FINAL REPORT

Technical Working Paper 04

Navigation and Channel Design

Client: T+T

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Royal HaskoningDHV
Enhancing Society Together

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1 Introduction

Te Manatū Waka / the New Zealand Ministry of Transport has appointed Tonkin & Taylor Ltd and their subconsultants (Royal HaskoningDHV, MetOcean Solutions, Pacific Marine Management, the University of Auckland, Discovery Marine Limited, and RMA Science) to undertake a feasibility study to understand whether it would be technically possible to locate a port in the Manukau Harbour from a navigation and operational reliability perspective.

The Manukau Harbour has previously been identified as a potential port location, however there are unanswered questions around the technical feasibility of this given the complex and dynamic nature of the harbour entrance along with other factors associated with greenfield port development. This is an engineering study, and environmental, social, and economic factors are not part of the current scope of work.

1.1 Purpose of the Document

This Final Navigation Technical Working Paper has been prepared by Royal HaskoningDHV and accompanies the study Final Report. It provides the results of the studies that were carried out for the concept design of the Navigation Channel.

This Navigation Technical Working Paper covers the concept design of the Navigation Channel in three distinct steps:

- Concept design of the Navigation Channel based on existing Metocean data, following PIANC guidelines (the 'initial concept design').
- Update of the initial concept design based on new survey data and hydraulic modelling results, using dynamic under keel clearance calculations (the 'updated concept design').
- Verification of the updated concept design using fast-time simulations, resulting in the 'final concept design'.

More details on the above methodology are provided in Section 1.2.

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1.2 Navigation Channel - Design Approach

This document covers the channel design aspects and navigation considerations for the approach into Manukau Harbour. The design follows a stepped and iterative process as shown in the below Figure 1-1. Basically, the process starts with an initial concept design based on available data and generic assumptions ("Step 1"). This initial concept design is then further refined in steps, as and when new data becomes available. The first iteration of the concept design is when the new Metocean survey results are made available, which then feeds into a dynamic under keel clearance calculation, leading to an updated channel concept design ("Step 2"). Finally, this channel design is verified (confirmed) by fast-time navigation simulations, which is captured in the final channel concept design ("Step 3"). [1]

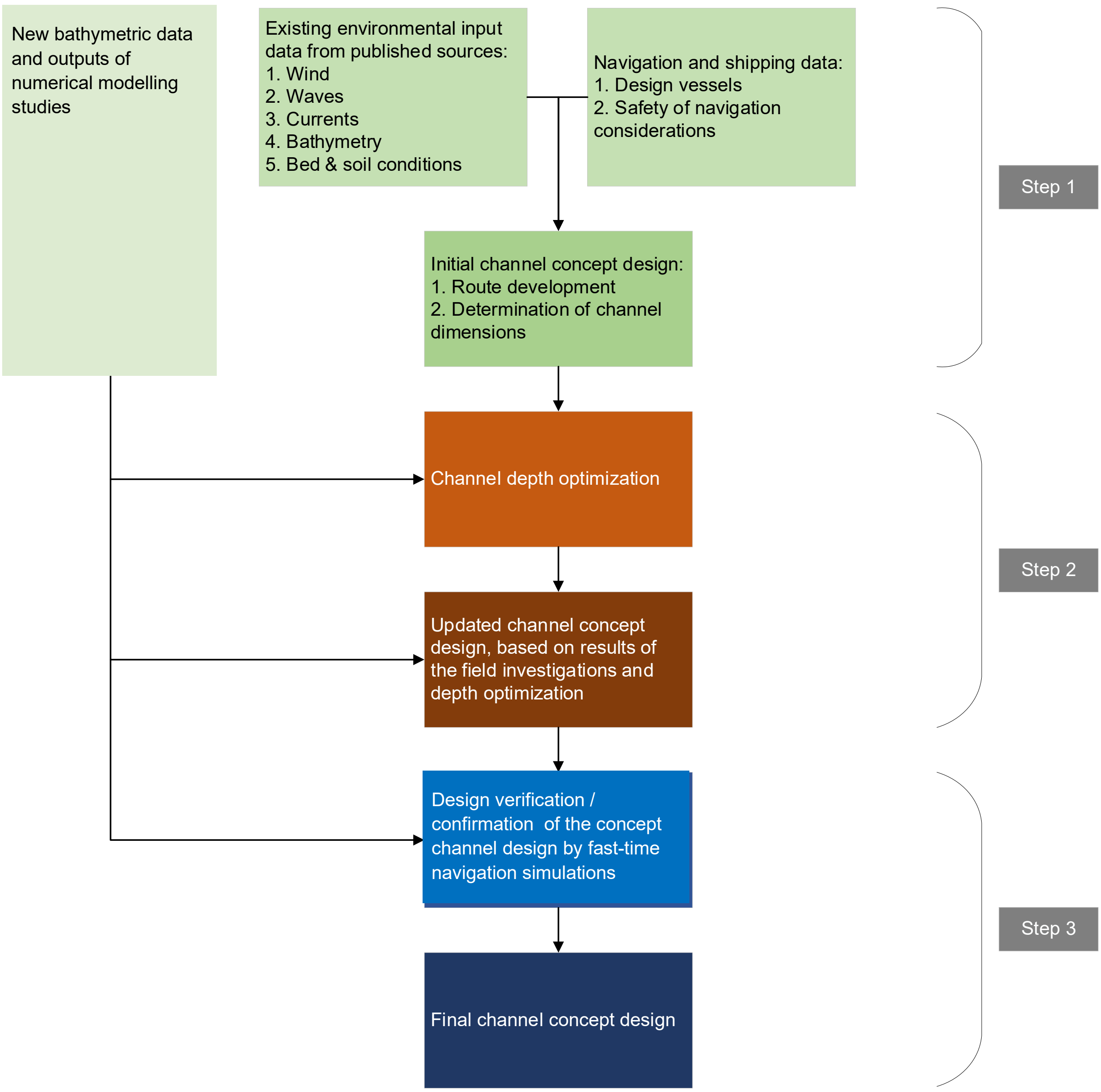

Figure 1-1: Navigation & Channel Design - Process Diagram

[1] *It is to be noted that the dredge levels referred to in this report exclude any potential 'overdredge' which is dependent on the chosen dredge method and plant used and is addressed in TWP06 - Dredging.*

2 Initial Channel Concept Design

Please refer to Appendix A for the specific details of the approach and the calculations. The main input parameters and calculation results are summarized below.

2.1 Design Vessels

Excerpt of data[2] on design vessels' parameters, relevant for determination of channel dimensions, is presented in Table 2-1.

Table 2-1: Design Vessels

Parameter	15k TEU Container Ship	10k TEU Container Ship	7k TEU Container Ship	LR2 Tanker
DWT, t	200 000	125 000	81 000	110 000
L_{OA}, m	365	351	272	260
B, m	53.6	45.8	42.8	45.0
T_{max}, m	16.0	15.0	15.0	15.5
T_{op}, m	12.4	14.2	14.3	15.5

Notes:

- Tanker LR2 will use high water to enter the port (approach known as "tidal window"), therefore, its draught is not used to determine the required channel depth.
- Draughts of 7k TEU and 10k TEU ships are the largest and are used to determine the minimum required channel depth. Container vessels usually call at ports on a schedule, which is independent from the tide. Therefore, a tidal window approach is not usually applied to container traffic. When, at an early operational stage, the container traffic is still limited, the tidal window could also be applied on container vessels to balance dredging volumes and availability of the channel. For the purpose of this report it has been assumed that container vessels should have access to the port at all times.
- The 15k TEU container vessel is the widest design vessel and used to determine the channel width.
- In accordance with recommendations by earlier reports [1] the largest container vessel (15,000 TEU) is not expected to call at the new port fully loaded, hence the lower operational vessels draft than the smaller container vessels (10,000 TEU and 7,000 TEU).

[2] *Manukau Harbour Port Feasibility Study – TWP01 Ship Traffic & Design Vessel. Pacific Marine Management Ltd, 2023*

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2.2 Design Results

The navigation channel is divided in three sections because the environmental conditions vary along the alignment. All sections are considered to be open water, and although the inner harbour area is less exposed, it still cannot be considered protected water in the sense of a sheltered port area.

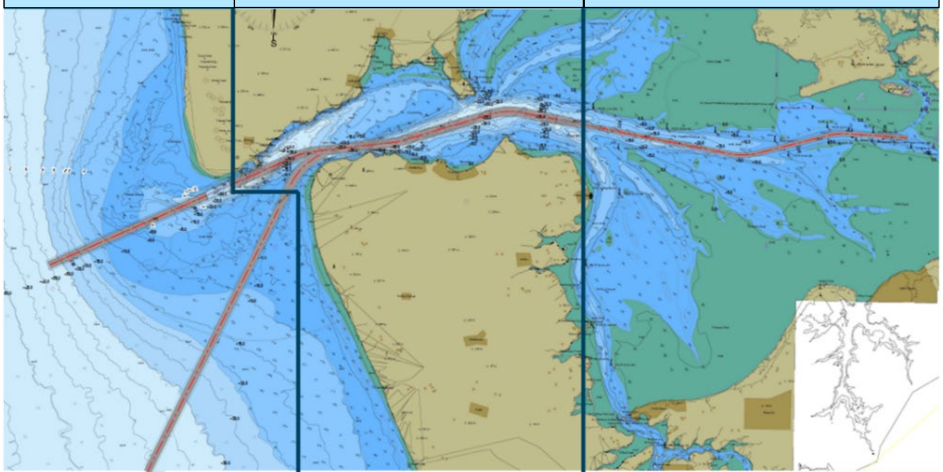
- Section A: the open and exposed area, including the bar area.
- Section B: the passage between the northern and southern headlands with mainly deep-water where wind and currents show a tunnelling effect, longitudinal to the channel alignment.
- Section C: the inner harbour area with mainly shallow water where the governing wind and wind driven waves are perpendicular to the navigation channel.

Both a southern oriented entrance (the ‘South Channel’) and a south-western oriented entrance (the ‘South-West Channel’) into the Harbour were considered at this initial concept stage (see Figure 2-1). This was reduced to one option only for the updated channel design.

Sections A and C will have a one-lane width to minimise dredging volumes. Section B will have a two-lane width. There is no need to restrict this Section to one-lane only as it is located in a naturally deep and wide area that can accommodate two-way traffic and could serve as a passing and/or waiting area. Such channel configuration (one-way – two-way – one-way) is proposed as it is deemed sufficient for the envisioned traffic.

The below figure presents the main dimensions of the entrance channel, based on PIANC guidelines. It is to be noted that this initial concept channel design has been based on pre-existing environmental data, while new site data was collected in parallel. The new data was included in the channel depth optimization study further elaborated on in the next section.

Section A	Section B	Section C



Channel Widths (m) (determined by 15k TEU Container Vessel)		
one-lane 295	two-lane 410	one-lane 220
Channel Depths (m CD) (determined by T_{op}= 14.3m of the 7k & 10k TEU Container Vessel)		
20.5	19.1	17.7

Figure 2-1: Initial Channel Design for Section A, B and C

A complete two-way channel has been considered but discarded due to the relatively low traffic volume during the design life. We are aware that the channel width is less than the LOA of the largest design vessel, which causes a concern in case such a vessel would lose control and gets stuck ("Suez Canal Ever Given" situation), but the mitigation for this situation in our view would be either to restrict access of these vessels during high wind or wave conditions, or to widen the one-way channel slightly to avoid this situation. In the end this will be a commercial decision and not a strictly technical consideration. Some delays to shipping during maintenance dredging will need to be accepted in the one-way channel and can be managed with a proper contractual arrangement with the dredging contractor. A reasonable shipping delay to maintenance dredging has been taken into account based on experience in other ports.

Should commercial shipping traffic increase to such an extent that maintenance dredging delays are significant, dredging capacity could be increased (larger dredger or supplementary dredger).

The concept design of the channel is robust enough to account for potential infragravity waves as well as currents due to channel confluence. These effects should be minor compared to the already incorporated environmental conditions and/or restricted to specific locations. Any of these issues could be taken into account in further design stages.

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3 Channel Design Depth Optimisation

Please refer to Appendix B for the specific details of the approach and the calculations. The main input parameters and calculation results are summarized below.

3.1 Starting Points

Compared to the initial concept design stage the following was updated:

- The South-West Channel alignment was chosen as the preferred channel to be taken forward. This was based on the difference in capital dredging volume between the two options and based on discussions with stakeholders and captains with experience in Manukau Harbour, who prefer the south-western entrance over the southern entrance.
- New site survey data was collected by Tonkin + Taylor and used to run wind, wave and current models by MetOcean Solutions as input into the channel depth optimization design by RHDHV.

3.2 Overview Methodology

When assessing the required channel depth to ensure safety for vessels while in transit, the risk of bottom touch is an important factor. Waves and currents affect the motions of a vessel when sailing through the channel resulting in vertical motions of the vessel. To avoid the vessel hitting the bottom of the channel due to these motions, additional margin is required. The margin in water depth, exceeding the vessel draught, is called the “gross under keel clearance” or gross UKC. Within the UKC, margins for different influences are included, as displayed in Figure 3-1.

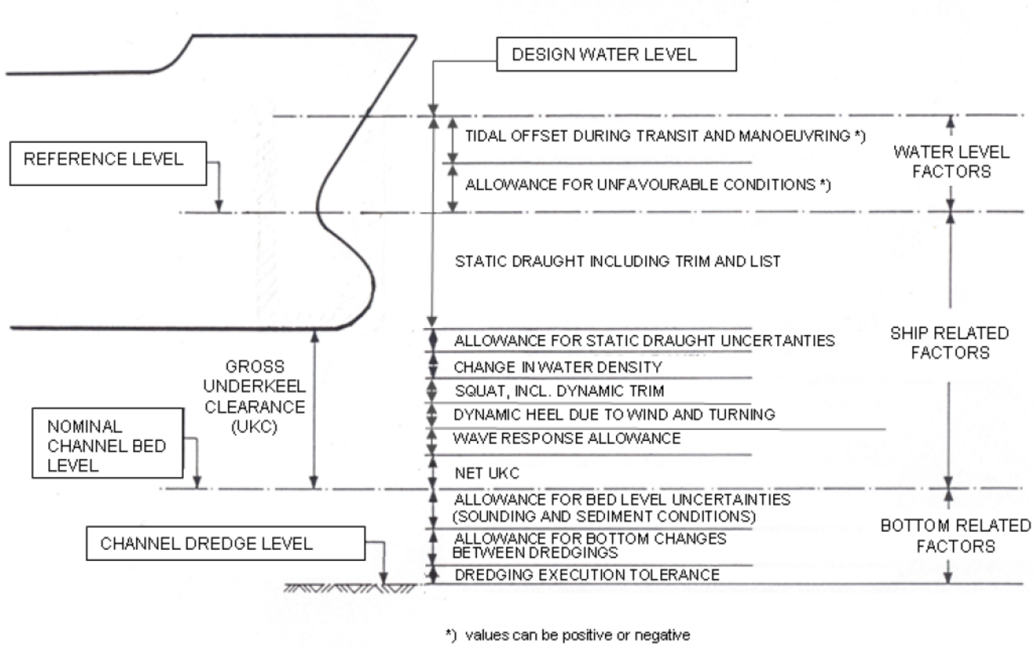

Figure 3-1: Under keel clearance schematisation

To ensure vessels can navigate the channel safely, the different ship related factors must be approximated and translated into depth margins. Following general design guidelines carefully results in a safe channel depth. However, this depth is usually slightly conservative and might be reduced if more detailed modelling

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approaches are applied to the relevant design vessels. As reduced channel depths result in significant reductions in dredging costs, a more detailed analysis is valuable in the feasibility stage of a new port project.

The analysis considers vessel characteristics and keelpoints, highlighting the importance of vessel draught and other factors in determining channel depth requirements. Critical keelpoints are strategically chosen on the vessel hull to assess the risk of bottom contact. Environmental conditions, including water level, current flow, wind, and waves, impact vessel motions and channel operability. Vessel responses to forward speed, current influences, wind, and waves are discussed, emphasizing the influence of wind on heeling and keelpoints. Manoeuvrability margin ensures effective ship manoeuvring by maintaining sufficient clearance. Probabilistic aspects, utilizing Rayleigh distribution, predict the probability of bottom touch based on wave responses. Downtime due to insufficient under keel clearance is determined by assessing probabilities hourly throughout the year, with a commonly accepted criterion of a 1% probability of bottom touch per transit. The overall approach combines vessel dynamics, environmental conditions, and probabilistic considerations to determine channel downtime percentages.

3.3 Used Input and Assumptions

The study incorporates three container vessels with varying capacities and dimensions, utilizing operational draughts. Assumptions include an 8-knot vessel transit speed over ground, with the actual speed dependent on current conditions. Minimal channel depths represent requirements, necessitating maintenance dredging for sedimentation. The assessment uses wave and current conditions based on the initial channel design, without incorporating changes with altered channel bed levels. Wind setup is not considered in this stage, reflecting a slightly conservative choice. Environmental data from MetOcean Solutions' wave and flow modelling includes 1D wave spectra, peak wave direction, water levels, and current speeds. Overall, these factors form the basis for evaluating vessel performance in the specified channel conditions.

3.4 Conclusions and Recommendations

For the detailed results, please refer to Appendix B. The conclusions drawn from the assessment of channel depth and bed levels in both the outer and inner channels present considerations for the navigability and safety of vessels. This comprehensive analysis encompasses the impact of vessel characteristics, environmental conditions, and operational parameters. The following key findings emerge from the evaluation:

3.4.1 Conclusions and Recommendations “Crossing the Bar” (Section A)

Incoming swell waves have significant influence on vessels sailing in this part of the channel. Therefore, the expected downtime here largely depends on the water level, current speed and wave conditions. The section was checked for both arrival and departure of a vessel, which results in opposite transit directions. It was found that the arrival is governing over the departure as during arrival the vessel sailing direction is similar to the dominant swell wave direction. Therefore, the waves are “stretched” resulting in longer observed wavelengths making them closer to the vessel length, thus more influential.

After analysis of the expected downtime per channel bed level for all 3 design vessels, the following can be concluded:

- The smallest, 7,000 TEU, vessel is critical for the channel depth design while crossing the bar as it is most sensitive to wave influences and has a large draught.

- A channel bed level of -19 m CD is advised as its downtime is very limited. It is noted that some operational limits would need to be included which will amplify the downtime slightly[3].
- Downtime for 0.5 m less depth (-18.5m CD) is still not very large. However, higher bed levels than -18.5m will lead to a rapid increase in downtime (refer to Figure 3-2). Here, deviations between modelling results and real life due to assumptions and simplifications or slightly different vessel characteristics in the different modelling steps involved could cause a less favourable outcome. Therefore, -18.5 m CD is not advised at this stage.

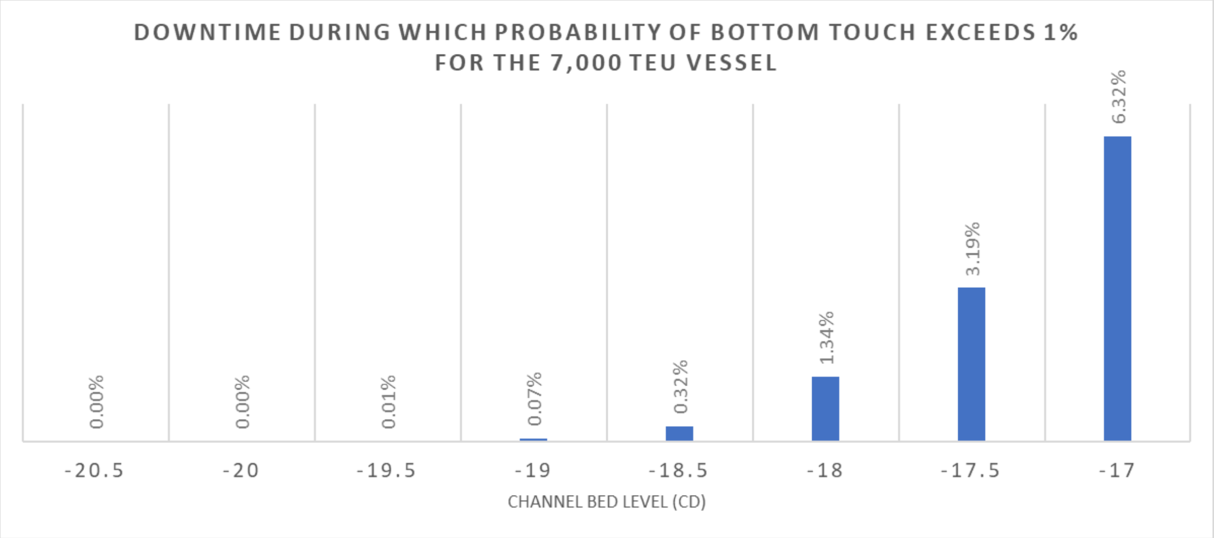

Figure 3-2: Downtime indications per bed level for the 7,000 TEU vessel (draught 14.3m)

3.4.2 Conclusions and Recommendations "Inner Channel" (Section C)

In the inner channel, an analysis of wave influence on the vessels showed that waves are not governing for the safe transit of vessels. The influence of the waves on the keel point motion was smaller than the required Manoeuvrability Margin. Therefore, the Manoeuvrability Margin became the limiting factor. This removes the statistical wave analysis from the analysis but instead reaches a deterministic approach in which the water level, current speed, vessel squat and heel angle are determined at each time step. The wind heel allowance was taken constant as no hourly wind conditions at the inner channel were available. The water level and current dependant squat were reassessed at each timestep. Combining these three factors with the vessel draught, the channel downtime for each bed level was determined. In this case the downtime is based on the time that insufficient navigational UKC was available. As the increase in squat and heel margin for the largest vessel proved to be less than the large difference in vessel draughts compared to the smaller container vessels, the two smaller vessels were assessed to be critical.

From the analysis of the results for smaller design vessels in the inner channel, the following can be concluded:

- The smaller design vessel (7K TEU Container Ship) with slightly higher draught is slightly more critical for the bed level determination in the inner channel.
- A bed level of -16.0 m CD is chosen here to avoid any operational restrictions.
- A bed level of -15.5 m CD leads to very low downtime. However, higher bed levels than -15.0 m CD led to a rapid increase in downtime (refer to Figure 3-3). Here, deviations between modelling results and real life due to assumptions and simplifications or slightly different vessel characteristics in the different

[3] *When setting limits, they have to be executable in planning operations. An advanced calculation will not be made each time so a rule of thumb will be applied which will be on the safe side, resulting in some extra channel downtime.*

modelling steps involved could cause a less favourable outcome. Therefore, -15.5 m CD is not advised at this stage.

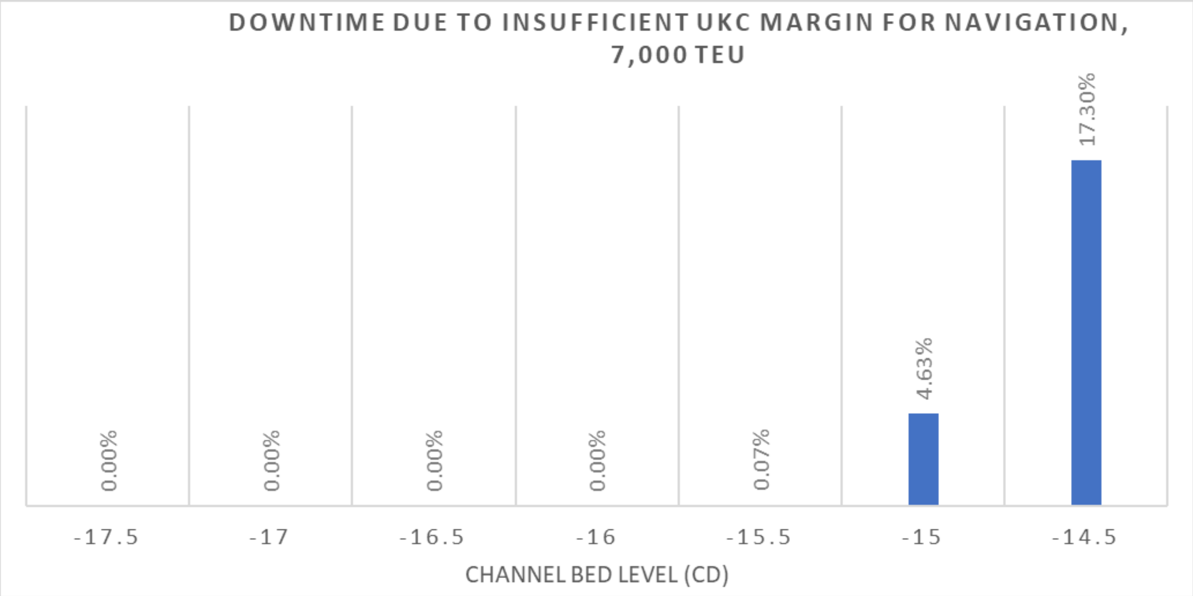

Figure 3-3: Downtime per bed level for the inner channel 7,000 TEU (draught 14.3m)

3.4.3 Future Considerations

- Certain assumptions were taken conservatively here such as the neglection of wind setup. In a more detailed design phase further optimisation might be achievable including more advanced environmental data including the wind setup.
- From a financial point of view, further channel depth reduction can be achieved by further limiting allowable environmental conditions for transit or introducing tidal windows for the transit of certain vessels. A cost-benefit analysis can be used to determine up to which downtime channel depth reduction still yields positive results.
- For the inner channel, squat limiting restrictions can be included (for example a lower speed limit at low water) to further investigate channel optimisations. However, this will not lead to major channel depth reduction.
- The provided results are based on one year of environmental conditions. No specific limiting conditions are defined. When taking the port into operations, these limits should be determined carefully to avoid incidents during extreme conditions.
- No climate change influences were considered at this stage. Influence of climate change is difficult to predict. A sea level rise will generally increase the UKC. However, more extreme and frequent storms might increase the swell wave conditions at the channel resulting in a less safe situation. Potential risks can be determined in further design stages. In any case, some increase in downtime should still be manageable and not severely change usability of the port.
- The used year (2012) was chosen as this was a year with relative high wave energy compared to other years in the 40 year hindcast set. Different years might result in very small increases or decreases in projected downtime but will not alter the conclusions.

4 Fast-time Navigation Simulations

Please refer to Appendix C for the specific details of the approach and the calculations. The main input parameters and calculation results are summarized below.

4.1 Starting Points

Following the channel depth optimization as presented in the previous Section, our team conducted a fast-time navigation modelling study to verify/confirm the updated design from a navigational point of view.

4.2 Model Description

To perform the fast-time manoeuvring simulations, “SHIPMA” software was used, which is a joint development of MARIN (Maritime Research Institute Netherlands) and Deltares (previously known as WL | Delft Hydraulics).

SHIPMA simulates the manoeuvring behaviour of vessels in a physically correct manner. In the programme, all relevant conditions are included, such as the vessel’s properties, environmental conditions, the track to be sailed and the usage of tugs. The SHIPMA program consists of two parts:

- The ship manoeuvring model, describing the horizontal motions of the ship as a result of all forces exerted on the ship.
- The track-keeping autopilot, which gives rudder, engine and tug commands based on deviations from the desired track, speed and heading. These commands are input for the ship manoeuvring model.

This section presents a brief description of the ship manoeuvring model and the track-keeping autopilot.

4.2.1 Ship Manoeuvring Model

The ship manoeuvring model calculates the horizontal motions of the ship as a result of all acting forces. The equations of motion are solved to compute the track of the ship, the course angle, the speed, etc. Vertical motions, except for squat, are not considered.

The model accounts for the specific characteristics of the modelled vessel, the forces of the tugs, and the environmental influences of water depth, wind, waves, currents, squat and bank suction.

Orders to the rudder, engine and tugs are determined in the autopilot part of the model. These orders are then passed to the ship manoeuvring model. The program determines the forces exerted on the ship by the rudder, the propeller and the environmental forces and computes the resulting ship response at short time intervals. This response results in a new position, heading, speed and course for each time-step.

4.2.2 Track-keeping Autopilot

For each simulation run a desired track with the speed along the track is specified. This track runs from the vessel’s starting position to the desired final position of the ship. The autopilot makes the ship follow the pre-specified track as closely as possible with the requested speed given the means of control and the response of the vessel.

The autopilot does not react to momentary deviations from the desired track but rather to expected "future" deviations, just like a human pilot would do. In the autopilot it is possible to define the “anticipation length”, which is typically set at 1 to 1.5 times the ship length, when the vessel transits through a channel.

4.2.3 Application of Environmental Conditions

Wind, waves and currents are applied in the model in the form of fields contained in input files. Each file stores information describing the domain of application of each condition, together with relevant characteristics of the condition.

For Manukau Harbour, the domain covers the entire channel, including 100 m wide zones on each side of it. The domain is covered by a mesh of 25 x 25 m, yielding more than 40,000 data points.

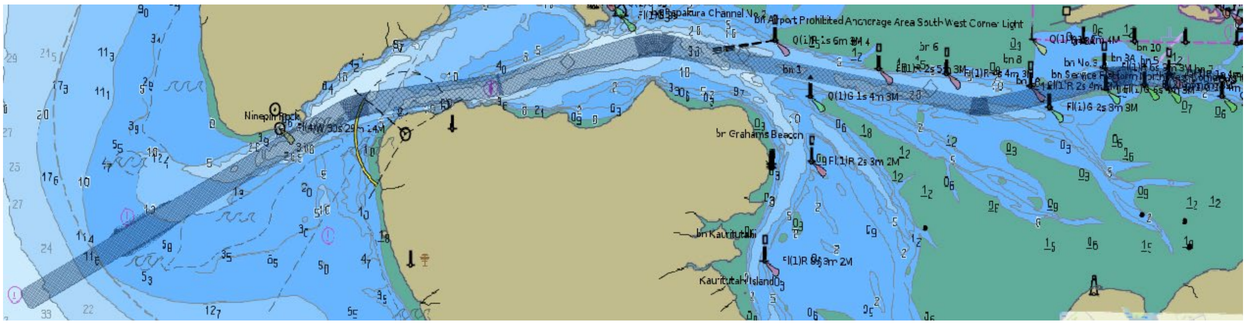

Figure 4-1: Channel Domain

4.2.4 Bank Suction

Bank suction is a phenomenon that occurs when vessels sail at speed in narrow channels with steep slopes. It is a hydrodynamic effect caused by asymmetric flow of water around the ship, leading to pressure difference between its sides. In general, resulting lateral force moves the vessel towards the closest bank.

For the deeper areas in the access channel, where the bank along the channel is deeper than the vessel draught, no bank suction will occur. However, along the track where the bank is shallower than the draught of the vessels, the vessels will experience more bank suction.

4.2.5 Vessel Model

The vessel used in the simulations is a partly/fully loaded container vessel with main dimensions LOA x B x T = 366 x 52.1 x 13.2 (SHIPMA Model "con038r1"). Among the available vessel models, the presented model is the closest match in terms of dimensions and manoeuvrability to the widest and longest design vessel (15K TEU Container Ship) and this is therefore representative of this class of ship. The vessel model has a single propellor and rudder with 72,400 kW power at 104 RPM. The windage area is 2,320 m^2 frontage and 13,435 m^2 lateral.

4.3 Environmental Conditions

4.3.1 Wind

Dominant wind directions in the area are SW (22% of the time) and W (17% of the time), as reported by PMM[4] based on NZ-wide wind hindcast model for the location at Manukau Heads. Average wind speed is 7.5m/s, whereas the 90th percentile wind speed reaches 12.2m/s. The maximum wind speed in the 39-year hindcast is 23.9m/s. The north-westerly and southerly wind directions are not dominant, and their impact on channel navigability would be less severe from the channel alignment perspective, compared to directions that were selected for the study. Winds coming from north were checked because they are almost perpendicular to the channel alignment, which is the most unfavourable condition from perspective of passage of a ship with large lateral windage.

[4] *"Manukau Harbour Port Feasibility Study – Navigational Operability", PMM (August 2023)*

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For the purposes of the fast-time simulations, the following conservative wind conditions are selected:

- 14 m/s wind from SW (225 degN),
- 14 m/s wind from W (270 degN), and
- 14 m/s wind from N (0 degN).

The choice of 14m/s winds from directions SW, W and N is deemed appropriate for the following reasons:

- this is a locally frequently present wind,
- this is a wind speed usually found as practical limit for channel passage,
- terminal operations are restricted or stopped at higher wind speeds, and
- although north is not a dominant wind direction (approximately 9% of the time), these winds are near perpendicular to the channel and will have the most adverse impact on the ship during the channel passage.

Simulating these conservative wind scenarios serves the purpose of establishing the technical feasibility of the channel: if the vessel is able to pass through the channel under the listed conditions, channel alignment and dimensions will be considered safe and appropriate. Selected wind speeds serve both as input parameters for wave modelling and as simulation scenarios.

4.3.2 Waves

Wave conditions in Manukau Harbour are a subject of numerical modelling performed by MOS[5] for the boundary conditions shown in Table 4-1. Results of the wave modelling are used as input for fast-time simulations. Separate swell and waves conditions are combined in the simulations.

Table 4-1: Wave Modelling Scenarios

Simulation ID	Wave - Model Run Description	Boundary Conditions
ss01	Swell & no wind	H_S = 1m, T_P = 12s, Dir = 235°
ss02	Swell & no wind	H_S = 2m, T_P = 13s, Dir = 235°
ss03	Swell & no wind	H_S = 3m, T_P = 14s, Dir = 235°
ss04	Swell & no wind	H_S = 4m, T_P = 15s, Dir = 235°
ss05	Swell & no wind	H_S = 2m, T_P = 10s, Dir = 280°
ss06	Swell & no wind	H_S = 3m, T_P = 11s, Dir = 280°
ss07	No swell & wind	Wind speed = 14m/s, Dir. SW (225°)
ss08	No swell & wind	Wind speed = 14m/s, Dir. W (270°)
ss09	No swell & wind	Wind speed = 14m/s, Dir. N (0°)

[5] *"Manukau Harbour Numerical Modelling", MOS (August 2023)*

Out of 9 given scenarios, 4 are selected for the fast-time simulations (highlighted in Table 4-1):

- 1 swell condition (ss04), and
- 3 wind-generated wave conditions (ss07, ss08 and ss09).

