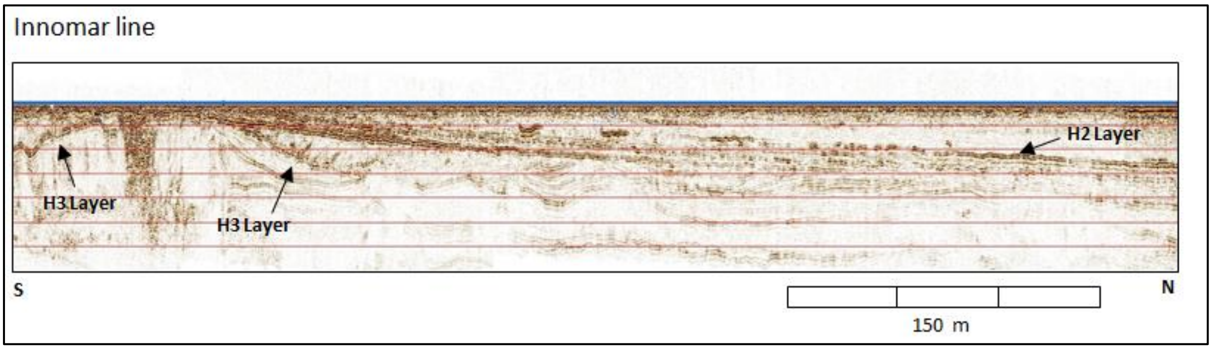


Figure 3-12: Data example Innomar SBP

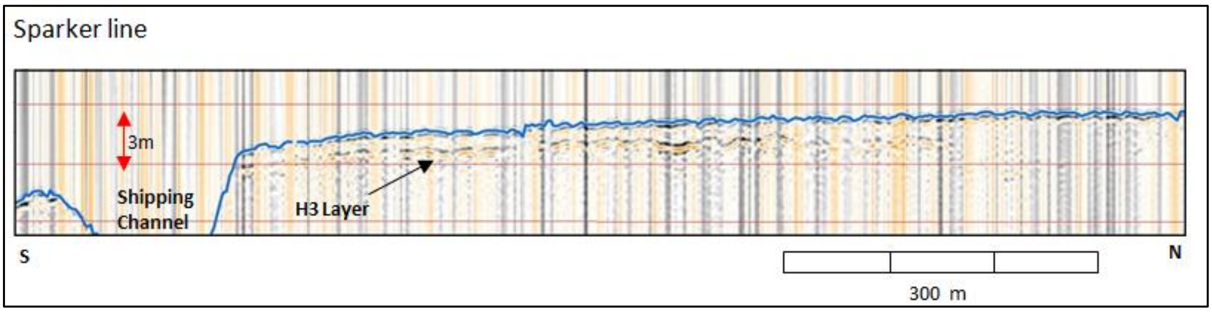


Figure 3-13: Data example Sparker SBP

The southern part shows discordant parallel reflectors in the sub-bottom data. One major reflector was interpreted to show the overall laying of the reflectors.

For the southern part of the survey area an additional seismic reflection survey was performed with a single channel sparker system. The first part of the proposed pipeline route is crossing one of the main shipping channels 'Maasgeul' to the port of Rotterdam. It is planned to perform a horizontal directional drilling (HDD) campaign to lay the pipeline through this channel. In order to properly map this area it was chosen to use a system which can penetrate deeper in the subsoil.

From the sparker data another isopach (H3) was created, which runs parallel to the isopach (H2) created from the clay layer. This isopach shows a layer of peat which starts around 2000 meter north of the shipping channel at a depth of 8 meters below seabed until it outcrops just at the northern edge of the channel. This is also seen in the borehole samples. Further noteworthy is a discontinuity in this layer, running from south-west to north-east through the survey area. The cause of this discontinuity is unknown.

In comparison to the Innomar system, the Sparker system has less vertical resolution. Therefore, the thin layering of the sand clay is not visible. On the other hand is the layer of peat rarely detectable in the Innomar data set due to the lower penetration depth.

Geohazards

For the interpretation of the geotechnical settings, geohazards play an important role. The term geohazards encompasses all those items observed in the seismic data that might pose a problem to the pipeline lay operations.

Buried objects can be classed as geohazard, which can be picked up by the sub-bottom profiler. They show up as hyperbola on the seismic records. The location (X, Y and Z below seabed) of detected buried contacts have been indicated and are presented in the listings. These objects might represent geohazards, such as boulders, however, due to the nature of the sub-bottom records no further identification is possible.

Palaeochannels and shallow gas are also common geohazards, but these were not detected in the sub-bottom data set.

3.8 Existing pipelines and infrastructure

One of the objectives of the main survey was to identify existing infrastructure of the Porthos pipeline route corridor (see paragraph 2.1). Two known pipelines and an umbilical as well as two subsea wells were detected. During this additional survey the 26 inch Taqa gas pipeline was detected again at the west side of the mid area. The results are presented in target listings and visible in the MAG geotiff (see figure *Figure 3-14*).

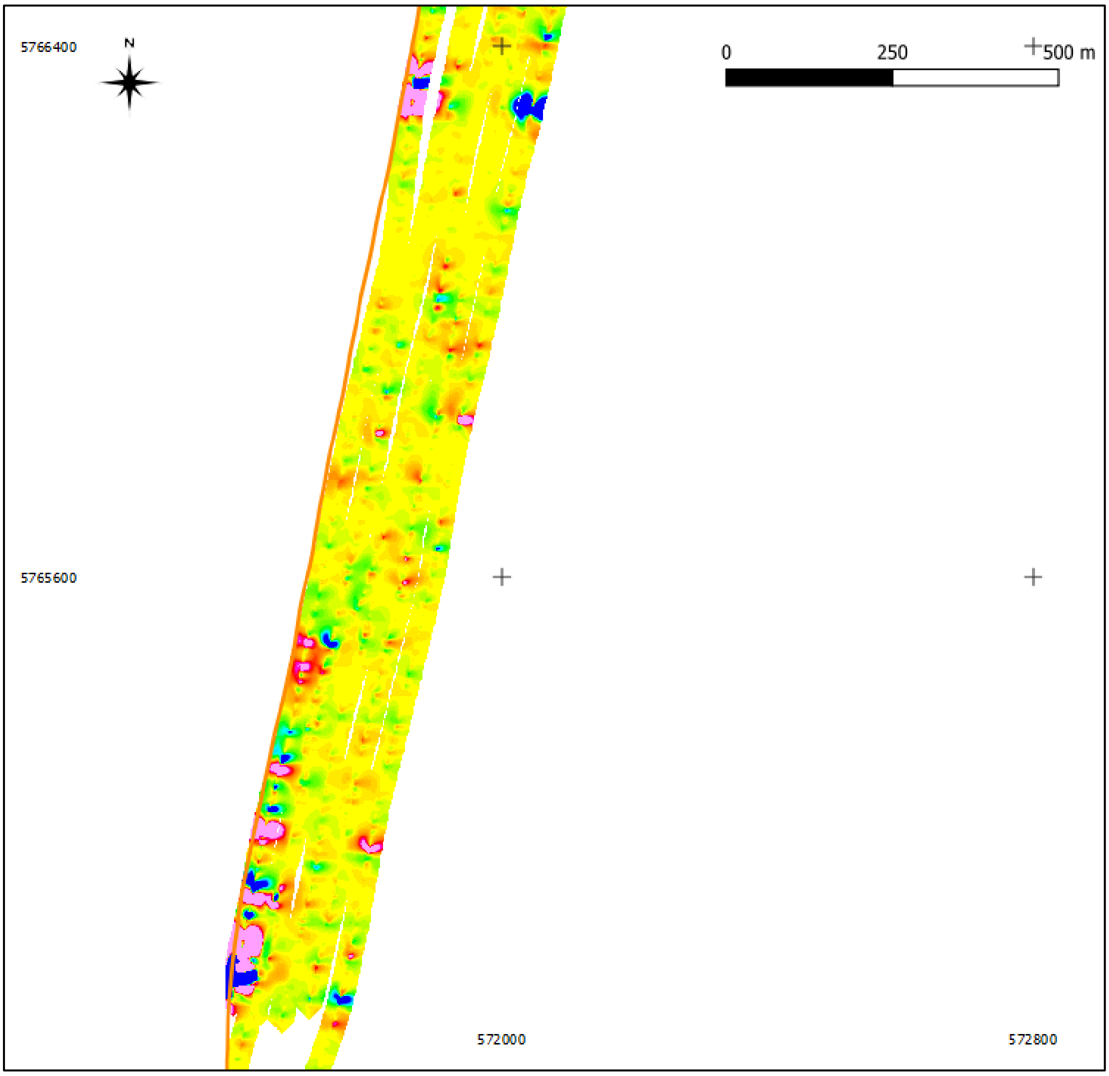


Figure 3-14: Taqa pipeline (orange line) in MAG data

4 OPERATIONAL METHODOLOGY

This chapter describes the methodology used during the survey. The technical procedures followed to ensure data quality and integrity are explained.

4.1 Preparation

Prior to the survey Deep BV has obtained all requirements to execute the survey. Routing and third party survey data was received well in advance to prepare the survey line planning. The vessel arrived pre-calibrated on site.

4.2 Health, safety and environment

The Party Chief had an overall responsibility for the survey activities, procedures and contact with the Client. All undertaken activities during the survey operations were described in daily reports, which were signed by the Party Chief and sent to the Client.

All personnel from Deep were committed to the HSE policy of the company. Additionally the role of the Party Chief was to inform the Client's Representative in case of any health, safety or environmental hazards as well as any near-miss.

4.3 List of personnel

To carry out the survey operations, the following personnel were involved in the fieldwork and processing phase of the project:

Name	Position	Phase
Joram Bootsma	Project Manager	preparations
Bernd monsma	Party Chief	preparations, mobilisation, survey
Sietse Bruinsma	Chief Hydrographic Surveyor	preparations, mobilisation, survey, processing
Jan Graven	Geophysicist	preparations, mobilisation, survey
Lasse Eriksen	Geophysicist	preparations, mobilisation, survey
Rob Morrow	Geophysicist	processing, reporting
Steven Pitka	Process Coordinator	processing, reporting
Robin D'haene	Hydrographic Surveyor	processing

Table 6 : List of personnel

4.4 Survey Vessel M.V. Seapal

M.V. Seapal performed the survey (MBES, SSS, MAG and SBP) in a 12 hours operation. The Seapal is a 20 meter long, dedicated offshore survey vessel operated by Deep BV. The vessel has hull mouted MBES transducers, a centre moon pool and a large A-frame on the aft deck for safe and easy deployment of towed equipment. The vessel is acoustically very quiet, leading to sub-bottom data with very low noise levels.

Figure 4-1 : Survey Vessel MV Seapal

An overview of survey equipment on board the Seapal is listed below.

Equipment description	**Equipment type**
Redundancy Primary DGPS receiver (Hor. <2cm, vert <5cm accuracy)	Septentrio AsteRx-U Marine GNSS receiver using 06-GPS (RTK via satellite) corrections.
Redundancy Primary DGPS receiver (Hor. <2cm, vert <5cm accuracy)	Septentrio AsteRx-U Marine GNSS receiver using 06-GPS (RTK via satellite) corrections.
Heading & motion reference units	1 x Ixblue Octans V
High Resolution Multibeam echosounder	Dual head R2sonic 2024
Parametric echosounder (sub-bottom profiler)	Innomar SES 2000 medium
Navigation / Survey data acquisition soft/hardware (full)	QPS QINSy Discover
Underwater positioning (USBL)	Sonardyne Mini Ranger
Sidescan sonar	Edgetech 4200 300kHz/600kHz
Magnetometer	Geometric G-882 caesium marine magnetometer
Sound Velocity Profilers	Reson Navitronics SVP-14/15 and Valeport miniSVS
Sufficient spare parts	Misc. Spares
Seismic reflection system	Geo-Spark 1000 Single Channel Sparker

Table 7 : List of equipment

4.5 Geodetic parameters

All geographical and projection co-ordinates are based on European Datum 1950 (ED50). Projection coordinates are expressed in Universal Transverse Mercator (UTM) grid, Zone 31, Northern Hemisphere.
GPS derived geographical coordinates were based on WGS84 datum using WGS84 - ED50 Common Offshore 1311 conversion. The used geodetic parameters are listed below:

Parameter	Value
Datum	ED50
Spheroid	Inrternational 1924
Semi-major axis	6378388.0000 m
Inverse flattening	297.000
Projection	UTM Zone 31N (North)
Latitude of Origin	0° N
Longitude of Origin	3° E (central meridian)
Scale factor at Origin	0.9996
X- Offset (false Easting)	500000.00m
Y- Offset (false Northing)	0.00m

Table 8: Geodetic parameters used during the survey.

All depths and heights are in meters relative to Lowest Astronomical Tide (LAT). Height reduction from ellipsoid height to LAT was done using the GEONZ97 Noordzee and LAT2006 model.

4.6 Schedule of key dates

Date	Comment
20 June 2020	Mobilisation
21 June 2020	Calibrations and start survey
22 June 2020	Changing SBP equipment
23 & 24 June 2020	Waiting on weather
25 June 2020	Technical problems
26 & 27 June 2020	Survey
28 June 2020	Technical problems
29 & 30 & 31 June 2020	Survey and demobilisation of personnel

Table 9: Key dates.

4.7 Mobilisation and demobilisation

The vessel arrived on the Porthos project site pre-calibrated from another project. A calibration verification of the MBES was performed first, whereupon the postion of the sidescan sonar data was checked against a seabed feature visible in the MBES data. All data coincides with the positions of the existing infrastructure on the seabed.

4.8 Execution of survey

This chapter describes the performance of the survey equipment during the execution of the survey. Survey operations on board MV Seapal took place in a 12 hour regime. Survey operations started on 21st June 2020 and were completed on 31st September 2020 (see Table 9).

4.8.1 Survey limitations

Survey limitations depended largely, but not exclusively, on wind, current, wave action, orientation of the survey lines and the amount of cable-out of the towed sensor. The limitation for the M.V. Seapal was a maximum wave height of approximately 1.5 metre (corresponding with a significant wave height of 1.2 metre).

4.8.2 Surface positioning system

Positioning of the vessel was primarily done by using a RTK GPS receiver using commercially available 06GPS RTK corrections received by 4G internet connection. The antenna of the system is placed in the vessel's mast, such that a free sight to the hemisphere is obtained. The RTK corrected GPS system is able to provide a high precision position solution in X, Y and Z, with accuracies better than 5 cm in all directions.
Should the 4G reception prove to be problematic a secondary GPS system was on stand-by, consisting of a DPGS receiver using MarineStar correction signals. MarineStar corrections are broadcasted via satellite, meaning reception will not be hampered by the distance from the shore. The accuracy of this system is better than 0.10 m in the horizontal and 0.15 m in the vertical plane. The survey software automatically switches to MarineStar when RTK is not available. In the case this happened extra care was taken that no discrepancies were present between RTK and MarineStar datasets.

4.8.3 USBL subsurface positioning system

The underwater positioning of the towed sensors was done using a USBL system. This comprises a vessel mounted transceiver communicating with a transponder mounted to the towed sensor. A pulse is send to the transponder via a connected wire, meaning the acoustic signal is one-way only. The time from the transmission of the initial acoustic pulse until the reply pulse is converted into a range. An array of transducers in the transceiver is used to calculate the angle to the subsea transponder. The position was calculated using the obtained range and bearing.

4.8.4 Heading and motion sensor

All vessel mounted sensors need to be compensated for the vessel's roll, pitch and heave motion. To achieve this, an Ixsea Octans MRU was used. The Octans MRU is an IMO grade fibre optic gyrocompass with an integrated motion sensor. In addition to the three solid-state fibre optic gyrocompass and accelerometers, the Octans MRU provides real-time heave data.
Besides providing real-time information on the vessel's motion, the Octans MRU also gives the vessel's heading. The survey software to continuously calculate all sensor positions uses the combined information of the vessel's roll, pitch, heave, heading together with equipment offsets. The motion and heading information is used for the multibeam and USBL system, while the roll and heave data is sent to the Innomar sub-bottom profiler.

4.8.5 Multibeam echosounder

All soundings were acquired using a R2Sonic dual head multibeam echosounder, mounted in the vessel's hull. A sound velocity profile (SVP) of the full water column was recorded prior to survey and when a change in sound velocity was noted. The SVP profiles were entered in the survey software (including the USBL top unit) to account for changes in subsea sound velocity. Constant sound velocity readings were taken by a small sound velocity probe mounted near the multibeam transducer. When these values deviate too much from the sound velocity profile the survey was stopped and a new profile was taken.

4.8.6 Sidescan sonar

For the detection of objects on the seafloor and seabed morphology, an Edgetech 4200 sidescan sonar system, operating at 300kHz and 600 kHz was employed. The system uses a sonar towfish that emits pulses down towards the seafloor across a wide angle, perpendicular to the path of the sensor through the water. The intensity of the acoustic reflections from the seafloor forms an image of the seabed. Objects on the seabed are identified by their high reflection and sharp edges, coupled to a shadow behind them. Besides locating objects, the sidescan sonar image also shows about the morphology, texture and features of the seabed.
The range was set to 75m (on either side of the towed fish). Sailing lines at 40 m offset achieved full coverage with sufficient overlap (300%) of the seabed. During survey operations, the towfish's height was kept below the maximum height above the seabed, at a maximum of 15% of the sonar range.

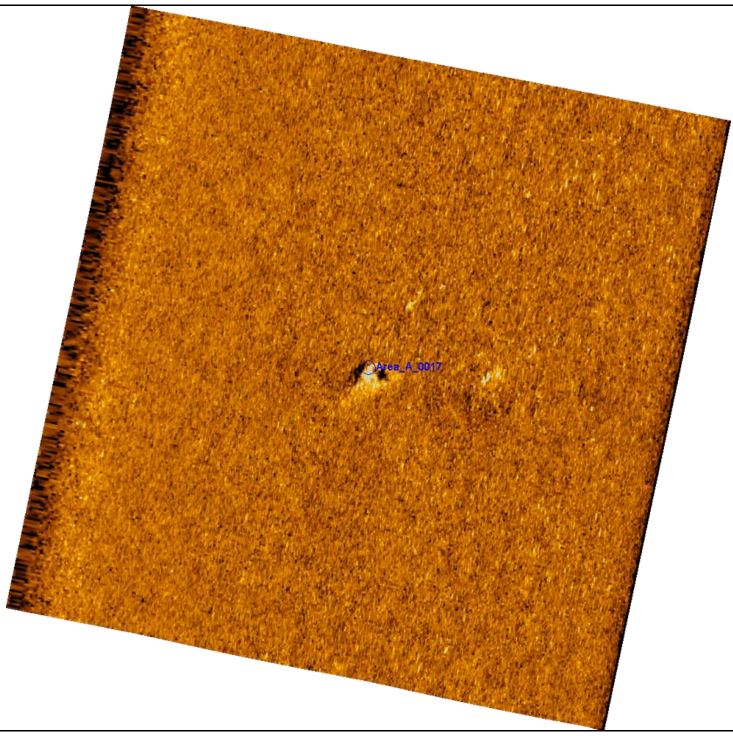


Figure 4-2: Sidescan sonar data showing a target.

4.8.7 Magnetometer

To detect the presence of ferromagnetic objects on and below the seabed a Geometric G-882 caesium vapour marine magnetometer was deployed. This sensor is a very sensitive marine grade magnetometer, capable of measuring the ambient magnetic field with a resolution of 0.1 nT. The presence of a ferromagnetic object will cause a (local) distortion of the magnetic field, which if large enough will be measured by the magnetometer. As the magnetometer measures the magnetic field around itself, the level of influence from a ferromagnetic object depends on its distance to the sensor and characteristics as size and orientation in the earth magnetic field. A large object will be detectable further away than a smaller object.

On the MV Seapal the magnetometer towfish was towed in a piggy-back configuration at a distance of approximately 12 meters behind the Edgetech sidescan sonar towfish. The magnetometer had a minimum distance to the vessel of 45m. Maximum height above seabed was 5 metre. The magnetometer data was presented online in a graph that shows the ambient magnetic field in nanoTesla (nT) untis.

4.8.8 Sub-bottom profiler

To map the shallow geology along the proposed cable route an Innomar Medium parametric sub-bottom profiler was used. The parametric system works by emitting two relatively high frequency acoustic waves. Interference between these two waves produces a resultant low frequency wave of 4, 5, 6, 8, 10, 12, or 15 kHz. Using this combination of two high frequency pulses allows the use of a low frequency signal with sub-bottom properties whilst maintaining a narrow beam, thus offering increased resolution in obtained data. The maximum penetration depth (i.e. detection range) is the result of signal interaction in both the water column and the top ground layers. Limiting factors are, amongst others, sediment type, degree of soil compaction, the presence of shallow gas in the sediment and turbidity of the water column.
The system was used at a frequency of 8 kHz as this gave the best combination of penetration and resolution.

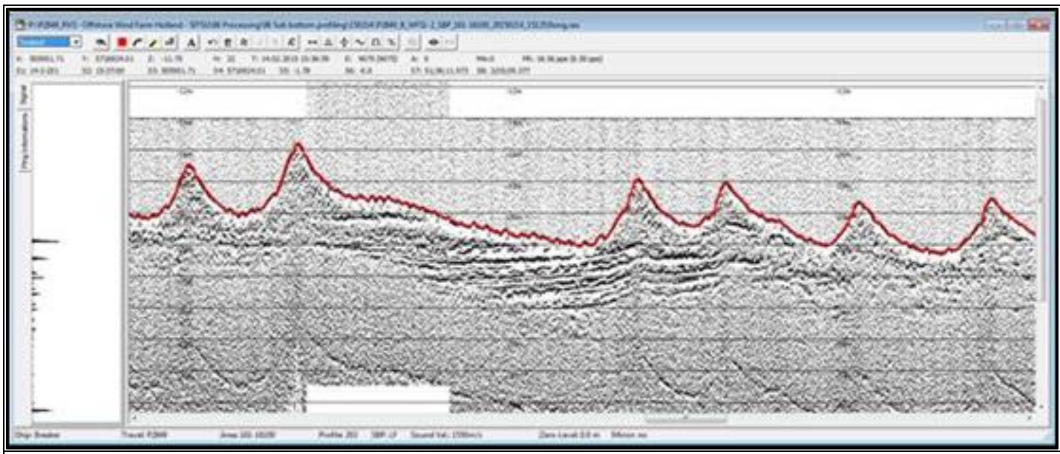


Figure 4-3 : Data from the Innomar system in sandy soils.

4.8.9 Single-channel sparker

In order to determine the shallow geology in the HDD area, a GeoMarine single channel sparker system was used. The sparker consists of two towed bodies. The LW200 source produces an acoustic signal by having 200 electrodes short a 6000 volt burst to the source frame. The resulting acoustic signal will reflect on clearly defined reflectors within the sub-soil, as well as on the seabed itself. These reflections are recorded by the streamer, which carries eight sensitive hydrophones. The sparker can be set to various energy levels, with higher levels producing bigger sub-soil penetration properties, at the cost of a reduced shot rate.

The sparker system was towed approximately 15 metres behind the survey vessel. The source was towed from the starboard aft bollard, while the streamer was towed from a pole extended over the starboard side. This arrangement kept the source and streamer away from the vessel's wake. By having both in still waters the signal-to-noise ratio is improved. Positioning of the sparker system was done by using a layback calculation in the QPS QINSy recording software.

Prior to starting the survey a number of test lines were sailed to determine the optimum geometry (source vs. streamer) and to test various power settings. The outcome of these test lines determined the settings used during the survey. The survey was initially performed at 300 Joule, shooting at 500ms.

4.9 Quality control during survey

During survey operations, online QC took place. This included monitoring status and/or quality indicators of the individual systems. Where possible automated alerts were used when a status- or quality indicator of one of the sensors was out of the specified range. The specific alerts for all survey systems were as follows:

- Multibeam echosounder:
  - Monitoring of data coverage;
  - Monitoring of hitcount;
  - Monitoring of 95% confidence level;
  - Monitoring of overlapping data between adjacent survey lines;
  - Continuous monitoring of sound velocity near the MBES transducer head with mini SVP profiler.

- Sidescan sonar:
  - Monitoring of data coverage;
  - Monitoring of height of fish above seabed;
  - Monitoring of overlapping data between adjacent survey lines.

- Magnetometer:
  - The magnetometer was presented online in a graph that shows the ambient magnetic field in nT;
  - Visual inspection of the presence of noise;
  - Monitoring of height of fish above seabed;
  - Monitoring the high quality value of the magnetometer;
  - Monitoring the distance to the vessel to avoid influence of the ship.

- Sub-bottom profiler / single-channel seismic:
  - Online QC of the parametric echosounder survey was achieved by continuously monitoring the online data. The Signal to Noise ratio (SNR) is of importance here, as this is directly related to the quality of the recorded data. The SNR was monitored online in two ways:
    - Monitoring of the amount of noise present in the water column;
    - Monitoring of the wiggle window, which shows the intensity of the returned signal. An increase of noise in the data will show itself by the wiggle having a more irregular shape and more erratic movements, as opposed to a smooth shape and movement when the SNR is good.

During the survey operations, offline QC was carried out to check the recorded data for inconsistencies that might have been missed during online acquisition. This included checking if the data quality and results were according to project specifications. When data quality or results were not meeting project specifications, additional survey lines were sailed.

5 DATA PROCESSING

In this chapter, the processing of the recorded survey data is described. It discusses the procedures carried out to check the quality of the acquired data, as well as the steps taken to obtain the final product.

5.1 Bathymetric data

An overview of the MBES processing flow is provided in Figure 5.1 below.

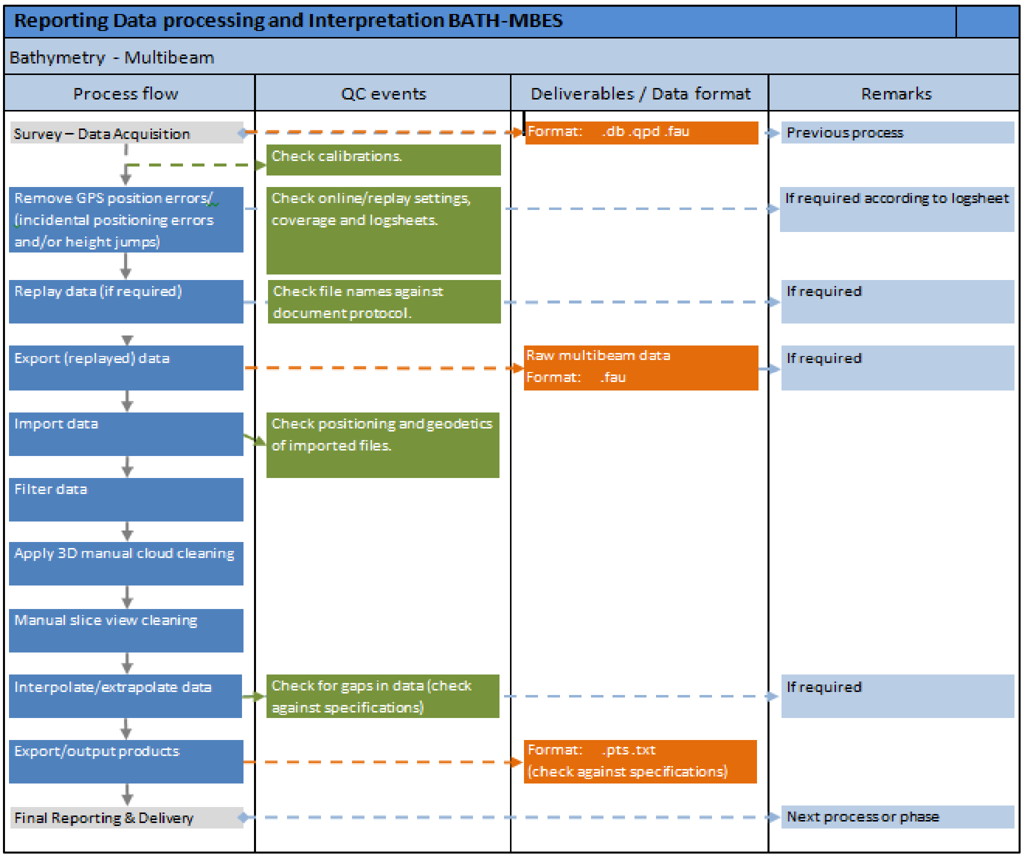


Figure 5-1 : MBES processing flowchart.

The MBES data from the R2Sonic was recorded in QINSy 8.10 as DB and FAU files. Errors related to height level (tidal or GPS) or sound velocity were checked during and directly after acquisition on board to be able to re-run a survey line when needed. Partly on board and back in the office, the MBES data was checked for positioning errors and beam spikes using BeamWorX AutoClean editing software. Outliers in the data, often referred to as 'spikes', could be adequately removed using the filtering techniques available. The overall bathymetric data quality and consistency was good (see paragraph 3.3) which is shown by the results of the various performed tests and regular checks.
The overlapping survey lines were checked for relative height differences and were shifted when needed. No significant errors were found.
When all checks were completed, two gridded Digital Terrain Models (DTM) were created with a 1x1 m grid cell size.

5.2 Sidescan sonar data

The sidescan sonar data was digitally recorded in Discover acquisition software as both XTF and JSF files. All sidescan sonar data was processed with SonarWiz 7.04.01 processing software.
Initially, data QC was performed to check for positioning errors, coverage and overall data quality. Subsequently, a multibeam geotiff image was used to check the geodetic settings / positioning of the files.

The next processing step is bottom tracking, using the SonarWiz bottom track module. All files were automatically tracked with the same settings. When needed, different auto tracking settings were applied. If the later proved unsatisfactory (for instance due to shoals of fish or undulating seabed), the bottom track was manually picked.
An overview of the sidescan sonar processing flow is shown in *Figure 5-2*.

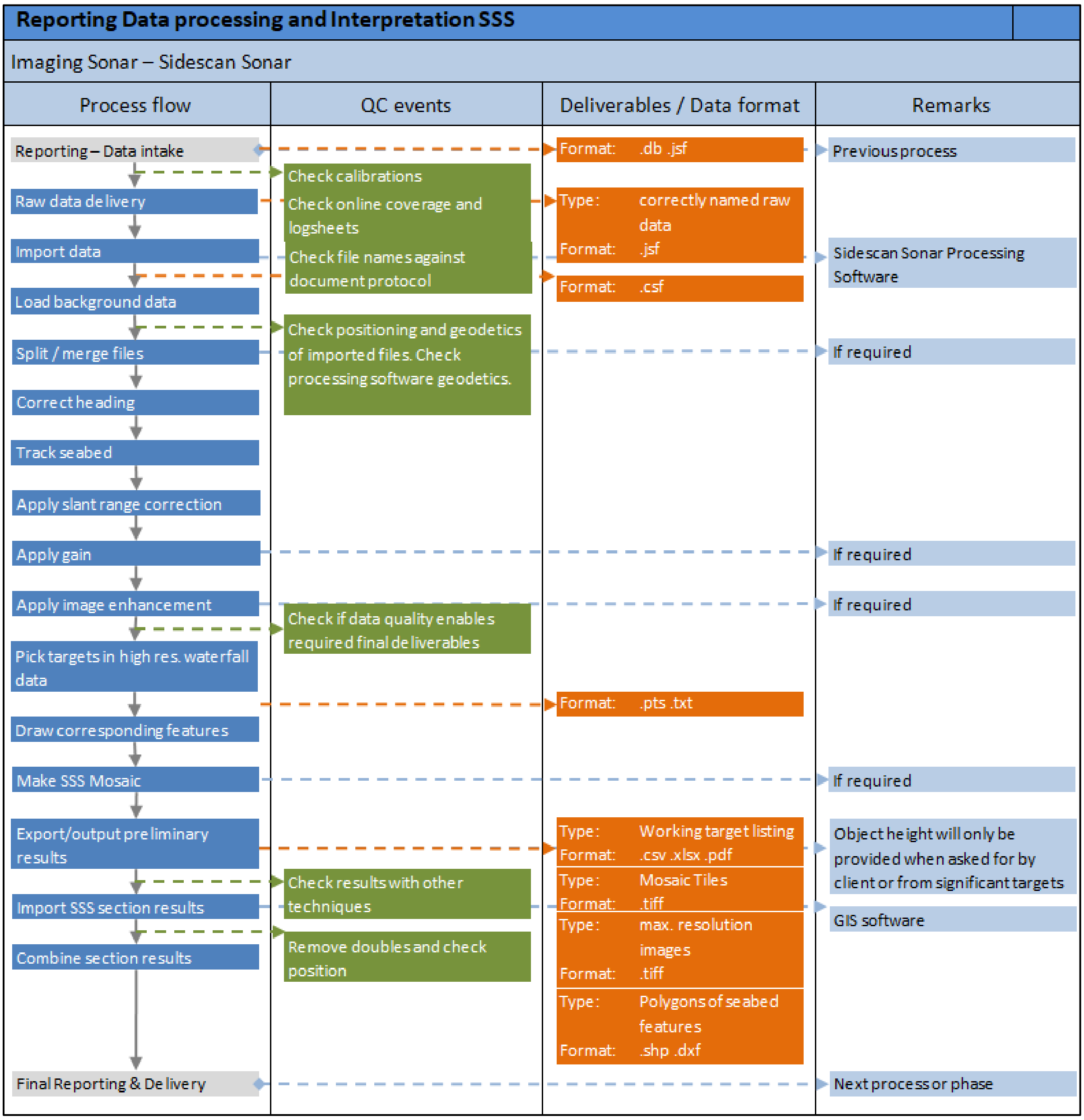


Figure 5-2: SSS processing flowchart.

Target detection on the sidescan data files was done by using the raw SSS waterfall data for optimal resolution. Except for the applying a gain normalisation filter, the imagery hardly required any pre-processing before contact picking could commence. All significant features, which measured more than 0.5x0.5x0.5 metres (man–made or natural) were picked. In addition, when target density in an area did not allow an individual identification of the targets these were clustered to one “multiple targets” object.
The position of each target was checked against the multibeam gridded data and overlapping SSS files. For targets seen in multiple lines, the file with the best positioning and target image resolution was used. Positioning accuracy of approx. 3m was achieved between the sidescan and multibeam data. Contacts seen in reciprocal sidescan lines had maximum offset of 5–7 m.

Eventually, a sidescan mosaic, using part of the data files, was generated to obtain an overview of the survey area for seabed features and surface geology. In order to generate a mosaic with comparable signal reflection for all files, the sonar files underwent image enhancement using an empirical gain normalization filter. Nadir transparency and ordering of the files was also applied. It has to be noted that the files containing the sidescan contacts were not necessarily used for the mosaic created, thus occasional position mismatches between the mosaic and target images may be present.

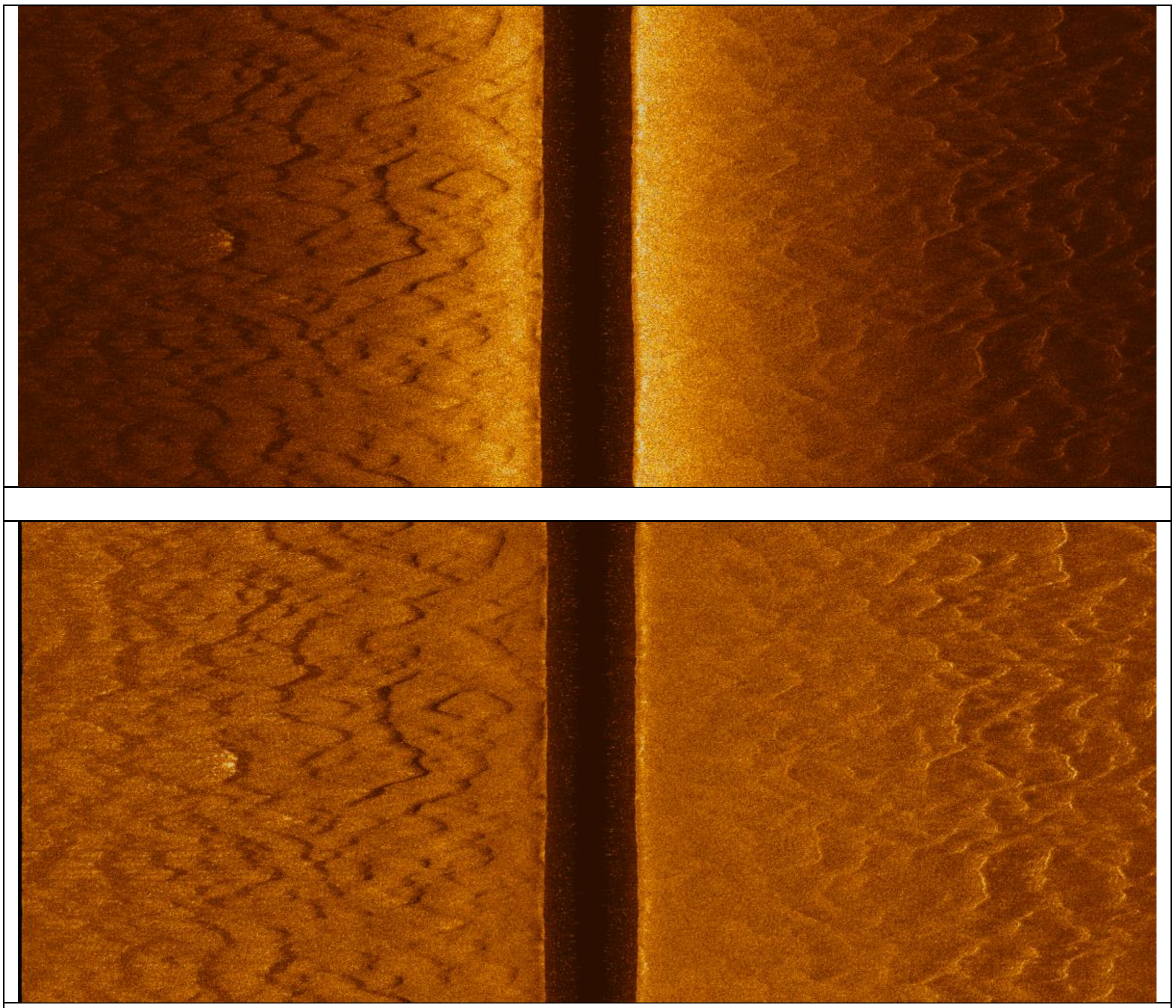


Figure 5-3: Sidescan sonar imagery before (top) and after (bottom) normalisation.

5.3 Magnetometer

An overview of the magnetometer processing workflow is presented in the figure below.

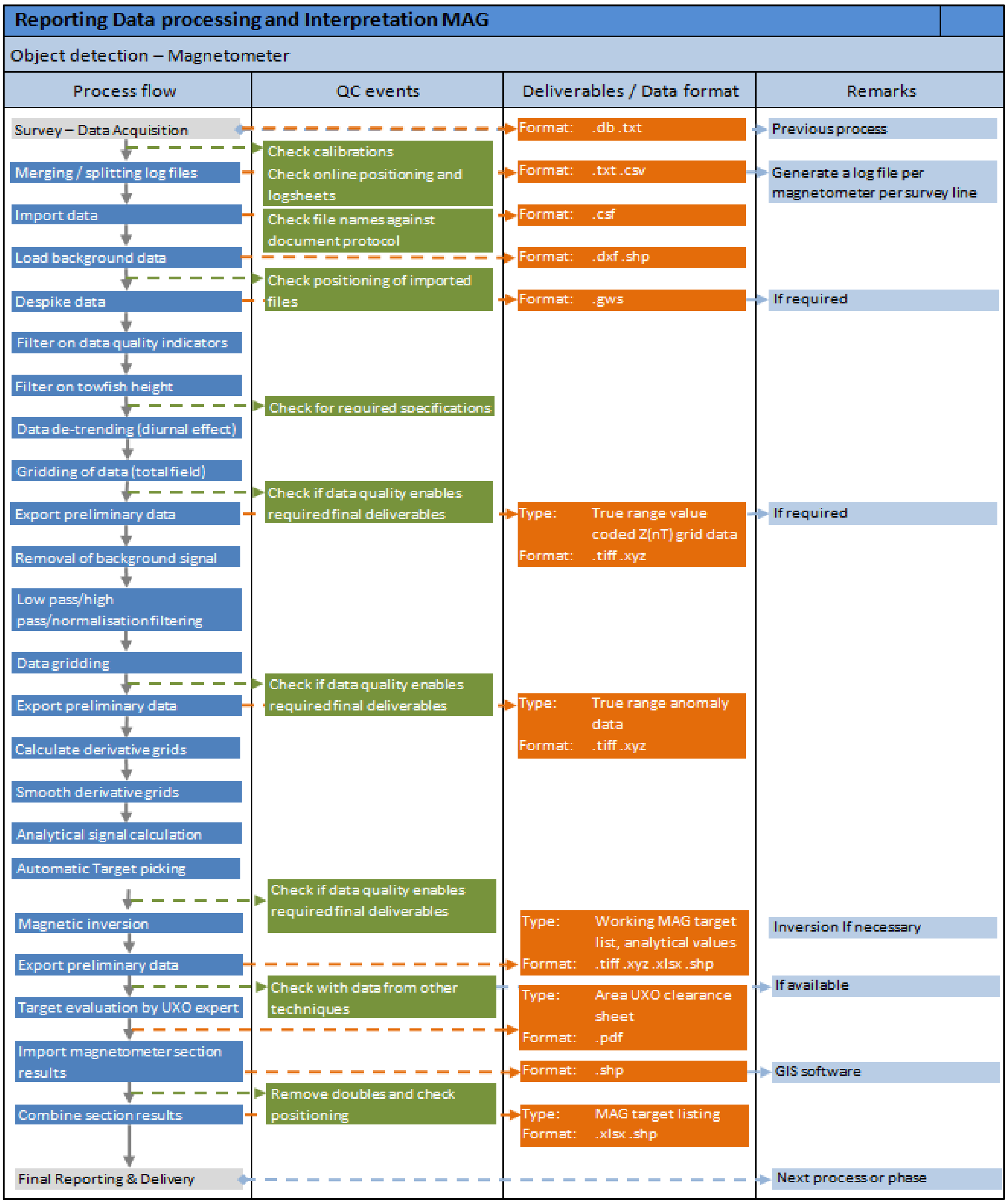


Figure 5-4: MAG processing flowchart.

Magnetometer data was recorded digitally in QINSy survey software. During survey, the magnetometer data was also logged in dedicated ASCII logfiles. These ASCII files contained all relevant data fields necessary for the magnetometer processing. The magnetometer was setup as a layback system, towed behind the sidescan sonar towfish that was positioned via the USBL system. The set layback was applied in QINSy and the calculated position exported in the ASCII file. The layback for the magnetometer was approximately 12 m from the USBL position of the sidescan sonar. Altimeter and depth sensors on the magnetometer had specific values for scale factor and bias.

Magnetometer scale and bias values were applied online in QINSy.

Merged raw Ascii data were imported in Oasis 9.3 processing software, where the track lines were initially inspected for positioning errors. Minor positioning errors were corrected while larger spikes or lines that show larger gaps were rejected and resurveyed.
Subsequently data with absolute sensor quality values less than 300 were also rejected. The sensor quality value is a variable that indicates how well the internal counter measures the magnetic field
Thereafter, raw magnetic reading spikes were removed and verification of sensor altitude over seabed took place. Since the scope of the survey is to detect large ferromagnetic objects (approximately 700kg), a maximum altitude of around 5m above seabed was accepted. Data obtained at altitudes over 5m above seabed was removed.
For coverage check, lines with altitude above 5m running over 20m along track were rejected and rerun. Moreover, track lines offset more than 20% of survey line spacing (40m) were also rerun to ensure sufficient detection.
After these QC steps, the data set was de-trended by removing the background values (i.e. the earth magnetic field). This was achieved by obtaining a value for background noise by nonlinear filtering and the subsequent generation of a residual magnetic field. This residual signal is generated by subtracting the background values from the original total field readings. Further control of filter settings was performed to avoid errors such as edge effects resulting in false anomalies and masking of real anomalies.

An example of data quality control and processing is shown in figure below.

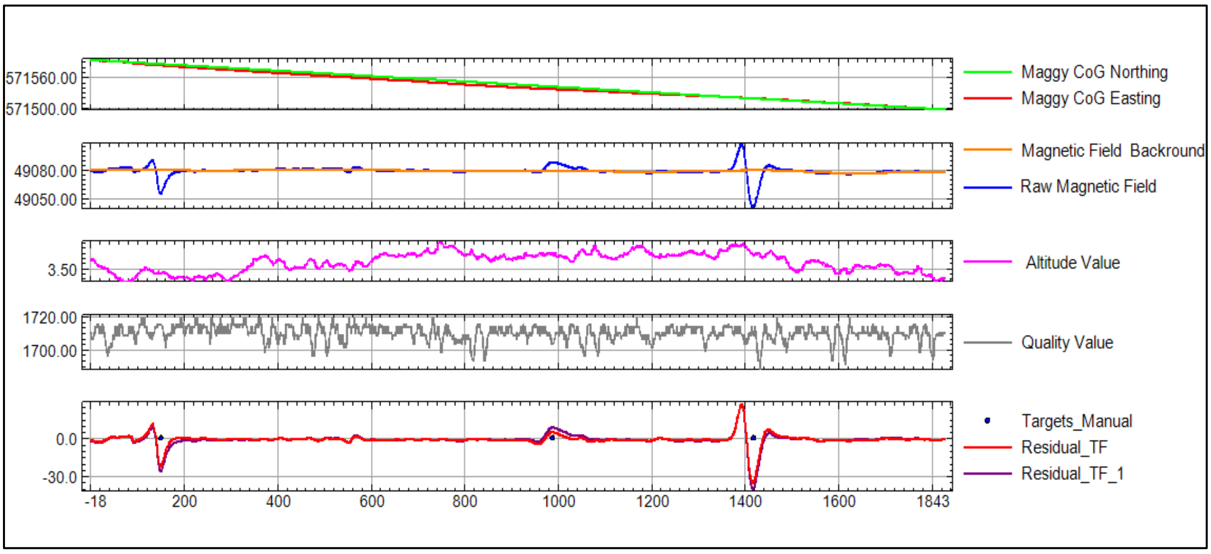


Figure 5-5: Example of profile view during QC and processing of magnetometer data.

Following the processing steps, the residual magnetic field was gridded using minimum curvature interpolation method in 1m cell size and maximum blanking distance of 25m. The generated grid was inspected for errors and the shape of magnetic anomalies is checked for consistency.

All processed lines are carefully checked for magnetic anomalies larger than -2.5 nT and +2.5 nT values (5nT peak to peak). Target picking was performed manually from the data profile view in conjunction with the residual total field gridded data. It should be noted that due to wide survey line spacing, ferromagnetic objects that cause the anomalies can be actually located at an (considerable) offset to the survey track line position where detected.

Besides ferromagnetic objects, linear group anomalies like pipelines that are present in the survey area were identified in the magnetometer data. All magnetic anomalies were cross-referenced with the sidescan sonar and multibeam data. Magnetometer contacts are presented in listings showing their characteristic attributes.

5.4 Sub-bottom profiler data

An overview of the Innomar SBP data processing flow is provided in figure below. The SBP survey data files were recorded in the Innomar SESWIN software. Two types of data file are recorded, SES files and RAW files. In most cases the SES files will give a better quality image and are therefore the files used during processing of the shallow geology, however for target detection the RAW files give a better image. The SES files and RAW files are imported individually into the ISE processing software. Heave corrections from the MRU are applied to the data to counter the effect of waves on the sub-bottom profiles. The principle of any sub-bottom profiler is based on the two way travel time of a returned acoustic pulse. To convert this to a depth in meters a sound velocity must be chosen. Based on previous experiences an assumed velocity through the sediments of 1600 m/s was entered into the acquisition software. QC consists of checking the data for positioning errors, though none were found in the data files.

Figure 5-6: SBP processing flowchart.

Shallow geology

The envelop data was used to interpret significant coherent seismic reflectors. The *SES* files were loaded into the GIS-viewer. Lines that were split during the acquisition phase, to avoid excessive file size, were merged together. Subsequently the seismographs are opened and the seabed is traced.

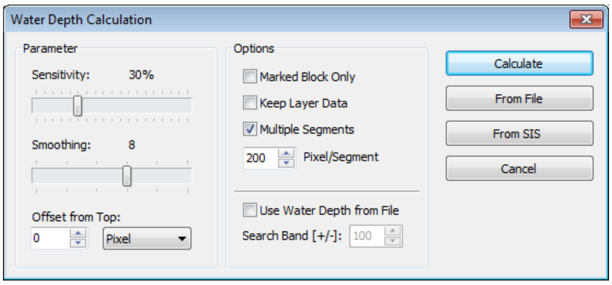


Figure 5-7: Water depth calculation module in ISE2.

Seabed tracing is done automatically by searching the profile for the first strong reflector. After the automatic detection the profiles are checked manually for any mis-interpretation. Figure 5-8 shows an example of a SBP profile before and after manual seabed correction.

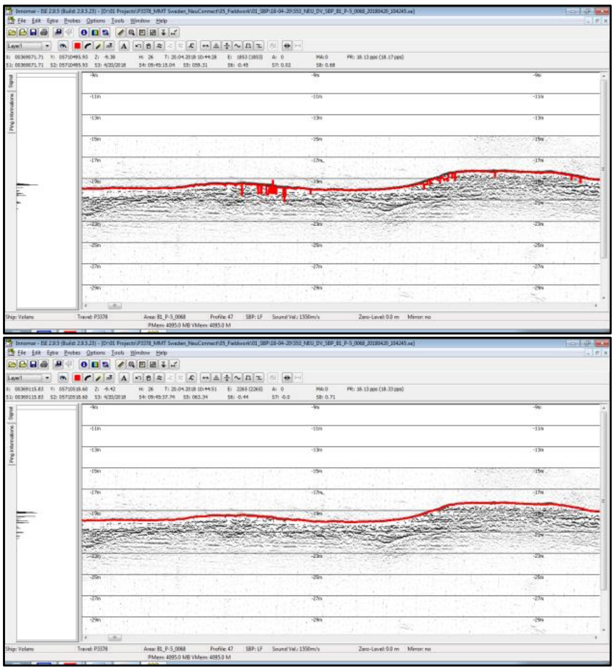


Figure 5-8: Example SBP data before (top) and after (bottom) manual seabed correction.

Geological horizons can be detected by their reflective properties. Significant, coherent, seismo-stratigraphic (geological) horizons visible in the SBP data were manually indicated. The indicated horizons are exported as *TXT* files with position in easting and northing and their depth below seabed. This allows the files to be placed below the multibeam derived bathymetry, thereby reducing the data to LAT.

Target detection

The full wave (*RAW*) files were loaded into the ISE2 software. Background information (pipelines, umbilical, etc.) was loaded into the GIS-view of ISE2 to allow for checks on the geodetic settings / positioning of the files. Additionally this provides a possibility to couple anomalies to know cable/pipeline crossings.

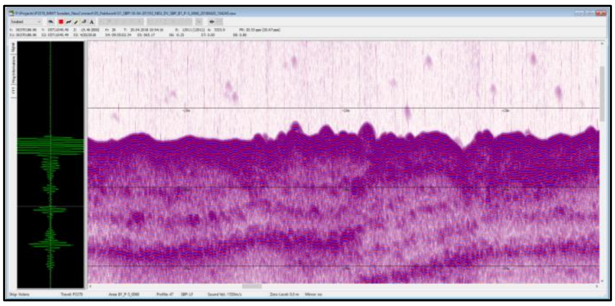


Figure 5-9: Example file of full wave SBP-data.

Observed anomalies were marked with use of the ISE2 Target Picker. Targets in form of a hyperbola were picked manually, as well as the seabed directly above the target. Sub-bottom contacts were listed in the target databases including;

- geo-referenced XY position;
- image (snap shot);
- anomaly depth;
- database file number.

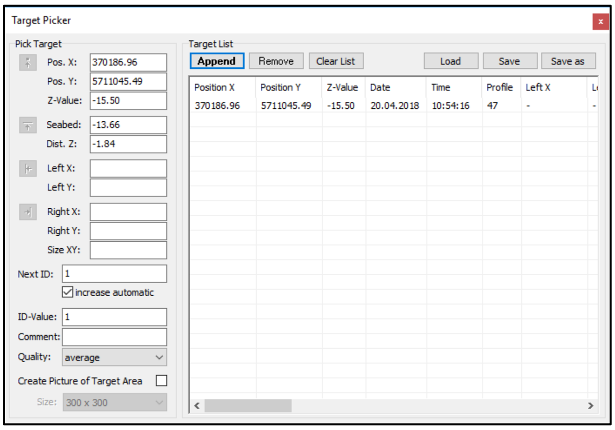


Figure 5-10: ISE2 SBP target picker.

5.5 Single-channel sparker data

The data processing was done using GeoSuite AllWorks processing software. This software is capable of processing the recorded seismic data (in *.sgy* format), and is specifically designed for use with the GeoMarine sparker systems.

The raw recorded data files normally show little or no usable information. While online filtering is applied to check the data quality during the survey, these filter steps are not included in the recorded data in order to keep the complete raw signal. Prior to interpretation the *.sgy* files were loaded in the processing software. A map overview was used to detect any positioning errors, but none were present. A number of filtering steps was used on the data to give the best results. These consist of a debias filter, bandwidth filter (200-3500) and linear or time varied gain (number decided per file). This can be seen in the two top images of *Figure 5-11*.

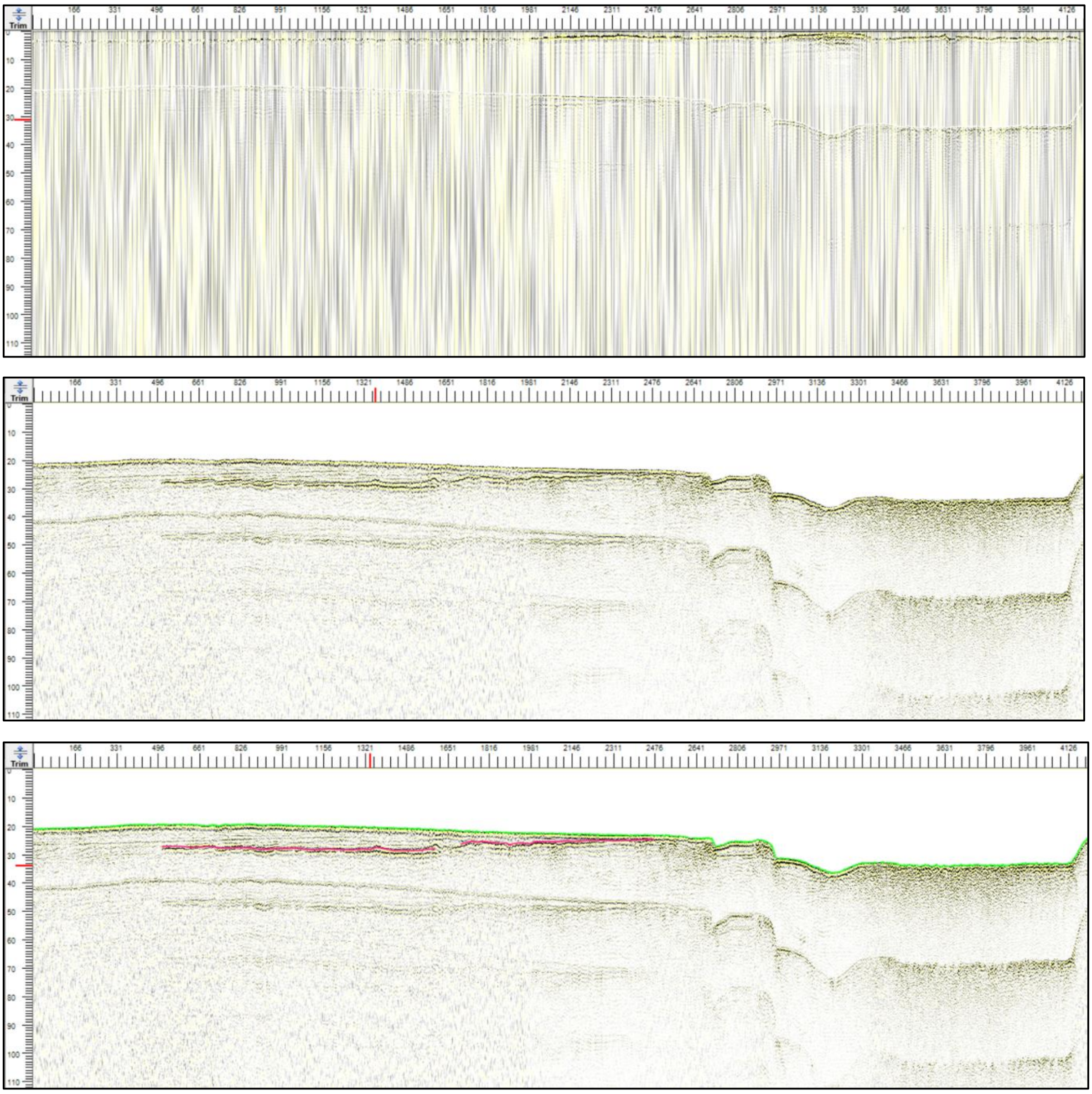


Figure 5-11: Processing steps on the sparker data.

Data interpretation (i.e. reflector picking) started with marking the seabed, followed by marking the multiple reflector to ease reflector interpretation, as shown in the third image of Figure 5-11. A recognisable reflector was picked, compared to geotechnical data and exported in an X, Y, Z format. To convert from Two Way Travel Time (TWTT) to depth the sound velocity through the sediments must be used. As this is not known an assumption of 1600 m/s was used. By subtracting the seabed’s depth from the reflector depth the data converted into X, Y, Thickness format.

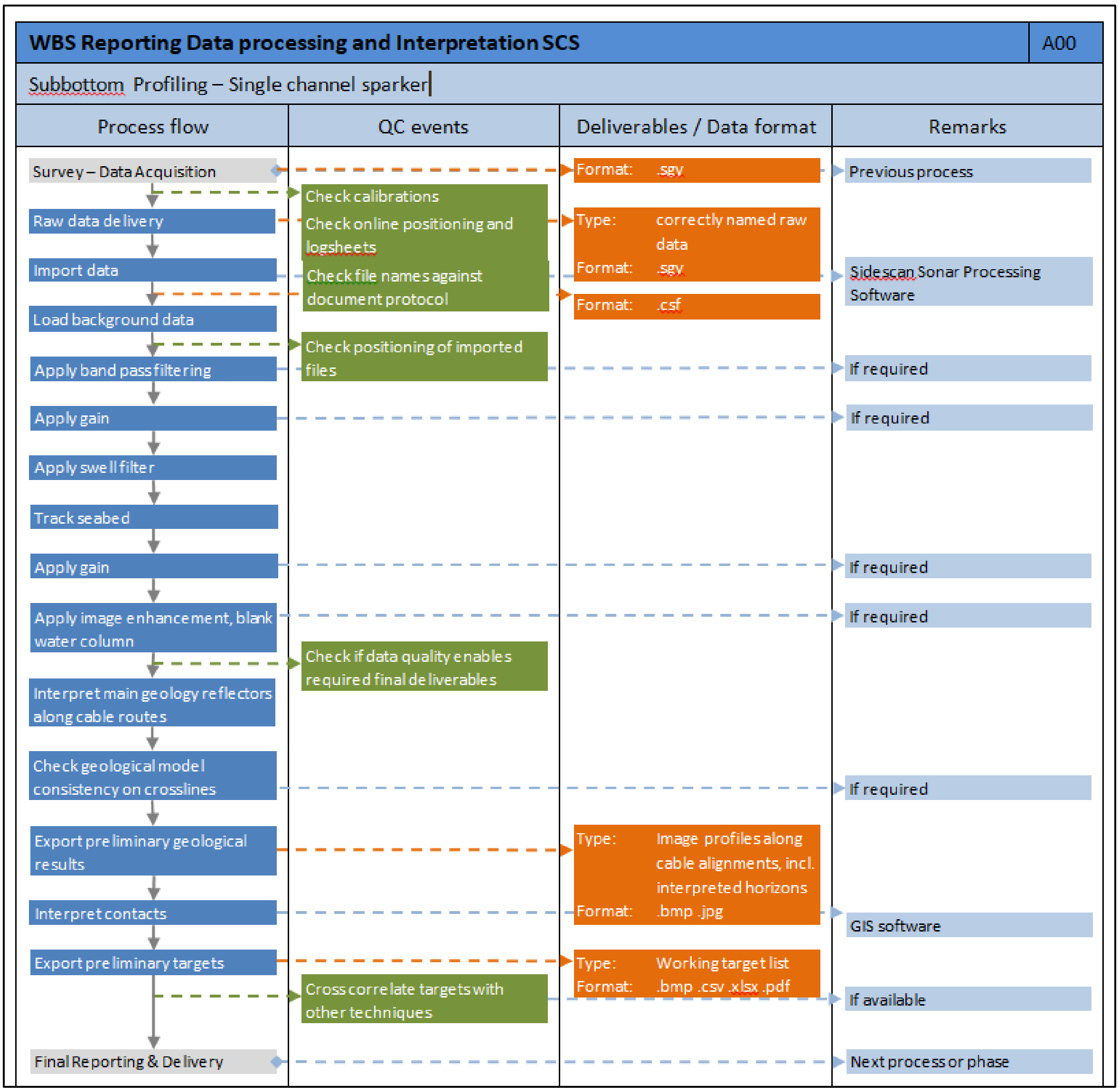


Figure 5-12: SCS processing flowchart.

APPENDICES

APPENDIX A – DAILY PROGRESS REPORTS AND TOOLBOX MEETINGS

FIELD OPERATIONS

LOGSHEET - DAILY PROGRESS REPORT OFFSHORE

DEEP BV
Johan van Hasseltweg 39D
1021 KN Amsterdam
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deep Hydrography & Geophysics

PROJECT No:	P3711	**SURVEYOR:**	JGA/LER/BMO
CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Ijmuiden	**PAGE:**	1 of 2
DATE:	20-05-2020		

Daily checks	
Findings of workplace risk assessment (HSE § 4.1):	*Ok*
Results height check (waterline or benchmark):	*n/a*
Averaged sound velocity:	*n/a*
Results absolute depth check on known object:	*n/a*
Results overlap old survey data:	*n/a*

Time	Event	Survey area
7:30	*On board Deep Seapal*	
	Mobilisation Sparker system	
	Installed USBL / Innomar transducers	
	Side scan sonar and Magnetometer installed.	
	Interfacing Innomar	
	Interfacing Sparker with Qinsy setup	
19:30	*End of day*	
	Statistics on page 2	

Checked (Deep BV):	BMO	20-05-2020	**Approved (client):**	{SIGNATURE}	{Date}

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PROJECT No:	P3711	**SURVEYOR:**	JGA/LER/BMO
CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Ijmuiden	**PAGE:**	2 of 2
DATE:	20-05-2020		

Weather conditions		Today's progress	Project progress	Progress accepted
Wind	*1/2 Bft VAR*	*Mobilisation ongoing*		
Sea state	0.2m Hs	*Sparker system installed*		
Visibility	Good	*MBES installed and inter-*		
Weather forecast 24 hours		*faced*		
Wind	*2 Bft SE*			
Sea state	*0.2m Hs*			
Visibility	*Good*			

Total survey line km	Accepted		Rejected	
	km	%	km	%
Brought forward				
Completed today				
Total				

Hours	Mob/ Demob	Calibrations Test	Transit	Survey	Other	WoW	Downtime		
							Equip.	Vessel	Other
Brought forward									
Today									
Total									

Consumption	Fuel	Lubes	Water
Brought forward			
Used today			
Total remaining			

Comments client

Comments Deep BV

Checked (Deep BV):	BMO	20-05-2020	**Approved (client):**	{SIGNATURE}	{Date}

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PROJECT No:	P3711	**SURVEYOR:**	JGA/LER/BMO
CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Hoek van Holland	**PAGE:**	1 of 2
DATE:	21-05-2020		

Daily checks	
Findings of workplace risk assessment (HSE § 4.1):	*Ok*
Results height check (waterline or benchmark):	*n/a*
Averaged sound velocity:	*1494.44 m/s*
Results absolute depth check on known object:	*n/a*
Results overlap old survey data:	*n/a*

Time	Event	Survey area
7:00	*On board Deep Seapal*	
	Transit towards survey area	
	Startup survey setup	
	Arrived at MB check location.	
8:45	*Sound velocity profile measured; AVG 1494.44 = m/s*	
8:50	*Start sailing check lines on known object*	
9:30	*Finished surveying object*	
	Transit to Area A to start Sparker operations	
10:10	*SVP measurement taken; AVG 1494.1 m/s*	
	Toolbox talk prior to deployment Sparker equipment	
10:20	*Deployed Sparker - setting up sparker.*	
11:30	*Start Sparker survey ops area A*	
16:00	*Dredger dredging in the South of Area A.*	
20:45	*Finished sparker operations Area A*	
	Recovering equipment	
21:00	*SVP profile southern area area A*	
	Transit to Scheveningen	
	Data backup	
21:45	*Moored alongside quay Scheveningen*	
	Travel to hotel	
22:00	*End of day*	
	Statistics on page 2	

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CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Hoek van Holland	**PAGE:**	2 of 2
DATE:	21-05-2020		

Weather conditions		Today's progress	Project progress	Progress accepted
Wind	*2 Bft SE*	*Completed Area A Sparker*		
Sea state	*0.2m Hs*			
Visibility	*Good*			
Weather forecast 24 hours				
Wind	*4-7 Bft SSW*			
Sea state	*0.5-1.2m Hs*			
Visibility	*Good*			

Total survey line km	Accepted		Rejected	
	km	%	km	%
Brought forward				
Completed today				
Total				

Hours	Mob/ Demob	Calibrations Test	Transit	Survey	Other	WoW	Downtime Equip.	Downtime Vessel	Downtime Other
Brought forward									
Today									
Total									

Consumption	Fuel	Lubes	Water
Brought forward			
Used today			
Total remaining			

Comments client

Comments Deep BV

Checked (Deep BV): BMO 21-05-2020 **Approved (client):** {SIGNATURE} {Date}

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CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Hoek van Holland	**PAGE:**	1 of 2
DATE:	22-05-2020		

Daily checks	
Findings of workplace risk assessment (HSE § 4.1):	*Ok*
Results height check (waterline or benchmark):	*n/a*
Averaged sound velocity:	*1494.44 m/s*
Results absolute depth check on known object:	*n/a*
Results overlap old survey data:	*n/a*

Time	Event	Survey area
7:00	*On board Deep Seapal*	
	Demobilising Sparker equipment	
8:30	*Interfacing and setting up USBLSBP / SSS / MAG*	
	Mobilisation ongoing	
	Interfaced USBL setup	
	Tested beacons USBL	
	Interfaced SSS + Rubtest	
19:00	*End of day*	
	Statistics on page 2	

Checked (Deep BV):	BMO	22-05-2020	**Approved (client):**	{SIGNATURE}	{Date}

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CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Hoek van Holland	**PAGE:**	2 of 2
DATE:	22-05-2020		

Weather conditions		Today's progress	Project progress	Progress accepted
Wind	*4-7 Bft SSW*			
Sea state	*0.5-1.2m Hs*			
Visibility	*Good*			
Weather forecast 24 hours				
Wind	*5-7 Bft WSW*			
Sea state	*1.1-1.5m Hs*			
Visibility	*Good*			

Total survey line km	Accepted		Rejected	
	km	%	km	%
Brought forward				
Completed today				
Total				

Hours	Mob/ Demob	Calibrations Test	Transit	Survey	Other	WoW	Downtime Equip.	Vessel	Other
Brought forward									
Today									
Total									

Consumption	Fuel	Lubes	Water
Brought forward			
Used today			
Total remaining			

Comments client

Comments Deep BV

Checked (Deep BV):	BMO	22-05-2020	Approved (client):	{SIGNATURE}	{Date}

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CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Scheveningen	**PAGE:**	1 of 2
DATE:	23-05-2020		

Daily checks	
Findings of workplace risk assessment (HSE § 4.1):	*Ok*
Results height check (waterline or benchmark):	*n/a*
Averaged sound velocity:	*n/a*
Results absolute depth check on known object:	*n/a*
Results overlap old survey data:	*n/a*

Time	Event	Survey area
7:00	*On board Deep Seapal; Waiting on weather*	
	Continue interfacing survey setup	
14:00	*Relocating to bunker fresh water.*	
	Installing extra screens survey/	
	Sailed a testline with SBP	
	Project administration	
	General maintenance and housekeeping	
19:00	*End of day*	
	Statistics on page 2	

Checked (Deep BV):	BMO	23-05-2020	**Approved (client):**	{SIGNATURE}	{Date}

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CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Scheveningen	**PAGE:**	2 of 2
DATE:	23-05-2020		

Weather conditions		Today's progress	Project progress	Progress accepted
Wind	*5-7 Bft WSW*			
Sea state	*1.1-1.5m Hs*			
Visibility	*Good*			
Weather forecast 24 hours				
Wind	*5-7 Bft WSW*			
Sea state	*1.1-1.4m Hs*			
Visibility	*Good*			

Total survey line km	Accepted		Rejected	
	km	%	km	%
Brought forward				
Completed today				
Total				

Hours	Mob/ Demob	Calibrations Test	Transit	Survey	Other	WoW	Downtime Equip.	Downtime Vessel	Downtime Other
Brought forward									
Today									
Total									

Consumption	Fuel	Lubes	Water
Brought forward			
Used today			
Total remaining			

Comments client

Comments Deep BV

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PROJECT No:	P3711	**SURVEYOR:**	SPA/LER/BMO
CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Scheveningen	**PAGE:**	1 of 2
DATE:	24-05-2020		

Daily checks	
Findings of workplace risk assessment (HSE § 4.1):	*Ok*
Results height check (waterline or benchmark):	*n/a*
Averaged sound velocity:	*n/a*
Results absolute depth check on known object:	*n/a*
Results overlap old survey data:	*n/a*

Time	Event	Survey area
7:00	*On board Deep Seapal*	
	Waiting on weather	
19:00	*End of day*	
	Statistics on page 2	

Checked (Deep BV):	BMO	24-05-2020	**Approved (client):**	{SIGNATURE}	{Date}

VERSION: 121218
DOCUMENT: P3711_200524_Deep_Seapal_DPR.xlsx

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CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Scheveningen	**PAGE:**	2 of 2
DATE:	24-05-2020		

Weather conditions		Today's progress	Project progress	Progress accepted
Wind	*5-7 Bft WSW*			
Sea state	*1.1-1.4m Hs*			
Visibility	*Good*			
Weather forecast 24 hours				
Wind	*3 Bft NW*			
Sea state	*0.6m Hs*			
Visibility	*Good*			

Total survey line km	Accepted		Rejected	
	km	%	km	%
Brought forward				
Completed today				
Total				

Hours	Mob/ Demob	Calibrations Test	Transit	Survey	Other	WoW	Downtime Equip.	Downtime Vessel	Downtime Other
Brought forward									
Today									
Total									

Consumption	Fuel	Lubes	Water
Brought forward			
Used today			
Total remaining			

Comments client

Comments Deep BV

Checked (Deep BV):	BMO	24-05-2020	**Approved (client):**	{SIGNATURE}	{Date}

FIELD OPERATIONS

LOGSHEET - DAILY PROGRESS REPORT OFFSHORE

DEEP BV
Johan van Hasseltweg 39D
1021 KN Amsterdam
T: +31-20-6343676
WWW.DEEPBV.NL

deep Hydrography & Geophysics

PROJECT No:	P3711	**SURVEYOR:**	SPA/LER/BMO
CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Scheveningen	**PAGE:**	1 of 2
DATE:	25-05-2020		

Daily checks	
Findings of workplace risk assessment (HSE § 4.1):	*Ok*
Results height check (waterline or benchmark):	*n/a*
Averaged sound velocity:	*n/a*
Results absolute depth check on known object:	*n/a*
Results overlap old survey data:	*n/a*

Time	Event	Survey area
7:00	*On board Deep Seapal*	
	Lost connection with USBL head. Troubleshooting; Head most likely broken	
9:45	*Sail out to area B to commence survey operations MB / SBP*	
10:25	*SVP measurement taken.*	
10:30	*Start sailing check line.*	
10:45	*Generator not working properly; keeps shutting down due coolant problem*	
	Surveyequipment running on the generator not working as it should	
	Decided to sail back to port to fix generator and get extra UPS from the office	
13:45	*Sail back to port of Scheveningen*	
14:30	*Moored alongside jetty Scheveningen*	
	Contacted Deep Office to arrange replacement USBL	
	LER driving back to Deep Office to get new UPS.	
15:45	*Survey equipment now running on small backup generator; all ok for 1 hour.*	
18:00	*Replacement altimeter arrived*	
	Start altimeter / depth calibration	
19:00	*Fixed the coolant issue on the generator.*	
19:30	*Finished calibration altimeter and depth sensor.*	
	Replaced UPS. survey equipment running fine on new UPS with repaired	
	main generator now running.	
20:15	*End of day*	
	Statistics on page 2	

Statistics on page 2

Checked (Deep BV):	BMO	25-05-2020	**Approved (client):**	{SIGNATURE}	{Date}

FIELD OPERATIONS

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deep Hydrography & Geophysics

PROJECT No:	P3711	**SURVEYOR:**	SPA/LER/BMO
CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Scheveningen	**PAGE:**	2 of 2
DATE:	25-05-2020		

Weather conditions		Today's progress	Project progress	Progress accepted
Wind	*3 Bft NW*	*Mag depth/alti calibration*		
Sea state	*0.6m Hs*			
Visibility	*Good*			
Weather forecast 24 hours				
Wind	*2/3 Bft VAR*			
Sea state	*0.3m Hs*			
Visibility	*Good*			

Total survey line km	Accepted		Rejected	
	km	%	km	%
Brought forward				
Completed today				
Total				

Hours	Mob/	Calibrations					Downtime		
	Demob	Test	Transit	Survey	Other	WoW	Equip.	Vessel	Other
Brought forward									
Today									
Total									

Consumption	Fuel	Lubes	Water
Brought forward			
Used today			
Total remaining			

Comments client

Comments Deep BV

Checked (Deep BV): BMO 25-05-2020 **Approved (client):** {SIGNATURE} {Date}

FIELD OPERATIONS

LOGSHEET - DAILY PROGRESS REPORT OFFSHORE

DEEP BV
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PROJECT No:	P3711	**SURVEYOR:**	SPA/LER/BMO
CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Scheveningen	**PAGE:**	1 of 2
DATE:	26-05-2020		

Daily checks	
Findings of workplace risk assessment (HSE § 4.1):	*Ok*
Results height check (waterline or benchmark):	*n/a*
Averaged sound velocity:	*1497 m/s*
Results absolute depth check on known object:	*n/a*
Results overlap old survey data:	*Within 5cm*

Time	Event	Survey area
7:00	*On board Deep Seapal*	
	Start up survey equipment	
7:35	*Transit to survey area B for MB / SBP operations*	
8:10	*Arrived at survey area*	
8:15	*SVP measurement taken; 1497 m/s*	
8:20	*Lowering Moonpool*	
8:30	*Start survey MB / SBP at area B*	*Area B*
11:35	*Finished survey MB / SBP at area B; transit towards area C*	
11:50	*Start survey ops MB/SBP at area C*	*Area C*
12:05	*Finished survey ops MB/SBP in area C; Transit towards area A*	
12:30	*Start survey ops MB/SBP at area A*	*Area A*
17:55	*Stopped survey ops MB/SBP area A*	*Area A*
18:00	*Moonpool up; transit back to port*	
18:45	*Moored alongside jetty Scheveningen*	
19:00	*Data backup and project administration*	
19:15	*Travel back to hotel. End of day*	
	Statistics on page 2	

Checked (Deep BV): BMO 26-05-2020 **Approved (client):** {SIGNATURE} {Date}

FIELD OPERATIONS

LOGSHEET - DAILY PROGRESS REPORT OFFSHORE

DEEP BV
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deep Hydrography & Geophysics

PROJECT No:	P3711	**SURVEYOR:**	SPA/LER/BMO
CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Scheveningen	**PAGE:**	2 of 2
DATE:	26-05-2020		

Weather conditions		Today's progress	Project progress	Progress accepted
Wind	*2/3 Bft VAR*	*Finished area B - MB/SBP*	*Finished Sparker area A*	
Sea state	*0.3m Hs*	*Finished area C - MB/SBP*	*Finished area B - MB/SBP*	
Visibility	*Good*		*Finished area C - MB/SBP*	
Weather forecast 24 hours				
Wind	*3/4 Bft N*			
Sea state	*0.3-0.6m Hs*			
Visibility	*Good*			

Total survey line km	Accepted		Rejected	
	km	%	km	%
Brought forward				
Completed today				
Total				

Hours	Mob/ Demob	Calibrations Test	Transit	Survey	Other	WoW	Downtime Equip.	Vessel	Other
Brought forward									
Today									
Total									

Consumption	Fuel	Lubes	Water
Brought forward			
Used today			
Total remaining			

Comments client

Comments Deep BV

Checked (Deep BV): BMO 26-05-2020 **Approved (client):** {SIGNATURE} {Date}

FIELD OPERATIONS

LOGSHEET - DAILY PROGRESS REPORT OFFSHORE

DEEP BV
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PROJECT No:	P3711	**SURVEYOR:**	SPA/LER/BMO
CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Scheveningen	**PAGE:**	1 of 2
DATE:	27-05-2020		

Daily checks	
Findings of workplace risk assessment (HSE § 4.1):	*Ok*
Results height check (waterline or benchmark):	*n/a*
Averaged sound velocity:	*1497 m/s*
Results absolute depth check on known object:	*n/a*
Results overlap old survey data:	*Within 5cm*

Time	Event	Survey area
7:00	*On board Deep Seapal*	
	Start up survey equipment	
7:10	*Transit towards survey area A*	
7:55	*SVP measurement taken; AVG = 1497.77 m/s*	
	Lowering moonpool. Sailing to start of line	
8:25	*Start survey operations MB/SBP area A*	
13:21	*Running X-lines for SBP*	
14:18	*MB/SBP completed area A*	
14:20	*Recover moonpool*	
14:25	*Transit to port*	
15:15	*Alongside jetty Scheveningen*	
	Pick up USBL from hotel.	
15:45	*Install USBL system*	
	Testing USBL system; all ok. Weather too rough to perform USBL cal.	
18:00	*Project administration and data backup.*	
19:00	*End of day.*	
	Statistics on page 2	

Checked (Deep BV):	BMO	27-05-2020	**Approved (client):**	{SIGNATURE}	{Date}

FIELD OPERATIONS

LOGSHEET - DAILY PROGRESS REPORT OFFSHORE

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PROJECT No: P3711
CLIENT: Porthos
LOCATION: Scheveningen
DATE: 27-05-2020

SURVEYOR: SPA/LER/BMO
VESSEL: Deep Seapal
PAGE: 2 of 2

Weather conditions		Today's progress	Project progress	Progress accepted
Wind	*3/4 Bft N*	*Finished area A - MB/SBP*	*Finished Sparker area A*	
Sea state	*0.3-0.6m Hs*		*Finished area B - MB/SBP*	
Visibility	*Good*		*Finished area C - MB/SBP*	
Weather forecast 24 hours				
Wind	*3/4 Bft NE*			
Sea state	*0.3-0.4m Hs*			
Visibility	*Good*			

Total survey line km	Accepted		Rejected	
	km	%	km	%
Brought forward				
Completed today				
Total				

Hours	Mob/ Demob	Calibrations Test	Transit	Survey	Other	WoW	Downtime Equip.	Downtime Vessel	Downtime Other
Brought forward									
Today									
Total									

Consumption	Fuel	Lubes	Water
Brought forward			
Used today			
Total remaining			

Comments client

Comments Deep BV

Checked (Deep BV): BMO 27-05-2020 **Approved (client):** {SIGNATURE} {Date}

FIELD OPERATIONS

LOGSHEET - DAILY PROGRESS REPORT OFFSHORE

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deep Hydrography & Geophysics

PROJECT No:	P3711	**SURVEYOR:**	SPA/LER/BMO
CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Scheveningen	**PAGE:**	1 of 2
DATE:	28-05-2020		

Daily checks	
Findings of workplace risk assessment (HSE § 4.1):	*Ok*
Results height check (waterline or benchmark):	*n/a*
Averaged sound velocity:	*1497 m/s*
Results absolute depth check on known object:	*n/a*
Results overlap old survey data:	*Within 5cm*

Time	Event	Survey area
7:00	*On board Deep Seapal*	
	Start up survey equipment	
7:25	*Transit towards calibration area.*	
8:05	*Arrived in calibration area.*	
	Do a quick MB survey so see if the area is suitable to deploy calibration frame	
8:45	*Toolbox talk prior to deploying USBL frame*	
9:00	*Deploying USBL Frame*	
9:05	*Start USBL calibration*	
11:30	*Finished USBL calibration*	
11:50	*Recovered USBL frame*	
12:15	*Generator keeps shutting down again. Replacing impellor.*	
13:20	*Generator fine again; toolbox talk.*	
13:30	*Deploying Magnetometer and Side scan in the water*	
	Adjusting settings and sailings to start of line.	
13:50	*Generator fails. Not save to continue survey because without generator*	
	no power on the winch. Decided to recover SSS + MAG and head back to port	
	to fix generator. Asked JR to send generator technician.	
14:00	*Recovered SSS+MAG back to deck*	
	Transit to port.	
15:00	*Alongside quaywall*	
	Modifying generator water inlet to operate better during waves.	
	Arranging stand alone generator to serve as a backup	
19:30	*Driving back to the hotel.*	
19:45	*End of day.*	
	Statistics on page 2	

Checked (Deep BV):	BMO	28-05-2020	**Approved (client):**	{SIGNATURE}	{Date}

FIELD OPERATIONS

LOGSHEET - DAILY PROGRESS REPORT OFFSHORE

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PROJECT No:	P3711	**SURVEYOR:**	SPA/LER/BMO
CLIENT:	Porthos	**VESSEL:**	Deep Seapal
LOCATION:	Scheveningen	**PAGE:**	2 of 2
DATE:	28-05-2020		

Weather conditions		Today's progress	Project progress	Progress accepted
Wind	*3/4 Bft N*	*USBL Calib*	*Finished Sparker area A*	
Sea state	*0.3-0.6m Hs*		*Finished area B - MB/SBP*	
Visibility	*Good*		*Finished area C - MB/SBP*	
Weather forecast 24 hours			*Finished area A - MB/SBP*	
Wind	*3/5 Bft NE*			
Sea state	*0.3-0.4m Hs*			
Visibility	*Good*			

Total survey line km	Accepted		Rejected	
	km	%	km	%
Brought forward				
Completed today				
Total				

Hours	Mob/ Demob	Calibrations Test	Transit	Survey	Other	WoW	Downtime Equip.	Downtime Vessel	Downtime Other
Brought forward									
Today									
Total									

Consumption	Fuel	Lubes	Water
Brought forward			
Used today			
Total remaining			

Comments client

Comments Deep BV

Checked (Deep BV):	BMO	28-05-2020	**Approved (client):**	{SIGNATURE}	{Date}

FIELD OPERATIONS

LOGSHEET - DAILY PROGRESS REPORT OFFSHORE

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WWW.DEEPBV.NL:

PROJECT No: n	P3711n	SURVEYOR:n	SPA/LERn
LIENT:n	Porthosn	VESSEL:	Deep Seapaln
LOCATION:	Scheveninge	PAGE:	1 ofn 2n
DATE:n	29/05/2020n		

Daily checksn	
Findings of workplace risk assessment (HSE § 4.1):S	OkS
Results height check (waterline or benchmark):S	n/aS
Averaged sound velocity:S	498.61 m/sS
Results absolute depth check on known object:S	n/aS
Results overlap old survey data:S	Within 5cmS

Timen	Eventn	Survey arean
7:00S	On board Deep Seapal	
	Start up survey equipment (BMO departing / SPA taking over PC role)S	
7:30S	Main vessel generator water inlets have been fixed S	
8:00S	Departure from harbor to survey areaS	
8:30S	Arrived on site, running test on main generator => OKS	
8:45S	Moonpool lowered, SVP S	
8:55S	and Mag deploymentS	
9:20S	tart running lines for S position check (Boxing well head)S	
9:30S	Communication lost on S and Mag	
9:40S	Recovering S and Mag	
10:00S	Winch cable or termination broken	
10:10S	etting up S for soft tow cable deployment using dynama winch	
10:55S	VP	
1:00S	and Mag deploymentS	
:30S	tart survey of S position checkS	
:35S	position check within specification, heading towards survey area	
2:40S	tart MAG/S survey of area B S	Area B
15:45S	MAG/S survey of area B completed	
16:05S	tart MAG/S survey of area CS	Area CS
6:35S	Weather deteriorating (Wave height > 1.2m), sailing lines from N to S direction	
17:50S	top survey / Recovering S / Mag / Moonpool	
18:05S	ailing to harbor S	
8:50S	AlongsideS	
9:00S	Backup / Administration	
	Statistics on page 2n	

hecked (Deep BV):n	SPAn	29/05/2020n	Approved (client): n	{SIGNATURE}	{Date}n

FIELD OPERATIONS

LOGSHEET - DAILY PROGRESS REPORT OFFSHORE

DEEP BV:
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PROJECT No: n	P3711n	SURVEYOR:n	SPA/LERn
LIENT:n	Porthosn	VESSEL:	Deep Seapaln
LOCATION:	Scheveninge	PAGE:	2 ofn 2n
DATE:n	29/05/2020n		

Weather conditionsn		Today's progress	Project progressn	Progress acceptedn
Windn	*4/5 Bft NES*	*position checkS*	*Finished Sparker area AS*	
Sea staten	*0.5-1.2m HsS*	*Area B - S /MAGS*	*Area B - MB/SBP/S /MAGS*	
Visibilityn	*GoodS*	*Area C - S /MAG = 60%S*	*Area C - MB/SBPS*	
Weather forecast 24 hoursn			*Area A - MB/SBPS*	
Windn	*3/4 Bft NES*			
Sea staten	*0.3-0.6m HsS*			
Visibilityn	*GoodS*			

Total survey line kmn	Acceptedn		Rejectedn	
	kmn	%n	kmn	%n
Brought forwardn				
ompleted todayn				
Totaln				

Hoursn	Mob/n Demobn	alibrationsn Testn	Transitn	Surveyn	Othern	WoWn	Downtimen Equip.n	Vesseln	Othern
Brought forwardn									
Todayn									
Totaln									

onsumption	Fueln	Lubesn	Watern
Brought forwardn			
Used todayn			
Total remainingn			

omments clientn

omments Deep BVn

hecked (Deep BV):n	SPAn	29/05/2020n	Approved (client): n	{SIGNATURE}	{Date}n

FIELD OPERATIONS

LOGSHEET - DAILY PROGRESS REPORT OFFSHORE

DEEP BV:
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ROJECT No: g	3711g	SURVEYOR:g	SPA/LERg
CLIENT:g	orthosg	VESSEL:	Deep Seapalg
LOCATION:	Scheveningeng	AGE:	1 ofg 2g
DATE:g	30/05/2020g		

Daily checksg	
Findings of workplace risk assessment (HSE § 4.1):u	*Okr*
Results height check (waterline or benchmark):u	*n/ar*
Averaged sound velocity:u	*1498.76 m.s-1r*
Results absolute depth check on known object:u	*n/ar*
Results overlap old survey data:u	*Within 5cmr*

Timeg	Eventg	Survey areag
7:00r	*On board Deep Seapalr*	
7:15r	*Start up survey equipmentr*	
7:30r	*SSS position verification processing / Survey checks r*	
8:50r	*Vessel sailing to survey arear*	
9:50r	*Ar ived at survey locationr*	
9:55r	*Moonpool deployed / SVPr*	
10:05r	*Deployment of SSS/MAG*	
10:10r	*Start SSS/MAG survey of Area Cr*	*Area Cr*
11:25r	*Area C completed, sailing towards area Ar*	
11:30r	*Survey 2 lines in opposite direction over a target to verify Mag positionning r*	
11:45r	*Mag position verified and validated r*	
11:50r	*Start SSS/MAG survey of Area Ar*	*Area Ar*
17:55r	*Recovering survey equipmentr*	
18:10r	*Sailing back to port r*	
19:00r	*Alongside / Backing up / Administrationr*	
	Statistics on page 2g	

Checked (Deep BV):g	SPAg	30/05/2020g	**Approved (client): g**	{SIGNATURE}	{Date}g

FIELD OPERATIONS

LOGSHEET - DAILY PROGRESS REPORT OFFSHORE

DEEP BV:
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deep Hydrography & Geophysics

ROJECT No: g	3711g	SURVEYOR:g	SPA/LERg
CLIENT:g	orthosg	VESSEL:	Deep Seapalg
LOCATION:	Scheveningeng	AGE:	2 ofg 2g
DATE:g	30/05/2020g		

Weather conditionsg		Today's progressg	roject progressg	rogress acceptedg
Windg	*3/4 Bft NEr*	*Area C - SSS/MAG r*	*Finished Sparker area Ar*	
Sea stateg	*0.3-0.8m Hsr*	*Area A - SSS/MAG 65 %r*	*Area B - MB/SBP/SSS/MAG*	
Visibilityg	*Goodr*		*Area C - MB/SBP/SSS/MAG*	
Weather forecast 24 hoursg			*Area A - MB/SBP 65 %r*	
Windg	*3/4 Bft NEr*			
Sea stateg	*0.3-0.6m Hsr*			
Visibilityg	*Goodr*			

Total survey line kmg	Acceptedg		Rejectedg	
	kmg	%g	kmg	%g
Brought forwardg				
Completed todayg				
Totalg				

Hoursg	Mob/g	Calibrationsg					Downtimeg		
	Demobg	Testg	Transitg	Surveyg	Otherg	WoWg	Equip.g	Vesselg	Otherg
Brought forwardg									
Todayg									
Totalg									

Consumptiong	Fuelg	Lubesg	Waterg
Brought forwardg			
Used todayg			
Total remaining			

Comments clientg

Comments Deep BVg

Checked (Deep BV):g	SPAg	30/05/2020g	Approved (client): g	{SIGNATURE}	{Date}g

VERSION: 121218
DOCUMENT: P3711_200530_Deep_Seapal_DPR.xlsx

FIELD OPERATIONS

LOGSHEET - DAILY PROGRESS REPORT OFFSHORE

DEEP BV:
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1021 KN Amsterd: m:
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WWW.DEEPBV.NL:

PROJECT No: n	P3711n	**SURVEYOR:n**	SPA/LERn
LIENT:n	Porthosn	**VESSEL:**	Deep Seapaln
LOCATION:	Scheveninge	**PAGE:**	1 ofn 2n
DATE:n	31/05/2020n		

Daily checksn	
Findings of workplace risk assessment (HSE § 4.1):S	*OkA*
Results height check (waterline or benchmark):S	*n/aA*
Averaged sound velocity:S	*1499.1 m.s-1A*
Results absolute depth check on known object:S	*n/aA*
Results overlap old survey data:S	*Within 5cmA*

Timen	Eventn	Survey arean
7:10A	*On board Deep SeapalA*	
7:15A	*Start up survey equipmentA*	
7:20A	*Departure from the harbor to survey areaA*	
7:55A	*rrived on site, deploy moon poolA*	
8:00A	*SVP*	
8:10A	*Deploy SSS/MAGA*	
8:25A	*Heading towards survey area*	
8:30A	*Start SSS/MAG survey of Area A*	*rea A*
11:40A	*Recover SSS/MagA*	
11:50A	*Start Mbes recognition lines followng shipping channel for safety of towfishA*	
12:05A	*Mbes safety line completed => Safe to tow parallel to the depth contours A*	
12:10A	*Deploy SSS / MAG*	
12:15A	*Start running lines across survey area for deepest section (South of Area A)*	*rea A*
14:25A	*rea A completed / Scope of work validatedA*	
14:30A	*Recovering SSS/MAG and moonpool A*	
14:40A	*Sailing back to Scheveningen harbor A*	
15:30A	*longside / LER off A*	
15:35A	*Deep Seapal sailing to base port of Ijmuiden*	
17:35A	*longside in IJmuiden*	
19:00A	*dministration / Backing up*	
	Statistics on page 2n	

hecked (Deep BV):n	SPAn	31/05/2020n	**Approved (client): n**	{SIGNATURE}	{Date}n

FIELD OPERATIONS

LOGSHEET - DAILY PROGRESS REPORT OFFSHORE

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PROJECT No: n	P3711n	**SURVEYOR:n**	SPA/LERn
LIENT:n	Porthosn	**VESSEL:**	Deep Seapaln
LOCATION:	Scheveninge	**PAGE:**	2 ofn 2n
DATE:n	31/05/2020n		

Weather conditionsn		Today's progress	Project progressn	Progress acceptedn
Windn	*3/4 Bft NEA*	*rea A - SSS/MAG 100%A*	*Finished Sparker area A*	
Sea stater	*0.3-0.5m Hs*		*Area B - MB/SBP/SSS/MAGA*	
Visibilityn	*Good*		*Area C - MB/SBP/SSS/MAGA*	
Weather forecast 24 hours			*Area A - MB/SBP/SSS/MAGA*	
Windn	*3/4 Bft NEA*			
Sea staten	*0.3-0.6m HsA*			
Visibilityn	*GoodA*			

Total survey line kmn	Acceptedn		Rejectedn	
	kmn	%n	kmn	%n
Brought forwardn				
ompleted todayn				
Totaln				

Hoursn	Mob/n	alibrationsn					Downtimen		
	Demobn	Testn	Transitn	Surveyn	Othern	WoWn	Equip.n	Vesseln	Othern
Brought forwardn									
Todayn									
Totaln									

onsumption	Fueln	Lubesn	Watern
Brought forwardn			
Used todayn			
Total remainingn			

omments clientn

omments Deep BVn

hecked (Deep BV):n	SPAn	31/05/2020n	Approved (client): n	{SIGNATURE}	{Date}n

APPENDIX B – EQUIPMENT CHECKS

FIELD OPERATIONS
CALIBRATION - MULTIBEAM DUALHEAD

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deep Hydrography & Geophysics

PROJECT No:	P3711	**SURVEYOR:**	SBR/BMO
LOCATION:	Ijmuiden	**VESSEL:**	Deep Seapal
DATE:	19-05-2020	**REMARKS:**	{Remarks}
PAGE:	1 of 1		

Equipment

Multibeam: ☐ Seabat 8101 ☐ Seabat 8125 ☐ R2Sonic 2022 ☑ R2Sonic 2024 ☐ :
☐ SeaSwath+ H ☐ Seaswath+ M

Frequency: 400 kHz

☑ PPS input ☑ Roll stabilized ☑ Sound Velocity at head

Calibration results portside

	Method	Logfiles	Correction
☑ Roll	Deep & flat bottom, opposite directions, same speed	001 002	21.48 °
☑ Pitch	Perpendicular to slope, opposite sailing direction, same speed	002 003	2.30 °
☑ Yaw	Perpendicular to slope or typical feature, same direction, same speed 50 % overlap in swath, slope or typical feature in the overlap	001 003	2.60 °

Calibration results starboard

	Method	Logfiles	Correction
☑ Roll	Deep & flat bottom, opposite directions, same speed	004 006	-20.82 °
☑ Pitch	Perpendicular to slope, opposite sailing direction, same speed	004 007	2.41 °
☑ Yaw	Perpendicular to slope or typical feature, same direction, same speed 50 % overlap in swath, slope or typical feature in the overlap	005 007	-2.29 °

Values calculated by using

☑ QINSy Calibrate alignment ☐ Autopatch

Checked (Deep BV): BMO 20-05-2020 **Approved (client):** {SIGNATURE} {Date}

FIELD OPERATIONS
CALIBRATION - POSITION CHECK MBES

DEEP BV
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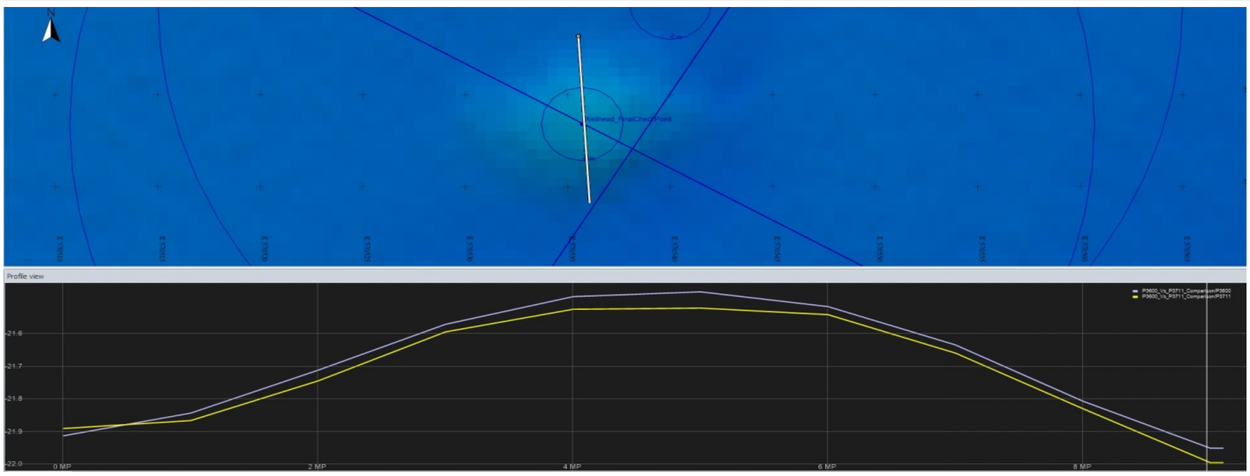
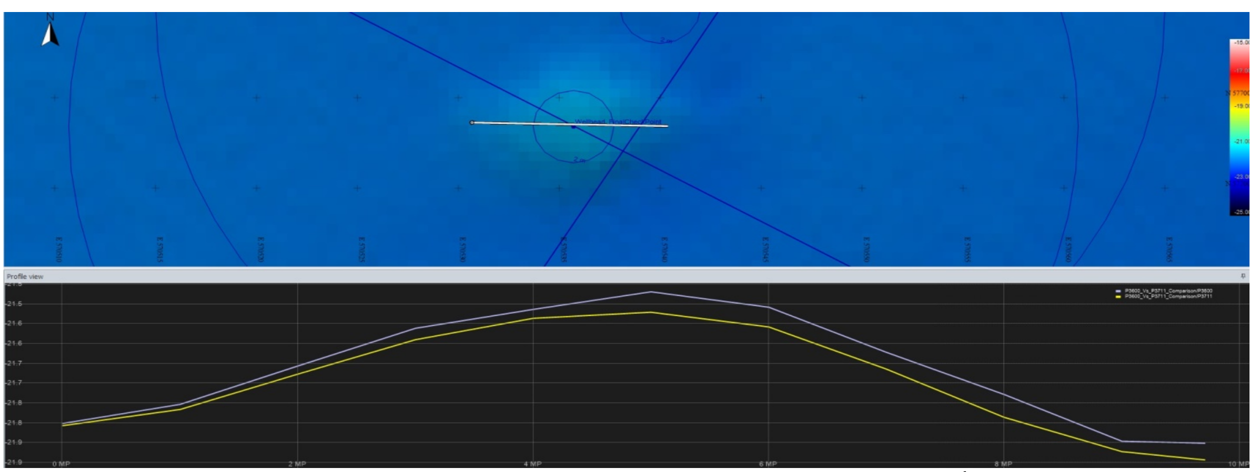
PROJECT No:	P3711	**SURVEYOR:**	LER/SPA/BMO
LOCATION:	Hoek van Holland	**VESSEL:**	Deep Seapal
DATE:	25-05-2020	**REMARKS:**	MBES Comparison between Breaker and Seapal on object
PAGE:	1 of 1		

Summary

Below a comparison between the object surveyed by the Breaker and the same object surveyed with the Deep Seapal
Two profiles are drawn. Top picture shows a north to south profile. Bottom picture shows a west to east profile



Comparison with previous survey. Profile drawn in a north to south direction



Comparison with previous survey. Profile drawn in a west to east direction

Local datum	
Horizontal datum:	*ED50*
Vertical reference:	*LAT2006*

Checked (Deep BV): BMO 25-05-2020 **Approved (client):** {SIGNATURE} {Date}

FIELD OPERATIONS

CALIBRATION - Depthsensor G-882

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PROJECT No:	P3711	**SURVEYOR:**	SPA/LER/BMO
LOCATION:	Scheveningen	**VESSEL:**	Deep Seapal
DATE:	25-05-2020	**REMARKS:**	{Remarks}
PAGE:	1 of 1		

Equipment	
Used instrument:	Altimeter VA500

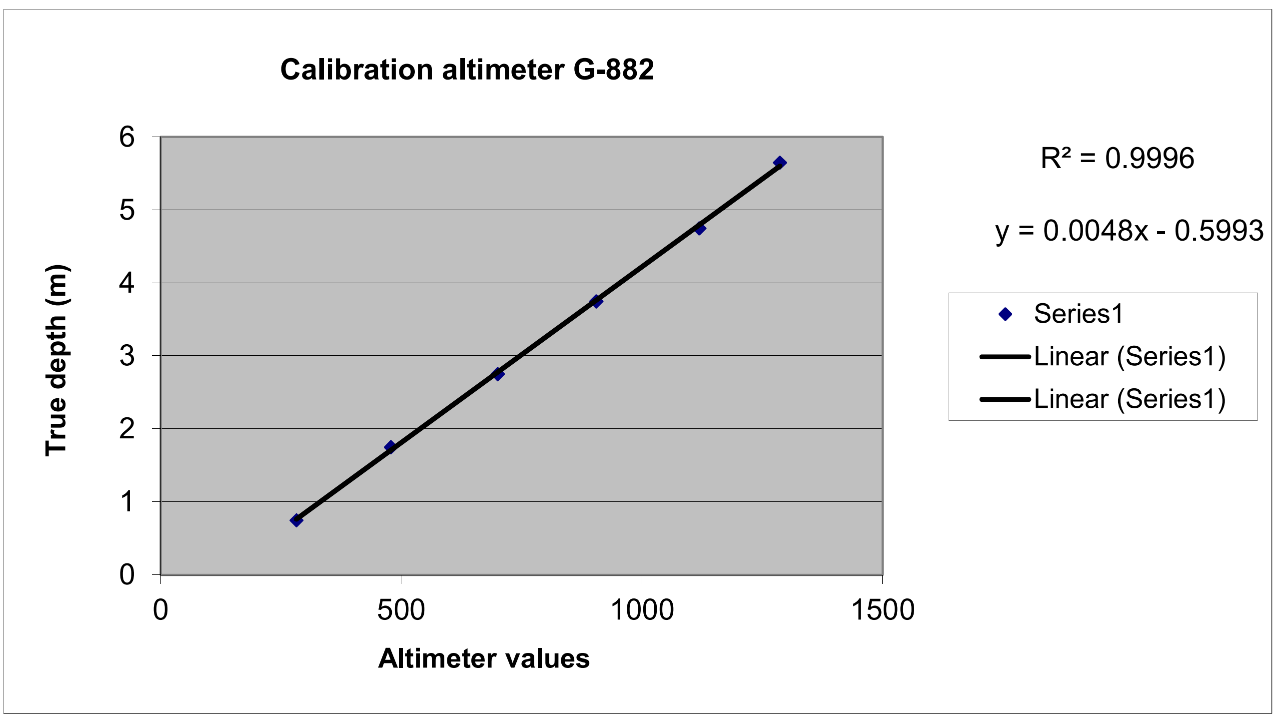
Raw altimeter values on known height:

True height (m)	Raw altimeter values
5.65	1287
4.75	1119
3.75	905
2.75	700
1.75	478
0.75	282

Corrected scale and C-O in Qinsy:

True height (m)	Altimeter (m)	Diff (m)
5.4	5.40	0.00
4.4	4.46	0.06
3.4	3.46	0.06
2.4	2.41	0.01
1.4	1.41	0.01
0.4	0.38	-0.02

Bias	-0.599294604
Scale	0.004819905
C-O fixed value QINSy	-124.337426



Checked (Deep BV):	BMO	25-05-2020	**Approved (client):**	{SIGNATURE}	{Date}

FIELD OPERATIONS

CALIBRATION - Depthsensor G-882

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PROJECT No:	P3711	**SURVEYOR:**	SPA/LER/BMO
LOCATION:	Scheveningen	**VESSEL:**	Deep Seapal
DATE:	25-05-2020	**REMARKS:**	{Remarks}
PAGE:	1 of 1		

Equipment	
Used instrument:	Depth sensor Geometerics Magnetometer G-882

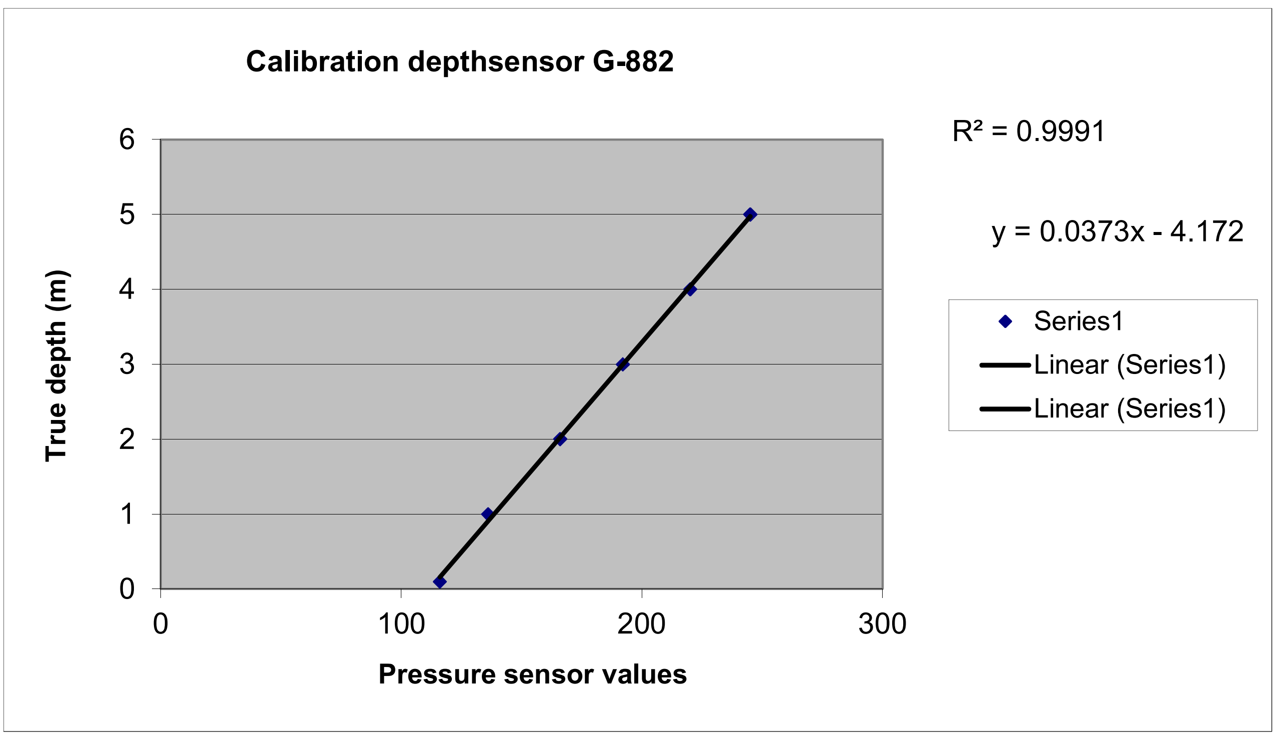
Raw pressure sensor values on known depths:

True depth (m)	Pressure sensor values
0.1	116
1	136
2	166
3	192
4	220
5	245

Corrected scale and C-O in Qinsy:

True depth (m)	Pressure sensor	Diff (m)
0.1	0.06	-0.04
1	1.02	0.02
2	2.03	0.03
3	3.03	0.03
4	4.04	0.04
5	5.05	0.05

Bias	-4.045375972
Scale	0.03673293
C-O fixed value QINSy	-110.1294118



Checked (Deep BV):	BMO	25-05-2020	**Approved (client):**	{SIGNATURE}	{Date}

Least Squares

LEAST SQUARES DEFINITIONS

Databases

C:\PROJECTEN\P3711\00_QINSY		
1120_P3711_SEA_200528_USBL_Cal_03_MBES_SSS_MAG - 0001	5/28/2020	09:01:19
1121_P3711_SEA_200528_USBL_Cal_08_MBES_SSS_MAG - 0001	5/28/2020	09:06:58
1122_P3711_SEA_200528_USBL_Cal_01_MBES_SSS_MAG - 0001	5/28/2020	09:12:52
1123_P3711_SEA_200528_USBL_Cal_06_MBES_SSS_MAG - 0001	5/28/2020	09:19:00
1124_P3711_SEA_200528_USBL_Cal_04_MBES_SSS_MAG - 0001	5/28/2020	09:25:31
1125_P3711_SEA_200528_USBL_Cal_07_MBES_SSS_MAG - 0001	5/28/2020	09:32:49
1126_P3711_SEA_200528_USBL_Cal_02_MBES_SSS_MAG - 0001	5/28/2020	09:38:36
1127_P3711_SEA_200528_USBL_Cal_05_MBES_SSS_MAG - 0001	5/28/2020	09:44:26

Properties

Object Name	**Deep Seapal**		
USBL System	**USBL MiniRanger**	Reference Point	**Ranger USBL**
Transducer Node	**Ranger USBL**	Target Node	**USBL_CAL CoG**
Gyro System	**Octans G5 [Gyro Compass]**	VRU System	**Octans G5**
Echosounder	**Manual**	Computation	**Septentrio 001 RTK**

Statistics

Number of USBL Observations	**572**	**100** %
Number of Used Observations	**505**	**88** %
Number of Disabled Observations	**67**	**11** %

LEAST SQUARES SETTINGS

USBL Observations

Alignment Corrections	**No Corrections**
Reference Point	**Actual USBL Transducer**
Sound Velocity	**Calibrated Sound Velocity**
Computation Parameters	**Scale, Angles, 3D Target Node Position**
Standard Deviations	**Scaled Calibration Standard Deviations**

Least Squares

LEAST SQUARES RESULTS

Computation Results

Parameter	Value	SD
Scale Factor	**1.00156**	**0.00560**
Roll Angle	**0.245** °	**1.102** °
Pitch Angle	**0.926** °	**0.528** °
Heading Angle	**-1.642** °	**0.372** °

Target Node Position

Coordinate	Value	SD
Easting TP	**572244.15** m	**0.35** m
Northing TP	**5769856.55** m	**0.35** m
Height TP	**-22.37** m	**0.82** m

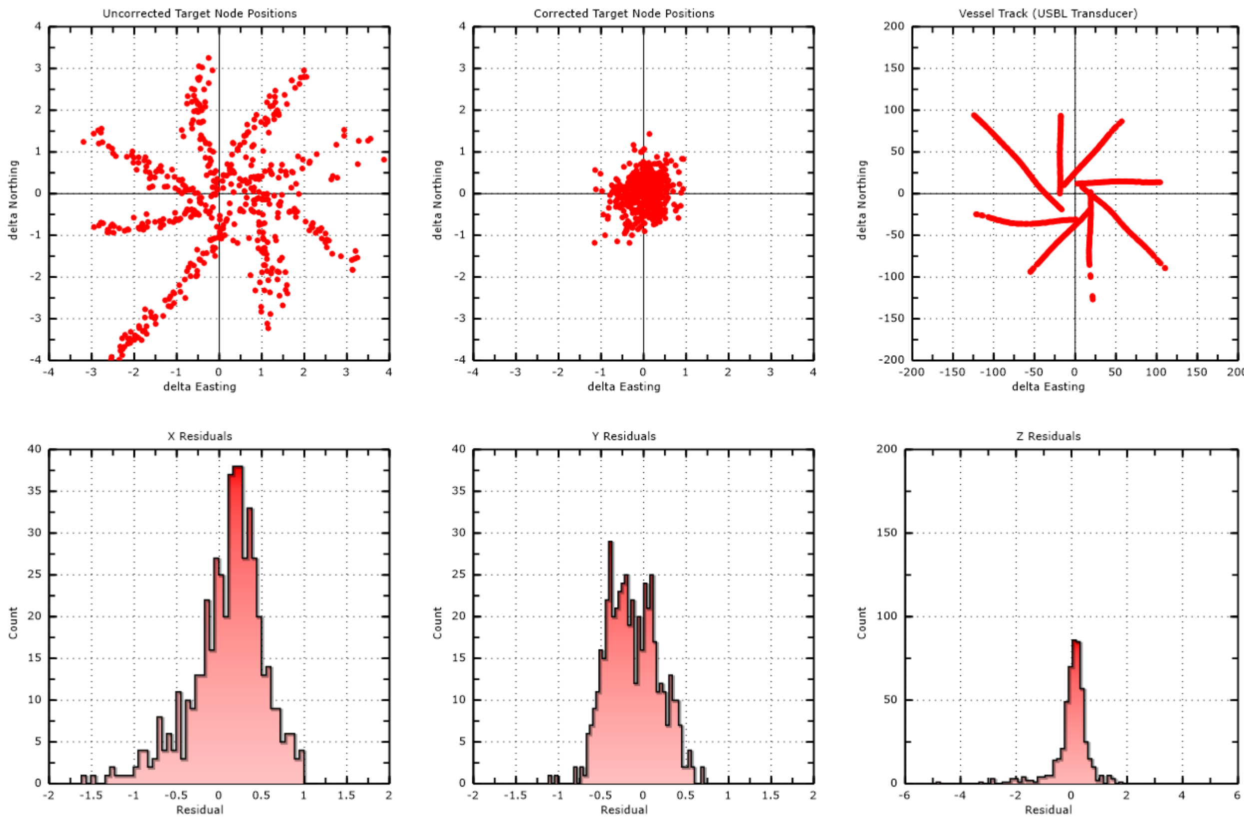
Target Nodes

Known Target Node Positions

Name	Easting	Northing	Height
None Defined			

Least Squares

LEAST SQUARES GRAPHS



Graph Origin

Coordinate	Value
Easting	**572244.15** m
Northing	**5769856.55** m
Height	**-22.37** m

Calibrated Target Node Position

Sound Velocity

USBL Observations

Sound Velocity	**Calibrated Sound Velocity**

USBL Calibration Results

Parameter	Value	Factor
Calibration Results	**1487.32** m/s	**1.00156**
Manually Set Values	**1485.00** m/s	**1.00000**

QINSy Database Settings

Parameter	Value	Factor
System-Used Velocity	**1485.00** m/s	**1.00000**
Calibrated Velocity	**1485.00** m/s	**1.00000**

1120_P3711_SEA_200528_USBL_Cal_03_MBES_SSS_MAG - 0001
1121_P3711_SEA_200528_USBL_Cal_08_MBES_SSS_MAG - 0001
1122_P3711_SEA_200528_USBL_Cal_01_MBES_SSS_MAG - 0001
1123_P3711_SEA_200528_USBL_Cal_06_MBES_SSS_MAG - 0001
1124_P3711_SEA_200528_USBL_Cal_04_MBES_SSS_MAG - 0001
1125_P3711_SEA_200528_USBL_Cal_07_MBES_SSS_MAG - 0001
1126_P3711_SEA_200528_USBL_Cal_02_MBES_SSS_MAG - 0001
1127_P3711_SEA_200528_USBL_Cal_05_MBES_SSS_MAG - 0001

Alignments

USBL Calibration Results

Parameter	Value	SD
Scale Factor	**1.00156**	**0.00560**
Roll Angle	**0.245** °	**1.102** °
Pitch Angle	**0.926** °	**0.528** °
Heading Angle	**-1.642** °	**0.372** °
Offset X	**0.00** m	**N/A** m
Offset Y	**0.00** m	**N/A** m
Offset Z	**0.00** m	**N/A** m
Easting TP	**572244.15** m	**0.35** m
Northing TP	**5769856.55** m	**0.35** m
Height TP	**-22.37** m	**0.82** m

USBL Target Node Positions

Error Ellipse	95 %	SD
Easting Center	**572244.15** m	**0.36** m
Northing Center	**5769856.55** m	**0.42** m
Semi-Major Axis	**1.04** m	**0.42** m
Semi-Minor Axis	**0.86** m	**0.35** m
Azimuth Major Axis	**20.866** °	
Grid Scale East	**0.99966**	
Grid Scale North	**0.99966**	

Manually Set Values

Parameter	Value	SD
Scale Factor	**1.00000**	**N/A**
Roll Angle	**0.100** °	**N/A** °
Pitch Angle	**0.600** °	**N/A** °
Heading Angle	**-1.500** °	**N/A** °
Offset X	**0.00** m	**N/A** m
Offset Y	**0.00** m	**N/A** m
Offset Z	**0.00** m	**N/A** m

QINSy Database Settings

Parameter	Value	SD
Scale Factor	**1.00000**	**N/A**
Roll Angle	**0.000** °	**0.050** °
Pitch Angle	**0.000** °	**0.050** °
Heading Angle	**0.000** °	**0.500** °

1120_P3711_SEA_200528_USBL_Cal_03_MBES_SSS_MAG - 0001
1121_P3711_SEA_200528_USBL_Cal_08_MBES_SSS_MAG - 0001
1122_P3711_SEA_200528_USBL_Cal_01_MBES_SSS_MAG - 0001

1123_P3711_SEA_200528_USBL_Cal_06_MBES_SSS_MAG - 0001
1124_P3711_SEA_200528_USBL_Cal_04_MBES_SSS_MAG - 0001
1125_P3711_SEA_200528_USBL_Cal_07_MBES_SSS_MAG - 0001
1126_P3711_SEA_200528_USBL_Cal_02_MBES_SSS_MAG - 0001
1127_P3711_SEA_200528_USBL_Cal_05_MBES_SSS_MAG - 0001

Porthos FEED Offshore Pipeline

Route Selection

Porthos

24/07/2020

CTR No.: LB010
Revision: 1.0

416010-00212 -TROF-ENG-PIP-INT-REP-0005

Intecsea
Worley Group

intecsea.com

Disclaimer

416010-00212 -TROF-ENG-PIP-INT-REP-0005 – Porthos FEED Offshore Pipeline: Route Selection

Rev	Description	Author	Review	INTECSEA approval	Date
1.0	Accepted by Client	OB	EK	FvdL	24-07-2020
0.1	Issued for Client Review	OB	EK	FvdL	11-05-2020
0.0	Issued for Client Review	OB	FvdL	FvdL	23-12-2019
A	Internal Review	OB	FvdL		19-12-2019

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1 Introduction

1.1 Project General

EBN (Energie Beheer Nederland), Gasunie and Port of Rotterdam, united in the PORTHOS consortium (Port of Rotterdam CO_2 Transport Hub & Offshore Storage) have initiated a plan to collect CO_2 from the industrial area of the port of Rotterdam and transport it to an abandoned gas field offshore for storage.

As part of this CCUS-project (Carbon Capture Utilization and Storage) a concept study was completed in 2018. PORTHOS now proceeds with the FEED phase in 2019, which will include the FEED design for the offshore pipeline section which extends from the last onshore horizontal weld connecting to the trenchless shore and Maasgeul crossing up to the bottom flange of the riser at the P18-A platform.

INTECSEA BV is performing the Front End Engineering & Design (FEED) of the offshore pipeline in between the above mentioned battery limits.

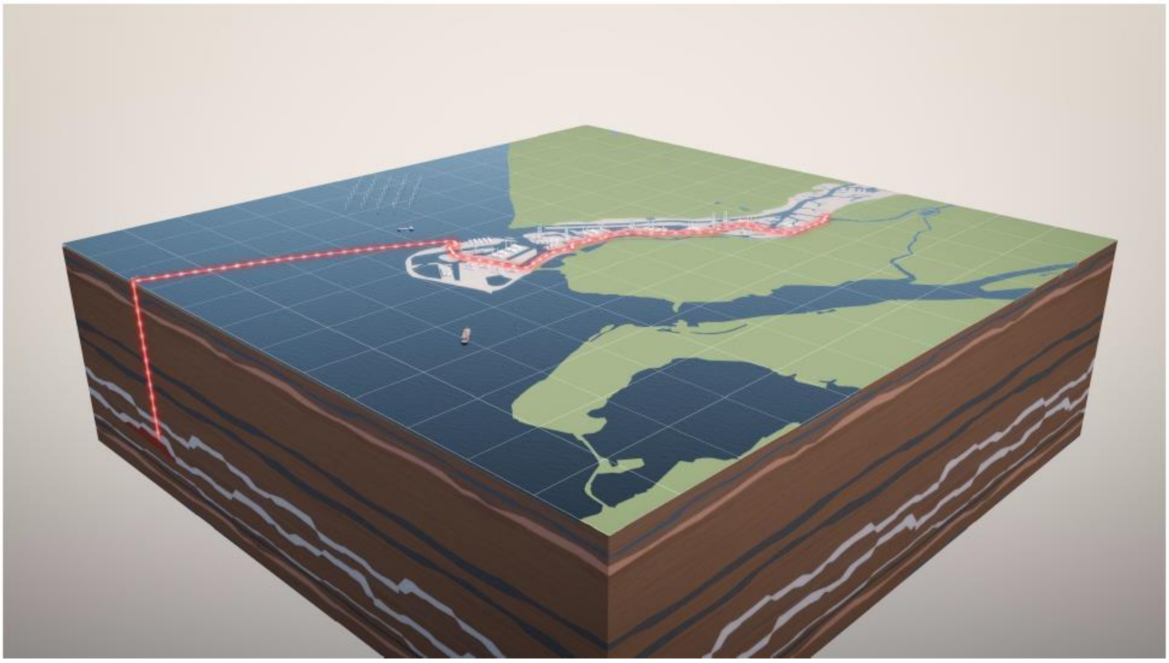

Figure 1-1 PORTHOS Overview

1.2 Scope of Document

This document summarises the process applied for the selection of the offshore pipeline route for the PORTHOS offshore pipeline between the battery limits as defined in the Design Basis Report (Ref. [1]).

1.3 Definitions

1.3.1 Abbreviations and Acronyms

Table 1-1: Abbreviations as used in the route selection report

AWTI	Above Water Tie-In
CCUS	Carbon Capture Utilization and Storage
CHO	Cultural Heritage Object
DoB	Depth of Burial
EBN	Energie Beheer Nederland
ED	European Datum
FEED	Front End Engineering & Design
GB	Great Britain
GD	Grid Distance
HbR	Havenbedrijf Rotterdam (Port of Rotterdam)
HDD	Horizontal Directional Drilling
HKZ	Hollandse Kust Zuid
IP	Intersection Point
KP	Kilometer Post
LAT	Lowest Astronomical Tide
MAG	Magnetometer
MBES	Multibeam Echo Sounder
MTO	Material Take Off
MV2	Maasvlakte 2
NAP	Normaal Amsterdams Peil
NEN	Nederlandse Norm (Nederlands Normalisatie Instituut)
NGD	Nautical Guaranteed Depth
NL	Netherlands
PoR	Port of Rotterdam
PORTHOS	Port of Rotterdam CO_2 Transport Hub & Offshore Storage
RD	Rijksdriehoek (system)
SBP	Sub Bottom Profiler
SSS	Side Scan Sonar
TD	True Distance
TOP	Top of Pipe
TP	Tangent Point
UK	United Kingdom
UM	Umbilical
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance

1.3.2 Other Definitions

Table 1-2: Definitions

CLIENT	PORTHOS (Cooperation between EBN, Gasunie and Port of Rotterdam)

ENGINEER	INTECSEA B.V. (Worley Group)
PROJECT	PORTHOS pipeline. Scope of work: pipeline between battery limits
Nearshore	Area south of the Maasgeul
Offshore	Maasgeul and area north of Maasgeul towards P18-A
HOLD	Data to be established / determined or to be received
Shall	The word “shall” indicates a mandatory requirement
May	The word ”may” indicates a possible course of action

1.4 Revision History

Revision	Description
1.0	Updated report based on latest information. Report updated for route definition: PORTHOS_06_20200625 Note, revision box of the previous revision showed 1.0 on the front- and title page, while this should have been 0.1. Deleted sections related to pending survey data.

1.5 HOLD Record

Location	Description of HOLD

2 Summary Conclusions and Recommendations

The PORTHOS CO_2 offshore pipeline route is generally based on the route as defined in the concept select phase. Technical feasibility is assessed by considering the existing subsea pipelines and cables and the presence of sand borrow and spoil areas and other seabed activities. In the routing, the pipeline constructability of the route, including seabed intervention scope is taken into account.

On and offshore routing criteria form the general basis for the routing study. This document lists a wide variety of constraints that were taken into consideration while selecting a suitable pipeline route.

The elements with the largest impact on the route are:

1. The onshore plot plan at the Maasvlakte claimed by Porthos and the substations of HbR and Stedin planned directly next the onshore plot plan,
2. the four (4) future TenneT cables of which the sea defence crossings have already been installed,
3. the Maasgeul and sea defence crossing,
4. the offshore sand extraction and spoil areas,
5. the existing offshore pipelines and cables and the platforms and subsea wellheads in the vicinity of the proposed PORTHOS pipeline corridor.

The location of the onshore plot area has changed from the initial plot east of the Tennet cables to an area directly west of the new TenneT plot area, that is more suitable for a short and less risky HDD trajectory with a feasible (trenched) Maasgeul crossing.

A proposal has also been prepared for the relocation of the planned onshore substations. Furthermore, additional measure may have to be taken to protect the PORTHOS assets within the influence zone of the planned wind turbine. The exit pit and expansion loop are located within the wind turbine's 2.2 m burial safety zone.

Offshore the proposed route remains at the south-west side of the existing cable and pipeline infrastructure between platform P18-A and subsea wellhead Q16-FA-1. One abandoned telecom cable is still crossing the PORTHOS pipeline route corridor. Removal of this cable before pipe laying is base case.

The Maasvlakte and the North Sea, and in particular the nearshore and offshore areas where the PORTHOS CO_2 pipeline is planned, are areas where several users with a variety of interests have to share the limited space. It is therefore not always possible to achieve the desired separation distances between the pipeline and third-party areas. The proposed pipeline route therefore needs to be aligned with amongst others Rijkswaterstaat, TenneT, Port of Rotterdam and operators/owners of subsea pipelines and cables.

It should be noted that the currently available pre-FEED project survey data does not cover the complete proposed route. Further route optimization may lead to a reduction of the area without survey data, but this may make the installation of the pipe more challenging.

The total length of the proposed route is approximately 19.2 km. length.

3 Routing Criteria

Ideally, to minimize the pipeline length and hence material and construction costs, a pipeline should be routed between the starting and end-point as close to a straight line as possible. However, other factors such as route obstructions, seabed soil conditions, geohazards, third party facilities, environmental considerations, etc. may necessitate the introduction of turning points into the pipeline routing. The major criteria for the selection and optimization of a subsea pipeline route are presented in the following subsections.

3.1 Offshore Routing Criteria

The following general criteria apply to all pipeline routing studies, and are considered worthwhile to re-state here, as they underpin the study:

- Minimize the pipeline distance from landfall initiation to landfall termination; economically the shortest route possible is the most advantageous.
- Avoid wherever possible restricted offshore areas such as anchorages, sanctuaries, shipping lanes, military areas, mining activities and spoil areas for waste or ammunition, etc.
- Take due consideration of third-party requirements i.e. liaison with fishing organizations, local and/or governmental authorities and other interested parties (environmental constraints).
- Avoid pipeline, cable and utilities crossings, but where this is not possible; the crossing angle should preferably be as close as possible to perpendicular; sufficient straight section should be available to avoid that adjacent curves affect the crossing.
- Bundle pipeline trajectories as much as possible close to (future) platforms to leave space for manoeuvring supply vessels, for anchoring drilling installations, construction vessels and for future platform extensions
- If possible put pipelines in designated offshore pipeline and cable corridors
- Avoid running parallel with high-voltage cables. If not possible otherwise, take into account requirements from pipeline-cable influence studies.
- Maintain consideration of future pipelines, facilities and cables.
- Follow a smooth seabed profile avoiding, wherever possible unstable seabed areas and steep slopes; minimisation of pipeline spanning and installation stress.
- Optimize where possible for seabed mobility characteristics

3.2 Nearshore Routing Criteria

Major criteria for nearshore route selection and landfall evaluation are summarized below:

- Local bathymetry: obstructions to routing, potential for spanning, extent of trenching;

- Geotechnical suitability: suitability for trenching and/or drilling;
- Third party interaction: presence of industrial, marine, fishing and military infrastructure and activities, restricted and anchorage areas that could affect the route or the construction method of the pipeline;
- Environmental and / or archaeological constraints: nature reserves or other environmental conditions that could affect the permitting process for the landfall location;
- Construction considerations: suitability of the onshore and nearshore sections for construction methods;
- Geohazards: potential for geohazards such as slope failure, liquefaction, coastal erosion, etc.;

3.3 Installation Criteria

Similarly, a routing study has to consider factors relating to the installation of the pipeline system:

- Consider the limitations of the installation equipment with regard to lay depth, lay curvature, initiation and termination;
- Provide a straight run at pipeline initiation and termination to aid pipeline installation. The length of the straight run should consider the pipeline installation method and the on-bottom pipeline resistance to directional change;
- Provide a sufficiently large straight section between two consecutive pipe bends to avoid interaction of the bends;
- Provide a sufficiently long straight section at pipeline/cable crossings e.g. minimum radius of curvature;
- Provide adequate clearance to adjacent pipelines and cables.

3.4 Curve Stability

Route curves shall be used where a straight pipeline route is not possible. The minimum allowable horizontal curvature of a pipeline depends on the installation method (especially lay tension), the soil properties and pipeline parameters. Specifically, the selected radius of curvature must be maintainable during pipe lay. It should be noted that the as-laid radius will very likely deviate locally from the theoretical constant radius. One of the aspects underlying this is the defined lateral laying tolerance.

3.5 Routing Constraints

This section provides an overview of the onshore and offshore routing constraints that have been studied as part of the PORTHOS offshore pipeline FEED project and were taken into consideration during the routing process; these are:

- Onshore plot area claimed for the CLIENT/project

- Onshore cables, pipelines, roads, train tracks
- Crossing of Waterstaatwerken
- Areas with shipping and maritime activities;
- Fishing areas
- Oil and gas activities;
- Existing / Planned offshore cables;
- Other existing / planned offshore pipelines;
- Explosive dumping grounds;
- Areas with cultural heritage objects, unexploded ordnance and wrecks.
- Environmentally protected areas.
- Sand extraction and spoil areas

The above routing constraints are briefly discussed in the following subsections.

3.5.1 Routing Objective

The routing objective is as follows:

The PORTHOS pipeline will be routed from the onshore plot area at the north side of the Maasvlakte area and west of the TenneT onshore plot area towards the south- or south-east side of the P18-A platform. The target box location near P18-A will be defined based on a preliminary spool piece layout. Both the target box location and spool piece layout partially depend on additional (safety) requirements which can be prescribed by TAQA, (owner of / responsible for P18-A).

3.5.2 Onshore Plot Area for Entry Point

The onshore plot area shown in Figure 3-1 is reserved for PORTHOS by Porthos/HbR. Porthos/HbR defined the boundaries of the area based on the available area and future developments in the vicinity of the area. The area will eventually be used for the entry point of the trenchless sea defence crossing, the onshore expansion spool and for the valve station.

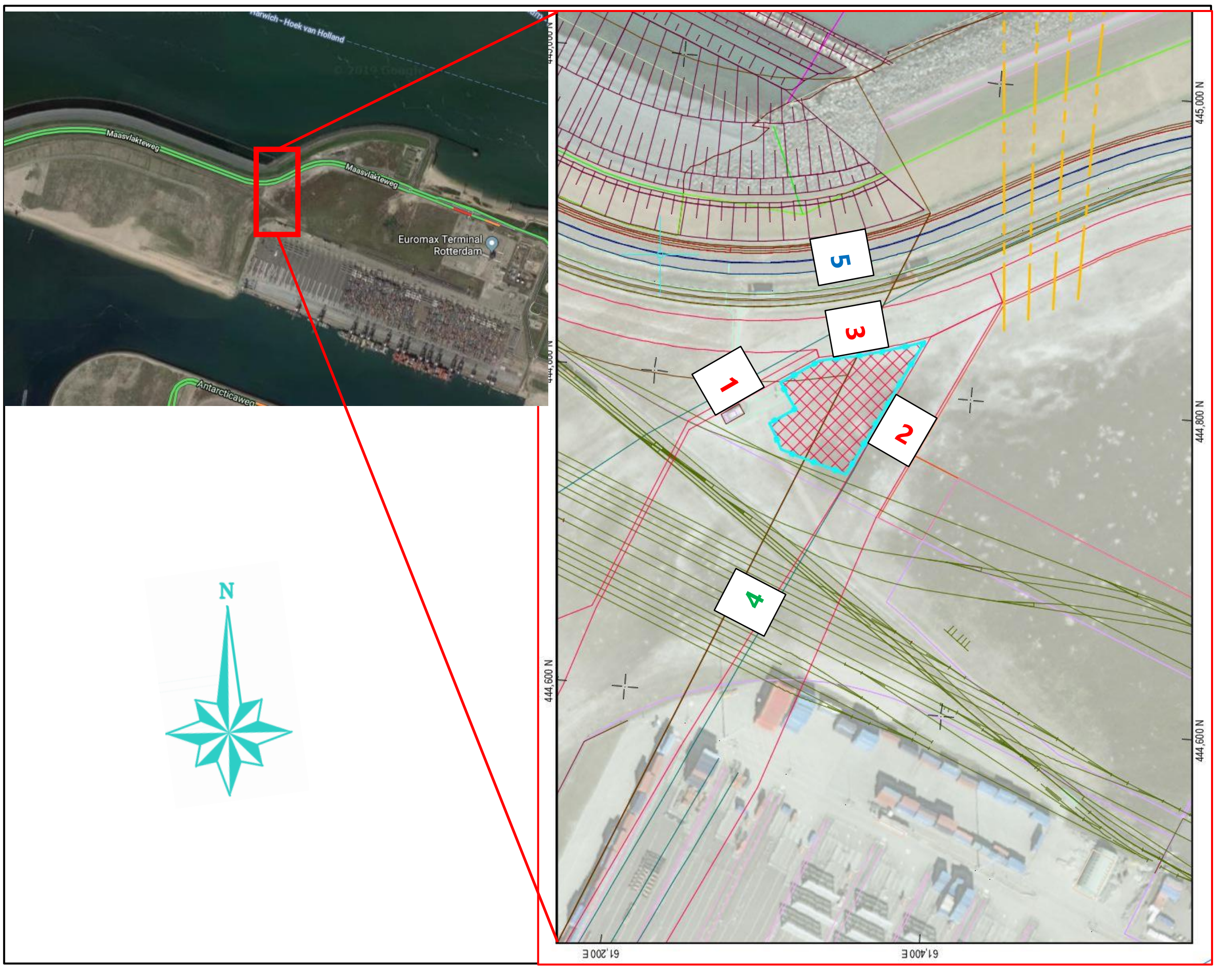

Figure 3-1 Claimed Onshore Plot Area for PORTHOS (red shaded)

3.5.3 Onshore Cable and Pipeline Corridors

Figure 3-1 shows the three cable and pipeline corridors around the PORTHOS plot area (indicated with red 1, 2 and 3). Figure 3-2 shows the type of pipeline and cable infrastructure.

Onshore pipelines and cables shall be crossed underneath with at least 2.5 m (reference is made to email 14-11-2019, HbR to Porthos) cover between top of drill diameter and ground level.

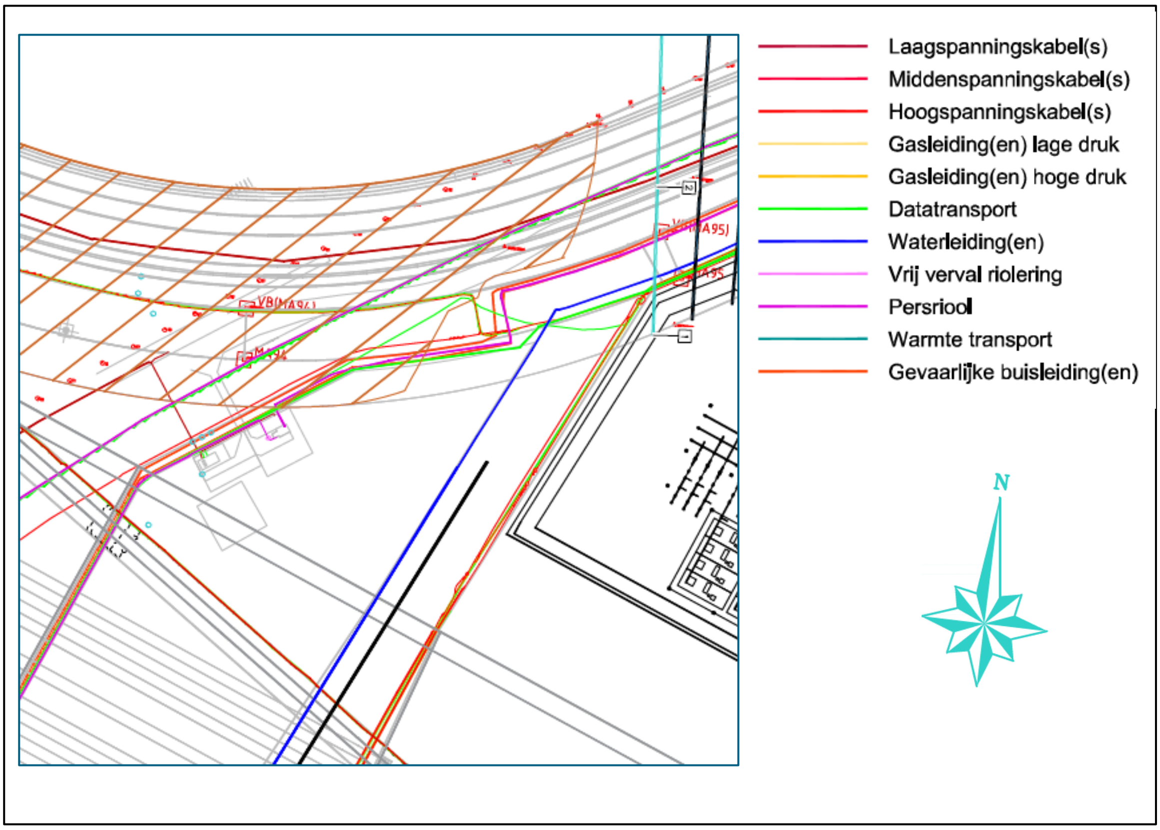

Figure 3-2 Pipeline and Cables within Pipeline- and Cable Corridor (Ref. [24])

3.5.4 Onshore Roads, Train Tracks and Buildings

Figure 3-1 shows the main road (Maasvlakteweg) and service road (Prinses Maximaweg) at the north side of the plot plan in blue (indicated with a "5") and the existing and planned train tracks at the south side of the plot plan in green (indicated with a "4").

The main road and service road will have to be crossed underneath with the pipeline. Crossings will be checked against NEN 3650 requirements.

At the south-west side of the onshore PORTHOS plot plan, a dirt road is identified which leads first to a sewage service point and the electrical substation and subsequently the dirt road leads to a gate in the fenced container terminal at the south side of the existing train tracks (Figure 3-3).

Northeast of the existing substation HbR and Stedin substations will be built before construction start of Porthos (Figure 3-4, Ref. [23]). A zone of at least five (5) meters is maintained between the PORTHOS pipeline OD and nearby buildings such as third-party sub stations. This requirement comes forth from "Besluit Externe Veiligheid Buisleidingen"

Figure 3-3: Dirt Road indicated in RED, passing sewage point and brick substation building (Source: Google Earth)

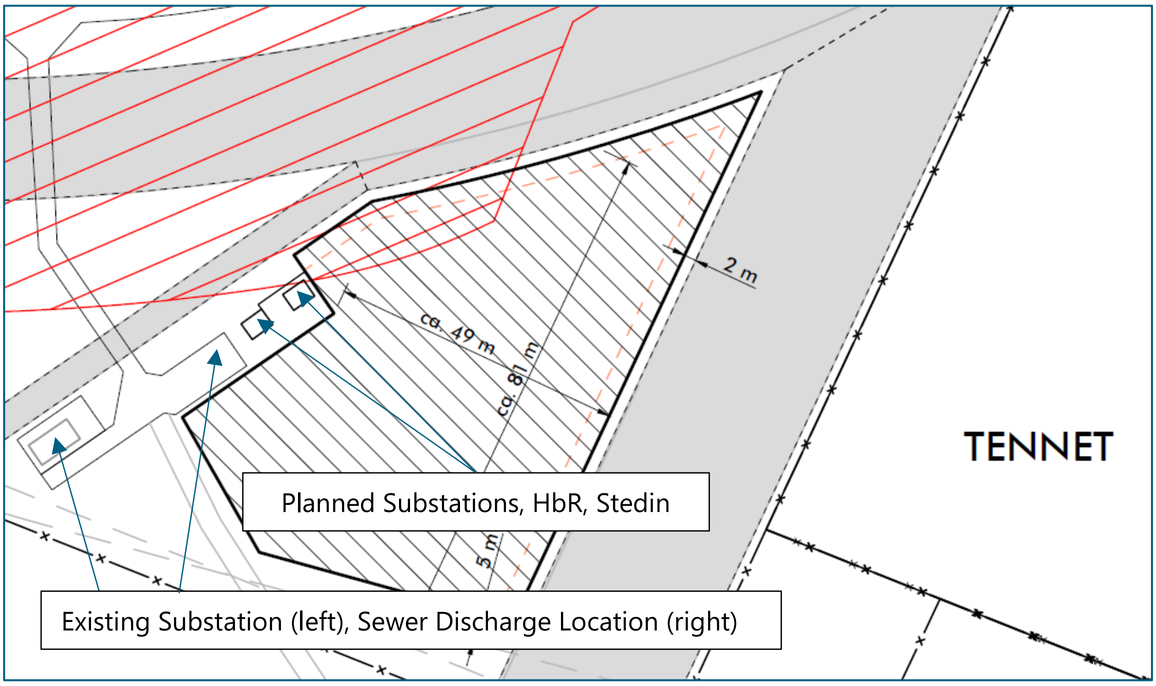

Figure 3-4: Existing and Planned Substations next to Porthos Onshore Plot Plan (Ref. [23])

3.5.5 Onshore Wind Turbines

Wind turbines are planned by Eneco to be installed on top of the sea defence around Maasvlakte 2. The wind turbines have a spatial impact, in particular on the first section of pipeline crossing with the sea defence. The following zones are defined around the wind turbine(s).

- Area designated for turbine installation purposes (Figure 3-5, Ref. [22])
- Area defined as "High Impact Zone" (Figure 3-5, Ref. [22])
- Two circular shaped burial depth zones around the easternmost wind turbine (HZ-01) centre point, representing critical distances. Distances are based on turbine properties and a set of wind turbine failure scenarios. The zones define the required top of pipe cover for PORTHOS. (Figure 3-6, Ref. [25])

The battery limit, the HDD entry pit and the first few meters of the HDD do not meet the defined depth requirement of 2.2 m. Additional measures, such as the installation of a concrete slab under ground level (or a roof construction above ground level), to protect above ground and shallow buried PORTHOS assets can be considered to meet the safety requirements that result from the wind turbine. Design of additional measures to protect the onshore pipeline against the impact of the wind turbine is not part of Intecsea scope of work.

The deeper sections of the HDD also have to comply with the 5.4 m cover requirement on top of pipe. The HDD entry angle (see Ref. [5]) will be sufficient to meet this requirement.

It is advised to align the PORTHOS route and possible precautions with owner of wind turbine.

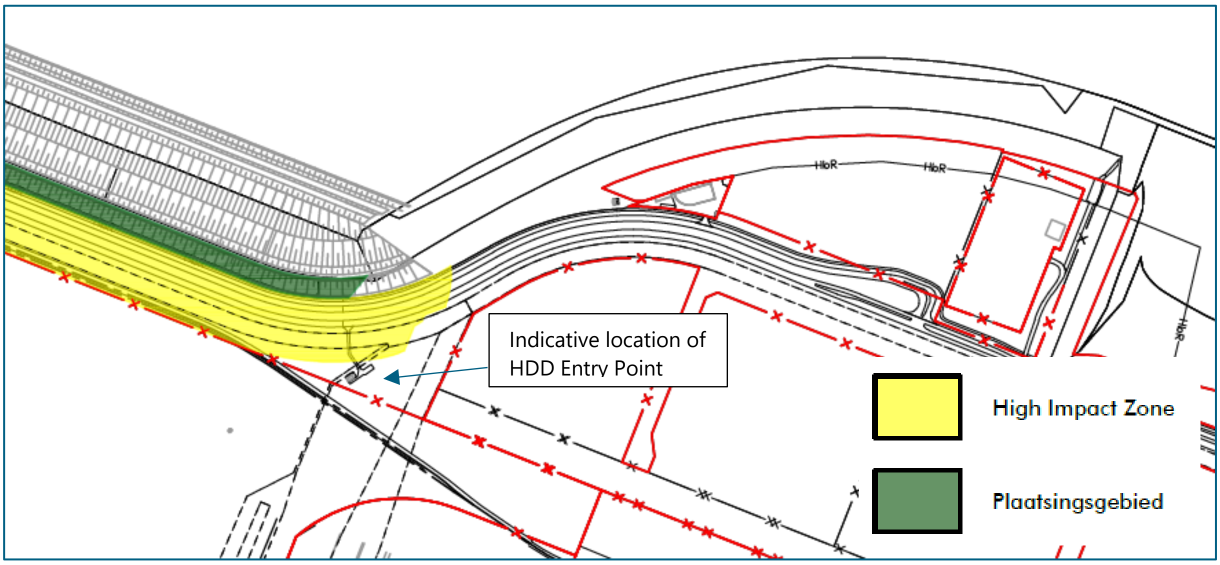

Figure 3-5: High Impact zone and Turbine Installation Area (Ref. [22])

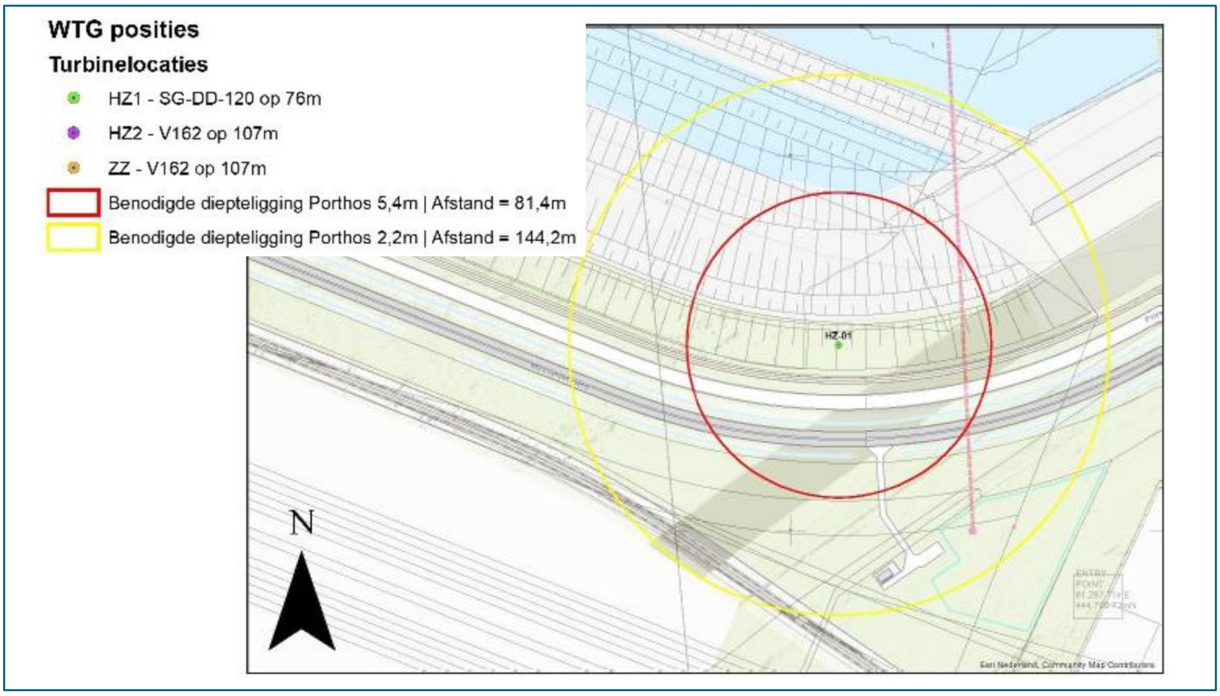

Figure 3-6: Result Impact Assessment: Impact Wind Turbine on Porthos Pipeline Burial Depth (Ref. [22])

3.5.6 Onshore / Nearshore Permit Areas

The following permit areas have been identified for Maasvlakte 1 (blue), Maasvlakte 2 (red) and TenneT HKZ (green) (Figure 3-7).

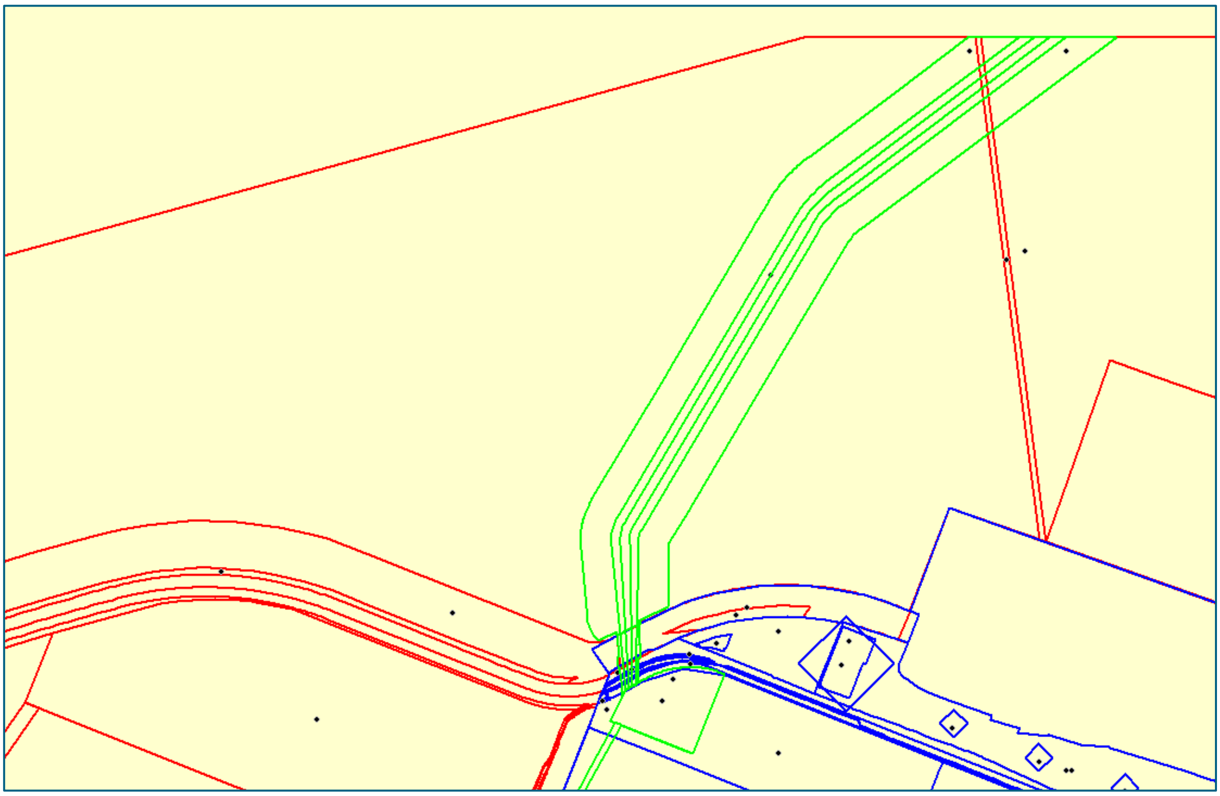

Figure 3-7: Permit Areas, Maasvlakte 1 (blue), Maasvlakte 2 (red), TenneT KHZ (green) (Ref. [28])

3.5.7 Sea Defence Crossing

The sea defence will be crossed in a straight line using a trenchless drill method. The routing/heading of the pipeline, in the horizontal plain, from the onshore plot plan to nearshore shallow plain (at north side of the sea defence), is not influenced by the presence of the sea defence.

The sea defence has an influence on the safety zone for crossing a "Waterstaatwerk", which sets code requirements for the entry and exit point of the crossing. The safety zone has been defined in accordance with NEN3651 (Ref. [11]).

The feasibility of the sea defence crossing route is determined by the technical feasibility of the drilling trajectory, given the crossing requirements of the pipeline with the sea defence and the required separation distance between the PORTHOS pipeline and the TenneT cables. In addition, the sea defence crossing route is also influenced by the Maasgeul crossing; care must be taken that the pipeline crossing with the Maasgeul is not unnecessarily long. Furthermore, the feasibility of the pipe string pull-in from offshore to onshore is also taken into consideration for the optimal sea defence crossing.

3.5.8 HKZ TenneT Cables - Electromagnetic Interference

Both in the sea defence crossing zone and in the nearshore zone, at the southern side of the Maasgeul, the pipeline route will be situated relatively close to the four TenneT HKZ cables.

An electromagnetic interference study has been carried out (Ref. [10]) in accordance with NEN3654 to investigate electrical and thermal influence by the four 220 kV cable connections of TenneT. The study established how the pipeline and high-voltage systems adversely affect each other from a safety and integrity point of view.

Two situations have been investigated for the HDD zone and the nearshore/offshore zone:

1. PORTHOS pipeline at a distance of 100 m from the TenneT cables
2. PORTHOS pipeline at a distance of 50 m from the TenneT cables

For both situations it was concluded in the study that no unacceptable thermal or electrical interference was caused by the presence of the HKZ power cables, that would be of impact on the PORTHOS pipeline. No additional measures are required to meet the requirements stipulated in NEN3654.

For routing, a minimum distance of 50 m will be used in the HDD and nearshore and offshore zones between the PORTHOS pipeline and the TenneT HKZ cables. 50 m is also considered as a safe margin at the HDD exit pit. The pit will be several meters deep, so the influence width of the dredged sides slopes should have sufficient margin relative to the TenneT cables.

3.5.9 **Environmentally Protected Areas**

The PORTHOS Pipeline crosses a Natura 2000 area ("Voordelta (VHR)") in the Maasvlakte nearshore zone. The exit pit of the trenchless HDD shore crossing is situated within the Voordelta area. The south side of the Maasgeul shipping channel is also the south-boundary of the mentioned Natura 2000 area.

The crossing length through this Natura 2000 area shall be kept to a minimum.

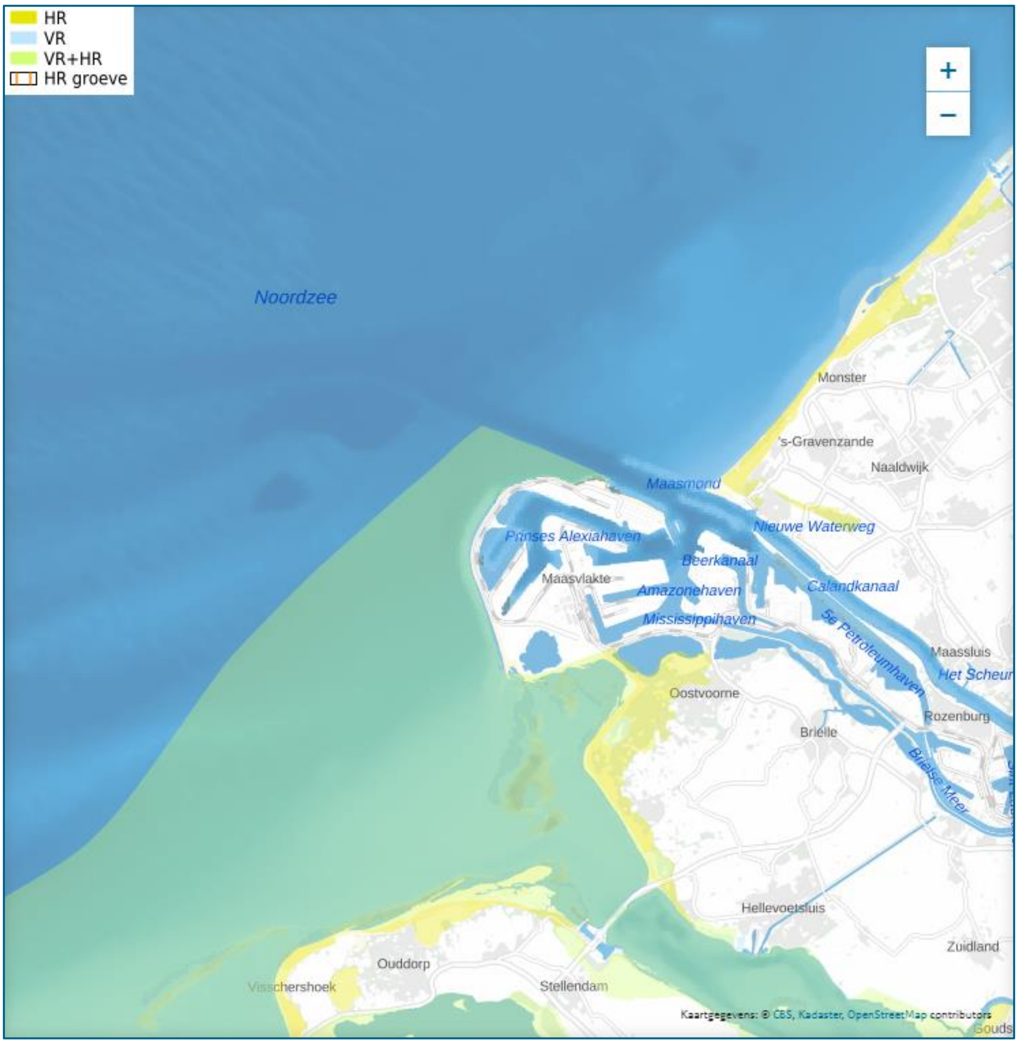

Figure 3-8: Natura 2000 area (Ref. [21])

3.5.10 Maritime Zones and Maritime Borders

The Porthos pipeline will cross several maritime zones and borders defined in the nearshore / offshore zone (Ref. [27]).