Swell condition “ss04” is selected due to it being the most unfavourable of all considered swell conditions: it has the largest wave height and the longest wave period. All wind-generated wave conditions are considered, since they should be applied in the model together with corresponding wind conditions.

Swell and wind waves had been treated separately during wave modelling stage. Resultant wave fields were later combined in SHIPMA, following the software’s standard input procedure for wind-generated and swell waves. Thus, simulations were run with all relevant environmental forces present.

4.3.3 Water Levels and Currents

Manukau Harbour tidal levels reflected in Table 4-2 are given for the benchmark at Onehunga[6]. All fast-time simulations are conservatively performed with the MLWS water level, as low water is the most unfavourable from perspective of the ship manoeuvrability. The current varies depending on the simulated tide cycle. The following 3 scenarios are considered:

- Peak ebb – the strongest currents during the falling tide.
- Peak flood – the strongest currents during the rising tide.
- Low water slack – weak currents during the low tide.

Table 4-2: Manukau Harbour Tidal Levels

Tidal Levels	m CD
Highest Astronomical Tide (LAT)	4.54
Mean High Water Springs (MHWS)	4.17
Mean High Water Neaps (MHWN)	3.34
Mean Sea Level (MSL)	2.43
Mean Low Water Neaps (MLWN)	1.44
Mean Low Water Springs (MLWS)	0.56
Lowest Astronomical Tide (LAT)	0.12

Note that tidal levels through the channel will differ. The tide data for Paratutae Island was adopted, with further adjustment of 5 – 10%, as no data was available for the crest of the entrance bar. Refer to TWP03 Coastal, range of MLWS in the area is +0.4m CD to +0.6m CD, with +0.4m CD reported for Paratutae Island at the harbour’s entrance. Water level variations of that magnitude have insignificant impact on concerned vessels’ manoeuvrability (and hence the channel’s alignment and width), therefore, this has not been considered.

[6] *“Manukau Harbour Port Feasibility Study – Coastal Processes”, T+T (August 2023)*

4.4 Simulation Sections

As explained in detail in Appendix A the channel, which is approximately 38 km long, is subject to varying environmental conditions. Accounting for that variability along the channel of this length in fast-time simulations is a difficult task due to inherent limitations of the used software. The approach is to split the channel into sections which are then treated separately. The split allows for sufficient degree of flexibility in defining environmental conditions while preserving the accuracy of simulations, each with their own combination of environmental forces acting on the ship. The following sections have been modelled (see Figure 4-2):

- Section A (section over the bar): from 0km to 13.5km
- Section B (middle section): from 13.5km to 26.5km
- Section C (end section): from 26.5km to 37.5km

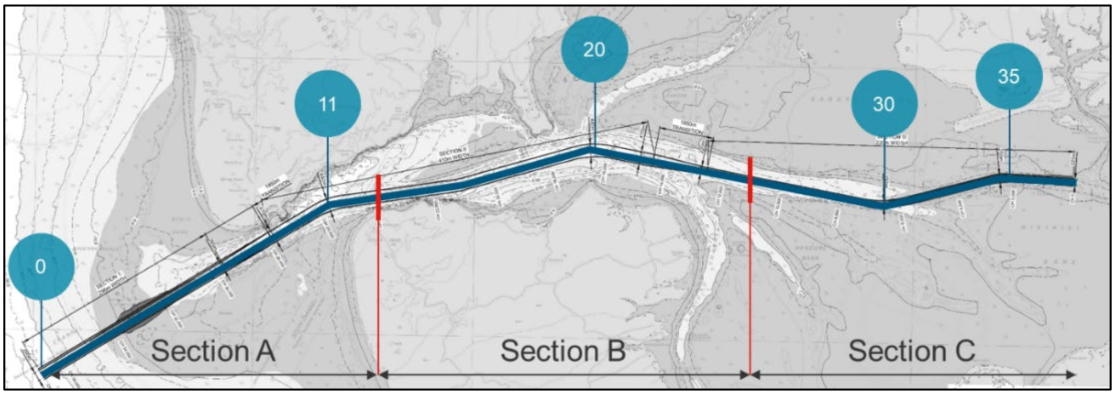


Figure 4-2: Channel Sections for Simulations

In total, 54 simulation runs are performed, categorized into three sections (A, B, and C), each comprising 18 cases. The cases cover various arrival and departure scenarios, considering different wind directions, wind speeds, wave conditions, water levels, and currents.

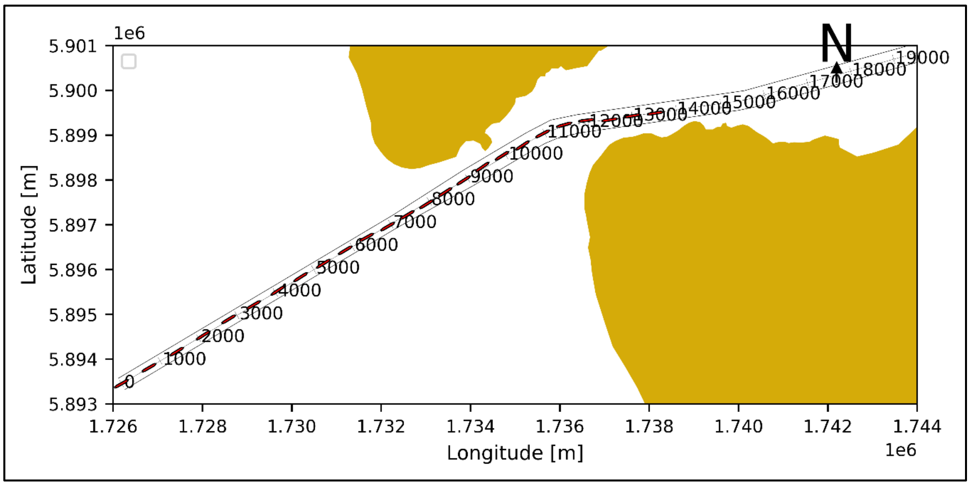


Figure 4-3: Typical arrival run output for Section A (section over the bar)

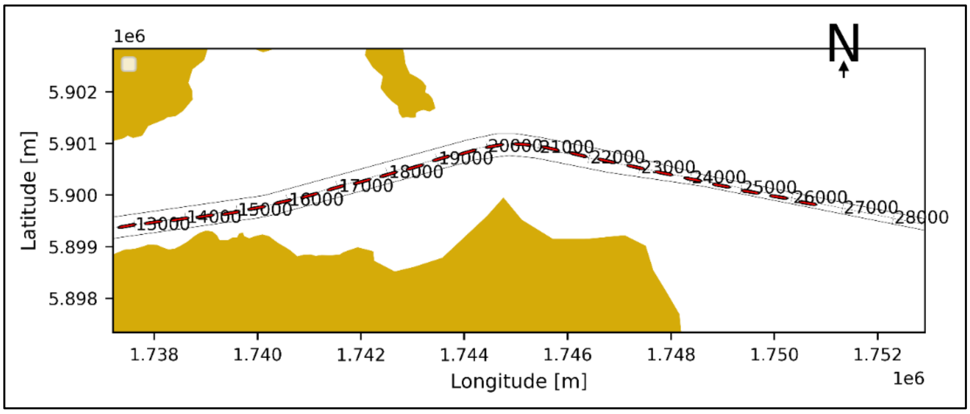


Figure 4-4: Typical arrival run output for Section B (middle section)

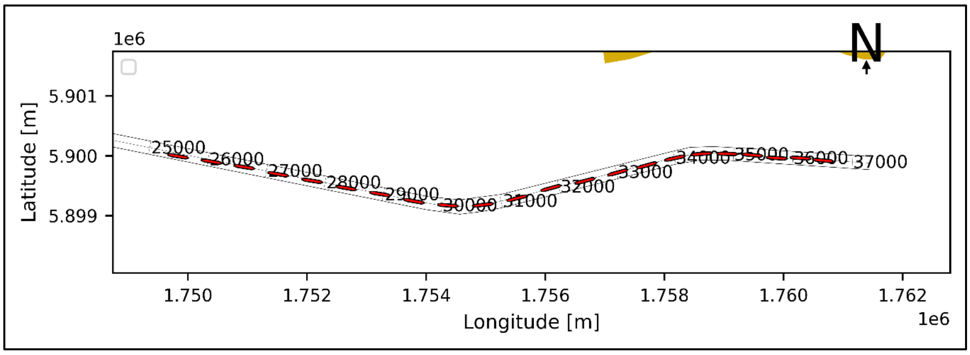


Figure 4-5: Typical arrival run output for Section C (end section)

4.5 Additional Runs

The purpose of the runs discussed in the previous sections was to check whether the channel width is sufficient for the largest vessel. This vessel, however, is not the only one anticipated to call at the potential future port. Other vessels, smaller in length and beam, but with larger draughts, will also visit the terminal, as explained in PMM report[7]. From the perspective of channel width, those vessels are not governing; in other words, if the largest vessel is able to manoeuvre successfully through the channel under investigated conservative combinations of environmental conditions, then smaller vessels are able, too.

While in the main set of simulations the passage speed is of no concern due to the fact that the largest ship has smaller draught, giving it an extra margin for bigger squat and thus allowing for flexibility in use of speed, the vessels with larger draughts will have to limit their speed to 8 knots. Adjusting the speed during passage under challenging conditions is one of the ways for mariners to retain or improve control over vessels. Thus, the purpose of additional runs, discussed in this chapter, is to check whether the shorter and narrower ships with deeper draughts can manoeuvre through dredged sections of the channel without exceeding the speed limit of 8 knots.

4.5.1 Ship Model used in Channel Section Over the Bar (Section A)

The vessel used in the simulations is a partly/fully loaded container vessel with main dimensions LOA x B x T = 347 x 42.91 x 14.5 (SHIPMA Model "con013g2"). Among the available vessel models, the presented model is the closest match in terms of dimensions and manoeuvrability to the design vessel. The vessel

[7] *"New Zealand Ports and Shipping Overview", PMM (March 2023)*

model has a single propeller and rudder with 54,860 kW power at 94 RPM. The windage area is 1,540 m^2 frontage and 8,641 m^2 lateral. Vessel speeds for varying telegraph settings are presented in Table 5-2.

Table 5-3: Telegraph setting of vessel model "con013g2"

Telegraph	RPM	Speed [kn]
Sea full	94	21.2
Harbour full	65	14.6
Half	50	11.2
Slow	35	7.9
Dead slow	25	5.6

4.5.2 Ship Model used in Inland Channel Section (Section C)

The vessel used in the simulations is a partly/fully loaded container vessel with main dimensions LOA x B x T = 318.2 x 42.80 x 13.5 (SHIPMA Model "con011r4"). Among the available vessel models, the presented model is the closest match in terms of dimensions and manoeuvrability to the design vessel. The vessel model has a single propeller and rudder with 54,860 kW power at 94 RPM. The windage area is 1,417 m^2 frontage and 8,690 m^2 lateral. Vessel speeds for varying telegraph settings are presented in Table 5-3.

Table 5-4: Telegraph setting of vessel model "con011r4"

Telegraph	RPM	Speed [kn]
Sea full	94	24.4
Harbour full	74	19.2
Half	58	15.0
Slow	44	11.4
Dead slow	30	7.8

4.6 Selected Conditions

In total, 12 additional runs are performed for the most adverse conditions in sections A and C:

- Section A: Arrival & Departure with westerly wind and corresponding wind-generated waves, for peak ebb, peak flood, and low water currents, with swell waves present.
- Section C: Arrival & Departure with south-westerly wind and corresponding wind-generated waves, for peak ebb, peak flood, and low water currents, with swell waves present.

Section B is not simulated, as the channel in this section is naturally deep.

4.7 Conclusions and Recommendations

For the detailed results of the fast-time modelling, please refer to Appendix C.

The following conclusions are drawn based on the outcomes of the fast-time simulations:

- Channel dimensions as per Sections 2 and 3 are adequate for the manoeuvres under examined conservative combinations of environmental conditions. The ship leaves the designated path only occasionally and for short periods of time, mostly in bends (refer to Appendix C for more details); the ship is able to return to the intended course swiftly and without significant effort, meaning that the channel width is sufficient. Narrowing the channel, however, is not recommended, as it may lead to greater instability of the ship's track, especially in shallow parts, where influence of bank suction is significant. Channel dimensions optimization may be investigated further during the following design stages, by means of real-time simulations.
- The ship retains sufficient control over its course throughout the entire channel, both during arrival and departure passages, as almost no instances of rudder use exceeding 20° are recorded (refer to Appendix C for more details). Most of the time, rudder angle remains within +10° to -10° range. It is therefore concluded that the channel alignment is appropriate.
- Additional runs with smaller vessels that have deeper draughts in dredged sections demonstrate that vessels are able to retain control with imposed speed limit of 8 knots, however in Section C under some conditions, manoeuvring is arguably difficult, as the ship has to resort to the maximum allowed rudder angles.

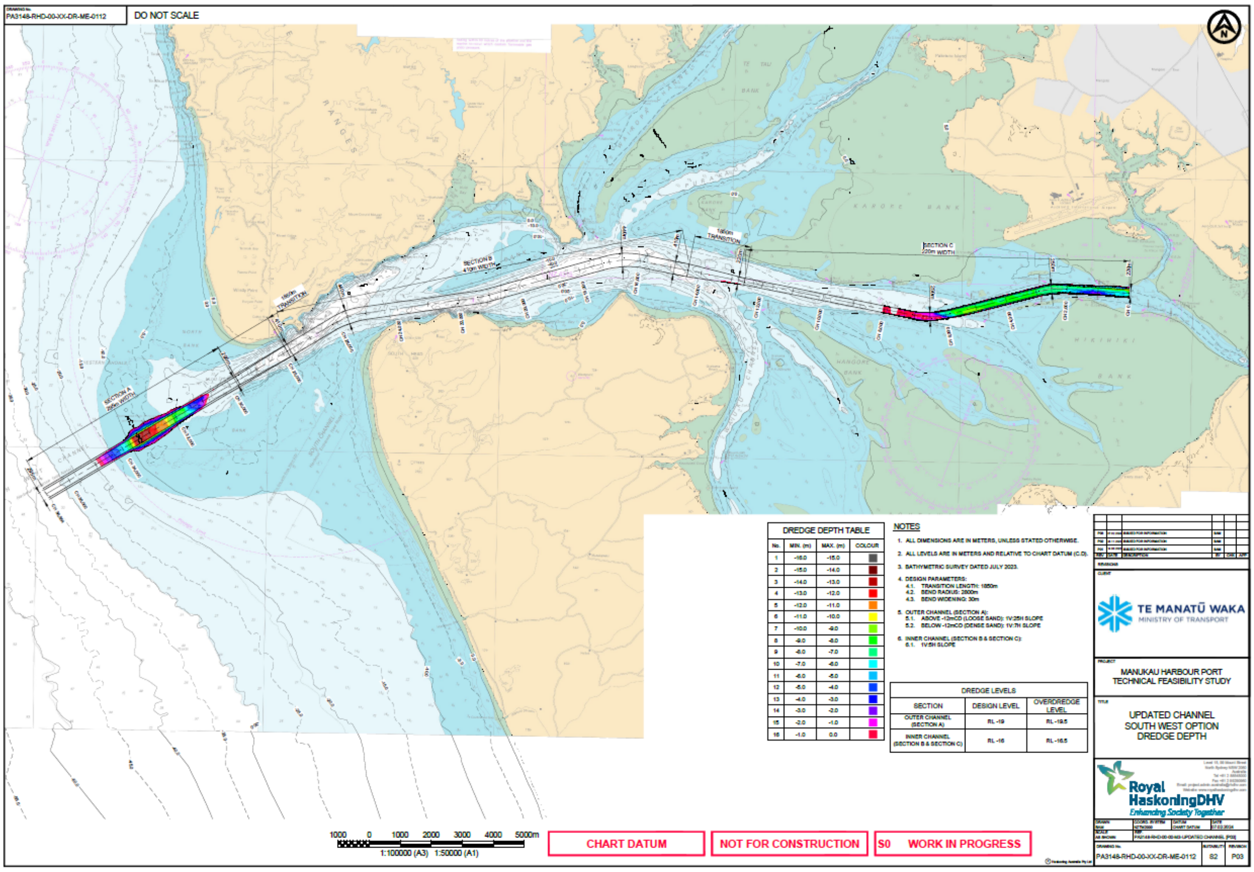
5 Final Channel Concept Design

5.1 South West Channel

Figure 6-1 below presents the final concept design of the Navigational Channel. Table 6-1 below provides the main dimensions of the Navigational Channel and the related capital dredging volume per section.

Table 6-1: South West Channel dimensions and capital dredging quantities

Section	Width (excl side slopes)	Depth (excl overdredge)	Length	Dredge volume (excl overdredge, incl side slopes) [8]
A	295 m	-19 m CD	9,000 m	12.4 million m^3
B	410 m	At natural water depth (deeper than -19m CD)	15,300 m	0 m^3
C	220 m	-16 m CD	12,600 m	12.7 million m^3
Total			**36,900 m**	**25.1 million m^3**



[8] *The volumes are based on the 2023 bathymetry collected as part of this study. The surface was created by MetOcean Solutions (refer to TWP03b). The survey tolerance was +/- 350mm (offshore) and +/- 150mm (inner harbour), Refer to TWP02 – Fieldwork for further details. Adoption of side slopes are described in TWP06 – Dredging.*

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Figure 6-1: Final Channel Concept Design and capital dredge volume (also refer to Appendix D)

5.2 South Channel vs South West Channel

After completion of the initial concept design (see Section 2) it was decided to select the South West channel for Section A as the preferred alignment of the Navigational Channel for reasons as explained in Section 3.1 (i.e. lower capital dredge volumes and preference from stakeholders on orientation). Consequently, the dynamic under keel clearance calculations and fast-time navigation simulations were carried out for the South West Channel only.

Following this, the sediment transport modelling work undertaken by MetOcean Solutions (refer to TWP03c) revealed high sediment infill rates for the South West channel. Although the capital dredge for the South channel would be over 50% higher than the South West channel a query was raised as to whether the maintenance dredge would be lower (also considering that from a navigational point of view, both options would be acceptable). For that purpose the initial South Channel design (refer to Appendix A) was used to carry out some limited infill rate model runs.

To make the capital dredging volumes comparable, the optimized cross-sectional channel design for the South West Channel was also adopted for the South Channel. It is to be noted that, strictly speaking, the channel depth and width of Section A (section over the bar) has not been confirmed by dynamic under keel clearance calculations or fast time simulation modelling for the South Channel. This simplification introduces a slight risk to the project in the sense that we cannot be sure if the channel dimensions for Section A and therefore the capital dredging volumes are an over- or under-approximation. In case the South Channel is considered preferred over the South West Channel in the next stage of design then this would need to do be checked.

Section B and C of the Navigational Channel are similar for both options so this only affects the section crossing the bar (Section A).

For the record we have included the channel dimensions and capital dredge volume of the South Channel, in Figure 6-2 and Table 6-2 respectively.

Table 6-2: South Channel dimensions and capital dredging quantities

Section	Width (excl side slopes)	Depth (excl overdredge)	Length	Dredge volume (excl overdredge, incl side slopes)
A	295 m *	-19 m CD *	13,700 m	28.5 million m^3
B	410 m	At natural water depth (deeper than -19 m CD)	13,800 m	4.8 million m^3 **
C	220 m	-16 m CD	12,600 m	12.7 million m^3
Total			**40,100 m**	**46.0 million m^3**

* *Not optimised by dynamic under keel clearance calculations or verified by fast time simulations*

** *This is due to the definition where section A ends and Section B begins*

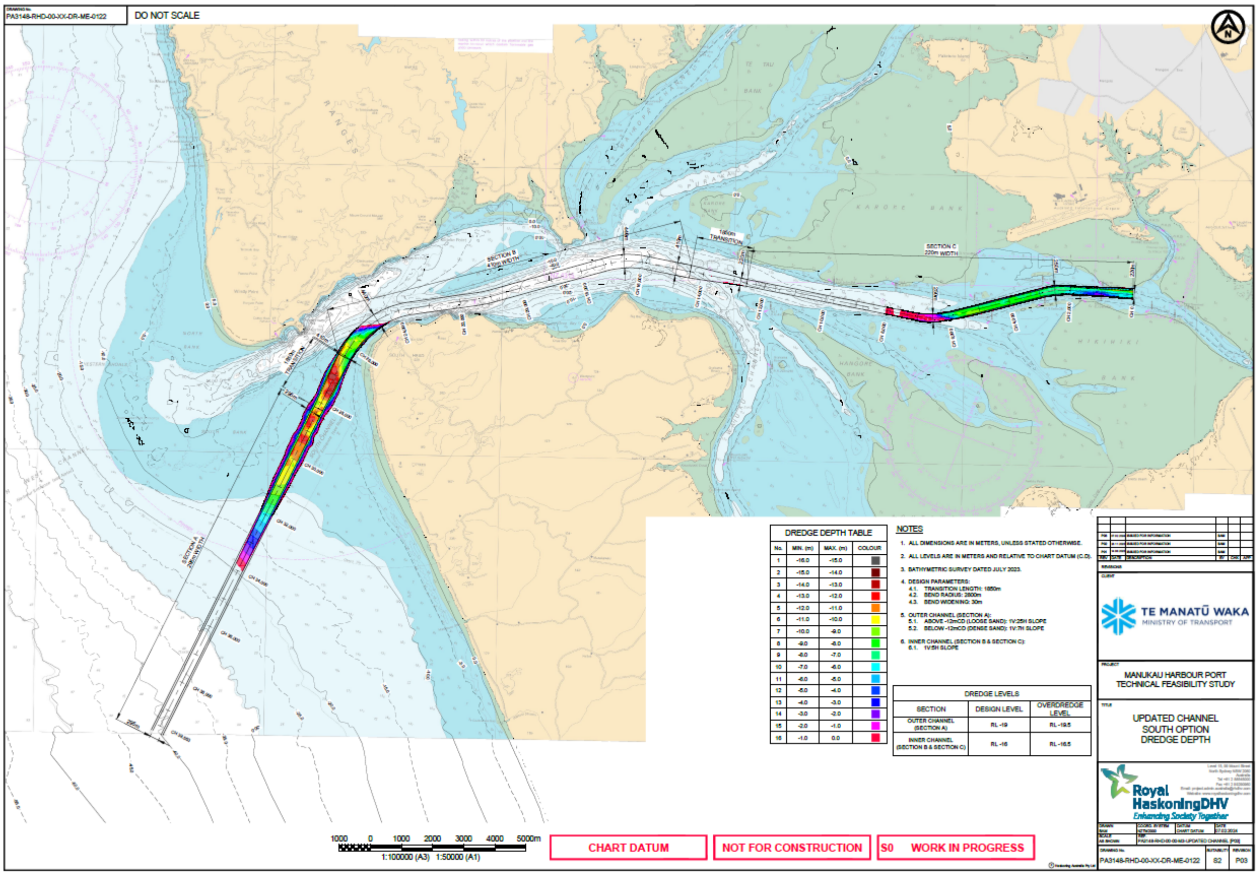

Figure 6-2: South Channel alignment and capital dredge volume [9]

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[9] *Assuming same cross-sectional dimensions as the final concept channel design (South-West Channel)*

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6 Future Considerations

In future project phases, further verification and optimizations of the channel concept design will be required, as part of the normal design process. The current concept design meets the requirements of the project starting points in terms of vessel size and future traffic volumes and is sufficiently conservative for this initial stage of the design to allow for some level of optimization in future phases when more information is available and financial-economical considerations will be taken into account (see also below). With the current channel design all design vessels can enter Manukau Harbour without any downtime due to insufficient water depth or manoeuvring space.

A few final considerations that we would like to share for further discussion in follow-on design stages.

- **Economical-financial considerations**

  The current navigational studies have only looked at technical feasibility of the Navigation Channel, leading to an optimized Channel from a technical point of view, thereby avoiding any downtime due to water depth limitation for all vessels[10]. This is also a bit of a 'worst-case scenario' approach. From a financial perspective, continued channel depth reduction and subsequently reduced capital and maintenance dredging could be pursued in next stages by imposing stricter environmental conditions for vessel transit or by introducing tidal windows for specific design vessels. A comprehensive cost-benefit analysis becomes instrumental in determining the optimal channel depth reduction that remains economically viable. This study will be mainly driven by the expected traffic mix and traffic volume over time. Such a study could also lead to a phased approach, whereby the Channel gets dredged deeper and wider after a certain number of years when traffic dictates this need, to limit the initial investment costs.

- **Real-time (full-bridge) simulations**

  The current (desk-top) fast time simulations confirmed that the Navigation Channel dimensions are sufficient for safe manoeuvring, with some minor concerns in the bends. In the next stages of development it is recommended to look at real-time (full-bridge) simulations to test these dimensions and see if e.g. width optimizations are possible in the straight sections and if the bends are indeed sufficiently wide. The great benefit of real-time simulations over fast-time simulations is that the former are carried out in a 3D-simulator by actual pilots who can provide detailed feedback on the channel alignment based on their real-life experience. This will also allow some discussions among experts about the most efficient dimensions, balancing commercial benefits and navigational safety.

- **Design vessels**

  For the concept design calculations of the Navigational Channel we have used the design vessels that were defined by PMM (refer to TWP01). Some discussions have been ongoing if an even larger vessel (container vessel up to 20,000 TEU) could be accommodated in the current Navigational Channel design. In principle, this is not impossible (depending on the increase in design vessel) but may lead to some downtime due to insufficient water depth and may also require reduced sailing speed to avoid grounding. However, any change to the set of design vessels should be incorporated in the next stage of the design of the channel, when also the financial-economical aspects are being looked at to get to an optimum design. Such financial-economical studies may also reveal that a reduction of the channel dimensions and therefore a reduced size of the design vessel may be more appropriate from a business case point of view.

[10] Tankers have not been considered in this study as a design vessel due to the limited tanker calls per year and will need to come in either partly laden or using the tide (or both).

- **One-way vs two-way channel**

  The current Navigation Channel design is a one-way channel, except for the middle section (Section B), which is already at sufficient natural water depth and width for 2-way traffic, not requiring any dredging. The reasoning for the one-way channel is the current traffic forecast which does not warrant a two-way channel[11], especially during the first decades. This decision is supported by the existence of a natural 'passing by' section B where 2-way traffic is possible. The length of Section B is significant, about 40% of the total channel length (refer to Table 6-1). This natural deep channel section reduces any potential waiting time significantly.

  It could be considered in future stages to look at a potential two-way channel, but this comes with considerable additional capital and maintenance dredging, especially when crossing the bar. It is our expert opinion at this stage of the project that these additional costs would not be justified and that some potential traffic congestion would be preferred from a commercial point of view. Again, it could be considered to look at a phased approach and allow for e.g. a slight widening of the Navigational Channel at some point in the future to allow 2-way traffic of the smaller vessels in case traffic supersedes the current projections. This will need confirmation in the next stage of the design process.

[11] *Note that this is not confirmed by any navigational traffic studies, this is based on expert judgment*

A. Initial Channel Concept Design

Report

Initial Channel Concept Design

Click to enter "Subtitle2"

Client: T+T

Reference: PA3184-RHD-XX-XX-RP-X-0002

Status: S3/P01

Date: 14 June 2023

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Classification
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Acronyms

Acronym	Definition
AtoN	Aids to Navigation
BH	Borehole
CD	Chart Datum
ENC	Electronic Navigational Chart
LAT	Lowest Astronomical Tide
LiDAR	Light Detection and Ranging
NIWA	National Institute of Water and Atmospheric Research
PIANC	World Association for Waterborne Transport Infrastructure
PMM	Pacific Maritime Management Ltd
POAL	Ports of Auckland Ltd
SW	Southwestern
TEU	Twenty Foot Equivalent Unit
UKC	Under Keel Clearance
UNISCS	Upper North Island Supply Chain Strategy
W	Western

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Glossary

Term	Definition
Aids to Navigation (AtoN)	Device external to a vessel designed to assist in the determination of its position and its safe course or to warn of changes or obstructions. In the case of channels such devices include buoys, piled beacons, leading lights, sector lights, radar reflectors, etc.
Anchorage area	Designated areas inside or outside of the harbour in which ships are permitted to lie at anchor.
Approach channel	An approach channel is defined as any stretch of waterway linking the berths of a port and the open sea.
Bank effects	Hydrodynamic effect caused by the proximity of a ship to a bank. Asymmetrical pressures acting on the ship may cause it to be sucked towards, and turned away from, the bank.
Channel	A channel is a feature of a waterway that has a width and depth that is sufficient to allow safe passage of the design ships. It might be dredged or may be naturally occurring.
Deadweight tonnage (DWT)	Weight (usually in metric tonnes) of a ship’s cargo, fuel, water, crew, passengers and stores.
Dredging	Loosening and lifting earth and sand from the bottom of water bodies.
Green Side	Also known as starboard side, which is a nautical term for watercraft and aircraft, referring to right side of the vessel, when aboard and facing the bow (front).
Hard-over rudder angle	When a rudder is "hard over", it means that the ship-handler has turned the rudder control all the way to one side or the other.
Heel	Rotation of a vessel about longitudinal X-axis due to non-oscillating motions from wind and current.
Knot	The knot is a unit of speed equal to one nautical mile per hour. 1 knot is equivalent to 1.852 km/h, 0.514 m/s and 1.151 mph.
Nautical Chart	Nautical charts are maps of coastal and marine areas, providing information for navigation. They include depth curves or soundings or both; aids to navigation such as buoys, channel markers, and lights; islands, rocks, wrecks, reefs and other hazards; and significant features of the coastal areas, including promontories, church steeples, water towers, and other features helpful in determining positions from offshore.
Nautical Mile	A nautical mile is a unit of length used in air, marine, and space navigation, and for the definition of territorial waters. It is defined as exactly 1,852 metres.

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Term	Definition
Panamax	Panamax is the term for the size limits for ships travelling through the Panama Canal.
Pilot	Pilot is a mariner who has specific knowledge of an often dangerous or congested waterway, such as harbours or river mouths. Maritime pilots know local details such as depth, currents, and hazards. They board and temporarily join the crew to safely guide the ship's passage, so they must also have expertise in handling ships of all types and sizes.
Red Side	Also known as port side, which is a nautical term for watercraft and aircraft, referring to left side of the vessel, when aboard and facing the bow (front).
Slow steam	Slow steaming is the practice of operating transoceanic cargo ships, especially container ships, at significantly less than their maximum speed.
Squat	Squat is the reduction of the under-keel clearance due to the suction effect induced by the higher current velocity between the sea bottom and the ship.
Swell waves	Swell waves are wind-generated waves that have travelled out of their generating area. Swell has more well-defined and flatter crests than wind waves. Swell wave periods are very regular, ranging from 8 to 30 s.
Trim	Trim is the difference between draught forward and the draught aft.
Tug	Tug is a small, powerful boat used for towing larger boats and ships, especially in harbour.
Vessel's beam (B)	Vessel's width.
Vessel's draught (T)	Draught is a vertical distance between water surface and the bottom of the hull.
Vessel's length overall (LOA)	Length overall is the maximum length of a vessel's hull measured parallel to the waterline.

1 Design Philosophy

1.1 Background

An important aspect in port planning and port design studies is the dimensioning of the port approach channel and port manoeuvring basin(s).

In this report the design of navigation channels is considered to be a two-stage process consisting of:

- Concept design;
- Detailed design.

The methodology is based on the initial premise of a design ship or, in some cases, design ships. The design process is an optimisation task between navigation, safety, economic and environmental factors, with consideration of any other constraints.

Process of channel concept design results in channel route and dimensions at the level of detail most suitable for technical feasibility study. Principles and considerations of channel concept design are outlined in this chapter.

There are many factors involved in making the right design assumptions and choices such as the prevalent design vessel(s) and their specific characteristics, wave climate, current regime, prevailing winds, availability of pilotage and tug assistance, traffic intensity, etc.

For the purposes of the project, the Concept Design approach described in PIANC WG121 – 2014 is adopted. Summary of this approach is presented in the following sections.

1.2 Channel Alignment

Development of the channel route is guided by the following general principles:

- Channel should be as short as possible, to minimize travel time and reduce fuel consumption.
- Dimensions (width and depth) of the channel should be sufficient along the entire channel, meaning that prevailing winds, currents and waves should be checked at different points of the route. These environmental conditions may vary from section to section, which could lead to some channel sections being deeper and wider than others.
- Obstacles that are too expensive to remove and areas where channel depth and width are hard to maintain should be avoided. Moreover, channel alignment should make use of existing natural channels as much as possible, to minimize dredging expenses.
- The channel should have as little bends as possible to ensure ease of navigation.
- Traffic intensity should be accounted for: if the terminal is busy, some or all channel sections may need to be able to accommodate 2-way traffic.

1.3 Vertical Channel Dimensions

This section contains basic definitions of the channel depth factors affecting the vertical design of approach or navigation channels. Figure 1-1 shows the required safe depth of a channel is determined by water level, ship and bottom factors. Each of these factors is interrelated with the others and described in subsections below.