Figure 3-9 below presents the zones/borders that apply along the Dutch coast.

1. "Basislijn": normal baseline runs where the sea dries out at low tide (low water line).
2. Province / municipal boundary: up to 1 km from the coastline
3. Zone up to 1 nautical mile: the ecological status of the Water Framework Directive applies up to this limit
4. Continuing NAP -20 meter line (-20 m (4.1) & 2 m buffer (4.2)): this depth line serves as the boundary of the coastal foundation and is important in particular for regulations regarding

excavation; these are not permitted landward of this border. The depth line typically also serves as the outer limit of the Natura 2000 areas. However around the Maasgeul different Natura 2000 boundaries apply, see section 3.5.9.

5. Zone up to 3 nautical mile: meaning of this zone has been largely dropped. The zone is still important for fishing

6. Zone up to 6 nautical mile: the zone is still important for fishing

7. Safety Zone, typically 500 m radius around offshore platforms, such as P18-A. Zone is not indicated on Figure 3-9).

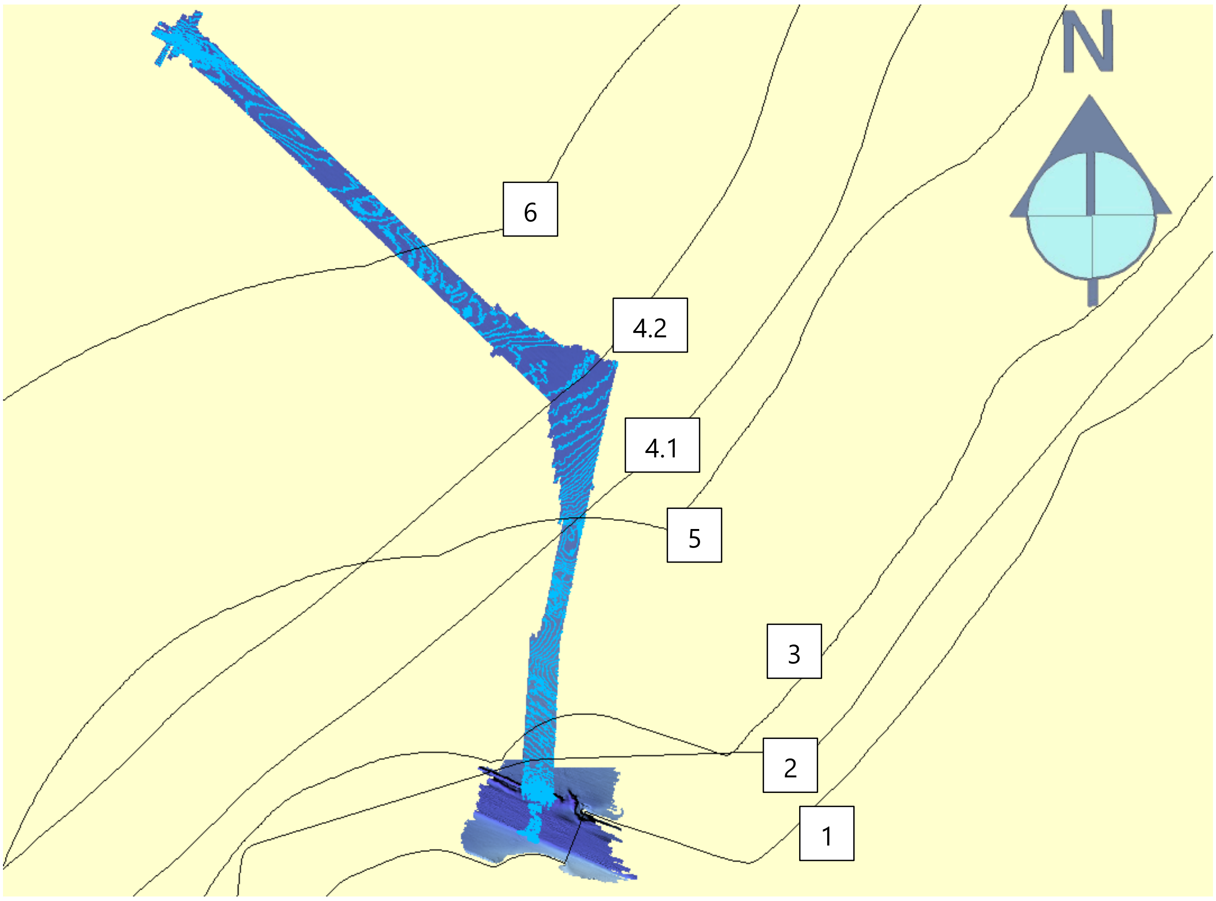

Figure 3-9: Offshore Pipeline: Maritime Zones and Maritime Borders (Ref. [22])

Other maritime zones result from crossing the Maasmond area.

Crossing of the Maasgeul and Noordberm and its side slopes with the PORTHOS pipeline cannot be avoided.

Two options have been considered to cross the Maasgeul:

1. Trenching and backfilling method

2. Extending the trenchless sea defence crossing up to the north side of the Maasgeul/Noordberm.

A cost- and risk assessment led to the decision to make trenching and backfilling the base case Maasgeul crossing method. See also Ref. [11]

The PORTHOS pipeline will cross two identified maintenance areas. Within these areas dredging equipment maintains at least the Nautical Guaranteed Depth. In 2012 the width of the Maasgeul was increased on the northern side with a berm of 245 m wide which is dredged to a depth of LAT -20.0 m. That section is referred to as the “Noordberm” and might in future be dredged to NGD depth similar to that of the main channel. Thereto, Noordberm is assessed in a comparable manner as the current main channel. At the head of the breakwaters, the width of berm is 0 m, and it increases to 245 m at approx. 1 km west of the tip of the northern breakwater.

Depth may locally exceed the Nautical Guaranteed Depth (NGD) in the Maasgeul. This is the case in the Noordberm, close to the current northern Maasgeul slope, where erosion gullies have been observed.

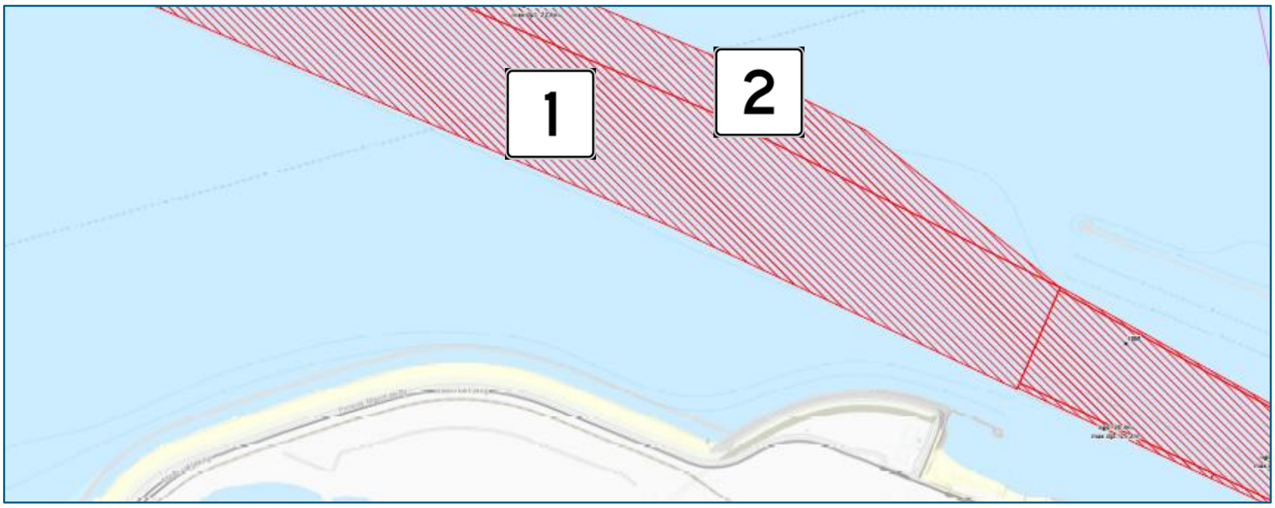

Figure 3-10: Maasgeul “onderhoudsvakken” relevant for PORTHOS (Ref. [20])

The Maasgeul maintenance areas are crossed by the proposed pipeline route with a heading of 002°22’32” (based on RD datum) or 000°29’36” (based on ED50 datum). This is a heading that results from an optimization where the following aspects play a role:

- Preferred straight offshore to onshore pipeline pull-in path that reaches from the north side of the Maasgeul (first tangent point) up to at least the southern fence of the onshore plot area.

- Distance to TenneT Beta-2 cable, minimum shall be: 50 m. According to NEN3654: There must be at least a horizontal distance of 100 m or as much more as the installation method requires between two pipes / cables that are not laid at the same time and / or the licensing authority or the owner of existing nearby cables and pipes so require. TenneT has been informed about the PORTHOS route and the TenneT cables have been included in a pipeline-cable influence study. The PORTHOS pipeline and the TenneT cables are not adversely affected by each other. Therefore 50 m separation distance shall be used as a minimum.

- Optimization of the entry location of the trenchless sea defence crossing within onshore plot area, taking into account:
  - Keep enough space for equipment during construction phase.
  - Keep enough space for the onshore expansion spool (not within scope of this report).
  - the required safety zone distance to the toe of the sea defence: order 50 m minimum.
  - The 5 m zone of influence around the PORTHOS pipeline within the onshore plot plan.

The first offshore tangent point (TP-1a) in the horizontal plain is located 397 m north of the northern boundary of maintenance area 2 (Noordberm). Order 400 m is deemed sufficient to make the transition from the pipeline's crossing depth in the Maasgeul/Noordberm up to the required burial depth just north of Noordberm slope. The 397 m transition length towards the first IP does account for the following:

- Vertical pipeline transition using sagbend & overbend from a safe pipeline burial depth within the Maasgeul/Noordberm towards the required burial depth just north of the Maasgeul/Noordberm. A short straight section (both vertical and horizontal plain) lies in between the vertical sagbend&overbend and the north Tangent Point (TP) of the first horizontal route curve.
- Morphological migration and scour processes of the northern slope of the Noordberm. The migration of the northern slope during PORTHOS' lifespan plays an important role. The impact is assessed in the Offshore Route Safety Study (Ref. [4]).
- Requirement as defined by HbR and Rijkswaterstaat ("Bodembeheerder").
- Burial depths of similar (adjacent) cables and pipelines in the Maasgeul area.

The routing design is based on the assumed execution method that the pipe string in between the onshore battery limit and the first tangent point at the northern side of the Maasgeul is installed by a combination towing and pulling in. Laying of the remaining part of the route up to platform P18-A is based on the assumption that laying will resume by recovery of the Maasgeul crossing pipe end just north of the Noordberm.

Laying the other way around, hence from P18-A towards the northern side of the Maasgeul will require an Above Water Tie-In (AWTI) just north of the Maasgeul. The consequences of using this (reverse) lay direction are not further investigated.

The inevitable crossing of the PORTHOS pipeline with the listed zones and borders may lead to additional (permit) requirements. No route optimization is possible relative to any of the maritime zones/borders.

3.5.11 Fishing Areas

The seabed is extensively covered with trawl scars throughout the majority of the surveyed route corridor, indicating considerable fishing activity in the area (Ref. [14]).

Fishing is allowed in the area apart from the Maasgeul area. Fishing activities are typically not allowed within an area of 500 m around platforms or subsea structures. To limit the impact on fishing activities the PORTHOS pipeline route will follow existing pipeline and cable routes where possible.

3.5.12 Shipping activities

Four types of shipping areas can be distinguished on the North Sea

1. Approach areas ("aanloopgebieden")
2. Shipping lanes
3. Offshore anchor areas
4. Research or merchant vessels working on the North Sea in a specific area or near an offshore structure

The highest shipping traffic load relevant for the PORTHOS project comes from route bounded vessels entering and leaving the Maasvlakte area.

The pipeline crossing with the Maasgeul shipping lane and the route towards Scheveningen harbour cannot be avoided with pipeline routing.

There are no strict pre-defined requirements in the horizontal plain for crossing the shipping lanes. Although pipeline length within channels needs to be kept to a minimum and offshore infrastructure (cables and pipelines) need to be bundled as much as possible in a corridor. This leads to a preferred perpendicular or close to perpendicular channel crossing.

The PORTHOS pipeline will be laid in such a way that it shall not present any danger or impediment to shipping.

3.5.13 Oil and Gas Activities

Oil and gas activities are clustered around the offshore hydrocarbon fields as presented in Figure 3-11. Crossing of oil and gas fields cannot be avoided.

Relevant for the routing of the PORTHOS pipeline are platform P18-A and subsea wellhead Q16-FA-1. Identified drilling locations along the route are: Q16-05, Q16-06, Q16-08 and P18-02.

Table 3-1: Oil and Gas Activities (UTM31N-ED50)

Name + type	Easting	Northing
P18-A - Platform	564303.87	5775794.65
P18-02 – Drilling Location	565845.00	5773940.00

Q16-FA-1 – Subsea Wellhead	571786.00	5768720.00
Q16-05 - Drilling Location	570560.00	5769982.00
Q16-06 - Drilling Location	571840.00	5768801.00
Q16-08 - Drilling Location	572606.00	5765132.00

The minimum separation distance to the pipeline is in principle 500 m unless reduction of this value can be agreed upon with the responsible operator.

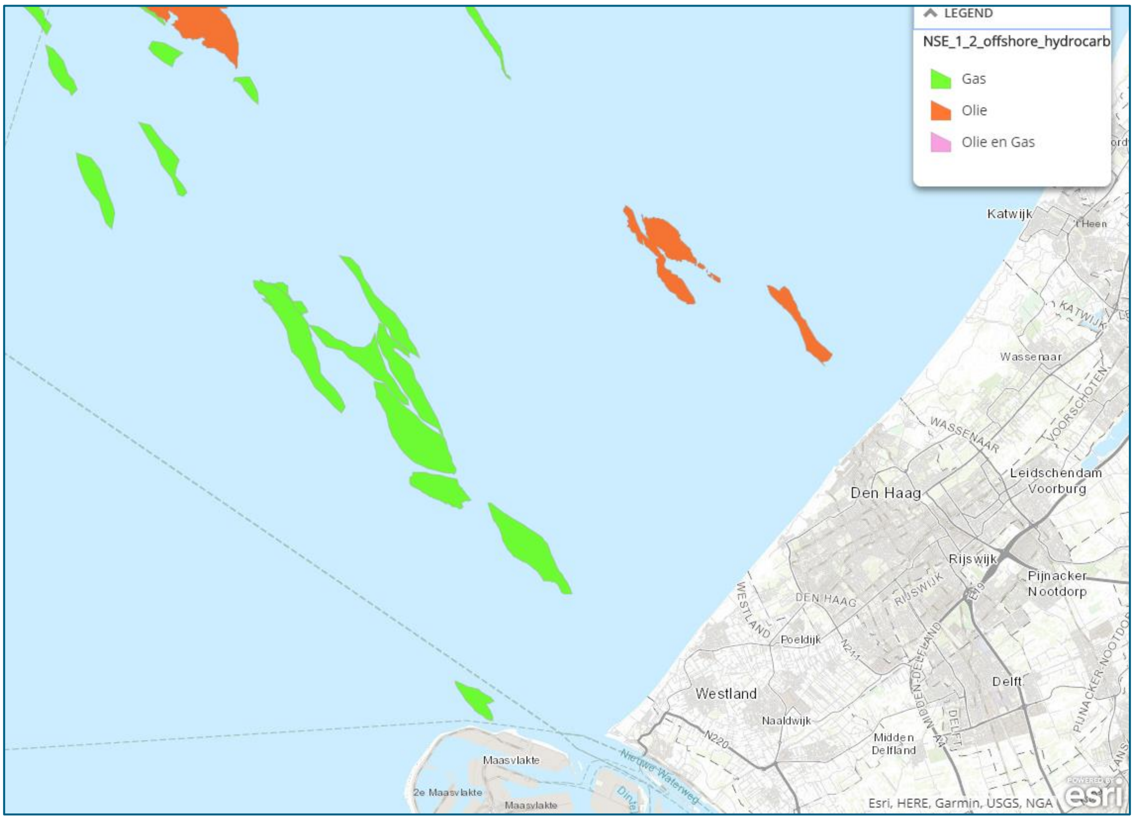

Figure 3-11: Offshore oil and gas reservoirs (Source: TNO North Sea Energy Atlas)

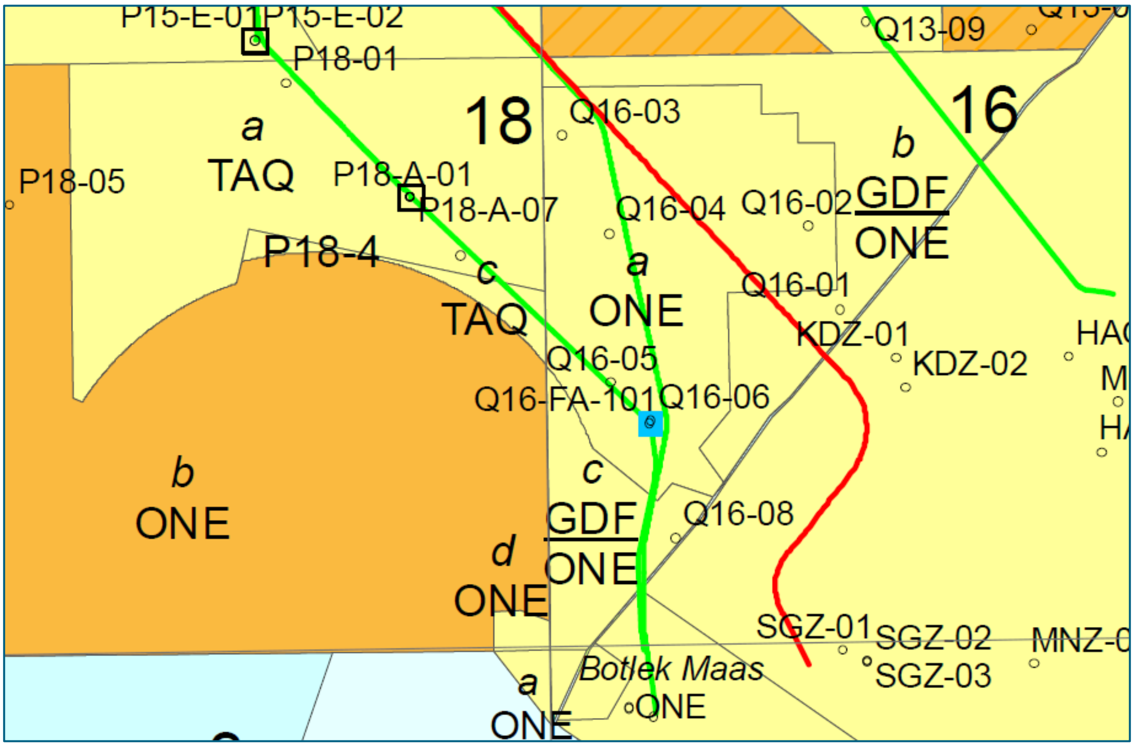

Figure 3-12: Offshore Platforms and Subsea Wells in blocks P15, P18 and Q16 (Source: TNO)

3.5.14 Existing/Planned Submarine Cables

The following types of cables can be distinguished in the North Sea:

1. North Sea control cables
2. North Sea electricity cables
3. North Sea telecom cables (in service and out of service)

For the PORTHOS route section eight (8) submarine cables have been identified, two (2) existing cables and six (6) planned.

1. "UK - NL 4" (KB0051), telecom cable Scheveningen (NL) to Lowesoft (GB) (1956), status: this cable is abandoned, owner unknown
2. "PL0138_UM", umbilical / control cable, Q16-FA-1 to P18-A – status: active, owner: Nederlandse Aardolie Maatschappij B.V.
3. "Evelop Scheveningen Buiten", electricity cable, status: granted/planned, owner: Scheveningen buiten
4. "PL0223_UM", umbilical / control cable, Q16-FA-1 to Maasvlakte, status: proposed, owner ENGIE E&P Nederland B.V.
5. 6. 7. and 8. "noz HKZ 1" to "noz HKZ 4" (Hollandse Kust Zuid), electricity cables (4), offshore wind area HKZ to Maasvlakte, status: planned/partially constructed, owner: TenneT

The proposed PORTHOS pipeline route leaving the Maasvlakte west of the future TenneT cables and passing subsea wellhead Q16-FA-1 at the south-west side, only crosses the abandoned UK-NL 4 telecom cable and the granted/planned Evelop Scheveningen Buiten electricity cable. The abandoned UK-NL 4 telecom cable was detected as unknown linear crossing during the DEEP magnetometer survey. Removal of the abandoned UK-NL 4 telecom cable is advised.

Another unknown crossing was detected just north of the P18-A to Q16-FA-1 infrastructure. This cable has no impact on the routing of the PORTHOS pipeline.

In principle, a minimum distance of 50 meters will be maintained between the PORTHOS pipeline and third-party cable infrastructure. In any case, coordination with the third parties is advised.

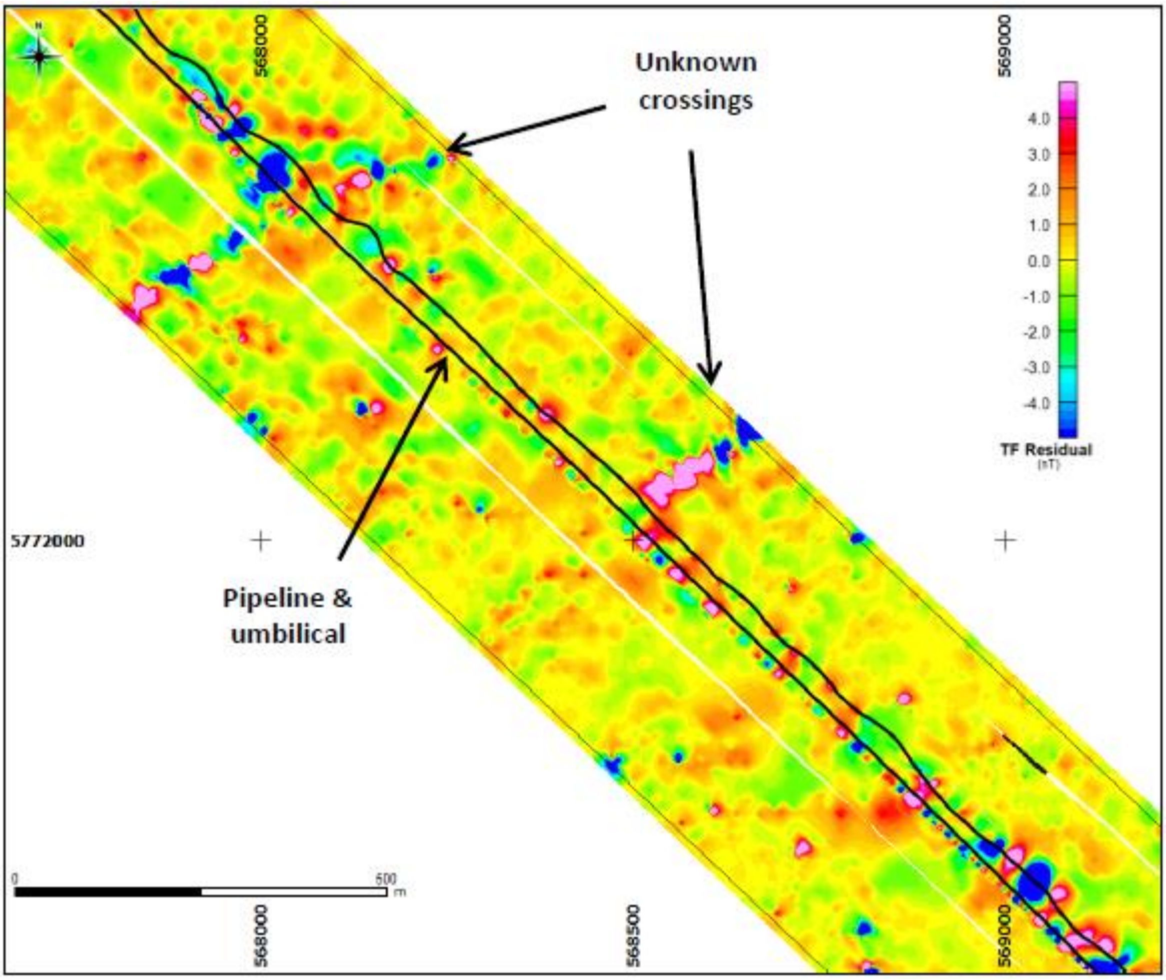

Figure 3-13: Magnetometer Data – P18-A to Q16-FA-1 infrastructure also showing unknown crossing (amongst others UK-NL 4 telecom cable) (Source: DEEP Survey Report (Ref. [13]))

The distance in between the active PL0138_UM umbilical and proposed PORTHOS route shall be more than 50 m. The same minimum distance of 50 m shall also be applicable for the PORTHOS Horizontal Directional Drill (HDD) section and the trenched section at the southern Maasgeul side bank.

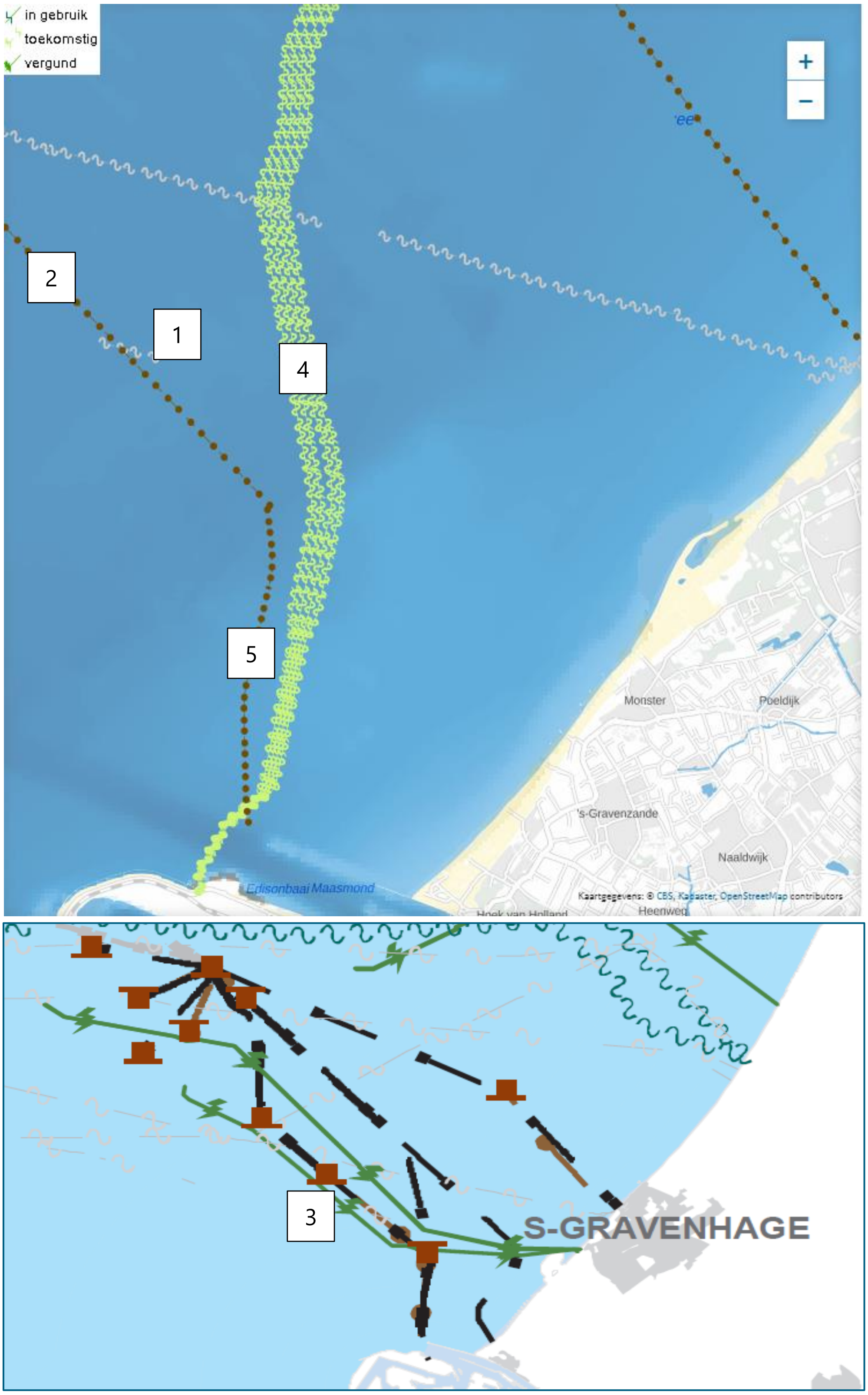

Figure 3-14: Offshore Cables (Source: Ref. [21]) (not shown in top figure: 3: Evelop Scheveningen Buiten)

3.5.15 **Existing/Planned Submarine Pipelines**

For the PORTHOS route section six (6) offshore pipelines have been identified, five (5) existing and one (1) planned.

1. "PL0138_HS", 2-inch methanol pipeline, Q16-FA-1 to P18-A, status: active, operator, Nederlandse Aardolie Maatschappij B.V.

2. "PL0138_PR", 8-inch gas pipeline, Q16-FA-1 to P18-A, status: active, operator: Nederlandse Aardolie Maatschappij B.V.

3. "PL0223_PR", 8-inch gas pipeline, Q16-FA-1 to Maasvlakte, status: proposed, operator: ENGIE E&P Nederland B.V.

4. "PL0099_PR", 26-inch gas pipeline, P15-D to Maasvlakte, status: active, operator: TAQA Energy B.V.

5. "PL0106_HS", 3-inch methanol pipeline, P18-A to P15-D, status: active, operator: TAQA Energy B.V.

6. "PL0106_PR", 16-inch gas pipeline, P18-A to P15-D, status: active, operator: TAQA Energy B.V.

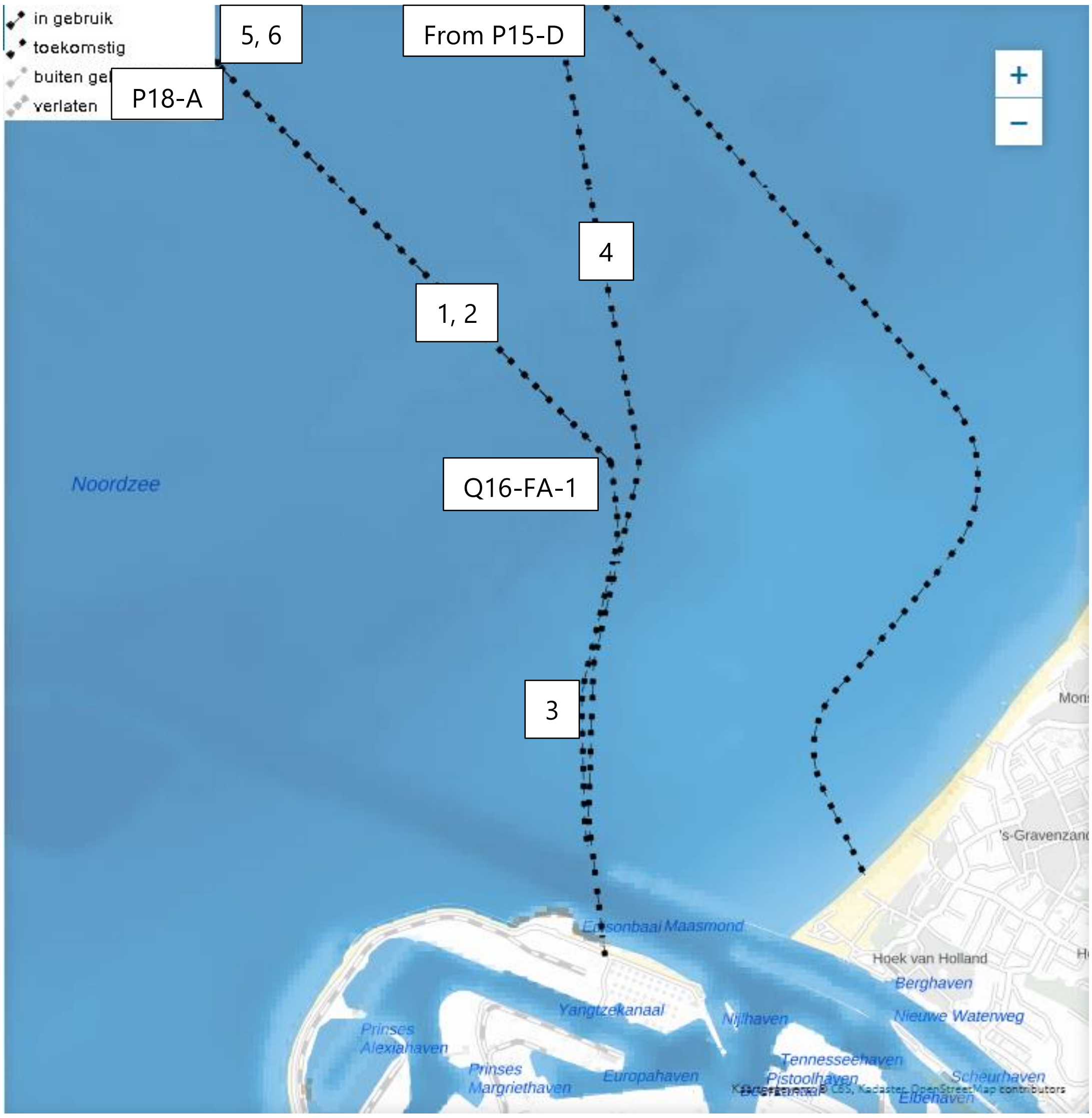

Figure 3-15: Offshore Pipelines (Source: Ref. [21])

Pipelines 1, 2 and 4 are detected by DEEP's survey. The 26-inch gas pipeline was detected both from magnetometer and sub-bottom data. The 2-inch methanol pipeline was detected from magnetometer data.

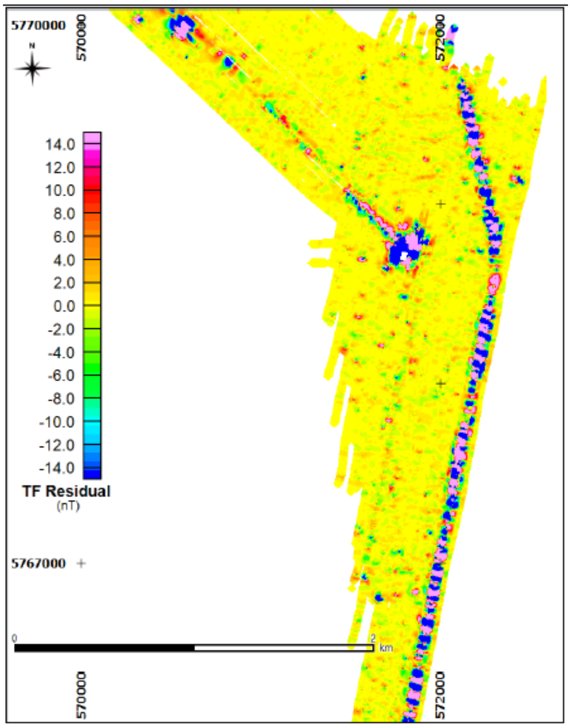

Figure 3-16: Detected pipelines, #1, 2 and 4 (Source: Ref. [13])

In principle, a minimum distance of 50 meters will be maintained between the PORTHOS pipeline and third-party pipeline infrastructure. In any case, coordination with the third parties is advised.

Crossings with existing pipelines shall be avoided where possible. Given the location of the onshore plot area, the preferred routing via the inner (south) side of Q16-FA-1 and the preferred arrival side near platform P18-A, pipeline crossings can be avoided.

The routing of PORTHOS will not be adjusted for a possible theoretical crossing with the proposed 8-inch gas pipeline (#3).

Not shown on Figure 3-15 are the possible/proposed plans around platform/subsea well P18-B (see Figure 3-17). Possible interactions with cable and pipeline infrastructure to/from this platform are ignored for this study as these plans seem premature if at all existing and the pipelines and cables are not yet found in North Sea cable and pipeline databases.

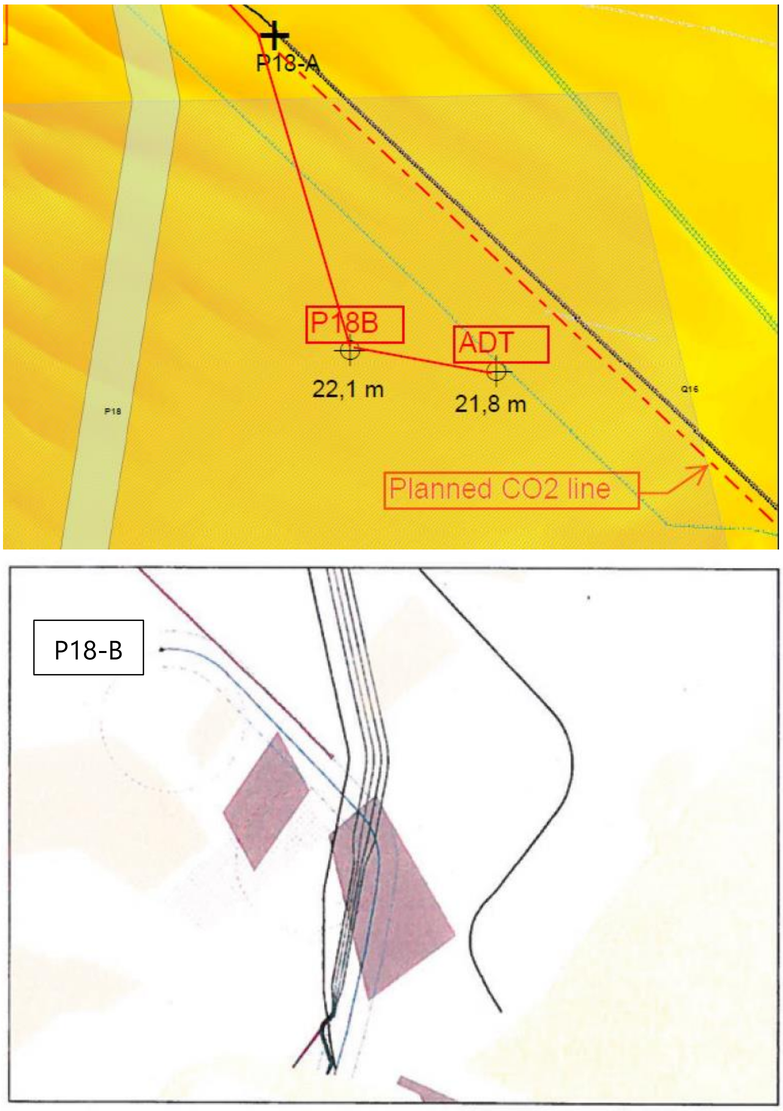

Figure 3-17: Possible developments around P18-B, top figure source: TAQA 2019 (source: email from TAQA to Porthos)), bottom: source: Oranje Nassau Energie (ONE) 2017 via RVO website

3.5.16 Existing Cables, Pipelines and Seabed Intervention near P18-A

Figure 3-17 shows the situation around platform P18-A. The indicated P18-A cables, pipelines and seabed interventions, such as rock dumping and placed matrasses will play a role in the design of the tie-in arrangement to the riser.

One of the starting points which significantly affects the routing of PORTHOS is the desire to end up south of TAQA Platform P18-A. Figure 3-19 shows a schematic representation of the PORTHOS Target Box, south of platform P18-A, and the preliminary fitted spool pieces from Target Box towards the riser location. TAQA provided “Memo on P18-A CO2 riser from IV FEED” (Ref. [29]) for the riser location.

The pipelay vessel can approach the platform P18-A up to safe distance. This safety zone distance may determine the target box location for the offshore end and is based on the type of lay vessel (dynamic positioning or not), the size of the vessel (especially the width and height), and the overhanging structures on platform. The owner of the P18-A, TAQA, may come with additional requirements that may affect the approach distance.

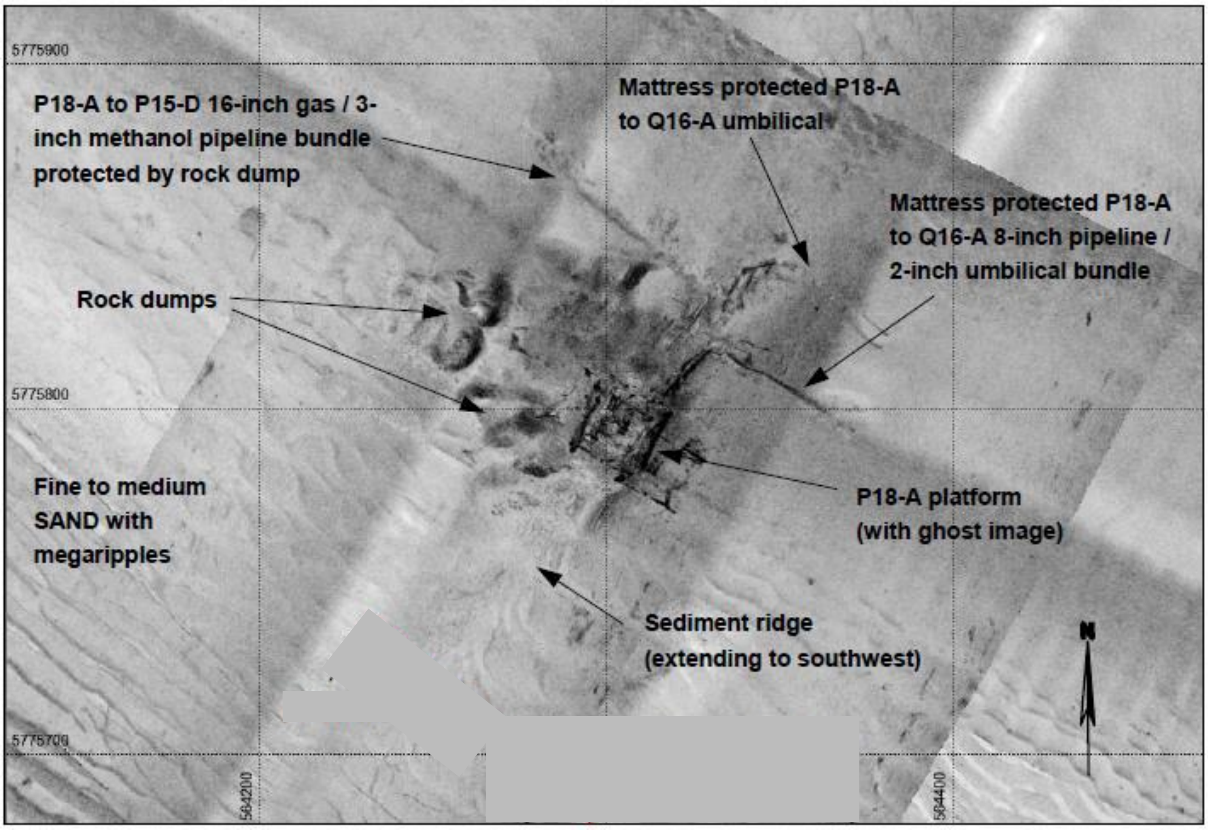

Figure 3-18: Detail of Platform P18-A showing identified cables, pipelines and seabed interventions (source: Ref. [14])

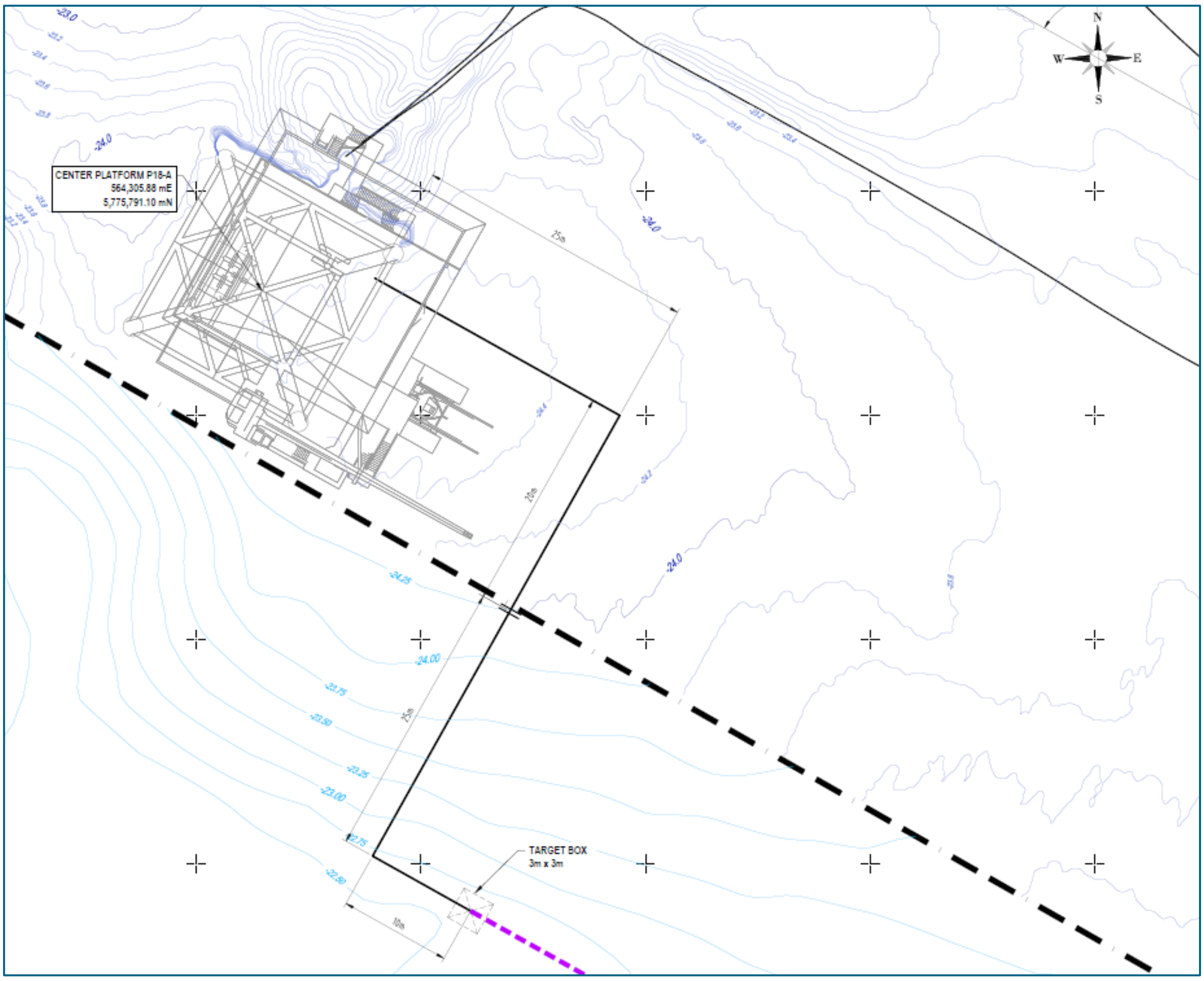

Figure 3-19: Schematic representation of the PORTHOS Target Box, south of platform P18-A, and the spool pieces from Target Box towards the riser location

3.5.17 Offshore Attention Areas

There are three areas for military purposes identified in the far vicinity of PORTHOS pipeline project. All three are former ammunition dump areas and further away than 500 m from the PORTHOS pipeline and shore crossing and therefore not further considered important for pipeline routing.

Figure 3-20: Offshore Military Areas – Indicated are former ammunition dump areas (Source: Noordzeeloket)

Other offshore attention areas for the pipeline routing are areas with wrecks, Unexploded Ordnance (UXO) and Cultural Heritage Objects (CHO). The PORTHOS offshore pipeline routing aims to avoid these objects and allowing for a safe working distance if required; this may vary per object. Local rerouting around these objects within the route corridor is not considered during FEED design.

3.5.18 Soil Dredging, Soil Spoil Related Areas

Figure 3-20 gives a complete overview of the defined 'dredging areas'. Dredging areas include sand extraction areas and sand spoil areas.

Colours indicate the following in the top figure:

- Grey line shading: "test extraction areas"
- Orange line shading: "other extraction areas"
- Sand colour filled: "sand extraction areas: type: licensed"
- Sand coloured boundaries: sand extraction areas: type: abandoned
- Red coloured boundaries: labelled as: "search areas MER 2017-2018"

Colours indicate the following in the bottom figure:

- Red line shading: Maasgeul maintenance blocks (dredging areas Rijkswaterstaat)

- Purple coloured boundaries
    - Group of areas on the left: see also top figure
    - Large area on the right: sand distribution area called Loswal Noord, which is part of the Dutch “Kustfundament”

The arrows in Figure 3-21 indicate corner locations that are closest to the proposed PORTHOS pipeline route.

The pipeline is as much as possible routed around the defined areas. Where the separation distances are small (i.e. < 500 m) or where crossing could not be avoided (e.g. the Maasgeul), the proposed pipeline crossing will be agreed with the operator of the affected area. Rerouting or fulfilling of additional requirements may be necessary, while local route optimization might be possible based on the preferences and requirements of the area operator.

The possibility of crossing of abandoned sand extraction areas to shorten the pipeline route is not included in the route consideration.

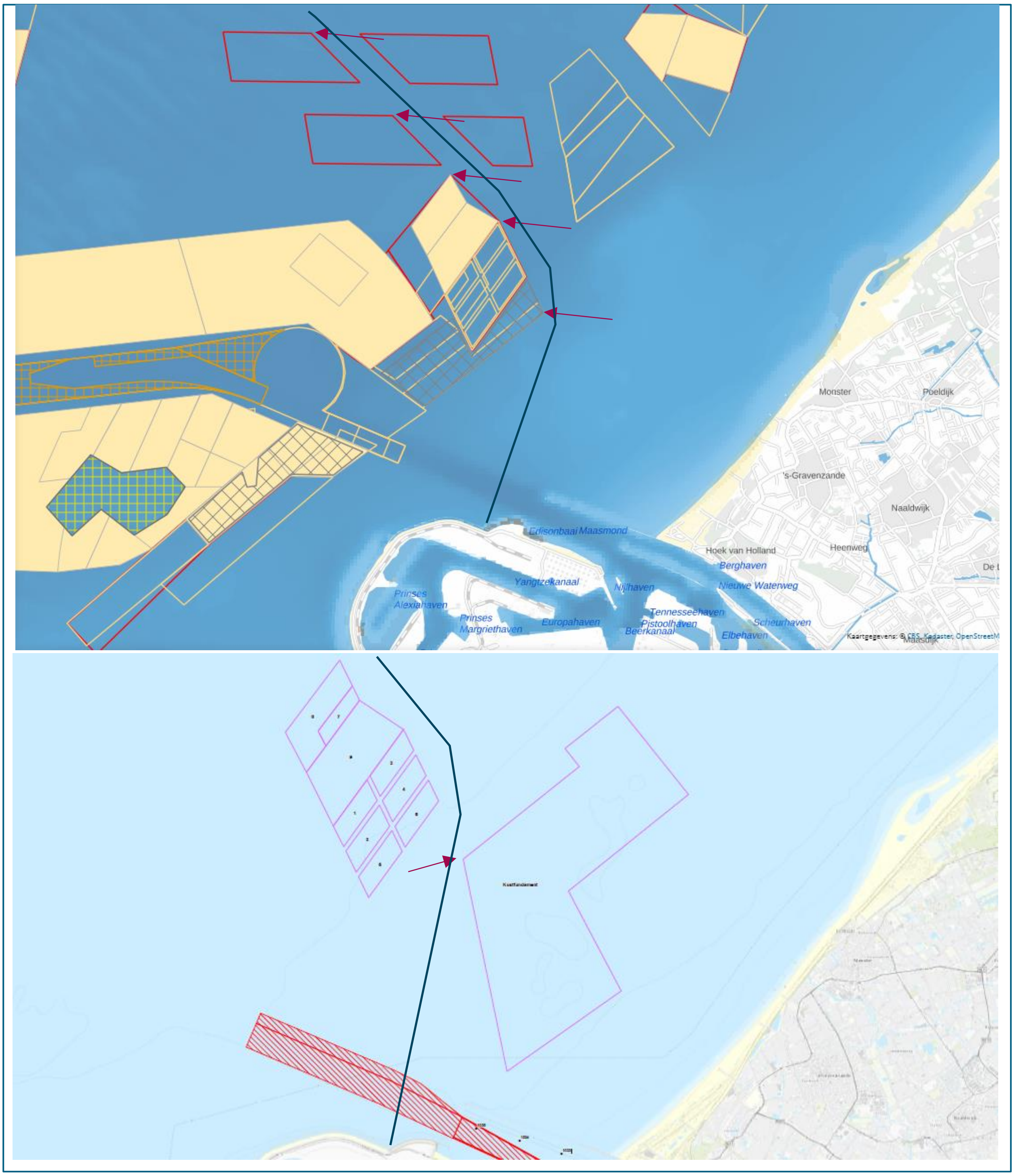

Figure 3-21: Sand Mining, Sand Spoil and Dredging Areas (Source subfigure 1: Ref. [21], Subfigure 2: Received Client Data showing amongst others boundary of "Kustfundament" spoil area). Note, routes are only indicative.

3.5.19 Geohazards and Typical Seabed Features[KE(1]

The most prominent identified “geohazards” and typical seabed features for the PORTHOS pipeline are listed below (Ref. [14]).

- Onshore geohazard around the onshore plot plan are not expected since the Maasvlakte is a reclamation area consisting of compacted sand. The pipeline crossing with the sea defence however needs to be checked for seepage, in accordance with NEN 3651, this to prevent damage to the sea defence. Routing that may lead to direct or indirect triggering of sea defence failure mechanisms shall be avoided. Also the minimum required drill depth under the sea defence (10 m) and the minimum required distance between the entry point and the sea defence (order 50 m) must be taken into account in accordance with NEN 3651.

- At the south side of the Maasgeul (see circled area in Figure 3-22) a possible geohazard is identified. Possible shallow gas/peat at a depth of 4-5 m below the surface may be encountered. In the Maasgeul no geohazards are identified (see rectangular box in Figure 3-22).

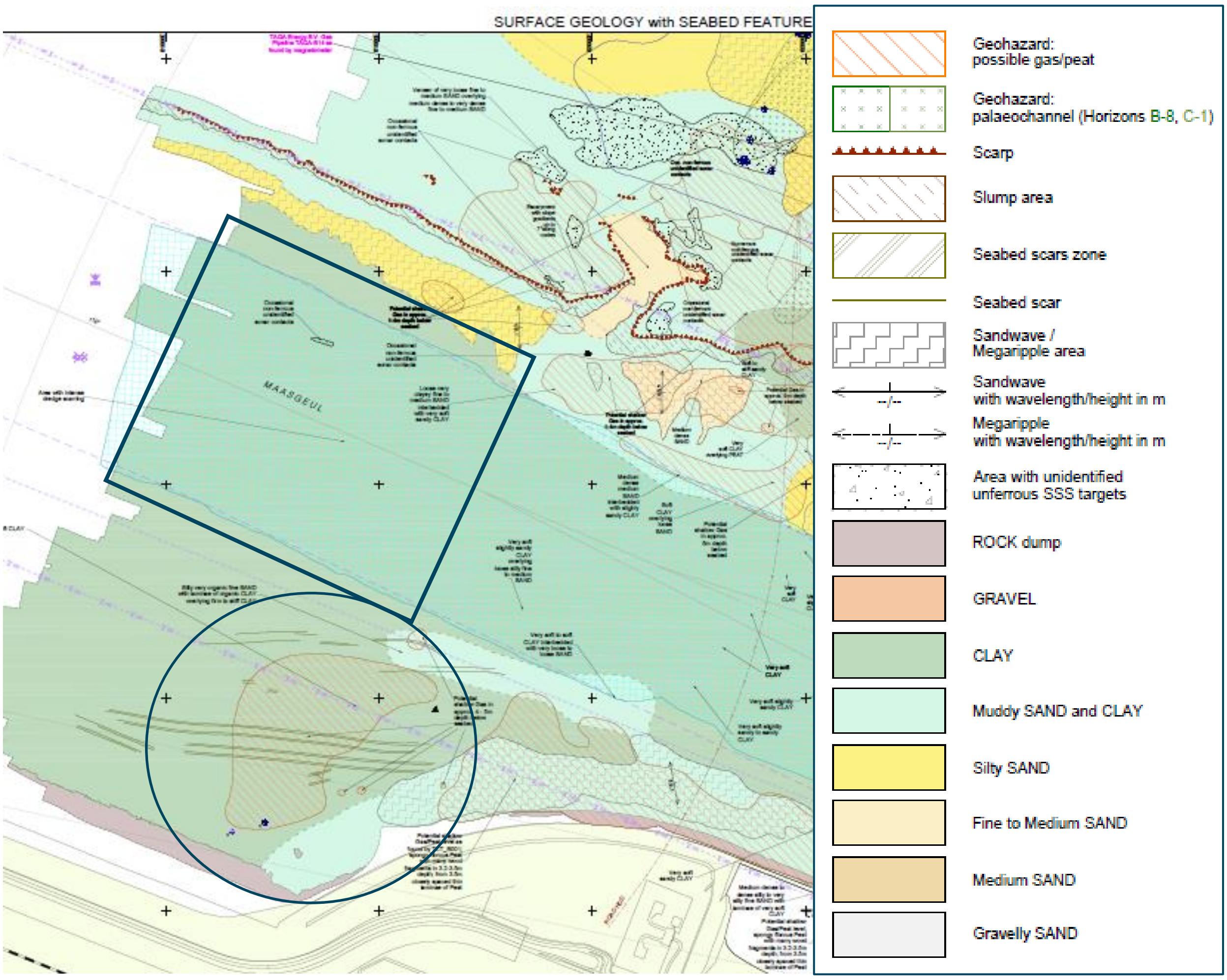

Figure 3-22: Surface Geology with Seabed Features (Ref. [17])

- On the northern side of the Maasgeul/Noordberm, where TenneT cables cross the northern Noordberm slopes, some more possible shallow gas/peat areas are identified. Depth of shallow gas typically varies from 1-5 m, with peaks depths to order 10 m. Shallow gas does not necessarily mean that the area cannot be crossed with a pipeline. However, if a more suitable route can be found around it, this is preferred.

- The Noordberm's northern side slope exhibit steep gradients, and comprises loose, potentially unstable sediments at seabed. This steep slope extends roughly three kilometre beyond the breakwater. The seabed on the northern slopes displays evidence of sediment movement, with the seabed having broken into blocks (up to eight metres long and one metre high) as a result of instability created by the dredging operations. The potential for further movement of the sediments on this slope is considered plausible (Figure 3-23). The seabed mobility study carried out for TenneT (Ref. [26]) establishes that the northern slope migrates northward with a rate in the order of meters per year. Also, a trend indicating erosion has been observed north of the Maasgeul. The seabed erodes a few centimetres a year. The southern Maasgeul slope is more regular.

- Locally, especially near the northern Noordberm wall, the water depth exceeds the NGD and the defined “maximum depth” for the Maasgeul/Noordberm. Narrow and relatively straight scour holes are observed. The holes are most likely formed due the flow regime, which is influenced by the breakwater, the construction of MV2 and the widening of the Maasgeul with the Noordberm. Depths may locally exceed LAT -30 m and depths can also vary over time (Ref. [26]).

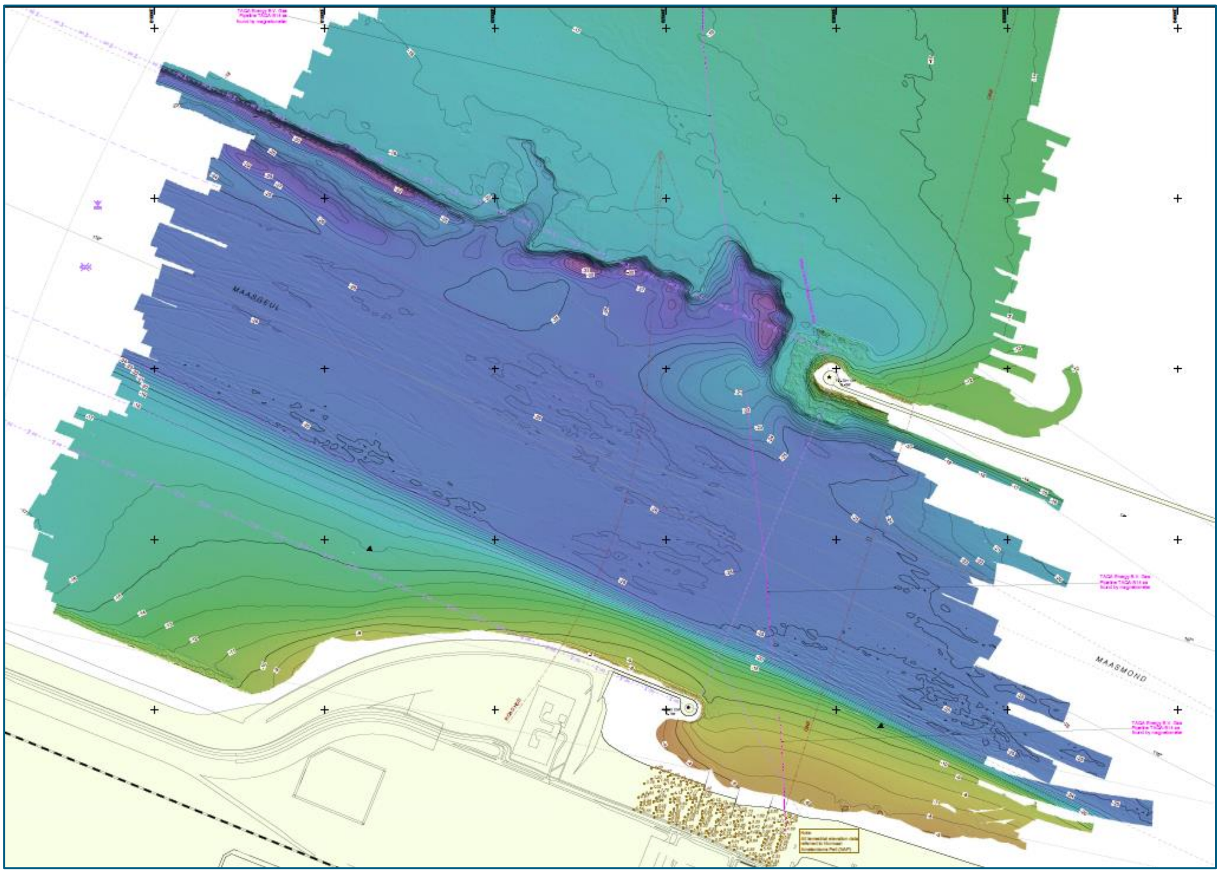

Figure 3-23: Indicative Bathymetry Data of Maasgeul (Ref. [16])

- Seabed mobility, most prominent around north Maasgeul slope, as indicated above and potentially around areas such as sand borrow areas and Loswal Noord, where human action at a location “A” may lead to seabed change (erosion/sedimentation) at another location “B”. From seabed mobility perspective basically no route optimization is possible. This is partly due to the preference to remain at west side of the TenneT assets and at the south side of the ONE-Dyas assets between Q16 and P18-A, and partly due to limited space available due to the preference to prevent further third-party interaction, e.g. with sand borrow areas. Seabed mobility will mainly have an effect on the required pipeline Depth of Burial (DoB). Establishing the DoB is part of the Offshore Route Safety Study (Ref. [4]). Routing completely around the seabed mobility areas is considered not feasible.

- Typical seabed feature: In the approach from the route curve near Q16 to platform P18-A poorly-developed megaripples have been observed (0.1 m to 0.2 m height, 8 m to 12 m wavelength, oriented northwest / southeast) The last three kilometres (up to platform P18-A) are characterized by well-developed megaripples (0.5 m height, 10 m to 20 m wavelength, oriented northwest / southeast) (Ref. [14]). Ripples with this minor magnitude will not affect the routing.

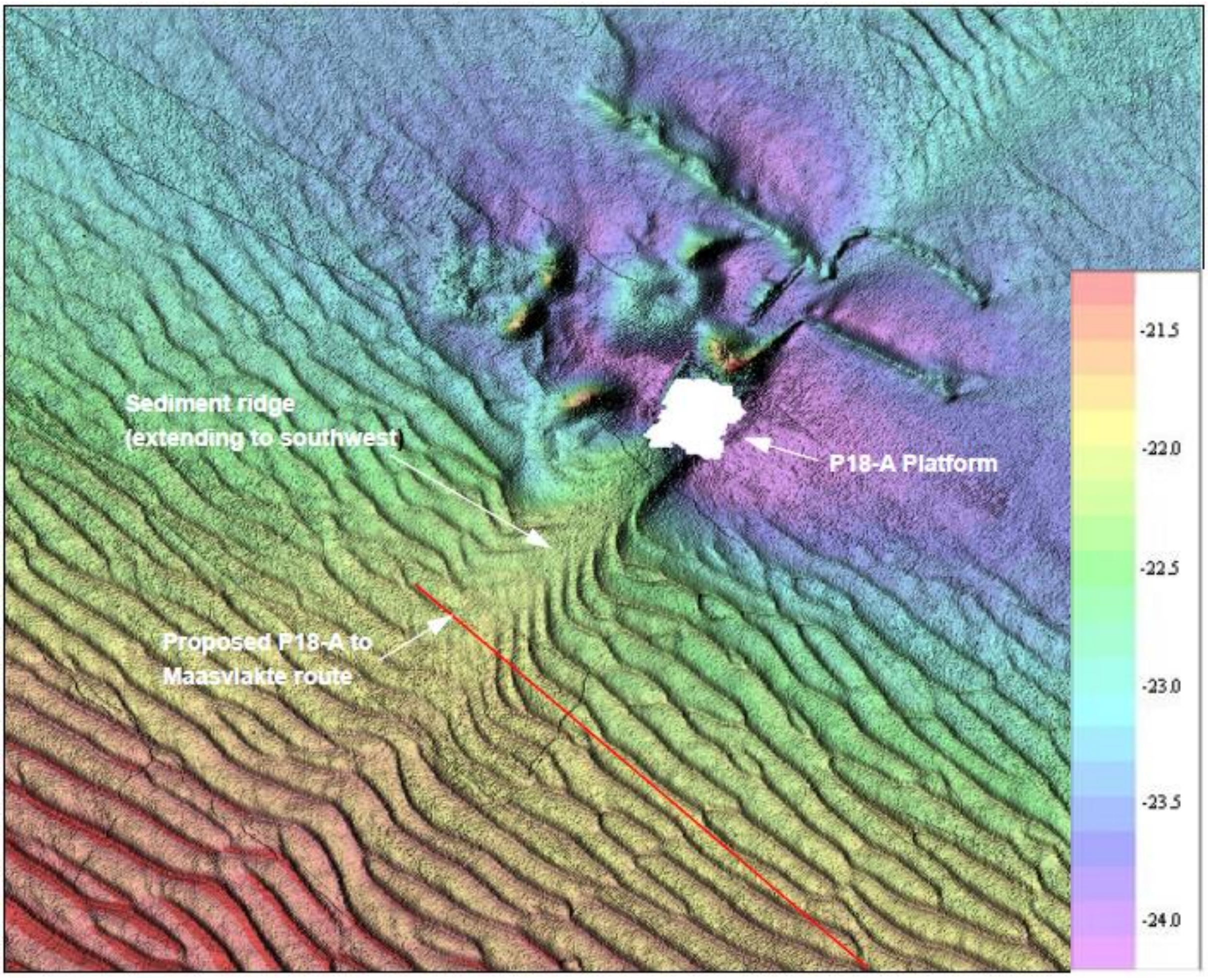

Figure 3-24: Well developed megaripples near P18-A Ref. [14], proposed P18-A to Maasvlakte route is indicative (Ref. [14])

4 Routing Input

This section provides an overview of additional input data.

4.1 CLIENT Supplied Survey Data

4.1.1 DEEP Survey

During the pre-FEED (Concept Study) phase various surveys have been performed (MBES, SSS, SBP, MAG) by DEEP (Ref. [13]) (Figure 4-1). The surveyed corridor is taken into account during the determination of the optimal FEED route.

During FEED phase an additional survey scope (MBES, SSS, SBP, MAG) was defined to fill the required gaps based on route ID "Porthos_04_20200221" (Ref. [8]). The as-surveyed area is presented in Figure 4-2.

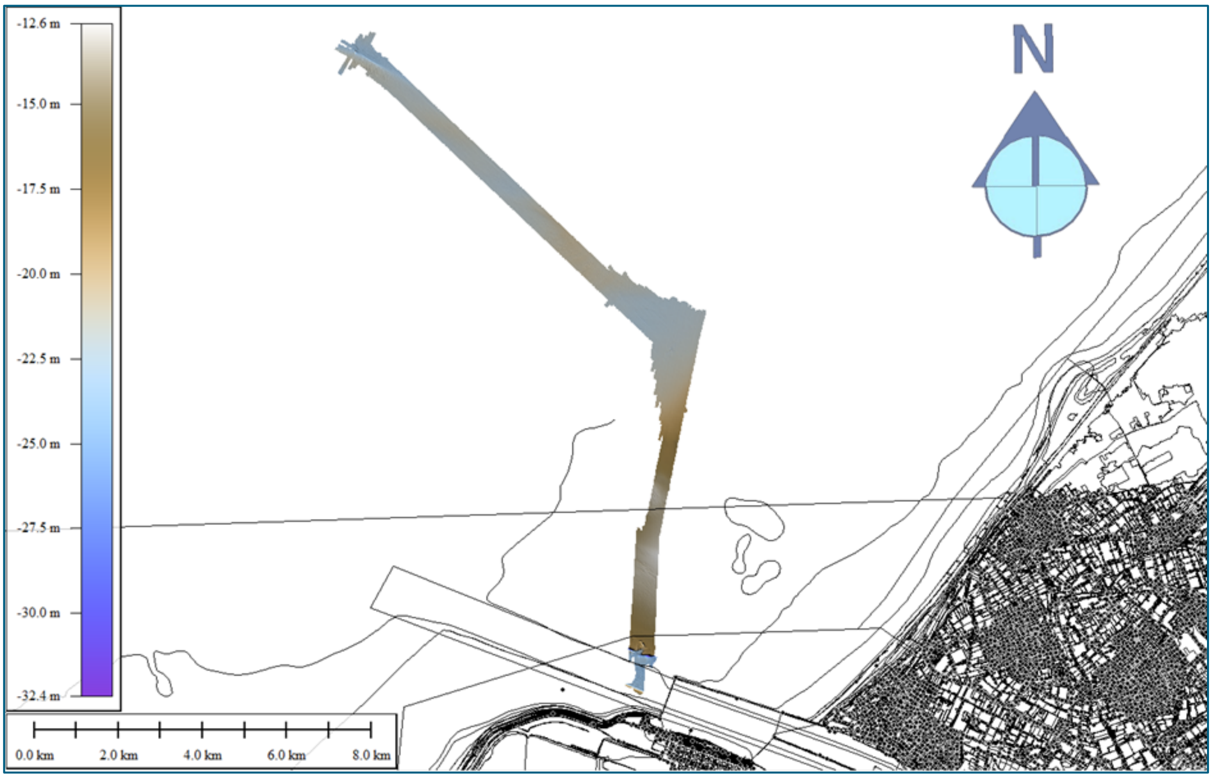

Figure 4-1: Corridor Surveyed by DEEP for Porthos (2019)

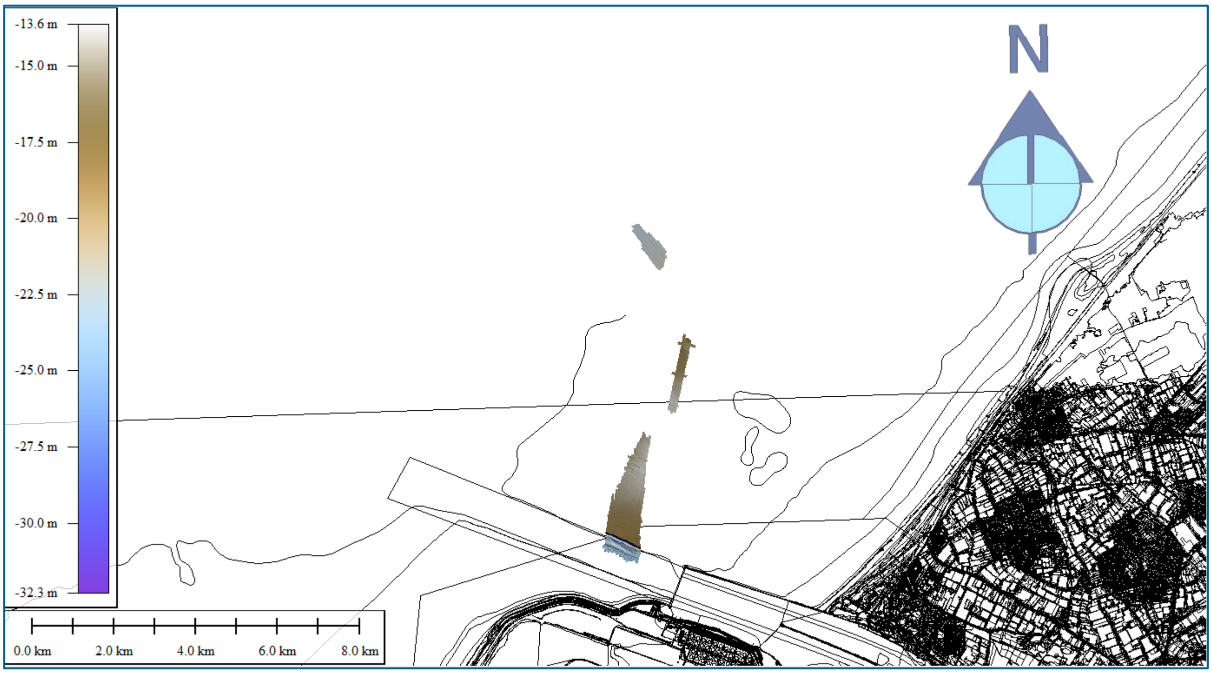

Figure 4-2: Additional Survey Scope Surveyed by DEEP for Porthos (2020)

4.1.2 Fugro Borehole Survey

Fugro conducted a geotechnical site survey along the pre-FEED-Update pipeline route. The survey was carried out in between the 2018 Concept Study Phase and the beginning of the FEED phase in 2019.

The survey included three boreholes (BH1 36 m penetration depth, BH2 35.5 m penetration depth, BH3 17 m penetration depth) to facilitate HDD design and execution across the Maasgeul shipping lane (Figure 4-3, Ref. [15]). The HDD was initially supposed to cross the Maasgeul.

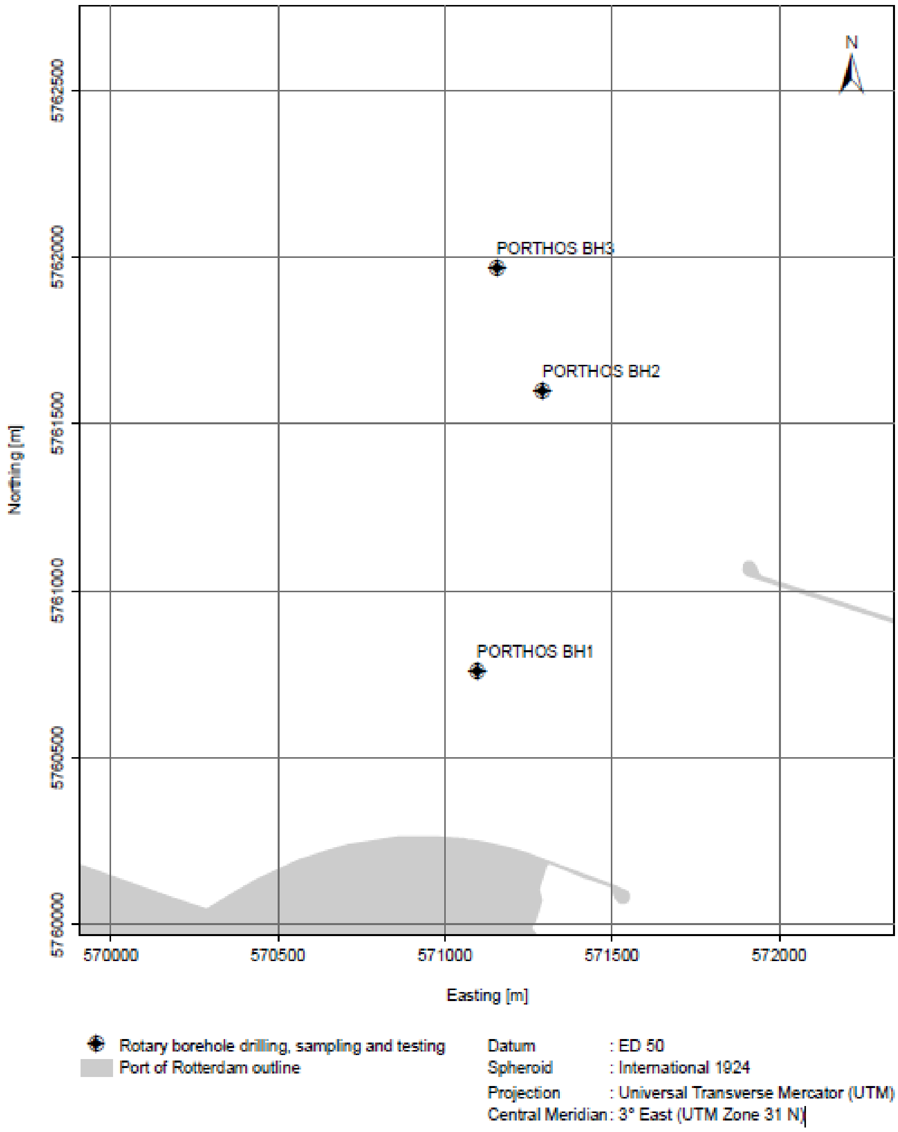

Figure 4-3: Fugro Boreholes BH1, BH2, BH3

0.0 m to 1.1 m - extremely low strength very dark grey sandy silty CLAY - with extremely closely spaced thin laminae of organic matter 1.1 m to 3.9 m - medium strength very dark grey CLAY, with few shells and shell fragments, with few organic matter - with closely to medium spaced thin to medium beds of dark grey clayey fine sand 3.9 m to 33.6 m - very dense light grey to grey slightly gravelly silica fine and medium SAND, with traces of organic matter, with traces of shell fragments from 3.9 m to 5.4 m - with closely spaced very thin beds of clay	0.0 m to 0.7 m - dark yellowish brown very organic medium SAND, with wood fragments - with putrid odour 0.7 m to 1.1 m - medium to high strength dark grey CLAY, with pockets and closely spaced thin to thick laminae of organic matter 1.1 m to 5.3 m - dense to very dense dark grey very silty silica fine and medium SAND, with traces of organic matter from 4.7 m - with closely spaced very thin to thin beds of sandy clay, with organic matter 5.3 m to 22.1 m - very dense dark grey gravelly silica medium SAND, with traces of organic matter	0.0 m to 3.2 m - thinly interbedded low strength to medium strength olive grey slightly sandy calcareous SILT and loose to medium dense olive grey SAND, with organic matter - at top many shells and shell fragments - with putrid odour 3.2 m to 16.9 m - medium dense to dense dark grey slightly silty to silty silica medium and coarse SAND

Figure 4-4: Fugro Boreholes BH1 (left), BH2 (middle) and BH3 (right)

4.2 Onshore Route Points

The coordinates of the onshore battery limit and the onshore entry point of the trenchless sea defence crossing are listed in Table 4-1. The initial coordinates have been established based on discussions with CLIENT during Workshop #2 (06-Dec-2019). These coordinates of the onshore battery limit and the onshore entry point have been updated again in April 2020 to avoid third party interaction with planned HbR, Stedin substations.

Table 4-1: Coordinates Onshore Battery Limit and Onshore Entry Point

Route Point	Coordinates RD Grid		Coordinates UTM31N-ED50		KP
	Easting [m]	Northing [m]	Easting [m]	Northing [m]	[km]
Battery Limit	61296.54	444786.25	570357.68	5759914.41	0.000
HDD Entry Point	61296.58	444787.25	570357.69	5759915.41	0.001

The battery limit is 1 m upstream of the HDD entry point, which is defined at ground level.

4.3 Offshore End Route Point

The coordinates of the preliminary end point of offshore pipeline within the Target Box, hence not considering the expansion spool towards P18-A, are listed in Table 4-2. These coordinates have been established based on discussions with CLIENT during Workshop #2 (06-Dec-2019). Minor adjustments have been made in April 2020 based on the further incorporation of the spool piece and the platform approach.

Table 4-2: Coordinates Preliminary Offshore End

Route Point	Coordinates UTM31N-ED50		KP
	Easting [m]	Northing [m]	[km]
Preliminary End	564 324.43	5 775 735.84	19.179

Table 4-3: Centre Platform P18-A

Route Point	Coordinates UTM31N-ED50	
	Easting [m]	Northing [m]
P18-A – on the southeastern side of the jacket, close to the northeastern leg. Coordinate = P18-2A6 well slot 3(1)	564 303.87	5 775 794.65

Notes: 1) As received from TAQA (e-mail TAQA to Intecsea & Porthos; 15-06-2020).

Route Point	Coordinates UTM31N-ED50

The proposed riser location on P18-A is indicated in the Memo provided by TAQA (Ref. [29]).

4.4 Route Definition Parameters

4.4.1 Naming Convention

A naming convention for the route definitions of PORTHOS pipeline has been adopted, of the format:

"Porthos_xx_yyyymmdd"

"xx" shall be used to indicate the route revision.

"yyymmdd" shall be used to indicate the date of the route update.

4.4.2 KP Numbering

Route KP (Kilometer Post) 0.0 is defined at the upstream battery limit.

KP value increases in offshore direction and have negative values for the onshore pipeline section towards the onshore compressor station.

KP values are defined as Grid Distance (GD) and is based on grid north bearing. True Distance (TD) is the distance over the surface and is critical to for instance calculate the actual length of pipe for Material Take Off (MTO).

4.4.3 Geodetic Parameters

Offshore locations will be specified in geographical or UTM co-ordinates using the ED50 system. Characteristic parameters of the ED50 reference system are listed in Ref. [1]

Near shore and onshore all ED50 co-ordinates will also be given in the RijksDriehoek (RD) system, which is the Dutch onshore reference system. Characteristic parameters of this system are listed Ref. [1]

The alignment of the trenchless sea-defence crossing, up to its exit point, shall be designed using both ED50 and the RD system.

4.4.4 Vertical Datum

Onshore the ground levels are defined by reference to Normaal Amsterdams Peil (NAP)

The water depths, tidal level and offshore levels are defined by reference to Lowest Astronomical Tide (LAT) level.

Water depth varies with tidal variation and storm surge setup. Together they form storm tide (combination of storm surge and the astronomical tide).

Breaking waves also contribute to the total water level through wave runup/setup.

- LAT = -1.03 m NAP.

5 Offshore Pipeline Route Selection

5.1 ROAD Project / PORTHOS Pre-FEED and PreFEED-Update Routes

Figure 5-1 shows the routes studied in the past. The Red Route (connected IP points) was studied during the ROAD project and the Pre-FEED study (Ref. [19]).

The green route was defined during the pre-FEED update study (Ref. [12]) based on an updated onshore plot area and a changed preferred pass side / arrival side near subsea wellhead Q16-FA-1 respectively platform P18-A.

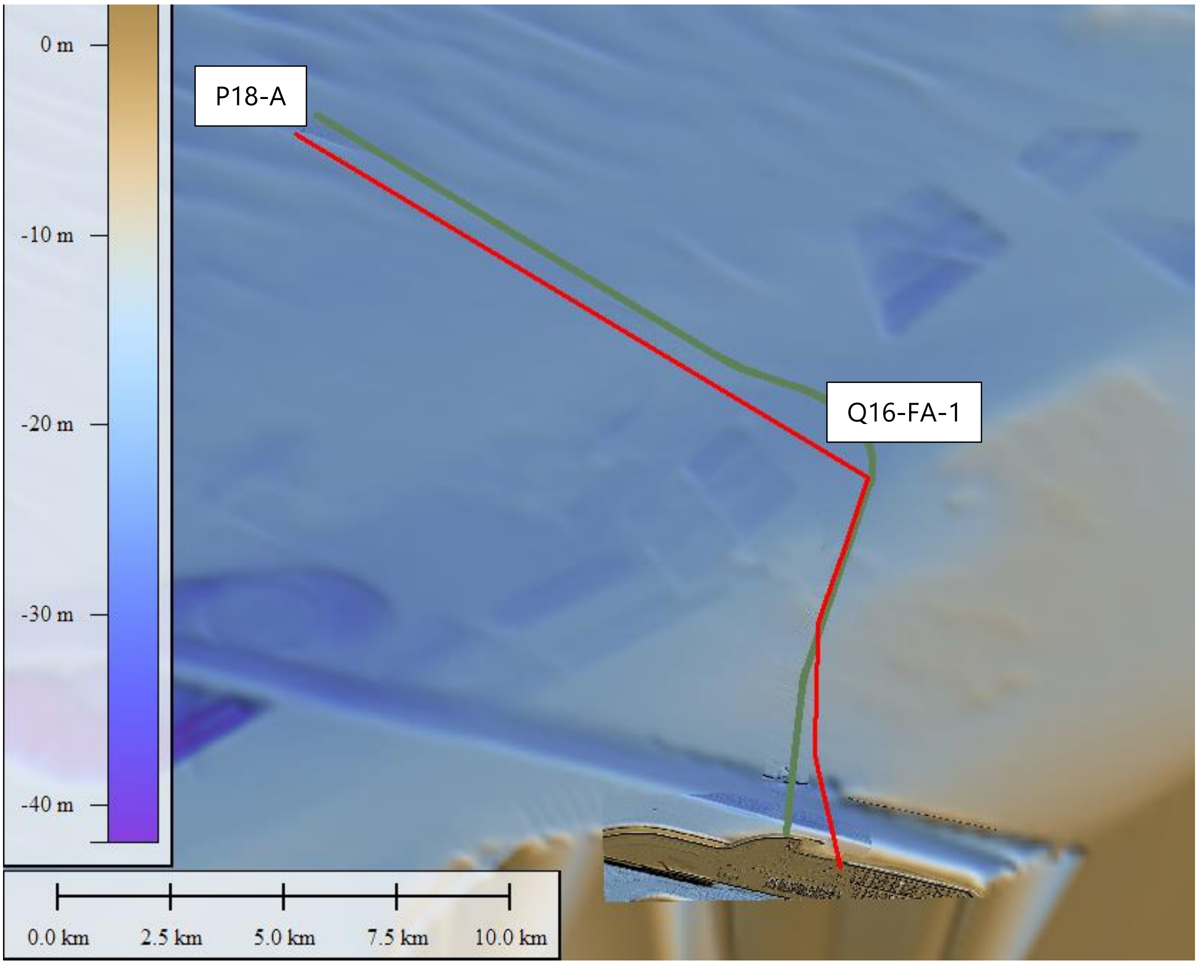

Figure 5-1: IP points of ROAD/Pre-FEED in Red, Pre-FEED-Update Route in Green

5.2 Proposed FEED Route

Figure 5-2 shows the optimized PORTHOS offshore pipeline route (Porthos_06_20200625) taking the routing criteria as discussed in chapter 3 into account. The onshore plot area is, compared to pre-FEED phase, moved further west and from subsea wellhead Q16-FA-1 to platform P18-A, the pipeline is routed completely at the south-west side of the existing cables, pipelines and Q16-FA-1, this to avoid unnecessary crossings requiring seabed intervention work. With the current straight section between P18-A and Q16-FA-1, one cable crossing cannot be avoided, this is the crossing with an abandoned section of the UK-NL 4 telecom cable. The base case is cable removal.

The location of the onshore battery limit and the HDD entry pit, within the onshore plot plan, has been optimized taking into account the integration of the onshore expansion loop and the planned HbR and Stedin sub stations. The eastern most substation is planned within the 5 m zone around the PORTHOS HDD trajectory. A displacement proposal for the planned sub stations is prepared (Ref. [9]) so that the 5 m influence zone requirement can be met.

Both the onshore HDD entry point and the planned expansion loop, which is not within the scope of Intecsea, are situated within the 2.2 m burial depth safety zone of the planned wind turbine. Additional impact protection measures may be required to protect PORTHOS assets with a burial depth < 2.2 m. Consultation with the owner of the wind turbine is also advisable for correct interpretation of the requirements.

The nearshore design is based on a 520 m directional drill from onshore towards the south side of the Maasgeul and then a straight trenched route that also crosses the Maasgeul. The heading of this onshore to nearshore transition is 2°22’32” (based on Dutch RD datum) This route has been chosen because of the most feasible straight through offshore-to-onshore pipe string pull-in method. The heading of the pipeline from the onshore entry point towards the first IP point at the north side of the Maasgeul is based on the 50 m separation distance with the future westernmost TenneT cable (Beta-2) and the optimized location of the onshore entry point of the directional drill.

It should be noted that the chosen route crosses the permit areas of Maasvlakte 2 and the nearshore permit area of TenneT HKZ (permit areas as shown in section 3.5.6). The permit area of Maasvlakte 1 is not crossed, although around the sea defence crossing the permit area of Maasvlakte 1 is only a few meters away from the HDD trajectory. In the nearshore and offshore zone, the chosen route will cross all maritime zones and borders as identified in Section 3.5.9; this is inevitable.

The pipeline route from the first tangent point of the first horizontal route curve just north of the Maasgeul is based on a lay direction Maasgeul → Target box at P18-A. Laying in the opposite direction would require an AWTI operation in the area just north of the Maasgeul which should be avoided since it significantly impacts installation complexity, schedule and cost.

The third wide route curve (4000 m radius) after the north-north-west oriented section is fitted to stay within the surveyed corridor and to minimize third party interaction (sand mining areas, and distance to Q16-FA-1).

Beyond the 4000 m radius route curve, between Q16 and P18-A, the PORTHOS route is close to parallel to the existing ONE-Dyas pipeline. The spacing decreases slightly closer to P18, but is minimal 50 m. The spacing between the PORTHOS pipeline and the “sand borrow area 9” (in its original shape) does not meet the 500 m requirement. An optimized “borrow area 9” shape is proposed to meet set requirements (Ref. [9]).

Table 5-1 shows the history of route development during PORTHOS FEED.

Table 5-1: Overview of Pipeline Routing History

Route Definition	**Reason for Update**
Porthos_01_20191204	Initial defined FEED route as presented during Workshop #2. Straight Maasgeul crossing
Porthos_02_ 20191204	Optimized FEED route as presented during Workshop #2. Curved Maasgeul crossing and reduction of possible additional survey scope compared to Porthos_01_20191204
Porthos_03_20191209	Porthos_01_20191204 was defined as base case offshore route, however some onshore and nearshore route optimization of Porthos_01_20191204 was deemed required, especially the onshore HDD entry location.
Porthos_04_20200221	Separation distance between PORTHOS pipeline route and existing/planned offshore assets (ONE-Dyas pipelines and TenneT cables) set at order 50 m. Separation distance between PORTHOS pipeline route and existing sand borrow areas set at order 500 m. Changes had influence on heading of HDD, route curves, and total pipeline length. Route optimization-corridor optimized to 30 m at right side and 50 m at left side relative to PORTHOS pipeline route (left/right: seen from ascending KP direction).
Porthos_05_20200420	Optimization of onshore HDD Entry Point due to two planned “Sub Stations” (HbR and Stedin) northeast of existing substation. Input received from Havenbedrijf Rotterdam (HbR). HDD onshore entry point moved further south (12.5 m) to facilitate the installation of the onshore expansion loop. Heading of HDD remains unchanged relative to Porthos_04_20200221. HDD exit point remains the same as well. Minor route modification of approach near P18-A, based on preliminary spool piece design.

Route Definition	Reason for Update
Porthos_06_20200625	Optimization of the crossing with the northern slope of the Maasgeul and approach towards the first horizontal route curve after crossing the Maasgeul. Radius of first horizontal route curve is also optimized.

The route overview is shown in drawing TROF-ENG-PIP-INT-DWG-0001 (Ref. [3]).

Details of the proposed HDD crossing can be found in drawing TROF-ENG-PIP-INT-DWG-0009 (Ref. [5]).

Details of the Maasgeul crossing can be found in drawing TROF-ENG-PIP-INT-DWG-0013 (Ref. [5]).

Route coordinates can be found in attached report TROF-ENG-PEN-INT-REP-0001 (Ref. [2]).

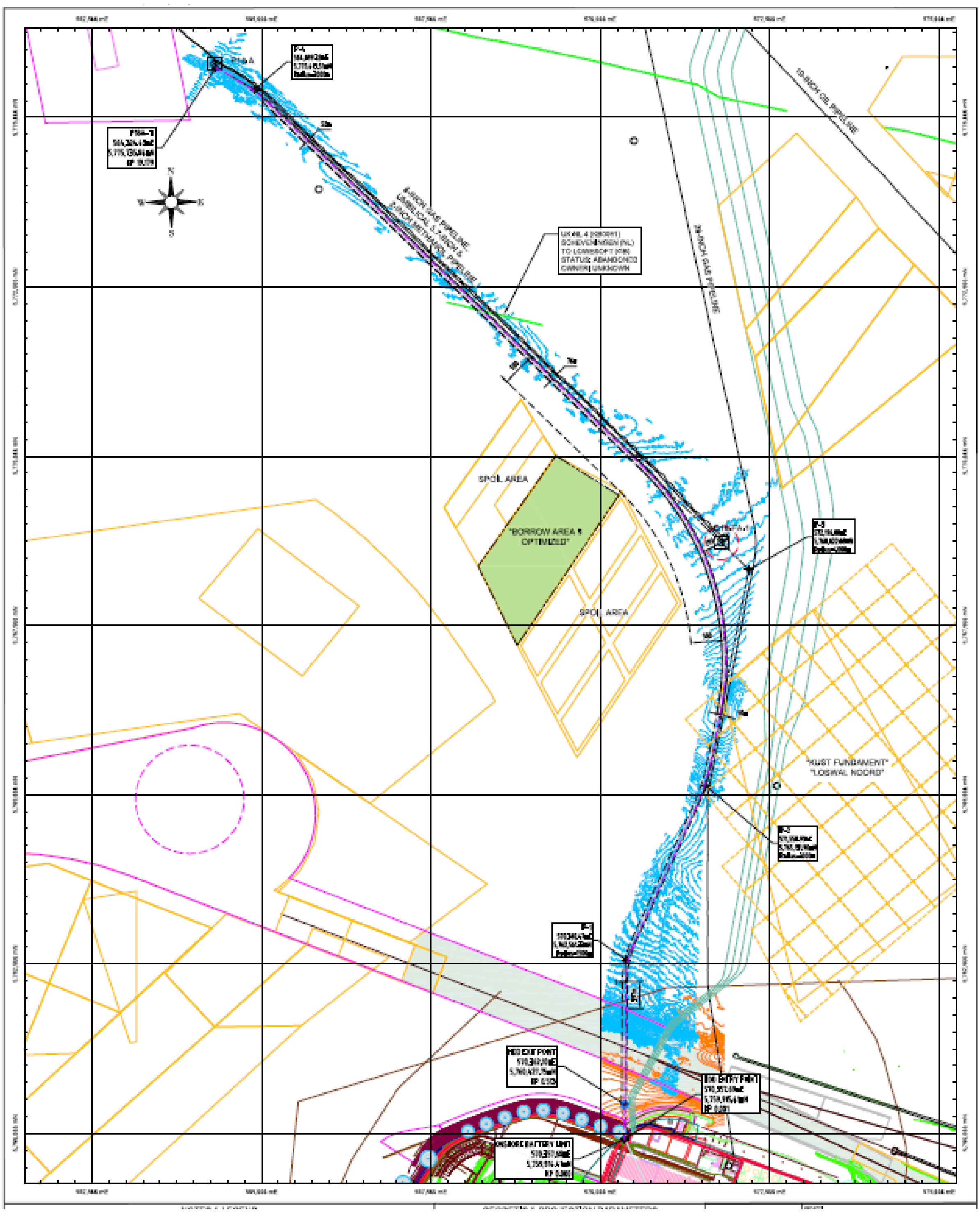

Figure 5-2: FEED Offshore Pipeline Route. Route Definition: Porthos_06_20200525 (Ref. [3])

5.3 Route Optimization Consideration

Four route optimizations are considered below.

5.3.1 Route optimization to cross Maasgeul: curved Maasgeul crossing

Relevant for Maasgeul crossing. This is an option which could be pursued depending on CONTRACTOR's capability to install the pipeline in a non-straight Maasgeul crossing configuration.

Advantage, shorter route and a closer-to-perpendicular crossing of the Maasgeul,

Advantage, closer to area surveyed by DEEP and Fugro (for TenneT),

Disadvantage, less common and more challenging pull-in and string positioning operation because of curved Maasgeul crossing.

This optimization is not further pursued in this FEED study.

5.3.2 Route optimization near platform P18-A: Separation distance between pipelay target box and platform

Advantage, shorter expansion spool

Disadvantage, optimal separation distance varies per pipelay vessel and trenching method. Alternatively, "sidewalking" needs to be considered.

This optimization will be pursued as much as possible in FEED.

5.3.3 Crossing through abandoned sand mining areas

Advantage, shorter route

Disadvantage, more third-party interaction.

This route optimization will not be further pursued because of the desired 500 m influence zone between the PORTHOS pipeline and the sand mining areas.

5.3.4 Crossing the northern Maasgeul slope further west or east relative to current crossing location

In Figure 5-3 from the TenneT Seabed Mobilization Report (Ref. [26]) the solid black lines denote the boundary and centre line of the navigation channel, the dashed black line indicate the location of the berm, and the red line represents a long-channel transect (AA') in the area of the northern channel slope, extending from x=0 (A) at the head of the northern breakwater, to 2000 m offshore (A').

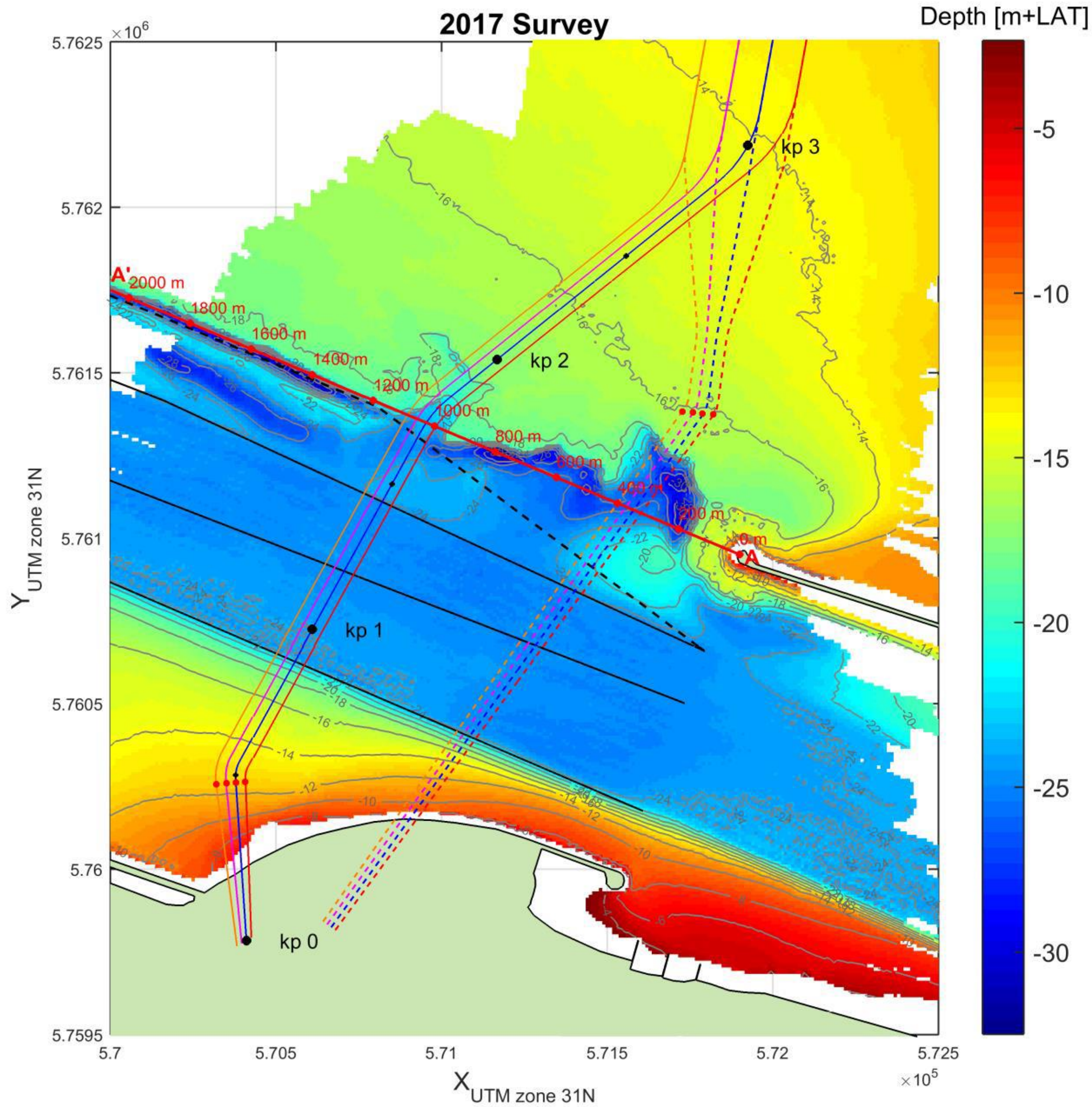

Figure 5-3: Red line represents a long-channel transect (A-A'). Relevant section on A-A' for PORTHOS: 1200-2000 m away from breakwater (Ref. [26])

The PORTHOS pipeline route currently selected crosses two erosion gullies approximately at x = 1750 m.

From x=1200 m up to x=3000 m (not visible on figure above) stretched, narrow and relatively straight scour holes are present. Although the exact cause is unknown, these scour holes are probably created by the in- and out flowing current along, and perpendicular to, the channel, creating eddies along the northern part of the channel, in combination with the local geology. The construction of Maasvlakte 2 has also had an impact on sediment erosion and deposition.

5.3.4.1 *Crossing more west between x ≈ 1400 -1750 m*

Crossing the northern slope of the Maasgeul more east can only be achieved with the described curved Maasgeul crossing. It should be noted that between x ≈ 1400 -1750 m the scour-hole-situation is not much different than at x = 1750 m (current crossing location).

5.3.4.2 *Crossing more west between x ≈ 1750 – 3000 m*

Maintaining the current onshore HDD entry point combined with a more westward facing HDD sea defence crossing (relative to current heading) is considered infeasible due to the crossing depth of the HDD under the planned substations. The 5 m influence zone of PORTHOS is most likely a show stopper. Crossing under the planned substations may even not be desired at all; this should be checked if the situation arises.

Crossing the northern slope of the Maasgeul more west (relative to current crossing location) requires an optimization of the onshore HDD entry point. The HDD entry point will have to be moved within the onshore plot plan to the east to facility a feasible HDD sea defence crossing heading that does not go below the planned substations.

Moving the HDD entry point further west could allow a crossing under the planned substations with adequate coverage (>5 m), but as mentioned above, the question is whether a crossing under the substations is desirable/allowed at all. The available space west of the moved HDD entry point for the HDD installation equipment also becomes limited.

Furthermore, when crossing the northern Maasgeul slope further west, a longer route curve will have to be made just north of the northern slope to return to the DEEP survey area.

Just like a crossing more west between x ≈ 1400 -1750 m, the scour holes are also observed between x = 1750 – 3000 m; hence, little to negligible benefit is gained from crossing the northern slope more west.

Figure 5-4 from Ref. [26] shows the expected shift of northern channel slope. From this figure a trend of increasing shift-rate, up to 5 m/y, can be derived, relative to the 2-2.5 m/y at x = 1750 m. Values like these should be double checked if the crossing situation more west arises.

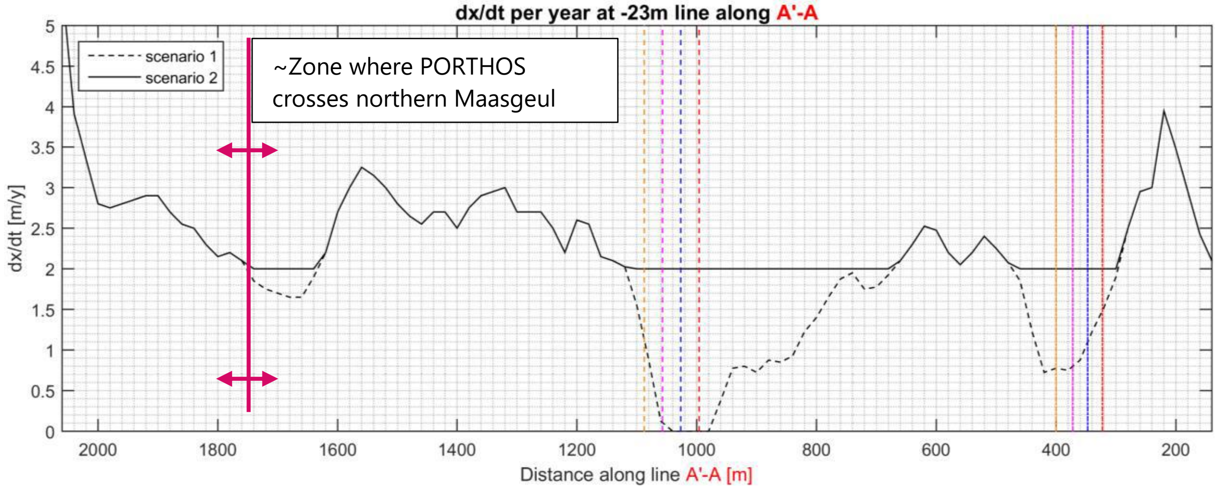

Figure 5-4: Northward migration (m/year) of the northern Maasgeul slope, as estimated based on data in the last decade. Scenario 1 is the actual situation, scenario 2 is used for the future prediction. See Figure 5-3 for line A'-A (Ref. [26])

The optimization of the pipeline's crossing with the Maasgeul and the side slopes is described in the Offshore Route Safety Study (Ref. [4]). The optimization has led to the latest route update "Porthos_06_20200625". Reference is also made to the Route Overview drawing (Ref. [3]) and the Maasgeul Crossing drawing (Ref. [6]) for the pipeline burial depths in and around the Maasgeul.

6 Route Curve Stability Check

This section documents the route curve stability safety factor, in order to ensure pipeline curve stability during pipe laying operations. The following exercise has been performed to check the feasibility of the applied curve radii of the offshore pipeline routes for the pipe laying operations.

The route curve stability is governed by the simplified formula hereafter:

$T \cdot SF \leq \mu_L \cdot W_s \cdot R$

Where

T total effective axial force

μ_L lateral pipe-soil friction factor (checked for 0.3 and 0.5)

R pipeline radius

SF structural safety factor (2.00 minimum recommended for installation)

Based on the above formula, the curve stability check is performed for the applied curve radii of Porthos_06_20200625.

Table 6-1: Safety Factors

IP	Applied Curve Radius [m]	Pipeline Submerged Weight [kN/m]	Maximum Effective Axial Force [kN]	Safety Factor	Route Curve Stab. Check
IP-1	1500	3.803	500	2	Ok
IP-2	3000	3.803	500	2	Ok
IP-3	4000	3.803 / 2.616	500	2	Ok / Ok
IP-4	3000	2.616	500	2	Ok

If needed for further route optimization, route curve radii can be reduced. One should however note that wider route curves are easier to control during laying.

7 References

Ref. [1] INTECSEA, Design Basis Report, Doc. No. TROF-ENG-PEN-INT-REP-0002

Ref. [2] INTECSEA, Route Coordinates, Doc. No. TROF-ENG-PEN-INT-REP-0001

Ref. [3] INTECSEA, Route Overview, Doc. No. TROF-ENG-PIP-INT-DWG-0001

Ref. [4] INTECSEA, Offshore Route Safety Study, Doc. No. TROF-ENG-RIS-INT-REP-0001

Ref. [5] INTECSEA, HDD Sea defence crossing, Doc. No. TROF-ENG-PEN-INT-REP-0009

Ref. [6] INTECSEA, Maasgeul Crossing, Doc. No. TROF-ENG-PEN-INT-REP-0013

Ref. [7] INTECSEA, HbR & Stedin Substation Displacement Proposal, Doc. No. TROF-ENG-PEN-INT-REP-0013

Ref. [8] INTECSEA, Additional Survey Scope, Doc. No. TROF-ENG-PIP-INT-SOW-0004

Ref. [9] INTECSEA, Borrow Area 9 Shape Optimization Proposal, Doc. No. TROF-ENG-PEM-INT-PRP-0001

Ref. [10] INTECSEA, Electromagnetic Interference Study HDD Section, Doc. No. TROF-ENG-PIP-INT-REP-0010

Ref. [11] INTECSEA Technical Note 416010-00212-EM-001 / TROF-ENG-PEN-INT-TNO-0001; Landfall and Maasgeul crossing

Ref. [12] INTECSEA, Porthos CCUS Concept Review, Project Key Plan, Doc. No. 406010-00198-001-MX-DOM-0001 rev A

Ref. [13] Deep B.V., Porthos Pipeline Route Survey, Doc. No. P3600_SURV_REP_R00

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Ref. [17] Fugro Survey B.V., Marine Geophysical & Geotechnical Route Surveys for Hollandse Kust Zuid - North Up Bathymetry and Seabed Feastures Chart No. 001 of 001, Doc. No. TT_HKZ_SBFBAT_nu5k_RD_001

Ref. [18] Marin, Verkeersdichtheid 2017

Ref. [19] Offshore Independents Rotterdam, Concept Selection Study - Offshore CO2 Pipeline, Doc. No. OI2018-132-EN-RP-0002 rev. A01

Ref. [20] RWS ZD A BB & Havenbedrijf Rotterdam, Onderhoud zoute bagger & havens Perceel III / Perceel IV, kaartnummer 435509-3-DT

Ref. [21] Ministerie van Verkeer en Waterstaat, "Informatiehuis Marien", Website: Noordzee Data

Ref. [22] Havenbedrijf Rotterdam, Zachte en harde zeewering irt windturbines juni 2018, Project HIC-Windturbines, Drawing No. 2018-306a

Ref. [23] Havenbedrijf Rotterdam, Alternatieve Locatie, Project: MV-Porthos compressorstation, Drawing No. 2019-575

Ref. [24] TenneT, Horizontaal Gestuurde Boring Maasmold (Kort) – Overzicht en Dwarsprofiel, Doc. No. 1003-0116-01-BT MT

Ref. [25] Pondera Consult, Analyse Benodigde Diepteligging PORTHOS Buisleiding i.r.t. Windpark Maasvlakte II

Ref. [26] Water Proof Marine Consultancy and & Services B.V., Seabed mobility update: route specific - Wind op Zee – Hollandse Kust (zuid) export cable, Doc. No. ONL-TTB-04046-AT010-E7

Ref. [27] Ministry of Defense, Dienst der Hydrografie

Ref. [28] https://www.ruimtelijkeplannen.nl/

Ref. [29] Iv-Offshore & Energy b.v., P18-A New Riser - Jacket Inplace + Fatigue, Doc. No. 190151-31-M-0001 A1

Appendix A
Route Coordinates

A.1 TROF-ENG-PEN-INT-REP-0001 - Route Coordinates

Please refer to route coordinate document: TROF-ENG-PEN-INT-REP-0001 (Ref. [2]) for the latest route.

The first three route points are also provided in RD grid coordinates.

Table 7-1: Coordinates RD: Route Definition: Porthos_06_20200625

Route Points	Coordinates RD Grid		Heading	Radius	KP
	Easting [m]	Northing [m]	[°] to GN	[m]	[km]
Onshore Battery Limit	61296.538	444786.248	2° 22' 32"	-	0.000
HDD Entry Point	61296.580	444787.247		-	0.001
HDD Exit Point	61317.82	445299.307		-	0.513

Table 7-2: Coordinates UTM31N-ED50 and Longitude Latitude – ED50. Route Definition: Porthos_06_20200625

Route Points	Coordinates UTM31N ED50		LL ED50		Heading	Radius	KP
	Easting [m]	Northing [m]	LATITUDE	LONGITUDE	[°] to GN	[m]	[km]
Onshore Battery Limit	570357.681	5759914.414	51° 59' 03.71" N	4° 01' 28.11" E	00° 29' 36"	-	0.000
HDD Entry Point	570357.690	5759915.414	51° 59' 03.74" N	4° 01' 28.11" E		-	0.001
HDD Exit Point	570362.101	5760427.745	51° 59' 20.32" N	4° 01' 28.72" E		-	0.513
TP-1a	570377.710	5762240.658	52° 00' 18.98" N	4° 01' 30.88" E		-	2.326
IP-1	570380.471	5762561.329	52° 00' 29.36" N	4° 01' 31.26" E	-	1500	-
TP-1b	570514.109	5762852.839	52° 01' 38.73" N	4° 01' 38.48" E	24° 37' 42"	-	2.958
TP-2a	571412.737	5764813.051	52° 01' 41.75" N	4° 02' 27.08" E		-	5.115
IP-2	571558.910	5765131.905	52° 01' 52.00" N	4° 02' 34.99" E	-	3000	-
TP-2b	571627.585	5765475.878	52° 02' 03.10" N	4° 02' 38.85" E	11° 17' 27"	-	5.813
TP-3a	571769.794	5766188.162	52° 02' 26.08" N	4° 02' 46.85" E		-	6.539
IP-3	572195.996	5768322.888	52° 03' 34.96" N	4° 03' 10.84" E	-	4000	-
TP-3b	570634.841	5769839.956	52° 04' 24.78" N	4° 01' 50.01" E	314° 10' 46"	-	10.526
TP-4a	565180.677	5775140.098	52° 07' 18.71" N	3° 57' 07.23" E		-	18.132

Route Points	Coordinates UTM31N ED50		LL ED50		Heading	Radius	KP
IP4	564899.324	5775413.506	52° 07' 27.68" N	3° 56' 52.63" E	-	3000	-
TP-4b	564557.126	5775605.371	52° 07' 34.03" N	3° 56' 34.77" E	299° 16' 43"	-	18.912
P18A-TI [1)]	564324.425	5775735.842	52° 07' 38.35" N	3° 56' 22.62" E		-	19.179

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Porthos - CO2 injection

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Summary

This report presents the results of a flow assurance analysis of the first elements of an offshore CO_2 transport and storage network that is being designed by the Porthos consortium. The network is intended to transport CO_2 from industrial sources in the Rotterdam harbour to offshore depleted gas fields. The scope of the flow assurance study was the offshore pipeline from the compressor outlet, from the Maasvlakte to the P18-A platform, and up to four injection wells in the P18-2 and P18-4 fields. These activities are part of TNO project 060.33502.

The goal of the simulations is to evaluate the operating envelope within pre-described boundary conditions and restrictions. The goal of this project is to:

- Define the required compressor discharge conditions (pressure and temperature)
- Evaluate potential start-up and shut-in procedures and evaluate any showstoppers in these processes.

Evaluation of the sizing of the main pipeline was part of the phase-1 activities and as such is not covered in this report.

To obtain the goals the following activities have been done:

- Transient simulations to obtain steady state operating conditions.
  In the simulations, the effect on the steady state results were evaluated for:
  - Variation well diameter
  - Variation reservoir parameter (pressure and accompanying injectivity index)
  - Variation wellhead temperature (for single well models)
  - Variation compressor outlet temperature
  - Variation pipeline pressure control
- Start-up simulation
  - Different starting conditions (gas, two-phase, liquid) conditions in the pipeline.
  - Variation of the reservoir pressure.
- Shutin/turn-down simulations
  - Variation reservoir pressures.
  - Variation shutin valve closure time.

For steady state conditions the following conclusions are found:

- At low reservoir pressure (20-40 bar), no steady state solution is found which comply with both the topside and downhole temperature restrictions when the pipeline pressure is maintained in the liquid state. Therefore, at low reservoir pressure the pipeline must be operated in gas or two-phase conditions. This puts limitations on the maximum injection rates per well or for all four wells combined.
- At reservoir pressures (40-300 bar), the required flow rate (170 kg/s) is achieved using four wells.
- At close to the maximum reservoir pressures, the compressor outlet temperature needs to be reduced. Otherwise no injection is possible.

For depressurization the following conclusions are found:

- The heat ingress in the pipeline is limited. Therefore, during depressurization or emptying the pipeline the temperature follows the pressure via the phase line and low temperatures conditions can occur in the complete pipeline. Therefore, a pressure control of the pipeline is recommended.

For shutin simulations the following conclusions are found:

- During well shutin, low fluid temperatures will occur in the well downstream of the choke. The temperature will go down to the corresponding phase line temperature. At a reservoir pressure of 20 bar, this means a temperature of -37 °C. At lower reservoir pressures this will lower even further. At higher reservoir conditions, the temperature will increase. -17, -5 and +30 °C at reservoir pressures of 60, 100 and 340 bar.
- During ramp-down, low temperatures occur mainly in the top part of the well. These temperatures go well below -10 °C.
- During ramp-down also the temperature in the pipeline itself will drop down to values below -20 °C.
- The low temperatures during shutin/ramp-down are difficult to avoid and as such it is recommended that all piping should be able to withstand the low temperatures.

From the start-up simulations the following conclusions are found:

- For all reservoir conditions, at initial choke valve opening, a short period of low temperature will occur downstream of the control valves. For the start-up, a faster valve-opening is beneficial with respect to the temperatures.
- In the sequencing of well opening and compressor ramp-up, the flow rates from the pipe to the wells must not decrease too quickly to avoid too low pressures (and therefore temperatures in the well and pipeline). Therefore, the compressor ramp-up must be done relatively soon after the well opening. The compressor can be ramped-up before the well opening at higher reservoir pressures with the limit that the pipeline pressure must not be higher than 85 bar.
- At low reservoir pressure, the system could be started up from low pressure (10, 30 bar) or medium pressure (60 bar). In case of medium-pressure conditions, the downhole temperature is too low for a limited period of time (less than 500 minutes).
- At low reservoir pressure, starting from high pressure pipeline conditions leads to long periods of too low temperatures (longer than 2000 minutes).
- At medium and higher reservoir pressures start-up can be done from medium-pressure (two -phase conditions) conditions within the temperature restrictions.

The base recommended operations (based on the set restrictions) are:

- At low reservoir pressure, the pipeline is operated in the gas phase and all well chokes are kept open to avoid pressure drop. The compressor outlet temperature is set to 80 °C.

- At mid to high reservoir pressures, the compressor outlet temperature is set to 40 °C. The setting is an optimization between cooling power and compressor power.

- At very high reservoir pressures, compressor outlet temperature must be set to 40 °C, otherwise injection is not possible.

Reservoir pressure [bar]	Compressor outlet temperature [°C]	Pipeline control	Well operations
20 – 40 bar	80	30	Full open
40 – 300 bar	40 - 80	30	1 well on pressure control. Other wells on mass control
300 – 340 bar	40	30	1 well on pressure control. Other wells on mass control

During well shutin, a fast closure the choke valves leads to very low temperatures. At low reservoir pressures the shutin procedure should be leaving the wells open while shutting down the compressor.

The main recommendations include:

- All piping material should be de designed for extreme low temperatures (-40°C, based on expected wellhead pressures of 10 bar).

- Update simulation model to include full heat transfer (rather than U-value approach) at the time the well design and pipeline design is set.. This to get more detailed temperature information on pipe wall temperatures and annulus fluid temperatures.

- Considering the fact that fluid temperatures less than -10°C are probably not avoidable, the restriction of -10°C for the topside temperature should be reconsidered/re-evaluated.

- The criterion of 15°C downhole temperatures is restrictive. Alternatives for hydrate preventions should be evaluated.

- An operational guidebook should be set up which describes the number of wells and control settings for each mass flow rate.

This guidebook should also contain guidelines of start-up and shutin procedures

Contents

Appendices

1 Introduction

1.1 Introduction

This report presents the results of a flow assurance analysis of the first elements of an offshore CO_2 transport and storage network that is being designed by the Porthos consortium. The network is intended to transport CO_2 from industrial sources in the Rotterdam harbour to offshore depleted gas fields. The scope of the flow assurance study was the offshore pipeline from the compressor outlet, from the Maasvlakte to the P18-A platform, and up to four injection wells in the P18-2 and P18-4 fields. These activities are part of TNO project 060.33502.

1.2 Project goals

The goal of the simulations is to evaluate the operating envelope within pre-described boundary conditions and restrictions (Chapter 2). The goal of this project is to:

- Define the required compressor discharge conditions (pressure and temperature)
- Evaluate potential start-up and shut-in procedures and evaluate any showstoppers in these processes.

Evaluating of the sizing of the main pipeline was part of the phase-1 activities and as such not covered in this report.

1.3 Project activities

To obtain the goals the following activities have been done:

- Transient simulations to obtain steady state operating conditions.
  In the simulations, the effect on the steady state results were evaluated for:
  - Variation well diameter
  - Variation reservoir parameter (reservoir pressure)
  - Variation wellhead temperature (for single well models)
  - Variation compressor outlet temperature
  - Variation pipeline pressure control
- Start-up simulation
  - Different start conditions (gas, two-phase, liquid) conditions in the pipeline.
  - Variation reservoir pressure.
- Shutin/turn-down simulations
  - Variation reservoir pressures.
  - Variation shutin valve closure time.

1.4 Report layout

Prior to discussing the simulation results an overview of the main trends in CO_2 injection are covered in Chapter 3. In Chapter 2, the boundary conditions and restrictions are presented with in Chapter 4 a discussion on the model used.

The results are presented in the Chapters 6 (steady state results), Chapter 7 (Start-up simulations), Chapter 8 (depressurization/venting) and Chapter 9 (Shutin/turn down). The Chapters 10 and 11 cover the main conclusions and discussion.

2 Boundary conditions and assumptions

2.1 Introduction

This section describes the boundary conditions and restrictions at the start of the project.

2.2 Boundary conditions

The following boundary conditions/assumptions are set in the project:

- Compressor outlet temperature 35 < T < 80 °C.
    - In the simulations a range of 40 to 80 °C is used as Gasunie had indicated that the last 5 °C required a huge investment.
- Desired flow total rates of 15 – 170 kg/s.
- A preferred mass flow rate of up to 70 kg/s per well.
- 4 wells available for injection (1 well in P18-4 compartment and 3 wells in the P18-2 compartment).
- Start reservoir pressure 20 bar; maximum Pres = 340 bar.
- Compressor control is based on suction pressure control.
    - This means that all CO_2 delivered to the low pressure network needs to be injected.
    - This means that not all the wells can be at mass flow control. This is important as from Chapter 2 it is clear that there are restrictions in mass flow rate.
- Pipeline Constraint
    - Preferred operation in single liquid phase condition.
    - Minimum discharge pressure compressor of 60 bar.
- Well Constraints
    - Downhole temperature T > 15 °C
    - Topside piping T > -10 °C
    - Erosion, Tubing vibrations, thermal/mass flow rate constraints for reservoir, thermal gradients in well (radial and axial)) are not considered at this stage

2.3 Simulation goals

The goal of the simulations are:

- Steady state results to obtain required compressor envelope
- Start-up scenarios
- Shut-in scenarios
- Discussion of cold vs warm start-up

3 General discussion

3.1 Introduction

In this chapter, some typical behaviour of CO_2 injection is discussed. This is done based on results for a simple pure vertical monobore geometry.

In section 3.2, results are presented for a free well. That means no pipeline is attached and no control choke is present at the wellhead. In section 3.3 results are presented with a control action at topside. This means for instance a pipeline pressure of pressure 85 bar and a mass controlled injection into the well.

3.2 CO_2 injection behaviour in wells free flow

3.2.1 Model description

The model used for this chapter is a simple monobore, pure vertical well of depth 3000m with a topside section of 100m horizontal (0.15m ID), with a heat transfer of 9.5 W/m2K with a vertical thermal gradient of 10 to 123 °C.

3.2.2 Base result

Some base results are given in Figure 1 with the downhole temperature and the wellhead pressure as function of mass flow rate. The behaviour can be divided into low and high reservoir pressures. Low reservoir pressure typically means up to a reservoir pressure of 50 bar. At that pressure, the accompanying phase line temperature is 15°C (for discussion on limitations and boundary conditions: Chapter 2).

At low reservoir pressure the important features are:

- The required wellhead pressure is strongly dependent on the wellhead temperature (higher temperatures require higher pressures).
- For a large range of mass flow rates, the required wellhead pressure is constant due to the fact that the wellhead is in two-phase conditions.
- The required wellhead pressure at low flow rates is (very) low.
- The downhole temperature decreases with increasing mass flow rate up to the point that two-phase conditions occur downhole. In that case the downhole temperature increases due to an increase in bottomhole pressure due to an increase reservoir pressure drop. When in two-phase conditions, the downhole temperature is independent of the wellhead temperature but only a function of the downhole pressure.
- The range of downhole temperatures higher than 15°C increases with increasing wellhead temperature.

At higher reservoir pressures the important features are:

- An almost constant wellhead pressure for all mass flow rates.
- The downhole temperature is almost always higher than 15°C and the remaining trend is that the bottomhole temperature decreases with increasing mass flow rate.

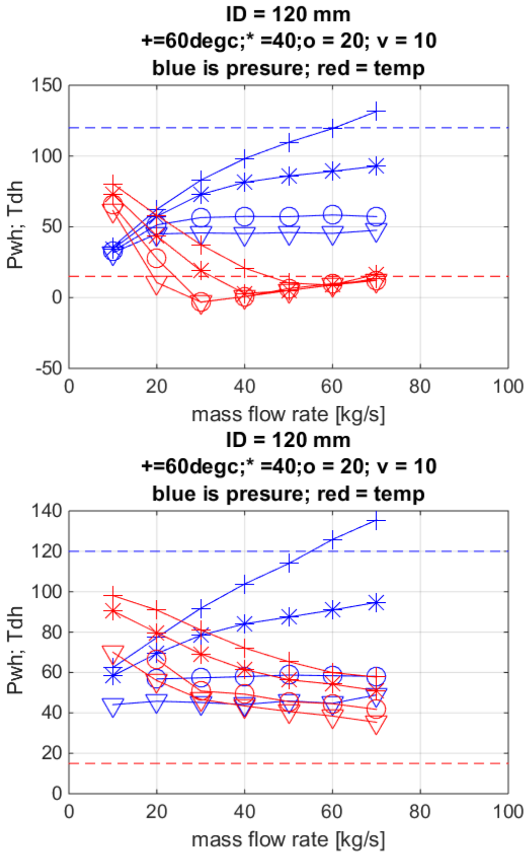


Figure 1: Wellhead pressures (blue) and downhole temperatures (red) as function of mass flow rate for a reservoir pressure of 20 bar (top) and 100 bar (bottom). Dashed lines indicate critical boundary conditions (120 bar and 15 °C). Each line is for a different wellhead temperature (10, 20, 40, 60 °C).

As example the pressure and temperature profiles in the well are plotted for:
Reservoir pressure 20 bar, Wellhead temperature 10 °C Figure 2
Reservoir pressure 20 bar, Wellhead temperature 40 °C Figure 3
Reservoir pressure 100 bar, Wellhead temperature 10 °C Figure 4
Reservoir pressure 100 bar, Wellhead temperature 40 °C Figure 5
Reservoir pressure 300 bar, Wellhead temperature 10 °C Figure 6
Reservoir pressure 300 bar, Wellhead temperature 40 °C Figure 7

The difference in behaviour between low and high pressures are directly clear. At low reservoir pressure, the well is mainly in the two-phase regime for the major part of the well. At high reservoir (300 bar), the complete well is in single phase supercritical conditions.

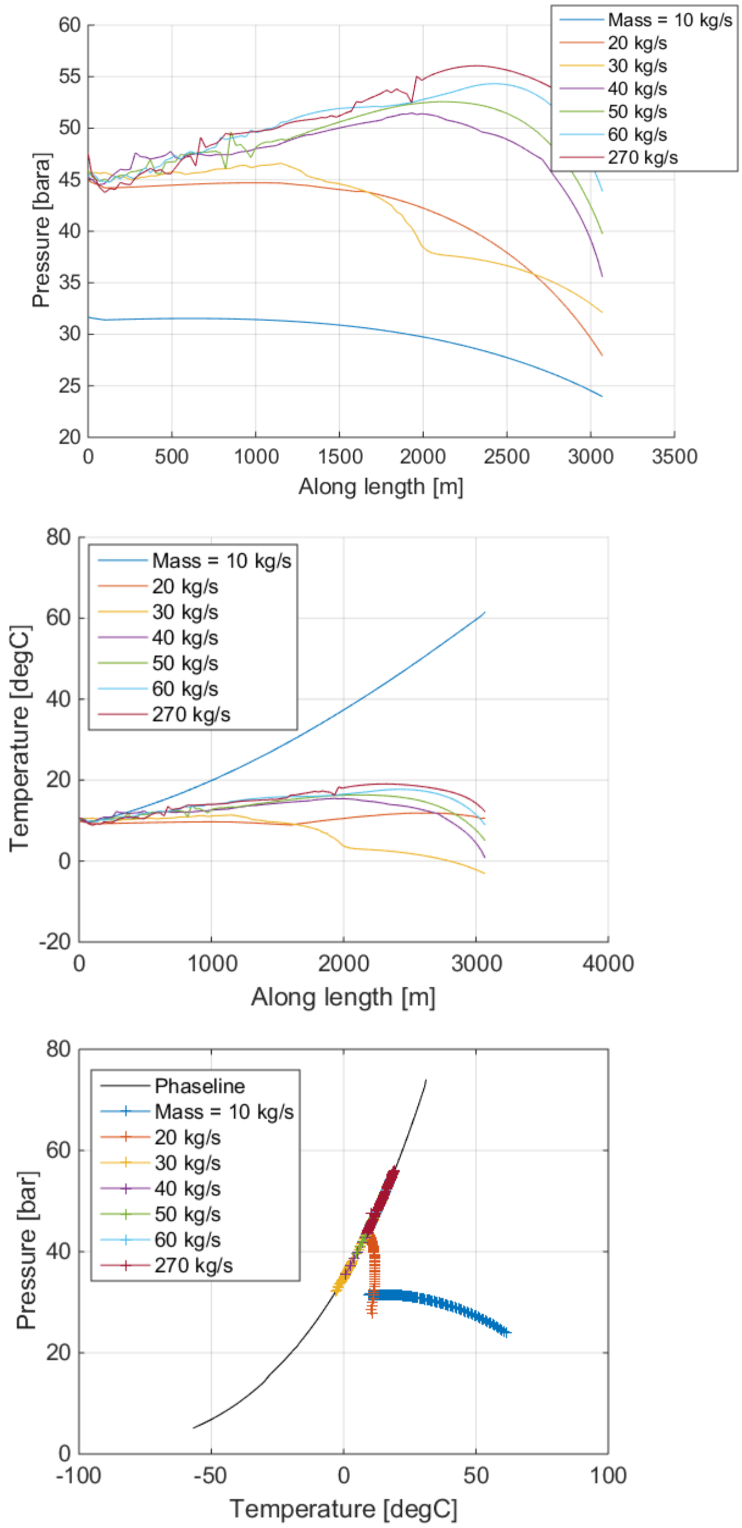


Figure 2: Pressure profile (top), temperature profile (middle) and P,T profile for a reservoir pressure of 20 bar and a wellhead temperature of 10°C. The mass flow ranges from 10 to 70 kg/s (edit one caption is wrong to be changed).

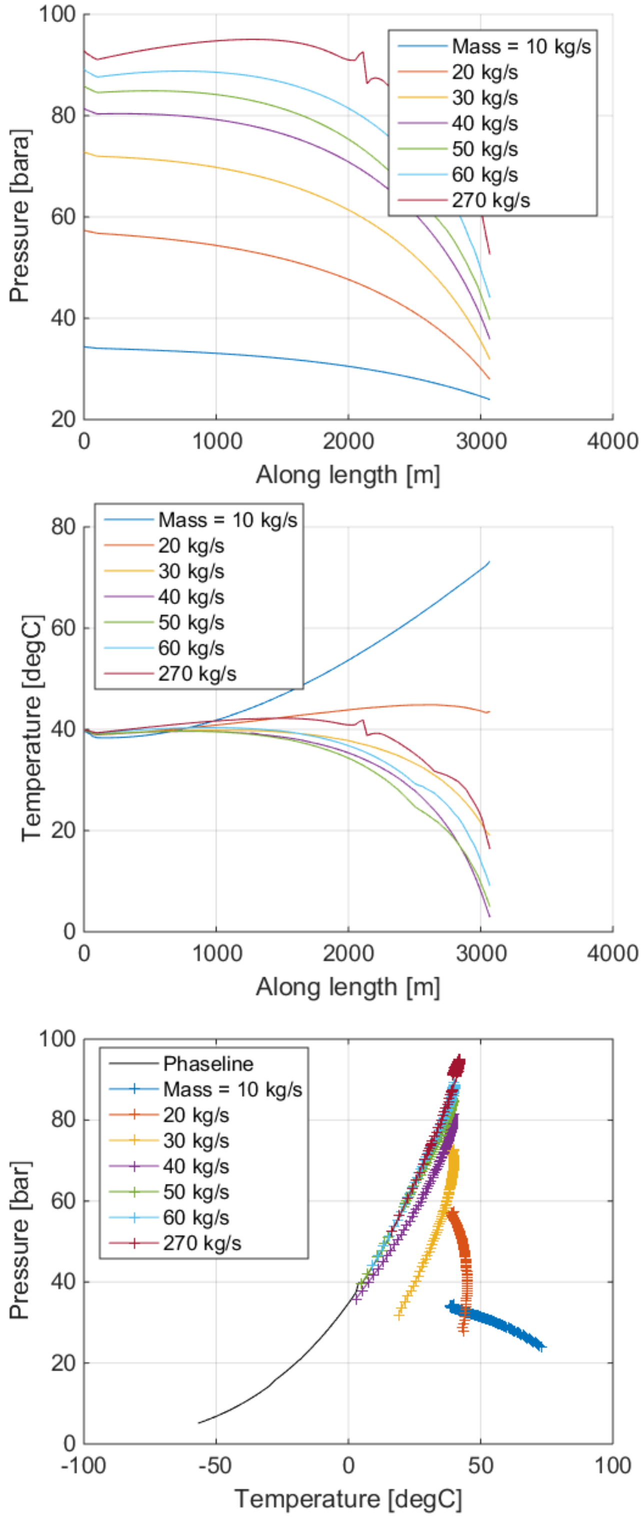


Figure 3: Pressure profile (top), temperature profile (middle) and P,T profile for a reservoir pressure of 20 bar and a wellhead temperature of 40°C. The mass flow ranges from 10 to 70 kg/s (edit one caption is wrong to be changed).

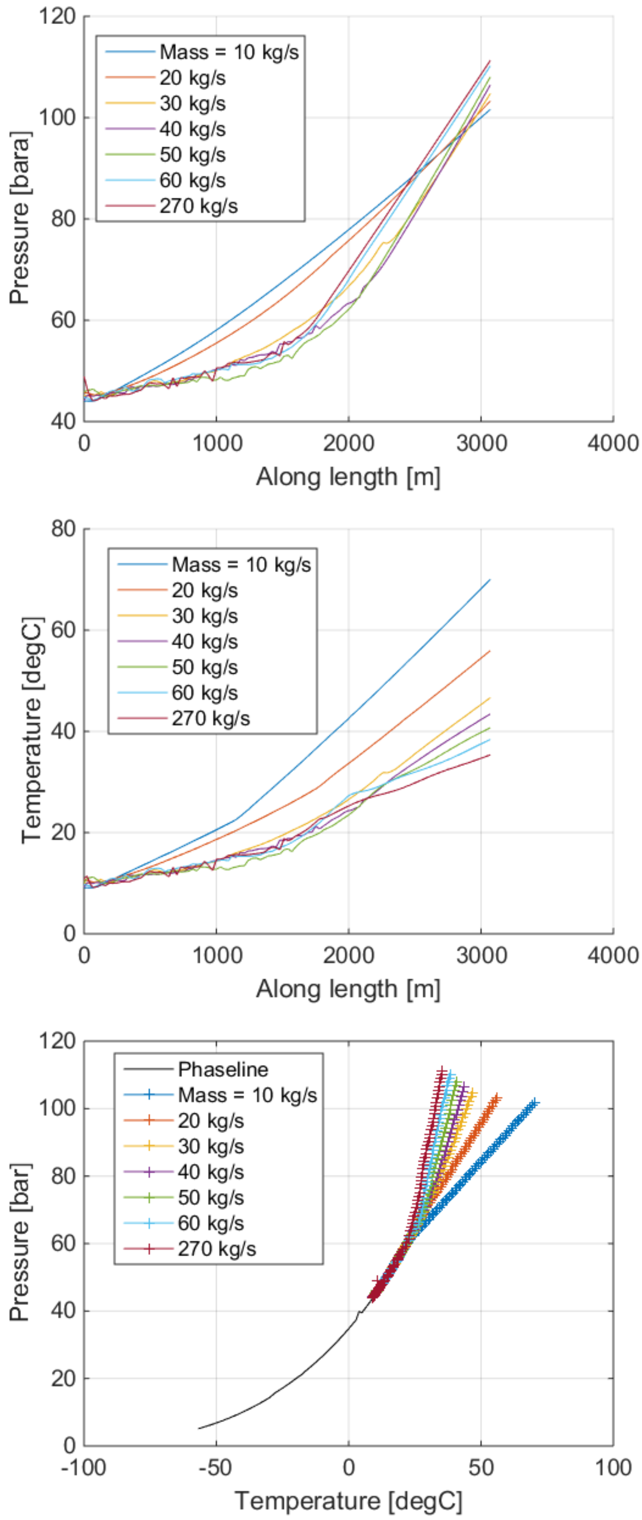


Figure 4: Pressure profile (top), temperature profile (middle) and P,T profile for a reservoir pressure of 100 bar and a wellhead temperature of 10°C. The mass flow ranges from 10 to 70 kg/s (edit one caption is wrong to be changed).

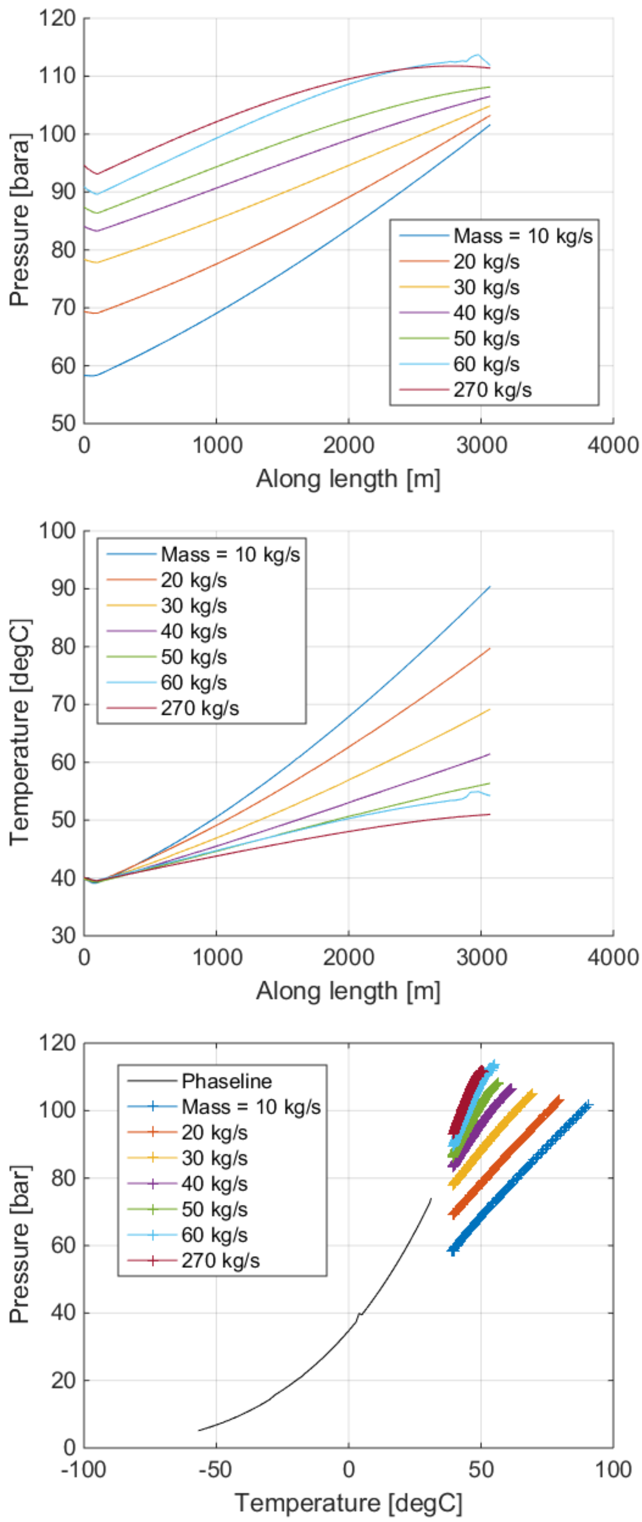


Figure 5: Pressure profile (top), temperature profile (middle) and P,T profile for a reservoir pressure of 100 bar and a wellhead temperature of 40°C. The mass flow ranges from 10 to 70 kg/s (edit one caption is wrong to be changed).

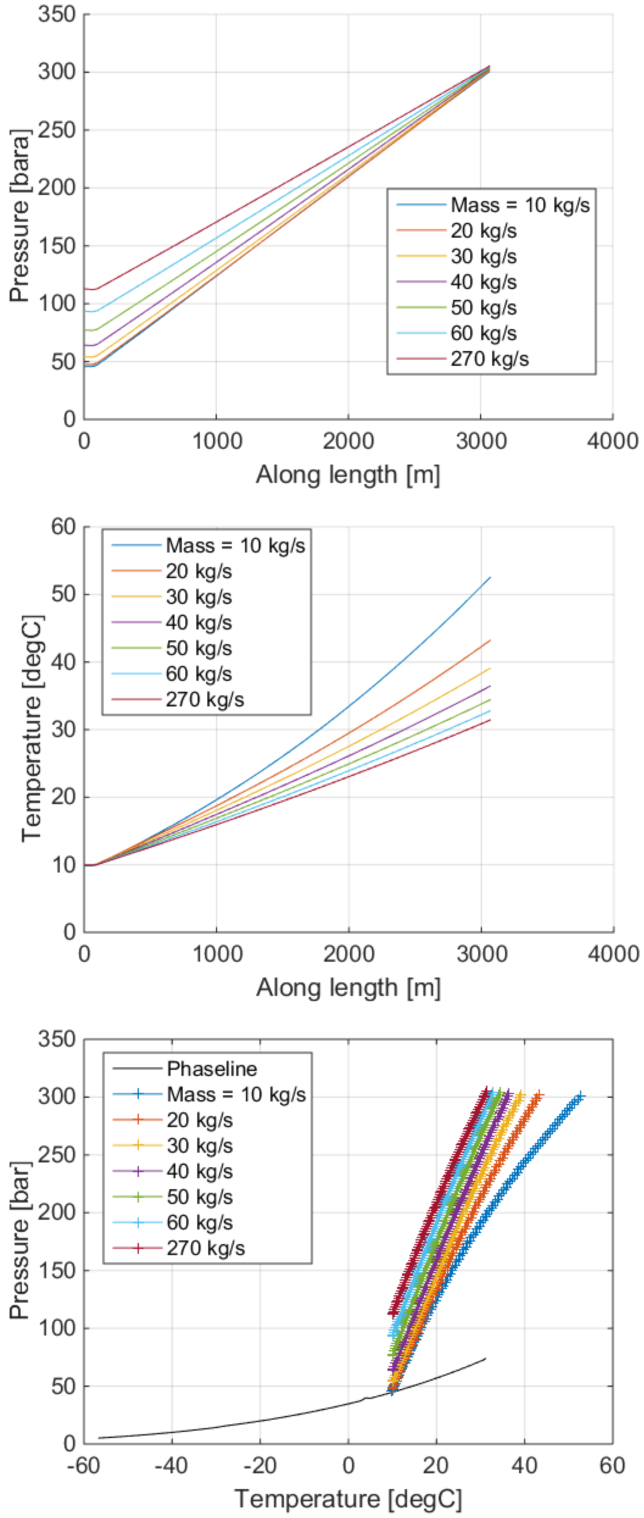


Figure 6: Pressure profile (top), temperature profile (middle) and P,T profile for a reservoir pressure of 300 bar and a wellhead temperature of 10°C. The mass flow ranges from 10 to 70 kg/s (edit one caption is wrong to be changed).

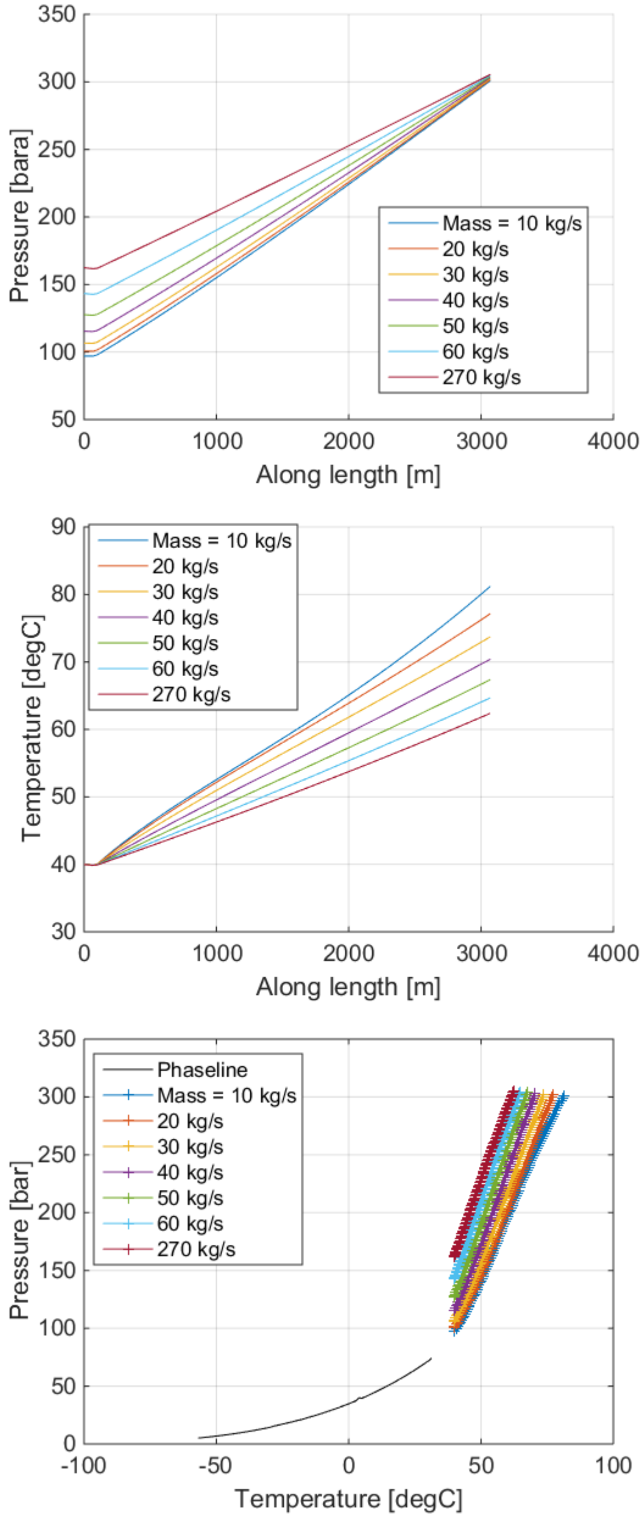


Figure 7: Pressure profile (top), temperature profile (middle) and P,T profile for a reservoir pressure of 300 bar and a wellhead temperature of 10°C. The mass flow ranges from 10 to 70 kg/s (edit one caption is wrong to be changed).

3.2.3 *Results influence reservoir pressure & influence well ID*

The influence of the well ID is plotted in Figure 8 in which the wellhead and downhole temperature are plotted as function of mass flow rate for a well with 50, 70, 90, 120 an d 150 mm. These diameters are chosen based on 2 3/8", 3½ ", 4 ½ " , 5½ " and 7" tubing (approximate mid strength class).

At low reservoir pressure it is found that:

- The range of allowed flow rates with respect to the bottomhole temperature increases for increasing diameter.
- At larger diameters, the required wellhead pressure decreases.
- At temperatures lower than the critical temperature, the required wellhead pressure is constant for a range of mass flow rates. The minimum mass flow rate for when the required wellhead pressure becomes constant, increases for larger diameters..
- At smaller diameters, the required wellhead pressure is severely limiting. At a diameter of 70mm, the maximum flow rate is just 30 kg/s (at 10°C).

At mid reservoir pressures it is found:

- For diameters larger than (and including) 90 mm, there are basically no downhole temperature restrictions.
- For diameters smaller than (and including) 90 mm, the wellhead pressure is limiting to the mass flow rates for al temperatures.

At higher reservoir pressures it is found:

- For diameters smaller than (and including) 120 mm, the wellhead pressure is severely limiting for the allowed injection rate at higher temperatures.

Based on this set, a number of aspects can be concluded:

- At low reservoir pressure, a high temperature and large diameter is better with respect to the downhole temperature.
- At high reservoir pressures, a smaller diameter is rapidly restricting with respect to the mass flow rate. In other words, at smaller diameters, the required mass flow rates cannot be injected within the available wellhead pressure envelope.

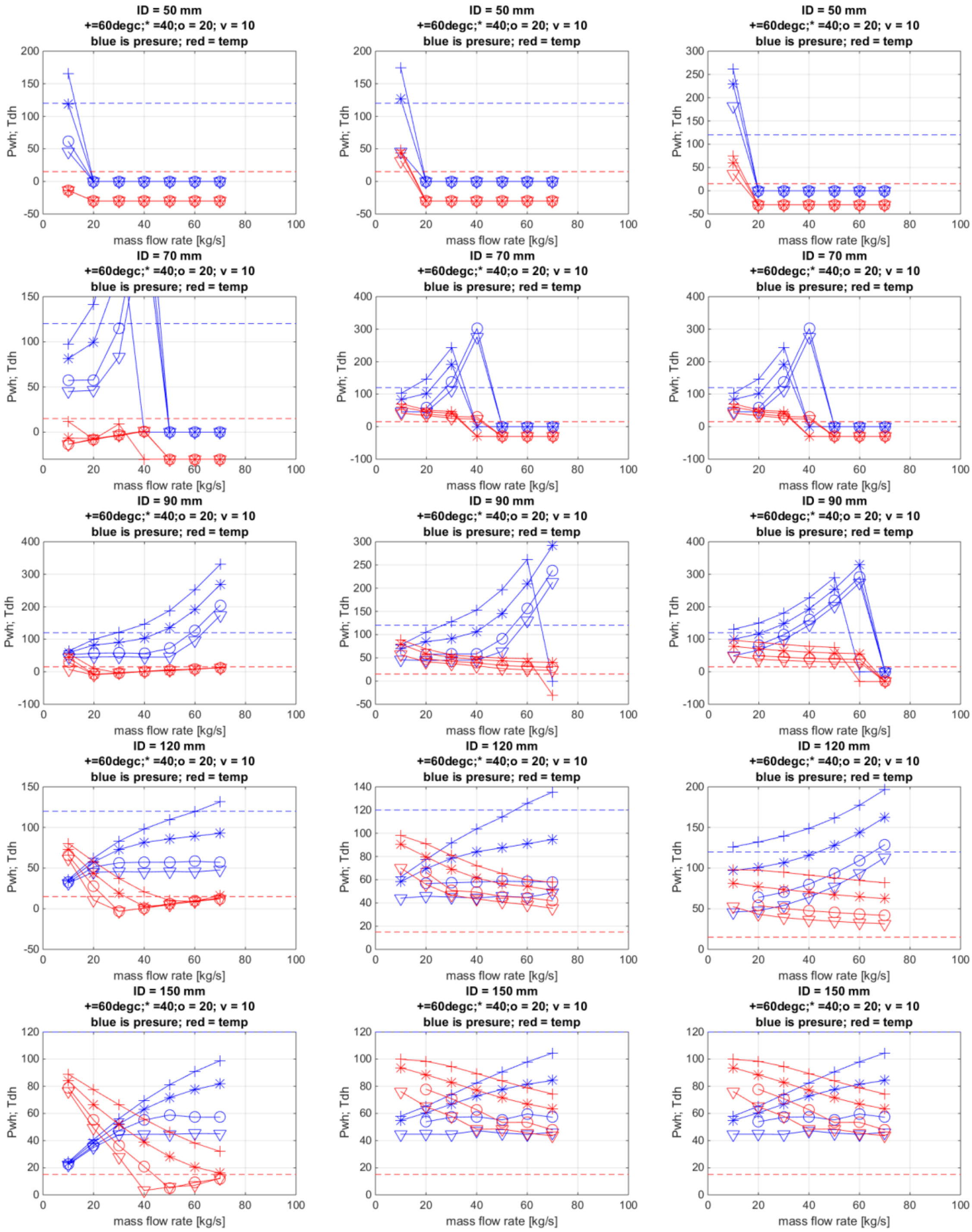


Figure 8: Influence well diameter (top to bottom rows) for a reservoir pressure of 20 bar (left), 100 bar (middle) and 300 bar (right). The simulations are limited to 350 bar. All cases with conditions higher than 350 bar are plotted as a pressure of 0 bar and a temperature of -30 °C.

3.3 CO_2 injection with controlled pipeline pressure

The results in the previous section are with a 'free' wellhead pressure. That is, there is no control choke at the wellhead. In this section a control valve is added. This control valve will keep the upstream pressure to a set value (or higher). It must be remarked that a section of 400m horizontal is used on the topside. This length was not set to very short as this would lead to numerical problems (with opening and closing of the choke the mass flow rate from the upstream side increases/decreases rapidly. This can lead to fast pressure variations in small volumes). Unfortunately that also meant some heat transfer was allowed in that section (for future cases, the heat transfer could be set to zero at those sections). This means the temperature arriving at the choke was not always similar to the 'inlet' temperature. This is especially true for low flow rates.

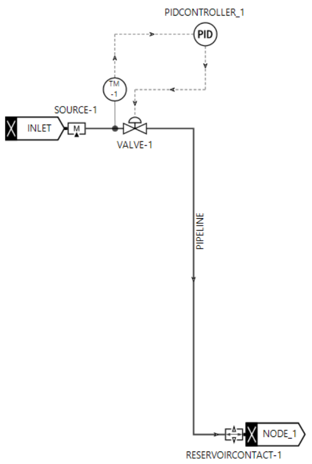


Figure 9: Model with control.