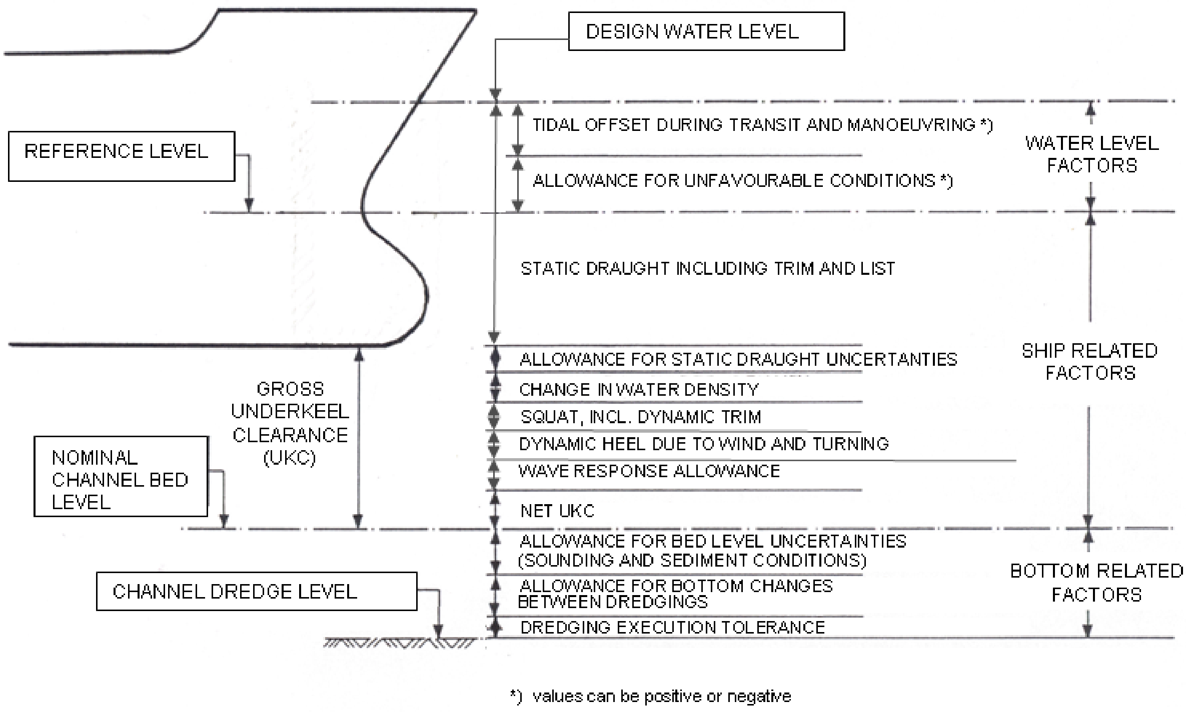

Figure 1-1: Channel Depth Factors[1]

1.3.1 Water Levels

The relevant water levels for the channel design include the Reference Level or (Chart) Datum and the Design Water Level which includes both tidal and meteorological effects.

- Reference Level: All channel depth factors should be related to the same datum level, normally (close to) the Lowest Astronomical Tide (LAT).
- Design Water Level: The design water level is the starting point for designing the appropriate channel depth. It depends not only on astronomical and meteorological effects, but also on the draught of the design ship(s), local operational and economic conditions, ecological requirements and currents.

1.3.2 Ship-Related Factors

Ship factors include static draught of the ship and the Gross Under keel Clearance (UKC). The Gross UKC is composed of six factors including allowance for static draught uncertainties, change in water density, ship squat and dynamic trim, dynamic heel, wave response allowance and Net UKC.

- The **ship's draught** is not always known with absolute certainty. It is usually measured with limited accuracy at the port of departure, where water densities can be different from those at the port of arrival, or where wave conditions around the draught markings on the ship's hull make accurate reading difficult. Another cause of uncertainty could be the static inclination to one side caused by an unbalanced load or ship damage.
- Differences in **water density** between seawater and fresh water will lead to differences in draught. If a ship moves into water of lower density, the draught will increase almost proportionally depending also on the verticality of the hull at the waterline.

[1] *PIANC WG 121 - 2014*

- **Squat** is a steady downward displacement consisting of a translation and rotation due to the flow of water past the moving hull. This water motion induces a relative velocity between the ship and the surrounding water that causes a water level depression in which the ship sinks.
- **Wave induced motion** increases the static draught of the ship. There are three translational motions (surge, sway and heave) and three rotational motions (roll, pitch and yaw). Surge (translation along longitudinal X-axis), sway (translation along transverse Y-axis) and yaw (rotation about vertical Z-axis) affect the horizontal design of the channel and its width. Heave (translation along vertical Z-axis), roll (rotation about longitudinal X-axis) and pitch (rotation about transverse Y-axis) affect the vertical design of the channel. In heave, the ship tends to follow the wave motions up and down. Ship movements are depicted in Figure 1-2.
- During turning of a vessel, heeling (rotation around longitudinal axis) will occur depending on the ship's speed, rate of turn, metacentric height and tugboat line forces. The difference between roll and heel is that roll is due to wave-induced oscillations while heel is due to non-oscillating motions from wind and currents. **Dynamic heel** can also occur when a beam wind and other horizontal or vertical asymmetrical forces on the vessel cause heeling of the vessel. Dynamic heel adds to the ship's draught and depends heavily on beam and windage. Ships with larger windage are more susceptible to wind-induced dynamic heel.

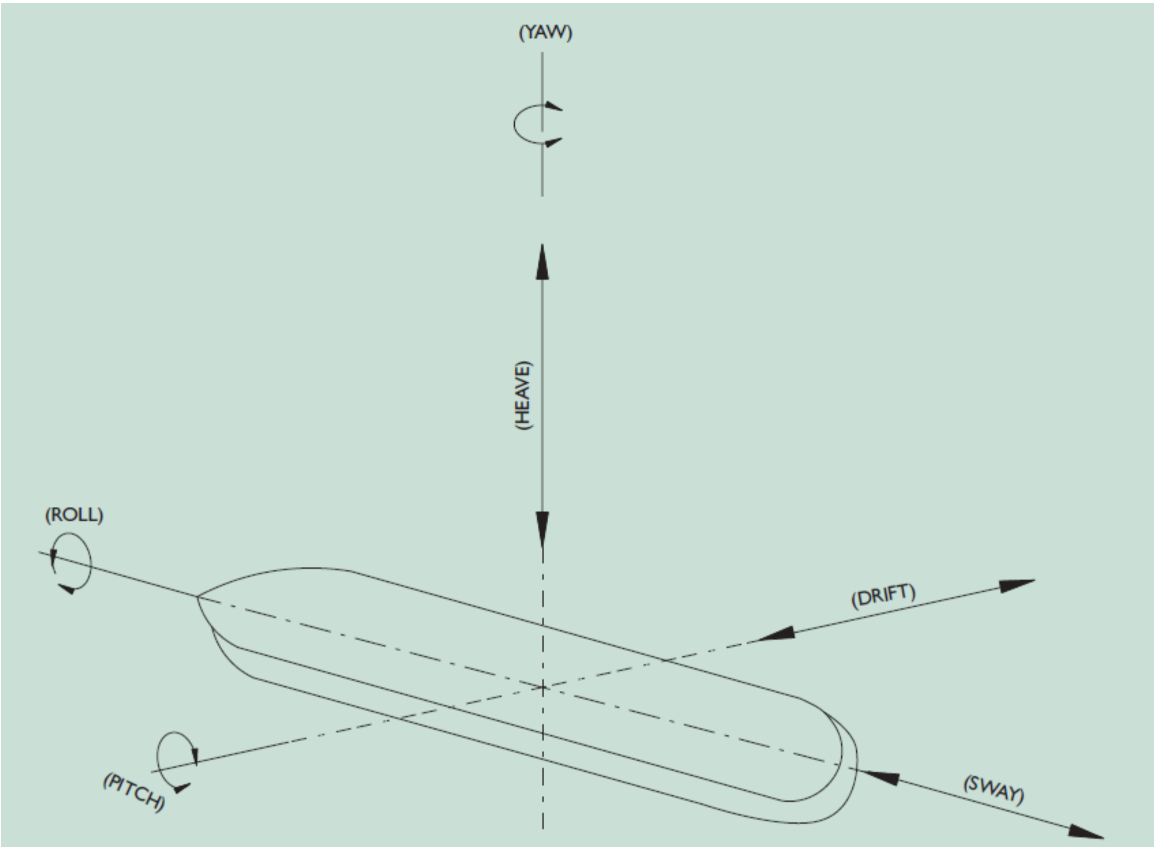

Figure 1-2: Ship Motions [2]

- **Net UKC** is the minimum margin remaining between the keel of the vessel and the nominal channel bed level, with the vessel moving at planned speed under the influence of the most severe winds and wave conditions designed for operational limit conditions. Thus, the required Net UKC is what is left as a

[2] *Recommendations for Maritime Works: ROM 3.1-99.*

'safety' margin for the ship after subtracting the other ship factors (wave-induced vertical ship motions, ship squat and dynamic heel) from the nominal channel bed level or depth.

1.3.3 Bottom-Related Factors

The channel bed itself has to be at a safe distance below the deepest point of the vessel. It is defined as the nominal, proclaimed, or advertised channel bed level or depth. The actual depth of the channel should always be at least this proclaimed value. The last group of factors in the design of the channel depth are the bottom factors that include allowance for bed level uncertainties, allowance for bottom changes between dredging and dredging execution tolerance.

- The allowance for **bed level uncertainties** is the uncertainty in the actual depth of the bottom due to tolerances in the measured bathymetric survey data. All sensors have a built-in tolerance or uncertainty that must be considered in the accepted nominal channel bed level or depth.
- The allowance for **bottom changes** between dredging has to do with possible sedimentation or siltation that could occur between (maintenance) dredging operations. This allowance is sometimes known as the 'Advance Maintenance' allowance. The dredged depth is purposely dredged deeper than the required nominal depth to give a cushion for anticipated sedimentation and increase the time before the next dredging cycle will be required. A similar allowance is needed for siltation of natural channels that are not normally dredged.
- The **dredging execution tolerance** is an over-dredging tolerance to ensure the nominal depth is achieved. The dredged bottom is not perfectly flat after dredging, so this over-dredge depth is often included to ensure the nominal depth is achieved.

1.3.4 Guidance on Minimum Required Channel Depth

Ship related factors are the most important in vertical channel design. Apart from ship draught T, the ship factors can be estimated separately for ship squat, dynamic heel and wave response allowance. For the purpose of this study, however, a simpler approach that combines them into one overarching ship related factor F_S is employed.

Ranges of values of minimum required channel depth are presented in Table 1-1.

Table 1-1: Determination of the Channel Depth

Vessel Speed	Wave Conditions	Channel Bottom	Inner Channel	Outer Channel
Ship Related factors F_S				
≤ 10 kts	None		1.10T	
10 – 15 kts			1.12T	
> 15 kts			1.15T	
All	Low swell: H_S < 1 m			1.15T to 1.2T
	Moderate swell: 1 m < H_S < 2 m			1.2T to 1.3T
	Heavy swell: H_S > 2 m			1.3T to 1.4T

Vessel Speed	Wave Conditions	Channel Bottom	Inner Channel	Outer Channel
Add for Channel Bottom Type				
All	All	Mud	0	0
		Sand/clay	0.4 m	0.5 m
		Rock/coral	0.6 m	1.0 m

For the outer channel the lower coefficient values are used for swell waves with period of 10 s, whereas higher values are used for the greater swell periods (more than 15 s).

1.4 Horizontal Channel Dimensions

1.4.1 Straight One Way Sections

The overall bottom width W of a straight one-way channel is determined as follows (Figure 1-3):

$$W = W_{BM} + \sum W_i + W_{BR} + W_{BG}, \text{ where:}$$

- W_{BM} – width of basic manoeuvring lane;
- $\sum W_i$ – additional widths to allow for the effects of wind, current etc;
- W_{BR}, W_{BG} – bank clearance on the 'red' and 'green' sides of the channel.

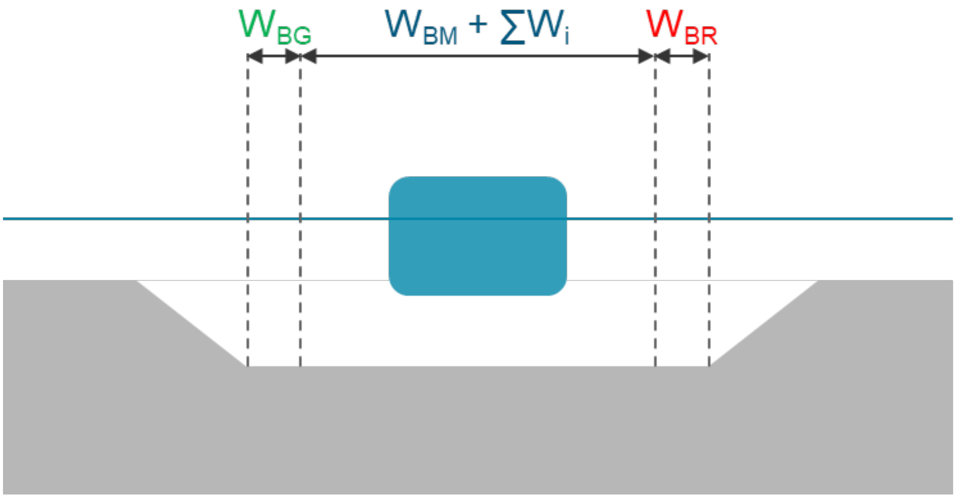

Figure 1-3: Channel Width Components Definition for one-way Channel

The following subsections cover each component in more detail.

1.4.1.1 Basic Manoeuvring Lane

The dynamics of ships are such that, when under manual control, they will follow a swept path, which, in the absence of any external forces from wind, waves, current, etc., will exceed their breadth by some amount.

This is due to the speed of response of both the ship-handler in interpreting the visual cues indicating the ship's position in the channel, and that of the ship in reacting to the rudder and main engine. The width of the swept path, which is the basic manoeuvring lane, will depend on a number of factors, but the key elements are:

- The inherent manoeuvrability of the ship (which will vary from ship to ship and with water depth/draught ratio).

- Ability of the ship-handler.
- Visual cues available to the ship-handler.
- Overall visibility.

The guideline distinguishes three manoeuvrability categories and their respective required minimum lane widths, which are presented in Table 1-2.

Table 1-2: Width of the Basic Manoeuvring Lane

Manoeuvrability	Good	Moderate	Poor
Basic Manoeuvring Lane, W_{BM}	1.3 B	1.5 B	1.8 B

1.4.1.2 Additional Width due to Environmental and Navigation Effects

Environmental and other navigation effects that require additional width are described below.

a) **Vessel Speed.** At higher vessel speeds the response time to deviation from the intended track becomes smaller, therefore requiring a wider channel.

b) **Cross wind.** Cross wind will affect the ship at all speeds but will have its greatest effect at low ship speeds. It is unlikely that a ship will be able to maintain a steady course at low speeds in a cross wind; the ship-handler will have to steer the ship slightly into the wind, resulting in the ship developing a drift angle and a slightly oscillatory course, therefore requiring a wider channel.

c) **Cross-current.** Cross-currents affect the course keeping motion similar to cross winds. However, in order to keep a straight course under cross-currents, the ship should be operated to run obliquely to the current, to compensate for the current velocity perpendicular to the ship's desired course (i.e. the line of the channel).

d) **Longitudinal current.** The longitudinal current affects the ship's ability to manoeuvre and stop.

e) **Waves.** The ship generally makes a yawing motion (see Figure 1-2) in waves due to unsteady wave forces. Therefore, the channel width should include the drift caused by such yawing.

f) **Aids to navigation.** Available aids to navigation and related aspects affect accuracy and variability of manoeuvring and the definition of channel boundaries and reference points. For positioning of a ship in a channel, there are many optical, radar and electronic devices for the channel and on board the ship. Availability of Aids to Navigation allows mariners to identify a vessel's location faster, improving reaction time and thus reducing minimum required width of the channel.

g) **Bottom surface.** The effect of bottom surface is only important in shallow waterways. Smooth and soft materials including silt and mud can affect both the manoeuvrability and propulsion of a ship. Hard channel bottom surfaces (i.e. rock, coral) will produce greater damage due to grounding than soft surfaces. Therefore, the shallower the water and harder the bottom, the wider the channel needs to be.

h) **Depth of the waterway.** Ship course stability generally increases as the water depth decreases. However, in shallow water also the turning ability is decreased and the vessel response to corrective rudder becomes sluggish. Therefore, the shallower the water the wider the channel needs to be for the slower response of the vessel.

Ranges of values of W_i, depending on characteristics of respective aspects, are presented in Table 1-3.

Table 1-3: Determination of Extra Widths due to Environmental and Other Navigation Conditions

Item	Aspect	Vessel Speed	Extra width
(a)	Vessel speed V_S (with respect to the water)		

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Item	Aspect	Vessel Speed	Extra width
	$V_S \geq 12$ kts	Fast	0.1 B
	8 kts $\leq V_S <$ 12 kts	Moderate	0
	5 kts $\leq V_S <$ 8 kts	Slow	0
(b)	Prevailing cross wind V_{cw}		
	Mild ($V_{cw} <$ 15 kts)	Fast	0.1 B
		Moderate	0.2 B
		Slow	0.3 B
	Moderate (15 kts $\leq V_{cw} <$ 33 kts)	Fast	0.3 B
		Moderate	0.4 B
		Slow	0.6 B
	Strong (33 kts $\leq V_{cw} <$ 48 kts)	Fast	0.5 B
		Moderate	0.7 B
		Slow	1.1 B
(c)	Prevailing cross-current V_{cc}		
	Negligible ($V_{cc} <$ 0.2 kts)	All	0
	Low (0.2 kts $\leq V_{cc} <$ 0.5 kts)	Fast	0.2 B
		Moderate	0.25 B
		Slow	0.3 B
	Moderate (0.5 kts $\leq V_{cc} <$ 1.5 kts)	Fast	0.5 B
		Moderate	0.7 B
		Slow	1 B
	Strong (1.5 kts $\leq V_{cc} <$ 2 kts)	Fast	1 B
		Moderate	1.2 B
		Slow	1.6 B
(d)	Prevailing longitudinal current V_{lc}		
	Low ($V_{lc} <$ 1.5 kts)	all	0

Item	Aspect	Vessel Speed	Extra width
	Moderate (1.5 kts $\le V_{lc} < 3$ kts)	Fast	0
		Moderate	0.1 B
		Slow	0.2 B
	Strong ($V_{lc} \ge 3$ kts)	Fast	0.1 B
		Moderate	0.2 B
		Slow	0.4 B
(e)	Beam and stern quartering wave height H_S		
	$H_S \le 1$m	All	0
	1 m < H_S < 3 m	All	0.5 B
	$H_S \ge 3$ m	All	1 B
(f)	Aids to Navigation		
	Excellent		0
	Good		0.2 B
	Moderate		0.4 B
(g)	Bottom Surface		
	If depth h ≥ 1.5 T		0
	If depth h < 1.5 T and the bed material is smooth and soft		0.1 B
	If depth h < 1.5 T and the bed material is rough and hard		0.2 B
(h)	Depth of Waterway		
	Deep waterway (h ≥ 1.5 T)		0
	Medium-depth waterway (1.5 T > h ≥ 1.25 T)		0.1 B
	Shallow waterway (h < 1.25 T)		0.2 B

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1.4.1.3 Bank Clearance

When a ship navigates in the vicinity of a channel edge, flow around the ship's hull varies and becomes laterally asymmetrical with respect to its longitudinal centre line. This generates hydrodynamic forces due to the asymmetrical flow. To avoid uncontrollable situations in a channel with underwater banks, additional width outside the manoeuvring lane is required. Values of the additional width, depending on the character of the bank and vessel's speed, are presented in Table 1-4.

Table 1-4: Additional Width for Bank Clearance

Width for bank clearance (W_{BR} and/or W_{BG})	Vessel Speed	Extra Width
Gentle underwater channel slope (1:10 or less steep)	Fast	0.2 B
	Moderate	0.1 B
	Slow	0
Sloping channel edges and shoals	Fast	0.7 B
	Moderate	0.5 B
	Slow	0.3 B
Steep and hard embankments, structures	Fast	1.3 B
	Moderate	1 B
	Slow	0.5 B

1.4.2 Straight Two Ways Sections

To avoid excessive interaction between two ships travelling past one another in a two-lane channel, it is necessary to separate the two manoeuvring lanes by a ship clearance lane. Values of the clearance lane, depending on the vessels' speed, are presented in Table 1-5. Total width of a two-way channel is determined as follows (Figure 1-4):

$$W = 2W_{BM} + 2\sum W_i + W_{BR} + W_{BG} + W_P$$, where:

- W_{BM}, W_i, W_{BR}, W_{BG} – components described in 1.4.1.
- W_P – width of the clearance lane between manoeuvring lanes.

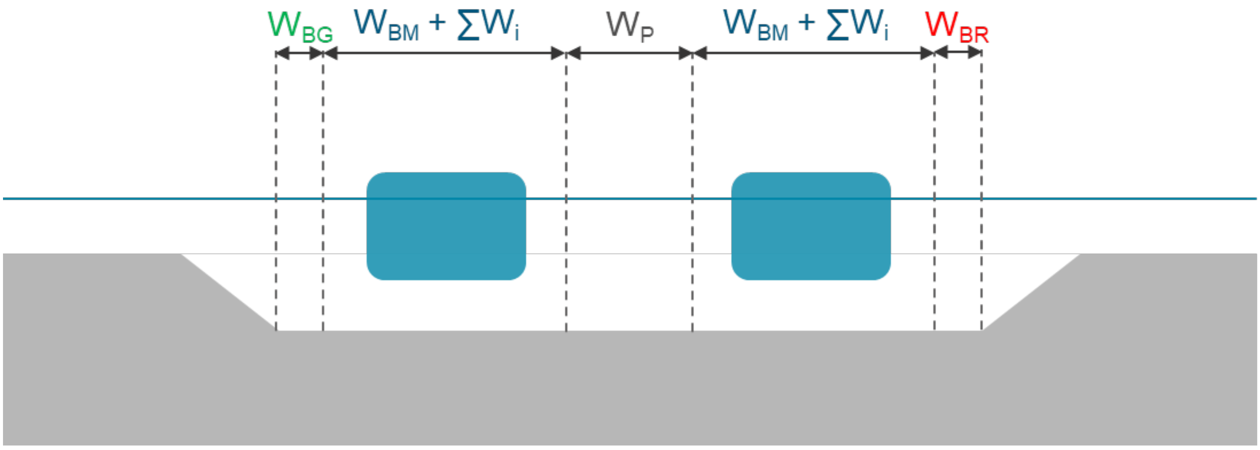

Figure 1-4: Channel Width Components Definition for two-way Channel

Table 1-5: Additional width for Passing Distance in two-way-traffic

Vessel speed V_S	Width for passing distance W_p
Fast ($V_S \geq 12$ kts)	2 B
Moderate (8 kts $\leq V_S <$ 12 kts)	1.6 B
Slow (5 kts $\leq V_S <$ 8 kts)	1.2 B

1.4.3 Bends

When navigating over curved stretches under constant environmental conditions over the whole track, the channel's width is determined with the same criteria as for navigating over straight sections, described in sections above. In bends, however, the width should be increased due to increased swept path and vessel's response speed. These factors are described in the following subsections.

1.4.3.1 Bend Radius

In determining bend radius and width, it is inadvisable to design bends which require hard-over rudder angles. This would give no 'reserve' of rudder to counter wind, wave or current and would therefore compromise safety. For Concept Design, it is suggested that turning radii and swept track width of the design ship at a steady rudder angle of less than hard-over should be used as a guide. Often ship-handlers require 15° to 20° rudder in a bend, as greater values give too little margin for safety and smaller values (implying a large radius) make turning difficult due to the length of the track and the handling problems of keeping a ship accurately on track in a gentle bend. Recommended turning radii for different ship types are presented in Table 1-6.

Table 1-6: Turning Radii for Different Ship Types

Ship Type	Turning Radius
Cargo ship	5 L_{OA}
Small cargo ship	6 L_{OA}
Container ship (over Panamax)	7 L_{OA}

Ship Type	Turning Radius
Container ship (Panamax)	6 L_{OA}
Very Large Bulk Carrier	6 L_{OA}
Large Bulk Carrier (Panamax)	6 L_{OA}
Small Bulk Carrier	5 L_{OA}
Very Large Crude Carrier	5 L_{OA}
Small tanker	5 L_{OA}
LNG ship	4 L_{OA}
Refrigerated cargo carrier	5 L_{OA}
Passenger ship	4 L_{OA}
Ferry boat	5 L_{OA}

1.4.3.2 Additional Swept Path Width

Additional width of the vessel's swept path produced by navigating with a drift angle in the bend (see Figure 1-5) is calculated as follows:

$$\Delta W_{DA} = \frac{L_{OA}^2}{aR_C}, \text{ where:}$$

- L_{OA} – vessel's length overall;
- a – factor depending on the ship type: $a = 8$ for normal ships and $a = 4.5$ for larger displacement ships.
- R_C – turning radius.

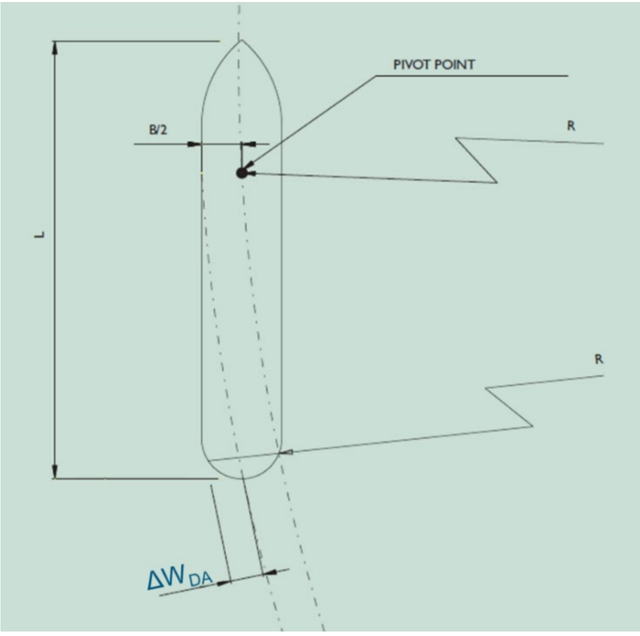

Figure 1-5: Additional Width for Turning[3]

1.4.3.3 Extra Width due to Vessel's Response Speed

This component is established for taking into consideration the manoeuvring difficulties caused by the ship not immediately responding to the handler's instructions and, consequently, the pilot must anticipate the manoeuvre by deviating from the fairway's theoretical axis. Additional width due to response speed in bends is calculated as follows:

$$\Delta W_{RT} = 0.4B,$$

where B is the vessel's beam.

[3] *Recommendations for Maritime Works: ROM 3.1-99*

2 Input Data

2.1 Design Vessels

Excerpt of data[4] on design vessels' parameters, relevant for determination of channel dimensions, is presented in Table 2-1. Vessel dimensions that are used for channel concept design are highlighted.

Table 2-1: Design Vessels

Parameter	15k TEU Container Ship	10k TEU Container Ship	7k TEU Container Ship	LR2 Tanker
DWT, t	200 000	125 000	81 000	110 000
L_{OA}, m	365	351	272	260
B, m	53.6	45.8	42.8	45.0
T_{max}, m	16.0	15.0	15.0	15.5
T_{op}, m	12.4	14.2	14.3	15.5

- Tanker LR2 will use high water to enter the port (approach known as "tidal window"), therefore, its draught is not used to determine the required channel depth[4].
- Draughts of 7k TEU and 10k TEU ships are the largest and are used to determine minimum required channel depth. Container vessels usually call at ports on a schedule, which is independent from the tide. Therefore, a tidal window approach is not usually applied to container traffic. When, at an early operational stage, the container traffic is still limited, the tidal window could also be applied on container vessels to balance dredging volumes and availability of the channel. For the purpose of this report it has been assumed that container vessels should have access to the port at all times.
- The 15k TEU container vessel is the widest design vessel and used to determine the channel width.
- In accordance with recommendations by earlier reports[4] the largest container vessel (15,000 TEU) is not expected to call at the new port fully loaded, hence the lower operational vessels draft than the smaller container vessels (10,000 TEU and 7,000 TEU).

2.2 Channel Sections

The navigation channel is divided in three sections (Figure 2-1) because the environmental conditions vary along the alignment. All sections are considered to be open water, and although the inner Harbour area is less exposed, it still cannot be considered protected water in the sense of a sheltered port area.

[4] *Manukau Harbour Port Feasibility Study – New Zealand Ports and Shipping Overview. Pacific Marine Management Ltd, 2023*

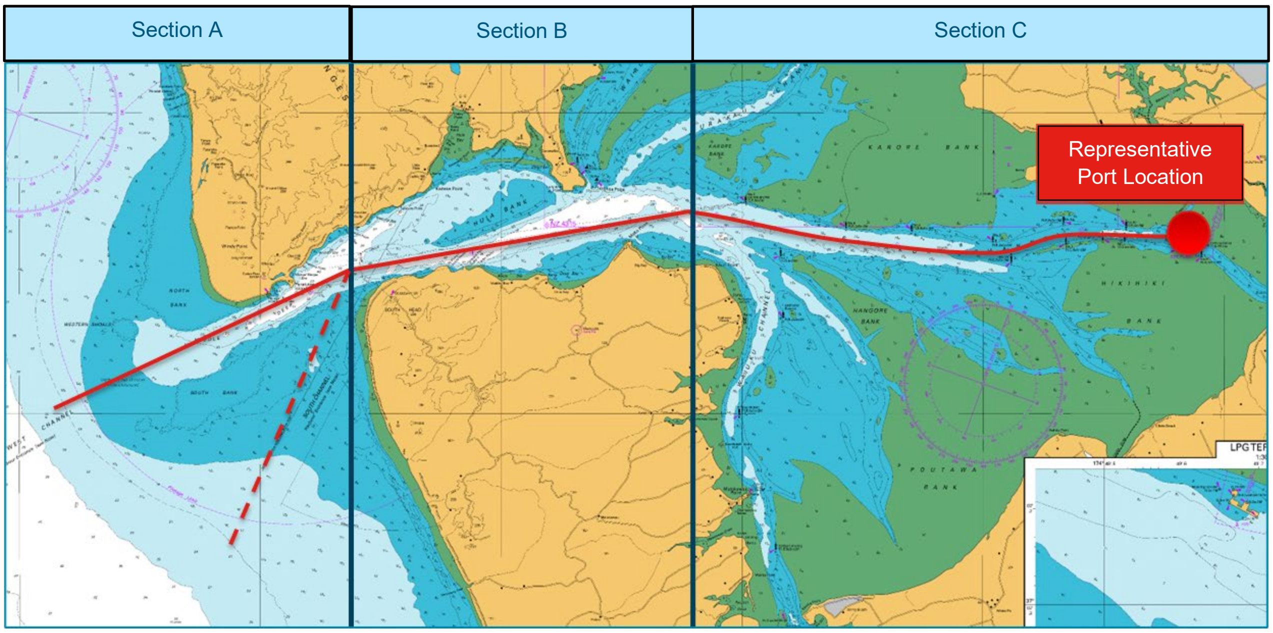

Figure 2-1: Channel Sections

- Section A: the open and exposed area, including the bar area.
- Section B: the passage between the northern and southern headlands with mainly deep-water where wind and currents show a tunnelling effect, longitudinal to the channel alignment.
- Section C: the inner harbour area with mainly shallow water where the governing wind and wind driven waves are perpendicular to the navigation channel.

2.3 Bathymetry

An extensive bathymetric survey campaign was carried out as part of the project scope of work. At this initial stage, since the design of the channel was carried out in parallel to these surveys, an initial assumed bathymetry was adopted (based on previous surveys and navigational charts), supplied by MetOcean Solutions.

2.4 Wind

Publicly available wind data is retrieved from the web portal of Auckland Council. Based on speed and direction datasets, spanning period from 2012 to 2022, wind roses were prepared (see Figure 2-2).

- Station 647301 is located nearshore and is relatively exposed, compared to station 740601, therefore, wind data retrieved for it is deemed representative of wind conditions at sea in the area encompassing the Channel Section A, located approximately 40 km away.
- Station 740601 is located in close proximity to the Channel Section B and is therefore deemed representative of wind conditions in the area. The station is sheltered by the landscape, which results in reduced presence of SW winds as can be seen in Figure 2-2.

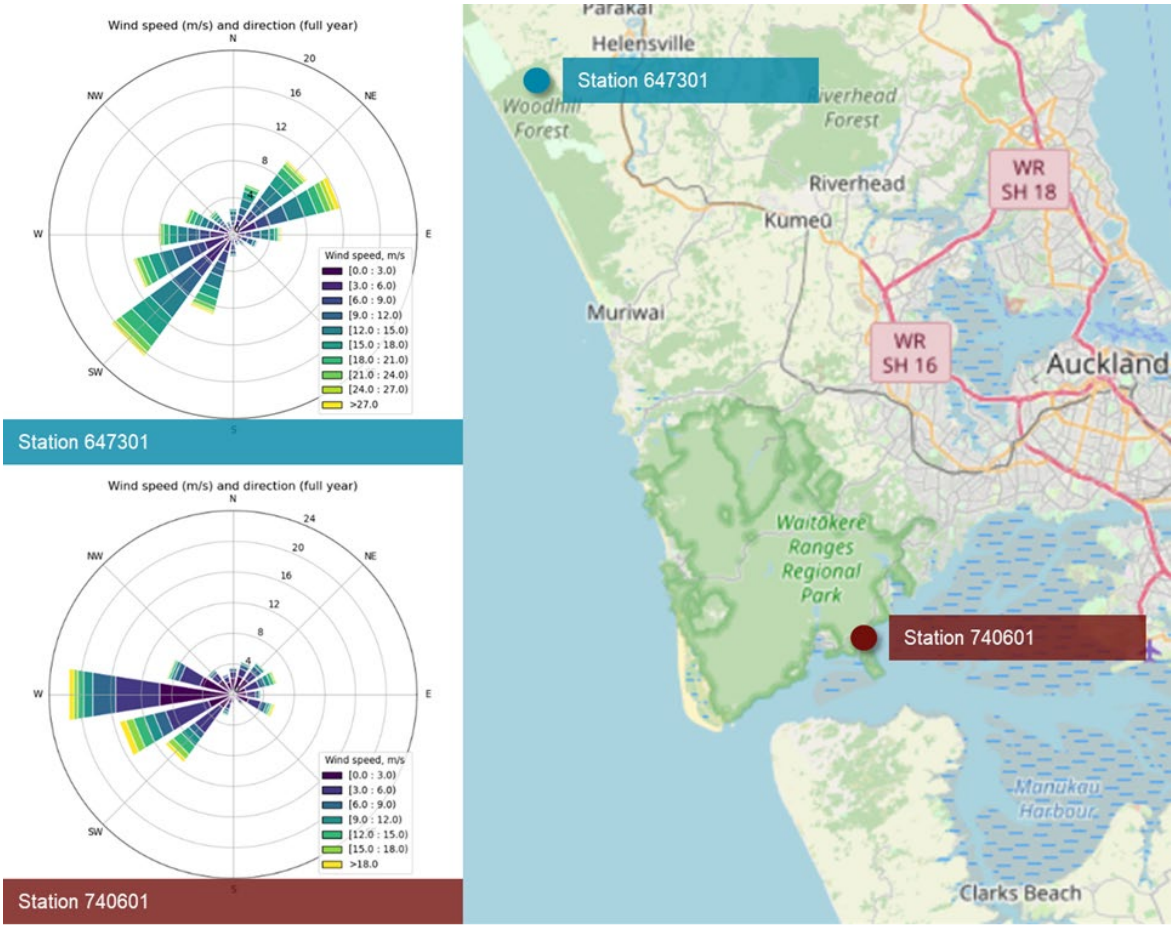

Figure 2-2: Wind Roses (based on Auckland Council records spanning 2012 - 2022)

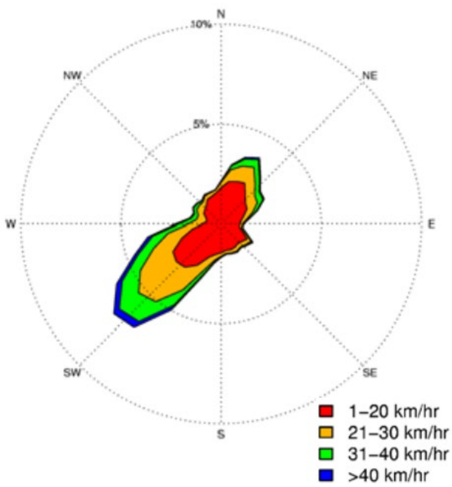

Figure 2-3: Wind Rose at Auckland Airport [5]

The wind rose (Figure 2-2) demonstrates that dominant wind directions are “west” and “southwest”. Despite wind speeds reaching 27 m/s (~52 kts), only their crosswind component is relevant to the design (see 1.4.1.2) of the navigation channel, which is obtained by accounting for the angle between the orientation of

[5] *The Climate and Weather of Auckland, 2nd Edition, NIWA*

the approach channel and dominant wind direction. Wind effect on channel width according to PIANC Guidelines[6] is as follows (see Table 1-3, item (b)):

- Section A: wind rose (station 647301) shows SW wind with speeds up to 50 kts with cross-component of 27 kts, which is within the **guideline "moderate" category (15 kts – 33 kts)**.
- Section B: wind rose (station 740601) shows W to SW wind with speeds up to 35 kts with cross-component of 9 kts, which is within the **guideline "mild" category (< 15 kts)**.
- Section C: wind rose of station 647301 is used to determine dominant wind direction in Section C, as no stations with sufficient wind records were found in the nearby area. Publicly available wind rose for Auckland Airport[7] (Figure 2-3) does not indicate upper limit of wind speeds, only showing the category "more than 40 km/h" (> 20 kts). Nevertheless, since both wind roses are obtained for relatively open areas (as opposed to the location of the station 740601, which is sheltered) and demonstrate similar frequencies, wind speed value was taken from wind rose for station 647301. The wind rose shows SW wind with speeds up to 40 kts, which is within the **guideline "strong" category (33 kts – 48 kts)**.