In this section results are given for:

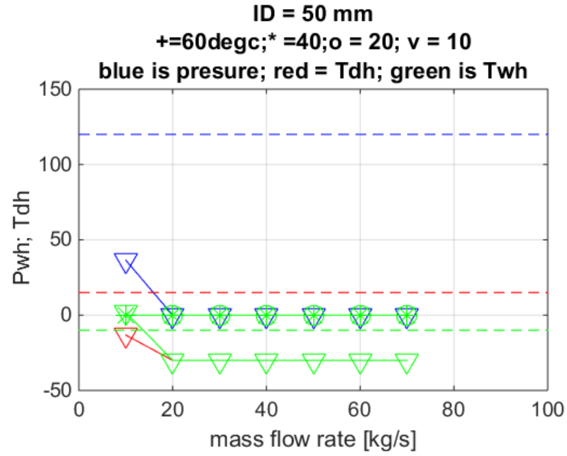
- Reservoir pressure 20 bar
- Pipeline pressure is minimally 85 bar

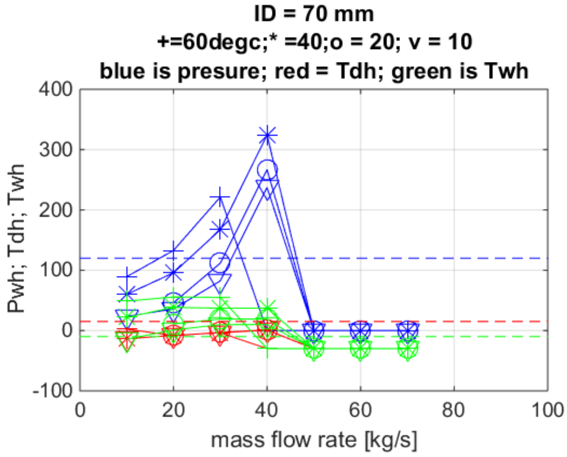
This condition is chosen as the low reservoir pressure is a strong limiting conditions as was shown in section 3.2.3.

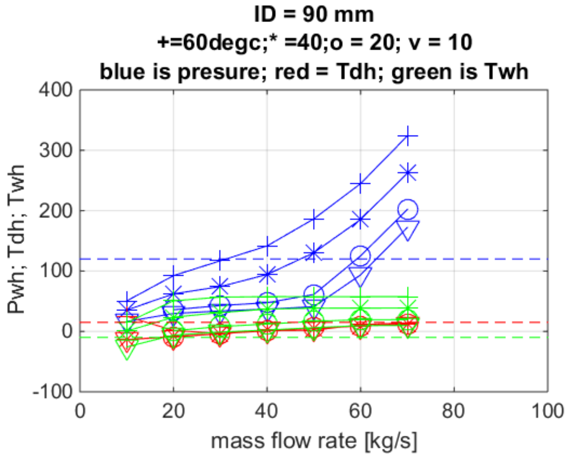
The results are given in Figure 10. The figures are complex but the important conclusions are:

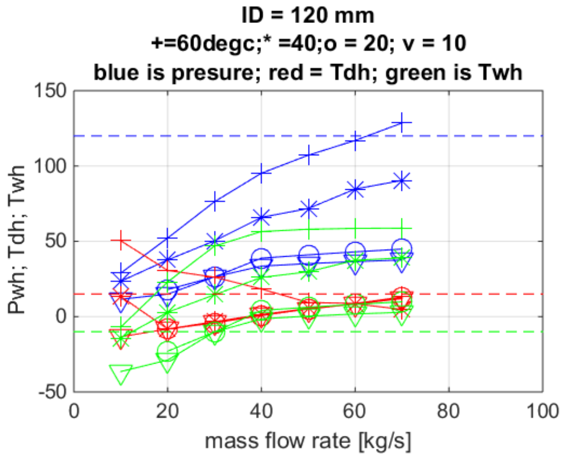
- At larger diameters, due to the low required wellhead pressures, a large pressure drop and therefore temperature drop occurs across the choke.
- The range of possible flow rates due to the downhole restriction (see Chapter 2) is limited due to this pressure drop across the control chokes.

This means that at low reservoir pressure, either the downhole temperature restriction is not achieved or the wellhead restriction. Only for the highest temperatures there is a margin of operation up to a flow rate of 40 kg/s in case of a ID = 120mm well. A side issue is that a low flow rates the cooling in the pipeline is such that 60 °C is difficult to achieve. This is only possible for high flow rates.


ID = 50 mm
+=60degc;* =40;o = 20; v = 10
blue is presure; red = Tdh; green is Twh
Pwh; Tdh
mass flow rate [kg/s]
150
100
50
0
-50
0
20
40
60
80
100


ID = 70 mm
+=60degc;* =40;o = 20; v = 10
blue is presure; red = Tdh; green is Twh
Pwh; Tdh; Twh
mass flow rate [kg/s]
400
300
200
100
0
-100
0
20
40
60
80
100


ID = 90 mm
+=60degc;* =40;o = 20; v = 10
blue is presure; red = Tdh; green is Twh
Pwh; Tdh; Twh
mass flow rate [kg/s]
400
300
200
100
0
-100
0
20
40
60
80
100



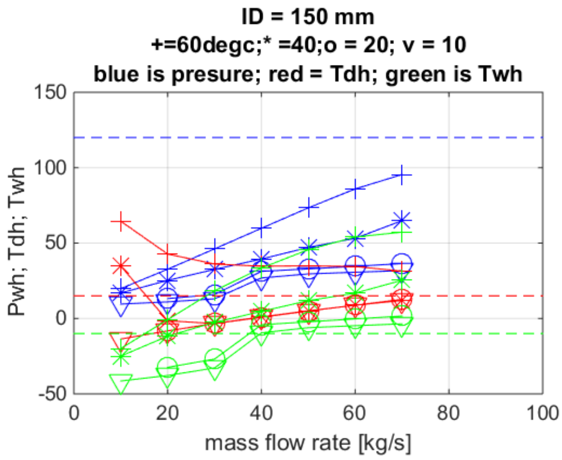


Figure 10: Wellhead pressures (downstream choke), wellhead temperatures (downstream choke) and downhole temperatures. The simulations are limited to 350 bar. All cases with conditions higher than 350 bar are plotted as a pressure of 0 bar and a temperature of -30 °C.

4 Simulation model(s)

4.1 Introduction

The simulations as presented have been done using OLGA 2017.1.0 with the single component CO_2 module using the P-H methodology. All simulations are done in transient mode simulating long enough to reach steady conditions (if any).

4.2 Basic model

The basic model is given in Figure 11. It consists of:
- Pipeline.
- 4 wells.
- A control valve at the pipeline inlet (to maintain a minimum discharge pressure of 60 bar).
- A control valve at the pipeline outlet to maintain the pipeline pressure at a minimum pressure.
- Each well has a control valve which is used in either mass flow or pressure control mode.

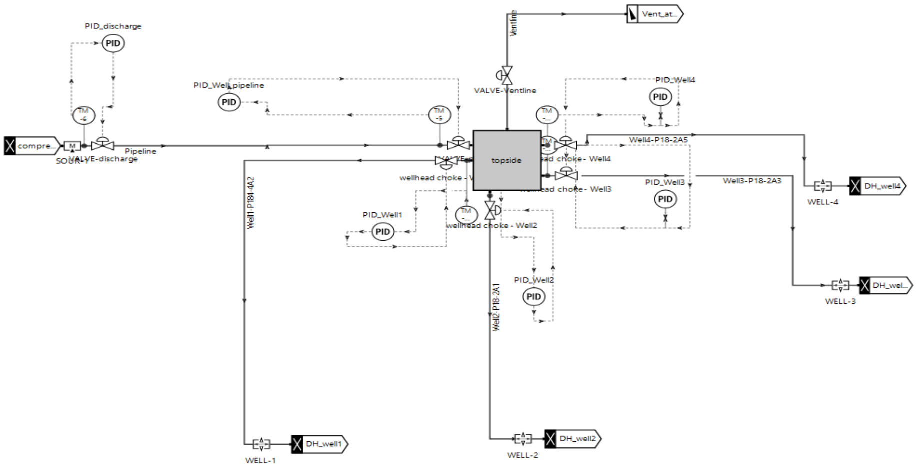


Figure 11: Olga model.

The controllers are all PID controllers with settings for the pressure controllers of:
Amplification: 2e-8
Bias: 0
Derivativeconst: 0 s
Error: 0
Integralconst: 5 [s]
The maximum change: 0.2

The mass flow controllers are set to:
Amplification: -0.0005
Bias: 0
Derivativeconst: 0 s
Error: 0

Integralconst: 5 [s]
The maximum change: 0.2

The control settings are not varied between cases and are relatively ‘soft’. That is the gain could be put higher (and still avoid unstable control). However, these settings seemed to work for almost all conditions and as such it was chosen to keep the settings more or less constant.

4.3 Pipeline geometry

The pipeline is modelled as:
- 22km, horizontal, (Inner) diameter = 0.4318m
- 25m, vertical, (Inner) diameter = 0.4318m
- 50m, horizontal, (Inner) diameter = 0.254m

The vertical diameter has been kept large as that is worst case for instabilities (in case we have two phase flow) but a 10” section was added for pressure drop.

Two controllers are added to the pipeline:
- Compressor outlet valve at a pressure control of 60 bar.
- Pressure controller at the horizontal section at ‘the platform’ .

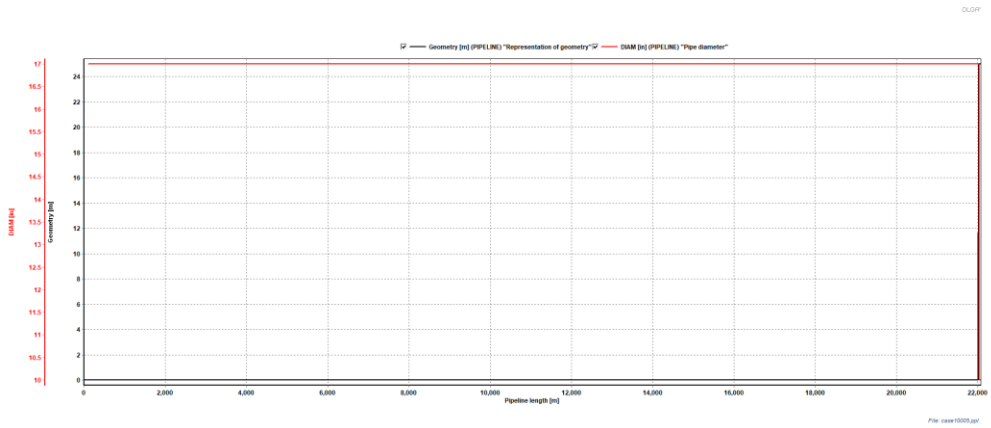


Figure 12: Pipeline geometry.

4.4 Well geometry

For the base model, the well inclination profiles of the wells P18-4A2, P18-2A1, P18-2A3 and P18-2A5 are used. For the base case, a tubing of 5.5” (0.12m ID) is used. The tubing diameter is used up to the point it could fit the casing/liner (as not for all a 5.5” tubing would fit down to the perforations). The detailed geometry used is given in Figure 13.

Well1 = P18-4A2 ID = 0.12m (5.5”)
Well2 = P18-2A1 ID = 0.12m (5.5”)
Well3 = P18-2A3 ID = 0.12m (5.5”)
Well4 = P18-2A5 ID = 0.12m (5.5”)

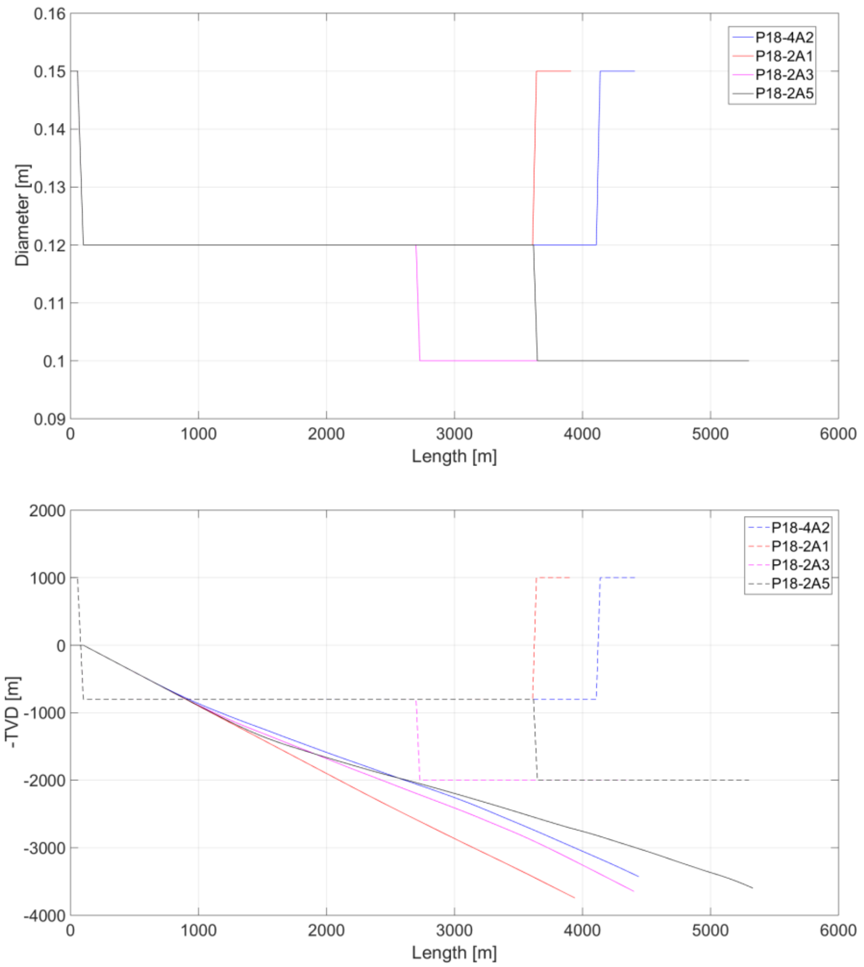


Figure 13: Well geometries used for the four wells. Diameter in bottom figures are scaled for visualisation.

The choice of diameters is based on :

- A larger diameter is 'better' for the downhole temperature (higher temperatures up to higher flow rates)
- A larger diameter is 'better' at high reservoir pressure
- A smaller diameter is 'better' with respect to topside temperature considerations (a smaller diameter builds up pressure faster with respect to mass flow rate and as such the pressure drop is less across control chokes at the wellheads.

A more detailed 'optimization' was done for 10°C injection cases. These are not reported in this report.

4.5 Reservoir

For the reservoir injectivity, a reservoir pressure dependent value is used. For all four wells the same injectivity (PI) index is used (based on P18-4 data). The injectivity is defined according:

$$m\ [kg/s] = \ PI\ \cdot \Delta p\ [Pa]$$

Table 1: Injectivity index used. * For 340 bar no data was available and the same value as for 300 bar was used.

Reservoir pressure [bara]	Injectivity index [(kg/s)/Pa]
20	2.53e-5
60	4.04e-5
100	6.14e-5
200	0.000109
300	0.000129
340	0.000129*

4.6 Heat transfer

For the heat transfer, at this stage an overall U value methodology is used. That is basically a steady state approach and less appropriate for dynamic simulations as the heat capacity of the walls are not included. However, as details on pipeline construction (insulation materials, burial depth, soil properties) and well selection (well used, annuli fluids) are not known the choice was made to use a U value methodology.

The pipeline is calculated using:
Ambient temperature: 10 °C
U value: 1.5/ m2-K (based on ID)
This includes the ‘riser’ and ‘topside’ part of the platform.

The wells are calculated using:
Vertical thermal gradient from 10 to 123 °C
U value: 9.5/ m2-K (based on ID)

5 Shutin-wellhead conditions

The shutin pressure for well P18-4A2 was calculated by ramping up the reservoir pressure after shutin. In Figure 14, the wellhead pressure is plotted as function of the reservoir pressure. This figure is obtained for a simulation in which the reservoir pressure was (linearly) increased slowly from 20 to 340 bar in 500000s (5.8 days). As the details of the results are determined by heat transfer, deviations might occur in case the details of the heat transfer and outer temperature will be different.

There are three regimes:

- At low reservoir pressure, the wellhead conditions are closely to single phase gas. In this region, the shutin wellhead pressure increases with the reservoir pressure (as the static head is in that case purely density and therefore pressure dependent).
- In the mid region, the wellhead is at two-phase conditions and all is dominated by heat transfer details (Figure 15). The wellhead pressure will be more or less constant as function of reservoir pressure and will be determined by the temperature.
- At high reservoir pressures, the wellhead is at liquid (supercritical) conditions and the wellhead pressure will increase with the reservoir pressure.

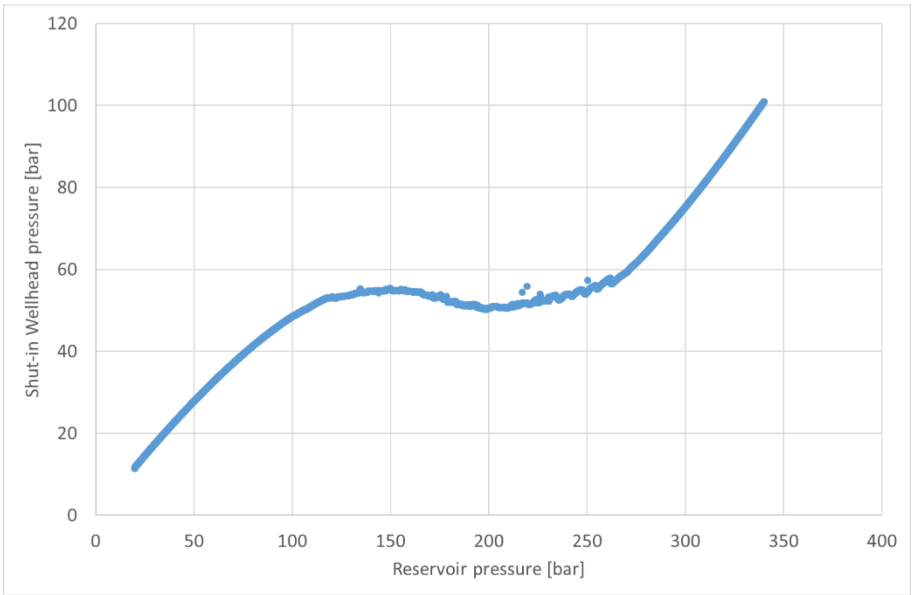


Figure 14: Shutin wellhead pressure for well P18-4A2. The reservoir pressure was increased from 20 to 340 bar in 500000s (5.8 days). For long term shutin case results of 12, 45, 45, 70 bar were obtained for 20, 100, 200, 300 bar reservoir pressure. The difference is due to the time allowed to reach steady state.

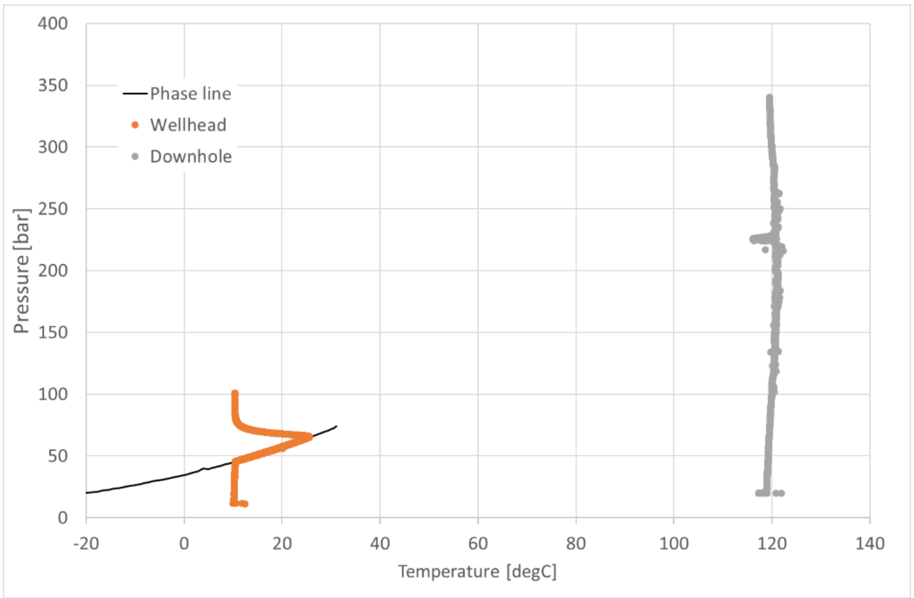


Figure 15: Wellhead and downhole condition for simulation with reservoir pressure increase.

6 Steady state

6.1 Introduction

In this chapter, the steady state results (final results of transient simulations) are discussed. These steady state simulations were done for a large range of models, flow rates and conditions. In this report only those results are presented with the model as described in Chapter 4. Previous models had no pipeline, a single well, no pipeline control valve or no compressor outlet control valve. When one well is used this is typically well-1 (P18-4A2).

In Section 6.2, an overview is given of the cases which have been simulated. The results of these cases are given in Annex A. In Section 6.3 a summary is given of the results.

6.2 Simulation cases

Case	***Pres***	***Tcompr***	***Wells***	***control***	***Mass flow***
4000	300	40	1 open	Platform (85 bar)	15
4001	300	40	1 open	Platform (85 bar)	30
4002	300	40	1 open	Platform (85 bar)	60
4002_45	300	40	1 open	Platform (85 bar)	45
4003	300	40	1 + 2 open	Platform (85 bar)	60
4004	300	40	All wells open	Platform (85 bar)	170
4119	300	80	All wells open	Platform (85 bar)	60
4120	300	80	All wells open	Platform (85 bar)	50
4005	340	40	All wells open	Platform (85 bar)	170
4006	340	40	All wells open	Platform (85 bar)	140
4110	340	80	All wells open	Platform (85 bar)	140
4111	340	80	All wells open	Platform (85 bar)	100
4113	340	80	All wells open	Platform (85 bar)	40
4114	340	80	All wells open	Platform (85 bar)	5
4130	340	40	1	Platform (85 bar)	30
4131	340	40	1	Platform (85 bar)	45
4132	340	40	1	Platform (85 bar)	38
4078^	100	40	All wells open	Platform (85 bar)	170
4079	200	40	All wells open	Platform (85 bar)	170
4080	100	40	1 open	Platform (85 bar)	60
4081	200	40	1 open	Platform (85 bar)	60
4082	100	40	1 open	Platform (85 bar)	30
4083	100	40	1 open	Platform (85 bar)	15
4084	200	80	1 open	Platform (85 bar)	30
4085	200	80	1 open	Platform (85 bar)	15
4118	200	80	All wells open	Platform (85 bar)	100
4127	100	80	All wells open	Platform (85 bar)	100
4124	100	80	1	Well (85)	15
4125	100	80	1	Well (85)	30

4127	100	80	1	Well (85)	60
4007	60	40	1 open	Platform (85 bar)	15
4008	60	40	1 open	Platform (85 bar)	30
4009	60	40	1 open	Platform (85 bar)	60
4010	60	40	1 open	Platform (85 bar)	100
4011	60	40	1 + 2 open	Platform (85 bar)	100
4012	60	40	All wells open	Platform (85 bar)	170
4013	60	40	All wells open	3 * mass; 1 P (85 bar)	170
4115	60	80	All wells open	3 * mass; 1 P (85 bar)	170
4116	60	80	All wells open	3 * mass; 1 P (85 bar)	100
4117	60	80	All wells open	3 * mass; 1 P (85 bar)	110
4121	60	80	1	Well 85	
4122	60	80	1	Well 85	
4123	60	80	1	Well 85	
4014	20	40	1 open	Platform (85 bar)	15
4015	20	40	1 open	Platform (85 bar)	30
4016	20	40	1 open	Platform (85 bar)	60
4017	20	80	1 open	P control at well (85)	15
4018	20	80	1 open	P control at well (60)	15
4019	20	80	1 open	P control at well (60)	60
4020	20	80	All open	3 * mass; 1 P (60 bar)	170
4021	20	80	All open	3 * mass; 1 P (60 bar)	120
4022	20	80	1 open	P control at well (60)	45
4023	20	80	1 open	P control at well (60)	30
4024	20	80	1 open	No control	15
4025	20	80	1 open	No control	30
4026	20	80	1 open	No control	45
4027	20	80	All wells open	No control	170
4028	20	80	All wells open	No control	140
4128	20	80	All wells open	No control	100
4129	20	80	All wells open	No control	90

6.2.1 *Results overview*

An overview of the results is given in Table 2 to Table 5. In these tables the main pressures and temperatures are given.

Pcomp: Compressor discharge pressure
Tcomp: Compressor discharge temperature
Pplatform: Pressure upstream of well control valves
Tdownstream: Temperature downstream of well control valves
Tdownhole: Downhole temperature at injection position

For a reservoir pressure of the 20bar, no case, with a liquid filled pipeline, adheres to both the wellhead and downhole temperature restriction (see Annex A). Therefore, only cases in which the pipeline pressure was not controlled are presented.

In general results have been calculated with for a single well starting at low flow rate and determining the maximum flow rates with respect to the temperature restriction (either wellhead or downhole), and for scenarios with all wells open, determining the maximum allowed flow rate with respect to the compressor pressure.

Table 2: Examples of results for a reservoir pressure of 20 bar. * The minimum wellhead temperature (Tdownstream) and downhole temperature are given if more than one well is used.

Reservoir pressure [bar]	Case	# wells	Mass flow rate [kg/s]	P comp [bar]	Tcomp [°C]	Control	P Platform [bar]	T* Down stream [°C]	T down hole* [°C]
20	4024	1	15	60	80	None	46	17	47
20	4025	1	30	80	80	None	80	42	17
20	4028	4	140	115	80	None	103	64	19
20	4128	4	100	90	80	None	81	58	35
20	4129	4	90	83	80	None	75	56	40

Table 3: Examples of results for a reservoir pressure of 60 bar. * The minimum wellhead temperature (Tdownstream) and downhole temperature are given if more than one well is used.

Reservoir pressure [bar]	Case	# wells	Mass flow rate [kg/s]	P comp [bar]	T comp [°C]	Control	P Plat form [bar]	T* Down stream [°C]	T down hole* [°C]
60	4007	1	15	85	40	Pipe: 85	30	-6	25
60	4008	1	30	85	40	Pipe: 85	56	18	27
60	4009	1	60	89	40	Pipe: 85	87	37	32
60	4011	2	100	89	40	Pipe: 85	75	31	31
60	4013	4	170	95	40	Well: 85	85	19	29
60	4121	1	15	86	80	Well: 85	85	-5	41
60	4122	1	30	87	80	Well: 85	85	39	46
60	4123	1	60	138	80	Well: 85	136	65	38
60	4115	4	170	155	80	3*well; P(85)	143	41	38
60	4116	4	100	100	80	3*well; P(85)	93	46	57
60	4117	4	110	119	80	3*well; P(85)	111	33	47

Table 4: Examples of results for a reservoir pressure of 100 bar. * The minimum wellhead temperature (Tdownstream) and downhole temperature are given if more than one well is used.

Reservoir pressure [bar]	Case	# wells	Mass flow rate [kg/s]	P comp [bar]	T comp [°C]	Control	P Plat form [bar]	T* Down stream [°C]	T down hole* [°C]
100	4083	1	15	85	40	Pipe 85	33	-2	50
100	4082	1	30	85	40	Pipe 85	52	15	53
100	4080	1	60	90	40	Pipe 85	87	37	51
100	4078	4	170	93	40	Pipe 85	76	32	50
100	4126	4	100	98	80	Pipe 85	90	60	82
100	4124	1	15	86	80	Well 85	85	9	60
100	4125	1	30	87	80	Well 85	85	45	71
100	4127	1	60	142	80	Well 85	139	64	60

Table 5: Examples of results for a reservoir pressure of 300 and 340 bar. * The minimum wellhead temperature (Tdownstream) and downhole temperature are given if more than one well is used.

Reservoir pressure [bar]	Case	# wells	Mass flow rate [kg/s]	P comp [bar]	T comp [°C]	Control	P Plat form [bar]	T* Down stream [°C]	T down hole* [°C]
300	4000	1	15	85	40	Pipe 85	58	21	64
300	4001	1	30	92	40	Pipe 85	90	35	73
300	4002_45	1	45	108	40	Pipe 85	105	33	62
300	4002	1	60	136	40	Pipe 85	133	32	58
300	4003	2	60	94	40	Pipe 85	91	37	77
300	4004	4	170	116	40	Pipe 85	108	36	68
340	4006	4	140	123	40	Pipe 85	116	36	68
340	4005	4	170	138	40	Pipe 85	130	36	66

6.3 Overview conclusions

For the different reservoir pressures the following is concluded:

- Reservoir pressure = 20 bar

Cases calculated with Tcompressor = 40 °C and 80 °C
Cases with T = 40 °C have a too low bottomhole pressure
With a pipeline at a pressure control of 85 bar, the minimum flow rate leads to a too low bottomhole temperature.
With a pipeline at a pressure control of 60 bar, the maximum flow rate is 30 kg/s.
At a pressure control of 60 bar, the maximum flow rate for all wells open is 120 kg/s

At open flow, the maximum flow rate for Well 1 is ~ 40 kg/s
At open flow, the maximum flow rate for all wells is ~ 140 kg/s

- Reservoir pressure = 60 bar

The cases are calculated with a compressor discharge temperature of Tcompressor = 40 °C. At those conditions, there are no limitations in mass flow rate due to the wellhead temperatures or downhole temperatures.
Due the compressor limit of P = 120 bar, the maximum mass flow rate is between 60 and 100 kg/s for a single well and higher than 170 k/s in case all wells are open.

With platform control, downstream of the choke control, two phase flow occurs
Recommended to use individual control (1 pressure control, rest mass flow control)

- Reservoir pressure = 300 bar

The cases are calculated with a compressor discharge temperature of Tcompressor = 40 °C. At those conditions, there are no limitations in mass flow rate due to the wellhead temperatures or downhole temperatures.
Due the compressor limit of P = 120 bar, the maximum mass flow rate is 45 kg/s for a single well and higher than 170 k/s in case all wells are open.

- Reservoir pressure = 340 bar

The cases are calculated with a compressor discharge temperature of Tcompressor = 40 °C. At those conditions, there are no limitations in mass flow rate due to the wellhead temperatures or downhole temperatures.
Due the compressor limit of P = 120 bar, the maximum mass flow rate is 140 kg/s in case all wells are open.

A summary of these conclusions is given in Table 6.

Table 6: Overview maximum flow rates.

Reservoir pressure	Maximum flow 1 well	Maximum flow 4 wells
20 bar - Tcomp = 80 °C	30 kg/s	140 kg/s
60 bar - Tcomp = 40 °C	60 kg/s	> 170 kg/s
300 bar - Tcomp = 40 °C	45 kg/s	> 170 kg/s
340 bar - Tcomp = 40 °C		140 kg/s
60 bar - Tcomp = 80 °C		110 kg/s
200 bar - Tcomp = 80 °C		100 kg/s
300 bar - Tcomp = 80 °C		45 kg/s
340 bar - Tcomp = 80 °C		0 kg/s

7 Start-up simulations

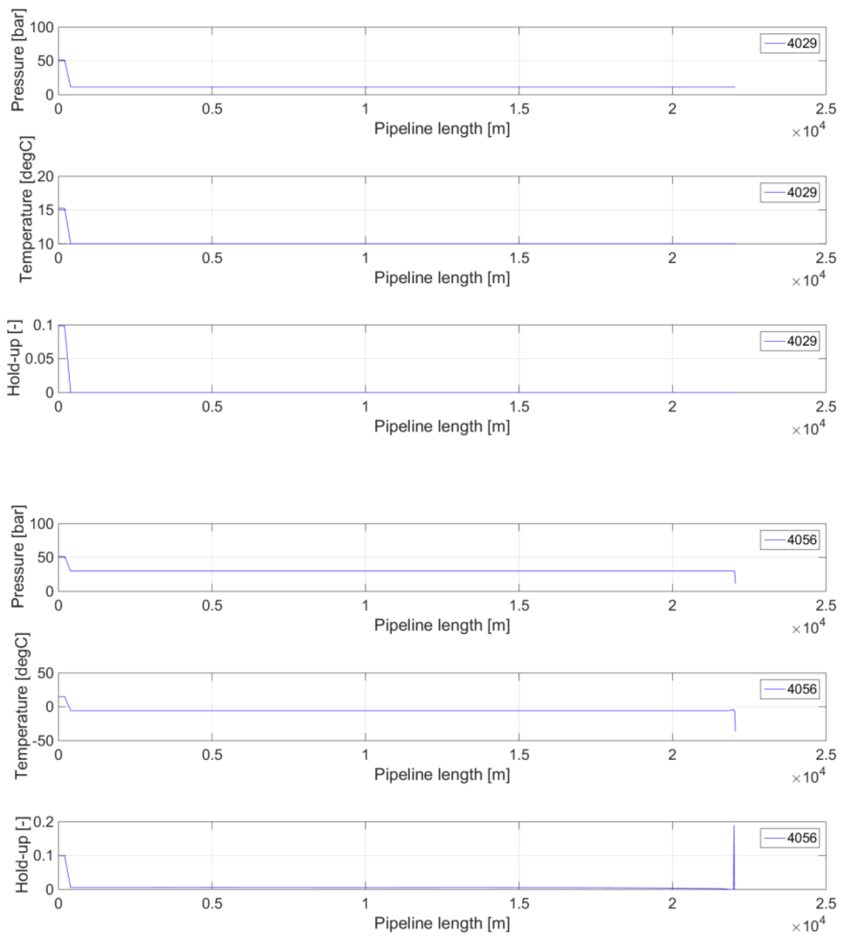
7.1 Introduction

In this Chapter an overview of start-up simulation are presented. In principle only low temperature start-up cases have been simulated as these are almost always worst cases.

Start-up simulations are done starting from three conditions (Figure 16):
- Low pressure (12 or 30 bar, 10°C; gas phase)
- Mid pressure (60 bar, 21°C; two-phase)
- High pressure (115 bar, 14°C; liquid phase)

The mid pressure conditions were obtained by closing in the pipeline at approximate 85 bar, 40 °C. When cooling down the conditions shift to the two-phase line conditions such that the total mass remains constant.

The high pressure conditions are assumed to be a near critical cases.



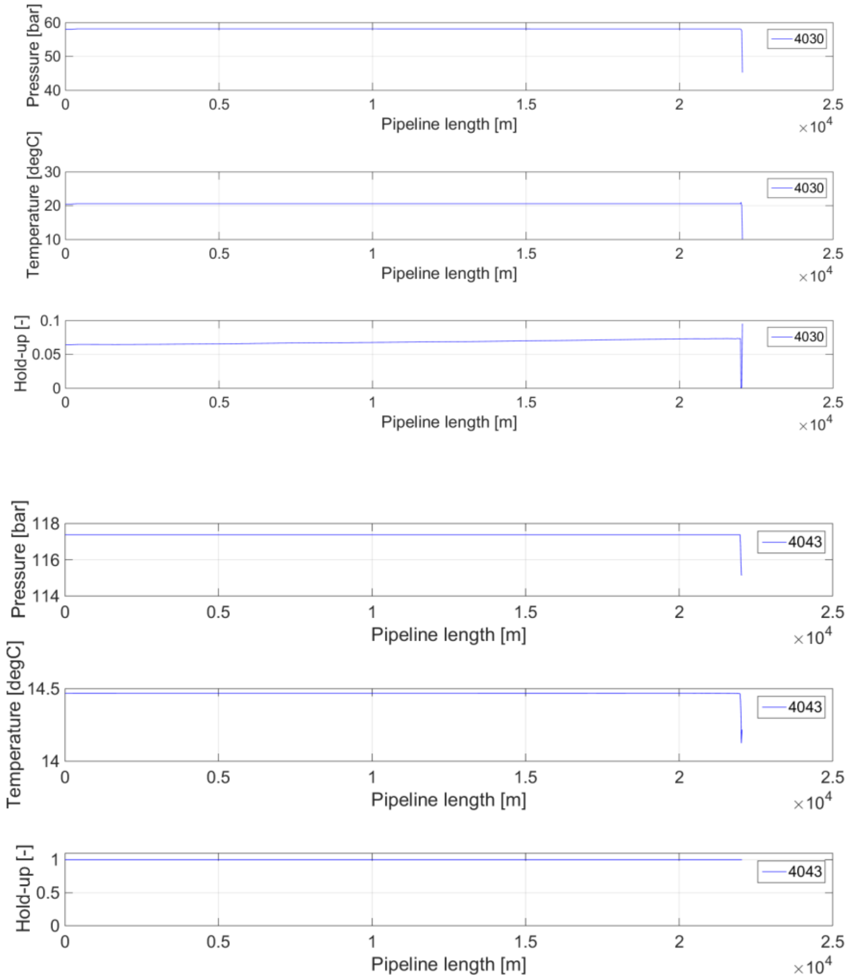


Figure 16: Pressure, temperature and hold-up profile for low (top 2 figures), middle and high pressures.

An overview of simulations ran is given in Section 7.2, with in Section 7.4, Section 7.5 and Section 7.6 start-up simulations at low reservoir pressure. In Section 7.9 and 7.10 the start-up cases for higher reservoir pressures are presented. Section 7.7 and Section 7.8 give a discussion on alternatives for low reservoir pressure start-up.

7.2 Simulations overview

In Table 7 an overview is given of the simulations ran. The different heading indicate:

Case:	Simulation case number
Pres:	Reservoir pressure [bar]
Tcmp:	Compressor outlet temperature [°C]
Wells:	Number of wells open or case number from which is restarted
Control:	Indication on how control is done None means the control settings are such that valves are full open (except discharge pressure control valve)

	Pipe N indicates that the pipeline pressure control valve is set to N bar
Mass flow	Compressor discharge mass flow rate [kg/s]

Table 7: Overview of simulations.

Case	***Pres [bar]***	***Tcmp [°C]***	***Wells***	***Control/ number of wells open***	***Mass flow [kg/s]***
4029	20	80	All wells open	Initialization at T = 10°C	
4030	20	80	All wells closed	Initialization at P ~85 bar (leading to a pipeline pressure of ~60 bar)	
4031	20	80		Shutin wells from 4028 (lading to a pipeline pressure of ~115 bar)	
Low pipeline pressure start-up with no control					
4032	20	80	Start from 4029	none	15
4033	20	80	Start from 4029	None	30
4034	20	80	Start from 4029	2 wells	60
4054	20	80	Start from 4029	4 wells	60
4055	20	80	Start from 4029	4 wells	170
Mid pipeline pressure start-up					
4035	20	80	Start from 4030		0
4036	20	80	Start from 4030	1 well full open	15 at t = 5000s
4037	20	80	Start from 4030	1 well full open	15 at t = 0s
4038	20	80	Start from 4030	2 wells Full open	60 at t = 5000s
4039	20	80	Start from 4038	3 wells Full open	90 at t = 1000s
4065	20	80	Start from 4030	Pipeline = 30 bar	0
4066	20	80	Start from 4030	Pipeline = 30 bar 1 well full open	15 at t = 5000s
4067	20	80	Start from 4030	Pipeline = 30 bar 1 well full open	Opening valve 10, 100, 300, 1000s
High pipeline pressure start-up					
4043	20	80		Initialization at t=10, 120 bar	
4044	20	80	Start 4043	Full open	15 at t = 5000s
4045*	20	80	Start 4043	Well 2 Control on 30 kg/s	15 at t = 5000s
4047*	20	80	Start 4043	Well 2 Control on 10 kg/s	15 at t = 5000s
4048	20	80	Start 4043	Well 2	15 at t = 5000s

				Control on 60 kg/s	
4046**	20	80	Start 4043	Full open @ t = 5000	15 at t = 0
4049	20	80	Crashes	Pipe 85 bar Well 60	
4050	20	80	Crashes	Pipe 0.05 Well 0.05	
Venting solution					
4051	20	80	Start 4043	Temporary vent	
4052	20	80	Start 4043	venting Well 1 open at 14000	15 at t = 10000
4053	20	80	Start 4043	Start at full open Well 1 + well 2	
4068	20	80	Start 4043	vent	
4069	20	80	Start 4068	Well 1 full open	15 at 5000s Well open at 1000
4071	20	80	Start 4068		Valve opening times
4072	20	80	Start 4068		15 at 1000 Well open at 5000
4074	20	80	Start 4068	Well 2 control	Control 15, 30, 45, 60 kg/s (60 *)
4075	20	80	Start 4068		15 at 1000 Well open at 6000
4076^	20	80	Start 4068	30 bar 4 wells open	15 at 10000s Well open at 1000
Low Pipeline pressure startup with pressure control					
4056	20	80	Pipe 30 bar	Initialization at T = 10°C	
4057	20	80	Start 4056	Pipe 30 bar (1 well full open)	30
4058+	20	80	Start 4056	None (1 well open)	30
4059++	20	80	Start 4056	None (1 well open)	30
4060	20	80	Start 4057	Open well 2	
4061	20	80	Start 4056	None (2 wells open)	60
4062	20	80	Start 4061	Open well 3	
4063	20	80	Start 4061	Open well 3 Variation opening time	topen = 10s, 100s 300s, 1000s
4064	20	80	Start 4060	Open well 2 Variation opening time	topen = 10s, 100s 300s, 1000s
4070	20	80	Start 4056	Pipe 30 bar (1 well full open)	15

High pipeline pressure start-up with Well ID = 0.09m					
5000	20	80		Vent	Well 1 0.09
5001	20	80	Start 5000		15 kg/s
High pipeline pressure start-up with choke in well (variation ID and position)					
6000	Initialization DHC position 4000m				
6001	20	80		Start 6000	15

6002	Initialization DHC position 3700m				
6003	20	80		Start 6002	15
6004	Initialization DHC position 3200m				
6005	20	80		Start 6004	15
6006	Initialization DHC position 2200m				
6007	20	80		Start 6006	15
6008	Initialization DHC position 1200m				
6009	20	80		Start 6008	15 kg/s
6010	20	80		Start 6000	Pressure control DHC

* Hydrodynamic slugging is turned -off; otherwise no convergence.
** This scenario is not useful as the pipeline pressure will rise too fast.
+ The maximum time step is limited
++ Hydrodynamic slugging is turned -off; otherwise no convergence.
^ Slip is turned-off otherwise no convergence

Case	***Pres***	***Tcmp***	***Wells***	***control***	***Mass flow***
4100	All 60	80	All wells closed	Pipe 85	For initialisation
4101	1*60 3*20	80	All wells closed	Pipe 85	For initialisation
4102	All 60	80	Start 4100	Pipe 85	15
4103	60; 3*20	80	Start 4101	Well 85	30
4104	60; 3*20	80	Start 4103	Well 85 Mass 15	30
4105	All 60	80	Start 4101	Well 1 open Pipe 30	15
4106	All 60	80	Start 4100	Well 1 open Pipe 30	30
4107	All 60	80	Start 4100	Well 1 open Pipe 30	60
4108	All 60	80	Start 4106	Opening well 2	60

Case	***Pres***	***Tcmp***	***Wells***	***control***	***Mass flow***
4200	All 100	40	All wells closed	Pipe 85	For initialisation
4201	All 100	40	*Start 4200- 1 well*	Pipe 85	15
4202	All 100	40	*Start 4200- 1 well*	Pipe 85	30
4203	All 100	40	*Start 4200- 1 well*	Pipe 85	60

Case	***Pres***	***Tcmp***	***Wells***	***control***	***Mass flow***
4300	All 200	40	All wells closed	Pipe 85	For initialisation
4301	All 200	40	*Start 4300- 1 well*	Pipe 85	15
4302	All 200	40	*Start 4300- 1 well*	Pipe 85	30
4303	All 200	40	*Start 4300- 1 well*	Pipe 85	60

Case	***Pres***	***Tcmp***	***Wells***	***control***	***Mass flow***
4400	All 300	40	All wells closed	Pipe 85	For initialisation
4401	All 300	40	Start 4400- 1 well	Pipe 85	15
4402	All 300	40	Start 4400- 1 well	Pipe 85	30

4403	All 300	40	Start 4400- 1 well	Pipe 85	60

Case	***Pres***	***Tcmp***	***Wells***	***control***	***Mass flow***
4500	All 340	40	All wells closed	Pipe 85	For initialisation
4501	All 340	40	Start 4500 – 1 well	Pipe 85	15
4502	All 340	40	Start 4500 – 1 well	Pipe 85	30
4503	All 340	40	Start 4500 – 1 well	Pipe 85	60
4504	All 340	40	Start 4500 – 2 wells	Well 1:85 Well 2:30 kg/s	60

7.3 Remarks valve openings

Before the general start-up behaviour is discussed, the detailed temperature behaviour around valves is discussed. As example, in Figure 18, the fluid temperature is plotted as function of time of well-2. This well is opened while well-1 is running at 30 kg/s (Figure 17). The opening time of the valve is varied from 10s to 1000s.

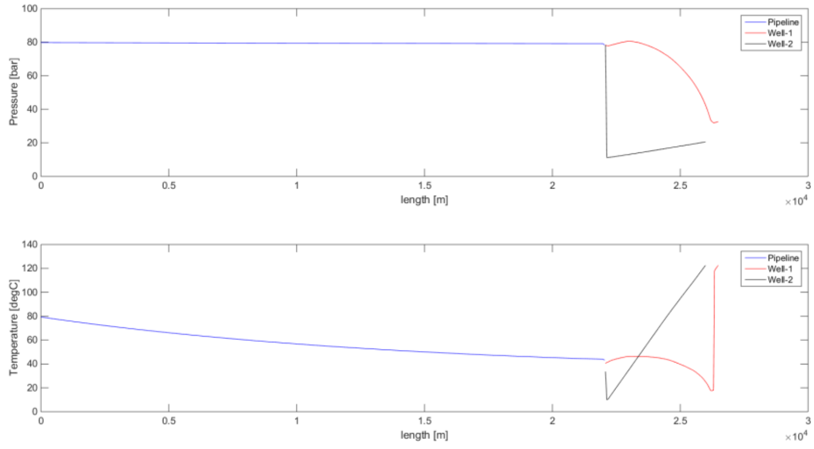


Figure 17: Initial conditions for case 4064.

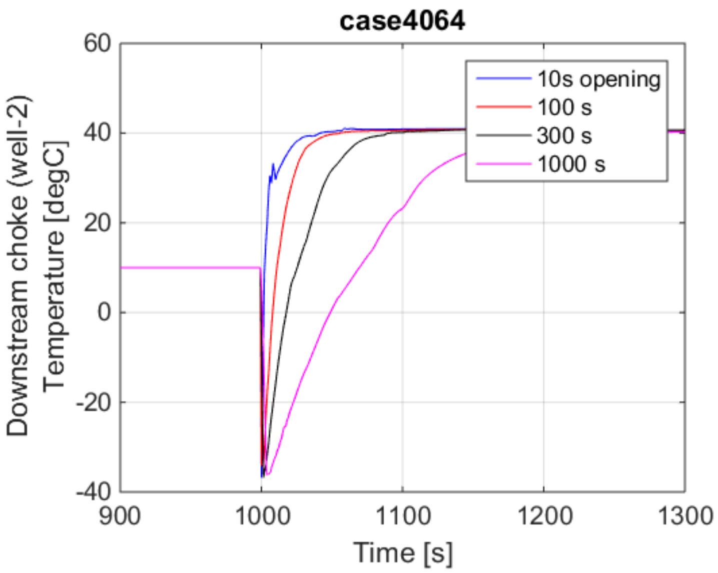


Figure 18: Temperature downstream choke of well-2 with different valve openings speeds (10s means the valve is opened from fully opened to fully closed in 10s).

As the conditions at the valve opening downstream of the valve are approximately 12 bar, when the CO_2 is expanded over the valve, the downstream conditions are for a short period at low temperature corresponding to the wellhead pressure and phase line temperature of approx. -38 °C. With a faster opening of the valve, the mass flow rate increases more rapidly through the valve resulting in

- A higher back pressure and therefore higher temperature
- A faster higher temperature arriving at the valve.

This will basically always occur when a new well is opened. A faster opening of the valves limits the period of low temperatures.

It must be remarked that the temperatures are fluid temperatures and not wall temperatures. When piping arrangements are known, a more detailed simulation can be done to determine actual wall temperatures when pipe thermal capacity is included.

7.4 Discussion start-up reservoir pressure 20 bar– low pipeline pressure

The start-up simulations are run from a low pressure pipeline conditions (Figure 19).
The sequence for the start-up are (Figure 20):

- The compressor mass flow rate is ramped up from 0 to a given flow rate from t = 1000s to 1600s.
- The pipeline pressure control valve is at p = 10 bar at t= 0s.
- For case 4032 and case4033, the well control was set to 10 bar at t= 0s (meaning full open).
- For case4033, the well 2 control was set to 1000 kg/s at t= 0s (meaning full open).

The sequence is setup such that the wells are first opened but that the pipeline pressure has not reduced too far down before the compressor is started up. However, the compressor is not started up too soon such that the pipeline is pressurized before the wells are opened.

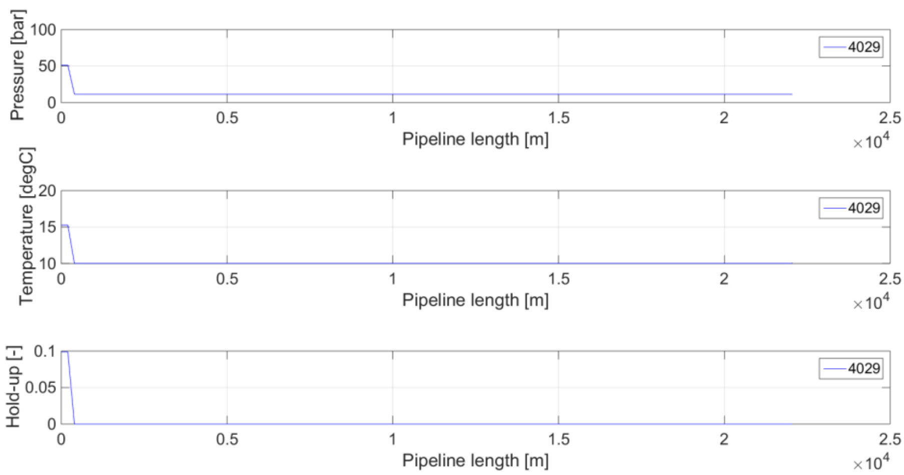


Figure 19: Initial conditions for start-up.

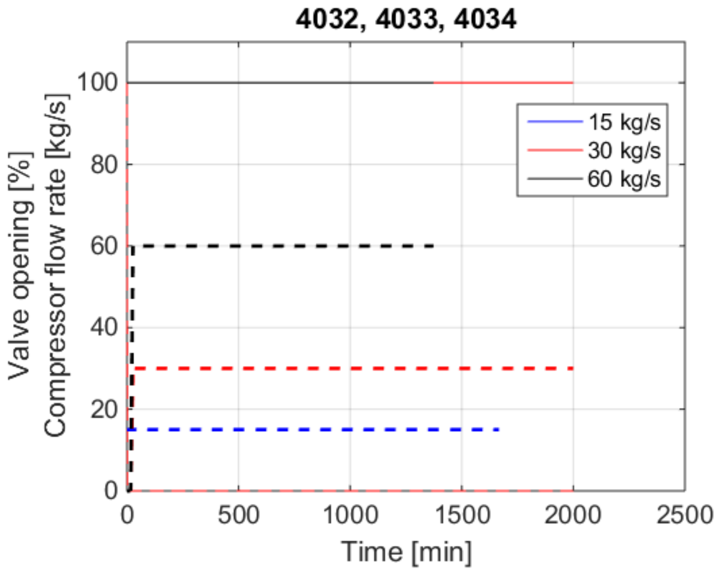


Figure 20: Compressor and valve openings.

The main parameters such as pipeline inlet pressure, the temperatures downstream of the choke valves and the downhole temperature are plotted as function of time in Figure 21. All pressures and temperatures comply with the restrictions. When the high temperatures have arrived at the platform other wells might be opened.

It must be remarked that the stabilization time before steady conditions are reached is nearly 500 – 1000 minutes (8-17 hrs).

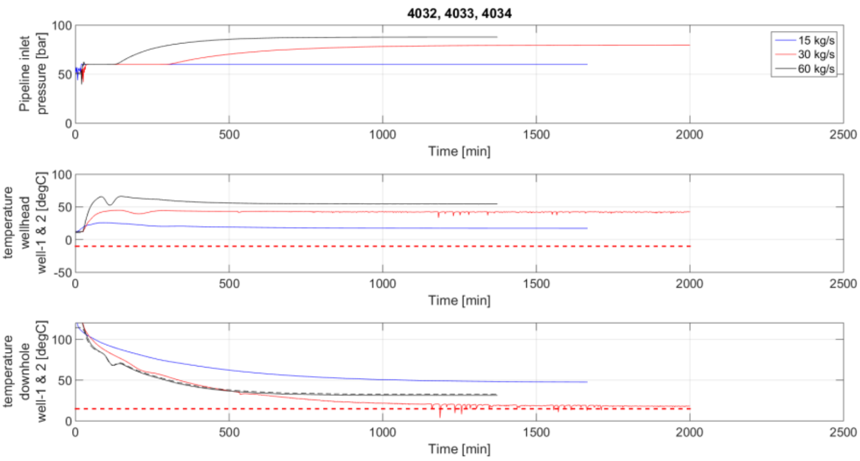


Figure 21:Pipeline inlet pressure, wellhead temperature (downstream choke valve) and downhole temperatures.

7.5 Discussion start-up reservoir pressure 20 bar– mid pipeline pressure

If the pipeline is at mid pressures (Figure 22), two potential start-up scenarios could be done:

- One in which the pipeline inventory is first emptied in the well by opening the well chokes prior to compressor start-up.
- Start-up the compressor while the pipeline is still flowing.

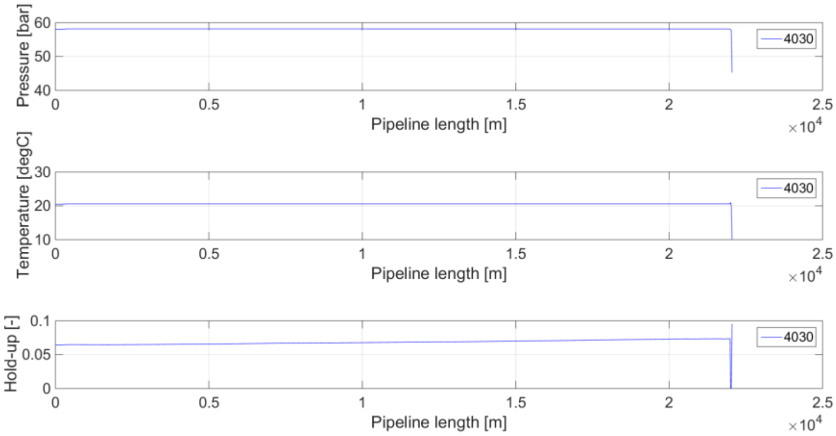


Figure 22: Initial conditions for start-up.

7.5.1 *Empty pipeline (no pipeline pressure control) (case4035)*

For case4035 the sequence is (Figure 23):

- The pipeline pressure control valve is set to p = 10 bar at t= 0s.
- The control valve of well-1 is set to 10 bar at t = 1000s.

The resulting temperatures are plotted in Figure 24.The wellhead temperatures are for a prolonged period too low (700 min).

Therefore, this scenario is not advised.

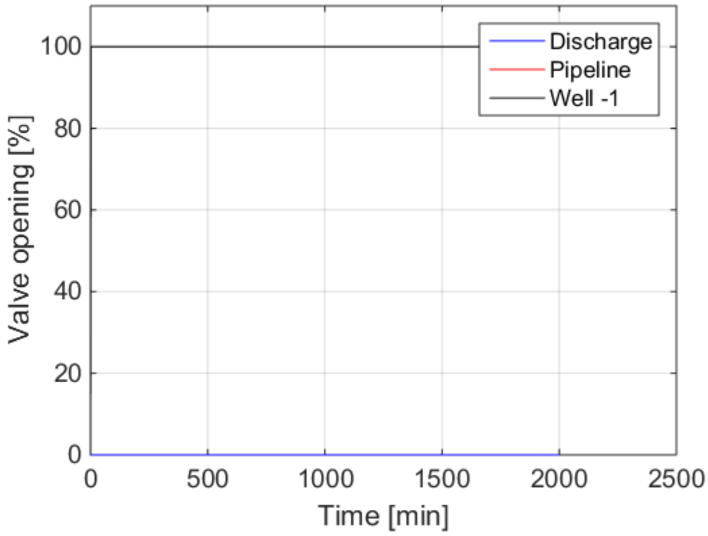


Figure 23: valve openings as function of time.

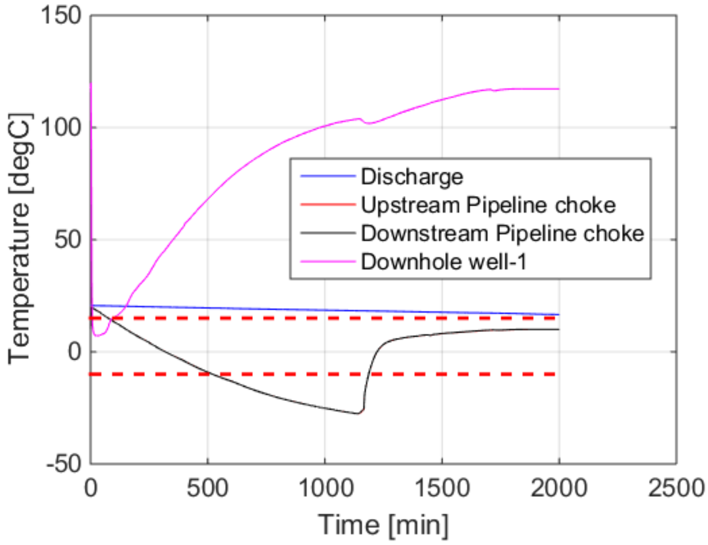


Figure 24: Resulting temperatures.

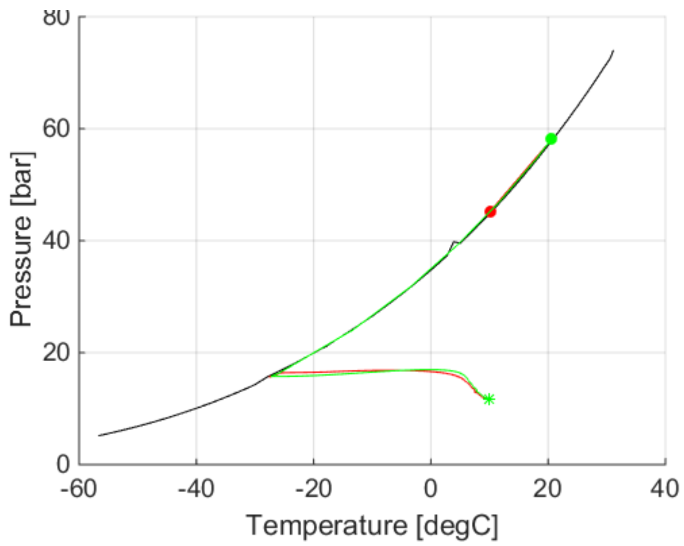


Figure 25: Pressure/temperature profile in the phase envelope. Black is the phase line. Green is downstream of the pipeline pressure control valve. Red at the pipeline inlet.

7.5.2 *Start-up without pipeline control (case 4036, 4037) (1 well)*

The second scenario is that the compressor is started up while the pipeline is emptied.

For case4036 the sequence is (Figure 26):

- The pipeline pressure control valve is set to p = 10 bar at t= 0s.
- The control valve of well-1 is set to 10 bar at t = 1000s.
- The compressor is ramped up from t = 5000 to 5600s.

For case4037 the sequence is (Figure 26):

- The pipeline pressure control valve is set to p = 10 bar at t= 0s.
- The control valve of well-1 is set to 10 bar at t = 1000s.
- The compressor is ramped up from t = 1 to 601s.

The resulting pressures & temperatures are given in Figure 27. Only for a short time (500 min) the downhole temperature criterion is just not met.

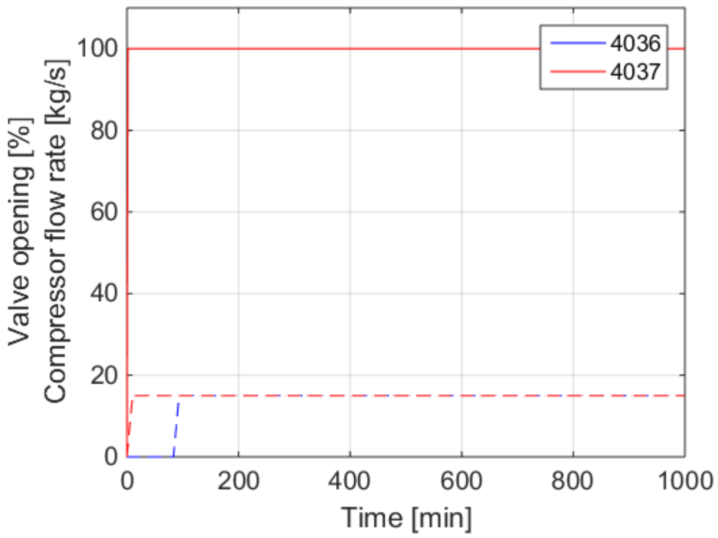


Figure 26: Valve (solid lines) and mass flow rates (dashed lines).

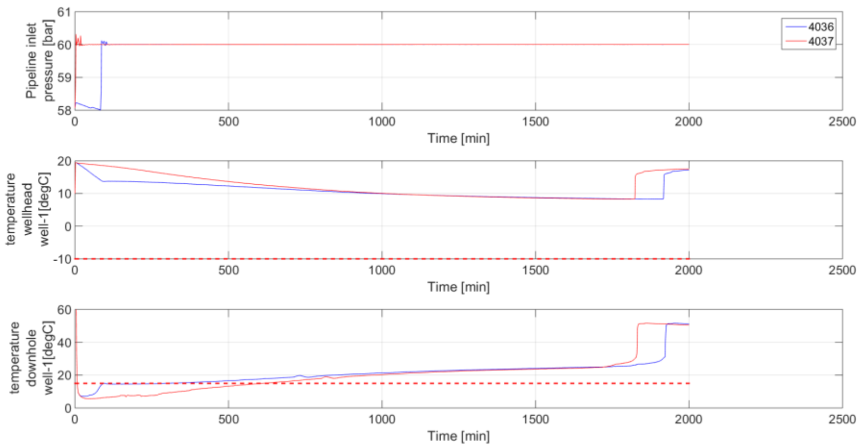


Figure 27: Resulting pressures and temperatures.

7.5.3 *Start-up without pipeline control (case4038) (2 wells)*

Case4038, is a start-up at higher mass flow rates with two wells open.

For case4038 the sequence is (Figure 28):

- The pipeline pressure control valve is set to p = 10 bar at t= 0s.
- The control valve of well-1 is set to 10 bar at t = 1000s.
- The control valve of well-2 is set to 1000 kg/s at t = 0s.
- The compressor is ramped up from t = 5000 to 5600s.

As with the previous start-up (Figure 27), for a short period, the downhole temperature criterion is not met but again this is for a shorter period (~200 minutes).

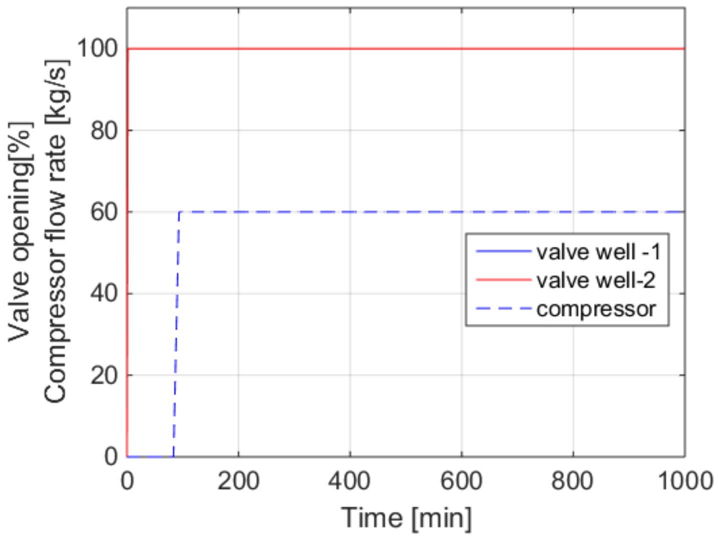


Figure 28: Valve opening (solid lines) and mass flow rate (dashed line).

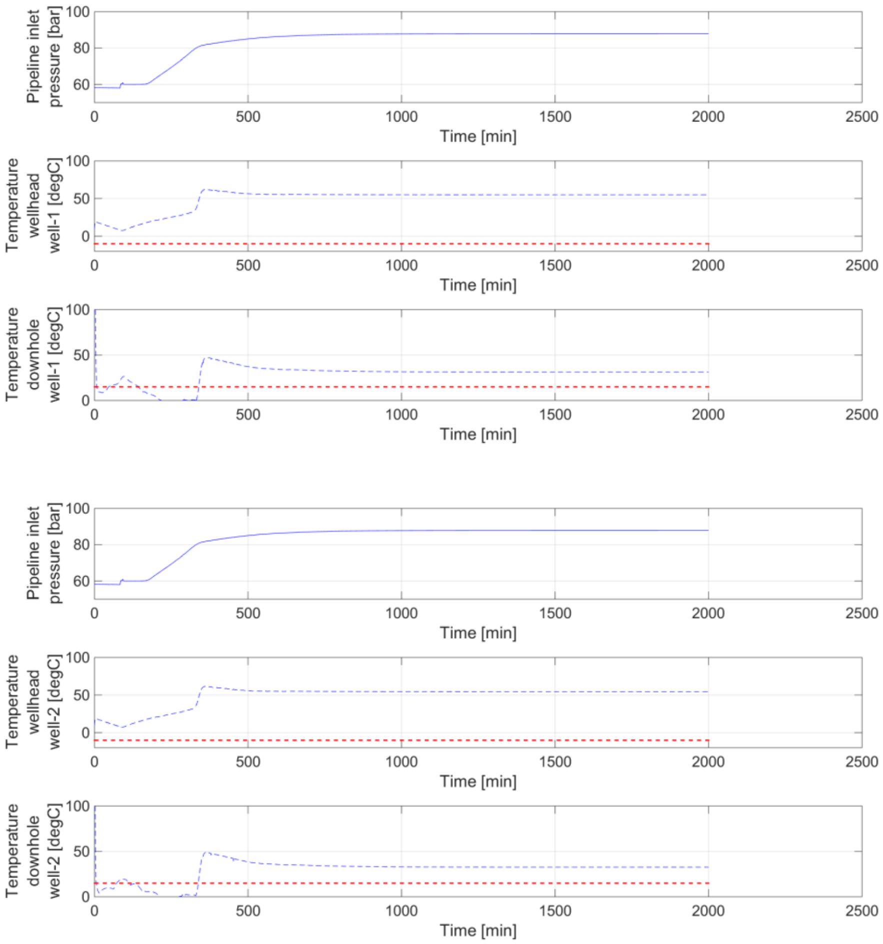


Figure 29: Pressures and temperatures for well-1 (top) and well-2 (bottom).

7.5.4 Start-up without pipeline control (case4039) (3 wells)

Finally, a large mass flow start-up with three wells is calculated.

For case4039 the sequence is:

- The pipeline pressure control valve is set to p = 10 bar at t= 0s.
- The control valve of well-1 is set to 10 bar at t = 1000s.
- The control valve of well-2 is set to 1000 kg/s at t = 0s.
- The control valve of well-3 is set to an opening 0, 0.05, 0.1, 0.2, 0.5 and 1 at t= 0, 100, 200, 300, 600, 700 s. (This sequence was chosen to open the well-3 in a controlled way. No variations for other sequences have been tried).
- The compressor is ramped up from t = 1000 to 1600s (from 60 to 90 kg/s).

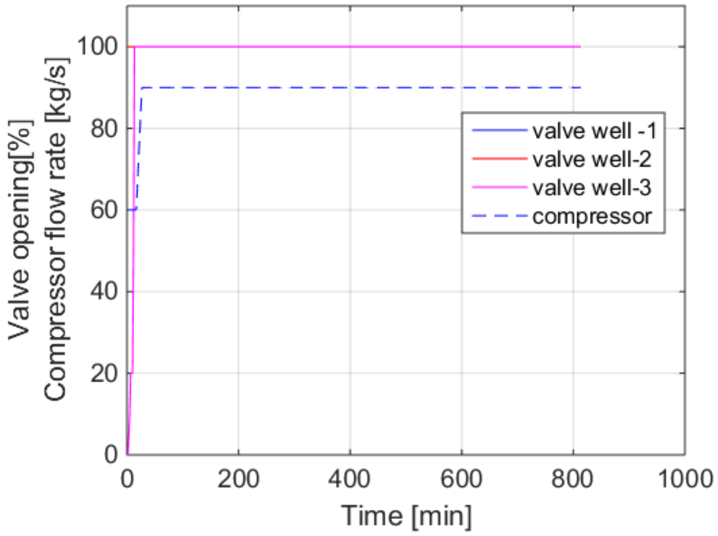
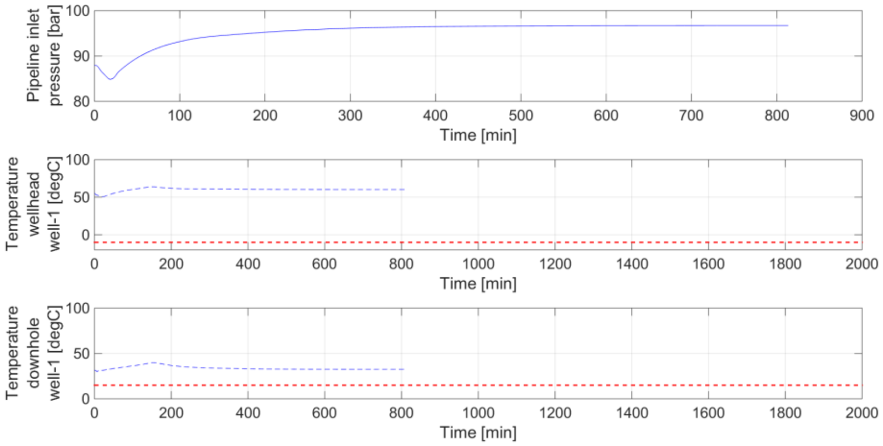


Figure 30: Valves (solid lines) and mass flow rate (dashed line).

The pressures and temperatures for the three wells are given in Figure 31. All conditions are met.



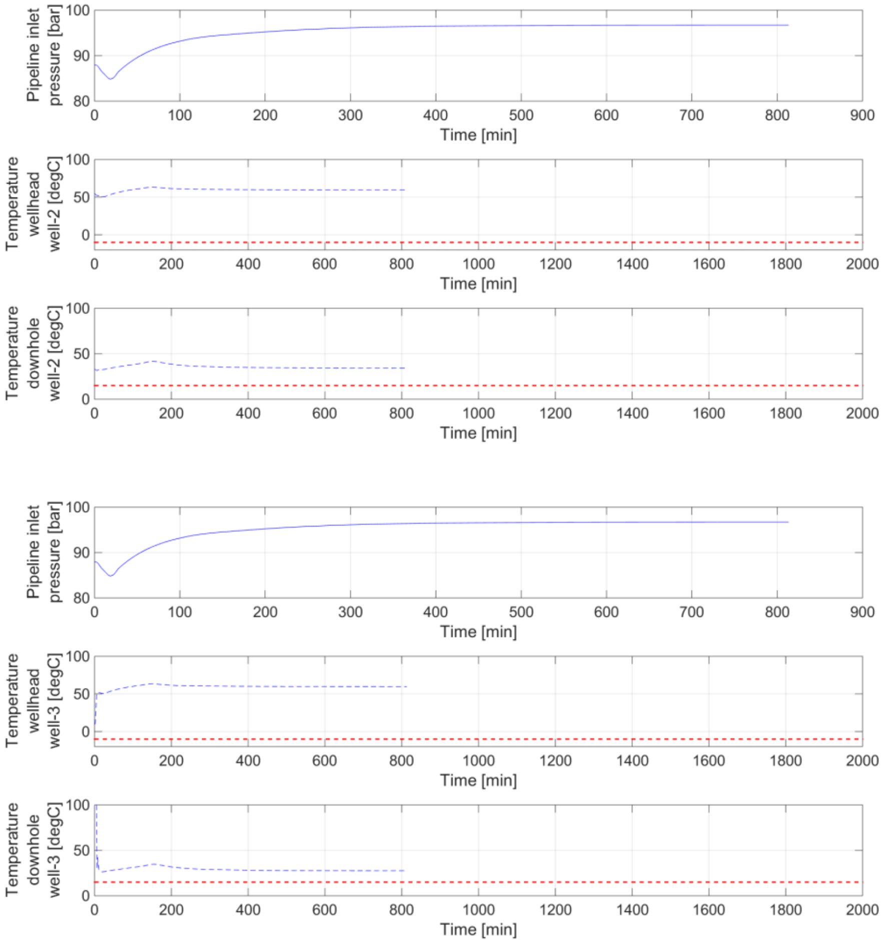


Figure 31: Pressures and temperatures for well-1, 2 and 3.

7.5.5 *Empty pipeline (with pipeline pressure control) (case4065)*

The previous start-up cases were without a pipeline pressure control. Case4065 is a case in which the pipe is emptied while there is a pressure control of 30 bar.

For case4065 the sequence is (Figure 32):

- The pipeline pressure control valve is set to p = 30 bar at t= 0s.
- The control valve of well-1 is set to 10 bar at t = 1000s.

As with the full pipeline emptying, the pressure and temperature drop (Figure 33, Figure 34). At a time of 440 min, the pressure control valves starts to close. Downstream of the valve the flow expands further down to 12 bar. This results again to temperatures of -38 °C before the heat transfer starts to kick-in.

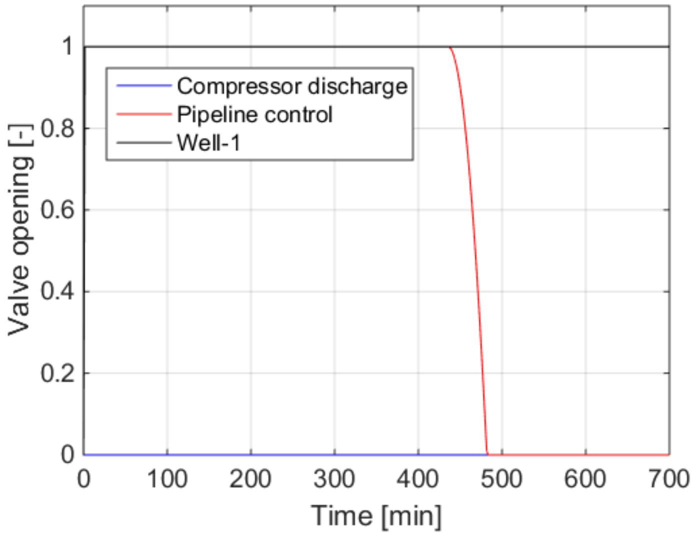


Figure 32: Valves as function of time.

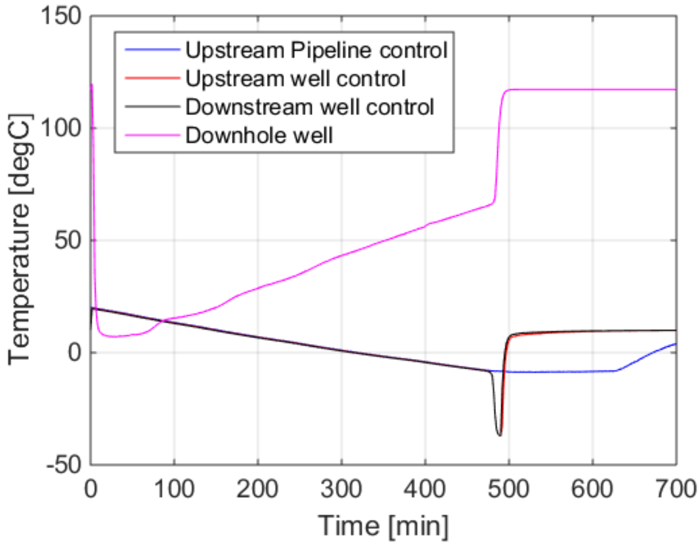


Figure 33: Temperatures as function of time.

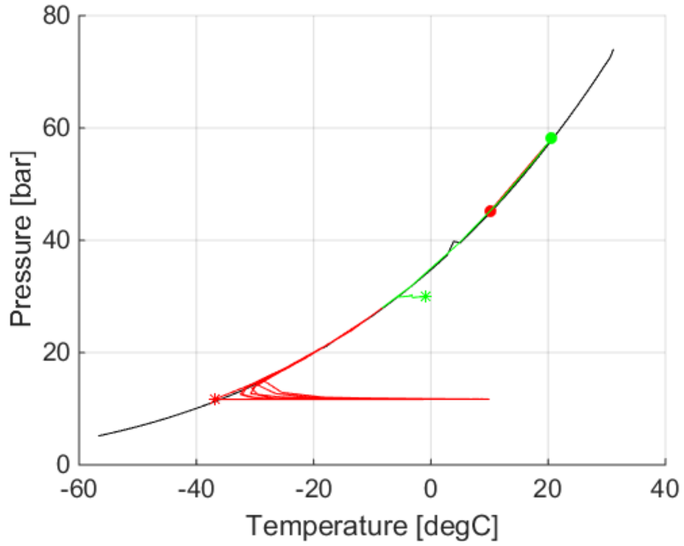


Figure 34: Pressure/temperature conditions in the phase envelope. Red indicated the conditions downstream of the pressure control valve. Green the conditions at the pipeline inlet.

7.5.6 *Start-up without pipeline control (case 4066) (1 well)*

For case4066 the sequence is (Figure 35):

- The pipeline pressure control valve is set to p = 30 bar at t= 0s.
- The control valve of well-1 is set to 10 bar at t = 1000s.
- The compressor is ramped up from t = 5000 to 5600s. (This means the pipeline pressure if emptied partly before the compressor is ramped up).

The resulting temperatures are given in Figure 36. Only a very short time the downhole temperature is too low.

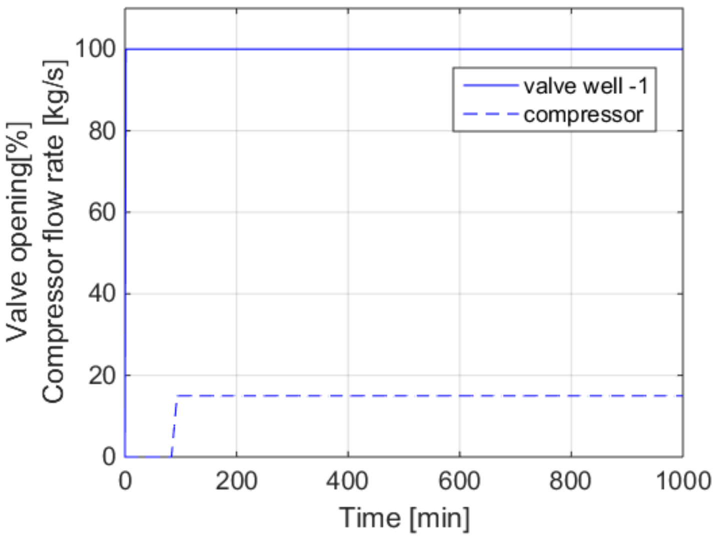


Figure 35: Valves (solid lines) and flow rates (dashed lines).

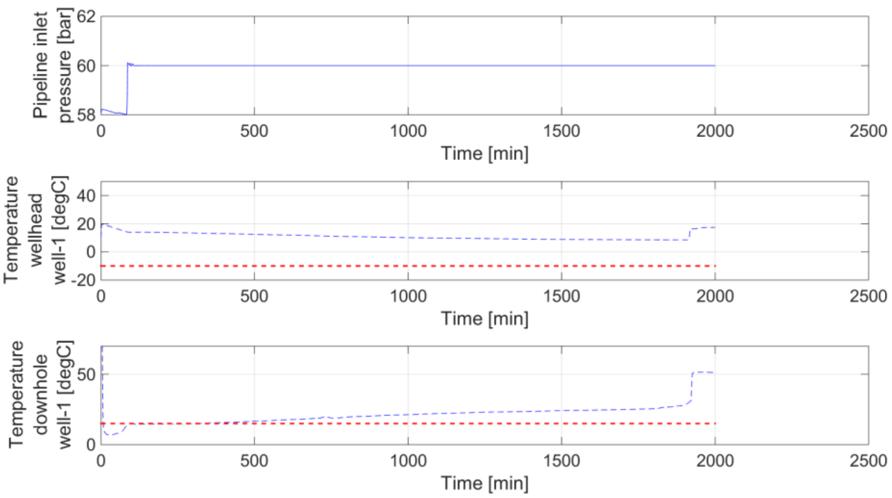


Figure 36: Pressures and temperatures as function of time.

7.6 Discussion start-up reservoir pressure 20 bar– high pipeline pressure

For the high pressure initial conditions (Figure 37), different strategies have been tried:

- First emptying the pipeline (case4044).
- Start up with the well (well2) the mass flow was limited (4045, 4047, 4048).
- A double pressure control (the pipeline at 85 bar and the well at 60 bar) (4049). (This case did not converge).
- Both the pipeline and well are at a limited opening (0.05) .

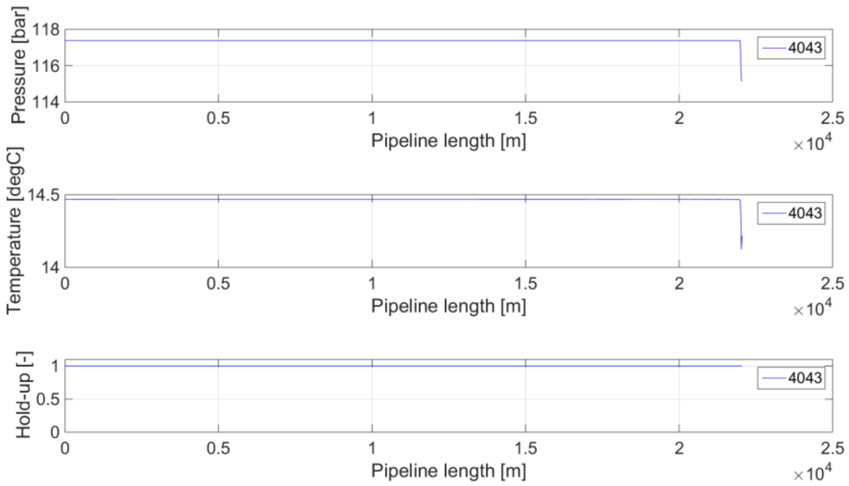


Figure 37: Initial conditions for high pressure start-up.

7.6.1 *Results case4044*

In case4044, the pipeline is emptied in to well-1 trying to release pressure (Figure 38 and Figure 39). However, this procedure leads to long periods of low downhole temperatures.

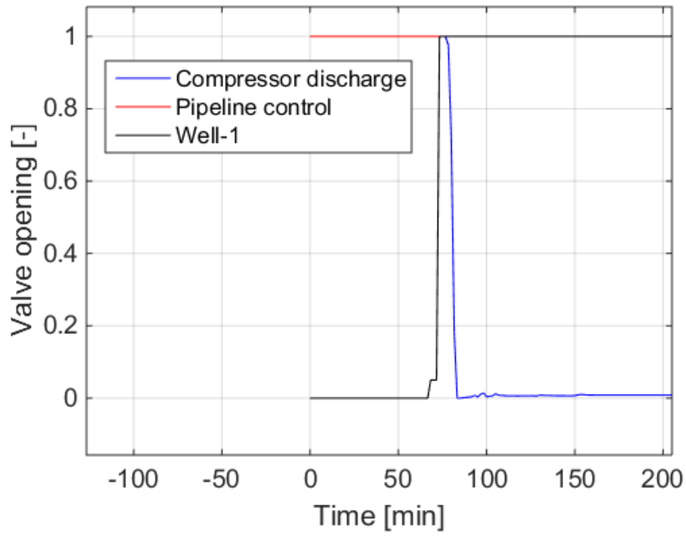


Figure 38: Valves as function of times.

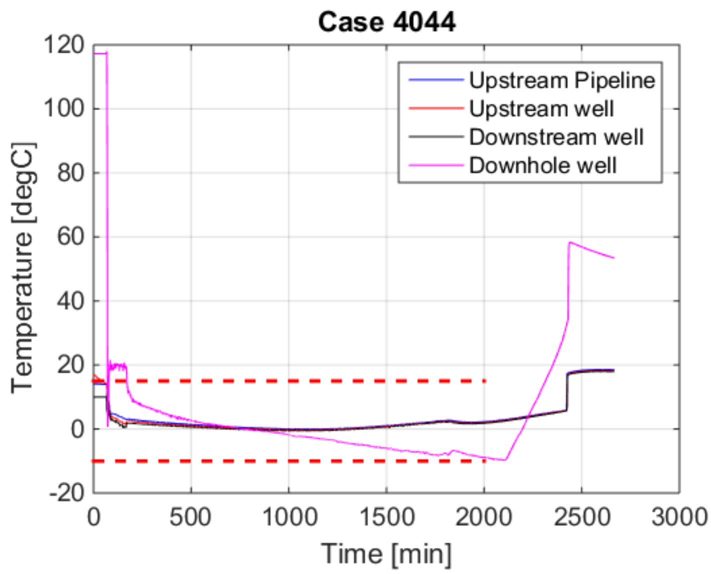


Figure 39: Resulting temperatures as function of time.

7.6.2 *Results case4045*

In case 4045, well-2 is used for injection and to limit the downhole temperature, the mass flow rate was constraint to 30 kg/s. However, both the topside wellhead temperature becomes too low as well as the downhole temperature.

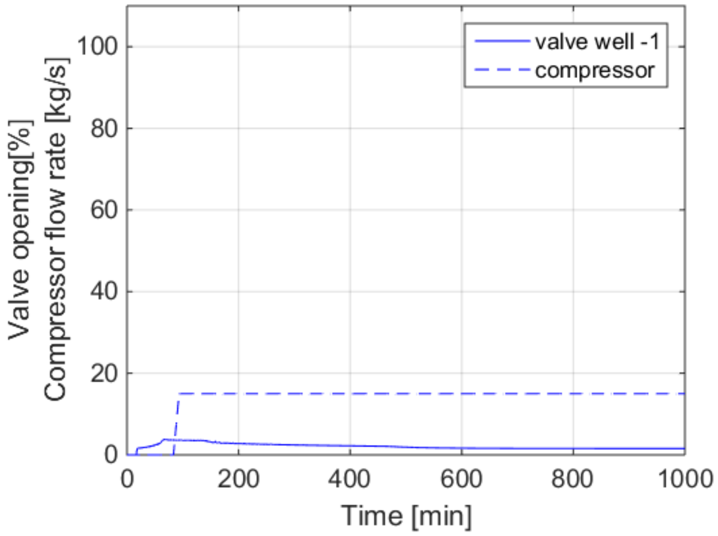


Figure 40: Valves and mass flow rates (dashed line).

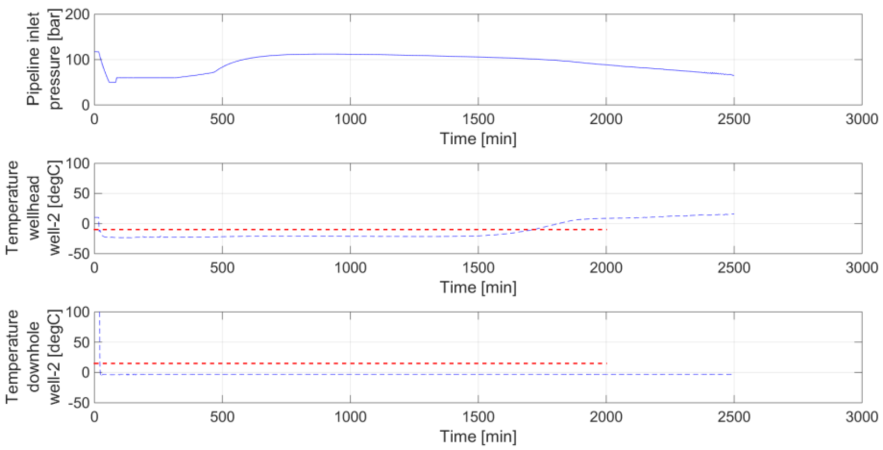


Figure 41: Temperatures and pressures as function of time.

7.6.3 *Results case4047 & 4048*

For completeness, the results of case4047 and case4049 are plotted in Figure 42 and Figure 43. In all these cases the temperatures are too low.

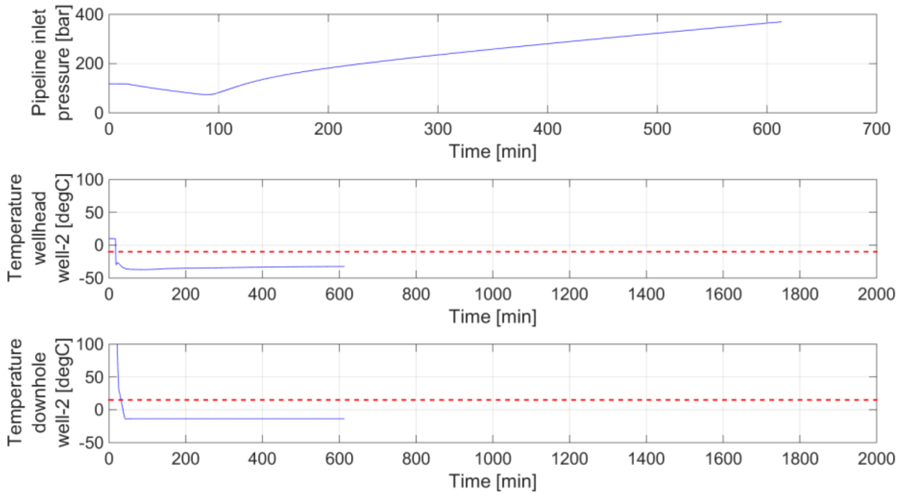


Figure 42: Results case4047.

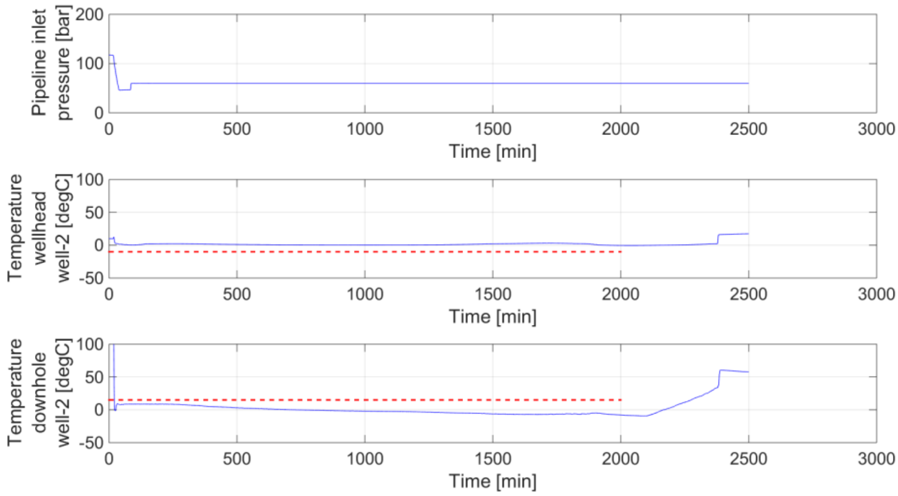


Figure 43: Results case4048.

7.7 Discussion venting

The high pressure start-up leads to long periods of too low temperatures. Therefore a set of venting solutions have been tried. The pipeline is vented down to a given pressure from which the system is started up again. (cases4051-4076).

If vented down to approximately 40 bar, the temperature in the pipeline is approximately 5 °C (for instance case4052). Different start-up scenarios, starting from this conditions were evaluated:

- First opening the wells
- First pressurizing the pipeline
- Mass flow control on the wells

Venting down to 40 bar, did lead to long periods of too low temperatures (Figure 44).
Venting down to 60 bar should lead to similar start-up sequences as discussed previously.

An alternative is that instead of venting, the pipeline pressure is slowly released into the well and that the topside piping is protected from the cold temperatures by local heating. As the bleed rate is low, the total heat capacity should be low. This scenario has not been calculated yet.

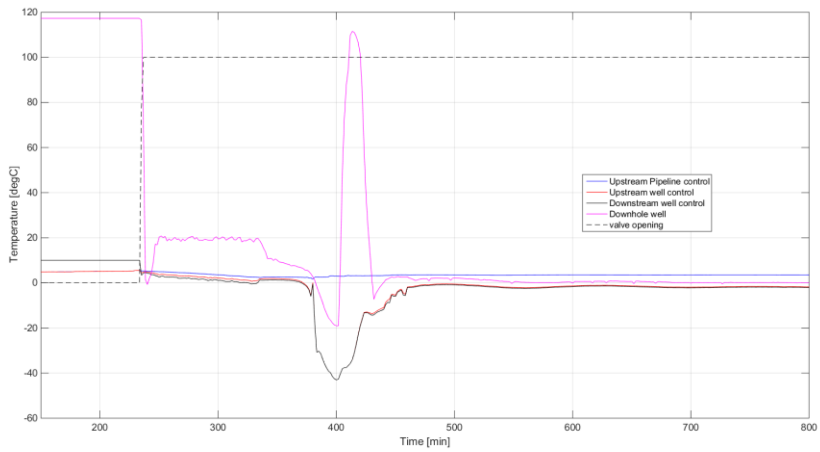


Figure 44: sharp peak is due to control action on the pipeline pressure control valve.

7.8 Discussions alternatives

Instead of venting a number of alternatives have been evaluated:

- Use of a very small ID well (0.09m). This increases the topside pressure at lower flow rates and keeps the flow rates at a given pipeline pressure limited.
- Adding N2 (5% mole fraction) in the hope that the temperature effects are reduced.
- Adding downhole chokes (different sizes and different depts).

These were trial simulations and more scenarios could potentially be simulated. However, the cases tried did not pass the temperature boundary condition limitations.

7.9 Discussion start-up reservoir pressure 60 bar – mid pipeline pressure

For the start-up with a reservoir pressure of 60 bar two sets of cases are analysed. The first set is that all wells are at a reservoir pressure of 60 bar (cases 4105, 4106, 4107). In addition to the basic start-up, the effect of opening a 2nd well is evaluated (4108).

7.9.1 Results 4105 – 4107

The initial pipeline conditions at a pipeline pressure of approximately 63 bar, 24°C with a liquid hold-up of approximately 0.26 (Figure 47).

For all cases a sequence of events has been used defined by:
- The chokes of wells 2, 3, and 4 (P18-2 wells) are closed.
- The choke valve of well-1 is set to a pressure control of 85 bar at t= 0s.
- The pipeline control valve is set to a pressure control of 1 bar at t= 0s (this is already open in the initialisation cases).
-The compressor is ramped from t= 1000s to t = 1300s from a flow rate of 0 kg/s to the desired flow rate.

The results are given in
Figure 45. For all three start-up scenarios, the calculated temperatures are higher than the temperatures limitations.

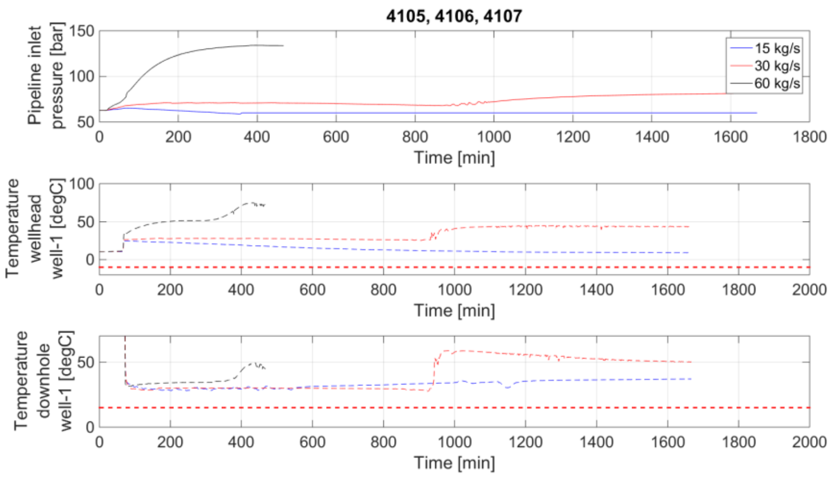


Figure 45: Resulting pressure and temperatures.

7.9.2 Results 4108 (opening 2nd well)

Case4108 is started from case4106 (with a reached steady conditions with a total mass flow rate of 30 kg/s).

The sequence of events is:
- The mass flow rate is increased to 60 kg/s at t = 0s.
- The choke at the second well well-2 is opened from 0 to 1 at t = 1000s.

Except for a very short period directly at opening of the choke valve (Figure 46) all temperatures meet the requirements.

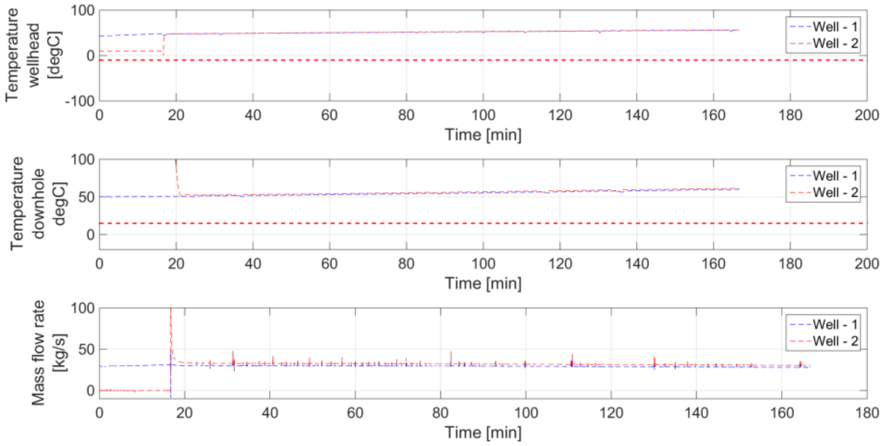


Figure 46: Resulting pressure and temperatures.

7.10 Discussion start-up reservoir pressure 100 – 340 bar – mid pipeline pressure

The higher pressure start-up cases have been done with pipeline conditions at a pipeline of approximately 63 bar, 24°C with a hold-up of approximately 0.26 (Figure 47).

For all cases a sequence of events has been used defined by (Figure 48):
- The chokes of wells 2, 3, and 4 (P18-2 wells) are closed
- The choke valve of well-1 is set to a pressure control of 85 bar at t= 0s.
- The pipeline control valve is set to a pressure control of 1 bar at t= 0s (this is already open in the initialisation cases).
- The compressor is ramped from t= 1000s to t = 1300s from a flow rate of 0 kg/s to the desired flow rate.

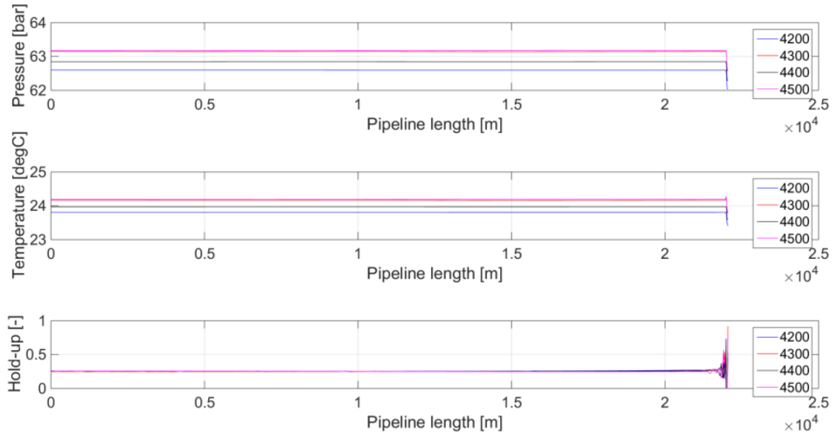


Figure 47: Pressure, temperature and hold-up profile at the start of the start-up sequence.

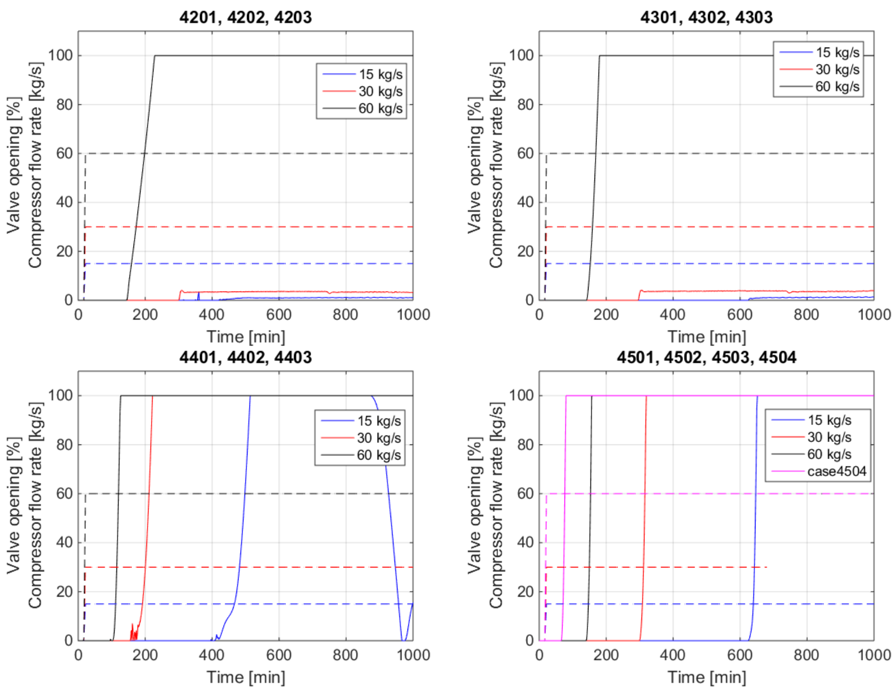


Figure 48: Compressor flow rates and valve openings at well 1 for the 4200, 4300, 4400 and 4500 series. Solid lines the valve opening [%]. Dashed lines indicate the compressor flow rates.

7.10.1 Results reservoir pressure 100 bar

For a reservoir pressure of 100 bar, the resulting pressures and temperatures are given in Figure 49. For all times, the temperatures are high enough both topside as well as downhole.

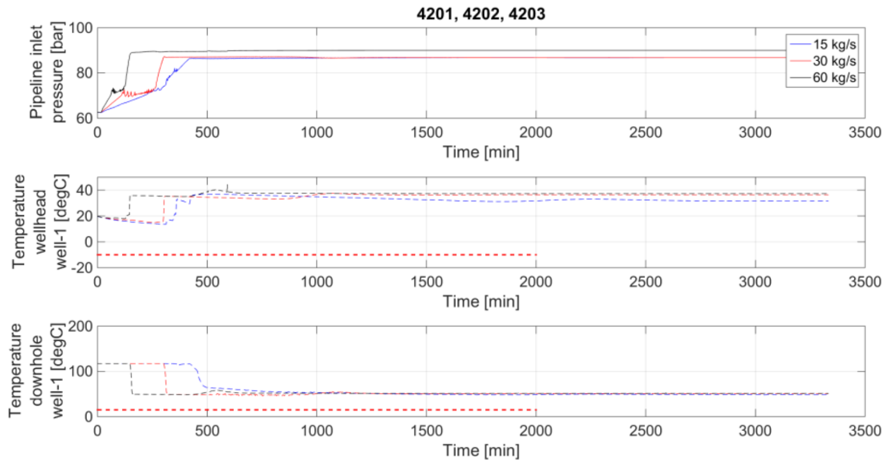


Figure 49: Pressures and temperatures as function of time.

7.10.2 *Results reservoir pressure 200 bar*

For a reservoir pressure of 200 bar, the resulting pressures and temperatures are given in Figure 50. For all times, the temperatures are high enough both topside as well as downhole.

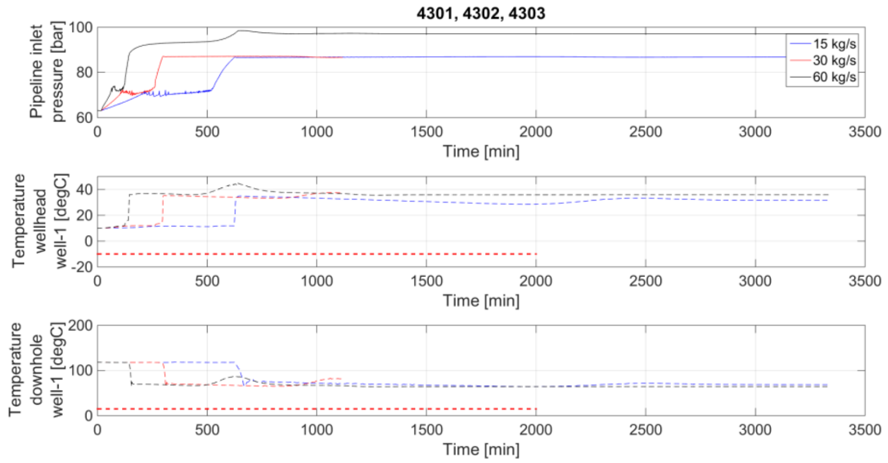


Figure 50: Pressures and temperatures as function of time.

7.10.3 *Results reservoir pressure 300 bar*

For a reservoir pressure of 300 bar, the resulting pressures and temperatures are given in Figure 51. For all times, the temperatures are high enough both topside as well as downhole. The high mass flow rate start-up might take longer than calculated as the maximum calculated compressor pressure is nearly 150 bar. Therefore, this start-up rate must be done with more than one well open.

Although, this specific case is not representative for the real life situations, no difficulties are expected as there are no temperatures limits downhole and the temperature effects topside are limited as the fluid is in the liquid state.

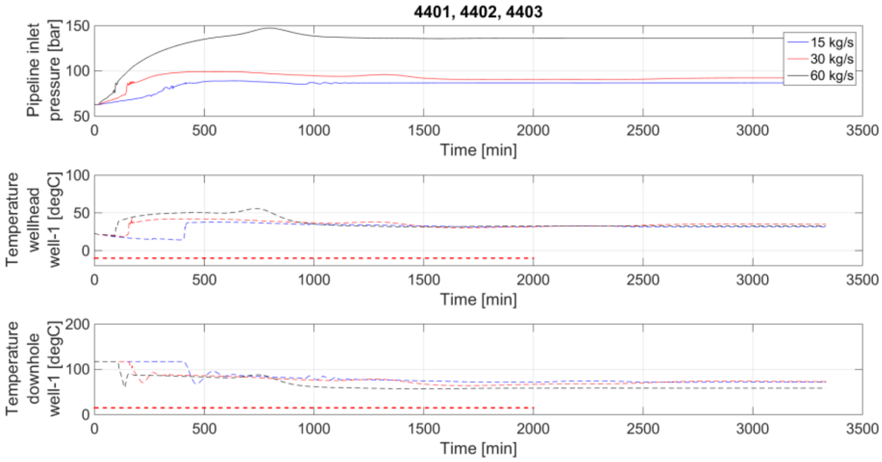


Figure 51: Pressures and temperatures as function of time.

7.10.4 *Results reservoir 340 bar*

For a reservoir pressure of 300 bar, the resulting pressures and temperatures are given in Figure 52 and Figure 53 For all times, the temperatures are high enough both topside as well as downhole. The high mass flow rate start-up might take longer than calculated as the maximum calculated compressor pressure is higher than 120 bar. Therefore, this start-up rate must be done with more than one well open.

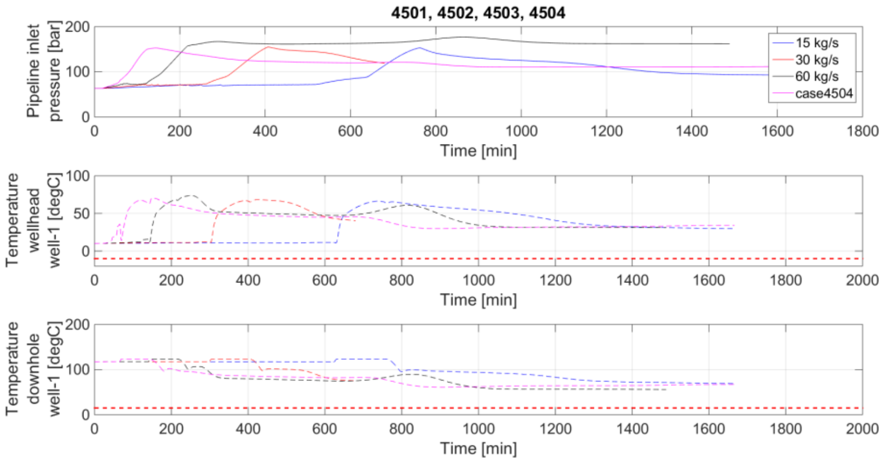


Figure 52: Pressures and temperatures as function of time.

8 Depressurization

An important event is venting or depressurizing the system. As most of the pipes are well insulated, there is no to little heat ingress. That means that the fluid temperature is almost adiabatic.

As an example, the pipeline is vented with initial conditions at the liquid state (115 bar, 15°C) (Figure 53). As soon as the venting starts, the pressure decreases rapidly as the pipeline is in liquid state. With the venting, the pipeline comes into two-phase conditions. With a continuation of the venting, the pipeline pressure decreases and the resulting temperature decreases fast.

This means that of venting continuous to atmospheric conditions, solid CO_2 will be formed and the temperature will drop down to extreme low temperatures. To avoid this it is recommended to keep venting/depressurization limited down to 30 bar. This 30 bar is chosen based on the fact that the phase line temperature for 30 bar is -5 °C. Even with some pressure undershoot this will limit fluid temperatures.

It must be remarked that this effect will occur with all venting or depressurization event. All sections which must be able to be depressurized fast will need to designed for extreme low temperatures.

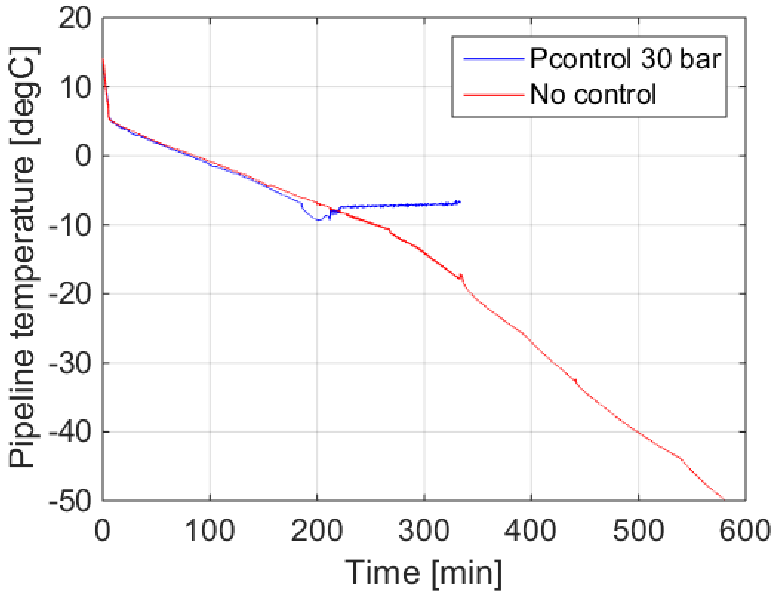


Figure 53: Pipeline temperature as function of time during a venting action with no pipeline control (red) or with the pipeline pressure control at 30 bar.

9 Shut-in/turn-down

9.1 Introduction

In this chapter two sets of simulations are presented. In the first set there are scenarios in which the mass flow is ramped down. The second set is a set in which the wells are shutin.

9.2 Simulation cases

Shutin at Pres = 20 bar

Case	*Pres*	*Tcmp*	*Wells*	*control*	*Mass flow*	*Start from*
7000	20	80	1	30	15->0; dt=300	4024
7001	20	80	1	30	30->0; dt = 300	4025
7002	20	80	4	30	140->0; dt = 300	4028
7005	20	80	1	no	15->0; dt=300	4024
7006	20	80	1	no	30->0; dt = 300	4025
7009	20	80	1	No	Well shutin	4025
7016	20	80	1	No	Well shutin 100	4025
7017	20	80	1	No	Well shutin 300	4025
7018	20	80	1	No	1000s	4025

Shutin at Pres = 60 bar

Case	*Pres*	*Tcmp*	*Wells*	*control*	*Mass flow*	*Start from*
7015	60	40	1	1 well	Well shutin	4009

The cases 7012-7014 have been wrongly initialised and are not reported

Shutin at Pres = 100 bar

Case	*Pres*	*Tcmp*	*Wells*	*control*	*Mass flow*	*Start from*
7008	100	40	4	Pipe (85)	170 -> 0	4078
7011	100	40	1	1 well	Well shutin	4078

Shutin at Pres = 340 bar

Case	*Pres*	*Tcmp*	*Wells*	*control*	*Mass flow*	*Start from*
7007	340	40	4	Pipe (85)	140->0	4006
7010	340	40	1	1 well	Well shutin	4006

9.3 Results well shutin for different reservoir pressures.

Well shutin simulations are done at different reservoir pressures. For a reservoir of 20 bar, the speed with which the valve was shutin was varied between 20 – 1000s (7009, 7016-7018). For reservoir pressures of 60, 100 and 340 bar only fast shutin cases were simulated.

For the shutin cases 7009, 7016-7018, the following sequences are calculated (Figure 54):

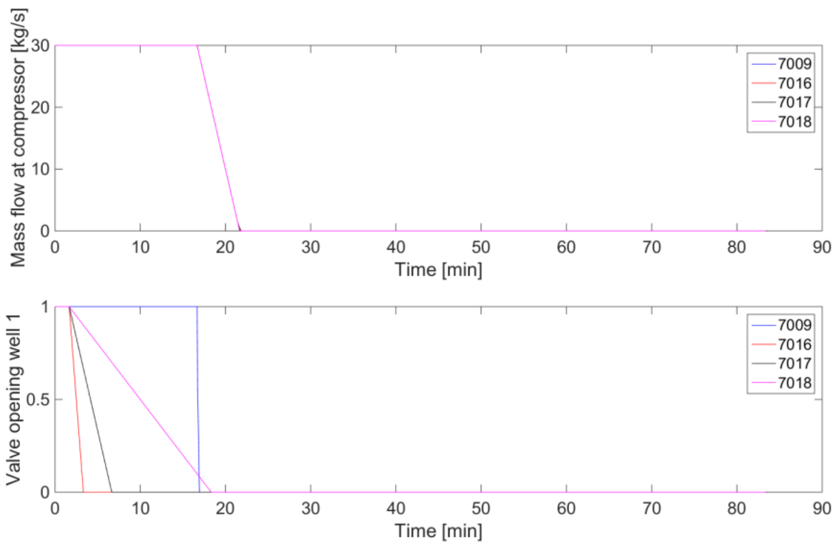
- Initial conditions are simulations at fixed mass flow ran long enough to obtain steady conditions.
- The mass flow is ramped down from t=1000s to t= 1100s
- The choke at well-1 is shutin at t = 1000s (7009) and at t = 100s (7016-7018).
- Similar sequences are done for the higher pressure cases.

During shut-in/depressurization low temperatures in the well will occur due to expansion. This occurs typically in the top region (top 1000 m) but at fast shut-in of the wellhead choke, the complete well can go down in temperature (basically following pressure gradient and following phase line). The well control valve shut-in-time does practically not matter (Figure 55).

At higher reservoir pressures, the minimum temperatures increase

- Reservoir pressure 20 bar -37 °C
- Reservoir pressure 60 bar -17 °C
- Reservoir pressure 100 bar -5 °C
- Reservoir pressure 340 bar +30 °C

For the higher pressures, the wellhead temperature is plotted in Figure 57. From this figure, it is more clear that the low temperature period can be in the order of 30 minutes. It must be remarked again, that for the current simulation model uses Uvalue methodology and therefore no heat-capacity of the walls and annulus fluids are included. This means that the heating up also occurs faster then will be in real-life but that the wall temperatures will be higher than the calculated temperatures.



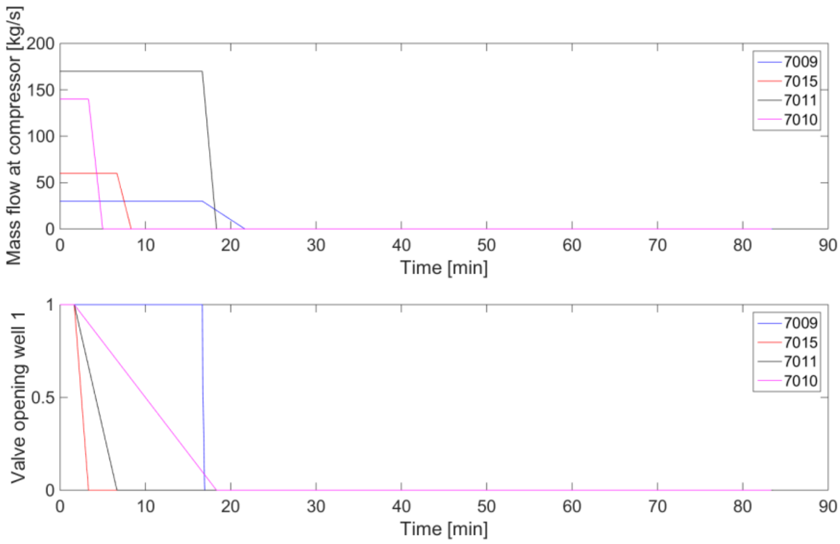


Figure 54: Sequences of flow rates and valves.

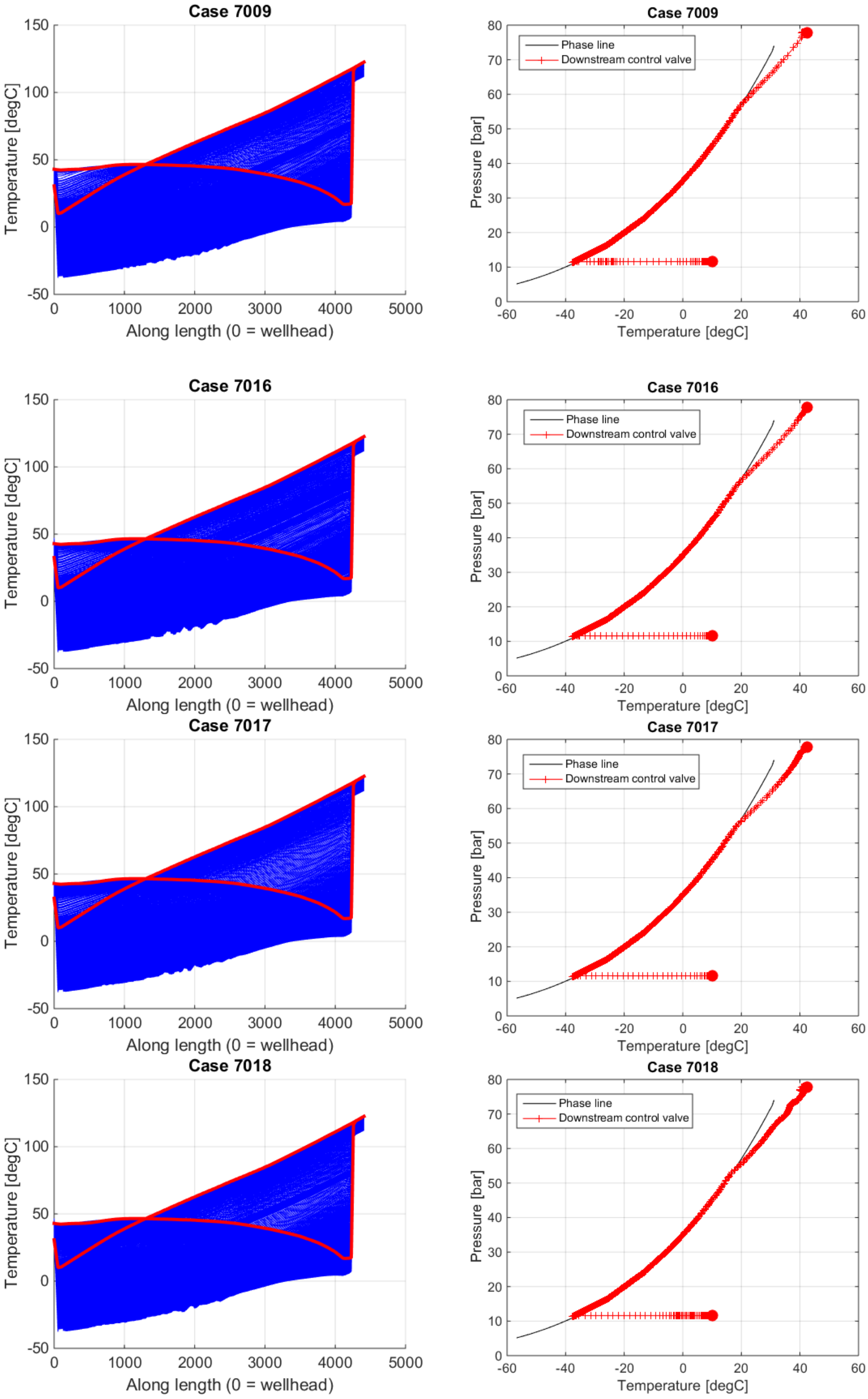


Figure 55: Temperature profile in the wells during ramp-down. The red lines indicate the initial and final profile. Each blue line is at a time step of 1 s. Right figures give pressure/temperature as function of time downstream of the choke at well-1. Cases 7009, 7016, 7017, 7018 are for cases without pipeline pressure control.

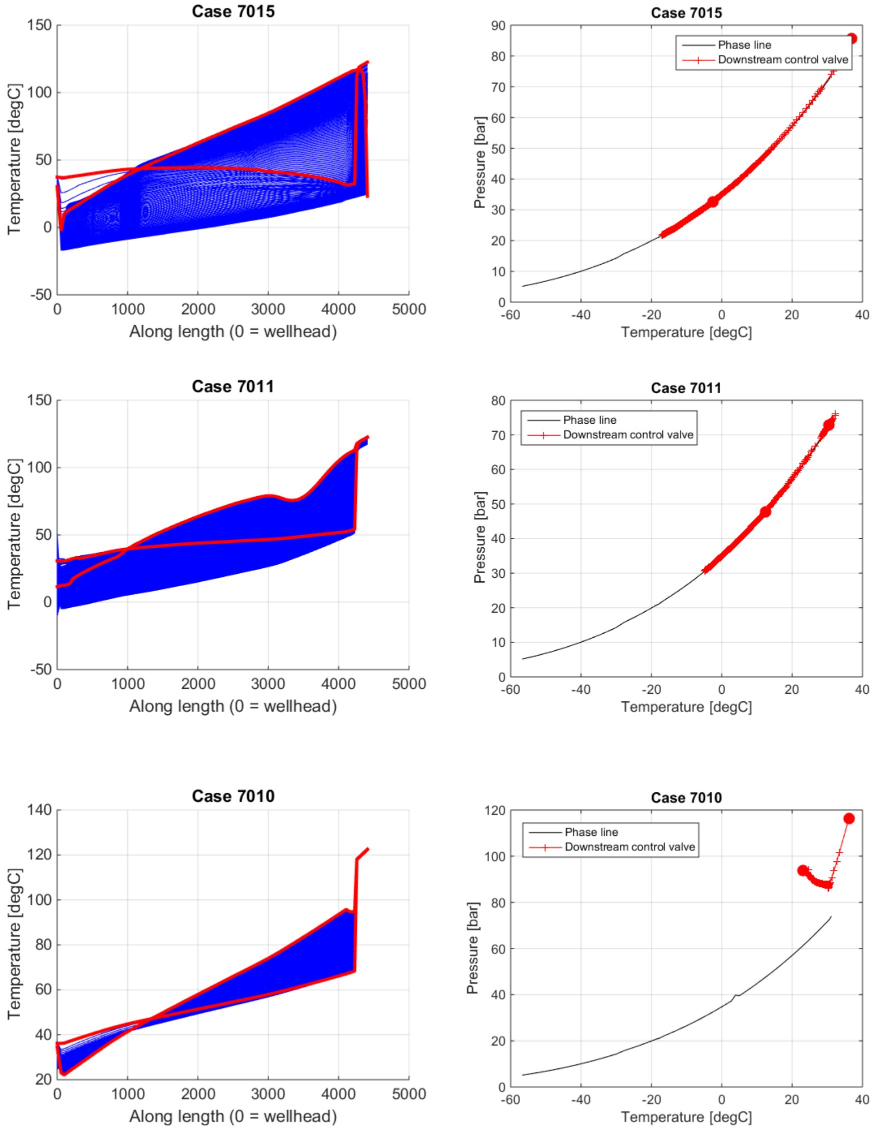


Figure 56: Temperature profile in the wells during ramp-down. The red lines indicate the initial and final profile. Each blue line is at a time step of 1 s. Right figures give pressure/temperature as function of time downstream of the choke at well-1.Cases 7015, 7011 and 7010 are for a reservoir pressure of 60, 100 and 340 bar.

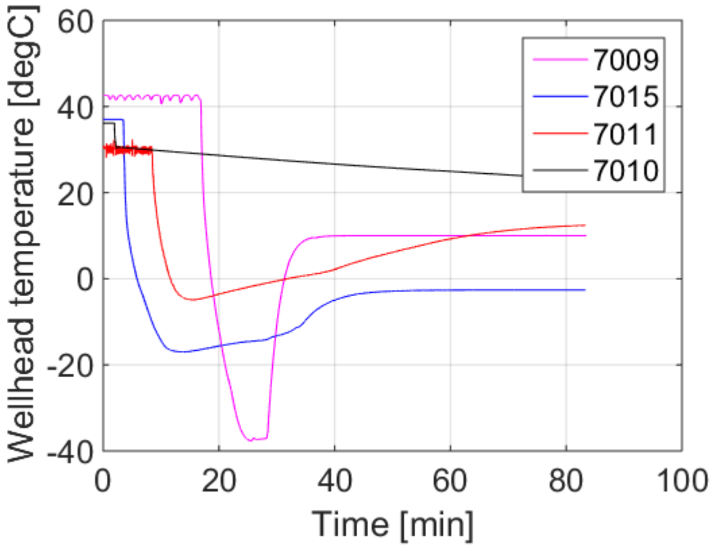


Figure 57: Wellhead temperature as function of time for the cases 7009 (20 bar), 7015 (60 bar), 7011 (100 bar), 7016 (340 bar).

9.4 Results turn-down reservoir pressure 20 bar

The cases with a reservoir pressure of 20 bar and including a pipeline control valve, the turn-down cases 7000, 7001, 7002, 7005 and 7006 are done. The sequences is mainly for (Figure 58):

- Mass flow rate is ramped down in 300s at t = 1000s.
- The well valves are kept open.

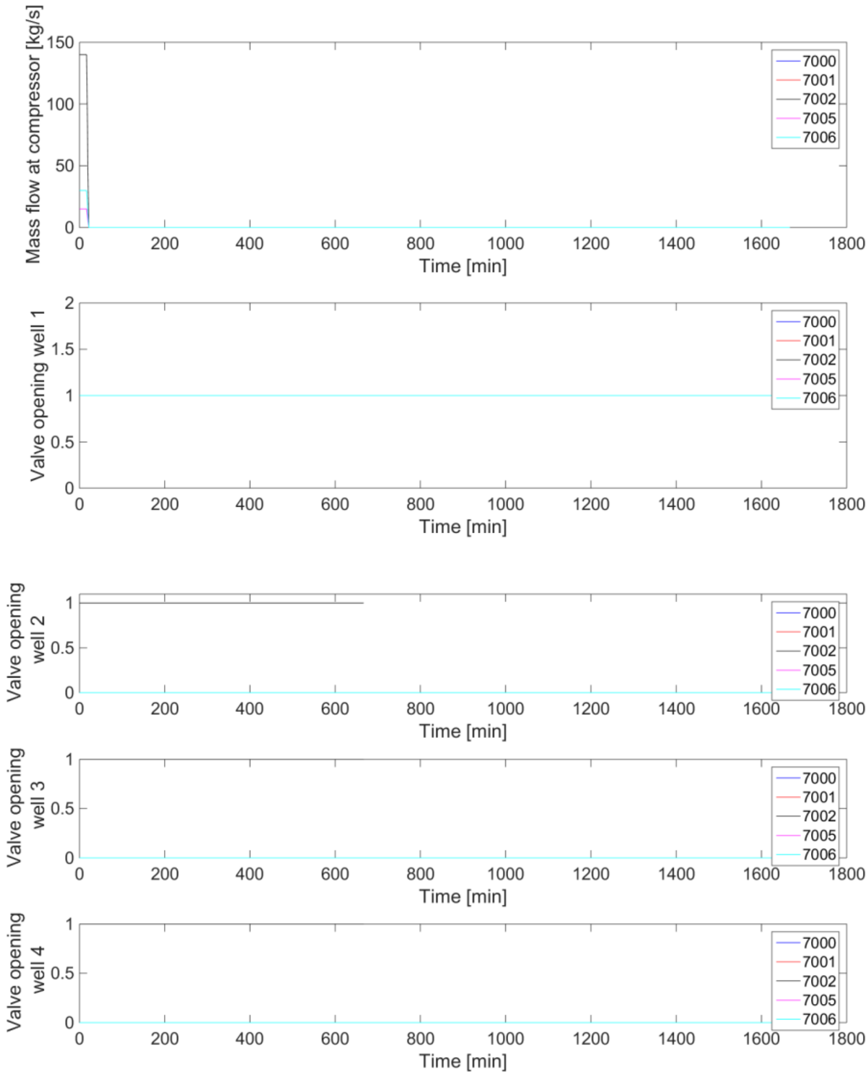


Figure 58: Mass flow rates and valve opening as function of time.

The resulting temperature profiles in well-1 are plotted in Figure 59 and the pipeline in Figure 60. The low temperature zone is mainly restricted to the topside in the well but the pipeline can get very cold with low temperatures down to -20 °C in the whole pipeline and very low temperatures downstream of the pipeline control valve.

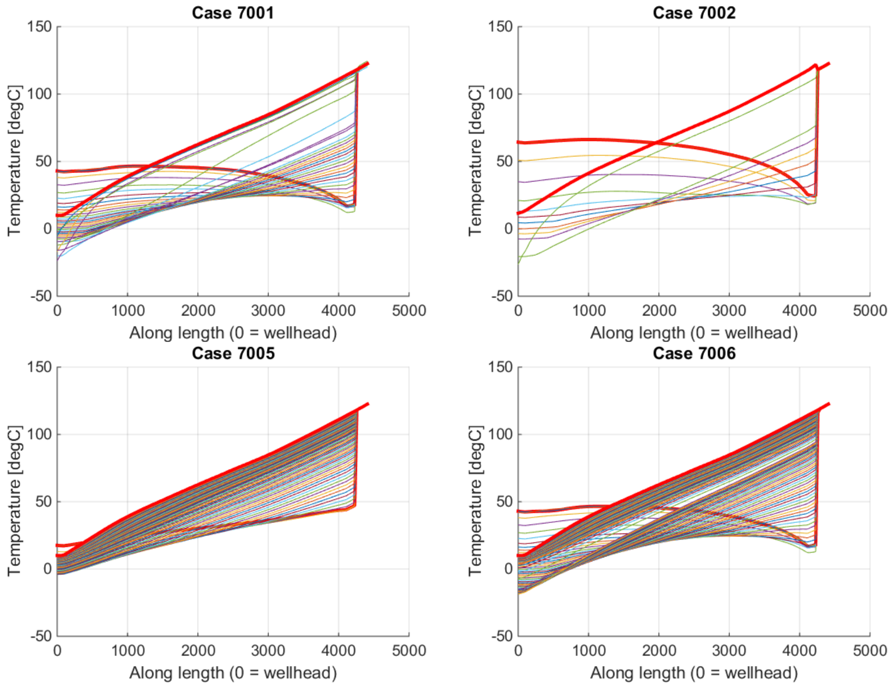


Figure 59: Temperature profile in the wells during ramp-down. The red lines indicate the initial and final profile. Each blue line is at a time step of 1000 s.

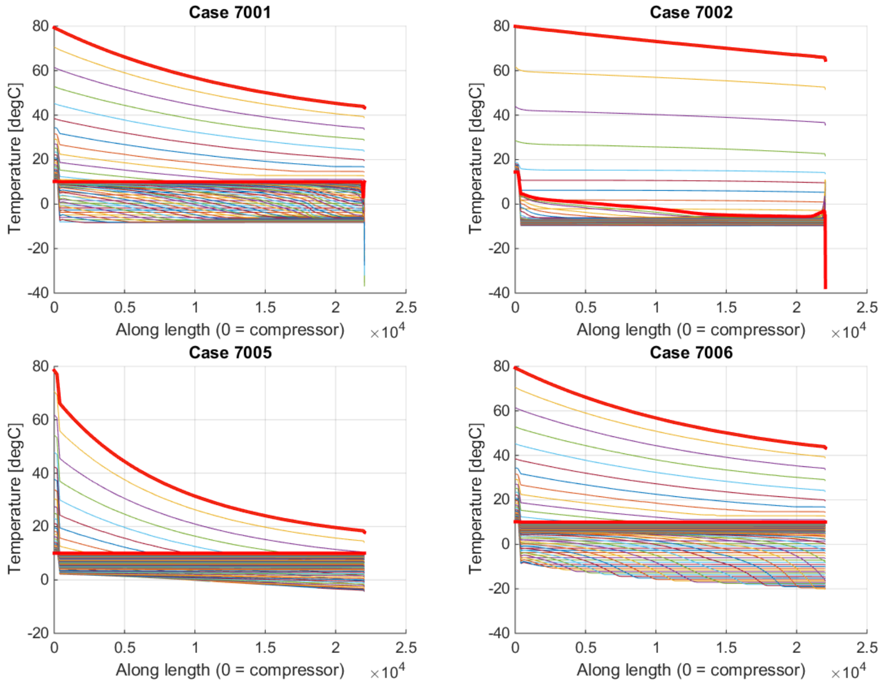


Figure 60: Temperature profile in the pipeline during ramp-down. The red lines indicate the initial and final profile. Each color line is at a time step of 1000 s. Cases 7001 and 7002 have a pipeline control of 30 bar. This means that downstream the valve, the expansion is deeper. This explains the sharp decrease observed in 7001 and 7002 results.

9.5 Results turn-down reservoir pressure 100 bar

For the case7008 with a reservoir pressure of 100 bar, the sequence of events simulated are (Figure 61):

- The mass flow rate is ramped down from t=0 to 100s
- The pipeline pressure controller is set to 85 bar
- Well-1 is at a pressure control of 10 bar (meaning full open)
- Well-2, 3, 4 is at a mass flow control at 1000 kg/s (meaning full open)

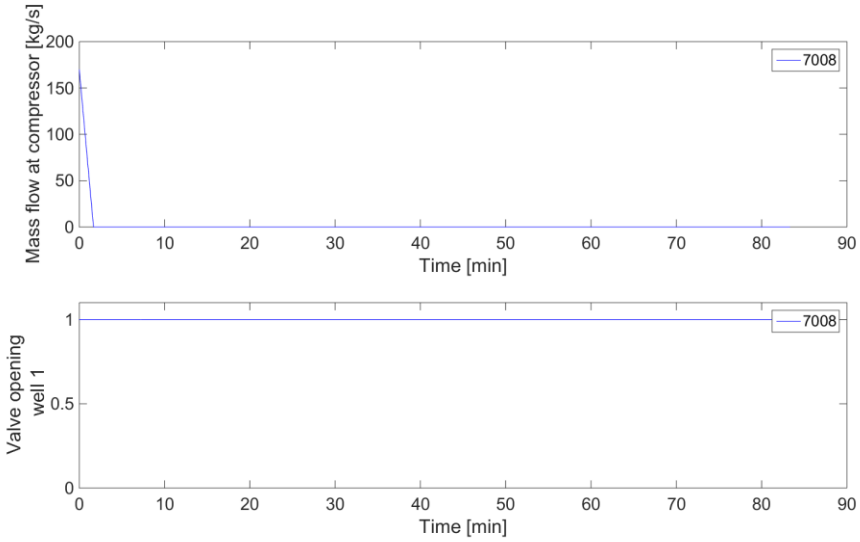


Figure 61: Mass flow rates and valve opening as function of time.

The resulting temperatures in all four wells and the pipeline is given in Figure 62 and in Figure 63. The minimum temperatures only just drop below 0 °C.

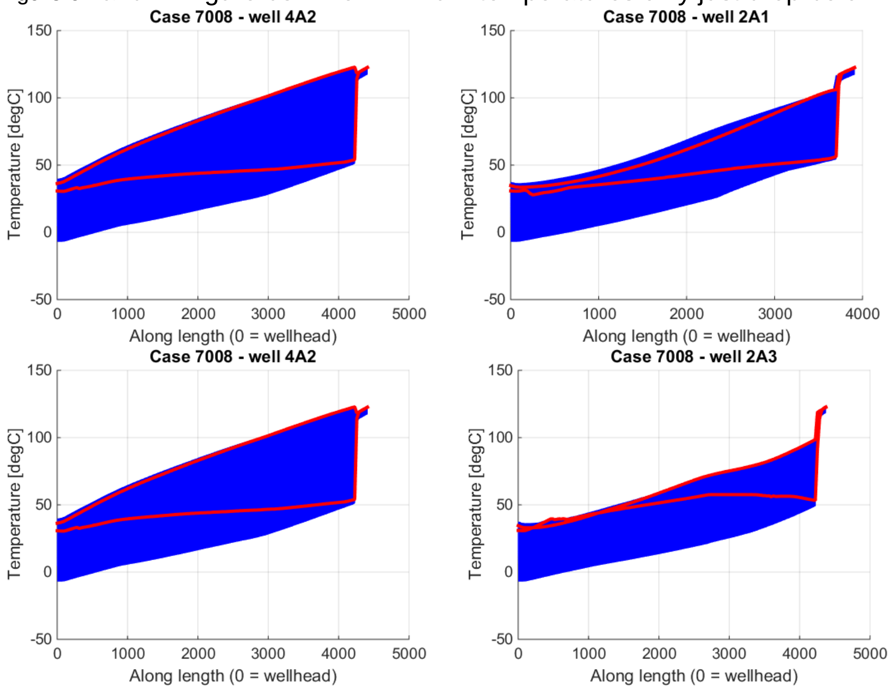


Figure 62: Temperature profile in the wells during ramp-down. The red lines indicate the initial and final profile. Each blue line is at a time step of 1 s.

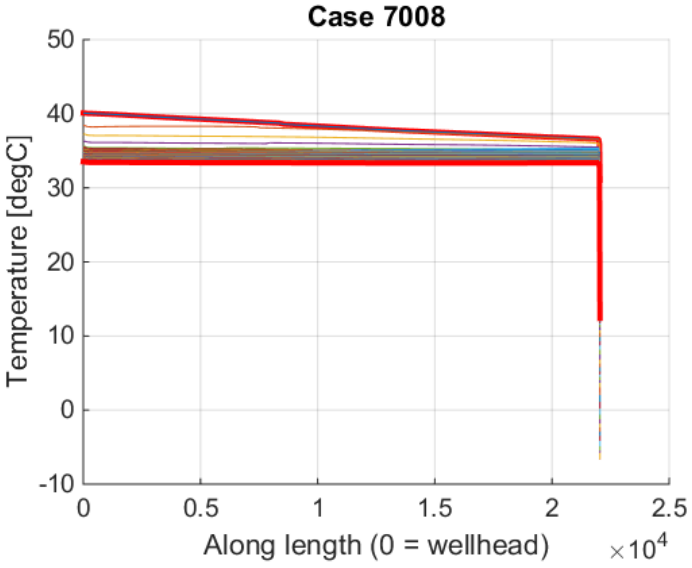


Figure 63: temperature profile in the pipeline. The red lines indicate the initial and final profile. Each coloured line is at a time step of 100 s

9.6 Results turn-down reservoir pressure 340 bar

Finally, for the case7007 with a reservoir pressure of 340 bar, the sequence of events simulated are (Figure 64):

- The mass flow rate is ramped down from t=0 to 100s
- The pipeline pressure controller is set to 85 bar
- Well-1 is at a pressure control of 10 bar (meaning full open)
- Well-2, 3, 4 is at a mass flow control at 1000 kg/s (meaning full open)

The resulting temperatures (Figure 65) all remain high.

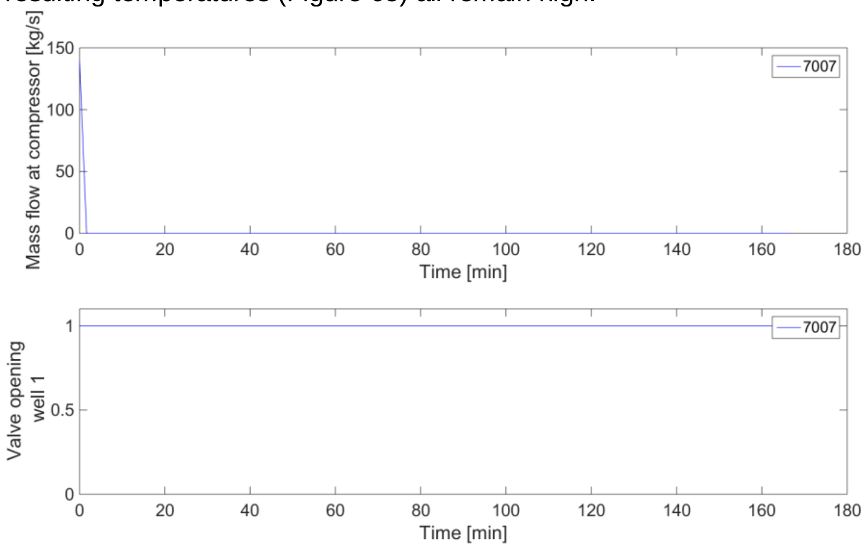


Figure 64: Mass flow rate and valve openings as function of time.

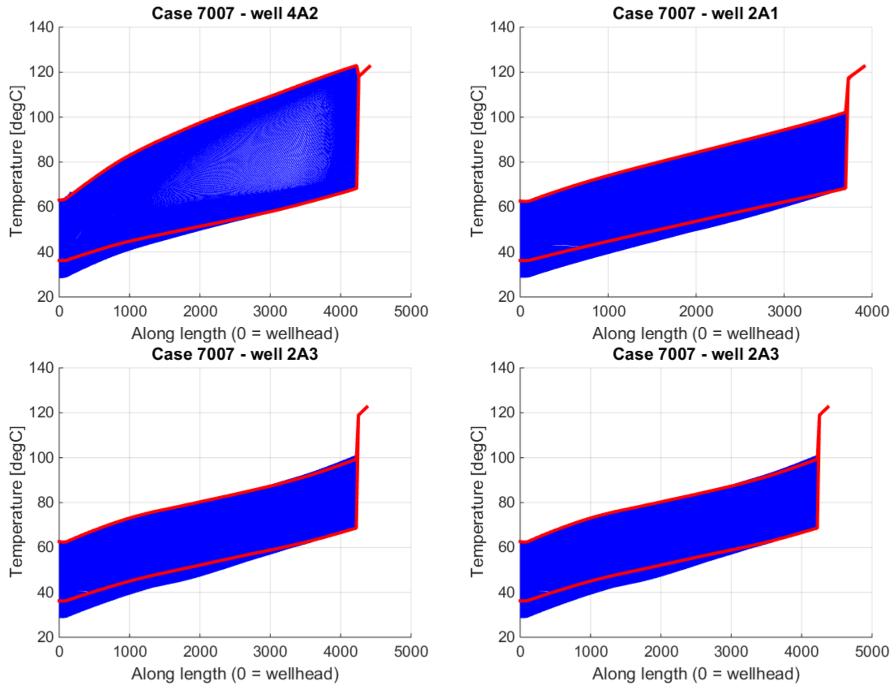


Figure 65: Temperature profile in the wells during rap-down. The red lines indicate the initial and final profile. Each blue line is at a time step of 1 s.

10 Discussion/ general remarks

This chapter summarises the conclusions and key results from the previous chapters.

The main concepts which determine injection:

- Phase line conditions link the temperature and pressure.
- The critical bottomhole pressure is 50 bar as this corresponds to a phase line temperature of 15 °C (which is the set downhole temperature limit).
- Keeping the mass flow rate and keeping the wellhead pressure high avoids low temperatures during steady operations. Smaller ID wells keep the wellhead pressure high already at low flow rates. However, small ID well limit the injection rate at low reservoir pressure due to too low downhole temperatures and at high reservoir pressures the rates are limited due to too high compressor pressures (too high friction).

- Scenario's in which the tubing diameter is changed after a period of operation have not been included in this report.

- Only a limited set of runs with more complicated well designs are done. Downhole valves, ICD's tuneable orifices etc are not included as this complicated the well design significantly and might risk of local freezing of components.

- The compressor discharge control valve is now set downstream of the compressor after-cooler. This as this is worst case for the simulations as we lose temperature across the valve. In reality this valve might be installed upstream of the cooler if so desired.
- In the simulations a dedicated pipeline pressure control valve is used. Downstream of the valve there is often two-phase flow.
    - The pipeline pressure control might also be done via a control on one of the wells. The other wells must be set on mass flow control.
    - The benefit of this is that upstream of the well control valves, there is single phase flow. This might be beneficial for metering.

- The flowing wellhead pressure is for a large range of conditions constant and not a function of mass flow rate but is mainly a function of temperature.
- The shutin wellhead pressure is for a large range of reservoir pressures constant.
    - Both conditions mean that the wellhead pressure is not a good control parameter and that his parameter cannot be used for flow allocation. Therefore, downhole gauges (pressure and temperature) are strongly recommended.

- The temperature downstream of valves is determined by a number of aspects:
    - Pressure drop and therefore temperature drop (mainly for a pressure drop across a valve with both upstream and downstream gas phase)

- Phase line temperature (mainly for expansion across a valve from liquid to low pressure resulting in two phase conditions downstream of the valve)
- Back pressure at the valve. At high flow rates, the well provides back pressure to the valves resulting is less temperature drop.

- A critical temperature of 15°C is used for downhole conditions. It has not been taken into account that the CO_2 expands in the reservoir resulting in lower temperatures in the near-well zone.
- The injectivity index is based on single phase assumption at reservoir temperature. Therefore it is likely that the pressure drop in the reservoir will be higher than calculated.

- In this report, no alternatives for hydrate prevention are evaluated.
- As low fluid temperatures might be unavoidable and piping (manifold, valves etc) needs to be designed for low temperatures, the topside low temperature restriction might be re-evaluated.

- The depressurization of the pipeline at high shutin pressure conditions is done via venting in this report. It might be evaluated whether slowly depressurizing and local heating of the pipe materials might work.

11 General conclusions & recommendations

11.1 General conclusions

For steady state conditions the following conclusions are found:

- At low reservoir pressure (20-40 bar), no steady state solution is found which comply with both the topside and downhole temperature restrictions when the pipeline pressure is maintained in the liquid state. Therefore, at low reservoir pressure the pipeline must be operated in gas or two-phase conditions.
- This puts limitations on the maximum injection rates per well or for all four wells combined.
- At reservoir pressures (40-300 bar), the required flow rate (170 kg/s) is achieved using four wells.
- At close to the maximum reservoir pressures, the compressor outlet temperature needs to be reduced. Otherwise no injection is possible.

For depressurization the following conclusions are found:

- The heat ingress in the pipeline is limited. Therefore, during depressurization or emptying the pipeline the temperature follows the pressure via the phase line and low temperatures conditions can occur in the complete pipeline. Therefore, a pressure control of the pipeline is recommended.

For shutin simulations the following conclusions are found:

- During well shutin, low fluid temperatures will occur in the well downstream of the choke. The temperature will go down to the corresponding phase line temperature. At a reservoir pressure of 20 bar, this means a temperature of -37 °C. At lower reservoir pressures this will lower even further. At higher reservoir conditions, the temperature will increase. -17, -5 and +30 °C at reservoir pressures of 60, 100 and 340 bar.
- During ramp-down, low temperatures occur mainly in the top part of the well. These temperatures go well below -10 °C.
- During ramp-down also the temperature in the pipeline itself will drop down to values below -20 °C.
- The low temperatures during shutin/ramp-down are difficult to avoid and as such it is recommended that all piping should be able to withstand the low temperatures.

From the start-up simulations the following conclusions are found:

- For all reservoir conditions, at initial choke valve opening, a short period of low temperature will occur downstream of the control valves. For the start-up, a faster valve-opening is beneficial with respect to the temperatures.
- In the sequencing of well opening and compressor ramp-up, the flow rates from the pipe to the wells must not decrease too quickly to avoid too low pressures (and therefore temperatures in the well and pipeline). Therefore, the compressor ramp-up must be done relatively soon after the well opening.

The compressor can be ramped-up before the well opening at higher reservoir pressures with the limit that the pipeline pressure must not be higher than 85 bar.
- At low reservoir pressure, the system could be started up from low pressure (10, 30 bar) or medium pressure (60 bar). In case of medium-pressure conditions, the downhole temperature is too low for a limited period of time (less than 500 minutes).
- At low reservoir pressure, starting from high pressure pipeline conditions leads to long periods of too low temperatures (longer than 2000 minutes).
- At medium and higher reservoir pressures start-up can be done from medium-pressure (two -phase conditions) conditions within the temperature restrictions.

11.1.1 Base operation

The base recommended operations (based on the set restrictions) are:

- At low reservoir pressure, the pipeline is operated in the gas phase and all well chokes are kept open to avoid pressure drop. The compressor outlet temperature is set to 80 °C.

- At mid to high reservoir pressures, the compressor outlet temperature is set to 40 °C. The setting is an optimization between cooling power and compressor power.

- At very high reservoir pressures, compressor outlet temperature must be set to 40 °C, otherwise injection is not possible.

Reservoir pressure [bar]	Compressor outlet temperature [°C]	Pipeline control	Well operations
20 – 40 bar	80	30	Full open
40 – 300 bar	40 - 80	30	1 well on pressure control. Other wells on mass control
300 – 340 bar	40	30	1 well on pressure control. Other wells on mass control

During well shutin, a fast closure the choke valves leads to very low temperatures. At low reservoir pressures the shutin procedure should be leaving the wells open while shutting down the compressor.

11.1.2 Shutin philosphy

During well shutin, a fast closure of the choke valves lead to very low temperatures. At low reservoir pressures the shutin procedure should be to leave the wells open while shutting down the compressor.

11.2 Recommedations

The main recommendations include:

- All piping material should be de designed for extreme low temperatures (-40°C, based on expected wellhead pressures of 10 bar).

- Update simulation model to include full heat transfer (rather than U-value approach) at the time the well design and pipeline design is set. This to get more detailed temperature information on pipe wall temperatures and annulus fluid temperatures.

- Considering the fact that fluid temperatures less than -10°C are probably not avoidable, the restriction of -10°C for the topside temperature should be reconsidered/re-evaluated.

- The criterion of 15°C downhole temperatures is restrictive. Alternatives for hydrate preventions should be evaluated.

- An operational guidebook should be set up which describes the number of wells and control settings for each mass flow rate.
- This guidebook should also contain guidelines of start-up and shutin procedures.

12 Signature

Delft, April 2019

TNO

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Heat Transfer and Fluid Dynamics

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Author

A Steady state results

In this annex, the results for the steady state results are added.

Case	***Twh***	***Tdh***	***Pplatform***	***Pcomp***	***Mass flow***
Reservoir pressure = 300 bar					
4000	21	64	58	85	18
	10	116			0
	10	118			0
	10	116			0
4001	35	73	90	92	28
	10	117			0
	10	118			0
	10	115			0
4002	32	58	113	136	60
	10	117			0
	10	118			0
	10	115			0
4002_45	33	62	105	108	45
4003	37	77	91	94	24
	37	78			36
	10	118			0
	10	115			0
4004	36	68	108	116	42
	36	69			53
	36	69			39
	36	70			36
Reservoir pressure = 340 bar					
4005	36	66	130	138	42
	36	66			53
	36	66			40
	36	67			35
4006	36	68	116	123	33
	36	68			45
	36	69			33
	36	69			29
Reservoir pressure = 200 bar					
4079	33	75	79	93	43
	33	74			50
	33	74			39
	33	74			37
4081	36	62	95	97	60
	13	118			0
	13	119			0
	12	116			0
Reservoir pressure = 100 bar					
4078^	32	55	76	93	40
	32	54			38

	32 32	51 51			40 45
4080	37 11 11 12	51 117 118 115	87	90	60 0 0 0
4082*	15 11 11 12	52 117 118 115	52	85	30 0 0 0
4083	-2 11 11 11	50 116 118 115	33	85	15 0 0 0
Reservoir pressure = 60 bar					
4007	-6 10 10 10	25 116 118 115	30	85	15 0 0 0
4008	18 10 10 10	27 116 118 115	56	85	28 0 0 0
4009	37 10 10 10	32 116 118 115	87	89	60 0 0 0
4010	35 10 10 10	35 116 118 115	143	147	100 0 0 0
4011	31 31 8 8	31 32 118 115	75	89	48 53 0 0
4012	30 30 30 30	31 33 30 29	72	93	59 56 44 41
4013	20 19 20 29	29 29 29 30	85	95	40 40 40 50
Reservoir pressure 20bar – control 85 bar					
4014	-10 10 10 10	-11 116 118 115	27	85.1	15 0 0 0
4015	17	-3	53	85.3	30

	10 10 10	116 118 115			0 0 0
4016	37 10 10 10	9 116 118 115	86	89	60 0 0 0
4017*	0.4 10 10 10	4.9 116 118 115	85	86	15 0 0 0
Reservoir pressure 20bar – control 60 bar					
4018	7 10 10 10	36 116 118 115	61	61	15 0 0 0
4019	64 10 10 10	9 116 118 115	134	137	60 0 0 0
4020	77 47 61 63	12 11 6 5	126	140	50 40 40 40
4021	62 52 62 62	29 32 25 24	96	106	33 30 29 28
4022	57 10 10 10	7 116 118 115	109	111	46 0 0 0
4023	43 10 10 10	18 116 118 115	79	81	30 0 0 0
Reservoir pressure 20 bar – no control					
4024**	17 10 10 10	47 116 118 1115	46	60	15 0 0 0
4025	42 10 10 10	17 116 118 115	78	80	30 0 0 0
4026***	58	8.3 116 118 115	107	109	43 0 0 0

4027	67 66 66 67	16 19 12 11	116	131	44 48 39 38
4028	64 64 64 64	24 27 20 19	103	115	37 40 32 31

* No hydrodynamic slugging used
** single phase
*** not 100% converged
^ crashes

Case	***Twh***	***Tdh***	***Pplatform***	***Pcomp***	***Mass flow***
4128	*58* *58* *58* *58*	*40* *42* *35* *35*	*81*	*90*	*26* *28* *23* *22*
4129	*56* *56* *56* *56*	*45* *46* *40* *40*	*75*	*83*	*24* *25* *21* *20*

Periplus Archeomare

Bureauonderzoek

Porthos Pijpleiding

Periplus Archeomare rapport 20A019-01

Auteurs:

R. van Lil en R.W. Cassée

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Inhoudsopgave

Periode	Tijd in jaren				
Nieuwe tijd Laat	1850	Na Chr.	-	Heden	
Nieuwe tijd Midden	1650	Na Chr.	-	1850	Na Chr.
Nieuwe tijd Vroeg	1500	Na Chr.	-	1650	Na Chr.
Late-Middeleeuwen	1050	Na Chr.	-	1500	Na Chr.
Vroege-Middeleeuwen	450	Na Chr.	-	1050	Na Chr.
Romeinse tijd	12	Voor Chr.	-	450	Na Chr.
IJzertijd	800	Voor Chr.	-	12	Voor Chr.
Bronstijd	2000	Voor Chr.	-	800	Voor Chr.
Neolithicum (Nieuwe Steentijd)	5300	Voor Chr.	-	2000	Voor Chr.
Mesolithicum (Midden Steentijd)	8800	Voor Chr.	-	4900	Voor Chr.
Paleolithicum (Oude Steentijd)	300.000	Voor Chr.	-	8800	Voor Chr.

Tabel 1. Archeologische perioden

Provincies:	Zuid-Holland	
Gemeenten:	Rotterdam	
Plaats:	Maasvlakte 2, Noordzee	
Beheerder gebied:	Rijkswaterstaat Zee en Delta	
Ligging waterbodem (t.o.v. LAT)	Maximum Gemiddeld Minimum	-2.78 m -19.81 m -35.31 m
Waterstaatkundige gegevens	Open zee, zout water, getijdenstroming	
Huidig watergebruik	Open vaarwater, vaargeul	
Toponiem:	Porthos Pijpleiding	
Kadastrale gegevens:	N.v.t.	
Kaartbladen:	37A, 30C en 1801	
Coördinaten (UTM31N ED50)	West	E 563228
	Oost	E 572185
	Noord	N 5776741
	Zuid	N 5760009
Oppervlakte onderzoeksgebied	42 km^2	
Bevoegd gezag:	Rijkswaterstaat Zee en Delta Gemeente Rotterdam	
Adviesorgaan namens bevoegd gezag:	Rijksdienst voor het Cultureel Erfgoed	
Contactpersoon namens bevoegd gezag:	Dhr. R. Duijts	
Deskundige namens het bevoegd gezag:	Mw. M. Snoek	
ARCHIS- onderzoeksmeldingsnummer (CIS-code):	4867975100	
Periplus-projectcode:	20A019-01	
Periode van uitvoering:	Juni 2020	
Beheer en plaats documentatie:	Periplus Archeomare BV, Amsterdam	

Tabel 2. Administratieve gegevens van het onderzoeksgebied

Samenvatting

Periplus Archeomare BV heeft in opdracht van Havenbedrijf Rotterdam een archeologisch bureauonderzoek uitgevoerd voor de toekomstige Porthos Pijpleiding.