2.5 Waves

Offshore wave roses, presented in Figure 2-4, are retrieved from report prepared by eCoast[8]. These conditions, however, are only applicable in Section A of the channel. Based on experience in similar projects, wave heights in channel Sections B and C are expected to be in the range between 1 m – 2 m. The wave climate offshore and inside the harbour will be confirmed by ongoing wave modelling. Once the results of the modelling are available, the channel design will be reviewed and confirmed or updated.

Wave effect on **channel depth** is as follows (see Table 1-1):

- Section A: offshore wave rose shown in Figure 2-4 indicates that waves of 4 m H_S occur in the area. This wave height falls within the **guideline category of heavy swells (H_S > 2 m)**.
- Section B: H_S of 1.7 m falls within the **guideline category of moderate swells (1 m < H_S < 2 m)**.
- Section C: H_S of 1.7 m falls within the **guideline category of moderate swells**, however, in the area of Section C, waves are expected to be primarily wind-driven and therefore, less strict requirement to channel depth should be applied (see Section 3.4).

Wave effect on **channel width** according to PIANC Guidelines[6] is as follows (see Table 1-3, item (e)):

- Section A: offshore wave rose shows waves with H_S of 4 m and T_P around 15 s, which is within the **guideline category H_S > 3 m**.
- Section B and C: expected wave height falls within the **guideline category 1 m < H_S < 3 m**.

[6] *PIANC WG 121 – 2014.*
[7] *The Climate and Weather of Auckland, 2nd Edition, NIWA*
[8] *Numerical Modelling of the Manukau Harbour Entrance: High-Level Estimates of Dredged Entrance Channel Infilling, eCoast, 2020*

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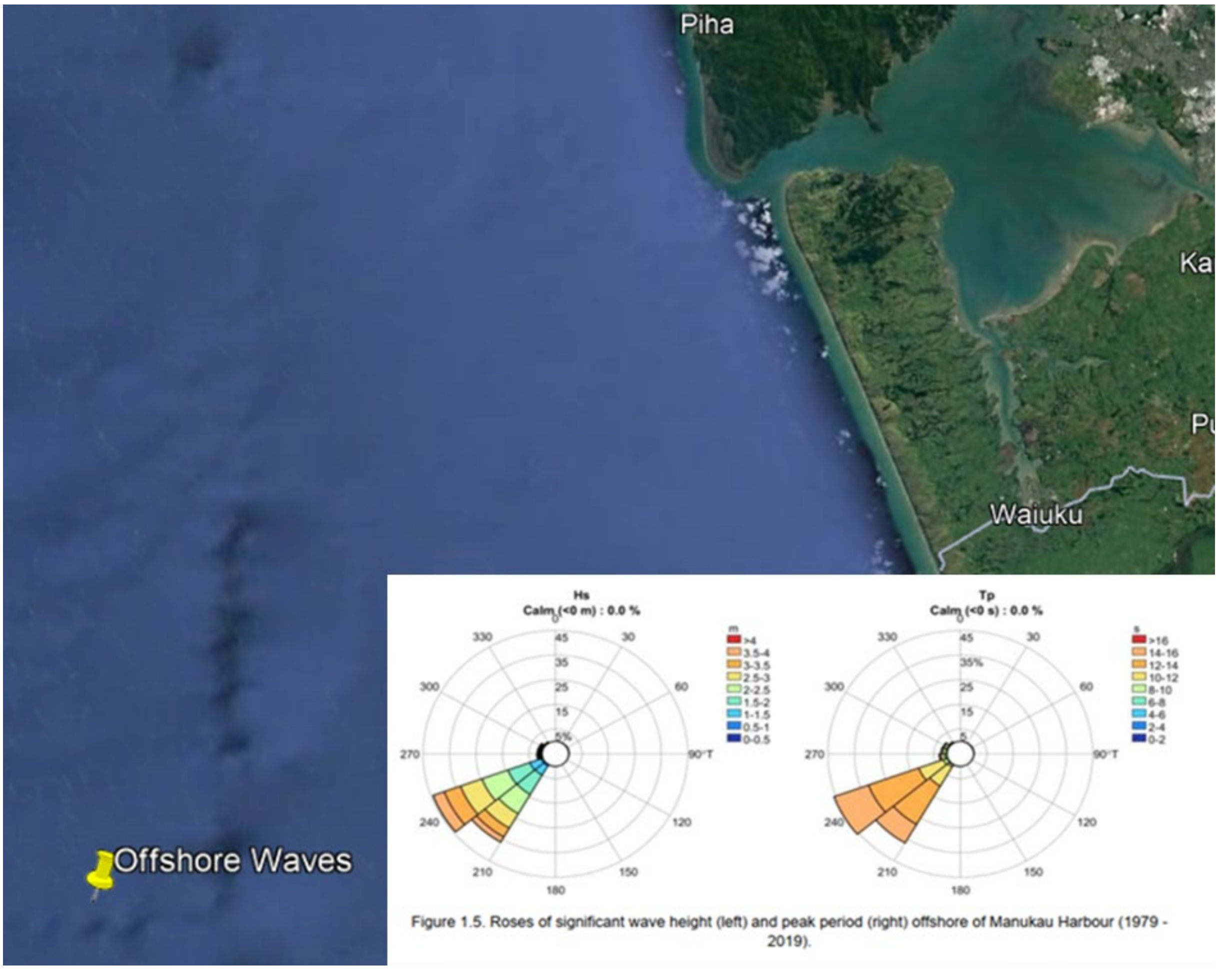

Figure 1.5. Roses of significant wave height (left) and peak period (right) offshore of Manukau Harbour (1979 - 2019).

Figure 2-4: Offshore Wave Rose[9]

2.6 Currents

2.6.1 Entrance Section (Channel Section A)

The PIANC Guideline recognizes cross current and longitudinal current. These will not appear at the same time. The current component with the largest influence on the channel design has been used. Current effects on the approach channel width according to PIANC Guidelines[10] is as follows (see Table 1-3, items (c) and (d)):

- As indicated in the eCoast report[8], longitudinal current in the area is expected to reach 4 m/s (8 kts), which exceeds current speeds indicated in the nautical chart[11]. Nevertheless, for the purpose of channel design, current speed is conservatively assumed to be 4 m/s (8 kts). Guideline considers this to be **Strong (> 3 kts)**, and for a vessel at Slow sailing speed (< 8 kts) an additional width of 0.4*B (B - vessel beam) should be added.
- Cross current is expected to reach 1 m/s (2 kts), as per eCoast report[8]. Guideline considers this to be **Moderate (1.5 kts – 3.0 kts)**, and for a vessel at Slow sailing speed (< 8 kts) an additional width of a 1.0*B should be added.

[9] Numerical Modelling of the Manukau Harbour Entrance: High-Level Estimates of Dredged Entrance Channel Infilling, eCoast
[10] PIANC WG 121 - 2014
[11] Nautical Chart for Manukau Harbour, 2012

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The Moderate Cross current has the largest influence on the channel width and therefore it will be used for determination of channel width in the Section A.

2.6.2 Harbour Sections (Channel Sections B & C)

Deepening of the existing channels in Section C slows current speeds down. Therefore, conservatively taken, the present current speeds as described in report by eCoast[12] are assumed for Sections B and C.

- Longitudinal current is expected to reach 1.6 m/s (3.1 kts). Because this value is on the margin between "Moderate" and "Strong" categories and because this speed is conservative, the Guideline category **Moderate (1.5 kts – 3 kts)** is used.
- Cross current is negligible.

2.7 Geotechnical Conditions

Geotechnical conditions made available to the design team are based on geotechnical investigation performed by Beca in 1988. Soil profiles relevant for the channel design are summarised in Table 2-2; locations of the boreholes are reflected in Figure 2-5.

Table 2-2: Draft Simplified Soil Profile (by T+T)

(a) Middle of the Harbour
Based on M4 & M13 – M15

Depth (m below seabed)	Soil description
0 – 11 m	Compact SAND
11 – 21 m	Stiff sandy SILT/CLAY
Below 21 m (EOH at 23.9 m)	Dense SAND

(b) South-eastern Banks
Based on M7 & M8

Depth (m below seabed)	Soil description
0 – 5.4 m	Very soft to soft sandy SILT/clayey silt Top 3 m soils could be loosely packed sandy layer
5.4 – 6.4 (or 10) m	Stiff SILT/CLAY
Below 6.4 (or 10) m (EOH at 10.45 m)	Densely packed SAND

Soil effect on channel depth according to PIANC Guidelines[13] is as follows (see Table 1-1):

- All Sections: bottom of the channel is situated within layers that belong to **the guideline category "Sand/Clay"**.

Soil effect on channel width according to PIANC Guidelines is as follows:

- All Sections:
  - Extra channel width due to bottom surface (see Table 1-3, items (g) and (h)): bottom of the channel is situated within layers that belong to **the guideline category "Smooth and Soft"**
  - Bank clearance (Table 1-4): where channel crosses through the area that will require underwater slopes steeper than 1:10, which **PIANC guideline recognizes as "Sloping channel edges and shoals"**.

[12] *Numerical Modelling of the Manukau Harbour Entrance: High-Level Estimates of Dredged Entrance Channel Infilling, eCoast, 2020*
[13] *PIANC WG 121 - 2014*

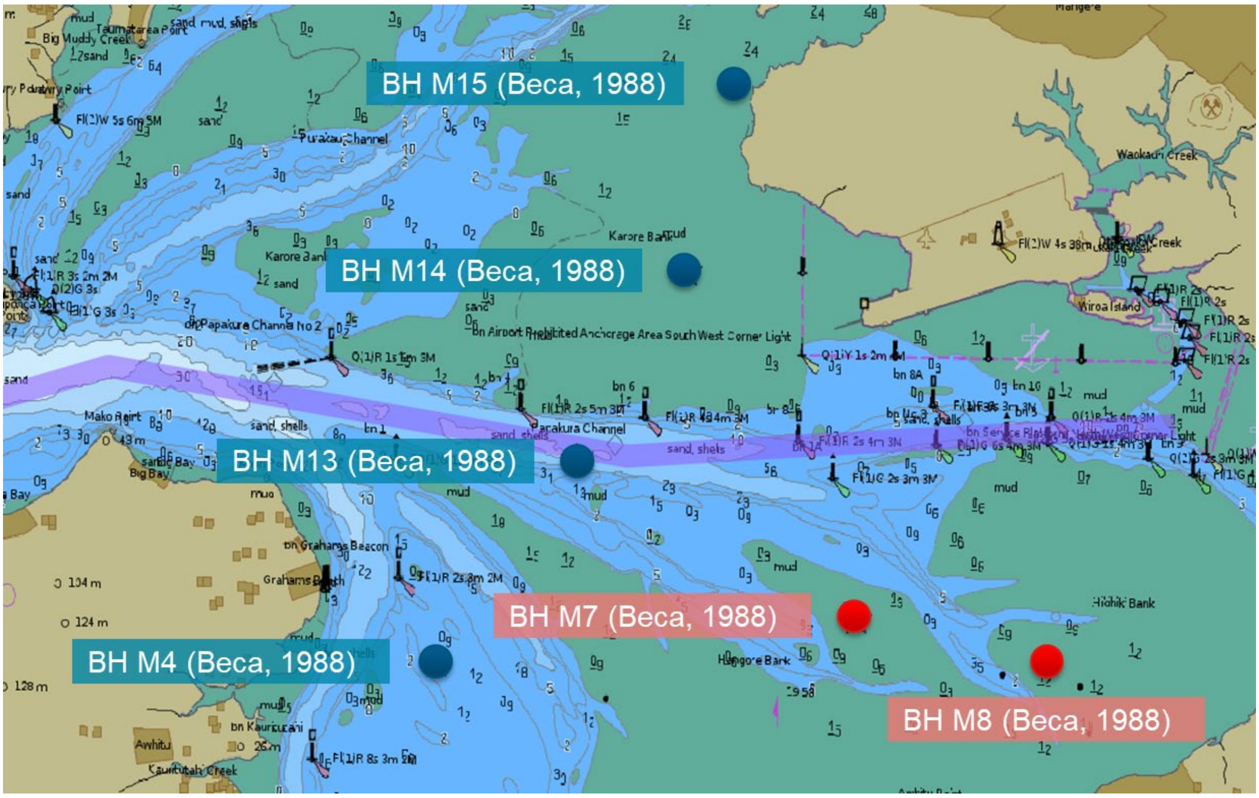

Figure 2-5: Marine Boreholes Location in the Area Adjacent to the Channel

2.8 Summary of Assumptions

- Two alignment options for Section A are possible: a South West Channel and a South Channel (Figure 2-1). At this stage the channel depth and the channel width are assumed to be equal for both options, as they are exposed to more or less the same environmental conditions.
- Sections A and C will have a one-lane width to minimise dredging volumes. This has some operational consequences that are described in section 4.1.
- Section B will have a two-lane width. There is no need to restrict this Section to one-lane only as it is located in a naturally deep and wide area that can accommodate two-way traffic and could serve as a passing and/or waiting area. Such channel configuration (one-way – two-way – one-way) is proposed as it is deemed sufficient for the envisioned traffic. The configuration might change in the future, should the further economic investigations suggest different traffic intensity.
- For the channel Section B and C mainly wind driven wave heights in the order of 1 m – 2 m H_S are expected.
  - For channel width this falls inside the guidance range of 1 m < H_S < 3 m (see Table 1-3, item I).
  - For channel depth:
    - This falls inside the guidance range of 1m < H_S < 2m (see Table 1-1).
    - Swell waves are assumed to be entering Section B, but no swell waves will propagate into Section C.
- For all channel Sections a conservative vessel sailing speed of less than 8 kts is assumed. Higher sailing speeds generally lead to narrower channels, otherwise a speed limit of 8 knots is assumed. For

the sailing speed in Section A also the swell conditions play a role which will likely require a sailing speed below 8 knots to avoid broaching.

- No tug support is envisioned for Sections A and B, because if the vessel must rely on tug support in these sections it will become logistically challenging. Nevertheless, in practice use of tugs could be an option.
- Tanker LR2 will use high water to enter the port, therefore, its draught is not used to determine required channel depth.
- Draughts of 7k TEU and 10k TEU ships are the largest and are used to determine minimum required channel depth.
- The 15k TEU container vessel is the widest design vessel and used to determine channel width.

3 Calculation Results

3.1 All Sections

1. Container vessels' manoeuvrability is categorized as "Moderate", therefore, width of basic manoeuvrability lane for all Sections is 1.5B (see Table 1-2), where *B* is the vessel's beam.
2. Turning Radii of all bends is 2800 m following guidance that suggests the radius for over Panamax vessel (container ships with capacity of 5k TEU and larger) to be 7 times the vessel overall length (in the case under consideration, L_{OA} of the 15k TEU ship is 387 m). Additional width of 30 m is introduced in bends to accommodate wider swept path and vessels' response speed (see Section 1.4.3).
3. Where existing depth is less than minimum required channel depth, dredging will be performed to create the channel, thus introducing underwater slopes. Banks of the channel in such sections are suggested to have slopes steeper than 1:10, where bed material allows, to minimize dredging:
    a. Section A (over the bar):
        i. Above -12 mCD, in loose sand: 1:25 (no bank clearance would be required).
        ii. Below -12 mCD, in dense sand: 1:7.5.
    b. Sections B and C (inner sections):
        i. In loose silty/clayey sand: 1:5.
        ii. In firm to hard clays: 1:3.

    Extra width of 0.3B is introduced for bank clearance on each side of the channel (see 1.4.1.3).

3.2 Channel Section over the Bar (Section A)

3.2.1 Width

Section A of the channel is a one-way section.

The minimum required width of Section A is as follows:

$$W = W_{BM} + \sum W_i + W_{BR} + W_{BG} =$$

$$= 1.5B + 3.4B + 0.3B + 0.3B = 5.5B = 294.8m, \text{ where:}$$

- *B*: width of the 15k TEU container vessel (B = 53.6 m).

Calculation of extra width due to environmental and other navigation conditions ($\sum W_i$) is presented in Appendix A2.1.

The width of Section A of the navigation channel is therefore 295 m.

3.2.2 Depth

The minimum required depth of Section A is as follows:

$$h = 1.4T + 0.5 = 20.5m, \text{ where:}$$

- *h: water depth (relative to LAT)*
- *1.4T*: ship-related factor F_S for heavy swell (see Table 1-1), with *T* being the operational draught of the 7k TEU container vessel (T = 14.3 m)
- *0.5*: extra depth due to channel bottom type (for "sand/clay" bottom type).

The depth of Section A of the navigational channel is therefore 20.5 m below LAT.

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3.3 Channel Section between South Head and Kauri Point (Section B)

3.3.1 Width

Section B of the channel is a two-way section.

The minimum required width of Section B is as follows:

$$W = 2W_{BM} + 2\sum W_i + W_{BR} + W_{BG} + W_P =$$

$$= 2 * 1.5B + 2 * 1.4B + 0.3B + 0.3B + 1.2B = 7.6B = 407.4m, \text{ where:}$$

- *B* – width of the 15k TEU container vessel (B = 53.6 m).

Calculation of extra width due to environmental and other navigation conditions ($\sum W_i$) is presented in Appendix A3.1.

The width of the Section B of the channel is therefore 410 m.

3.3.2 Depth

The minimum required depth of Section B is as follows:

$$h = 1.3T + 0.5 = 19.1m, \text{ where:}$$

- *h:* water depth (relative to LAT)
- *1.3T*: ship-related factor F_S for moderate swell (see Table 1-1), with *T* being the operational draught of the 7k TEU container vessel (T = 14.3 m)
- *0.5:* extra depth due to channel bottom type (for “sand/clay” bottom type).

The depth of Section B of the navigation channel is therefore 19.1 m below LAT.

3.4 Channel Section between Kauri Point and the Terminal (Section C)

3.4.1 Width

Section C of the navigation channel is a one-way section.

The minimum required width of Section C is as follows:

$$W = W_{BM} + \sum W_i + W_{BR} + W_{BG} =$$

$$= 1.5B + 2B + 0.3 + 0.3 = 4.1B = 219.8m, \text{ where:}$$

- *B*: width of the 15k TEU container vessel (B = 53.6 m).

Calculation of extra width due to environmental and other navigation conditions ($\sum W_i$) is presented in Appendix A4.1.

The width of Section C of the navigation channel is therefore 220 m.

3.4.2 Depth

The minimum required depth of Section C is as follows:

$$h = 1.2T + 0.5 = 17.7m, \text{ where:}$$

- *h:* water depth (relative to LAT)
  - *1.2T:* ship-related factor F_S. Although wave conditions, based on assumed wave height, fall within the guideline category “moderate swell” (see Table 1-1), the lower value of 1.2 is selected, as waves entering the area of Section C are expected to be wind-driven.
  - *T*: operational draught of the 7k TEU container vessel (T = 14.3 m)

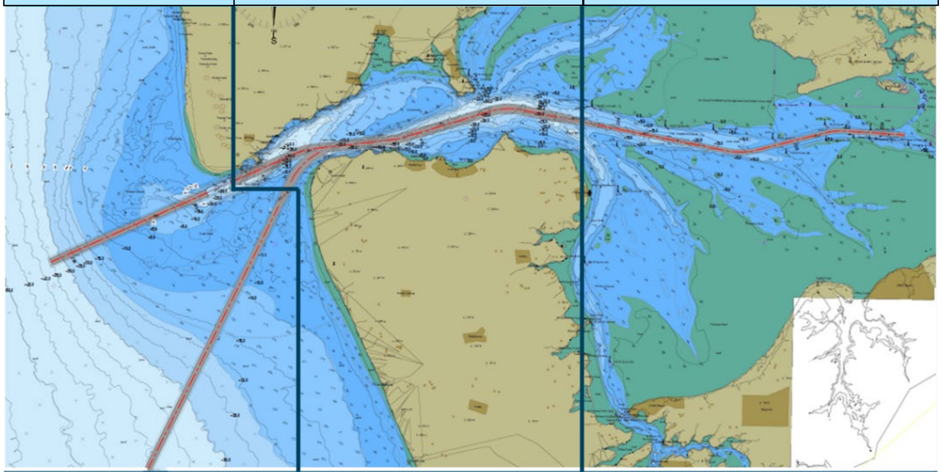
- *0.5*: extra depth due to channel bottom type (for "sand/clay" bottom type).

Depth of the Section C of the channel is therefore 17.7 m below LAT.

3.5 Results Summary

Determined channel dimensions are presented in Figure 3-1.

Section A	Section B	Section C



Channel Widths (m) (determined by 15k TEU Container Vessel)		
one-lane 295	two-lane 410	one-lane 220
Channel Depths (m CD) (determined by T_{op}= 14.3m of the 7k & 10k TEU Container Vessel)		
20.5	19.1	17.7

Figure 3-1: Results Summary

4 Discussion & Way Forward

Operational considerations play an important role in channel design, feed into the risk assessment and may justify altering the initial design. Discussion on operational details, as well as the way forward, are presented in this chapter.

4.1 Operational Details & Risk Mitigation Measures

- A channel width smaller than the length of the largest vessel introduces the risk that the vessel can be grounded with bow and stern on opposite sides of the channel. This can be mitigated by widening the channel or by introducing operational limits such as transiting against the tidal current only for ships that are too long, pilot training, (escort-) tug support, salvage readiness, etc.
- One-lane channel sections may require traffic management and holding/waiting areas in Section B. Some natural spaces are available for holding/waiting, but it may also be necessary to dredge or otherwise realise these.
- One-lane channel sections may be used as a two-lane channel by small vessels. This will increase the channel capacity.
- Anchorage areas offshore may need to be identified with proper water depth and good holding ground. Waiting vessels can also decide to slow steam, circle or drift during waiting.

- Maintenance dredging operations can influence the availability of the channel. Dredging operations will need to be clearly communicated and planned with minimum impact on port access.
- Port location is indicative. Adjustment at a later stage is possible but will influence the dredging volume (length of the channel, manoeuvring area).
- Pilot boarding in extreme conditions may be challenging, but there are various options such as helicopter boarding.
- As mentioned in Section 2.8, LR2 tankers and other deep draft vessels will utilise tidal window to enter the port. These vessels will require tidal increase in addition to the design depth of 1.7 m in Section A and 1.4 m in Section C of the channel. In Section B the natural depth is such that the LR2 tanker etc. does not require the tidal window.

4.2 Way Forward

Selection of one of the two alignments of the Section A: South West Channel or South Channel route. From navigation perspective both options can be made feasible with similar dimensions for channel width and channel depth. The following is noted:

- In the South Channel the bend angle at the transition between Sections A and B is larger, but there is sufficient natural space and water depth to accommodate the larger bend with extra width.
- The two channels have a different orientation relative to the swell/waves. In the South West Channel the vessel is likely more prone to pitching, whereas in the South Channel the vessel is likely more prone to rolling.

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A1 Channel Section A – Calculation Notes

A1.1 Section A – Extra Width due to Environmental and Other Navigation Conditions (selected values highlighted)

Item	Aspect	Vessel Speed	Extra width
(a)	Vessel speed V_S (with respect to the water)		
	$V_S \geq 12$ kts	Fast	0.1 B
	8 kts $\leq V_S <$ 12 kts	Moderate	0
	5 kts $\leq V_S <$ 8 kts	Slow	0
(b)	Prevailing cross wind V_{cw}		
	Mild ($V_{cw} <$ 15 kts)	Fast	0.1 B
		Moderate	0.2 B
		Slow	0.3 B
	Moderate (15 kts $\leq V_{cw} <$ 33 kts)	Fast	0.3 B
		Moderate	0.4 B
		Slow	0.6 B
	Strong (33 kts $\leq V_{cw} <$ 48 kts)	Fast	0.5 B
		Moderate	0.7 B
		Slow	1.1 B
(c)	Prevailing cross-current V_{cc}		
	Negligible ($V_{cc} <$ 0.2 kts)	All	0
	Low (0.2 kts $\leq V_{cc} <$ 0.5 kts)	Fast	0.2 B
		Moderate	0.25 B
		Slow	0.3 B
	Moderate (0.5 kts $\leq V_{cc} <$ 1.5 kts)	Fast	0.5 B
		Moderate	0.7 B
		Slow	1 B
		Fast	1 B

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Item	Aspect	Vessel Speed	Extra width
	Strong (1.5 kts ≤ V_{cc} < 2 kts)	Moderate	1.2 B
		Slow	1.6 B
(d)	Prevailing longitudinal current V_{lc}		
	Low (V_{lc} < 1.5 kts)	all	0
	Moderate (1.5 kts ≤ V_{lc} < 3 kts)	Fast	0
		Moderate	0.1 B
		Slow	0.2 B
	Strong (V_{lc} ≥ 3 kts)	Fast	0.1 B
		Moderate	0.2 B
		Slow	0.4 B
(e)	Beam and stern quartering wave height H_S		
	H_S ≤ 1m	All	0
	1 m < H_S < 3 m	All	0.5 B
	H_S ≥ 3 m	All	1 B
(f)	Aids to Navigation		
	Excellent		0
	Good		0.2 B
	Moderate		0.4 B
(g)	Bottom Surface		
	If depth h ≥ 1.5 T		0
	If depth h < 1.5 T and the bed material is smooth and soft		0.1 B
	If depth h < 1.5 T and the bed material is rough and hard		0.2 B
(h)	Depth of Waterway		
	Deep waterway (h ≥ 1.5 T)		0
	Medium-depth waterway		0.1 B

Item	Aspect	Vessel Speed	Extra width
	(1.5 T > h ≥ 1.25 T)		
	Shallow waterway (h < 1.25 T)		0.2 B
		Sum of W_i	3.4 B

A1.2 Section A – Depth (selected values highlighted)

Vessel Speed	Wave Conditions	Channel Bottom	Inner Channel	Outer Channel
Ship Related factors F_S				
≤ 10 kts	None		1.10T	
10 – 15 kts			1.12T	
> 15 kts			1.15T	
All	Low swell: H_S < 1 m			1.15T to 1.2T
	Moderate swell: 1 m < H_S < 2 m			1.2T to 1.3T
	Heavy swell: H_S > 2 m			1.3T to **1.4T**
Add for Channel Bottom Type				
All	All	Mud	0	0
		Sand/clay	0.4 m	**0.5 m**
		Rock/coral	0.6 m	1.0 m

A2 Channel Section B – Calculation Notes

A2.1 Section B – Width (selected values highlighted)

Item	Aspect	Vessel Speed	Extra width
(a)	Vessel speed V_S (with respect to the water)		
	V_S ≥ 12 kts	Fast	0.1 B
	8 kts ≤ V_S < 12 kts	Moderate	0

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Item	Aspect	Vessel Speed	Extra width
	5 kts ≤ V_S < 8 kts	Slow	0
(b)	Prevailing cross wind V_{cw}		
	Mild (V_{cw} < 15 kts)	Fast	0.1 B
		Moderate	0.2 B
		Slow	0.3 B
	Moderate (15 kts ≤ V_{cw} < 33 kts)	Fast	0.3 B
		Moderate	0.4 B
		Slow	0.6 B
	Strong (33 kts ≤ V_{cw} < 48 kts)	Fast	0.5 B
		Moderate	0.7 B
		Slow	1.1 B
(c)	Prevailing cross-current V_{cc}		
	Negligible (V_{cc} < 0.2 kts)	All	0
	Low (0.2 kts ≤ V_{cc} < 0.5 kts)	Fast	0.2 B
		Moderate	0.25 B
		Slow	0.3 B
	Moderate (0.5 kts ≤ V_{cc} < 1.5 kts)	Fast	0.5 B
		Moderate	0.7 B
		Slow	1 B
	Strong (1.5 kts ≤ V_{cc} < 2 kts)	Fast	1 B
		Moderate	1.2 B
		Slow	1.6 B
(d)	Prevailing longitudinal current V_{lc}		
	Low (V_{lc} < 1.5 kts)	all	0
	Moderate (1.5 kts ≤ V_{lc} < 3 kts)	Fast	0
		Moderate	0.1 B

Item	Aspect	Vessel Speed	Extra width
		Slow	0.2 B
	Strong (V_{lc} ≥ 3 kts)	Fast	0.1 B
		Moderate	0.2 B
		Slow	0.4 B
(e)	Beam and stern quartering wave height H_S		
	H_S ≤ 1m	All	0
	1 m < H_S < 3 m	All	0.5 B
	H_S ≥ 3 m	All	1 B
(f)	Aids to Navigation		
	Excellent		0
	Good		0.2 B
	Moderate		0.4 B
(g)	Bottom Surface		
	If depth h ≥ 1.5 T		0
	If depth h < 1.5 T and the bed material is smooth and soft		0.1 B
	If depth h < 1.5 T and the bed material is rough and hard		0.2 B
(h)	Depth of Waterway		
	Deep waterway (h ≥ 1.5 T)		0
	Medium-depth waterway (1.5 T > h ≥ 1.25 T)		0.1 B
	Shallow waterway (h < 1.25 T)		0.2 B
Sum of W_i			1.4 B

A2.2 Section B – Depth (selected values highlighted)

Vessel Speed	Wave Conditions	Channel Bottom	Inner Channel	Outer Channel

Ship Related factors F_S				
≤ 10 kts	None		1.10T	
10 – 15 kts			1.12T	
> 15 kts			1.15T	
All	Low swell: H_S < 1 m			1.15T to 1.2T
	Moderate swell: 1 m < H_S < 2 m			1.2T to **1.3T**
	Heavy swell: H_S > 2 m			1.3T to 1.4T
Add for Channel Bottom Type				
All	All	Mud	0	0
		Sand/clay	0.4 m	**0.5 m**
		Rock/coral	0.6 m	1.0 m

A3 Channel Section C – Calculation Notes

A3.1 Section C – Width (selected values highlighted)

Item	Aspect	Vessel Speed	Extra width
(a)	Vessel speed V_S (with respect to the water)		
	V_S ≥ 12 kts	Fast	0.1 B
	8 kts ≤ V_S < 12 kts	Moderate	0
	5 kts ≤ V_S < 8 kts	Slow	0
(b)	Prevailing cross wind V_{cw}		
	Mild (V_{cw} < 15 kts)	Fast	0.1 B
		Moderate	0.2 B
		Slow	0.3 B
	Moderate (15 kts ≤ V_{cw} < 33 kts)	Fast	0.3 B
		Moderate	0.4 B
		Slow	0.6 B

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Item	Aspect	Vessel Speed	Extra width
	Strong ($33 \text{ kts} \leq V_{cw} < 48 \text{ kts}$)	Fast	0.5 B
		Moderate	0.7 B
		Slow	1.1 B
(c)	Prevailing cross-current V_{cc}		
	Negligible ($V_{cc} < 0.2 \text{ kts}$)	All	0
	Low ($0.2 \text{ kts} \leq V_{cc} < 0.5 \text{ kts}$)	Fast	0.2 B
		Moderate	0.25 B
		Slow	0.3 B
	Moderate ($0.5 \text{ kts} \leq V_{cc} < 1.5 \text{ kts}$)	Fast	0.5 B
		Moderate	0.7 B
		Slow	1 B
	Strong ($1.5 \text{ kts} \leq V_{cc} < 2 \text{ kts}$)	Fast	1 B
		Moderate	1.2 B
		Slow	1.6 B
(d)	Prevailing longitudinal current V_{lc}		
	Low ($V_{lc} < 1.5 \text{ kts}$)	all	0
	Moderate ($1.5 \text{ kts} \leq V_{lc} < 3 \text{ kts}$)	Fast	0
		Moderate	0.1 B
		Slow	0.2 B
	Strong ($V_{lc} \geq 3 \text{ kts}$)	Fast	0.1 B
		Moderate	0.2 B
		Slow	0.4 B
(e)	Beam and stern quartering wave height H_S		
	$H_S \leq 1\text{m}$	All	0
	$1 \text{ m} < H_S < 3 \text{ m}$	All	0.5 B
	$H_S \geq 3 \text{ m}$	All	1 B

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Item	Aspect	Vessel Speed	Extra width
(f)	Aids to Navigation		
	Excellent		0
	Good		0.2 B
	Moderate		0.4 B
(g)	Bottom Surface		
	If depth h ≥ 1.5 T		0
	If depth h < 1.5 T and the bed material is smooth and soft		0.1 B
	If depth h < 1.5 T and the bed material is rough and hard		0.2 B
(h)	Depth of Waterway		
	Deep waterway (h ≥ 1.5 T)		0
	Medium-depth waterway (1.5 T > h ≥ 1.25 T)		0.1 B
	Shallow waterway (h < 1.25 T)		0.2 B
Sum of W_i			2.0 B

A3.2 Section C – Depth (selected values highlighted)

Vessel Speed	Wave Conditions	Channel Bottom	Inner Channel	Outer Channel
Ship Related factors F_S				
≤ 10 kts	None		1.10T	
10 – 15 kts			1.12T	
> 15 kts			1.15T	
All	Low swell: H_S < 1 m			1.15T to 1.2T
	Moderate swell: 1 m < H_S < 2 m			**1.2T** to 1.3T

Vessel Speed	Wave Conditions	Channel Bottom	Inner Channel	Outer Channel
	Heavy swell: H_S > 2 m			1.3T to 1.4T
Add for Channel Bottom Type				
All	All	Mud	0	0
		Sand/clay	0.4 m	**0.5 m**
		Rock/coral	0.6 m	1.0 m

B. Under Keel Clearance Assessment

REPORT

Probabilistic Under Keel Clearance Study

Client: T+T

Reference: PA3148-RHD-XX-XX-RP-X-0003

Status: S0/P01.01

Date: 4 December 2023

Royal HaskoningDHV
Enhancing Society Together

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Document title:	Probabilistic Under Keel Clearance Study
Subtitle:	
Reference:	PA3148-RHD-XX-XX-RP-X-0003
Your reference	
Status:	S0/P01.01
Date:	4 December 2023
Project name:	Manukau Harbour PFS
Project number:	PA3148
Author(s):	Coen Eggermont

Drafted by:	Coen Eggermont
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Date:	27/11/2023
Approved by:	Bas van Dijk
Date:	30/11/2023

Classification
Project related

Table of Contents

Appendices

1 Introduction

Earlier studies identified that the current Ports of Auckland Ltd (POAL) freight operation in the Waitematā Harbour is likely to run out of capacity to cater for Auckland's long-term freight needs. The Manukau Harbour has previously been identified as a potential port location. However, there are unanswered questions around the technical feasibility of this given the complex and dynamic nature of the harbour entrance along with other factors associated with greenfield port development.

Te Manatū Waka / the New Zealand Ministry of Transport has appointed Tonkin & Taylor Ltd and their subconsultants (Royal HaskoningDHV, MetOcean Solutions, Pacific Marine Management, the University of Auckland, Discovery Marine Limited, and RMA Science) to undertake a feasibility study to understand whether it would be technically possible to locate a port in the Manukau Harbour from a navigation and operational reliability perspective. Environmental, social, and economic factors are not part of the current scope of work.

This study will support on-going work by the Ministry on the National Freight and Supply Chain Strategy, which is examining New Zealand's freight system for the next 30 years.

1.1 Purpose of the Document

This document is drafted to explain the analysis approach which was used to determine a sufficiently safe channel depth which avoids excessive risk of bottom touch without being overly conservative.

- **Section 2** describes a simplified description of the methodology with the aim to provide a general understanding of the followed approach.
- **Section 3** provides an overview of the used input information for the channel depth assessment.
- **Section 4** presents the results of the analysis.
- **Section 5** presents the conclusions regarding required channel depth and further recommendations for future design and studies.
- **The Appendices** provide a summarised overview of the mathematical and technical description of the used methodology.

2 Overview Methodology

When assessing the required channel depth to ensure safety for vessels while in transit, the risk of bottom touch is an important factor. Waves and currents affect the motions of a vessel when sailing through the channel resulting in vertical motions of the vessel. To avoid the vessel hitting the bottom of the channel due to these motions, additional margin is required. The margin in water depth, exceeding the vessel draught, is called the “gross under keel clearance” or gross UKC. Within the UKC, margins for different influences are included, as displayed in Figure 2-1.

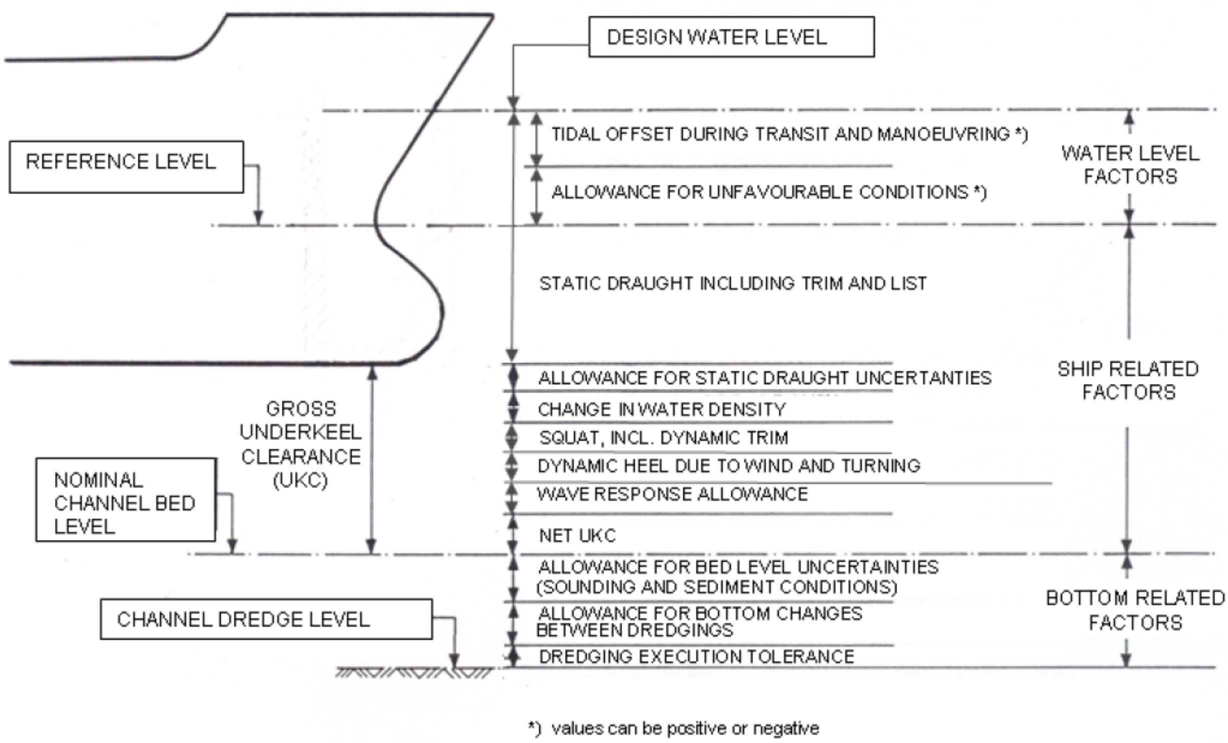


Figure 2-1: under keel clearance schematisation [1]

To ensure vessels can navigate the channel safely, the different ship related factors must be approximated and translated into depth margins. Following general design guidelines carefully results in a safe channel depth. [2] However, this depth is usually slightly conservative and might be reduced if more detailed modelling approaches are applied to the relevant design vessels. As reduced channel depths result in significant reductions in dredging costs, a more detailed analysis is valuable in the feasibility stage of a new port project.

2.1 Vessel Characteristics and Keelpoints

As indicated in Figure 2-1, the most important factor when determining channel depth requirements is the vessel draught. However, other vessel characteristics also play an important role as they influence how a vessel responds to different environmental conditions. The length, beam, displacement and hull shape, amongst others, influence the response of the vessel and therefore affect the required margins. In assessing the vertical motions of the vessel, a number of critical points on the bottom of the vessel are considered. These “keelpoints” are chosen in such a way that due to different motions and rotations of the vessel, one of these points would be the first point of contact with the bottom. If none of these keelpoints are in unacceptable danger of bottom touch, the rest of the vessel is also safe from bottom touch. A schematic representation of the location of critical keelpoints is presented in Figure 2-2.

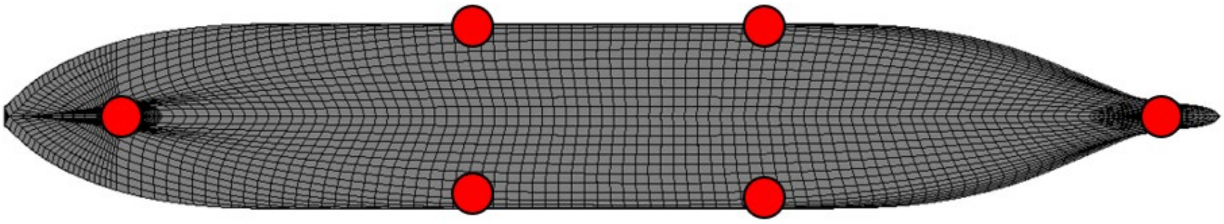


Figure 2-2: Critical keelpoints on vessel hull (in red)

The choice of keelpoints is based on the hull shape of the vessel. For large container vessels, the keel exists of a flat plane. All points within this plane are the lowest part of the vessel. When such a plane is rotated around the longitudinal and transversal axis, one of the outer corners of this plane will always be the lowest point. Therefore, one of these points will always be the first to touch the bottom. If none of these points is in danger of touching the bottom, the rest of the vessel is also guaranteed not to touch the bottom.

2.2 Channel Downtime and Environmental Conditions

A port does not necessarily require 100% operability. It might be worthwhile to accept some "channel downtime" if the loss of function or financial implications of this downtime do not outweigh the required extra costs for dredging and maintaining an increased channel depth. To determine how much downtime can be expected, insight must be gained in the environmental conditions which will be experienced during transit of vessels throughout the year. The effect of the environmental conditions on the vertical motions are explained in the following sections. Relevant environmental conditions are:

- **Water level:** vessels will arrive at and depart from the port throughout the year. Astronomical tides and other factors can influence the water level at a certain moment in time. It is therefore important to consider these water levels when assessing the safety from bottom touch of vessels in transit.
- **Current flow:** Currents in the channel influence the speed with which the vessel moves through the water. As will be explained further on, this also influences the vessel vertical motions and required UKC.
- **Wind:** Especially for vessels with large vertical, above-water areas such as container vessels, wind blowing against the side of the vessel can cause the vessel to heel. The wind pushes the against the vessel which causes the vessel to roll over slightly. This is further explained in Section 2.5. This heel angle will cause keelpoints on the sides of the vessel to increase or decrease in depth, influencing the required UKC.
- **Waves:** waves cause the vessel to move when it is navigating the channel. These wave-induced motions can cause increases in depth of certain keelpoints resulting in a larger required UKC.

To determine how much downtime is to be expected during a typical year, information about the abovementioned environmental conditions is required. To determine water levels, current flow and wave conditions, hydrodynamic modelling and wave modelling were applied in this study. In these models, an initial channel depth as determined in [2] was used to ensure the influence of the, still to be dredged, channel was included in determining the environmental conditions in different sub-sections of the channel. To do this, the channel was divided into sub-sections with lengths of 1 km within which environmental conditions are assumed to be uniform. The obtained environmental conditions were used as input when modelling the vessel motions. An overview of the sub-sections in the outer channel is presented in Figure 2-3

Apart from channel depth restrictions, navigational aspects during adverse weather conditions can also cause channel downtime. At this stage, additional downtime related to navigation considerations cannot be determined. In further design stages, real time navigation simulations can be used to determine limiting conditions for navigation.

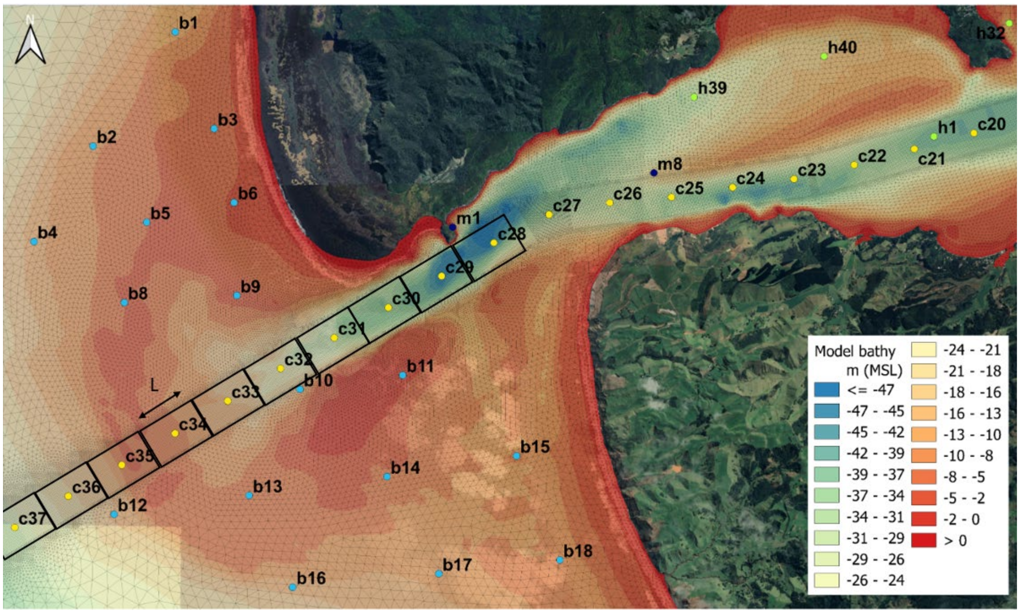


Figure 2-3: Used output points of hydrodynamic modelling and indication of channel sub-sections. [3]

2.3 Vessel Motions

When discussing vessel motions, some general terminology is applied. Some standard terms regarding vessel dimensions are presented in Figure 2-4. The motions of a vessel are described in three translational directions and three rotational directions. An indication of these six directions, or degrees of freedom, is presented in Figure 2-5. The degrees of freedom and general dimensions presented in these figures are used throughout this report. An offset from the normal in the roll direction along the x-axis is called heel. An offset from the normal in the pitch direction along the y-axis is called trim.

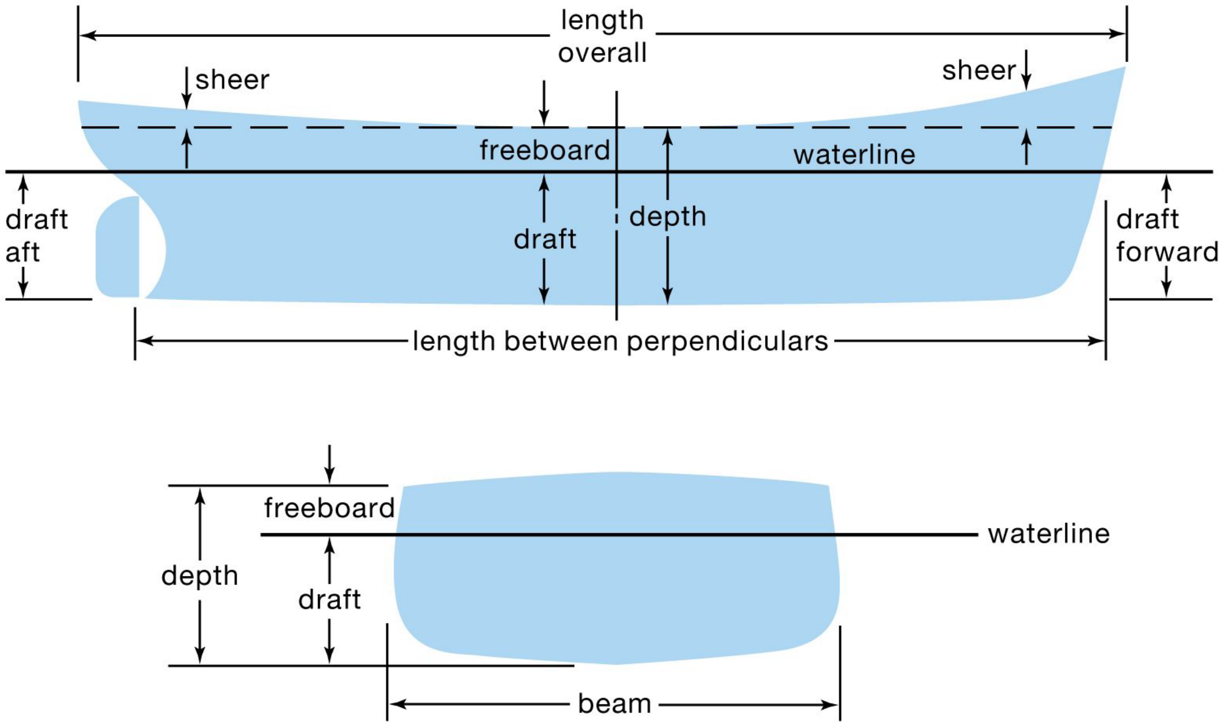


Figure 2-4: General terminology vessel dimensions [4]

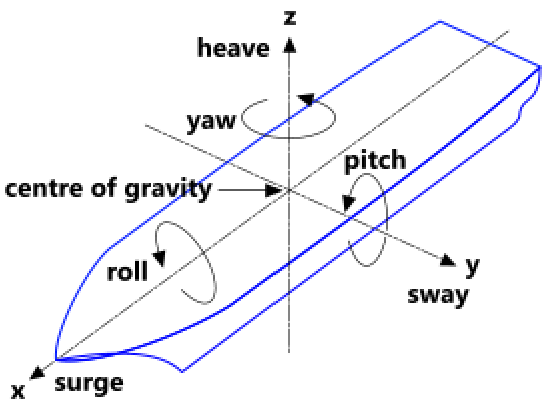


Figure 2-5: Indication of motion directions and terminology for vessels. [5]

2.4 Vessel Motions due to Forward Speed and Current Influences

A vessel moving through water will sink deeper into the water. This effect is called 'squat' and increases with higher speeds. Additionally, dynamic trim, which is a rotation in pitch direction, will cause the bow of the vessel to sink even deeper into the water and the stern less. Both aspects must be included in determining the required UKC of a vessel sailing through a channel. The speed of the vessel involved in these calculations is the speed through the water. In general, the speed of a vessel during transit will be chosen based on the speed over ground. To determine the speed through the water, the current flow speed and direction relative to the vessel heading must be included to determine the correct value of the squat and dynamic heel.

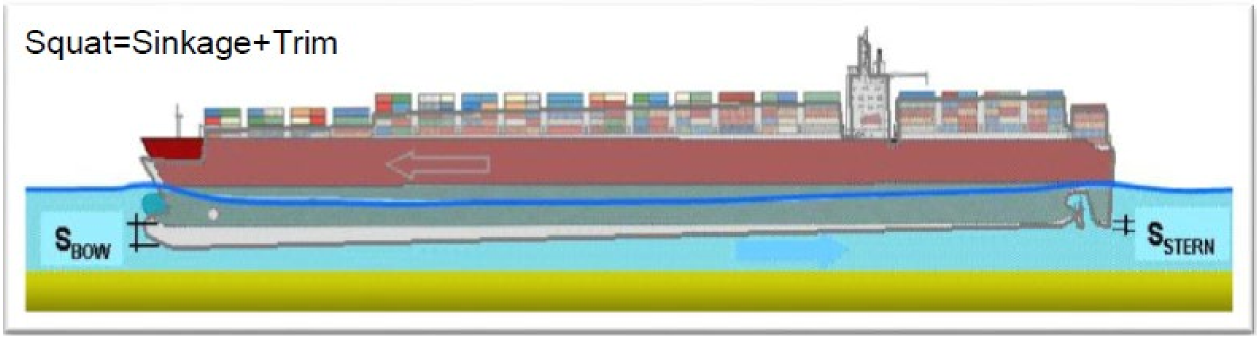


Figure 2-6: overview of squat and dynamic trim [1]

2.5 Vessel Response to Wind

Container vessels typically have large vertical areas due to the high stacks of containers on deck. These vertical areas are susceptible to wind which will cause horizontal forces on the vessel. These horizontal forces will result in an overturning moment which is countered by the hydrostatic righting moment, as is schematised in Figure 2-7. The hydrostatic righting moment increases with larger ‘heel’ angles, which can be expressed as the degrees of roll of the vessel. The equilibrium angle the vessel reaches will mainly depend on:

- Wind speed
- Vertical profile of the wind
- Vertical area of the vessel including container stacks
- Aerodynamic interaction between wind and vessel shape
- Hydrostatic parameters of the vessel

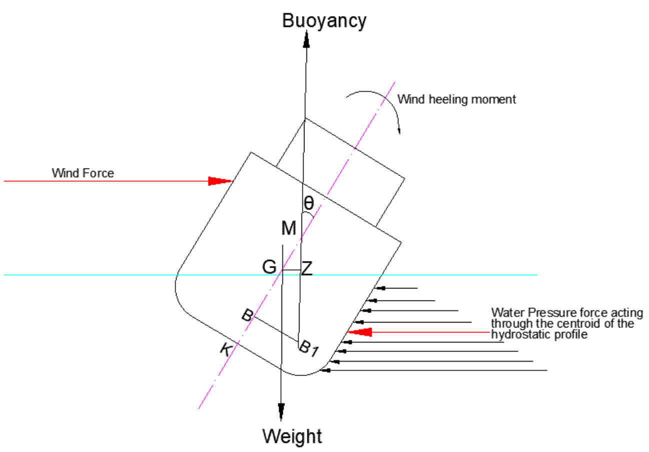
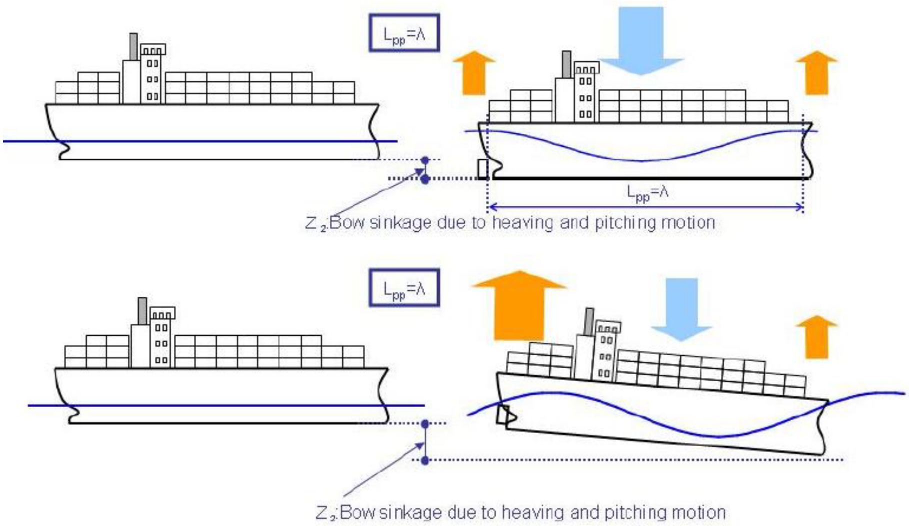


Figure 2-7: Schematic of wind force being countered by water pressure and the resulting moment being countered by the righting moment. [6]

As can be seen from Figure 2-7, the heel angle causes the downwind end of the vessel to sink deeper into the water while the upwind side of the vessel sinks less deep than the average vessel draught. This influences the keelpoints on the side of the vessel.

2.6 Vessel Response to Waves

The most dynamic influence on the vessel motions comes from the vessel wave interaction. In general, waves are non-uniform. This can be easily observed when looking at the ocean. Not every wave has equal height, length or direction. This variability in wave heights results in a variability in vessel motions. Many factors affect the way a vessel responds to incoming waves when sailing through a channel. One of the most important factors is the vessel length compared to the wavelength, and the vessel beam compared to the wavelength. As depicted below, a vessel sailing in waves will experience heave, pitch and roll motions depending on the wave direction relative to the ship. If waves are much shorter than the relevant dimension (beam for roll, length for pitch), the vessel will experience little motions. If the wavelength is similar to the vessel length, pitch and heave motions increase. The effect of the wave on the vessel not only depends on the wave conditions but also on the vessel speed relative to the waves. A vessel travelling against the wave propagation direction will encounter shorter waves than a vessel sailing in the wave propagation direction. When determining the vessel response to waves when sailing through the channel, this influence needs be considered.



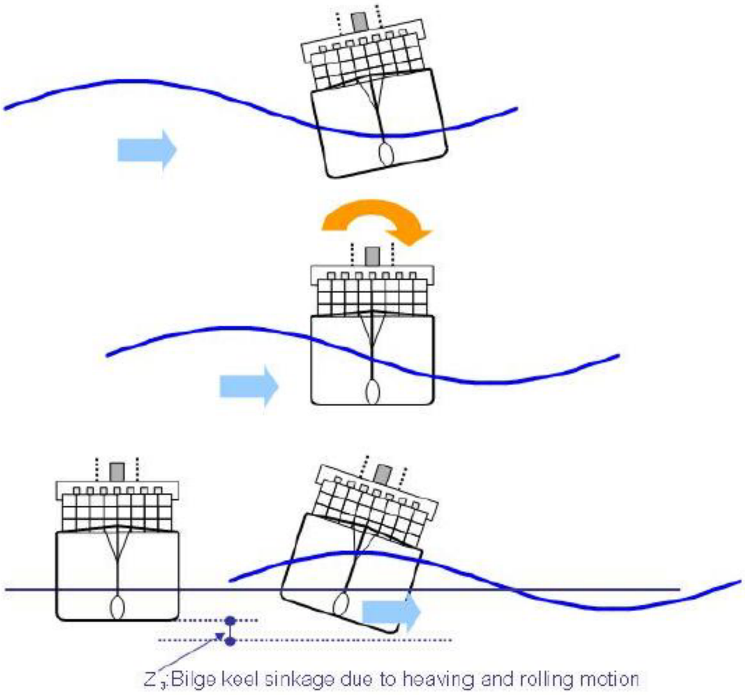


Figure 2-8: Wave ship interaction and governing keelpoints [1]

The response of a vessel in waves can be determined using diffraction analysis. In the realm of naval engineering, diffraction analysis emerges as a computational cornerstone for predicting how waves interact with a ship's hull. This method, rooted in intricate mathematical modelling, meticulously considers the ship's geometry and dimensions. By exploring the bending of waves around the vessel, diffraction analysis yields hydrodynamic coefficients, enabling the prediction of a ship's response across various wave frequencies. This method requires a 3D panel mesh representing the underwater part of the hull. An example of such a mesh is presented in Figure 2-9.

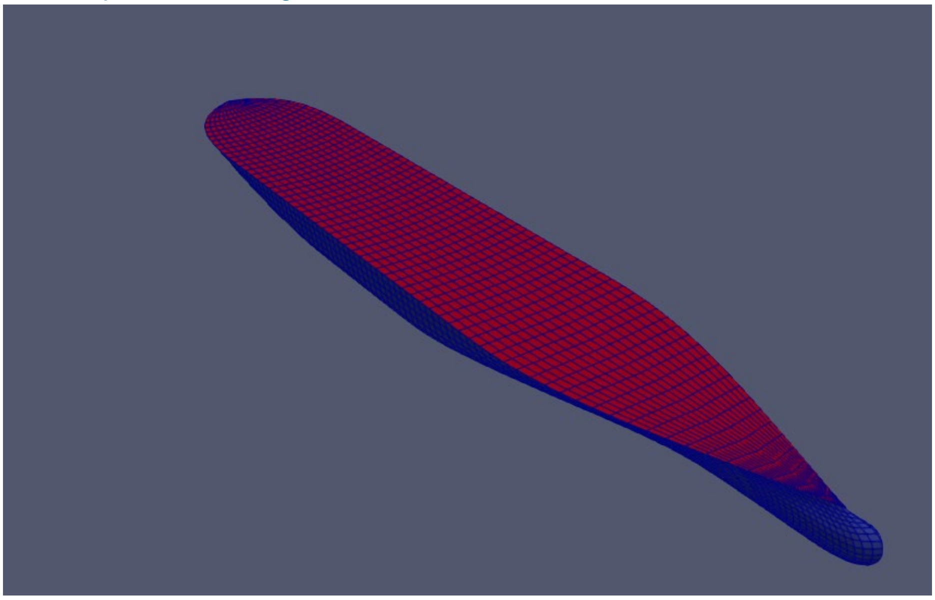


Figure 2-9: Example of 3D hull shape panel mesh

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Using the diffraction calculations, the response of the vessel is determined in surge, sway, heave, roll, pitch and yaw directions. These are then translated to vertical motions at the critical keelpoints.

2.7 Manoeuvrability Margin

To ensure that ships can manoeuvre well, there should always be enough clearance between the time-averaged position of the keel and the channel bottom. This is the vertical Manoeuvrability Margin (or MM), which also influences the horizontal movements of the ships. A ship with a very low Manoeuvrability Margin will be slow and hard to steer, increasing the chances of hitting other ships or going off course. The movements of the ships caused by waves, such as heave, pitch and roll, do not have a significant influence on manoeuvrability. Therefore, only the movements that change the lowest average position of the ship's bottom matter for calculating the Manoeuvrability Margin (= depth – draught – squat – heel). This is why Manoeuvrability Margin is a separate check that should always be done in channel design (and operation), no matter which method (deterministic, semi-probabilistic, or probabilistic) is used. The value of Manoeuvrability Margin that is acceptable depends on the type of ship, the size and shape of the channel, and the traffic of ships (including whether they go one way or two way). A minimum value of 5% of draught or 0.6 m, whichever is bigger, has been shown to be enough for most ship sizes, ship types and channels.

2.8 Probabilistic Aspects

The determination of the vessel response to incoming wave conditions while sailing through the channel is determined in the "frequency domain". This means that these responses can be related to probabilistic calculations. As mentioned in Section 2.6, waves are not uniform in real life. The largest wave height you may see when looking at the ocean for a certain amount of time depends on two factors:

1. **The sea state**: The sea state changes over time but is relatively constant during shorter periods of time. The sea state, in this case, is described by the wave spectrum. A wave spectrum refers to a graphical representation or mathematical description of the distribution of wave energy across different frequencies within a given range. Each wave you will observe has a certain probability of occurrence which can be determined based on the wave spectrum.
2. **The time you spend watching**: If you observe only one wave, it is more likely that you will observe a wave that is relatively average for that sea state. The more waves you watch, the more likely it is you will observe an extremely large wave in that same sea state. In other words, the largest wave you will observe will in general increase the longer you observe that sea state.

The two aspects listed above are combined in a Rayleigh distribution determining the probability that the largest wave you observe exceeds a certain height if you watch for a certain time.

As waves generally follow the Rayleigh distribution, based on linear wave theory, it is assumed that the vertical motions of a keel point also follow the Rayleigh distribution. These two assumptions are based on the following:

1. **Vessel response state:** The sea state influences how the vessel will move, which we call the vessel response state. The vessel response state is a combination of the sea state and the sensitivity of the vessel to specific waves.
2. **The time spent sailing the channel:** Similar to observation time, the longer a vessel spends in the channel, the more waves it encounters, the larger the largest expected keel point motion becomes.

From wave modelling, the sea state in different sub-sections of the channels is known. This information consists of timeseries describing a single sea state at each hour throughout one year. Combining the sea state in each sub-section with the time spent in said sub-section, the probability that the vertical downward motion of the keel point exceeds the available UKC is determined. In other words, the probability of a bottom touch per sub-section is determined. These probabilities are then combined to determine the total probability of bottom touch in one transit through the channel.

2.9 Downtime Determination

As mentioned, for every hour of one year, the current speed, water level and wave state per 1 km long sub-section is known from modelling results. The transit through the outer channel takes less than one hour assuming a speed over ground of 8 knots. This means, one transit fits in one hour. To determine downtime due to insufficient under keel clearance, the aforementioned approach is repeated for each hour in the year. This results in a bottom touch probability if a transit would happen during that specific hour. Multiple choices for acceptable probabilities of bottom touch can be made. However, the commonly used criterium is that for each transit, the probability of bottom touch may not exceed 1%, which is a recommended criterium according to PIANC [1] and is adopted for example by Port of Rotterdam. Using this criterion, for each hour it is determined if a transit during that hour would be safe, in other words, if the probability of bottom touch exceeds 1%. By taking all hours during the year that a transit would be unsafe and dividing that by the number of hours in the year, a ‘channel downtime percentage’ is determined.

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3 Used Input and Assumptions

Specific input for this study and relevant assumptions are listed. A short note on the influence of each assumption is included.

3.1 Vessel Characteristics

The following vessel parameters were used in the analysis. Draughts given are (partly laden) operational draughts which are not necessarily the maximum draughts of the vessels.

Vessel	Large container vessel	Medium container vessel	Small container vessel
Container capacity (TEU)	15,000	10,000	7,000
LOA (m)	365	351	272
LPP (m)	349	335	268
Beam (m)	53.6	45.8	42.8
Draught (m)	12.4	14.2	14.3
Maneuverability Margin (m)	0.62	0.71	0.72

3.2 Assumptions

The following assumption lie at the base of this study:

- The vessel transit speed is 8 knots over ground. The vessel's speed through the water is therefore dependent on the actual current speeds at the time of transit.
- The channel depths shown are the minimal required depth. This means that maintenance dredging should be executed if the channel depth becomes less than the stated depth due to sedimentation.
- The wave and current conditions used in the assessment are modelled using the initial channel design as described in the modelling report [3]. In changing the channel bed level, no change in wave conditions is incorporated in this assessment as this would require iterative wave modelling which is not feasible at this stage.

3.3 Used Environmental Data

The used environmental data in this study was obtained from wave and flow modelling which was executed by MetOcean Solutions. Their approach and results are further described in the numerical modelling report [3]. The data received consists of 1D wave spectra including the peak wave direction at each hourly time step and output location was received. Water levels relative to mean sea level and current speeds and directions were also included.