Het bureauonderzoek heeft uitgewezen, dat binnen het onderzoeksgebied scheeps- en vliegtuigwrakken en *in situ* prehistorische resten verwacht kunnen worden.

Binnen het onderzochte gebied zijn resten van negen scheepswrakken bekend. Het merendeel (zeven) is nog niet geïdentificeerd, dus de archeologische waarde van deze wrakken is nog niet vastgesteld. Naast de bekende wrakken kunnen nog onontdekte resten van scheeps- en vliegtuigwrakken voorkomen.

Op basis van de uitkomst van dit onderzoek wordt geadviseerd om een inventariserend veldonderzoek (opwaterfase) uit te voeren om de archeologische verwachting te toetsen. Voorafgaand aan het leggen van een pijpleiding wordt standaard een geofysische en geotechnische *pre-lay route survey* uitgevoerd. De data van deze *surveys* kunnen worden gebruikt voor de toets (zie onderstaande tabel).

Archeologische Verwachting	Methode	Doel	Opmerking
Scheeps- en vliegtuigwrakken	Side Scan Sonar	Opsporen, karteren en begrenzen van wrakken	Wrakken die op de bodem liggen of uit de bodem steken
	Multibeam	Morfologische karakterisering van wraklocaties; opsporen van (deels) begraven wrakken waarvan de aanwezigheid wordt gemarkeerd door een slijpgeul	In aanvulling op side scan sonar
	Subbottom Profiler	Opsporen begraven objecten waaronder mogelijke scheeps- en vliegtuigwrakken	Aard van het begraven object kan niet direct worden vastgesteld
	Magnetometer		
Prehistorische landschappen en nederzettingen (kampplaatsen)	Subbottom Profiler	Karteren pleistocene landschap; specificeren van verwachting	Ondersteund door, en gevalideerd met sondeer- en boorgegevens
	Geologische Boringen	Vaststellen lithostratigrafie, aard laaggrenzen (erosief of geleidelijk) en kenmerken van bodemvorming en rijping; specificeren van verwachting	Selectie van boringlocaties voor archeologische onderzoek <u>voordat</u> kernen worden gebruikt voor destructief geotechnisch onderzoek
	Sonderingen	Vaststellen lithostratigrafie	Korreleren met boorgegevens

Wanneer de onderzoeksmethoden, als in de tabel beschreven, worden toegepast tijdens de *route survey* en de ingewonnen data van voldoende kwaliteit is, dan kan de benodigde archeologische beoordeling van de pijpleidingroute worden uitgevoerd.

Het verdient aanbeveling de *technische Scope of Work* af te stemmen met het archeologisch team alvorens met de survey werkzaamheden te beginnen. De eisen die voor het archeologische onderzoek aan

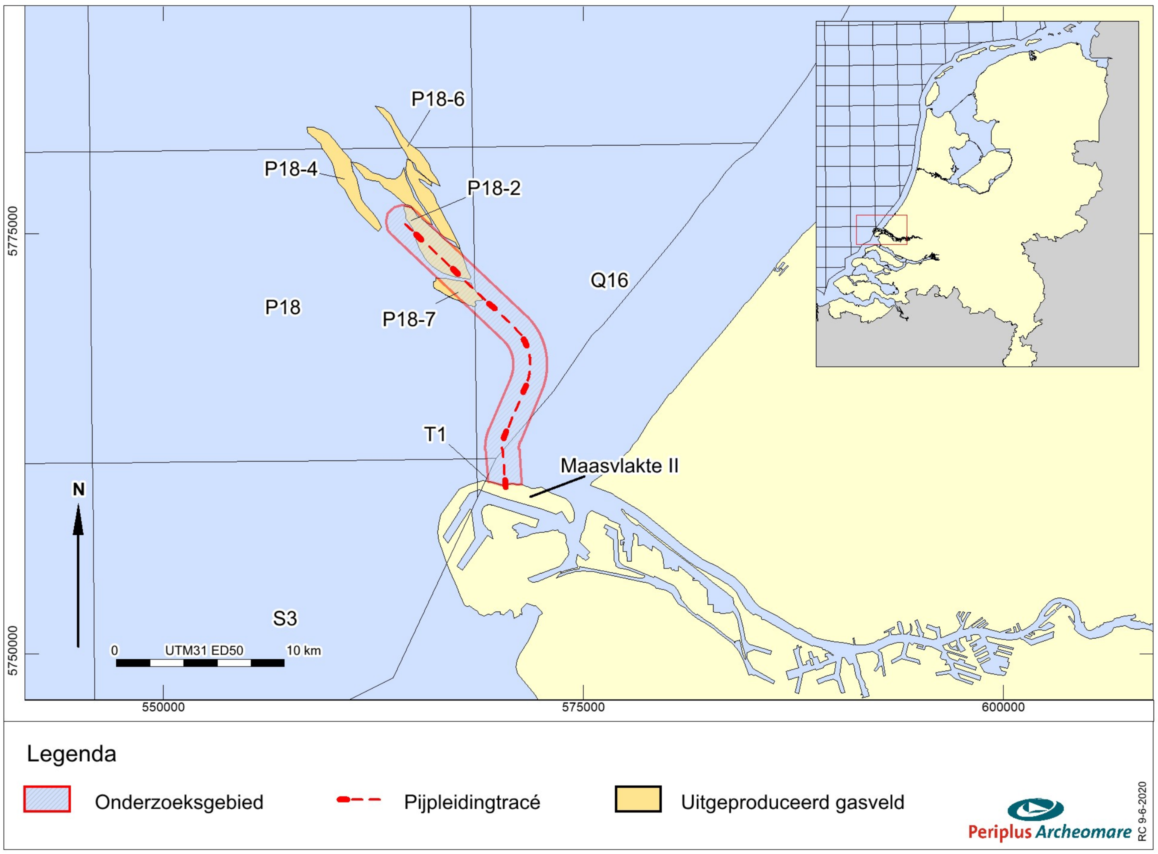
de geofysische opnamen worden gesteld dienen te worden vastgelegd in een Programma van Eisen (PvE), en dat voorafgaand aan het onderzoek dient te zijn ondertekend door bevoegd gezag.

Het is voor de analyse van boorkernen voor archeologische doeleinden van belang dat deze kernen intact zijn. Monsters die zijn gebruikt voor sterkteproeven en korrelgroottebepalingen zijn in de regel niet meer geschikt voor archeologisch onderzoek, omdat ze niet meer intact zijn. Afstemming van het gebruik van de monsters is daarom van belang. Een mogelijkheid zou kunnen zijn, dat de kernen voorafgaand aan het gebruik voor de bepaling van fysische parameters (sterkte/korrelgrootte) door een gecertificeerd KNA (Kwaliteitsnorm Nederlandse Archeologie) prospector waterbodems worden onderzocht. De prospector kan ook een selectie maken van monsters voor specialistisch onderzoek, bijvoorbeeld C14-analyses of onderzoek van pollen, dierlijke en plantaardige macroresten, mollusken, diatomeeën, et cetera. De eisen en randvoorwaarden die aan het archeologische booronderzoek worden gesteld dienen te worden vastgelegd in een PvE en/of Plan van Aanpak (PvA). Het wordt aanbevolen de eisen die worden gesteld aan het geofysisch onderzoek (*sidescan sonar, multibeam, subbottom profiler*) en het geotechnisch onderzoek (boringen en sonderingen) onder te brengen in één allesomvattend PvE.

1. Inleiding

1.1. Algemeen

Periplus Archeomare BV heeft in opdracht van Havenbedrijf Rotterdam een archeologisch bureauonderzoek uitgevoerd voor de toekomstige Porthos pijpleiding.

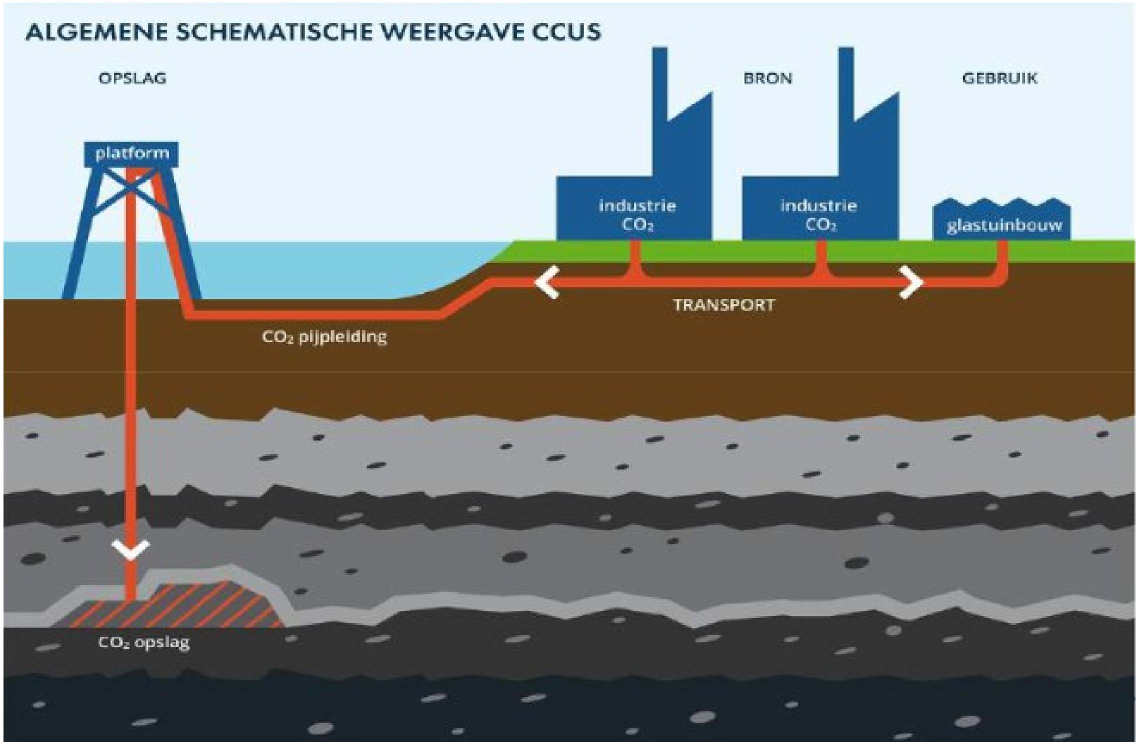


Afbeelding 1. Ligging van het onderzoeksgebied

1.2. Aanleiding

Het Havenbedrijf Rotterdam heeft met haar partners Gasunie en EBN de intentie om de aanleg van een CO_2-transport en opslag infrastructuur in de Rotterdamse haven naar de P18-velden op de Noordzee te realiseren waarin de opslag van CO_2 zal plaatsvinden. Het beoogde pijpleidingtracé zal gelegd worden onder de bodem van de Noordzee naar de uitgeproduceerde gasvelden in de Noordzee.[1] De CO_2-infrastructuur op zee heeft een lengte van 21 km. Het transport- en opslagsysteem bestaat uit een leiding op land, het compressorstation, een leiding op zee en de opslag van CO_2 in de diepe ondergrond van de Noordzee (afbeelding 2). Het afvangen van CO_2 bij industrieën om het vervolgens te gebruiken of ondergronds op te slaan (Carbon Capture Usage and Storage, kortweg CCUS) is één van de maatregelen om de klimaatdoelstellingen te halen.

[1] Havenbedrijf Rotterdam, Energie Beheer Nederland, en N.V. Nederlandse Gasunie, 2019.



Afbeelding 2: Schematische weergave van het transport- en opslagsysteem.

In de Erfgoedwet (2016), voortgekomen uit het verdrag van Malta (1992), is de bescherming van het archeologische erfgoed geregeld. Door geplande werkzaamheden (het installeren van een pijpleiding in de zeebodem) kunnen eventuele archeologische waarden worden aangetast. Als het bodemarchief door geplande bodemingrepen wordt bedreigd geldt de wettelijke verplichting om archeologisch onderzoek te verrichten. Dit gegeven vormde de directe aanleiding voor het verrichten van het onderhavige onderzoek.

1.3. Doelstelling

Het doel van het bureauonderzoek is het specificeren van de archeologische verwachting voor het plangebied.

Het onderzoek is uitgevoerd conform de Kwaliteitsnorm Nederlandse Archeologie Waterbodems (*KNA* 4.1). Een stroomdiagram met de opeenvolgende fasen binnen het archeologische proces is als bijlage 2 bij dit rapport opgenomen.

Overigens is er een eerder initiatief geweest om een CO_2 leiding aan te leggen naar de P18 velden, het ROAD-project. Dit project is uiteindelijk niet doorgegaan. Het beoogde tracé overlapt grotendeels met onderhavig onderzoek. De hieruit voortgekomen rapporten, opgesteld door archeologisch bureau RAAP zijn meegenomen in dit onderzoek.

1.4. Onderzoeksvragen

Voor het archeologisch bureauonderzoek waterbodems zijn de volgende onderzoeksvragen opgesteld:

- *Zijn er archeologische waarden in het plangebied bekend? Zo ja: Wat is de aard, omvang, (diepte)ligging en datering van deze vindplaatsen?*

- *Kunnen in het plangebied, naast eventuele bekende waarden, archeologische resten verwacht worden? Zo ja: Wat is de aard, omvang, (diepte)ligging en datering van de verwachte archeologische resten?*

- *Vormt de aanleg van pijpleiding een bedreiging voor bekende of verwachte archeologische waarden? Zo ja: Kan een aantasting van archeologische waarden door planaanpassing worden voorkomen of beperkt?*

Indien de archeologische waarden niet kunnen worden behouden:

- *Welke vorm van nader onderzoek is nodig om de aanwezigheid van archeologische waarden en hun omvang, ligging, aard en datering voldoende te kunnen bepalen om te komen tot een selectiebesluit?*

Het bureauonderzoek is uitgevoerd door R. van Lil (Senior KNA-Prospector Specialisme Waterbodems) en R.W. Cassée (KNA-archeoloog waterbodems i.o.).

Deze bladzijde is met opzet leeg gelaten ten behoeve van dubbelzijdig afdrukken

2. Methoden en technieken

Het bureauonderzoek is uitgevoerd conform de Kwaliteitsnorm Nederlandse Archeologie (*KNA-*waterbodems 4.1; Protocol 4002). Het betreft in het bijzonder de specificaties LS01wb, LS02wb, LS03wb, LS04wb en LS05wb. Dit gedeelte van het onderzoek wordt gerapporteerd conform LS06wb.

Voor het bureauonderzoek zijn de volgende werkzaamheden verricht:

- Afbakening plangebied en vaststellen van de consequenties van het mogelijk toekomstige gebruik;
- Beschrijving van de huidige situatie;
- Beschrijving van de historische situatie en mogelijke verstoringen binnen het onderzoeksgebied;
- Beschrijving van bekende archeologische waarden en aardwetenschappelijke gegevens;
- Beschrijven mogelijke aanwezigheid bouwhistorische waarden (onder water).

Op grond van deze onderdelen wordt een gespecificeerde verwachting van het gebied opgesteld (specificatie LS05wb). Hierin wordt verwoord of, en zo ja, welke archeologische waarden verwacht kunnen worden. De eigenschappen van deze waarden zullen zo gedetailleerd mogelijk worden aangegeven.

Op basis van de gespecificeerde verwachting worden de onderzoeksvragen beantwoord in hoofdstuk 3. De effectbeoordeling per route variant wordt gepresenteerd in hoofdstuk 4. Het onderzoek wordt afgesloten met een advies in hoofdstuk 5.

2.1. Bronnen

De volgende bronnen zijn geraadpleegd voor het onderzoek:

- Nationaal Contact Nummer (NCN)
- Dienst der Hydrografie
- TNO grid model geologie Noordzee
- GeoTOP grid model geologie land
- Rijkswaterstaat Noordzee
- *TNO-NITG*; geologische boringen en kaarten
- Archis III, beheerd door de Rijksdienst voor het Cultureel Erfgoed
- Databases Periplus Archeomare
- Nederlandse Federatie voor Luchtvaart Archeologie (NFLA)
- Stichting Aircraft Recovery Group 40-45
- Diverse bronnen op Internet

Voor een volledig overzicht van de geraadpleegde bronnen en literatuur zie referenties op pagina 55.

Schuingedrukte woorden worden toegelicht in de verklarende woordenlijst op pagina 53.

Deze bladzijde is met opzet leeg gelaten ten behoeve van dubbelzijdig afdrukken

3. Resultaten

3.1. Afbakening plangebied en vaststellen van de consequenties van het mogelijk toekomstige gebruik (LS01wb)

Het plangebied is gedefinieerd door de opdrachtgever en gebaseerd op het beoogde pijpleidingtracé. Het onderzoeksgebied is bepaald door een bufferzone van één kilometer rondom het plangebied. De reden voor deze uitbreiding is het feit dat de geregistreerde posities van bekende waarnemingen op de Noordzee tot wel één kilometer kunnen afwijken van de werkelijke locatie.

Het onderzoeksgebied ligt direct ten noorden van de Tweede Maasvlakte (gemeente Rotterdam). Vanaf de Maasvlakte loopt het beoogde tracé eerst noordwaarts af en buigt daarna af naar het noordwesten, richting de uitgeprocedeerde P18 gasvelden (afbeelding 1).

Op zee wordt de leiding door een legschip in de zeebodem ingegraven tot zeker een diepte van 0.6 meter. In de Maasgeul komt de leiding dieper te liggen, namelijk op drie meter onder de zeebodem. De leiding komt op veilige afstand van andere reeds bestaand kabels en leidingen te liggen. De leiding zelf zal bestaan uit een geïsoleerde koolstofstalen buis met een lengte van 21 km. De maximale diameter van de leiding is 0.68 m (406 mm leiding, 2 x 26 mm isolatie en 2 x 110 mm Concrete Weight Coating). Hiermee komt de maximale verstoringsdiepte onder zeebodem uit op minder dan 1.5 meter en onder de Maasgeul op minder dan 4 meter.

Door de ingreep kunnen minimaal tot de verstoringsdiepte archeologische resten worden aangetast. Het gaat hierbij om een directe verstoring. Indirecte verstoringen zoals slijpgeulvorming worden beperkt geacht.

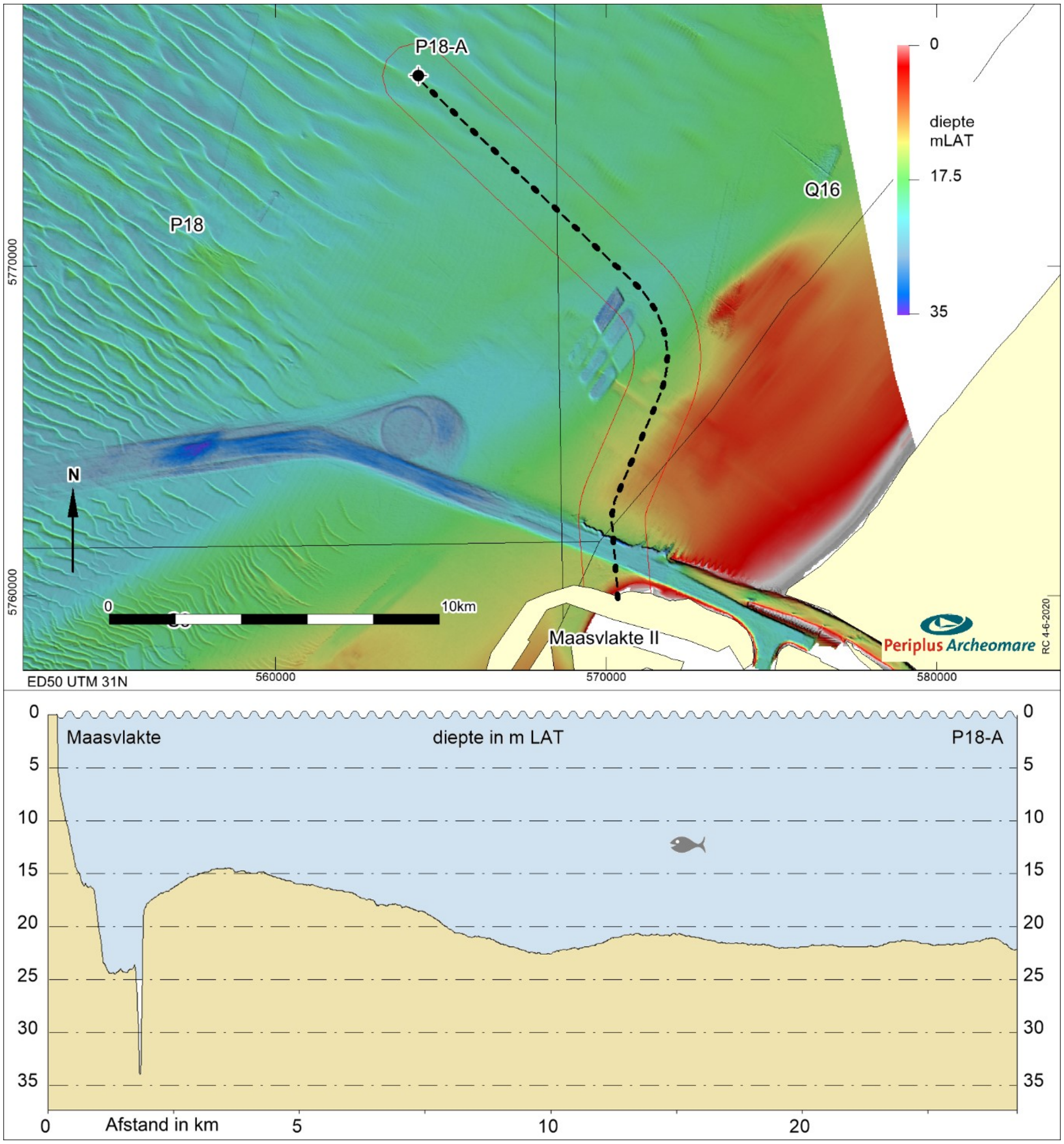
3.2. Beschrijving van de huidige situatie (LS02wb)

De onderstaande afbeelding toont het onderzoeksgebied op een samengestelde generieke dieptekaart. De dieptegegevens zijn afkomstig van de Dienst der Hydrografie (25x25m grid, 2009). De diepte in het onderzoeksgebied varieert van 2.8 m LAT tot 35.3 m LAT. De gemiddelde diepte is 19.8 m LAT.

In het profiel lijken grote sedimentaire structuren, zoals zandgolven, te ontbreken. Zwak ontwikkelde zandgolven zijn in P-block wel aanwezig, maar doordat de pijpleiding parallel aan de noordwest – zuidoost strekkende toppen van deze zandgolven is georiënteerd, zijn de zandgolven niet goed zichtbaar in het profiel.

Kleinere sedimentaire structuren, zoals de enkele decimeters hoge megaribbels, zijn wel aanwezig in het P-block en mogelijk ook in andere delen langs de pijpleidingroute, maar zijn door de grootte van de gridcellen (25 x 25 m) op deze schaal niet waarneembaar.

In het centrale deel van het onderzoeksgebied zijn 6 parallellogramvormige verdiepte zandwingebieden waarneembaar. Verder zijn ook verdiepingen zichtbaar in Maasgeul in het zuidelijke deel van de route.



Afbeelding 3. Diepte langs het tracé in meter ten opzichte van LAT.

Het onderzoeksgebied wordt doorkruist door verschillende bestaande kabels en pijpleidingen. Een overzicht van deze kabels en leidingen is weergegeven in de onderstaande afbeelding en tabellen. De ligging van de kabels en leidingen zijn gebaseerd op de gegevens van Rijkswaterstaat (augustus 2019). *As Built* data van de operators van betreffende kabels en leidingen zijn niet opgevraagd. Uit de geofysische surveys zullen de exacte posities van deze leidingen kunnen worden vastgesteld.

Het komt vaak voor dat op zee buiten gebruik gestelde kabels (niet pijpleidingen) worden aangetroffen die niet in de Rijkswaterstaat database voorkomen. Deze kabels worden tijdens de route survey met één of meer magnetometers opgespoord en in kaart gebracht.

Nr.	Naam	Type	Methode	Van	Naar	Status
KB0051	UK - NL 4	Telecom	Surface Laid	Scheveningen (NL)	Lowesoft (GB)	Verlaten
-	Noz hkz 1	Electra				Toekomstig
-	Noz hkz 2	Electra				Toekomstig
-	Noz hkz 3	Electra				Toekomstig
-	Noz hkz 4	Electra				Toekomstig

Tabel 3. Overzicht van elektra- en telecomkabels

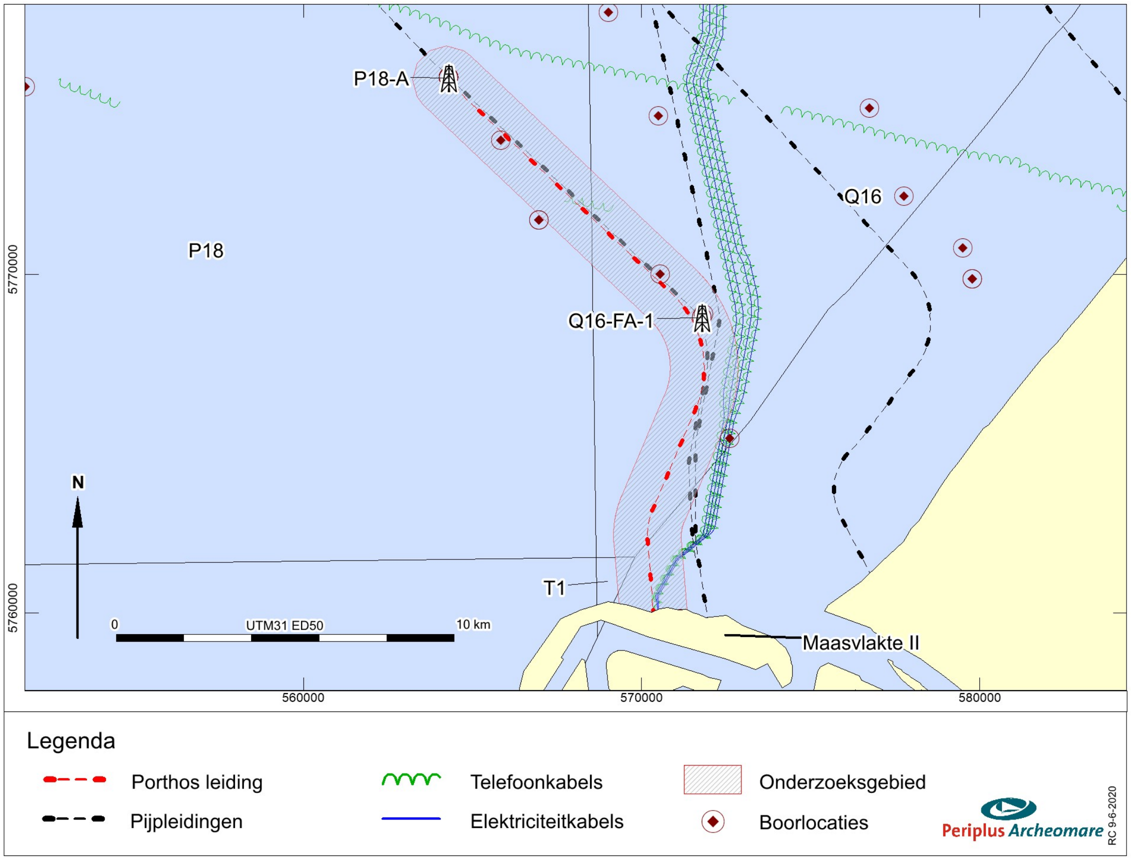
Nr.	Operator	Stof	Diameter (Inch)	Van	Naar	Status
PL0099_PR	TAQA Energy	Gas	26	P15-D	Maasvlakte	Actief
PL0106_HS	TAQA Energy	Methanol	3	P18-A	P15-DP	Actief
PL0138_PR	NAM	Methanol	2	Q16-FA-1	P18-A	Actief
PL0223_PR	ENGIE E&P	Gas	8	Q16-FA-1	Maasvlakte	Gepland

Tabel 4. Overzicht van pijpleidingen

Naast de pijpleidingen en kabels zijn 11 boorgaten van exploratieboringen in het onderzoeksgebied bekend (zie afbeelding 4). Vanuit de 11 boorlocaties zijn inclusief de sidetracks in totaal 17 boringen uitgevoerd. De gegevens van de boringen zijn opgenomen in tabel 5. Als sidetracks zijn uitgevoerd worden enkel de gegevens van de laatste sidetrack van betreffende put getoond in deze tabel.

Boorgat	UTM31 ED 50 E	UTM31 ED 50 N	Resultaat	Eigenaar	Start	Eind	Status	NITG_nr.
P18-02	565845	5773940	Gas	TAQA	13/03/1989	05/06/1989	Suspended	BP180673
P18-A-01	564303	5775792	Gas	TAQA	08/07/1990	10/09/1990	Producing/ Injecting	BP180674
P18-A-02	564302	5775791	Gas	TAQA	08/04/1991	20/06/1991	Producing/ Injecting	BP180681
P18-A-03-S2	564302	5775791	Gas	TAQA	19/06/1993	31/08/1993	Producing/ Injecting	BP180676
P18-A-04	564302	5775791	Droog	TAQA	16/05/1993	18/05/1993	Abandoned	BP180677
P18-A-05-S1	564302	5775790	Gas	TAQA	08/05/1997	16/07/1997	Producing/ Injecting	BP180678
P18-A-06-S1	564302	5775790	Gas	TAQA	24/06/2003	17/08/2003	Producing/ Injecting	BP180680
P18-A-07-S1	564303	5775793	Gas	TAQA	13/03/2003	17/06/2003	Producing/ Injecting	BP180684
Q16-05	570560	5769982	Olie en gas	ONE-Dyas B.V.	09/07/1985	20/09/1985	Abandoned	BQ160979
Q16-06	571840	5768801	Technisch mislukt	ONE-Dyas B.V.	28/04/1989	07/05/1989	Abandoned	BQ160980
Q16-FA-101-S1	571786	5768720	Gas	ONE-Dyas B.V.	26/06/1989	04/10/1989	Producing/ Injecting	BQ160982

Tabel 5. Overzicht van boorputten in het onderzoeksgebied



Afbeelding 4. Het onderzoeksgebied in relatie met de bestaande kabels en leidingen.

Overige infrastructuur

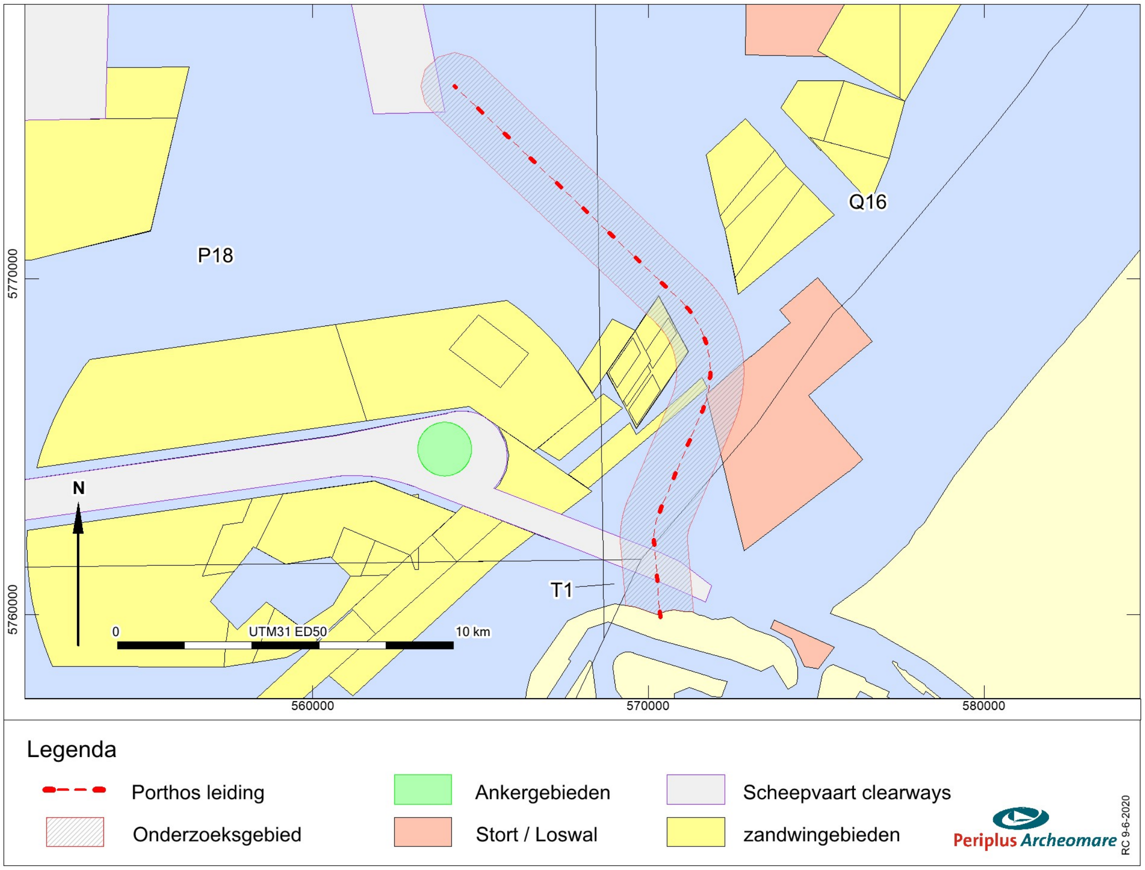
Naast de kabels en leidingen wordt het onderzoeksgebied doorkruist door andere infrastructuur. Een overzicht is weergegeven in afbeelding 5. Het gaat om scheepvaartroutes, ankergebieden, stort- en loswallen en zandwingebieden. Een overzicht van de stort- en loswallen en de zandwingebieden die het plangebied (deels) overlappen zijn weergegeven in de onderstaande tabellen.

Naam	Omschrijving	STATUS	In Gebruik	Uitgeput	Windiepte (m)
P18	Zandwinning	Vergund	Ja	Nee	2
Q16C-4	Zandwinning	Vergund	Ja	Nee	10
Q16C	Zandwinning	Verlaten	Nee	n.v.t.	2

Tabel 6. Zandwingebieden die route corridors overlappen

Naam	Status	Soort
Verdiepte loswallen	Actief	Stort Loswal
KF Maasgeul	Actief	Stortvak

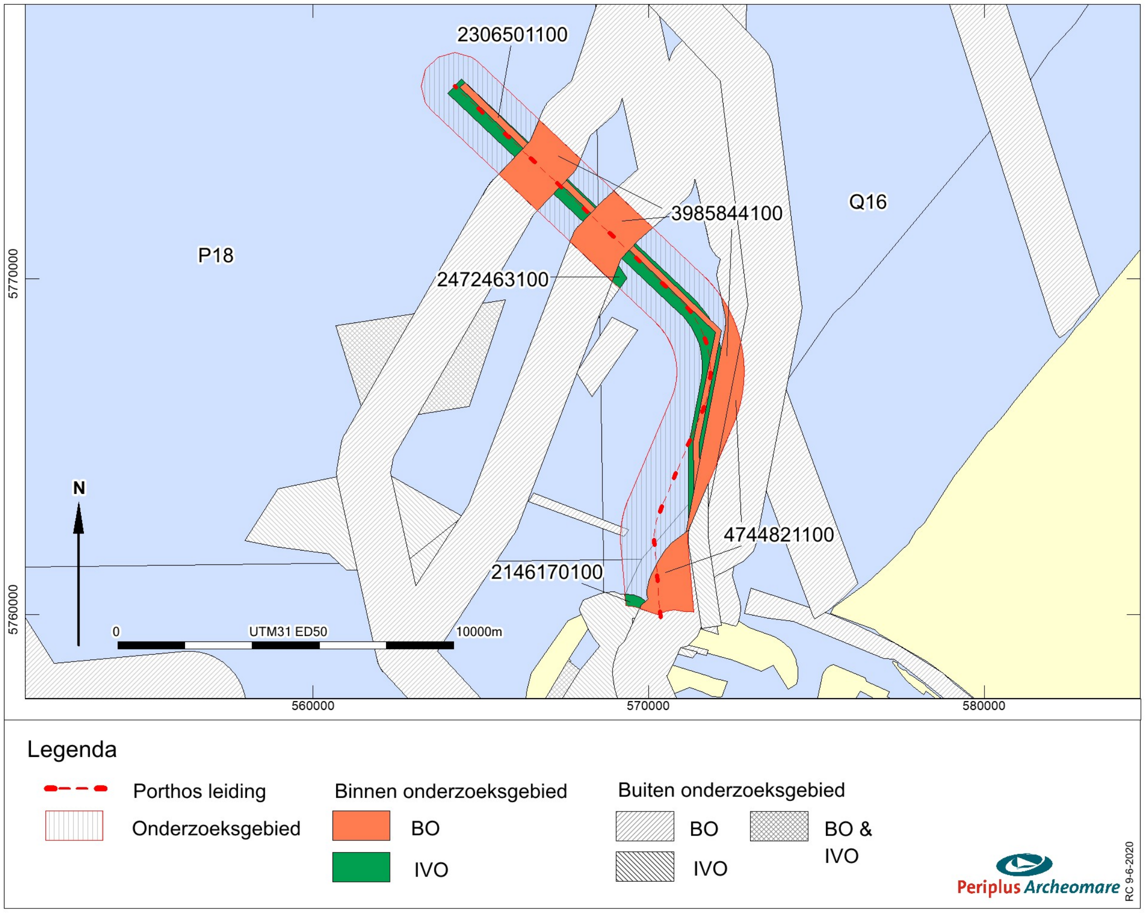
Tabel 7. Stort- en loswallen die route corridors overlappen



Afbeelding 5. Overige infrastructuur in en rondom de onderzoeksgebieden

Eerder uitgevoerde onderzoeken in het gebied

Een overzicht van de eerder uitgevoerde (archeologische) onderzoeken rondom en in het onderzoeksgebied is weergegeven in de onderstaande afbeelding en tabel.



Afbeelding 6. Overzicht van de eerder uitgevoerde onderzoeken langs de routevarianten

Archis nr. Zaaknr.	Omschrijving	Jaar	Type Onderzoek	Uitvoerder
2146170100	Aanleg Tweede Maasvlakte[2]	2007	IVO	RAAP
2205721100	Rotterdam Euromax kade[3]	2004	BO	Gemeente Rotterdam
2209107100	Rotterdam Scheepswrak Maasvlakte II MIVO[4]	2009	IVO	ADC
2213862100	Zandwingebied Maasvlakte 2[5]	2008	IVO	ADC/PPA
2306501100	ROAD[6]	2010	BO	RAAP
2329190100	Verbreding Maasgeul, Noordzee[7]	2011	BO	PPA
2338595100	Twintig meter diep[8]	2011	IVO	Gemeente Rotterdam
2357849100	Buisleiding Waterstaatswerken[9]	2012	IVO	RAAP

[2] Schute, I., 2007.
[3] Guiran, A.J., 2004.
[4] Waldus, W.B., e.a. 2009a.
[5] Waldus, W.B., e.a. 2009b.
[6] Kroes, R.A.C., 2010
[7] Lil, R. van, en Waldus, W.B., 2011.
[8] Moree, J.M., en Sier, M.M. (red.), 2014.
[9] Kroes, R.A.C., 2013

Archis nr. Zaaknr.	Omschrijving	Jaar	Type Onderzoek	Uitvoerder
2367341100	Vistochten Maasvlakte 2[10]	2015	IVO	Universiteit Leiden
2402527100	Zandwingebied P18J-West[11]	2013	BO & IVO	PPA
2414312100	Zandwingebied P18P[12]	2013	BO	PPA
2449719100	Rotterdam Maasvlakte 2 Prinses Alexiahaven[13]	2015	BO & IVO	BOOR
2472463100	Zandwingebied Q16K[14]	2015	IVO	PPA
2480806100	Verdieping Nieuwe Waterweg, Botlek en Petroleumhavens.[15]	2015	BO	BOOR
3985844100	Net op zee, Hollandse Kust zuid[16]	2016	BO	PPA
4744821100	Exportkabels IJmuiden Ver[17]	2019	BO	PPA

Tabel 8. Overzicht van de eerder uitgevoerde archeologische onderzoeken in het gebied

De relevante resultaten van de verschillende onderzoeken, die overlap hebben met het Porthos plangebied, worden besproken in paragraaf 3.3. Een verwijzing naar de rapporten van de onderzoeken is opgenomen in de referentielijst op pagina 55.

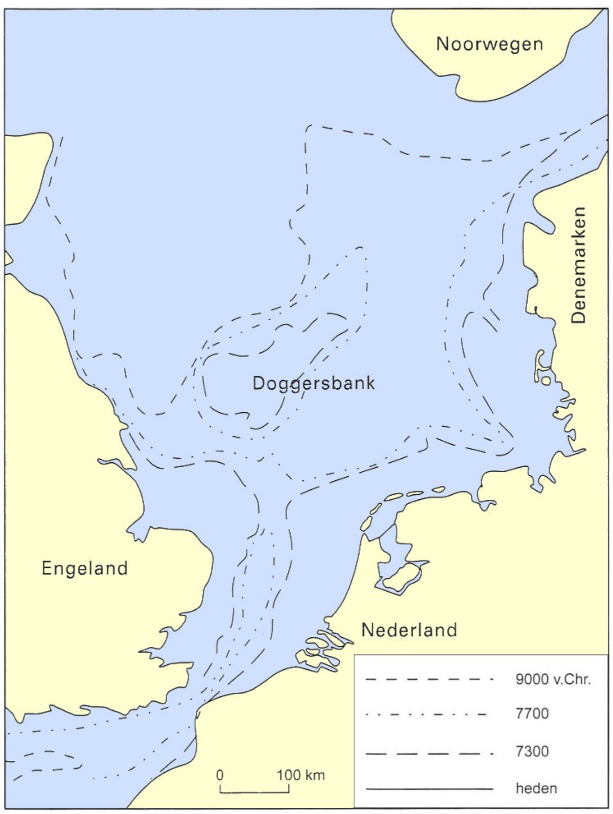
[10] Kuitems, M., e.a., 2015.
[11] Brenk, S. van den, e.a., 2013.
[12] Lil, R. van, e.a., 2013.
[13] Schiltmans, D.E.A., 2015b
[14] Lil, R. van, en Muis, L.A., 2015.
[15] Schiltmans, D.E.A., 2015a
[16] Lil, R. van, e.a., 2016.
[17] Brenk, S. van den, e.a., 2019.

3.3. Historische situatie en mogelijke verstoringen (LS03wb)

Prehistorische bewoning in het Noordzeebekken

De Noordzeebekken vormde ca 12.000 jaar geleden een uitgestrekt dekzandlandschap waar een *toendraklimaat heerste*. Aan het eind van de laatste IJstijd (ca 11.500 jaar geleden) steeg de temperatuur en als gevolg daarvan smolten de noordelijke gletsjers. Door het vrijkomende water steeg de zeespiegel en raakte het Noordzeebekken geleidelijk opgevuld. De bewoners van het gebied moesten naar hoger gelegen gebieden vertrekken.[18]

Een voorbeeld van een hoger gelegen gebied is de Doggersbank in het noorden van het Nederlands Continentaal Plat. Restanten van het toendra-landschap en zijn bewoners worden regelmatig aangetroffen in de netten van vissers. Het bekendst zijn de vele fossielen die bij de Doggersbank zijn opgevist. In het Noordzeegebied kunnen resten van oerbossen (Berk, Den, Eik, Iep en Hazelaar) voorkomen. Vondsten hiervan zijn wel bekend langs de kust van Engeland en in de Westerschelde, maar (nog) niet voor de Nederlandse kust of het Nederlandse deel van het continentaal plat.[19].



Afbeelding 7. Reconstructie van de historische kustlijnen in het Noordzeebekken.

De zeespiegelstijging viel samen met het verdrinken van oude landschappen. Deze landschappen zijn door middel van geofysische en geotechnische technieken in beeld gebracht. Recent is bijvoorbeeld op basis

[18] Gaffney e.a. 2005.
[19] Commentaar van de RCE

van seismische gegevens uit de olie-industrie een prehistorisch landschap in beeld gebracht nabij de Engelse oostkust.[20]
De archeologische resten uit de Noordzee die in Nederland bekend zijn, betreffen naast de vondsten die door vissers zijn gedaan voornamelijk losse vondsten uit zandwingebieden. Zo zijn bij de aanleg van de Maasvlakte I en II en de Zandmotor verscheidene benen artefacten uit het Jong *Paleolithicum en Mesolithicum* aangetroffen, die wat betreft stijlkenmerken zijn onder te verdelen in clusters.[21]

Mesolithicum in de Yangtzehaven
Op de locatie waar nu de Yangtzehaven ligt lag rond 9000 voor Chr. een duincomplex.[22] Het duin lag in de monding van de Rijn-Maas en was hierdoor onderhevig aan continue verandering. Dit duincomplex vanaf circa 8250 tot 6500 voor Chr. door mensen gebruikt. Groepen jager-verzamelaars kwamen en gingen generaties lang naar het duincomplex om daar – tijdelijk – te wonen. Hoe frequent en hoe lang zij op het duin verbleven is niet bekend. In het tijdbestek van anderhalf millennium heeft men tijdens elk seizoen op het duincomplex tijdelijk gewoond, gejaagd, voedsel verzameld en geleefd. Dit blijkt uit de vondsten die gedaan zijn tijdens de opgraving van Yangtzehaven in 2011.[22] De vondsten variëren van bewerkt vuursteen tot verbrand bot en plantaardige macro fossielen.

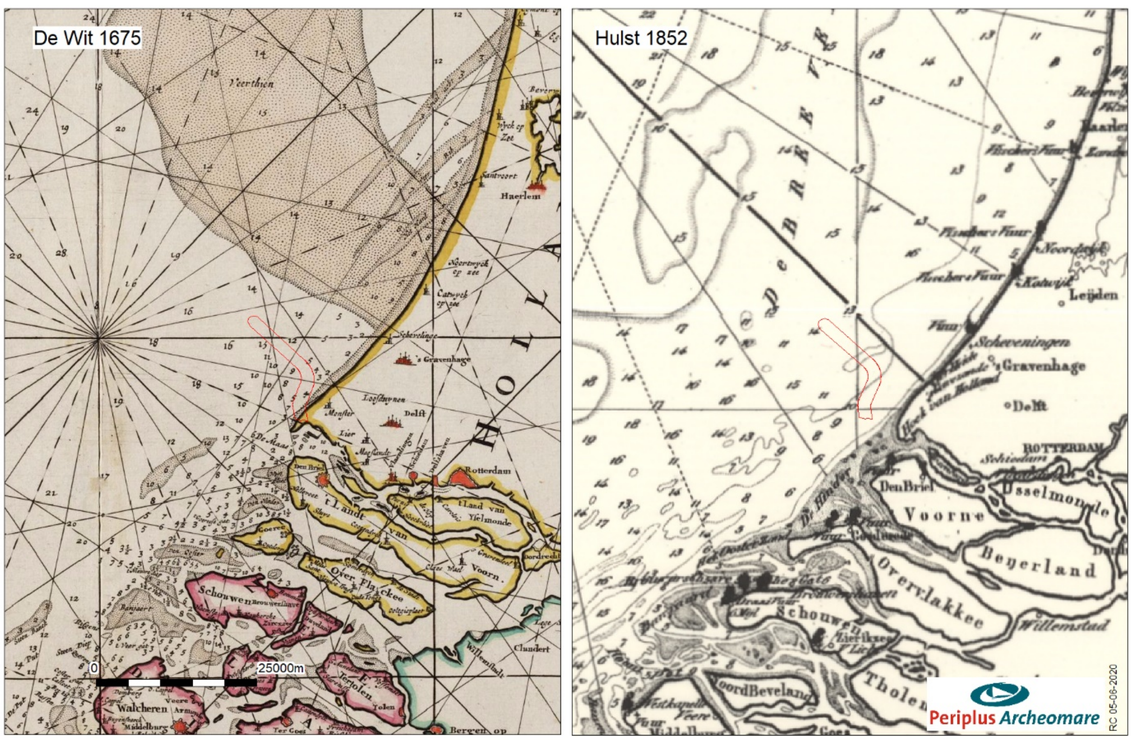
Bewoningssporen in het kustgebied uit de protohistorie
De zandige strandwallen en duinen die de natuurlijke bescherming vormen van het kustgebied hebben zich gedurende het laatste millennium v. Chr. gestabiliseerd. Vanaf de late IJzertijd tot en met de Middeleeuwen zijn bewoningssporen bekend uit de kuststrook van Holland. Er bestaan aanwijzingen dat zich gedurende de Romeinse Tijd versterkingen bevonden langs de kust van Zeeland en Zuid-Holland.[23] Het meest aansprekende voorbeeld vormt de tot nu toe niet gelokaliseerde Brittenburg voor de kust bij Katwijk aan Zee.[24] Voor de Scheveningse kust is vastgesteld dat zich hier een *vicus* heeft bevonden bij de Scheveningse weg.[25] Een dergelijke civiele nederzetting kan over het algemeen direct in verband worden gebracht met een Romeins legerkamp. Deze is eveneens tot op heden echter nog niet gelokaliseerd. Het is niet ondenkbaar dat (verspoelde) resten van Romeinse forten zich bevinden in de huidige strand- en duinzone. Naast nederzettingen en militaire infrastructuur kunnen Romeinse cultusplaatsen voorkomen. In Zeeland zijn twee tempelcomplexen gewijd aan de godin Nehallennia bekend. De eerste tempel is een complex dat al in de 17e eeuw is aangetroffen op het strand van Domburg. De verwachting is dat de vindplaats nu grotendeels in zee ligt. De tweede tempelcomplex is in de 70-tiger jaren van de vorige eeuw aangetroffen ten noordwesten bij het huidige Colijnsplaat. De resten liggen in een geul op een oude kleilaag in de Oosterschelde op meer dan 30 m diepte. De overblijfselen bestaan onder meer uit grote natuurstenen altaarstukken en keramische bouwmaterialen, zoals daktegels.

Scheepvaart
De eerste aanwijzingen voor scheepvaart op de Noordzee dateren uit het Neolithicum. Bewijs hiervan kan bijvoorbeeld worden gevonden in prehistorische begravingen in het Rijnland. In deze regio was de toegang tot tin beperkt en werd daarom beschouwd als een luxe goed. Het moest worden geïmporteerd

[20] Zie het project 'North sea paleolandscapes' van de Universiteit van Birmingham.
[21] Verhart 2005 159.
[22] Peeters, J.H.M., e.a., 2014.
[23] Hessing 2005, 98.
[24] Dijkstra en Ketelaar 1965.
[25] Waasdorp 1999.

uit andere regio's. Een van deze regio's lag het in zuidwesten van Engeland.[26] Aan de andere kant van de Noordzee zijn op de Britse eilanden sporadisch Alpiene jade bijlkoppen gevonden.

Na de eerste contacten in het Neolithicum is sprake van een intensivering van de scheepvaart op de Noordzee met enkele historisch goed gedocumenteerde pieken. Een voorbeeld hiervan is het Dover-schip uit 1550 v. Chr. Deze boot staat bekent als de oudste boot waarvan het bekent is dat deze op zee heeft gevaren.[27] Gedurende de Romeinse tijd geldt de Noordzee en in het bijzonder het Kanaal als verbindingsbrug voor het imperium. Vanaf de vroege Middeleeuwen ontstaan machtscentra langs de kust van de Noordzee.[28] Deze waren georiënteerd op de Noordzee en scheepvaart, handel en overzeese contacten speelden daarbij een centrale rol. Verder moeten in dit verband ook de raids (plundertochten) van de Vikingen genoemd worden. Vanaf de Late Middeleeuwen en de Nieuwe tijd waren de internationale handel en de scheepsbouw dermate ontwikkeld dat de Noordzee een opstap vormde voor wereldwijde vaarroutes. De scheepvaartgeschiedenis is in hoofdlijnen met vele bekende en tot op heden onbekende schipbreuken samengegaan. Scheepswrakken vormen de sporen van het maritieme verleden en deze kunnen onder gunstige conserveringsomstandigheden in de waterbodem bewaard zijn gebleven.



Afbeelding 8. Ligging van het onderzoeksgebied op oude kaarten

[26] Van Noort, 2012.
[27] Clark, 2004.
[28] Kramer e.a. 2003

Vliegtuigwrakken

In totaal stortten tijdens de oorlogsjaren meer dan 5000 vliegtuigen neer in Nederland.[29] Verschillende bronnen zijn niet eenduidig over het aantal vliegtuigen die nog in het Noordzeegebied vermist worden. Bekend is wel dat het gaat om honderden vliegtuigen.[30]

Gezien de oorlogshandelingen die boven de Noordzee hebben plaatsgevonden kunnen ook in het plangebied vliegtuigwrakken voorkomen. Tijdens de impact kunnen zware onderdelen van het vliegtuig (zoals de motor) diep in de bodem doordringen. Op land en in het Waddengebied zijn dergelijke onderdelen meters onder het maaiveld teruggevonden. Door de grote waterdiepte (meer dan 10 meter) in het grootste deel van het onderzoeksgebied mag worden aangenomen dat een gevechtsvliegtuig tijdens zijn crash sterk door het water wordt afgeremd, waardoor het op, en niet in de waterbodem beland. Migrerende zandgolven kunnen een wrak later afdekken. Door de geringe dikte van de zandige toplaag in het plangebied wordt verwacht dat eventuele grotere onderdelen op de bodem liggen of uit de bodem steken.

Bekende verstoringen in het plangebied

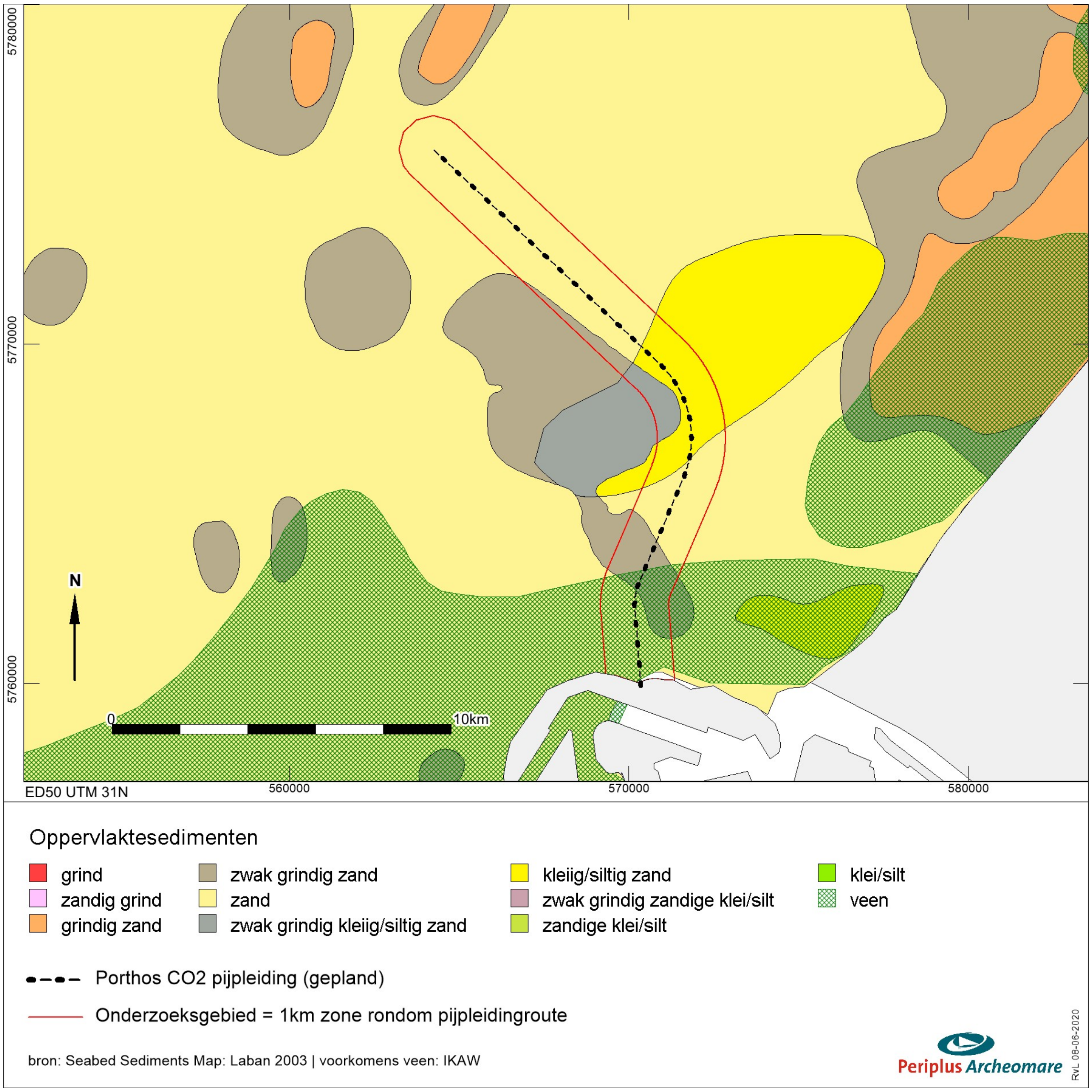
Het onderzoeksgebied wordt doorkruist door verschillende kabels, pijpleidingen, zandwingebieden en vaarroutes (zie paragraaf 3.2). De kabels en pijpleidingen zijn geploegd aangelegd waarbij de bodem verstoord is. Visserij met sleepnetten kan hebben geleid tot verstoring van de toplaag van de bodem. Dit is vooral van belang voor eventuele archeologische resten, zoals uit de bodem stekende wrakdelen, die aan deze netten kunnen blijven haken.

3.4. Geologische gegevens (LS04wb)

De archeologische verwachting voor prehistorische resten is sterk gerelateerd aan de *geogenese* van het plangebied. De *geogenese* kan worden herleid uit de aanwezige *lithostratigrafische* eenheden, de aard van laaggrenzen (erosief versus non-erosief) en indicaties voor bodemvorming in de sedimenten. Daarom vormen geofysische en geologische data een belangrijke bron om vragen met betrekking tot de aard, diepteligging, voorkomen, gaafheid en conservering van te verwachten archeologische resten in het plangebied te beantwoorden.

[29] Bron: NOS Journaal, 01-05-2016.

[30] Nederlandse Federatie voor Luchtvaart Archeologie, NFLA.



Afbeelding 9. Oppervlaktesedimenten

De zeebodem binnen het onderzoeksgebied bestaat uit zand met plaatselijk een bijmenging van grind, silt en klei (zie afbeelding 9). De zandige sedimenten maken deel uit van het *Bligh Bank Laagpakket*, een mobiele zandlaag waarin door getijstromen en golfwerking ruggen, duinen, stroomribbels en - in de ondiepere delen - golfribbels zijn gevormd. In het Maasmondgebied doorkruist de pijpleiding een gebied met veen. Dit veen is gekarteerd in de eerste 3,5 km van het tracé.

De opeenvolging van *holocene* afzettingen bestaat van ‘onder’ naar ‘boven’ uit de *Formatie van Nieuwkoop,* de *Formatie van Echteld*, de *Formatie van Naaldwijk*, en het *Bligh Bank Laagpakket.* Van KP8.000 tot KP19.276 (put P18-A), bestaat de *holocene* laag op veel plaatsen enkel uit het Bligh Bank Laagpakket.

De sedimenten die onder de *holocene* afzettingen schuil gaan bestaan uit uiteenlopende *pleistocene* afzettingen. De belangrijkste *pleistocene* eenheid in het onderzoeksgebied wordt gevormd door *Formatie van Kreftenheye*. De rivierafzettingen van deze eenheid komen in bijna het gehele onderzoeksgebied voor aan de top van de *pleistocene* opeenvolging. Nabij locatie P18-A ontbreekt de *Formatie van Kreftenheye* plaatselijk. Hier wordt de top van het *Pleistoceen* gevormd door mariene afzettingen van de *Eem Formatie*.

De *Formatie van Boxtel* is binnen het onderzoeksgebied niet gekarteerd. Toch moet er rekening mee worden gehouden dat ook deze eenheid plaatselijk kan voorkomen, omdat:

a) het detail van de beschikbare geologische kaarten beperkt is,
b) de *Formatie van Boxtel* in dit deel van de Noordzee soms lastig is te onderscheiden van de *Formatie van Kreftenheye*,[31]
c) de Boxtel Formatie onshore een gekend en belangrijk archeologisch niveau voor archeologische resten uit alle perioden is, en
d) tijdens onderzoek in de Yangtze haven rivierduinen van het Laagpakket van Delwijnen | Formatie van Boxtel zijn aangetroffen.

De opeenvolgende lithostratigrafische eenheden in het onderzoeksgebied, en de milieus waarin de sedimenten van deze eenheden zijn afgezet, worden in onderstaande tekst in meer detail besproken.

Eem Formatie

De *Eem Formatie* bestaat hoofdzakelijk uit schelpenhoudende mariene zanden met schelpen en plaatselijke kleilagen die tijdens het Eemien interglaciaal in de Eem zee zijn afgezet.[32] Op de overgang van het *Eemien* naar het *Weichselien* koelde het klimaat af. De zeespiegel daalde doordat water werd vastgelegd in het ijs van de zich uitbreidende poolkappen. Dit had tot gevolg dat de Eem Zee zich terugtrok. Tijdens de regressie van de Eem Zee werden brak- en zoetwaterkleien afgezet in de lagunes en meren die achter bleven in de glaciale bekkens. Deze lacustriene- en lagunaire afzettingen worden apart geclassificeerd als het *Brown Bank Laagpakket* binnen de *Eem Formatie*.

Formatie van Kreftenheye

De *Formatie van Kreftenheye* is opgebouwd uit afzettingen van de Rijn.[33] Tijdens het *Weichselien* traden in de zomermaanden pieken op in de afvoer van smeltwater vanuit het achterland. De rivier voerde in deze perioden grote hoeveelheden zand en grind naar het Noordzeegebied. De Rijn stroomde door een droog periglaciaal landschap en had een vlechtend karakter. De afzettingen zijn daardoor slecht gesorteerd. De zandige sedimenten van de *Formatie van Kreftenheye* zijn soms moeilijk te onderscheiden van de afzettingen van de *Eem Formatie*. Dit is zeker het geval als in de *Formatie van Kreftenheye* geremanieerde schelpen van de *Eem Formatie* voorkomen. Het onderscheid met de *Formatie van Boxtel* die plaatselijk boven de *Formatie van Kreftenheye* voorkomt kan ook lastig zijn, vooral als het om fluviatiele afzettingen binnen de *Formatie van Boxtel* gaat. In de omgeving van de Maasvlakte II zijn de zanden aan de top gelaagd en gaan veelal geleidelijk over in oeverafzettingen van de Laag van Wychen. Deze graduele ontwikkeling markeert het verzanden en verlaten raken van de rivierbedding.[34]

Tijdens het archeologisch onderzoek in de Yangtze haven zijn aan de top van de Formatie van Kreftenheye twee stugge kleilagen onderscheiden, die als Laag van Wychen (KRWY-1 en KRWY-2) zijn geclassificeerd. De twee kleilagen worden gescheiden door rivierduinzanden van het Laagpakket van Delwijnen |

[31] Pers. Comm. S. van Heteren.
[32] Eemien: interglaciaal (warme periode), circa 130.000 tot 115.000 jaar geleden.
[33] Weichselien: ijstijd van circa 115.000 tot 12.000 jaar geleden.
[34] Vos en Cohen 2015.

Formatie van Boxtel. De Laag van Wychen bestaat uit overstromings(rivier)kleien van de Rijn en Maas uit het Vroeg Holoceen.

De onderste laag (KRWY-2) bestaat uit grijze leem, zandige klei en kleiig zand en is intern gelaagd. De laag is rond 9500 voor Chr. afgezet. In de Yangtze haven zijn geen duidelijke kenmerken van bodemvorming waargenomen en de afzettingen zijn relatief slap, op basis waarvan wordt aangenomen, dat de rivierduinen kort na depositie van deze kleien zijn gevormd.

De bovenste laag (KRWY-1) bestaat uit stevige, matig siltige tot sterk siltige humeuze klei. De kleilaag is rond 8000 voor Chr. afgezet. Aan de basis is de klei kalkrijk; naar boven toe bevat kalkloze humeuze bodemniveaus, die erop wijzen dat het gebied slechts periodiek overstroomde. Het humusgehalte neemt van nader naar boven toe, waardoor de kleur gradeert van grijs naar donkergrijsbruin.

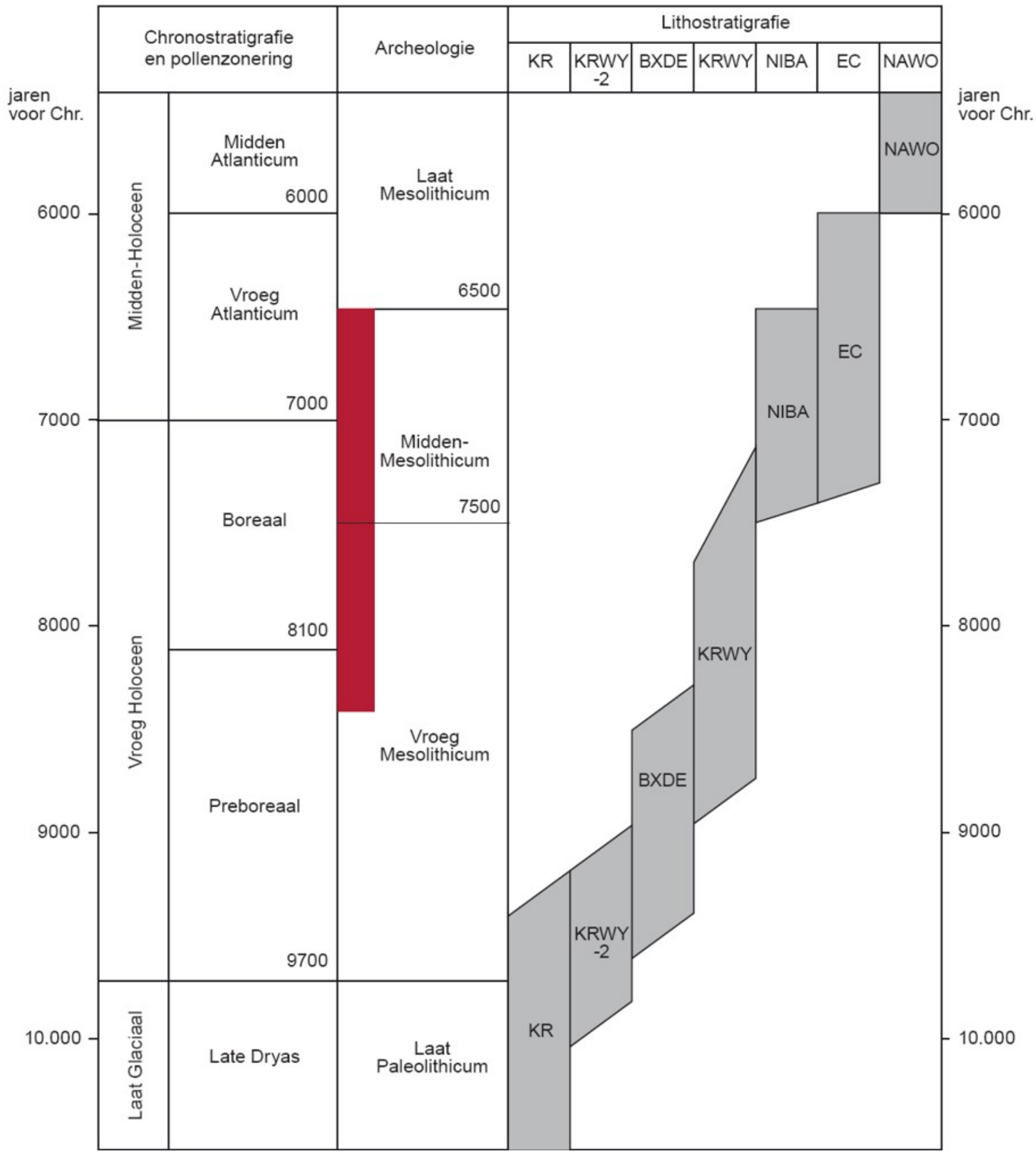
De geotechnische campagne die in 2010 door Fugro is uitgevoerd biedt aanwijzingen dat de Formatie van Kreftenheye en de Laag van Wychen ook ten noorden van de Maasgeul aanwezig zijn. De aanwezigheid van het Laagpakket van Delwijnen in de ondergrond van het pijpleidingtracé is onzeker, maar hierbij moet bedacht worden dat de rivierduinen zeer plaatselijk kunnen voorkomen.

Formatie van Boxtel

De *Formatie van Boxtel* is opgebouwd uit eolische afzettingen van het *Laagpakket van Wierden* (dekzand), het *Laagpakket van Delwijnen* (rivierduinzand) en/of beekafzettingen van het *Laagpakket van Singraven* (klei, leem en fijn zand). De afzettingen dateren uit de laatste fase van het *Weichselien* en het Vroeg *Holoceen*.[35] Aan het eind van het *Weichselien* stond de zeespiegel meer dan 100 meter lager dan nu. Het zuidelijke Noordzeegebied lag droog. Tijdens periodiek extreem droge en koude omstandigheden was er maar weinig vegetatie. De polaire winden hadden vrij spel en over grote delen van het Noordzeegebied en Nederland werd fijn zand (dekzand) afgezet. Het dekzand behoort tot het *Laagpakket van Wierden*.

In de ondergrond van de Yangtze-haven zijn rivierduinen aangetroffen. Deze duinen zijn in het Vroeg Holoceen, circa 9500 tot 8500 v. Chr., gevormd. De duinen bestaan uit kalkrijk matig fijn zand. In de top van het duinzand is een tot 50 cm dikke humeuze gebioturbeerde bodem gevormd. De dalen en flanken zijn veelal afgedekt door de bovenste Laag van Wychen. De bovenste Laag van Wychen en de toppen van lagere duintjes zijn afgedekt met veen van de Basisveen Laag binnen de Formatie van Nieuwkoop. Plaatselijk komt in de Yangtze haven ook direct op de rivierduinen veen voor op plaatsen waar de bovenste Laag van Wychen ontbreekt. De hogere duinen zijn afgetopt door erosie tijdens afzetting van de *Formatie van Naaldwijk* en/of het Bligh Bank Laagpakket. Een samenvatting van de chrono- en lithostratigrafie, en de archeologie in het gebied van de Maasmonding is weergegeven in afbeelding 10.

[35] Holoceen: interglaciaal (warme periode), 12.000 jaar geleden tot heden.



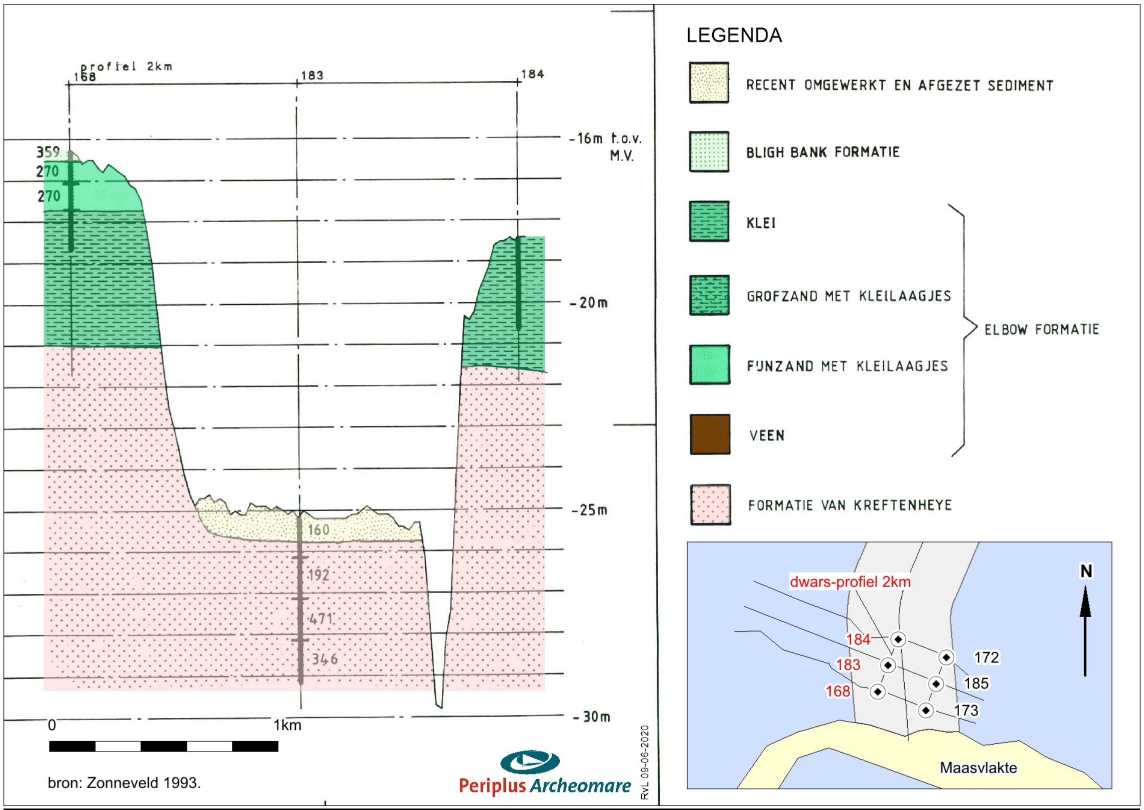
Afbeelding 10. Stratigrafische tabel met tijdindelingen, archeologische perioden, laageenheden en hun chronologie in de Yangtzehaven. Met de rode balk wordt de periode van menselijk gebruik van het rivierduincomplex (bepaald aan de hand van 14C-dateringen) aangegeven (uit: Vos en Cohen, 2015).

<u>Formatie van Nieuwkoop</u>

In het Maasmondgebied is een groot veengebied gekarteerd, dat zich naar het west-zuidwesten uitstrekt in de Noordzee (zie afbeelding 9). In tegenstelling tot wat deze afbeelding suggereert kunnen de veenlagen afgedekt zijn door jongere afzettingen. Het gaat hier om vroeg-holocene kustveenafzettingen. Dit veen wordt geclassificeerd als de *Basisveen Laag*. De Basisveen Laag is veelal donkerbruin, kleiig en amorf. De veenlagen in de Yangtze haven zijn tussen 7250 en 6500 v. Chr. afgezet. Ook elders langs de pijpleidingroute kunnen veenlagen van de *Basisveen Laag* voorkomen.

Formatie van Echteld

In 1993 is op verzoek van Rijkswaterstaat-directie Noordzee door de Afdeling Mariene Geologie van de Rijks Geologische Dienst onderzoek gedaan naar de geologische opbouw van de Maasgeul in verband met plannen tot overdimensionering van deze geul. Het doel van dit onderzoek was na te gaan wat de eventuele toepassingsmogelijkheden zijn met het weg te baggeren materiaal. Het onderzoek is uitgevoerd door onder anderen assistent-geoloog P.C. Zonneveld, die ook het onderzoeksrapport heeft opgesteld.[36] In afbeelding 11 is een profiel uit het rapport weergegeven, waaruit de lithostratigrafie aan weerszijden van de Maasgeul duidelijk naar voren komt.



Afbeelding 11. Dwarsprofiel op Maasgeul (Zonneveld 1993; profiel 2km)

Het profiel bevat 3 boringen (168, 183 en 184). Boring 184 ligt slechts op 38 meter ten westen van de geplande route van de Porthos pijpleiding. Op deze locatie, direct ten noorden van de Maasgeul, dagzoomt een ruim 3 meter dikke kleilaag. De kleilaag is toentertijd gekarteerd als de Elbow Formatie. De Elbow Formatie is een verouderde naam die werd gebruikt voor de classificatie van vroeg-*holocene* afzettingen in het Noordzeegebied. Het ging hierbij zowel om klastische mariene sedimenten die nu als Laagpakket van Wormer binnen de Formatie van Naaldwijk worden geclassificeerd, als om organoleptische afzettingen (veen), die nu tot de Basisveen Laag | Hollandveen Laagpakket binnen de Formatie van Nieuwkoop worden gerekend.

[36] Zonneveld 1993.

In het verleden is de kleilaag in de Maasmonding wel als lagunaire afzettingen van de Laag van Velsen geïnterpreteerd.[37] De Laag van Velsen bestaat uit humeuze klei en vormt de basis van het Laagpakket van Wormer.

Volgens de huidige stand van wetenschap wordt de kleilaag geclassificeerd als de Formatie van Echteld, die in het Maasmondgebied is opgebouwd uit humeuze zoetwatergetijden(rivier)afzettingen.[38] Kenmerkend is het voorkomen van houtresten en rietresten. Indicaties voor bodemvorming ontbreken. De kleien zijn, zo is de interpretatie van Vos en Cohen, onder water afgezet in een gebied waar de sedimentatie - ondanks hoge sedimentatiesnelheden - de snelle verdrinking van het landschap niet kon bijhouden. Het begin van de sedimentatie van de humeuze kleien valt samen met het begin van de afzetting van veen, rond 7250 v. Chr., en duurt tot rond 6000 v. Chr.