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4 Results

For two sections, the channel bed level was assessed to investigate the downtime due to conditions which are unsafe for transit because of the probability of bottom contact. As discussed in Section 2.2, some downtime may be acceptable if the loss of function or financial implications of this downtime do not outweigh the required extra costs for dredging and maintaining an increased channel depth. As the middle section of the channel (also referred to as Section B) is already deep, this part was not assessed. The two parts which are considered are the parts where actual dredging reduction is possible. The western part is “crossing the bar” (also referred to as Section A) and the eastern part is “the inner channel” (Also referred to Section C). Both sections are indicated in Figure 4-1.

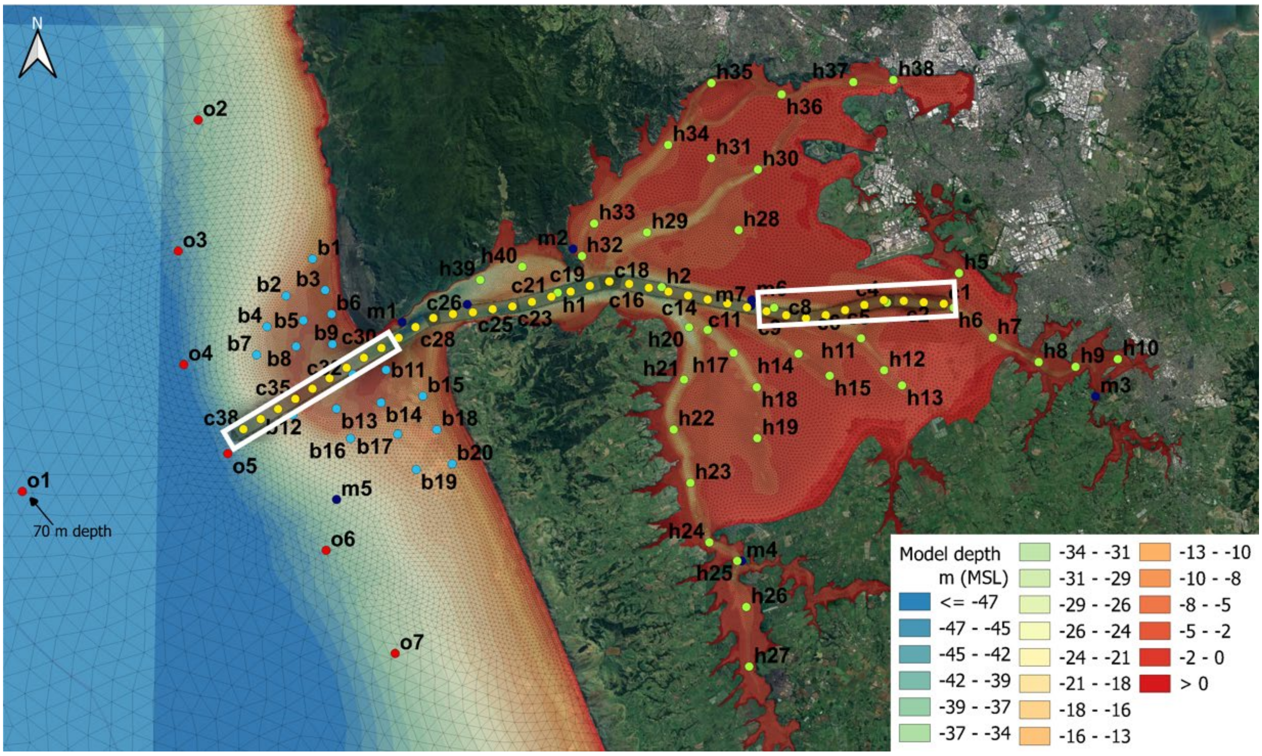

Figure 4-1: To be dredged sections of the channel [3]

4.1 Crossing the Bar (Section A)

Incoming swell waves have significant influence on vessels sailing in this part of the channel. Therefore, the expected downtime here largely depends on the water level, current speed and wave conditions. The section was checked for both arrival and departure of a vessel, which results in opposite transit directions. It was found that the arrival is governing over the departure as during arrival the vessel sailing direction is similar to the dominant swell wave direction. Therefore, the waves are “stretched” resulting in longer observed wavelengths making them closer to the vessel length, thus more influential. The expected downtime per channel bed level for all 3 design vessels is presented in below figures. From these three figures, the following can be concluded:

- The 7,000 TEU vessel with 14.3 m draught, is the most critical in terms of under keel clearance, this can be explained by the fact that the shorter length, smaller beam and specific stability parameters make this vessel more sensitive to the waves occurring in this channel.
- The initial channel design of -20.5 m, as expected, leads to no downtime in a typical year.
- The highest bed level which leads to no downtime in the analysed year is -20.0 m

- Very limited downtime is found when channel depth is -19.0 m CD. 0.07% amounts to roughly 6 hours per year.
- If the channel depth is reduced further, the downtime increases rapidly.

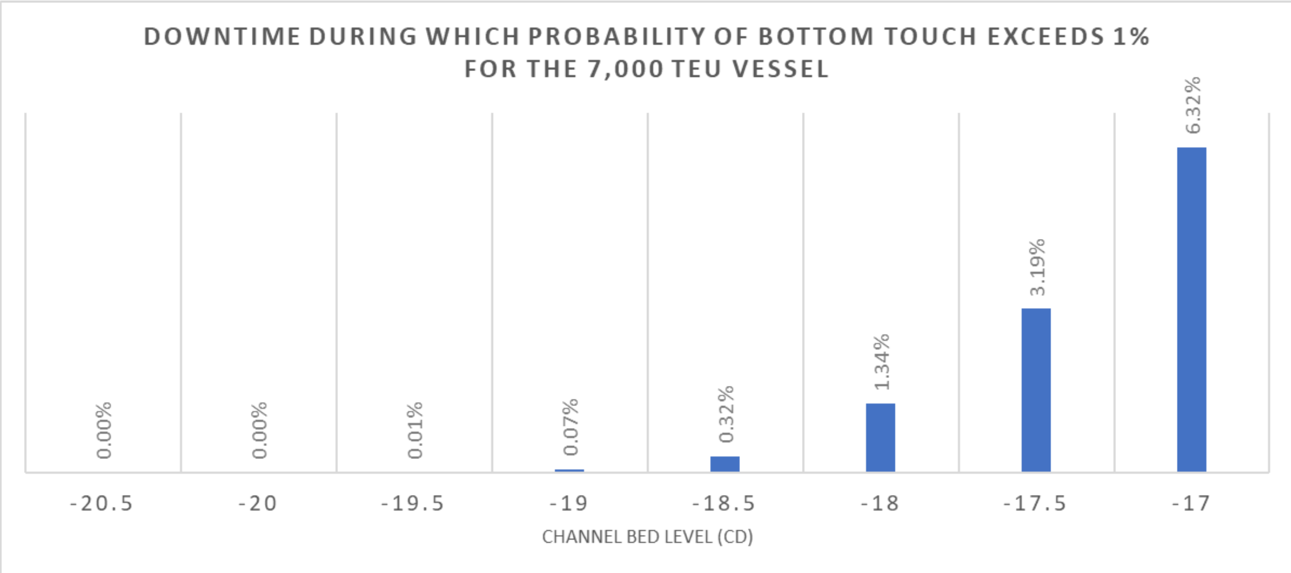

Figure 4-2: Downtime indications per bed level for the 7,000 TEU vessel (draught 14.3m)

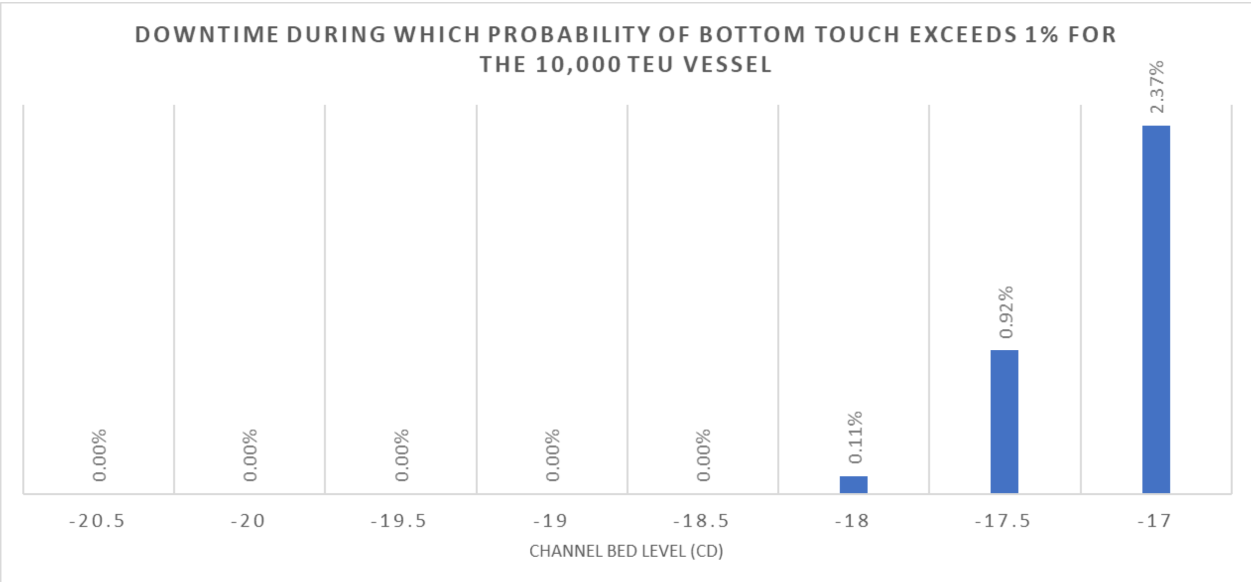

Figure 4-3: Downtime indication per bed level for the 10,000 TEU vessel (draught 14.2m)

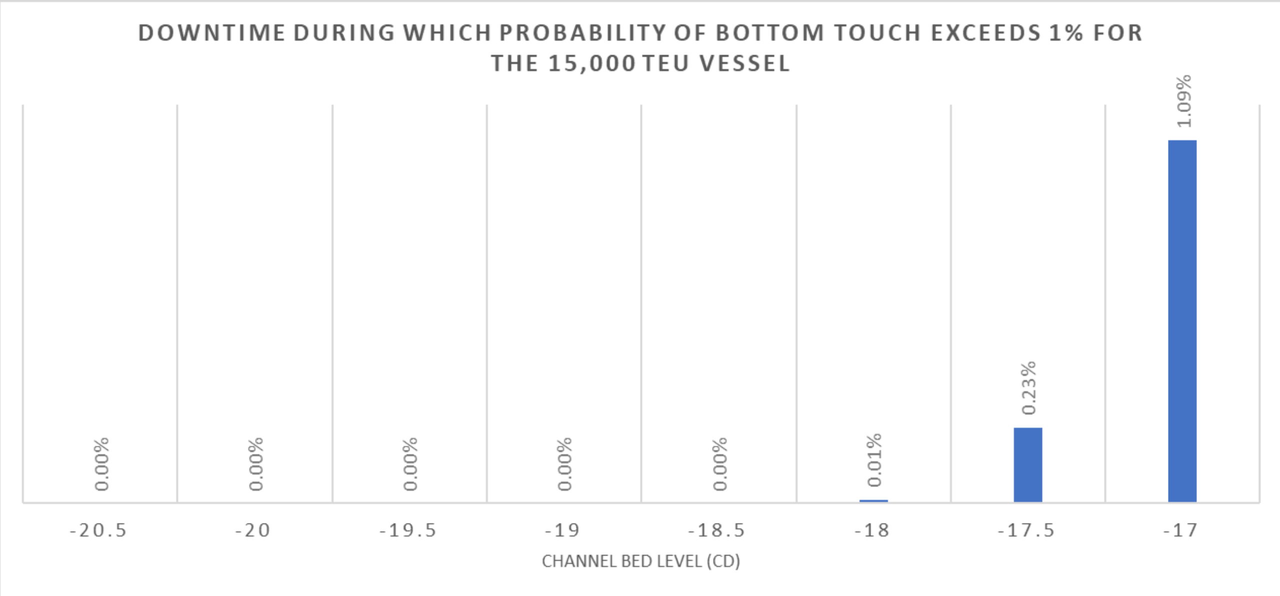

Figure 4-4: Downtime indication per bed level for the 15,000 TEU vessel (draught 12.4m)

4.2 The Inner Channel (Section C)

In the inner channel, an analysis of wave influence on the vessels showed that waves are not governing for the safe transit of vessels. The influence of the waves on the keel point motion was smaller than the required Manoeuvrability Margin. Therefore, the Manoeuvrability Margin became the limiting factor. This removes the statistical wave analysis from the analysis but instead reaches a deterministic approach in which the water level, current speed, vessel squat and heel angle are determined at each time step. The wind heel allowance was taken constant as no hourly wind conditions at the inner channel were available. The water level and current dependant squat were reassessed at each timestep. Combining these three factors with the vessel draught, the channel downtime for each bed level was determined. In this case the downtime is based on the time that insufficient navigational UKC was available. As the increase in squat and heel margin for the largest vessel proved to be less than the large difference in vessel draughts compared to the smaller container vessels, the two smaller vessels were assessed to be critical. The results for the smaller design vessels in the inner channel are presented in Figure 4-5 and Figure 4-6. From these figures, the following can be concluded:

- The smaller design vessel (7,000 TEU) with slightly deeper draught than the 10,000 TEU vessel is slightly more critical for the bed level determination in the inner channel.
- Up to -16 m, no downtime due to insufficient navigational margin is expected.
- Very little downtime is expected for a bed level of -15.5 m.
- A significant jump in downtime occurs when going to -15.0 m bed level.

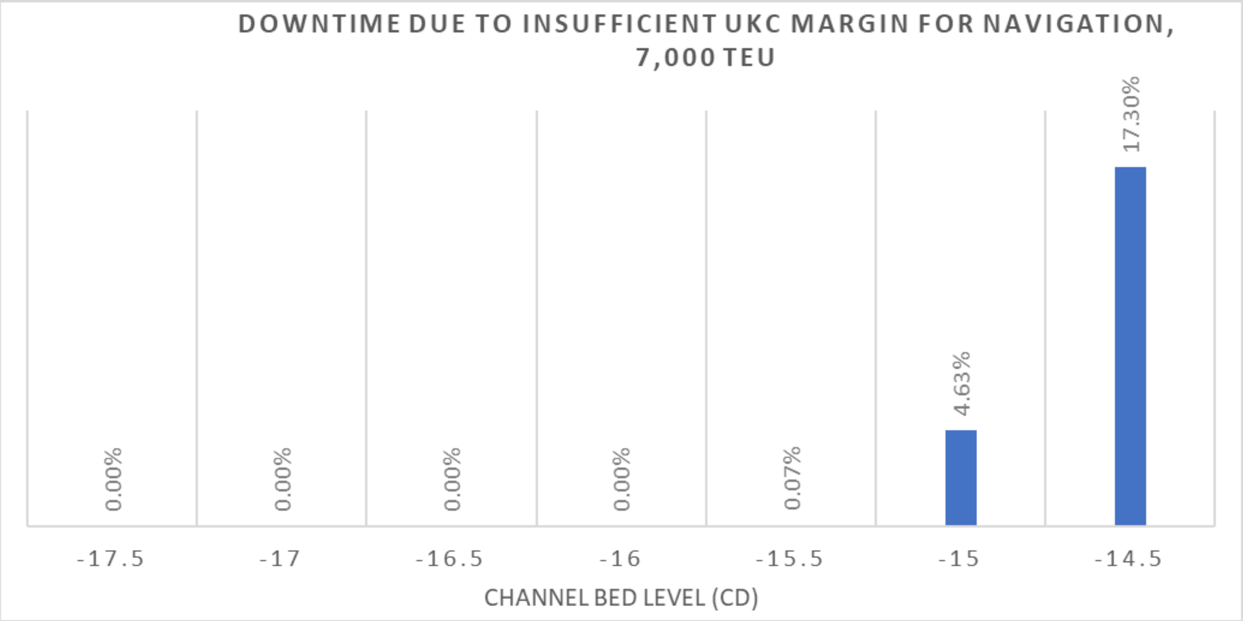

Figure 4-5: Downtime per bed level for the inner channel 7,000 TEU (draught 14.3m)

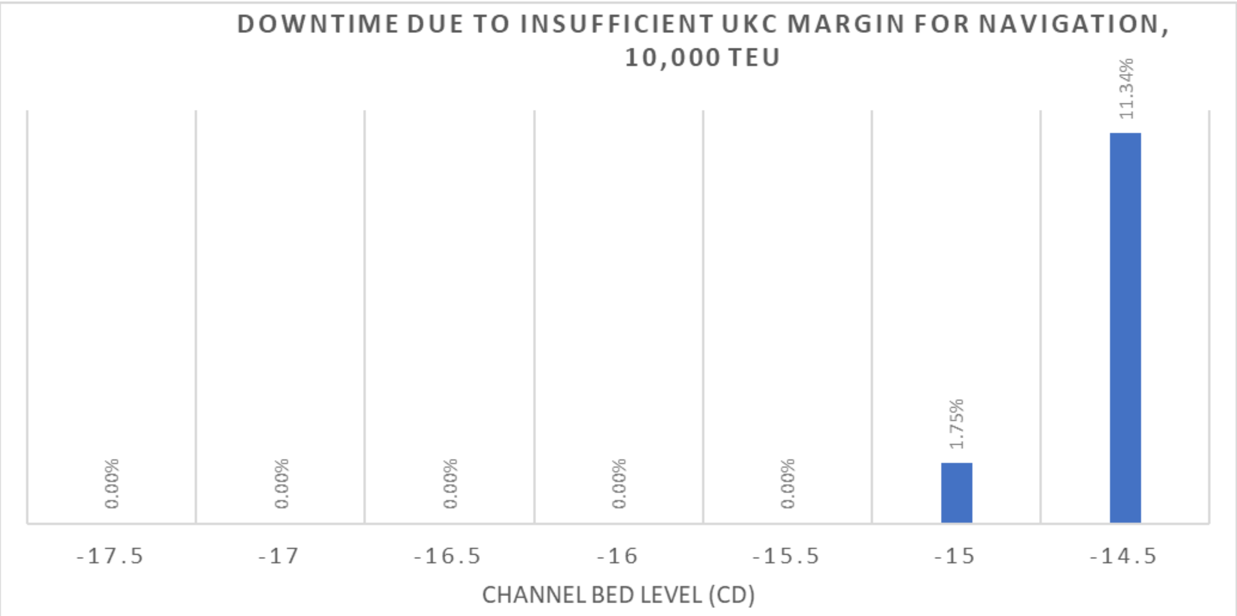

Figure 4-6: Downtime per bed level for the inner channel 10,000 TEU (draught 14.2m)

5 Conclusions and Recommendations

Conclusions of the analysis are stated and some recommendations for future design steps are given.

5.1 Conclusions "Crossing the Bar"

- The smallest, 7,000 TEU, vessel is critical for the channel depth design while crossing the bar as it is most sensitive to wave influences and has a large draught.
- A channel bed level of -19 m CD is advised as its downtime is very limited. It is noted that some operational limits would need to be included which will amplify the downtime slightly[1]. A more precise approach, for example a Dynamic Under Keel Clearance (DUKC) system, can be used to avoid unnecessarily conservative operational rules.
- Downtime for 0.5 m less depth (-18.5m CD) is still not very large. However, higher bed levels than -18.5m will lead to a rapid increase in downtime. Here, deviations between modelling results and real life due to assumptions and simplifications or slightly different vessel characteristics in the different modelling steps involved could cause a less favourable outcome. Therefore, -18.5 m CD is not advised at this stage.

5.2 Conclusions Inner Channel

- The smaller design vessel with slightly higher draught is slightly more critical for the bed level determination in the inner channel.
- The recommended bed level of -16.0 m CD leads to no downtime and avoids operational restrictions.
- A bed level of -15.5 m CD leads to low downtime but leaves no margin for operational variations. Furthermore, higher bed levels such as -15.0 m CD lead to a rapid increase in downtime. Here, deviations between modelling results and real life due to assumptions and simplifications or slightly different vessel characteristics could cause a less favourable outcome. Therefore, -15.5 m CD is not advised at this stage.

5.3 Recommendations

- From a financial point of view, further channel depth reduction can be achieved by further limiting allowable environmental conditions for transit or introducing tidal windows for the transit of certain vessels. A cost-benefit analysis can be used to determine up to which downtime channel depth reduction still yields positive results.
- For the inner channel, squat limiting restrictions can be included (for example a lower speed limit at low water) to further investigate channel optimisations. However, this will not lead to major channel depth reduction.
- The provided results are based on one year of environmental conditions. No specific limiting conditions are defined. When taking the port into operations, these limits should be determined carefully to avoid incidents during extreme conditions.
- No climate change influences were considered at this stage. A sea level rise will generally increase the UKC. However, more extreme and frequent storms might increase the swell wave conditions at the channel resulting in a less safe situation. Potential risks can be determined in further design stages.

[1] *When setting limits, they have to be executable in planning operations. An advanced calculation will not be made each time so a rule of thumb will be applied which will be on the safe side, resulting in some extra channel downtime.*

6 References

[1] P. WG121, “Harbour approach channels design guidelines,” PIANC, 2014.

[2] RHDHV, “Navigation and channel design,” 2023.

[3] M. Solutions, “Manukau Harbour Numerical Modelling,” MetOcean Solutions, 2023.

[4] I. Encyclopaedia Brittanice, “Vessel dimensions,” 2012.

[5] Calglata, “Calqlata,” [Online]. Available: https://www.calqlata.com/productpages/00081-help.html. [Accessed 25 11 2023].

[6] S. Ghosh, “Marine Insight,” 3 1 2022. [Online]. Available: https://www.marineinsight.com/naval-architecture/ships-sail-against-the-wind/. [Accessed 25 11 2023].

A1 Definitions

Vessel conventions

The vessel coordinate system is defined as follows:

• The X-axis is defined as positive from aft perpendicular (APP) to bow.

• The Y-axis is defined as positive from centerline (CL) to port side (PS)

• The Z-axis is defined as positive from keel upwards

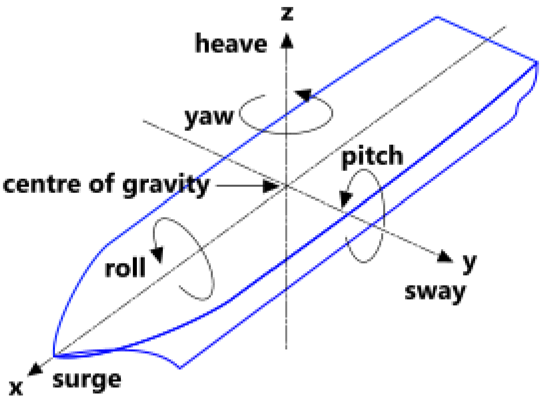

Figure 6-1: Indication of motion directions and terminology for vessels. [5]

Wave directions

Wave headings are defined as incoming directions with respect to stern. 0º wave is incoming from stern, 90º is incoming from starboard, 180º is incoming from the bow and 270º is incoming from portside.

Absolute vessel motions

The basic motions of the vessel are given at the center of gravity (further denoted as “CoG”). The following six motion components are defined:

Translation along x-axis:	Surge	x
Translation along y-axis:	Sway	y
Translation along z-axis:	Heave	z
Rotation along x-axis:	Roll	φ
Rotation along y-axis:	Pitch	θ
Rotation along z-axis:	Yaw	ψ

The considered vessels have a vertical-longitudinal plane of symmetry. This means that motions can be split into symmetric and anti-symmetric components. Surge, heave and pitch motions are symmetric motions while sway, roll and yaw are anti-symmetric motions. For symmetric motions, a point to starboard has the same motion as the mirrored point to port side.

According to the linearized theory, the response to a regular wave will have the same frequency, but a different amplitude. There is also a phase shift between wave and response. These amplitudes and phase shifts are calculated by DIFFRAC in the CoG for different frequencies and wave directions. Once the motions have been solved in the CoG, the harmonic (absolute) vertical displacement in a point $P(x_b, y_b, z_b)$ on the ship-bound axes system is given by:

$$z_p = z - x_b\theta - y_b\phi$$
$$= z_{pa}\cos(\omega_e t + \epsilon_{zp})$$

$$= z_{pa}\left(\cos\left(\epsilon_{zp}\right)\cos(\omega_e t) - \sin\left(\epsilon_{zp}\right)\sin(\omega_e t)\right)$$

For channel design depth optimization purposes, the vertical motion at the keel determines the needed wave reserve to accommodate vessel responses. Six keel points are identified per vessel: two points at respectively stern and bow (resulting in highest pitch response) and four (forward and aft) shoulder points (resulting in highest coupled roll-pitch responses), see also Figure 6-2. The y-coordinates at the shoulder points are slightly moved outwards which is conservative. The shoulder points are defined at both sides of the vessel, as the roll-component is an anti-symmetric mode of motion.

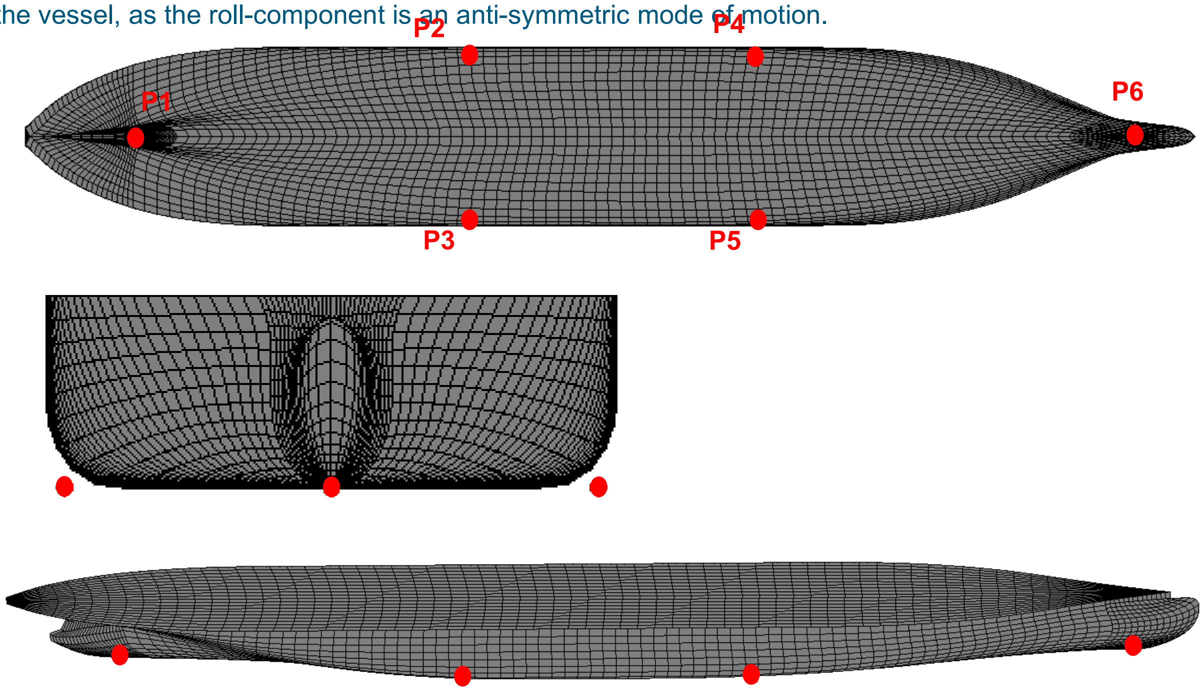

Figure 6-2: location of reference points. Upper: bottom view of vessel, middle: front view of vessel, lower: side view of vessel

Encounter frequency

In case of a ship navigating in the sea, the ship will oscillate with the circular frequency of encounter. This encounter frequency is a function of the wave frequency ω, wave number k, ship speed $U$and wave direction β:

$$\omega_e = \omega - k\ U\ \cos(\beta)$$

For a range of wave frequencies and wave directions, the relation between wave and encounter frequency is illustrated in Figure 6-3 SEQ Figure * ARABIC \s 1

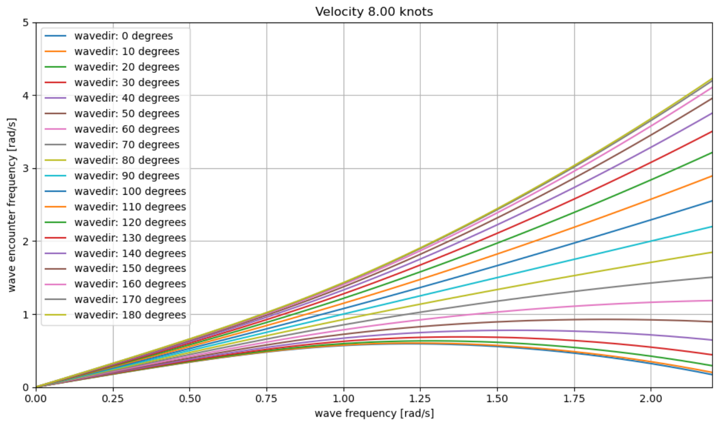

Figure 6-3: relation between wave and encounter frequency for given ship speed and water depth

The following comments are made:

- For beam seas (β=90º), $\omega = \omega_e$
- The frequency of encounter can be zero which means the ship stays within the wave profile. For following seas (β=0º), this occurs at approx. $T_0 = \frac{2\pi U}{g}$.
- In case ω_e is negative, DIFFRAC will treat it as its absolute value and puts the phase and amplitude to zero.

The pressure part proportional to U will give speed-dependent added mass and damping terms. For this reason, the added mass and damping coefficients must be evaluated for ω_e. This is included in the calculation of vessel motion responses. In the body boundary condition of the potential formulation, an additional speed dependent term will occur when forced pitch motions are analyzed. In this case, a flow has to be set up to counteract this incident velocity. This is neglected in DIFFRAC. However, for initial estimation of the channel dredge design, it is considered sufficient to neglect the latter.
In Figure 6-4 the vertical motion RAOs for a 0º and 180º incoming wave are shown for the small container vessel. For the two considered wave directions, the motion in a point portside is the same as the mirror point on the starboard side. It can be seen from the figure that for a wave coming from the stern, the motions are higher at P1 (stern) than at P7 (bow), while for a wave coming from the bow this is vice versa. For a 0º incoming wave with an 8 kn forward speed, it can be verified from Figure 6-3 SEQ Figure * ARABIC \s 1 that the encounter frequency is below approximately 0.6 rad/s.

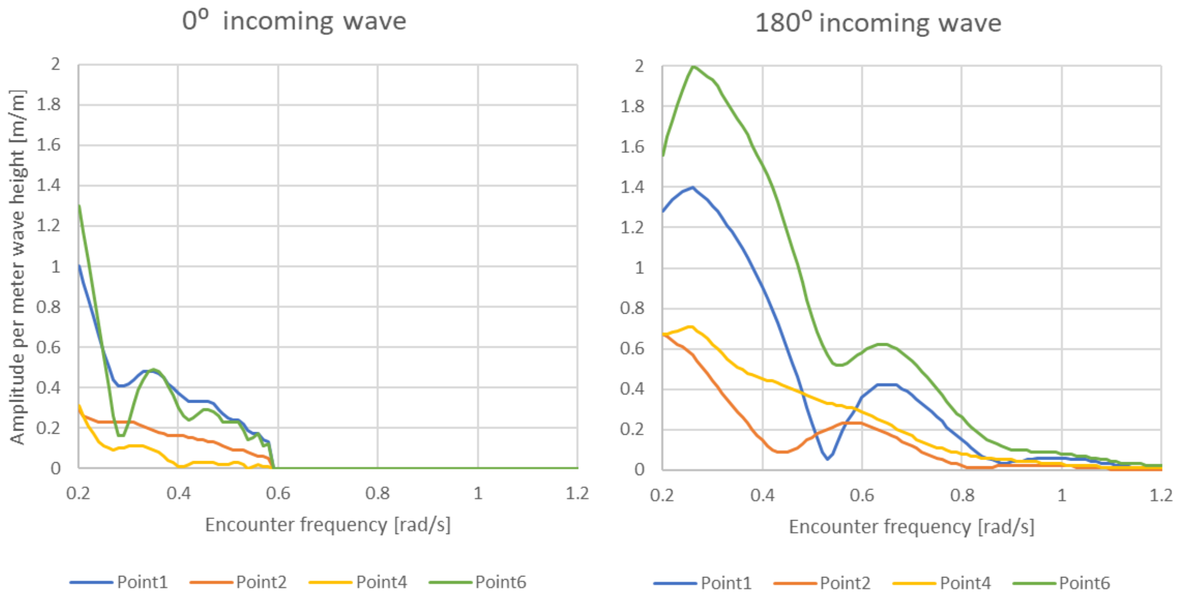

Figure 6-4: vertical motion RAOs for a 0deg (left) and 180 deg (right) incoming wave

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A2 Spectral Integration and Rayleigh Distribution

For the determination of the vessel response, a Response Amplitude Operator (RAO) is used to relate the vertical movement of the vessel to the wave spectrum is. These RAO's were determined using DIFFRAC as described above. This is a numerical tool approximating the vessel response to occurring wave conditions in the trenched channel. The RAO depends on the wave direction relative to the vessel and the speed of the vessel. Using this RAO, the vertical movement due to roll, pitch and heave motions of the vessel can be determined for 6 critical keel points. Following the approach from PIANC guidelines on navigation channel design [2.], the RAO and wave spectrum can be combined and integrated to determine the zero moment values of the irregular distribution of the motion for each keel point. These zero moment values relate to the variances of the Rayleigh distributions of the vertical motions of the keel points. The scaled parameter is related to the square root of the variance. So, for larger areas under the response spectrum, larger zero moments are found which lead to larger variances.

After determining the zero moment for each keel point, the second moment of the spectrum in the encounter frequency domain is determined. Using both the zero and second moment the mean-upcrossing period of each keelpoint is determined.

To determine probabilistic values based on the zero moment values found by integration of the response spectrum, some additional formulae, as described below, were used according to PIANC [2]. The mean zero-upcrossing period of each keelpoint is determined using the response spectrum of each keelpoint. To do this, the second order moment is determined following the equation below.

$$m_2 = \int_0^\infty f_e^2 * S_r(f_e) * df_e = \int_0^\infty f_e^2 * S_r(f) * df$$

Using m_2 and m_0, the mean zero-upcrossing period can be determined using the following formula:

$$T_z = \sqrt{\frac{m_0}{m_2}}$$

As waves are assumed Rayleigh distributed, the keelpoint motions are assumed to be Rayleigh distributed as well. The combination of the obtained spectral moments with the Rayleigh distribution is presented in the following formula:

$$P(z > ukc) = 1 - e^{-\frac{ukc^2}{2m_0}}$$

The number of vertical motions, or zero crossings is obtained by dividing the time spend in a channel sub-section by the zero-upcrossing period. This number of zero crossings is then combined with the Rayleigh distribution to find probability of bottom touch in the sub-section following:

$$P_{bottom\ touch} = 1 - P(z > ukc)^N$$

Where N is the number of zero-upcrossings.

Combining the different probabilities of bottom touch following general probabilistic theory results in a probability of bottom touch in the whole channel.

C. Fast-time Navigation Simulations

REPORT

Manukau Harbour Technical Feasibility Study

Fast-Time Simulations Report

Client: T+T

Reference: PA3148-RHD-XX-XX-RP-X-0004

Status: Draft/P01

Date: 11 December 2023

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Enhancing Society Together

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Document title:	Manukau Harbour Technical Feasibility Study
Subtitle:	Fast-Time Simulations Report
Reference:	PA3148-RHD-XX-XX-RP-X-0004
Your reference	
Status:	Draft/P01
Date:	11 December 2023
Project name:	Manukau Harbour Technical Feasibility
Project number:	PA3148
Author(s):	Daniil Popov

Drafted by:	Daniil Popov
Checked by:	Jacco Valstar
Date:	6 December 2023
Approved by:	Bas van Dijk
Date:	11 December 2023

Classification
Project related

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Appendices

Acronyms

Acronym	Acronym description
NZGD	New Zealand Geodetic Datum
CD	Chart Datum
RPM	Rotations per minute
LW	Low Water
PE	Peak Ebb
PF	Peak Flood

Glossary

Glossary Term	Glossary Text
Course	The course of a ship is the direction in which the ship is to be steered.
Heading	Heading is the direction where the ship's bow is pointed.
knot	Measure of speed used in navigation. 1 knot = 0.51 m/s
Speed over ground	Vessel's speed relative to a fixed object, for example land or buoys.
Speed through water	Vessel's speed relative to water.
Swell waves	Swell waves are wind-generated waves, created in the deep ocean at some distance from the site, and the wind that created them may be too distant to be felt at site or may have stopped blowing or changed its direction by the time the waves reach the site.
Tug	Tug is a small, powerful boat used for towing larger boats and ships, especially in harbours.
Wind waves	Wind waves are locally generated waves. These are generated by winds that are acting on the sea surface bordering on the site.
Windage area	Windage area is the area of a ship that is exposed to the wind.

1 Introduction

Earlier studies identified that the current Ports of Auckland Ltd (POAL) freight operation in the Waitematā Harbour is likely to run out of capacity to cater for Auckland's long-term freight needs. The Manukau Harbour has previously been identified as a potential port location. However, there are unanswered questions around the technical feasibility of this given the complex and dynamic nature of the harbour entrance along with other factors associated with greenfield port development.

Te Manatū Waka / the New Zealand Ministry of Transport has appointed Tonkin & Taylor Ltd and their subconsultants (Royal HaskoningDHV, MetOcean Solutions, Pacific Marine Management, the University of Auckland, Discovery Marine Limited, and RMA Science) to undertake a feasibility study to understand whether it would be technically possible to locate a port in the Manukau Harbour from a navigation and operational reliability perspective. Environmental, social, and economic factors are not part of the current scope of work.

This study supports on-going work by the Ministry on the National Freight and Supply Chain Strategy, which is examining New Zealand's freight system for the next 30 years.

Purpose of this document is to describe tasks performed and conclusions drawn with regards to the confirmation of the channel's width and alignment. Channel is tested by means of ship passage simulation under variety of challenging environmental conditions, using ship models corresponding to anticipated vessels.

Structure of the document is as follows:

- **Section 2** provides a simplified description of the methodology with the aim of providing a general understanding of the followed approach.
- **Section 3** gives an overview of used environmental conditions. It also describes the model setup process and lists the performed simulation runs.
- **Section 4** presents results of a selection of runs to demonstrate feasibility of channel width and alignment.
- **Section 5** provides background for and description of simulations for additional runs in dredged sections of the channel.
- **Section 6** presents the conclusions of the study.

2 Methodology

2.1 Model Description

For performing fast-time manoeuvring simulations, “SHIPMA” software is used, which is a joint development of MARIN (Maritime Research Institute Netherlands) and Deltares (previously known as WL | Delft Hydraulics).

SHIPMA simulates the manoeuvring behaviour of vessels in a physically correct manner. In the programme, all relevant conditions are included, such as the vessel’s properties, environmental conditions, the track to be sailed and the usage of tugs. The SHIPMA program consists of two parts:

- The ship manoeuvring model, describing the horizontal motions of the ship as a result of all forces exerted on the ship.
- The track-keeping autopilot, which gives rudder, engine and tug commands based on deviations from the desired track, speed and heading. These commands are input for the ship manoeuvring model.

This section presents a brief description of the ship manoeuvring model and the track-keeping autopilot.

2.1.1 Ship Manoeuvring Model

The ship manoeuvring model calculates the horizontal motions of the ship as a result of all acting forces. The equations of motion are solved to compute the track of the ship, the course angle, the speed, etc. Vertical motions, except for squat, are not considered.

The model accounts for the specific characteristics of the modelled vessel, the forces of the tugs, and the environmental influences of water depth, wind, waves, currents, squat and bank suction.

Orders to the rudder, engine and tugs are determined in the autopilot part of the model. These orders are then passed to the ship manoeuvring model. The program determines the forces exerted on the ship by the rudder, the propeller and the environmental forces and computes the resulting ship response at short time intervals. This response results in a new position, heading, speed and course for each time-step.

2.1.2 Track-keeping Autopilot

For each simulation run a desired track with the speed along the track is specified. This track runs from the vessel’s starting position to the desired final position of the ship. The autopilot makes the ship follow the pre-specified track as closely as possible with the requested speed given the means of control and the response of the vessel.

The autopilot does not react to momentary deviations from the desired track but rather to expected "future" deviations, just like a human pilot would do. In the autopilot it is possible to define the “anticipation length”, which is typically set at 1 to 1.5 times the ship length, when the vessel transits through a channel.

2.1.3 Application of Environmental Conditions

Wind, waves and currents are applied in the model in the form of fields contained in input files. Each file stores information describing the domain of application of each condition, together with relevant characteristics of the condition.

For Manukau Harbour, the domain covers the entire channel, including 100 m wide zones on each side of it. The domain is covered by a mesh of 25 x 25 m, yielding more than 40,000 data points.

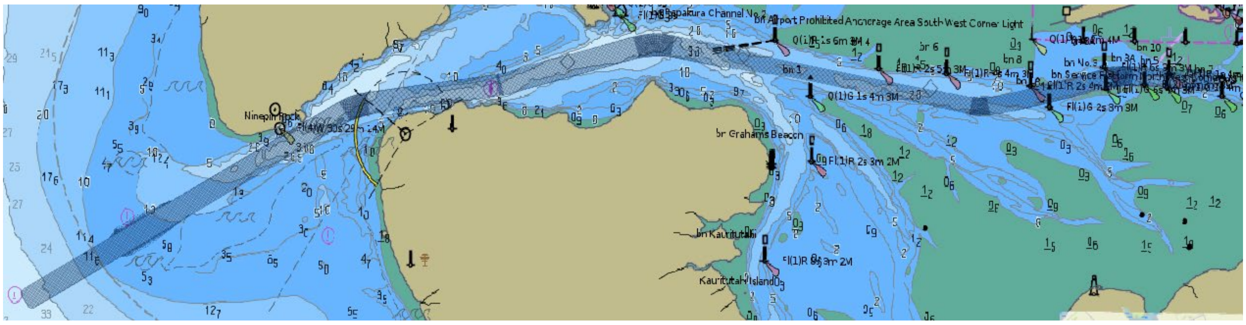

Figure 2-1: Channel Domain

Wave input files contain the following information at each point of the domain:

- Point coordinates in NZGD (m),
- Wave height Hs (m), and
- Wave direction (deg. N).

It is important to note that the wave period T_P (s) is only specified once and is applicable to the entire domain. As wave period vary significantly throughout the domain, fast-time simulations are split into three sections to account for this, further explained in Appendix A1.

The current input files contain the following information at each point of the domain:

- Point coordinates in NZGD (m),
- Current speed (m/s), and
- Current direction (deg. N).

The wind input file is structured similar to the current input file, but the mesh of datapoints in the domain is much less dense as wind is more uniform.

- Point coordinates in NZGD (m),
- Wind speed (m/s), and
- Wind direction (deg. N).

2.1.4 Bank Suction

Bank suction is a phenomenon that occurs when vessels sail at speed in narrow channels with steep slopes. It is a hydrodynamic effect caused by asymmetric flow of water around the ship, leading to pressure difference between its sides. In general, resulting lateral force moves the vessel towards the closest bank.

For the deeper areas in the access channel, where the bank along the channel is deeper than the vessel draught, no bank suction will occur. However, along the track where the bank is shallower than the draught of the vessels, the vessels will experience more bank suction.

2.1.5 Vessel Model

The vessel used in the simulations is a partly/fully loaded container vessel with main dimensions LOA x B x T = 366 x 52.1 x 13.2 (SHIPMA Model “con038r1”). Among the available vessel models, the presented model is the closest match in terms of dimensions and manoeuvrability to the design vessel. The vessel model has a single propellor and rudder with 72,400 kW power at 104 RPM. The windage area is 2,320 m^2 frontage and 13,435 m^2 lateral.

2.2 Sailing Strategy

2.2.1 Vessel Speed

The vessel model has a dead slow engine setting of 23 RPM which gives the vessel a speed of 2.8m/s. The vessel speed is kept at dead slow where it is possible. The vessel speed is increased at locations where this is necessary to follow the specified track (so-called “telegraph settings”). Telegraph settings for the vessel are shown in Table 2-1.

Table 2-1: Telegraph setting of vessel model “con038r1”

Telegraph	RPM	Speed [kn]
Sea full	104	24.5
Harbour full	70	16.5
Half	55	13.0
Slow	39	9.2
Dead slow	23	5.4

2.2.2 Use of Tugs

The purpose of the simulations under consideration is to demonstrate that the vessel has enough space for unassisted passage, therefore, no tugs are used.

2.2.3 Autopilot Settings

The simulations are performed using the following autopilot settings:

- Rudder angle is limited to 70% of the maximum 35 degrees rudder angle,
- No use of power bursts,
- No use of side thrusters.

These settings ensure that there is spare capacity available to respond to unforeseen and / or occasional disturbances. When the vessel can maintain the intended course using these autopilot settings and remain within the criteria defined in Section 2.3, the autopilot settings remain unchanged in the simulations and the manoeuvre is considered feasible. When the run is considered not feasible the autopilot settings can be changed to investigate if there are alternative settings that give a better result and whether this could be considered acceptable. These simulations will be reported and discussed leading either to a conclusion of the run being feasible, feasible with comment or not feasible. In this study this was never necessary.

2.3 Assessment Criteria

2.3.1 Deviation from the Track

A simulation is considered acceptable when the swept path of the vessel combined with margins for bank clearance fit within the channel boundaries. The swept path is visually checked in the SHIPMA simulation runs.

With fast-time manoeuvring software it is possible to simulate the behaviour of the vessel as a result of all environmental forces acting on the vessel. The vessel is steered by an autopilot, which can perfectly adapt to the environmental conditions. As such, the human factor element is not included in the simulations. The fast-time manoeuvring simulations are a good tool to assess how large the swept path width is that directly relates to the environmental conditions and the manoeuvring behaviour of the vessel. Contributions related to human factors and to the safety distance to the banks would need to be added to the physical path width of the vessel.

The following criteria are used to assess the safety distance to the banks, in which B is the beam of the vessel:

- > 1 B Feasible,
- 0.5 – 1 B Critical,
- < 0.5 B Unacceptable.

2.3.2 Rudder

The use of the rudder was limited to 70% in the autopilot settings to reserve a margin for occasional disturbances. In the simulations it is checked whether the vessel used the full 70% of the rudder angle. If the rudder reaches the 70% limit it gets close to the limit of safe operation. Furthermore, the use of the rudder in combination with high propeller speeds is assessed using the Spr-parameter which is defined as follows:

$$Spr = \left(\frac{\delta}{20}\right)\left(\frac{n}{n_{half}}\right)^2$$

Where:

δ Rudder angle

n Propeller RPM

n_{half} Propeller RPM at HALF AHEAD

The idea behind this criterion is that it is acceptable / safe to use a rudder angle of 20° in combination with the propeller revolutions for a telegraph setting of “half ahead” or slower, for which the corresponding Spr value is 1. Spr values less than 1 are acceptable, while values larger than 1 indicate that runs are more difficult. The value of Spr can be exceeded on occasions, but not for longer, sustained periods of time. Using the limits of the Spr criterion, the maximum rudder angle for each telegraph setting can be calculated and is given in Table 3-3. The 70% limit of the maximum rudder angle corresponds to 24.5°.

Table 2-2: Maximum rudder angle per telegraph setting

Telegraph	Revolutions per minute	Maximum rudder angle
Sea full	104	5.6
Harbour full	70	12.3
Half ahead	55	20
Slow	39	24.5
Dead slow	23	24.5

3 Environmental Conditions and Simulations Setup

3.1 Environmental Conditions

3.1.1 Wind

Dominant wind directions in the area are SW (22% of the time) and W (17% of the time), as reported by PMM[1] based on NZ-wide wind hindcast model for the location at Manukau Heads (see Figure 3-1).

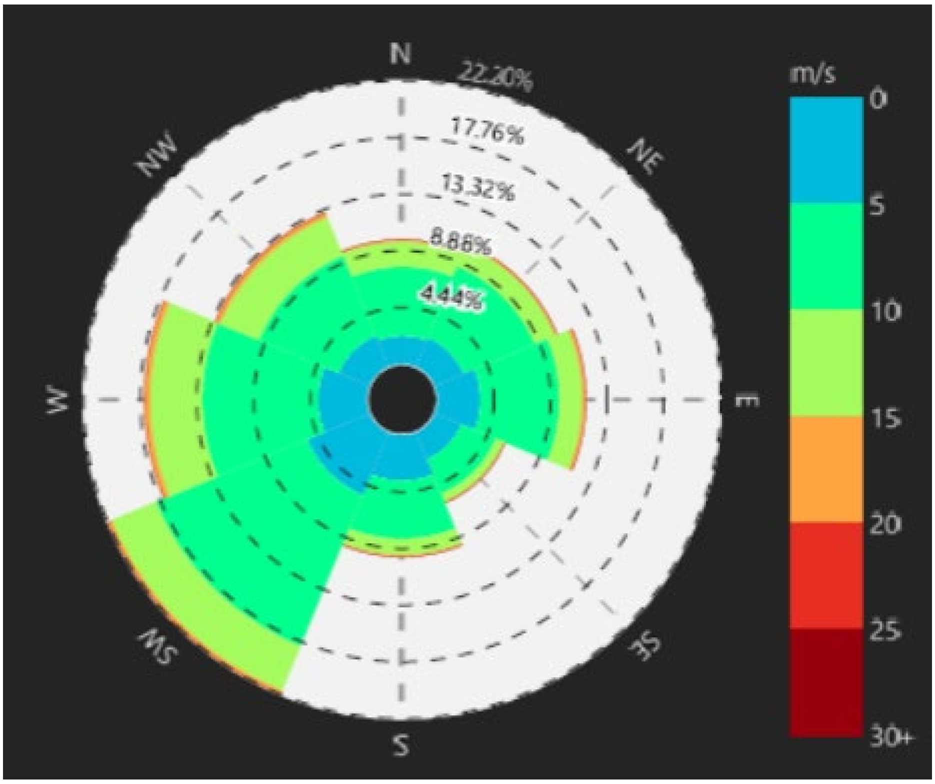

Figure 3-1: Wind Rose for Manukau Heads[1]

Average wind speed is 7.5m/s, whereas the 90th percentile wind speed reaches 12.2m/s. The maximum wind speed in the 39-year hindcast is 23.9m/s.

For the purposes of the fast-time simulations, the following conservative wind conditions are selected:

- 14 m/s wind from SW (225 degN),
- 14 m/s wind from W (270 degN), and
- 14 m/s wind from N (0 degN).

The choice of 14m/s winds from directions SW, W and N is deemed appropriate for the following reasons:

- this is a locally frequently present wind,
- this is a wind speed usually found as practical limit for channel passage,
- terminal operations are restricted or stopped at higher wind speeds, and

[1] *"Manukau Harbour Port Feasibility Study – Navigational Operability", PMM (August 2023)*

- although north is not a dominant wind direction (approximately 9% of the time), these winds are near perpendicular to the channel and will have the most adverse impact on the ship during the channel passage.

Simulating these conservative wind scenarios serves the purpose of establishing the technical feasibility of the channel: if the vessel is able to pass through the channel under the listed conditions, channel alignment and dimensions will be considered safe and appropriate.

Selected wind speeds serve both as input parameters for wave modelling (see Section 3.1.2) and as simulation scenarios.

3.1.2 Waves

Wave conditions in Manukau Harbour are a subject of numerical modelling performed by MOS[2] for the boundary conditions shown in Table 3-1. Results of the wave modelling are used as input for fast-time simulations as described in Section 2.1.3. Separate swell and waves conditions are combined in the simulations.

Table 3-1: Wave Modelling Scenarios

Simulation ID	Wave - Model Run Description	Boundary Conditions
ss01	Swell & no wind	H_S = 1m, T_P = 12s, Dir = 235°
ss02	Swell & no wind	H_S = 2m, T_P = 13s, Dir = 235°
ss03	Swell & no wind	H_S = 3m, T_P = 14s, Dir = 235°
ss04	Swell & no wind	H_S = 4m, T_P = 15s, Dir = 235°
ss05	Swell & no wind	H_S = 2m, T_P = 10s, Dir = 280°
ss06	Swell & no wind	H_S = 3m, T_P = 11s, Dir = 280°
ss07	No swell & wind	Wind speed = 14m/s, Dir. SW (225°)
ss08	No swell & wind	Wind speed = 14m/s, Dir. W (270°)
ss09	No swell & wind	Wind speed = 14m/s, Dir. N (0°)

Out of 9 given scenarios, 4 are selected for the fast-time simulations (highlighted in Table 3-1):

- 1 swell condition (ss04), and
- 3 wind-generated wave conditions (ss07, ss08 and ss09).

Swell condition "ss04" is selected due to it being the most unfavourable of all considered swell conditions: it has the largest wave height and the longest wave period. All wind-generated wave conditions are considered, since they should be applied in the model together with corresponding wind conditions (see Section 3.1.1).

3.1.3 Water Levels and Currents

Manukau Harbour tidal levels reflected in Table 3-2 are given for the benchmark at Onehunga[3]. All fast-time simulations are conservatively performed with the MLWS water level, as low water is the most unfavourable

[2] *"Manukau Harbour Numerical Modelling", MOS (August 2023)*
[3] *"Manukau Harbour Port Feasibility Study – Coastal Processes", T+T (August 2023)*

from perspective of the ship manoeuvrability. The current varies depending on the simulated tide cycle. The following 3 scenarios are considered:

- Peak ebb – the strongest currents during the falling tide.
- Peak flood – the strongest currents during the rising tide.
- Low water slack – weak currents during the low tide.

Table 3-2: Manukau Harbour Tidal Levels

Tidal Levels	m CD
Highest Astronomical Tide (HAT)	4.54
Mean High Water Springs (MHWS)	4.17
Mean High Water Neaps (MHWN)	3.34
Mean Sea Level (MSL)	2.43
Mean Low Water Neaps (MLWN)	1.44
Mean Low Water Springs (MLWS)	0.56
Lowest Astronomical Tide (LAT)	0.12

3.2 Simulation Sections

As explained in detail in the initial channel concept design report[4], the channel, which is approximately 38 km long, is subject to varying environmental conditions. Accounting for that variability along the channel of this length in fast-time simulations is a difficult task due to inherent limitations of the used software. The approach is to split the channel into sections which are then treated separately. The split allows for sufficient degree of flexibility in defining environmental conditions while preserving the accuracy of simulations, each with their own combination of environmental forces acting on the ship.

The following sections are proposed (see Figure 3-2):

- Section A (section over the bar): from 0km to 13.5km
- Section B (middle section): from 13.5km to 26.5km
- Section C (end section): from 26.5km to 37.5km

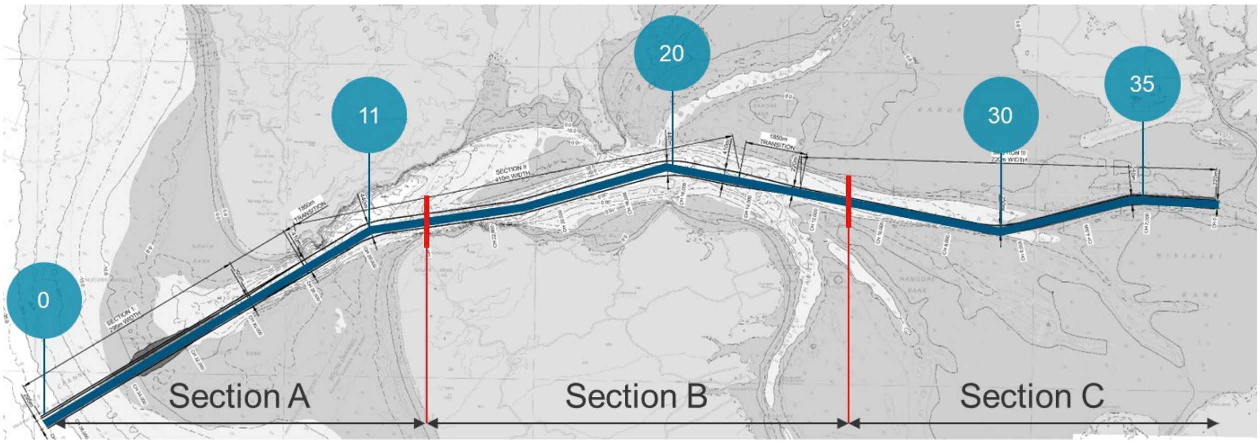

Figure 3-2: Channel Sections for Simulations

[4] *"Interim Technical Working Paper. Navigation and Channel Design", RHDHV (June 2023)*

3.3 Simulations Case Matrix

In total, 54 simulation runs are performed, 18 for each section of the channel (see Table 3-3).

Table 3-3: Simulations Case Matrix

SN	ID	Direction	Wind (Dir m/s)	Wind Waves (relates to wind conditions)	Water Level & Current	Swell Waves
Channel Section A						
1	A-Arr-N-PF-Swell	Arrival	N 14	ss09	Peak Flood	ss04
2	A-Arr-W-PF-Swell	Arrival	W 14	ss08	Peak Flood	ss04
3	A-Arr-SW-PF-Swell	Arrival	SW 14	ss07	Peak Flood	ss04
4	A-Arr-N-PE-Swell	Arrival	N 14	ss09	Peak Ebb	ss04
5	A-Arr-W-PE-Swell	Arrival	W 14	ss08	Peak Ebb	ss04
6	A-Arr-SW-PE-Swell	Arrival	SW 14	ss07	Peak Ebb	ss04
7	A-Arr-N-LW-Swell	Arrival	N 14	ss09	Low Tide Slack	ss04
8	A-Arr-W-LW-Swell	Arrival	W 14	ss08	Low Tide Slack	ss04
9	A-Arr-SW-LW-Swell	Arrival	SW 14	ss07	Low Tide Slack	ss04
10	A-Dep-N-PF-Swell	Departure	N 14	ss09	Peak Flood	ss04
11	A-Dep-W-PF-Swell	Departure	W 14	ss08	Peak Flood	ss04
12	A-Dep-SW-PF-Swell	Departure	SW 14	ss07	Peak Flood	ss04
13	A-Dep-N-PE-Swell	Departure	N 14	ss09	Peak Ebb	ss04
14	A-Dep-W-PE-Swell	Departure	W 14	ss08	Peak Ebb	ss04
15	A-Dep-SW-PE-Swell	Departure	SW 14	ss07	Peak Ebb	ss04
16	A-Dep-N-LW-Swell	Departure	N 14	ss09	Low Tide Slack	ss04
17	A-Dep-W-LW-Swell	Departure	W 14	ss08	Low Tide Slack	ss04
18	A-Dep-SW-LW-Swell	Departure	SW 14	ss07	Low Tide Slack	ss04
Channel Section B						
19	B-Arr-N-PF-Swell	Arrival	N 14	ss09	Peak Flood	ss04
20	B-Arr-W-PF-Swell	Arrival	W 14	ss08	Peak Flood	ss04
21	B-Arr-SW-PF-Swell	Arrival	SW 14	ss07	Peak Flood	ss04
22	B-Arr-N-PE-Swell	Arrival	N 14	ss09	Peak Ebb	ss04
23	B-Arr-W-PE-Swell	Arrival	W 14	ss08	Peak Ebb	ss04
24	B-Arr-SW-PE-Swell	Arrival	SW 14	ss07	Peak Ebb	ss04
25	B-Arr-N-LW-Swell	Arrival	N 14	ss09	Low Tide Slack	ss04

SN	ID	Direction	Wind (Dir m/s)	Wind Waves (relates to wind conditions)	Water Level & Current	Swell Waves
26	B-Arr-W-LW-Swell	Arrival	W 14	ss08	Low Tide Slack	ss04
27	B-Arr-SW-LW-Swell	Arrival	SW 14	ss07	Low Tide Slack	ss04
28	B-Dep-N-PF-Swell	Departure	N 14	ss09	Peak Flood	ss04
29	B-Dep-W-PF-Swell	Departure	W 14	ss08	Peak Flood	ss04
30	B-Dep-SW-PF-Swell	Departure	SW 14	ss07	Peak Flood	ss04
31	B-Dep-N-PE-Swell	Departure	N 14	ss09	Peak Ebb	ss04
32	B-Dep-W-PE-Swell	Departure	W 14	ss08	Peak Ebb	ss04
33	B-Dep-SW-PE-Swell	Departure	SW 14	ss07	Peak Ebb	ss04
34	B-Dep-N-LW-Swell	Departure	N 14	ss09	Low Tide Slack	ss04
35	B-Dep-W-LW-Swell	Departure	W 14	ss08	Low Tide Slack	ss04
36	B-Dep-SW-LW-Swell	Departure	SW 14	ss07	Low Tide Slack	ss04
Channel Section C						
37	C-Arr-N-PF-Swell	Arrival	N 14	ss09	Peak Flood	ss04
38	C-Arr-W-PF-Swell	Arrival	W 14	ss08	Peak Flood	ss04
39	C-Arr-SW-PF-Swell	Arrival	SW 14	ss07	Peak Flood	ss04
40	C-Arr-N-PE-Swell	Arrival	N 14	ss09	Peak Ebb	ss04
41	C-Arr-W-PE-Swell	Arrival	W 14	ss08	Peak Ebb	ss04
42	C-Arr-SW-PE-Swell	Arrival	SW 14	ss07	Peak Ebb	ss04
43	C-Arr-N-LW-Swell	Arrival	N 14	ss09	Low Tide Slack	ss04
44	C-Arr-W-LW-Swell	Arrival	W 14	ss08	Low Tide Slack	ss04
45	C-Arr-SW-LW-Swell	Arrival	SW 14	ss07	Low Tide Slack	ss04
46	C-Dep-N-PF-Swell	Departure	N 14	ss09	Peak Flood	ss04
47	C-Dep-W-PF-Swell	Departure	W 14	ss08	Peak Flood	ss04
48	C-Dep-SW-PF-Swell	Departure	SW 14	ss07	Peak Flood	ss04
49	C-Dep-N-PE-Swell	Departure	N 14	ss09	Peak Ebb	ss04
50	C-Dep-W-PE-Swell	Departure	W 14	ss08	Peak Ebb	ss04
51	C-Dep-SW-PE-Swell	Departure	SW 14	ss07	Peak Ebb	ss04
52	C-Dep-N-LW-Swell	Departure	N 14	ss09	Low Tide Slack	ss04
53	C-Dep-W-LW	Departure	W 14	ss08	Low Tide Slack	ss04
54	C-Dep-SW-LW	Departure	SW 14	ss07	Low Tide Slack	ss04

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4 Simulation Results

Results of all runs listed in Section 3.3 are presented in Appendices A2 – A7. All simulations demonstrated that the ship manoeuvres within the spatial limits defined in Section 2.3.1 and retains good control under the examined conservative combinations of environmental conditions, thus proving that the channel dimensions and alignment allow for safe passage.

For illustration purposes, 6 runs are selected and described in the following sub-sections.

4.1 Arrival Runs

The following three sub-sections describe results of arrival runs through each channel section (in order from A to C). In these runs, the ship's route starts at the 0m mark corresponding to the channel entrance and ends 350m after the 37,000m mark, which corresponds to the channel's end. In the figures, marks are shown every 1,000m. The vessel location in the figures is plotted every 2 minutes.

4.1.1 Run "A-Arr-W-PE-Swell"

This simulation run is performed for arrival through channel section A with westerly wind and corresponding wind-generated wave conditions, during peak ebb, with swell waves also present. All section A arrival simulations start at the 0m mark and end 500m after the 14,000m mark.

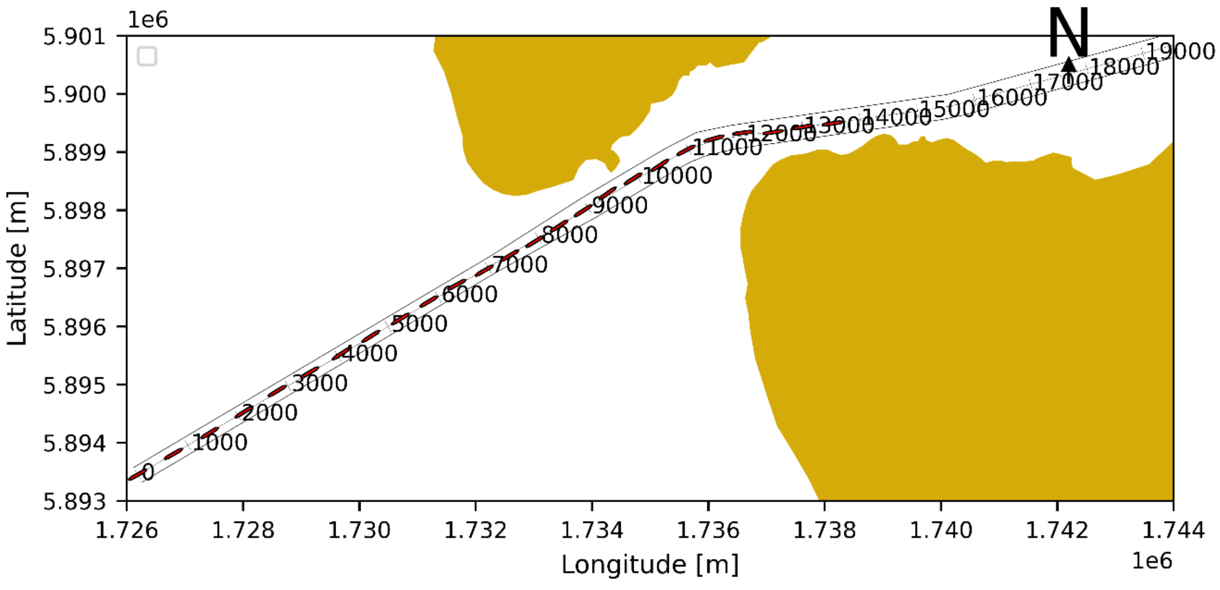

Figure 4-1: A-Arr-W-PE-Swell - Ship's Path

As shown in Figure 4-1, the vessel remains on the channel centre line or is in direct proximity to it. Small deviations from the centre line are observed in the bend, between 11,000m and 12,000m marks, which is typical for turning vessels and is therefore of no concern (and taken into account in the initial concept design).

The ship enters the channel with the propeller set at 55 RPM ("half ahead") and speed of 6m/s (see Figure 4-2). While the propeller speed remains constant, the vessel's speed gradually decreases to below 4.25m/s between the 8,000m and 10,000m marks. Deceleration is caused by the strong ebb current (2.0m/s – 2.5m/s between 6,000m and 10,000m, not shown in the figure).

The rudder remains in almost straight position until the vessel reaches the entrance to the bend at the 10,000m mark, where it is set to -10° to make the turn to the right. After the bend, it returns to an almost straight position.

To conclude, the deviations from the track and rudder usage remained well within the set limits, therefore, the channel alignment and dimensions are considered appropriate for passage under given environmental conditions.