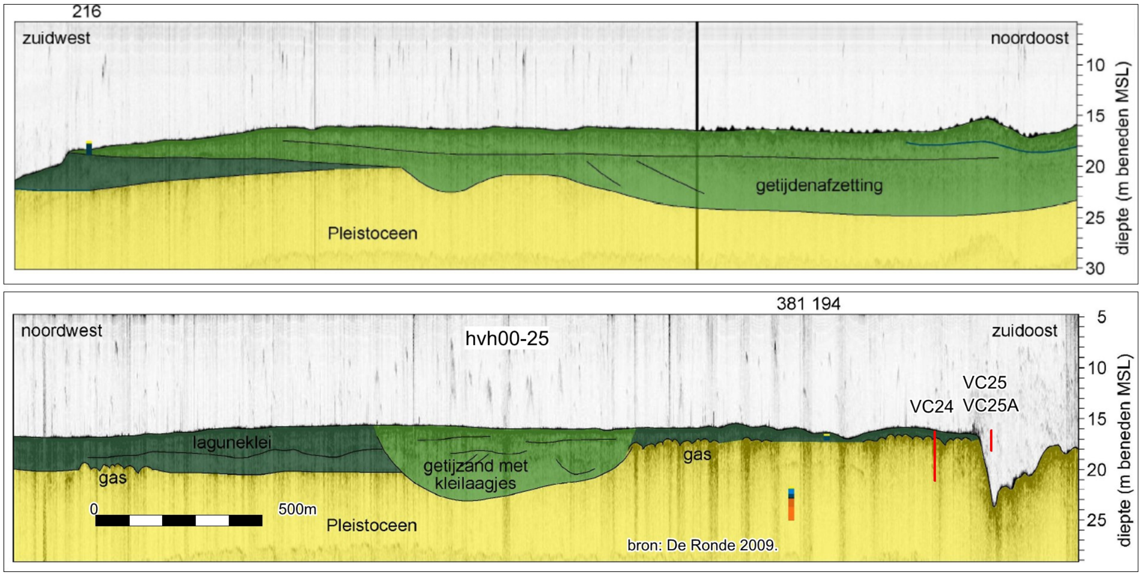
In afbeelding 11 is te zien dat de boringen 168 en 184, waarin de 'Elbow' Formatie voorkomt, niet tot in de top van de *pleistocene* afzettingen van de Formatie van Kreftenheye zijn gezet. De kleilaag zou daarom kunnen bestaan uit verschillende lithostratigrafische eenheden. De beschrijving van de olijfgrijze kleilaag in boring 168 *'doorworteld, wisselend gelaagd met silt en veendetritus.'* wijst op het voorkomen van zoetwatergetijden-(rivier)afzettingen van de Formatie van Echteld. Toch kan ook de aanwezigheid van gelaagde estuariumafzettingen van het Laagpakket van Wormer niet volledig worden uitgesloten. De overgang tussen beide eenheden wordt door Vos en Cohen ook beschreven als geleidelijk.

Omdat het onderste deel van de kleilaag niet is bemonsterd, kan niet worden uitgesloten dat onder de Formatie van Echteld kleiig veen van de *Basisveen Laag* en/of stugge overstromings(rivier)kleien van de *Laag van Wychen* voorkomt. Een aanwijzing dat dit daadwerkelijk het geval is zijn de vibrocore boringen, die in augustus 2010 door Fugro aan de noordkant van de Maasgeul zijn gezet (zie afbeelding 12).[39]

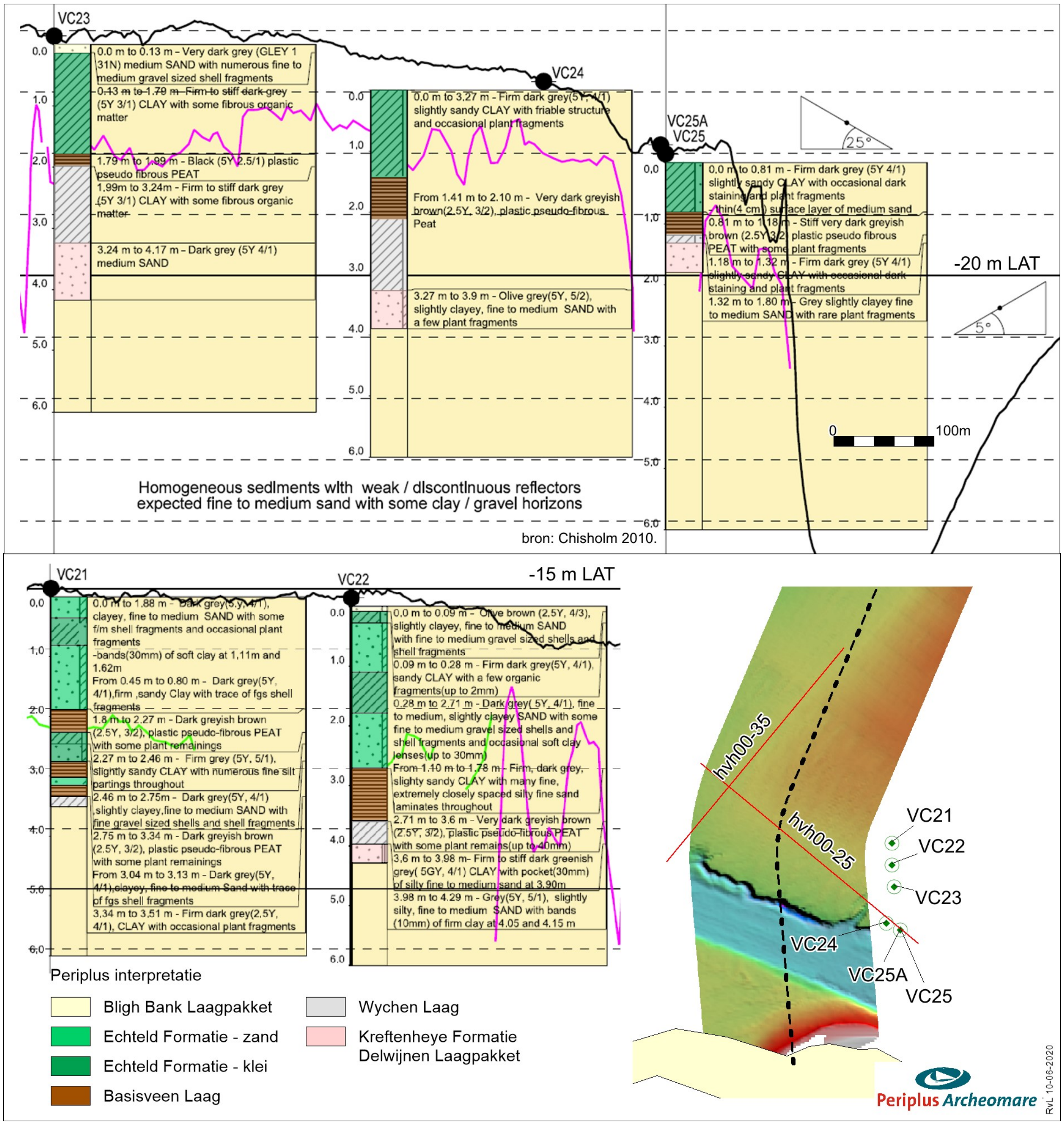
De boringen VC23 t/m VC 25A zijn gezet tot diepten variërend van 1.90 m (VC25|25A) tot 4.80 m (VC24) onder de zeebodem. De boringen tonen een consistent beeld van een kleiïge opeenvolging, waarbinnen van 'onder' naar 'boven' zand, klei, veen en klei voorkomt. Het zand dat onder in de boringen is aangetroffen bestaat uit fluviatiele afzettingen van de Formatie van Kreftenheye of eolische afzettingen van de het Laagpakket van Delwijnen | Formatie van Boxtel. De top van het zand ligt in VC23 en VC25 op -19.4 m LAT, wat op deze locatie overeen komt met 20.4 m NAP. De top van het duintje waarop de vroeg-mesolithische nederzetting is aangetroffen lag 2 meter hoger, rond -18.4 m NAP, ofwel -17.4 m LAT.

Aan de top van de Formatie van Kreftenheye komt een stevige donkergrijze kleilaag met plantenresten voor. Deze laag interpreteren wij als de Laag van Wychen. De Laag van Wychen is afgedekt door veen van het Basisveen Laagpakket.

[37] Guiran 2004; Hessing 2005; Kroes 2010.
[38] Vos
[39] Chisholm 2010.



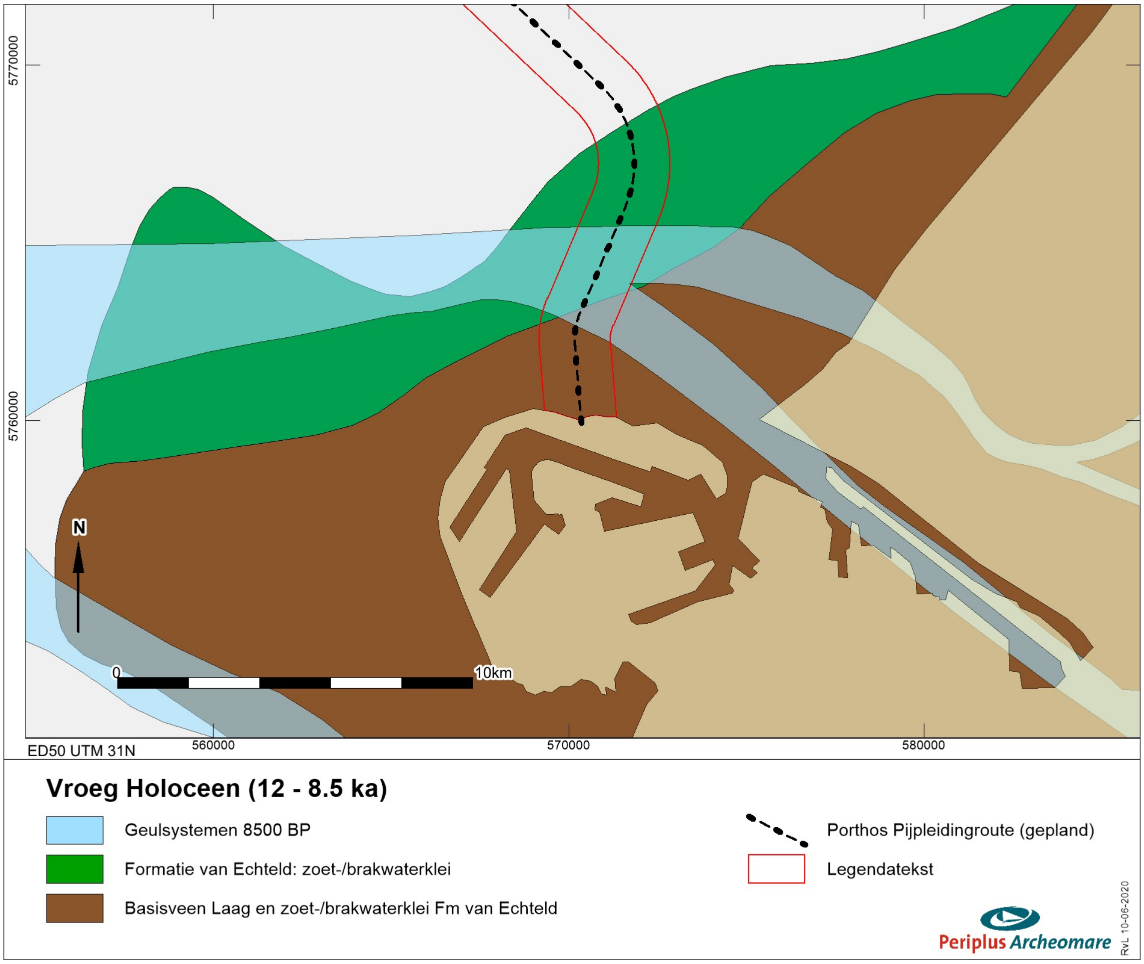
Afbeelding 12. Seismisch profiel en vibrocore boringen ten noorden van de Maasgeul; voor locatie profiellijnen zie afbeelding (bron: De Ronde 2009)



Afbeelding 13. Vibrocore profiel uit Fugro rapport - Alignment Charts (bron: Chisholm 2010)

Meer naar het noorden, in de boringen VC22 en VC 21 (niet weergegeven in afbeelding 12) verandert het beeld, in die zin, dat boven het veen is afgedekt door kleiïg zand met tussengeschakelde zandlagen. Deze boringen vallen de geulen van 8500 BP, die door Hijma zijn gekarteerd (zie afbeelding 14).[40]

[40] Hijma 2009.



Afbeelding 14. Vroeg-holocene voorkomens van veen en zoet-/brakwaterklei (bron: Hijma 2009)

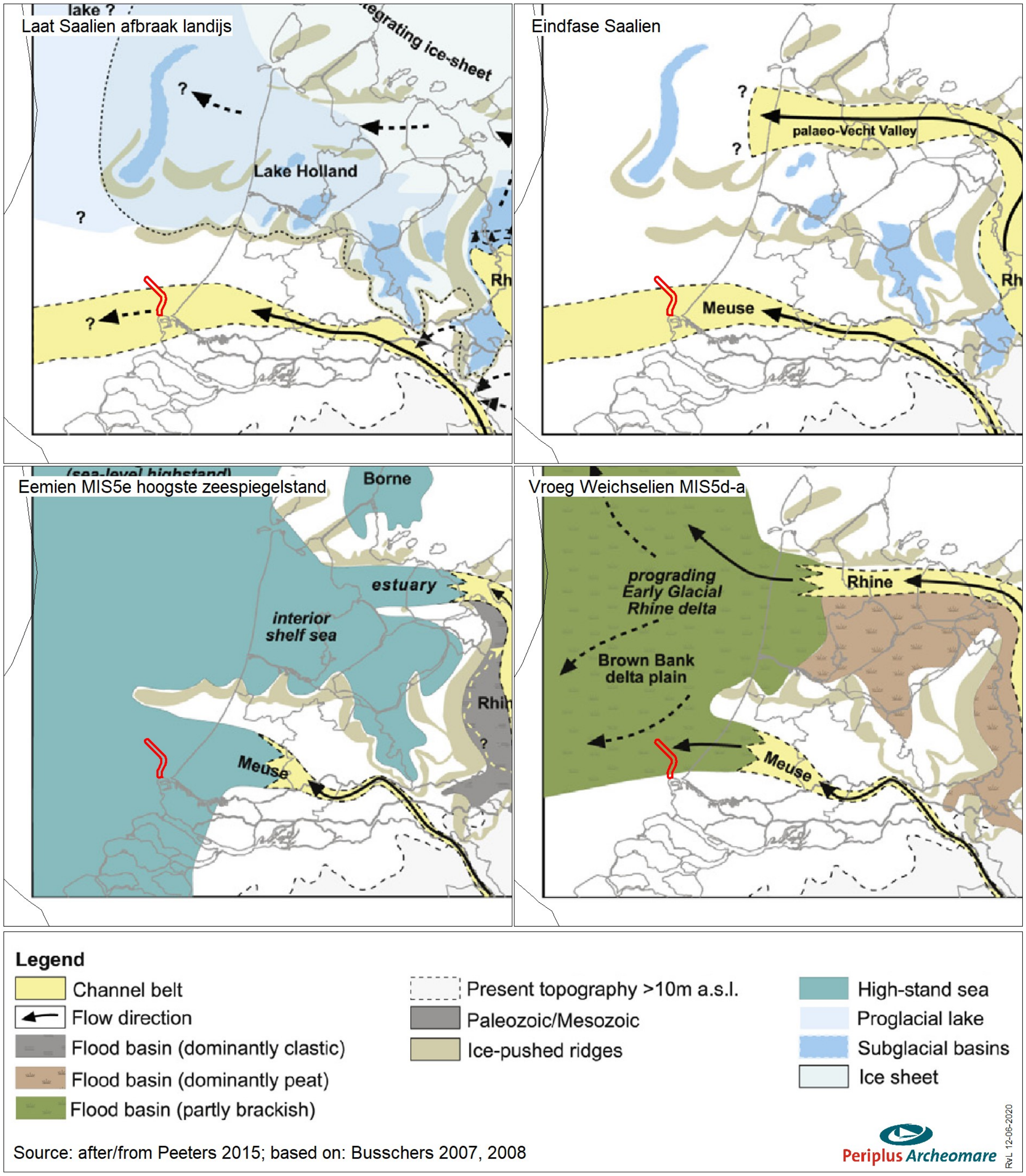
Formatie van Naaldwijk

Langs de Nederlandse kust zijn de *pleistocene*- en vroeg-*holocene* eenheden plaatselijk bedekt door gelamineerde/gelaagde sterk siltige klei van het *Laagpakket van Wormer | Formatie van Naaldwijk*. In de omgeving van de Yangtze-haven gaat het om gelaagde kalkhoudende estuariene brakwaterafzettingen. De laagovergang met de onderliggende zoetwatergetijdenkleien van de Formatie van Echteld is geleidelijk, en markeert de overgang van een zoetwater- naar een brakwatermilieu, rond 6250 v. Chr. Het *Laagpakket van Wormer* komt volgens grid data van TNO, uitgezonderd de Maasgeul, in de eerste 2.7 km van het pijpleidingtracé voor.

Bligh Bank Laagpakket

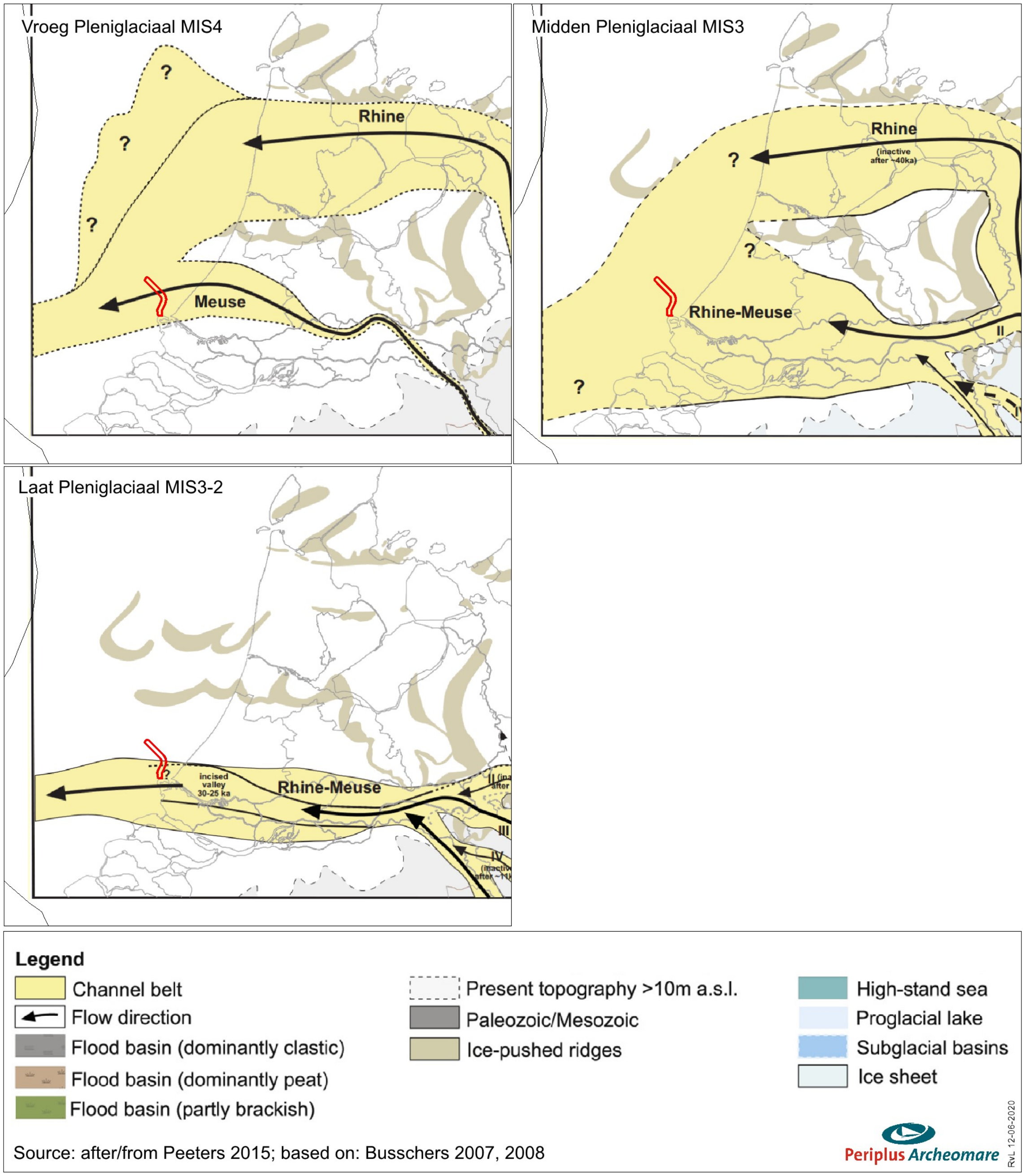
Het *Bligh Bank Laagpakket* bestaat uit mariene, matig fijn tot matig grof kalkrijk geelbruin zand met plaatselijk kleilenzen. Aan de basis kan het *Bligh Bank Laagpakket* grindig zijn.

Paleogeografische kaarten geven een goed beeld van de landschappelijke ontwikkeling tijdens de ijstijden en het warme Eem interglaciaal. Afbeelding 15 en afbeelding 16 laten duidelijk de sterke invloed van het Maas/Rijn-systeem tijdens het *Weichselien* en verklaard het voorkomen van deze rivierafzettingen aan de top van de pleistocene opeenvolging in een groot deel van het onderzoeksgebied. Voor zover de afzetting van deze rivierzanden en -grinden niet tot sterke erosie heeft geleid kunnen onder de Formatie van Kreftenheye afzettingen van de Eem Formatie en Brown Bank Laagpakket voorkomen.



Afbeelding 15. Landschappelijke ontwikkeling tijdens het Laat Saalien, Eemien en Vroeg Weichselien

Het laatste plaatje van afbeelding 16 toont de situatie in de laatste fase van het Weichselien (Laat Pleniglaciaal), voor het Holoceen. De vroeg-*holocene* afzettingen van de Laag van Wijchen, Laagpakket van Delwijnen, Basisveen Laag, Formatie van Echteld en het Laagpakket van Wormer zijn binnen het rivierdal van het Maas/rijn-systeem aangetroffen. Ten noorden van de knik in het pijpleidingtracé, dat is, waar de pijpleidingroute naar het noordwesten afbuigt (rond KP 8.000), worden de oudere rivierafzettingen direct afgedekt door mariene zanden en kleien van het Bligh Bank Laagpakket. Mogelijk komen plaatselijk ingesneden oudere geultjes van het Laagpakket van Wormer voor.



Afbeelding 16. Landschappelijke ontwikkeling tijdens de koudste fasen van het Weichselien.

In tabel 9 is de lithostratigrafische opeenvolging en de aard, ouderdom en genese van de opeenvolgende afzettingen in het onderzoeksgebied samengevat.

Formatie	**Laagpakket Laag**	**Lithologie**	**Ouderdom**	**Genese**	**Opmerking**
Southern Bight	Bligh Bank	zand	Holoceen	open marien	mobiele laag
Naaldwijk	Wormer	siltige klei en zand	vanaf 6000 v. Chr.	estuarien	brakwater getijdenafzettingen
Echteld	-	klei	7250 - 6000 v. Chr.	zoetwater-getijden	zoetwatergetijden (rivier)afzettingen
Nieuwkoop	Basisveen	veen	7250 - 6500 v. Chr	organoleptisch	kustveen
Kreftenheye	Wychen – 1	klei	8000 v. Chr.	fluviatiel	overstromingskleien
Boxtel	Delwijnen	fijn zand	9000 v. Chr	eolisch	rivierduinen
	Wierden	fijn zand	Weichselien tot Vroeg Holoceen	eolisch	dekzand; poolwoestijn
	Singraven	zand, leem, klei en veen		fluviatiel	beekafzettingen
Kreftenheye	Wychen – 2	leem en klei	9500 v. Chr	fluviatiel	overstromingskleien
	-	zand	Weichselien	fluviatiel	beddingafzettingen
Eem	Brown Bank	klei met zandlaagjes	Eem - Vroeg Weichselien	lagunair - lacustrien	lagunes en brak- tot zoetwatermeren
	-	zand en klei	Eemien	open marien	schelpenhoudend

Tabel 9. Lithostratigrafie binnen het onderzoeksgebied

3.5. Archeologische waarden (LS04wb)

Archeologie Continentaal Plat algemeen

Door de Rijksdienst voor het Cultureel Erfgoed is in samenwerking met Rijkswaterstaat dienst Zee en Delta en *TNO-NITG* op basis van geologische en archeologische waarnemingen een globale archeologische kaart voor het Continentaal Plat opgesteld (zie afbeelding 17).[41]

De Globale Archeologische Kaart van het Continentale Plat geeft de trefkans van goed geconserveerde scheepswrakken (en daarmee veelal een scheepsvondst van hoge archeologische waarde) voor het Nederlandse deel van het Continentale Plat weer. Deze kaart is echter zeer beperkt bruikbaar, mede door de kleinschaligheid van 1: 500.000. Daarnaast hangt de mate van conservering sterk samen met geologie en morfologie. De achterliggende redenering hierbij is dat in geulafzettingen of gebieden met een "slap" sediment, een wrak snel wegzakt in de bodem en daardoor in goede staat bewaard blijft. In andere gebieden is de trefkans op scheepsresten niet per definitie lager, maar wel de trefkans op een goed geconserveerd schip waarbij de lading en de uitrusting van het schip nog aanwezig is.

Op de kaart zijn ook gebieden aangegeven waar venen en kleien bewaard zijn gebleven. Deze afdekking met klei/veen zegt uitsluitend iets over de mogelijke ligging van *pleistocene* afzettingen aan/nabij de zeebodem. Daar waar *holocene* kleien/venen zijn geërodeerd, kunnen *pleistocene* niveaus met artefacten/faunaresten aanwezig zijn. Waar het om vroeg *holocene* afzettingen gaat, kunnen bewoningsresten uit de Prehistorie voorkomen gerelateerd aan afgedekte *pleistocene* en vroeg-*holocene* landschappen.

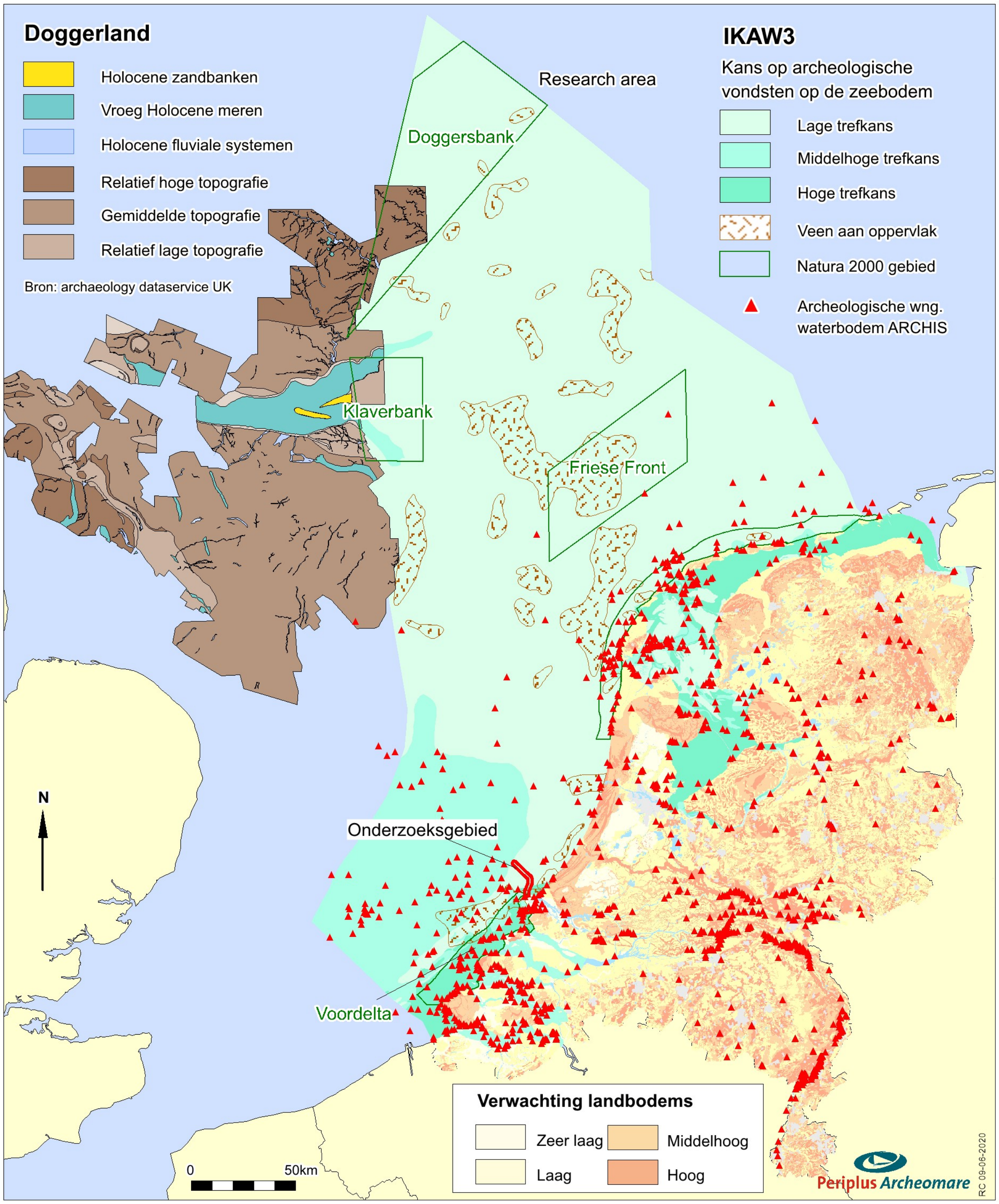
Uit onderzoek is gebleken dat de kans op het aantreffen van prehistorische bewoningsresten in de Noordzee veel groter is dan aanvankelijk werd gedacht.[42] De archeologische verwachtingskaart voor het Nederlands Continentaal Plat zal daarom moeten worden herzien. In 2016 heeft Deltares een eerste kaart opgezet van het prehistorische potentieel van de Noordzee, in opdracht van het RCE.[43]

Volgens dit model is in het zuiden van het beoogde tracé voornamelijk resten uit het Mesolithicum en Midden Paleolithicum te verwachten (afbeelding 18). In het noordelijk deel zijn ook paleolithische resten te verwachten.

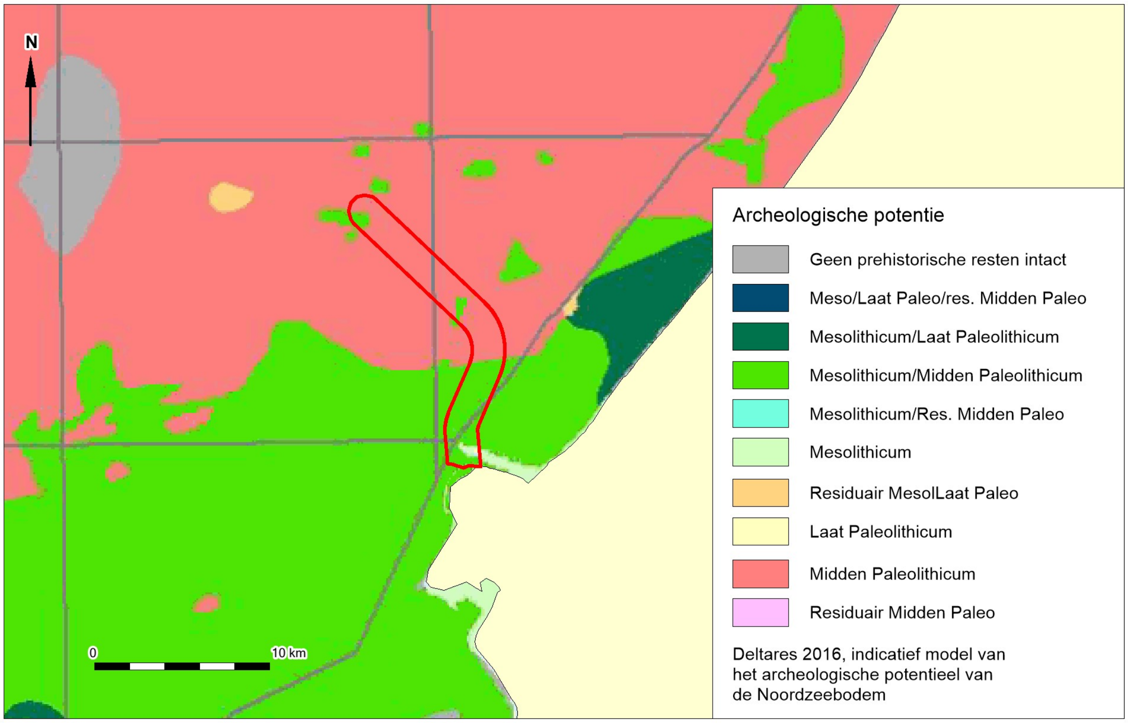
[41] IKAW 3^{e} generatie, RCE 2008.

[42] Zie het project 'North Sea paleolandcapes' van de Universiteit van Birmingham en North Sea Research and management Framework 2009 (Peeters 2009).

[43] Vonhögen-Peeters, 2016. In opdracht van de RCE.



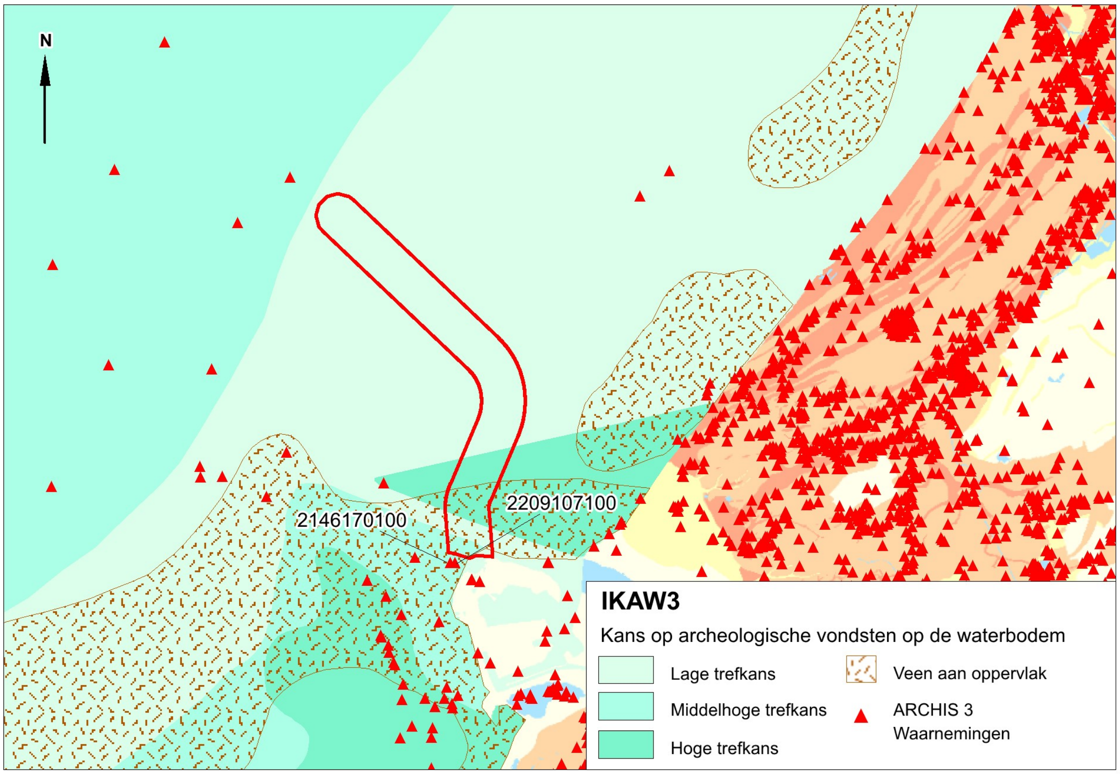
Afbeelding 17. Overzichtskaart archeologiewaarden van het Nederlands Continentaal Plat.



Afbeelding 18. Archeologische potentie voor prehistorische vondsten

Omgeving onderzoeksgebied
ARCHIS II is de officiële database van de Rijksdienst voor het Cultureel Erfgoed waarin alle archeologische vondsten en waarnemingen binnen Nederland en de territoriale wateren zijn opgeslagen. De database bevat meer dan 85.000 locaties (voornamelijk op land) waar archeologische waarnemingen gedaan zijn.

Onderstaande afbeelding geeft een overzicht van bekende waarnemingen uit ARCHIS geprojecteerd op de IKAW3.



Afbeelding 19. Overzicht van de ARCHIS-waarnemingen binnen het onderzoeksgebied.

Binnen het onderzoeksgebied zijn volgens ARCHIS geen archeologische waarnemingen bekend, direct ten zuiden van het onderzoeksgebied zijn twee waarnemingen bekend. Dit zijn zaakwaarnemingen 2146170100 en 2209107100. Beide waarnemingen betreffen onderzoeken die gedaan zijn in verband met de aanleg van de Tweede Maasvlakte. Tijdens de onderzoeken zijn scheepswrakken aangetroffen. Alle aangetroffen vondsten in het wrak, alsmede het wrak zelf, stammen uit de Nieuwe Tijd. Het gaat onder andere om enkele stukken hout, textiel en metaal.

Overige objecten en waarnemingen
Voor een overzicht van bekende waarnemingen binnen het onderzoeksgebied is gebruik gemaakt van de database van het Nationaal Contact Nummer (NCN). De NCN-database is eigendom van en wordt beheerd door Rijkswaterstaat Zee en Delta. Toestemming voor het gebruik van de gegevens is verleend door de contactpersoon bij Rijkswaterstaat Zee en Delta[44]. Binnen de NCN-database heeft ieder object op de

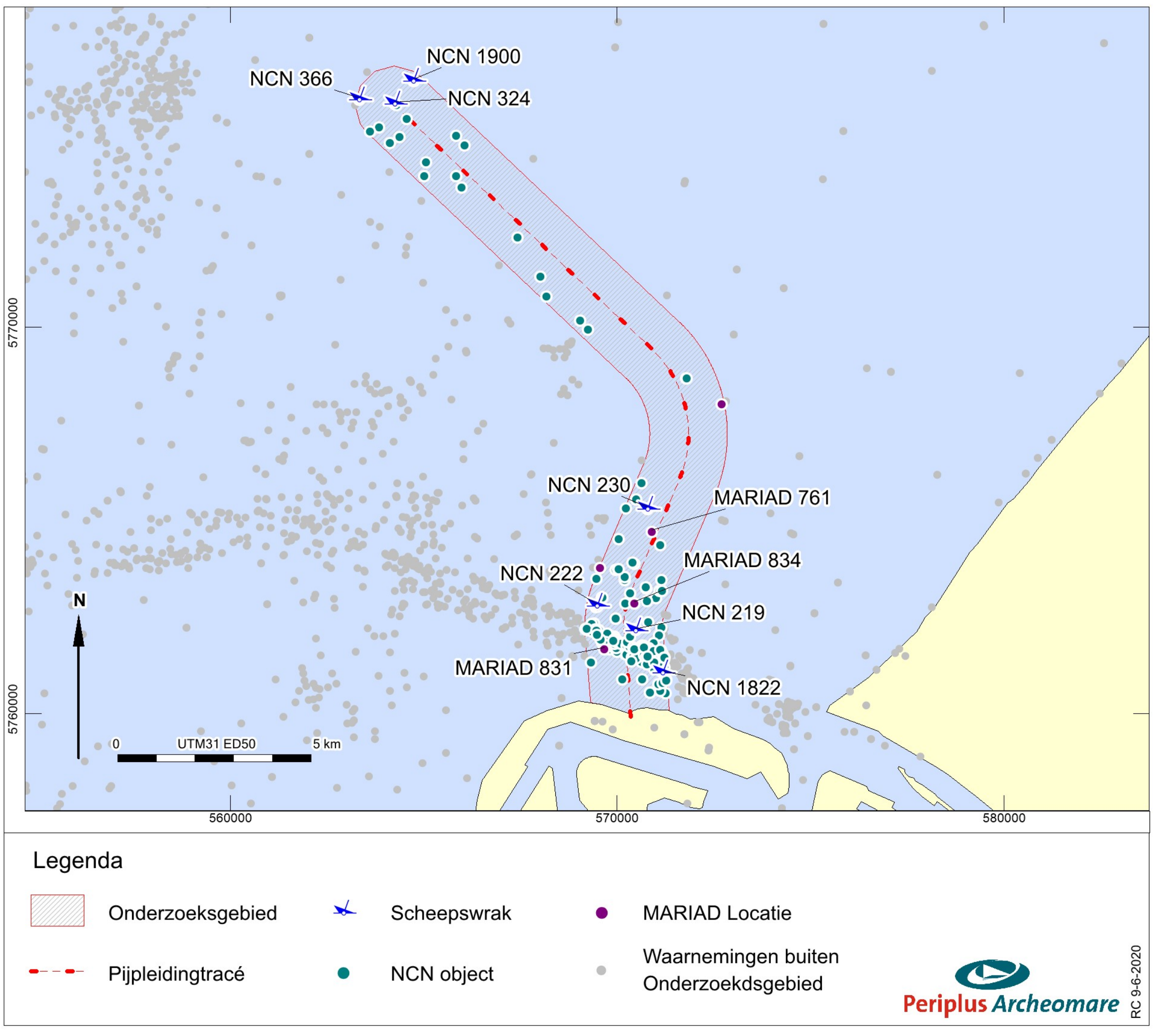
[44] P. de Boer, gegevensbeheerder RWS (ZD) per e-mail

Nederlandse waterbodem een uniek nummer (NCN). Dit is gebaseerd op één of meerdere onderliggende databases.

Het Nationaal Contact Nummer (NCN)
De NCN-database combineert de gegevens van drie verschillende overheidsbronnen:

- Het Wrakkenregister van de Dienst der Hydrografie;
- De SonarReg92 objecten database van Rijkswaterstaat;
- De ARCHISII-database van de Rijksdienst voor het Cultureel Erfgoed

In totaal zijn zeven NCN wrakken en 148 andere bekende waarnemingen bekend binnen het onderzoeksgebied. Een overzicht wordt gegeven in de afbeelding 20 en in tabel 10 en tabel 11 op de volgende bladzijde.



Afbeelding 20. Bekende wrakken (NCN) binnen het onderzoeksgebied.

NCN	Omschrijving	RWS	DHY	Easting	Norhting	R95
219	Dit was voorheen RWS_nr 1930	3148	1930	570385	5761989	5
222	Dit was voorheen RWS_nr 1948	75	1948	569387	5762626	5
230	Geen omschrijving in database	1920	1969	570700	5765129	5
234	Geen omschrijving in database	40	0	564161	5775605	100
366	Geen omschrijving in database	161	2951	563234	5775714	0.1
1822	Het wrak is geborgen	0	1928	571084	5760899	1000
1900	1899 wrak gerapporteerd. Wegens de aanwezigheid van platform P18-A is geen verder onderzoek uitgevoerd op dit wrak.	0	2047	564648	5776200	1000

Tabel 10. Bekende wrakken in het onderzoeksgebied.

Geen van de bekende wrakken is opgenomen in de ARCHIS-database van de Rijksdienst voor het Cultureel Erfgoed. Eén wrak (NCN 1822) is verwijderd en is tijdens een meting uitgevoerd door Rijkswaterstaat in 2018 niet waargenomen. Een ander wrak (NCN 1900) is gezonken voor 1950 en heeft nog geen archeologische waarde toegewezen gekregen. Van de overige vijf wrakken is geen datum van zinken bekend en is de archeologische waarde nog niet bepaald. Afgezien van de mogelijk archeologische waarde kunnen alle bekende wrakken obstakels vormen voor de voorgenomen werkzaamheden.

Overige objecten

Naast de wrakken zijn in de SonarReg database van Rijkswaterstaat nog 148 andere contacten bekend binnen het onderzoeksgebied. Een overzicht wordt gegeven in afbeelding 20 en de onderstaande tabel.

Object	Aantal
Bodemverstoring	10
Kabel/ketting	12
Man made object	1
Onbekend	124
Steen	1
Eindtotaal	**148**

Tabel 11. Overzicht van de overige objecten binnen het onderzoeksgebied

De objecten hebben geen archeologische verwachting, maar kunnen wel obstakels vormen voor de voorgenomen werkzaamheden.

MARIAD

In afbeelding 20 zijn ook de locaties binnen het onderzoeksgebied uit de Maritiem Archeologische Database (MARIAD) opgenomen. Dit is een verzameling van wrakgegevens uit diverse bronnen (archieven, sportduikers) die nog niet geverifieerd zijn en daarom (nog) niet zijn opgenomen in de formele SonarReg database van Rijkswaterstaat of de ARCHIS3 database van de Rijksdienst voor het Cultureel Erfgoed.

Binnen het onderzoeksgebied zijn acht MARIAD-waarnemingen bekend. Vijf van de acht wrakken zijn te correleren aan wrakken in de SonarReg database van Rijkswaterstaat en worden niet meegenomen in de onderstaande tabel. De drie wrakken die overblijven zijn niet bekend in de SonarReg database. Deze wrakken zijn vermeld in de onderstaande tabel.

NCN	Omschrijving	Easting	Norhting	R95
761	Niets bekend, alleen gekarteerd	570898	5764752	1500
831	Wrak van de 'Stubbenkammer', gezonken in 1967.	570448	5762891	30
834	Wrak van de 'Clearwater', gezonken in 1968, 5 september 1968 gelicht door bok van v.d. tak bergingsbedrijf en naar Maassluis vervoerd.	569664	5761706	30

Tabel 12. MARIAD-wrakken in het onderzoeksgebied dien niet bekend zijn in de SonarReg database.

Vliegtuigwrakken

In totaal stortten tijdens de oorlogsjaren meer dan 5000 vliegtuigen neer in Nederland.[45] Verschillende bronnen zijn niet eenduidig over het aantal vliegtuigen uit de Eerste en Tweede Wereldoorlog dat nog in het Noordzeegebied vermist wordt. Het gaat in ieder geval om honderden.[46]

Voor het IJsselmeergebied bezit Rijkswaterstaat een overzichtskaart waarop vondsten en vermissingen zijn weergegeven. Een vergelijkbare kaart van de Noordzee bestaat (nog) niet.[47] Geen van de bekende vliegtuigwrakken ligt binnen, of de directe nabijheid, van het onderzoeksgebied

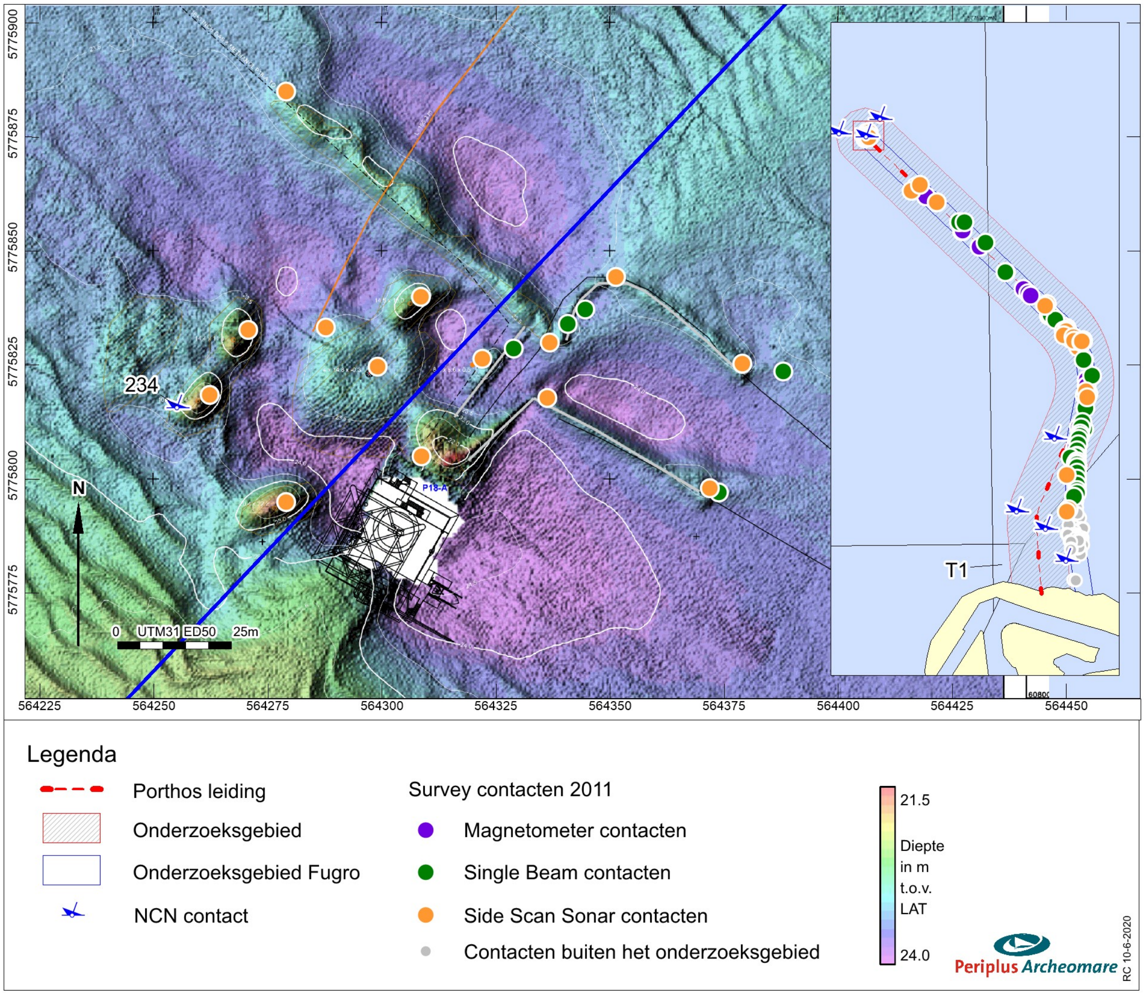
Contacten Survey ROAD-project 2011

In 2011 heeft Fugro Survey BV een survey uitgevoerd binnen het huidige onderzoeksgebied voor het ROAD-project.[48] Een overzicht van alle gevonden contacten met zijn opgenomen in onderstaande afbeelding. De contacten zijn opgenomen met een *Magnetometer*, S*ingle Beam Echo Sounder* (SBES) of met een Side Scan Sonar (SSS). Uit de afbeelding is op te maken dat, met uitzondering van NCN 234, geen van de NCN-wrakken gevonden zijn tijdens de 2011 survey.

NCN 234 staat in de SonarReg database van Rijkswaterstaat geïnterpreteerd als een wrak. Uit de opnames van Fugro blijkt dat het mogelijk gaat om een steendump of een betonnen matras.

Omdat een volledige nieuwe survey langs de nieuwe route van het Porthos pijpleiding heeft plaatsgevonden in 2019 en 2020, zal een nieuw Inventariserend Onderzoek (Opwaterfase) worden opgesteld. Hierin zullen de resultaten van de survey voor het ROAD-project worden meegenomen, waar relevant.

45 Bron: NOS Journaal, 01-05-2016.
46 Nederlandse Federatie voor Luchtvaart Archeologie, NFLA.
47 Persoonlijk commentaar Majoor A. Kappert, voormalig bergingsofficier Koninklijke Luchtmacht
48 Chisholm, J., 2010.



Afbeelding 21: Contacten survey 2011 in het onderzoeksgebied.

3.6. Gespecificeerde verwachting (LS05wb)

Bewoningsresten

In de ondergrond van het geplande tracé van de Porthos pijpleiding kunnen intacte prehistorische landschappen en aan deze landschappen gerelateerde archeologische resten uit het Paleolithicum en Mesolithicum voorkomen. De archeologische verwachting betreft resten kampplaatsen, begravingsresten en verloren of gedumpte jachtattributen uit de Vroege Prehistorie. Resten uit deze perioden worden verwacht binnen een opeenvolging van vroeg-*holocene* sedimenten, die in sterk uiteenlopende milieus zijn afgezet (rivierduinen, overstromingskleien, veen, zoetwatergetijdenafzettingen, brakwater-estuariene afzettingen. De rivierduinen vormden door hun relatief hoge ligging in het landschap preferente locaties voor de inrichting van kampplaatsen. Dat deze duinen ook daadwerkelijk voor bewoning, blijkt uit de mesolithische resten die op een rivierduintje in de Yangtze haven op 20 meter –NAP zijn aangetroffen. De correlatie tussen archeologische niveaus en lithostratigrafische eenheden is in onderstaande tabel samengevat.

Formatie	**Laagpakket Laag**	**Ouderdom**	**Opmerking**	**Archeologische Verwachting***	**Periode**
Southern Bight	Bligh Bank	Holoceen	mobiele laag	I, IV	ME – NT
Naaldwijk	Wormer	vanaf 6000 v. Chr.	brakwater getijdenafzettingen	I, II, IV	LMESO
Echteld	-	7250 - 6000 v. Chr.	zoetwatergetijden (rivier)afzettingen	I, II en IV, mogelijk III	MMESO
Nieuwkoop	Basisveen	7250 - 6500 v. Chr	kustveen	II en IV, mogelijk III	MMESO
Kreftenheye	Wychen – 1	8000 v. Chr.	overstromingskleien	II en III	VMESO
Boxtel	Delwijnen	9000 v. Chr	rivierduinen	III	MESO
	Wierden	Weichselien tot Vroeg Holoceen	dekzand	III	LPALEO - VMESO
	Singraven		beekafzettingen	II, III (rand beekdal) en IV	LPALEO – VMESO
Kreftenheye	Wychen – 2	9500 v. Chr	overstromingskleien	II en III	LPALEO – VMESO
	-	Weichselien	beddingafzettingen	II en IV	MPALEO – VMESO
Eem	Brown Bank	Eem - Vroeg Weichselien	lagunaire en lacustriene kleien	II en III (oevers)	MPALEO
	-	Eemien	mariene afzettingen	IV	MPALEO

Tabel 13. Archeologische verwachting gerelateerd aan de lithostratigrafie

*

Archeologische verwachting	
I	Scheepswrakken en scheepvaartgerelateerde objecten; vliegtuigwrakken
II	Verloren of gedumpte objecten, waaronder vuurstenen en benen jachtattributen, visweren, visfuiken en boomstamboten
III	Nederzettingen en begravingsresten
IV	Verspoelde artefacten

In tabel 13 is te zien dat resten van prehistorische nederzettingen (III) in rivierduinen van het Laagpakket van Delwijnen, dekzand van het Laagpakket van Wierden en beekafzettingen van het Laagpakket van Singraven worden verwacht. De locaties waar intacte rivierduinen, dekzandruggen en –kopjes, of randen van beekdalen binnen het pijpleidingtracé voorkomen is niet bekend.

In het Maasmond-gebied kunnen in de context van onderwaterkleien van de Echteld Formatie en het Laagpakket van Wormer verloren en gedumpte objecten en/of verspoelde artefacten voorkomen. Ten noorden van de Maasgeul liggen deze afzettingen plaatselijk ontsloten aan de zeebodem. Daarom kunnen de Formatie van Echteld en het Laagpakket van Wormer ook scheepswrakken bevatten.

De aanwezigheid van kampplaatsen (III) wordt gemarkeerd door vuurstenen en benen artefacten, botresten, houtskool en/ of verbrande zaden en noten (hazelnootdoppen). De grootte van de kampplaatsen kan variëren van klein (eenmalig kortstondig gebruikte jachtkampen) tot groot (herhaald intensief gebruik en seizoen bewoning).

Het is onbekend in hoeverre het *vroeg-holocene* landschap, en daarmee de gaafheid van de verwachte prehistorische nederzettingen, ter plaatse van de pijpleidingroute door erosie is aangetast. Gezien de zeer snelle ‘verdrinking’ van het *pleistocene* landschap in het Vroeg Holoceen en de afdekking van archeologische niveaus door veen en klei kunnen prehistorische resten (zeer) goed geconserveerd zijn. Deze verwachting geldt zowel voor organische als anorganische resten. Indien de archeologische niveaus niet door menselijk handelen (denk bijvoorbeeld aan zandwinning) of natuurlijke processen (erosie) zijn aangetast, kunnen daarom prehistorische resten met een zeer hoge fysieke kwaliteit worden verwacht. Dit in tegenstelling tot de vroeg-mesolithische vindplaatsen die in de hooggelegen zandgebieden van Nederland zijn aangetroffen. Bij deze vindplaatsen is de vondstlaag vaak opgenomen in de bouwvoor en bevinden de grondsporen zich direct onder de bouwvoor en boven de grondwaterspiegel. De fysieke kwaliteit van deze vindplaatsen is altijd in meer of mindere mate aangetast.

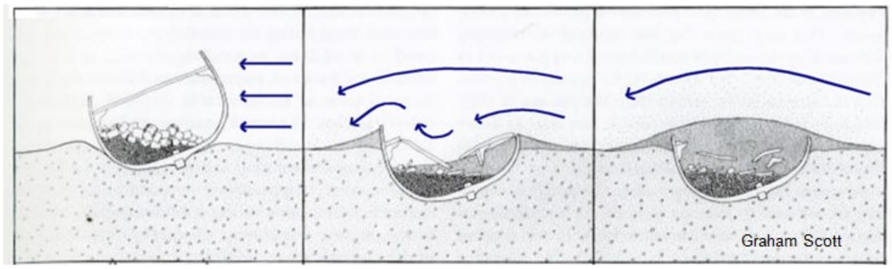
Een ander punt waarop de verwachte nederzettingen langs het pijpleidingtracé zich onderscheiden van de bekende vindplaatsen op het vasteland is hun lage ligging in het Noordzeegebied. Van de vroeg-holocene bewoners van het Noordzeegebied, van hun nederzettingen en van de wijze waarop zij zich handhaafden in het snel veranderende landschap is weinig bekend. De informatiewaarde van de verwachte nederzettingen in het gebied is daarom groot. Dit wordt ook gesteld in de Nationale Onderzoeksagenda voor de Vroege Prehistorie: *Vindplaatsen en eventuele omringende fenomenen die zich bevinden in paleolandschappelijke contexten die nog niet of nauwelijks zijn onderzocht, hebben per definitie een grote informatiewaarde.*[49]

Historische scheepswrakken

Binnen het onderzoeksgebied zijn negen scheepswrakken bekend. Van de meeste van deze wrakken zijn weinig details bekend; de herkomst en ouderdom zijn nog niet vastgesteld. Deze wrakken kunnen dus van archeologische waarde zijn. Binnen het onderzoeksgebied kunnen ook onontdekte wrakken voorkomen, die zijn afgedekt door migrerende zandgolven.

[49] Nationale Onderzoeksagenda, hoofdstuk 11: De Vroege Prehistorie.

Indien een schip zinkt en uiteindelijk op de zeebodem terecht komt, zal door de getijdenstroming het casco zich snel in een losse, zachte bodem inslijpen tot op het niveau van een harde bodem. Hoe dikker de laag met los materiaal, hoe meer van het schip hierin wordt verpakt en bewaard blijft.
Vooral in gebieden waar de losse laag bestaat uit materiaal met een hoger kleigehalte zal die afdichting een sterke conserverende werking hebben. In meer zandige gebieden zal dit effect door de grotere zandfractie veel minder groot zijn.



Afbeelding 22.Voorbeeld van een wrakvormingsproces (Graham Scott).

Op het moment dat wrakken door erosie of andere oorzaken aan het oppervlak van de zeebodem komen te liggen kunnen zij worden aangetast door voortgaande erosie en zeeorganismen zoals de paalworm. Het hout van scheepswrakken wordt door de paalworm opgevreten wat leidt tot een sterke aantasting van de gaafheid en conservering van het wrak.

Vliegtuigwrakken
In totaal stortten tijdens de oorlogsjaren meer dan 5000 vliegtuigen neer in Nederland.[50] Verschillende bronnen zijn niet eenduidig over het aantal vliegtuigen dat nog in het Noordzeegebied vermist wordt. Het gaat in ieder geval om honderden. In de omgeving van het onderzoeksgebied is meerdere meldingen van vliegtuigwrakken bekend. Het is denkbaar dat zich meerdere onontdekte resten bevinden in de omgeving.

[50] Bron: NOS Journaal, 01-05-2016.

4. Beantwoording onderzoeksvragen

Op basis van de resultaten van het bureauonderzoek worden de onderzoeksvragen beantwoord.

Zijn er archeologische waarden in het plangebied bekend? Zo ja: Wat is de aard, omvang, (diepte)ligging en datering van deze vindplaatsen?
Binnen het onderzoeksgebied zijn zeven scheepswrakken bekend in de NCN-database en drie scheepswrakken bekend in de MARIAD-database. Van de in totaal tien bekende wrakken binnen de het onderzoeksgebied zijn twee wrak geborgen (NCN 1822 en MARIAD 834) en is van één wrak bekend dat deze gezonken is voor 1950 (NCN 1900). Daarnaast blijkt een tiende wrak (NCN 234) geen wrak te zijn maar gaat het mogelijk om een rock dump. Voor de resterende zeven wrakken is de archeologische waarde nog niet bepaald.

Kunnen in het plangebied, naast eventuele bekende waarden, archeologische resten verwacht worden? Zo ja: Wat is de aard, omvang, (diepte)ligging en datering van de verwachte archeologische resten?
In het onderzoeksgebied kunnen onontdekte scheeps- en vliegtuigwrakken en overblijfselen van prehistorische nederzettingen verwacht worden. Binnen het gebied zijn zes scheepswrakken bekend waarvan het merendeel nog niet is onderzocht of geïdentificeerd, en waarvan de archeologische waarde dus nog niet is bepaald.

a) Scheeps- en vliegtuigwrakken
De verwachting betreft vooral scheepswrakken uit de Middeleeuwen tot en met de Nieuwe tijd, hoewel ook het voorkomen van vaartuigen uit de Prehistorie en Romeinse tijd zoals boomstamboten niet kan worden uitgesloten. Het gaat om geïsoleerde vindplaatsen met in de omgeving mogelijk objecten die aan het wrak gerelateerd zijn, zoals verloren lading of door erosie verspoelde delen van het wrak of de lading. Scheepswrakken kunnen overal in het gebied voorkomen; locaties zijn moeilijk te voorspellen. Resten worden vooral binnen het Bligh Bank Laagpakket, de Formatie van Naaldwijk en de Formatie van Echteld verwacht. De dikte van de laag holocene afzettingen varieert langs route van 0 tot 12 meter. De gaafheid en conservering van wrakken is sterk afhankelijk van het materiaal (hout of staal) en de context van de resten. Schepen die kort na het vergaan zijn afgedekt door sediment en ingebed in sediment bewaard zijn gebleven kunnen gaaf en goed geconserveerd zijn. Wrakken die aan het oppervlak liggen staan bloot aan erosie en aantasting door mariene organismen zoals de paalworm.

De verwachting voor vliegtuigwrakken betreft overblijfselen van gevechtsvliegtuigen uit WOII. Door de grote impact tijdens een crash kunnen resten over een groot gebied verspreid voorkomen.

b) Prehistorische nederzettingen
De verwachting betreft kampplaatsen en begravingen uit het Midden en Laat Paleolithicum, en het Mesolithicum. De grootte van de kampplaatsen kan variëren van klein (eenmalig kortstondig gebruikte jachtkampen) tot groot (herhaald intensief gebruik en seizoen bewoning). *In situ* resten worden verwacht in gebieden waar het *pleistocene* landschap intact is. Dit is mogelijk het geval waar het *pleistocene* landschap is afgedekt door klei en veen van de *Laag van Wychen* (KRWY-2), de *Basisveen Laag* en/of de *Formatie van Echteld*. De *lithostratigrafische* context van de kampplaatsen wordt gevormd de *Formatie van Boxtel*. Het gaat om rivierduinen van het *Laagpakket van Delwijnen,* dekzandafzettingen van het *Laagpakket van Wierden* en beekafzettingen van het *Laagpakket van Singraven*. Deze eenheden liggen *offshore* en *nearshore* op een diepte van meer dan 20 mLAT. Langs de Hollandse kust kunnen dekzandkopjes en -ruggen op geringere diepte voorkomen.

De oevers van lagunes en meren zijn op de overgang van het Eemien naar het Weichselien (circa 115.000 jaar geleden) gebruikt voor de inrichting van kampplaatsen van Neanderthalers. De kleiige afzettingen van het *Brown Bank Laagpakket* vormen de context voor in situ resten uit het Midden Paleolithicum. Indien het *pleistocene* landschap intact aanwezig is worden nederzettingen van hoge fysieke kwaliteit verwacht. De informatiewaarde van overblijfselen is groot.

In de pleistocene rivierafzettingen van de *Formatie van Kreftenheye* en de vroeg-*holocene* afzettingen van de *Basisveen Laag*, de *Formatie van Echteld* en het *Laagpakket van Wormer*, kunnen verloren of gedumpte objecten, waaronder vuurstenen en benen jachtattributen, visweren, visfuiken en boomstamboten verwacht worden. De mariene zanden en kleien van de *Eem Formatie* en het *Bligh Bank Laagpakket* kunnen verspoelde artefacten bevatten.

Vormt de aanleg van de pijpleiding een bedreiging voor bekende of verwachte archeologische waarden? Zo ja: Kan een aantasting van archeologische waarden door planaanpassing worden voorkomen of beperkt?
In hoeverre de aanleg van de pijpleiding daadwerkelijk een bedreiging vormt voor *in situ* resten is op dit moment lastig in te schatten, omdat het voorkomen, de aard, omvang, diepteligging en intactheid van de verwachte resten niet op detailniveau niet bekend zijn.

Indien de archeologische waarden niet kunnen worden behouden:
Welke vorm van nader onderzoek is nodig om de aanwezigheid van archeologische waarden en hun omvang, ligging, aard en datering voldoende te kunnen bepalen om te komen tot een selectiebesluit?
Om de aanwezigheid van archeologische waarden en hun omvang, ligging, aard en datering te kunnen bepalen wordt een vervolgonderzoek in de vorm van een geofysisch onderzoek (opwaterfase) geadviseerd.

Met geofysische technieken (*sidescan sonar, multibeam en magnetometer*) kan meer informatie verkregen worden over de aanwezigheid van bekende en onbekende archeologische resten in het plangebied. Zodoende wordt de verwachting voor scheeps- en vliegtuigwrakken getoetst en aangescherpt.

Door combinatie van seismisch onderzoek (*subbottom profiler*) en boringen (*vibro core*; boreholes) kan inzicht worden verkregen over de aard, ontwikkeling en intactheid van de gestapelde prehistorische landschappen in de ondergrond van de routes. Indien boringen worden gezet in het kader van geotechnisch onderzoek is het van belang om voordat de monsters worden gebruikt voor destructief onderzoek zoals korrelgrootte-analyses en sterkteproeven een beeld wordt verkregen van de locaties waar boormonsters zijn genomen, waarvan de analyse kan bijdragen aan beantwoording van de archeologische doelstelling: het de genese van de afgedekte prehistorische landschappen.

Aan de hand van de resultaten van deze onderzoeken kan de pijpleidingroute worden aangepast binnen de grenzen van surveygebied. Ook de resultaten van het onderzoek naar niet gesprongen explosieven kunnen aanleiding geven tot het verleggen van de pijpleidingroute. Wanneer binnen het onderzochte gebied voldoende ruimte kan worden gevonden voor het verleggen van de route, kunnen de archeologische waarden op die manier behouden blijven.

5. Conclusies en advies

Het bureauonderzoek wijst uit dat binnen het onderzoeksgebied scheeps- en vliegtuigwrakken en, indien het *pleistocene* landschap intact is, *in situ* prehistorische resten verwacht kunnen worden.

Binnen het onderzochte gebied zijn resten van negen scheepswrakken bekend. Het merendeel (zeven) is nog niet geïdentificeerd, dus de archeologische waarde van deze wrakken is nog niet vastgesteld. Naast de bekende wrakken kunnen in het onderzoeksgebied nog onontdekte resten van scheeps- en vliegtuigwrakken voorkomen.

Op basis van de uitkomst van dit onderzoek wordt geadviseerd om een inventariserend veldonderzoek (opwaterfase) uit te voeren om de archeologische verwachting te toetsen.[51] Voorafgaand aan het leggen van de pijpleiding wordt standaard een geofysische en geotechnische *pre-lay route survey* uitgevoerd. De data van deze *surveys* kunnen worden gebruikt voor de toets (zie onderstaande tabel).

Archeologische Verwachting	**Methode**	**Doel**	**Opmerking**
Scheeps- en vliegtuigwrakken	Side Scan Sonar	Opsporen, karteren en begrenzen van wrakken	Wrakken die op de bodem liggen of uit de bodem steken
	Multibeam	Morfologische karakterisering van wraklocaties; opsporen van (deels) begraven wrakken waarvan de aanwezigheid wordt gemarkeerd door een slijpgeul	In aanvulling op side scan sonar
	Subbottom Profiler	Opsporen begraven objecten waaronder mogelijke scheeps- en vliegtuigwrakken	Aard van het begraven object kan niet direct worden vastgesteld
	Magnetometer		
Prehistorische landschappen en nederzettingen (kampplaatsen)	Subbottom Profiler	Karteren pleistocene landschap; specificeren van verwachting	Ondersteund door, en gevalideerd met sondeer- en boorgegevens
	Geologische Boringen	Vaststellen lithostratigrafie, aard laaggrenzen (erosief of geleidelijk) en kenmerken van bodemvorming en rijping; specificeren van verwachting	Selectie van boringlocaties voor archeologische onderzoek voordat kernen worden gebruikt voor destructief geotechnisch onderzoek
	Sonderingen	Vaststellen lithostratigrafie	Korreleren met boorgegevens

Tabel 14. Toetsing van archeologische verwachting met geofysische methoden

Wanneer de onderzoeksmethoden, als in de tabel beschreven, worden toegepast tijdens de *route survey* en de ingewonnen data van voldoende kwaliteit is, dan kan de benodigde archeologische beoordeling van de pijpleidingroute worden uitgevoerd.

[51] Conform KNA-waterbodems protocol 4103.

Het verdient aanbeveling de *technische Scope of Work* af te stemmen met het archeologisch team alvorens met de survey werkzaamheden te beginnen. De eisen die voor het archeologische onderzoek aan de geofysische opnamen worden gesteld dienen te worden vastgelegd in een Programma van Eisen (PvE), en dat voorafgaand aan het onderzoek dient te zijn ondertekend door bevoegd gezag.[52]

Het is voor de analyse van boorkernen voor archeologische doeleinden van belang dat deze kernen intact zijn. Monsters die zijn gebruikt voor sterkteproeven en korrelgroottebepalingen zijn in de regel niet meer geschikt voor archeologisch onderzoek, omdat ze niet meer intact zijn. Afstemming van het gebruik van de monsters is daarom van belang. Een mogelijkheid zou kunnen zijn, dat de kernen voorafgaand aan het gebruik voor de bepaling van fysische parameters (sterkte/korrelgrootte) door een gecertificeerd KNA (Kwaliteitsnorm Nederlandse Archeologie) prospector waterbodems worden onderzocht. De prospector kan ook een selectie maken van monsters voor specialistisch onderzoek, bijvoorbeeld C14-analyses of onderzoek van pollen, dierlijke en plantaardige macroresten, mollusken, diatomeeën, et cetera. De eisen en randvoorwaarden die aan het archeologische booronderzoek worden gesteld dienen te worden vastgelegd in een PvE en/of Plan van Aanpak (PvA). Het wordt aanbevolen de eisen die worden gesteld aan het geofysisch onderzoek (*sidescan sonar, multibeam, subbottom profiler*) en het geotechnisch onderzoek (boringen en sonderingen) onder te brengen in één allesomvattend PvE.

[52] Conform KNA-waterbodems protocol 4001.

Lijst met afbeeldingen

Lijst met tabellen

Verklarende woordenlijst en toelichting afkortingen

Term	**Omschrijving**
Antropogeen	Door menselijk handelen
Allerød interstadiaal	Het Allerød-interstadiaal is warme en nattere periode tijdens het laatste glaciaal (IJstijd) dat duurde van 13.900 tot 12.850 jaar geleden.
ARCHIS	ARCHeologisch Informatie Systeem. Het door de Rijksdienst voor het Cultureel Erfgoed beheerde archeologische informatiesysteem
Crevasse afzetting	Een crevasse afzetting bestaat uit een doorbraak van een rivier die niet heeft doorgezet. Door de doorbraak is een afzetting ontstaan met sediment uit de oeverwal. Crevasse-afzettingen zijn bewaard gebleven doordat ze hoger liggen in het landschap.
Discordant	Hiaat tussen twee sedimentaire lagen, komt vaak tot uiting in een hoekverschil
Geogenese	Ontstaansgeschiedenis
Geofysisch onderzoek	Non-destructief onderzoek van natuurlijke en antropogene fenomenen, op, aan of onder de waterbodem door de inzet van een surveyschip dat is toegerust met specialistische meetapparatuur (side scan sonar, single/multibeam echo sounder, magnetometer, subbottom profiler, etc.)
Geotechnisch onderzoek	Bodem penetrerend onderzoek door middel van grondboringen of sonderingen om de samenstelling en fysieke eigenschappen van de ondergrond vast te stellen.
Holoceen	Jongste geologisch tijdperk (vanaf de laatste IJstijd, circa 9000 v.Chr. tot heden)
In situ	Ter plaatse, in de oorspronkelijke toestand
Klastische *rivierafzettingen*	Klastisch wil zeggen dat een gesteente of sediment is opgebouwd of bestaat uit fragmenten van afgebroken gesteente (zogenaamde klasten).
KNA	Kwaliteitsnorm Nederlandse Archeologie
LAT	Lowest Astronomical Tide
Lithostratigrafie	Studie van de gesteentelagen binnen de stratigrafie en geologie.
Magnetometer	Techniek om afwijkingen veroorzaakt door de aanwezigheid van ferro-magnetisch materiaal (ijzer) in het natuurlijke magnetische veld te detecteren
Mesolithicum	De periode (8800-4900 voor Chr.) die begint na het aflopen van de laatste ijstijd en eindigt wanneer een samenleving overschakelt op landbouw en veeteelt en tal van nieuwe technologieën ontwikkelt of overneemt (Neolithicum)
Multibeam echosounder	Vlakdekkend akoestisch meetinstrument dat met verschillende bundels of beams de waterdiepte onder een meetvaartuig meet, waarna een gedetailleerd topografisch model van de waterbodem kan worden gemaakt
Nearshore	Het kustnabije deel van de zee vanaf de 0m dieptecontourlijn tot 3km uit de kust, of het punt waarop de waterdiepte sterk toeneemt
Offshore	Diepere deel van de zee, dat verder van de kust verwijderd ligt dan het *nearshore* gedeelte
Paleolithicum	De oudste periode in de voorgeschiedenis van de mens en zijn materiële cultuur (300.000-8800 v. Chr.)
Pleistoceen	Geologisch tijdperk dat ongeveer 2 miljoen jaar geleden begon. De tijd van de IJstijden maar ook van gematigd warme perioden. Het Pleistoceen eindigt met het begin van het *Holoceen, ca 11700 jaar geleden*
Seismiek	Een methode om een beeld te krijgen van de ondergrond met behulp van kunstmatig opgewekte akoestische golven.

Term	**Omschrijving**
Side scan sonar	Akoestisch meetinstrument dat vlakdekkend de sterkte van reflecterende geluidssignalen van de waterbodem onder een meetvaartuig registreert. Vergelijkbaar met het maken van een zwart/wit foto van de waterbodem; wordt gebruikt om objecten op te sporen en bodemmorfologie en type te classificeren
Stratigrafie	De volgorde van opeenvolgende gesteentelagen. Hiermee kunnen aardlagen worden beschreven en gedateerd.
Stroomribbels	Asymmetrisch golfpatroon van het bodemoppervlak veroorzaakt door langsstromend water. De steile zijden van de ribbels liggen altijd aan de stroomafwaartse kant.
Survey	Onderzoek, standaardterm uit de offshore-industrie
TNO-NITG	De Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek
Toendraklimaat	het klimaat zoals dat heerst op de toendra en andere klimatologisch gelijksoortige gebieden.

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Atlassen en Kaarten

- Geologische kaarten *TNO-NITG*; GeoTOP-model Laag van Wijchen en Hollandveen Laagpakket
- Globale Archeologische Kaart van het Continentale Plat
- Indicatieve Kaart van Archeologische Waarden (IKAW, versie 3)
- Noordzeeatlas

Internetbronnen

- Dienst der Hydrografie (www.hydro.nl)
- DINOloket (www.dinoloket.tno.nl)
- Noordzeeloket (www.noordzeeloket.nl)
- Olie en Gasportaal (www.nlog.nl)
- North Sea Paleolandscapes, University of Birmingham (http://www.iaa.bham.ac.uk)
- Stichting Aircraft recovery Group 40-45 (http://www.arg1940-1945.nl)

Overige bronnen

- ARCHIS III, archeologische database Rijksdienst voor het Cultureel Erfgoed
- Correspondentie en gesprekken met Majoor P. Petersen en Majoor A. Kappert, bergingsofficieren Koninklijke Luchtmacht
- Databases Periplus Archeomare
- KNA Waterbodems 4.1
- Nationale Onderzoeksagenda Archeologie 2.0
- SonarReg contacten database Rijkswaterstaat Zee en Delta

Bijlage 1. Archeologische en geologische tijdschaal

Chronostratigrafie

Serie	Etage - Chronozone				Tijd
Holoceen	**Laat Subatlanticum**				**1150 n. Chr**
	Vroeg Subatlanticum				0
					450 v. Chr
	Subboreaal				3700
	Atlanticum				7300
	Boreaal				8700
	Preboreaal				9700
Pleistoceen	Weichselien	Laat Glaciaal		Jonge Dryas	11.000
				Allerød	12.000
				Oude Dryas	12.100
				Bølling	13.000
		Pleniglaciaal	L		17.000
				Late Glacial Max	20.000
					31.500
				Denekamp	34.000
			M		40.000
				Hengelo	41.500
					45.000
			V	Moershoofd	50.000
					71.000
		Vroeg Glaciaal		Odderade	74.000
				Brørup	
				Amersfoort	
					114.000
	Eemien				126.000
	Saalien				236.000
	Oostermeer				241.000
	onbenoemd				322.000
	Belvédère				336.000
	onbenoemd				384.000
	Holsteinien				416.000
	Elsterien				463.000

Archeologische periode

Tijdperk					Datering
Nieuwe tijd			C		1850
			B		1650
			A		1500
Middeleeuwen			Laat	B	1250
				A	1050
			Vroeg	D	900
				C	725
				B	525
				A	450
Romeinse tijd			Laat		270
			Midden		70 n. Chr.
			Vroeg		15 v. Chr.
Prehistorie	Metaaltijden	IJzertijd	Laat		250
			Midden		500
			Vroeg		800
		Bronstijd	Laat		1100
			Midden		1800
			Vroeg		2000
	Steentijd	Neolithicum	Laat		2850
			Midden		4200
			Vroeg		4900/5300
		Mesolithicum	Laat		6450
			Midden		8640
			Vroeg		9700
		Paleolithicum	Laat	B	12.500
			Jong	B	16.000
				A	35.000
			Midden		250.000
			Oud		

Bijlage 2. Protocol KNA 4.1 Waterbodems