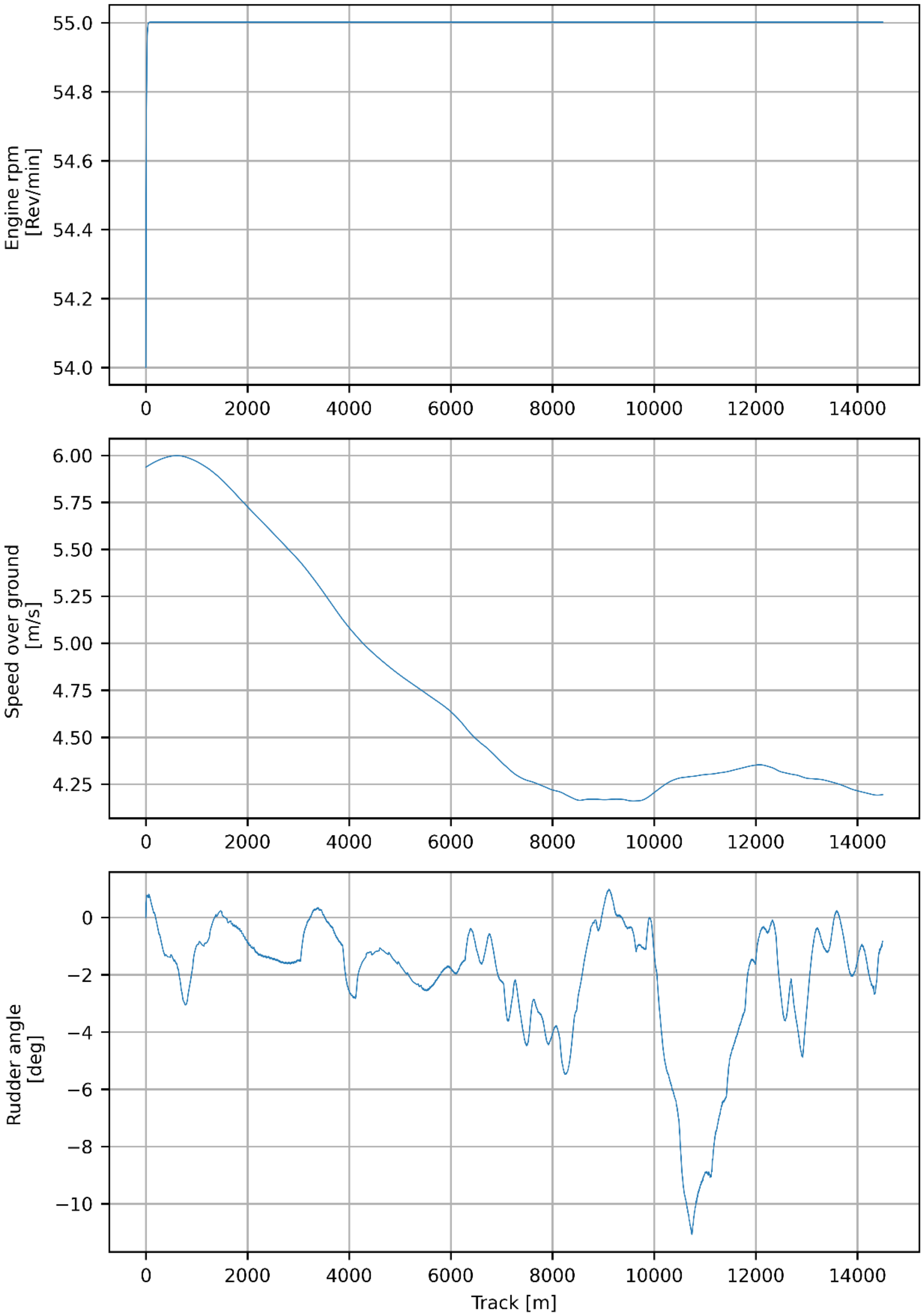

Figure 4-2: A-Arr-W-PE-Swell - RPM, Speed and Rudder Angle

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4.1.2 Run “B-Arr-W-PE-Swell”

This simulation run is performed for arrival through channel section B with westerly wind and corresponding wind-generated wave conditions, during peak ebb, with swell waves also present. All section B arrival simulations start 680m after the 12,000m mark and end 300m after the 27,000m mark.

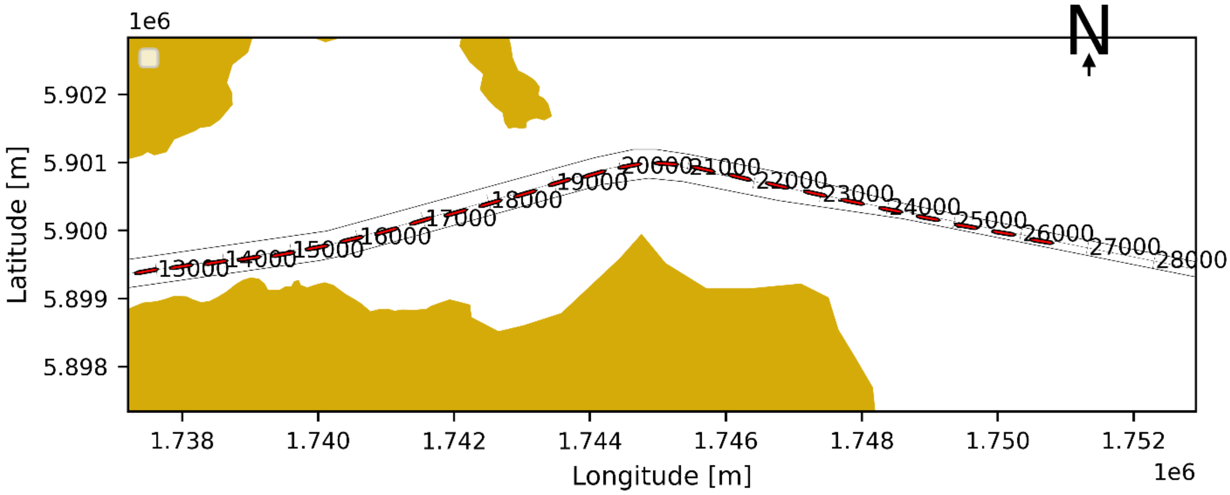

Figure 4-3: B-Arr-W-PE-Swell - Ship's Path

As shown in Figure 4-3, the vessel remains at the channel centre line or is in direct proximity to it. Small deviations from the centre line are observed in bends, around the 15,000m mark and between 20,000m and 21,000m marks, which is typical for turning vessels and is therefore of no concern (and taken into account in the initial concept design).

The propeller speed remains at 55 RPM throughout the entire section, whereas the ship accelerates from 4.3m/s at the beginning of the section to approximately 4.7m/s at the end (see Figure 2-4). Speed increase is caused by the fact that currents in this section of the channel are generally weaker than currents in section A: 1.5m/s – 2.0m/s in section B, except for the increment of the channel around the 19,000m mark. Here, current speed exceeds 2.2m/s, causing the “dent” in vessel’s speed.

Similar to section A, the rudder is almost straight throughout the section except for when the ship is turning right after the 20,000m mark.

To conclude, deviations from the track and rudder usage remained well within the set limits, therefore, the channel alignment and dimensions are considered appropriate for given environmental conditions.

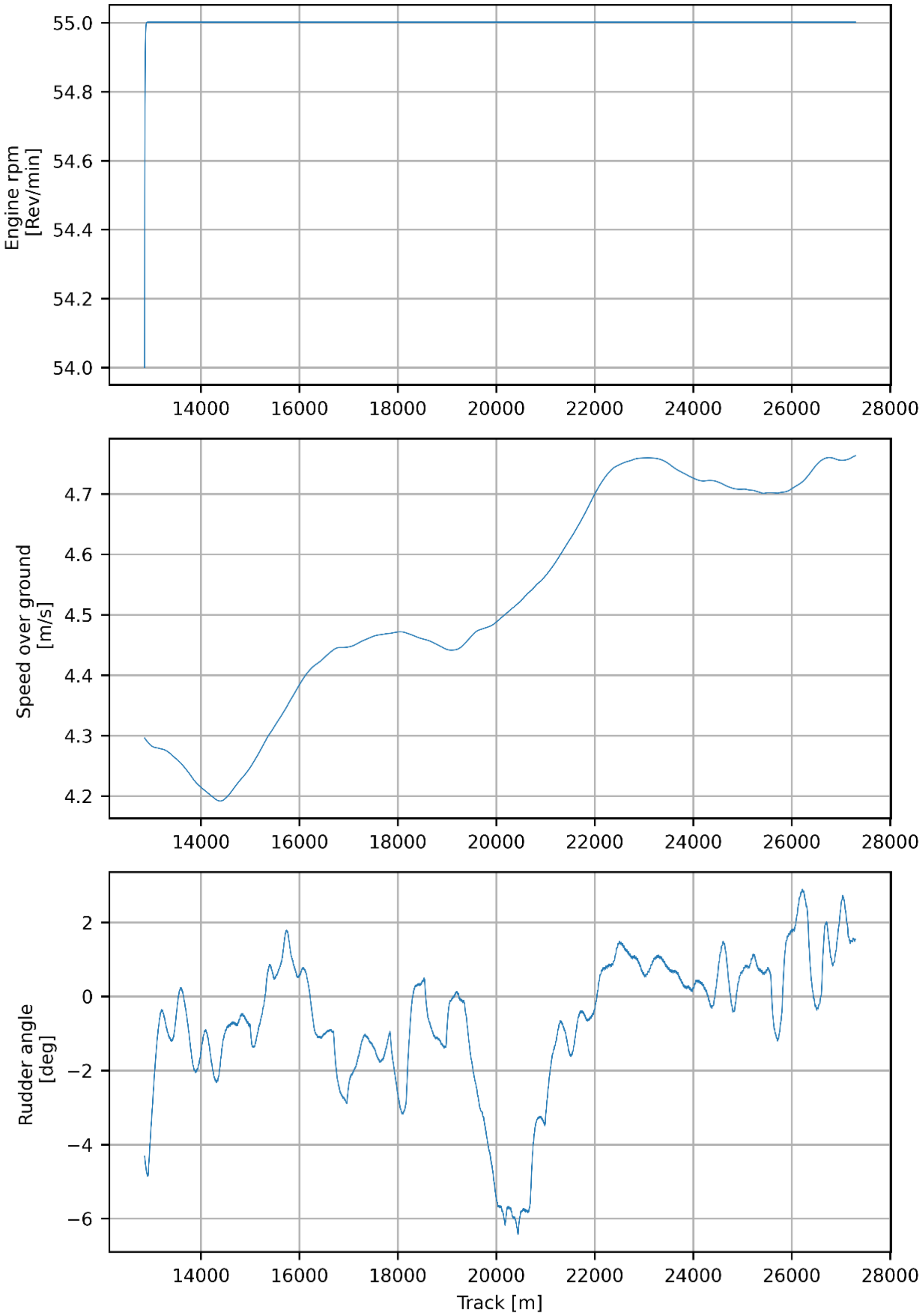

Figure 4-4: B-Arr-W-PE-Swell - RPM, Speed and Rudder Angle

4.1.3 Run “C-Arr-W-PE-Swell”

This simulation run is performed for arrival through channel section C with westerly wind and corresponding wind-generated wave conditions, during peak ebb, with swell waves also present. All section C arrival simulations start 500m after the 25,000m mark and end 350m after the 37,000m mark.

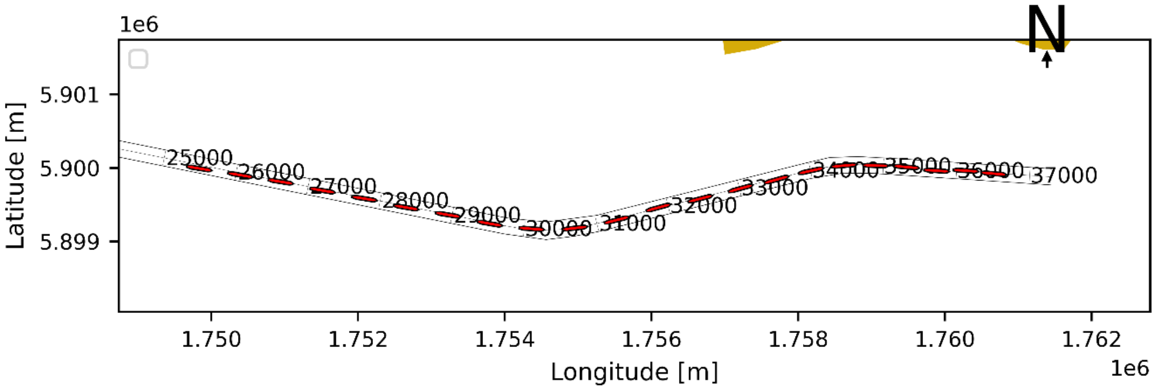

Figure 4-5: C-Arr-W-PE-Swell - Ship's Path

As shown in Figure 4-5, the vessel remains at the channel centre line or is in direct proximity to it. Small deviations from the centre line are observed at the beginning of the track at the 25,000m mark and in bends, between the 30,000m and 31,000m and 34,000m and 35,000m marks. While the deviation from the track in the bend is usual, the deviation in the straight section around the 25,000m mark is caused by the current and wind. The ship is nevertheless able to withstand the environmental forces and returns to the track by the 27,000m mark without significant effort.

The ship enters the section with propeller speed set at 55 RPM, which it maintains until the point 500m after the 32,000m mark, where it is reduced to 39 RPM (“slow”). Then, at 36,000m mark, the RPM are reduced further to 23 (“dead slow”). The vessel decelerates as the engine slows down: the ship’s speed decreases from 4.6m/s at the beginning of the section to below 3.0m/s at the end (see Figure 2-6). It is important the ship is able to reach the speed of 3.0m/s to 4m/s through the water or below at the end of the channel, as this is the speed at which port tugs are able to safely attach the lines and guide the vessel to berth. This means that speed over ground in the results should be less than 2.5m/s in peak ebb runs and be lower than 3.5m/s in peak flood runs.

Similar to rudder use in sections A and B, rudder remains in almost straight position throughout the entire section except for bends, where it is set to 7.5° during the first turn and -10° during the second.

To conclude, deviations from the track and rudder usage remained well within the set limits. Moreover, the vessel is able to reduce the speed to 3.0m/s at the end of the channel, therefore, the channel alignment and dimensions are considered appropriate for given environmental conditions.

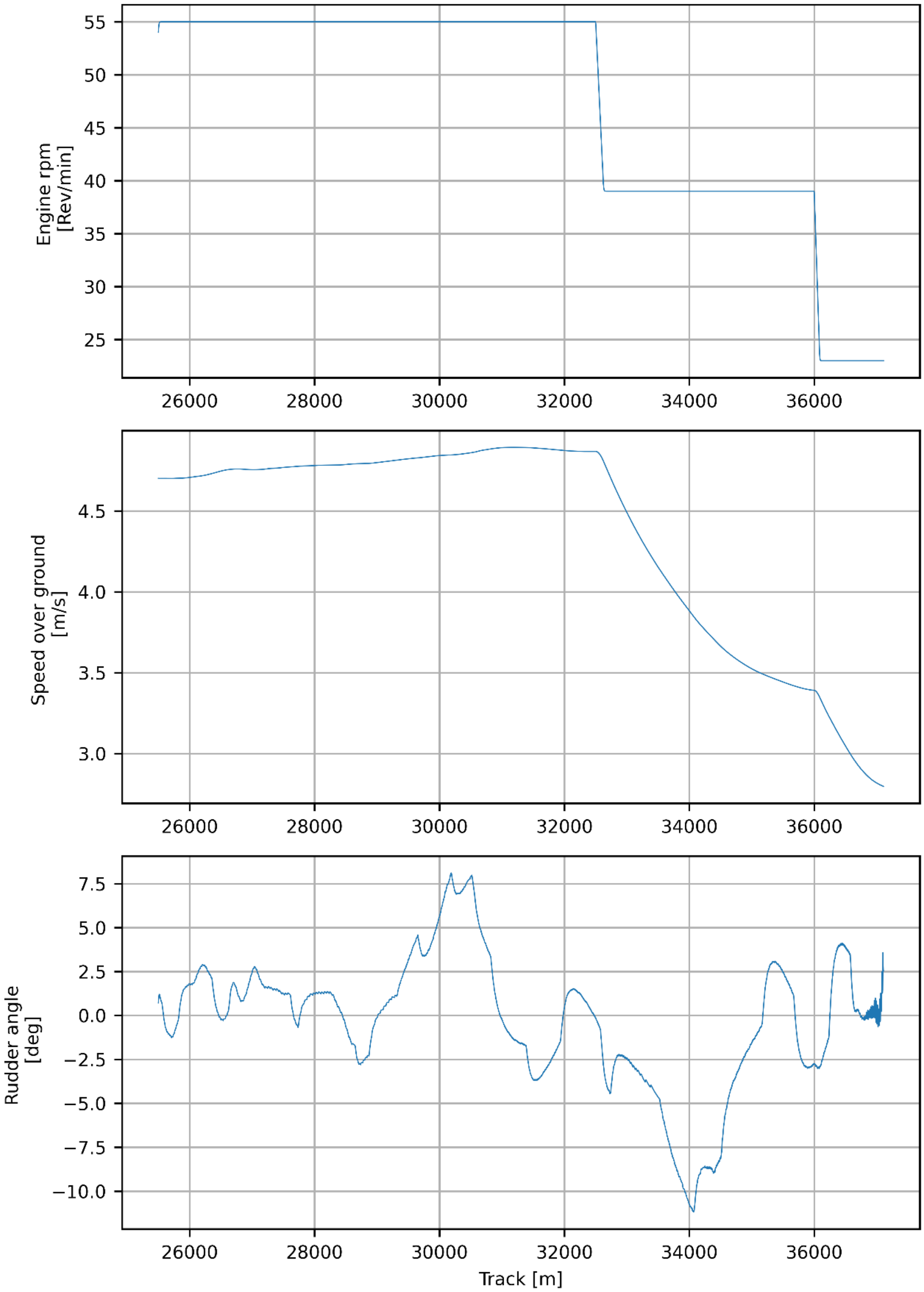

Figure 4-6: C-Arr-W-PE-Swell - RPM, Speed and Rudder Angle

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4.2 Departure Runs

The following three sub-sections describe results of departure runs through each channel section (in order from C to A). In these runs, the ship's route starts at the 0m mark corresponding to the channel's end and ends 350m after the 37,000m mark, which corresponds to the channel's entrance. In the figures, marks are shown every 1,000m. The vessel location in the figures is plotted every 2 minutes.

4.2.1 Run "C-Dep-N-PF-Swell"

This simulation run is performed for departure through channel section C with northerly wind and corresponding wind-generated wave conditions, during peak flood, with swell waves also present. All section C departure simulations start at the 0m mark and end 900m after the 11,000m mark.

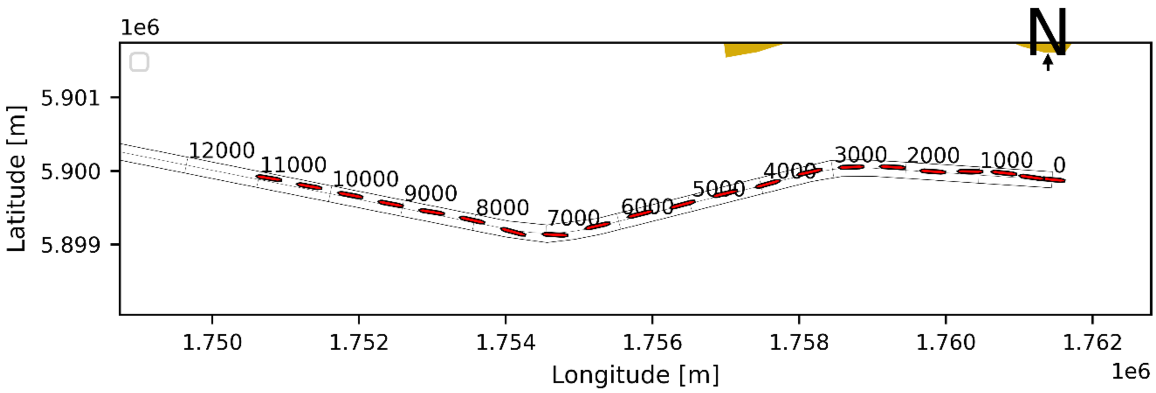

Figure 4-7: C-Dep-N-PF-Swell - Ship's Path

As shown in Figure 4-7, the vessel remains at the channel centre line or is in direct proximity to it. Small deviations from the centre line are observed at the beginning of the track at the 10,000m mark, in bends between the 2,000m and 3,000m and 6,000m and 8,000m marks, and at the end of the simulated section from the 10,000m mark onwards. While the deviation from the track in the bend is usual, deviations in straight sections are caused by the current and wind.

Typically, vessels that manoeuvre out of harbours at low speed are assisted by tugs to have a controlled acceleration from zero. Therefore, for all departure runs in channel section C the ship starts with the propeller speed set at 23 RPM ("dead slow"). In the simulation under consideration, the propeller speed then increases to 55 RPM and remains the same throughout the section. As can be seen in Figure 4-8, the vessel's speed increases accordingly, from 2.0m/s at the start to 5.0m/s at the 6,000m mark, after which it slightly decreases due to influence of currents flowing in the direction opposite to the ship's movement.

Limited rudder action is observed at the beginning of the route, as the ship is correcting course. After that, aside from when the ship is in bends, the rudder remains in an almost straight position.

To conclude, deviations from the track and rudder usage remained well within the set limits. Therefore, the channel alignment and dimensions are considered appropriate for passage under given environmental conditions.

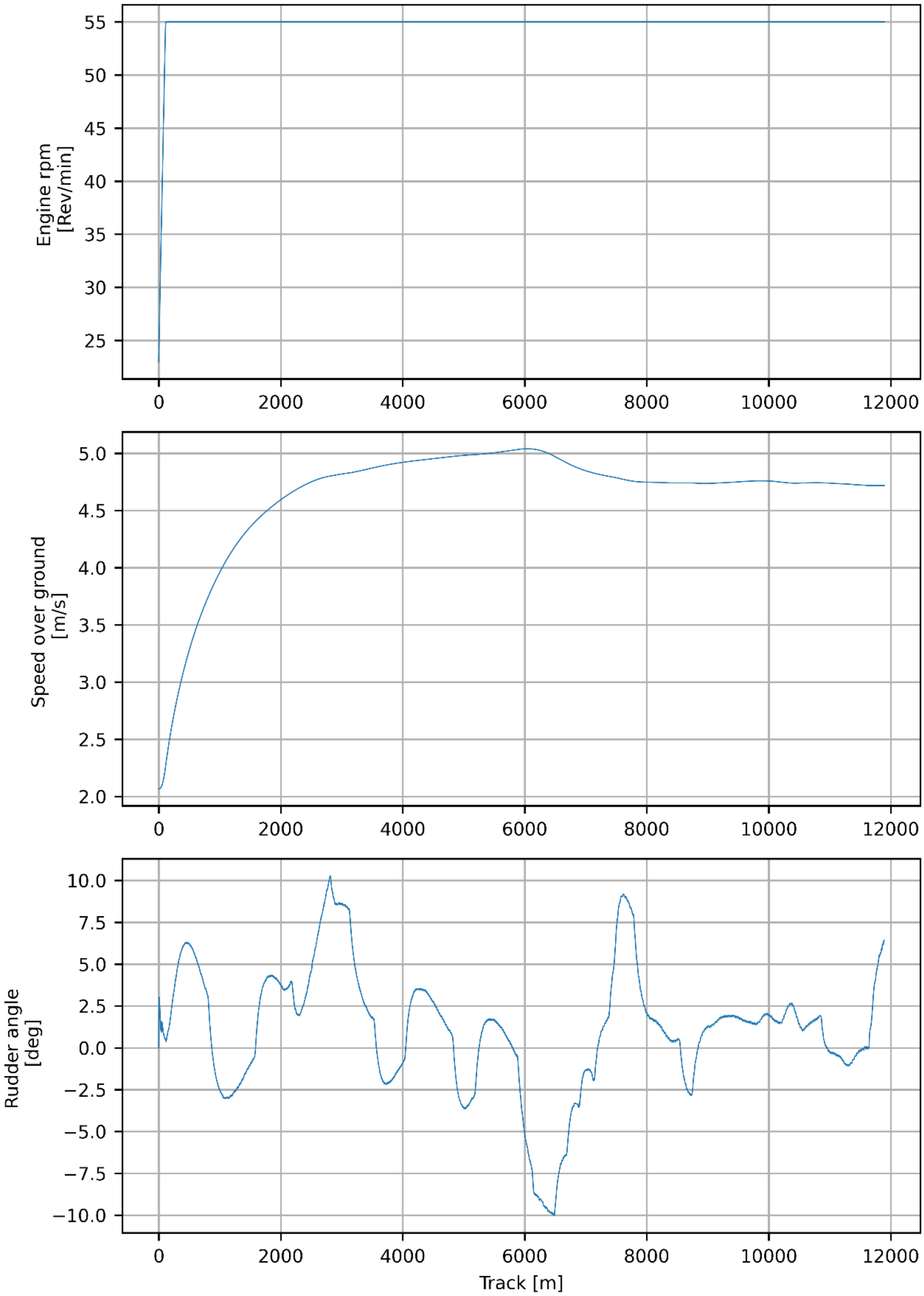

Figure 4-8: C-Dep-N-PF-Swell - RPM, Speed and Rudder Angle

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4.2.2 Run "B-Dep-N-PF-Swell"

This simulation run is performed for departure through channel section B with northerly wind and corresponding wind-generated wave conditions, during peak flood, with swell waves also present. All section B departure simulations start at the 10,000m mark and end 700m after the 24,000m mark.

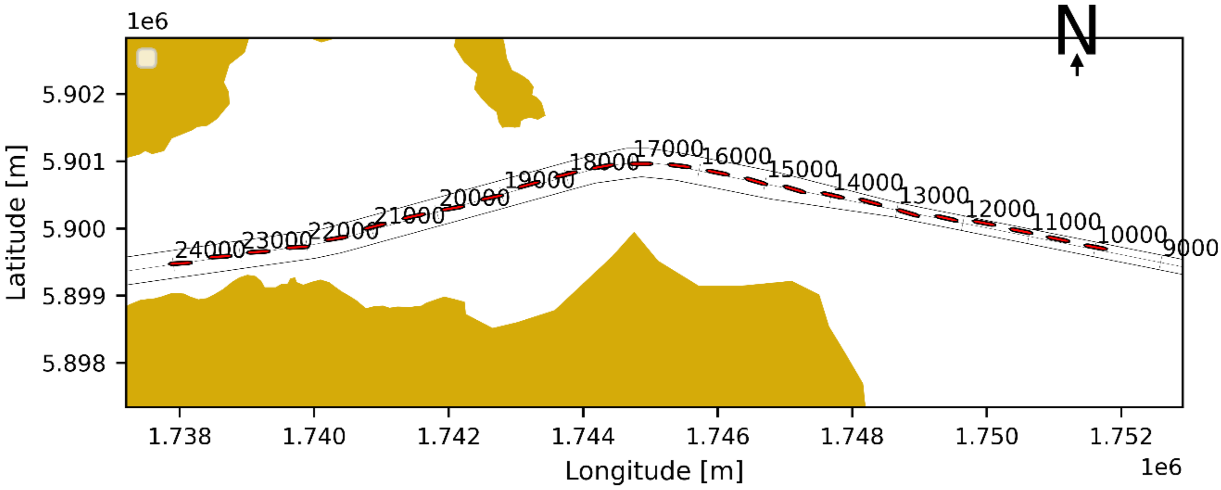

Figure 4-9: B-Dep-N-PF-Swell - Ship's Path

As shown in Figure 4-9, the vessel remains at the channel centre line or is in direct proximity to it. Small deviations from the centre line are observed at the beginning of the track between the 10,000m and 12,000m marks and in bends between the 16,000m and 17,000m marks and at the 21,000m mark. While the deviation from the track in the bend is usual, deviations in straight sections are caused by the current and wind. Despite adverse environmental conditions, these deviations do not grow or persist, as the vessel is able to correct the course without significant effort.

The propeller speed of the vessel is set at 55 RPM ("half ahead") throughout the entire section, whereas vessel's speed varies slightly, but remains within the range between 4.7m/s and 5.0m/s (seeFigure 4-10).

Limited rudder action is observed at the beginning of the route, as the ship is correcting course. After that, aside from when the ship is in bends, the rudder remains in an almost straight position.

To conclude, deviations from the track and rudder usage remained well within the set limits. Therefore, the channel alignment and dimensions are considered appropriate for passage under given environmental conditions.

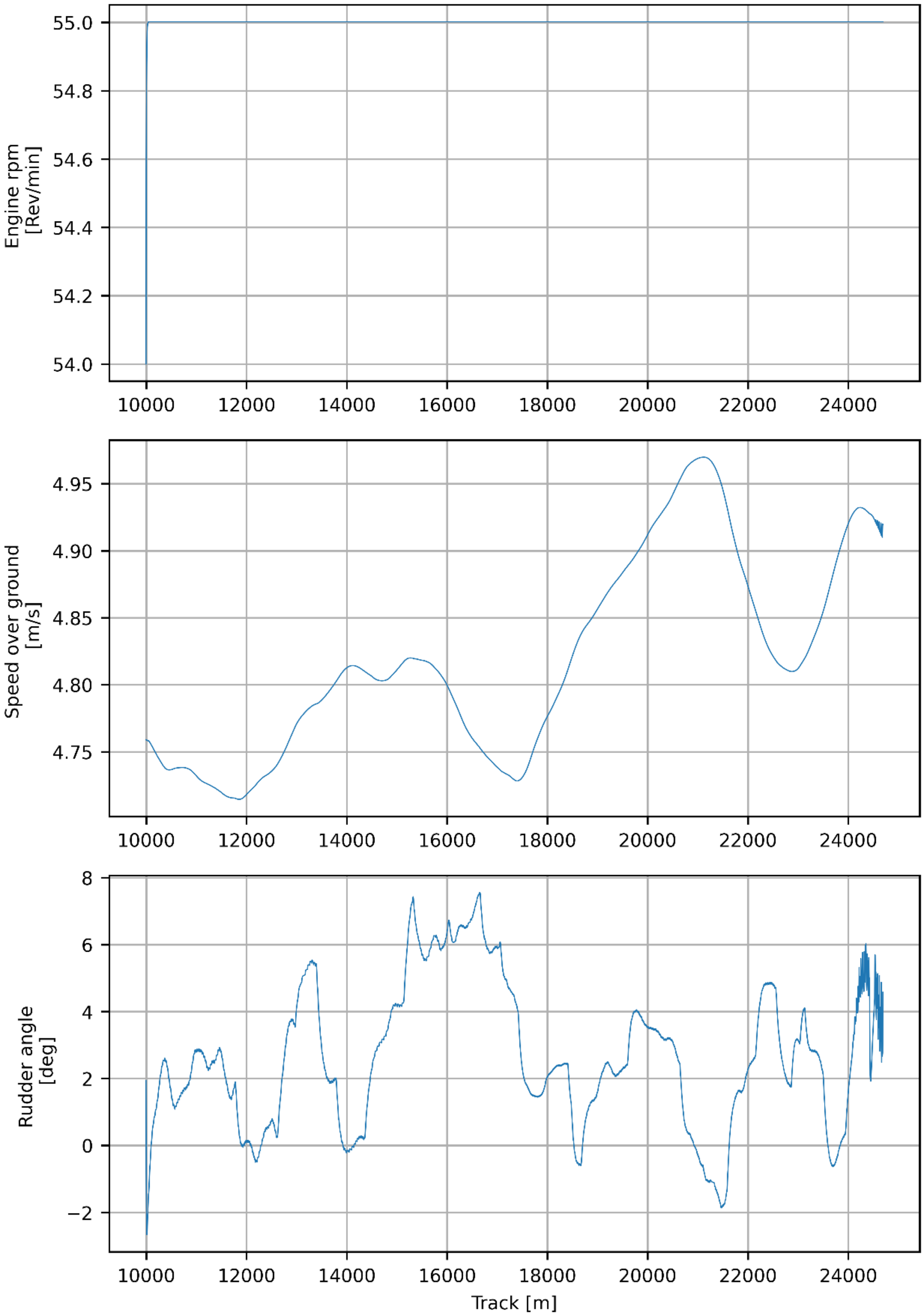

Figure 4-10: B-Dep-N-PF-Swell - RPM, Speed and Rudder Angle

4.2.3 Run "A-Dep-N-PF-Swell"

This simulation run is performed for departure through channel section A with northerly wind and corresponding wind-generated wave conditions, during peak flood, with swell waves also present. All section A departure simulations start 850m after 22,000m mark and end 350m after the 37,000m mark.

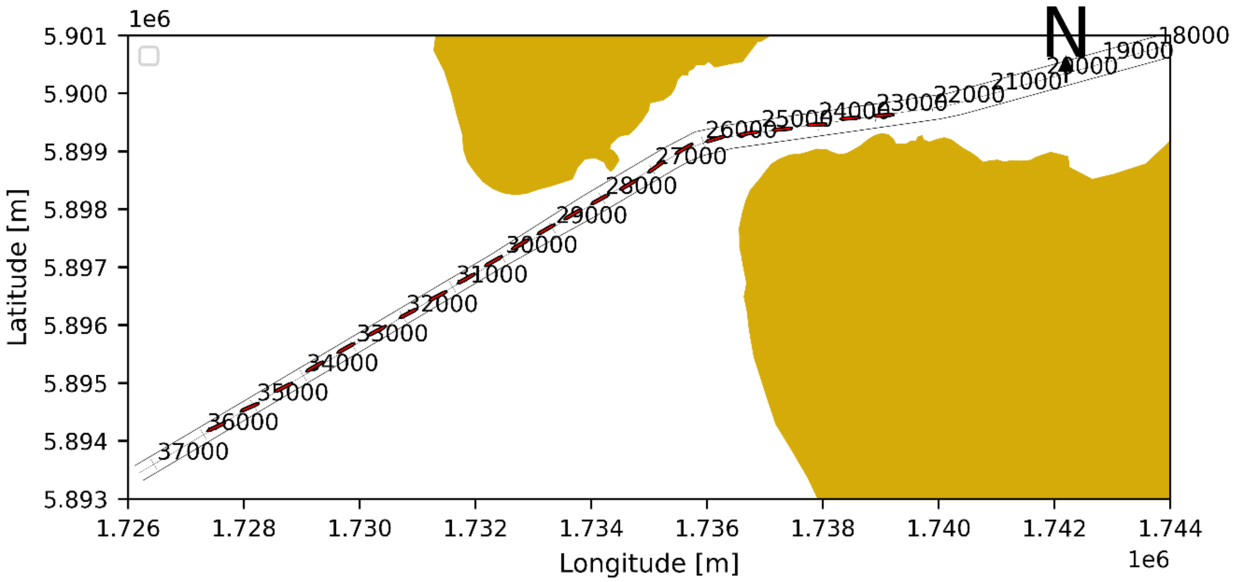

Figure 4-11: A-Dep-N-PF-Swell - Ship's Path

As shown in Figure 4-11, the vessel remains at the channel centre line or is in direct proximity to it. Small deviations from the centre line are observed in bends between the 25,000m and 26,000m marks and in the straight section between the 29,000m and 30,000m marks. While the deviation from the track in the bend is usual, deviations in straight sections are caused by the current and wind. Despite adverse environmental conditions, these deviations do not grow or persist, as the vessel is able to correct the course without significant effort.

The propeller speed of the vessel is set at 55 RPM ("half ahead") throughout the entire section, whereas speed of the vessel increases from 4.8m/s at the beginning to 5.8m/s as the vessel moves towards the exit from the channel (see Figure 4-12). Limited decrease in speed between the 28,000m and 30,000m marks is caused by the strong flood current.

Limited rudder action is observed at the beginning of the route, as the ship is correcting course. After that, aside from when the ship is in bends, the rudder remains in an almost straight position.

To conclude, deviations from the track and rudder usage remained well within the set limits. Therefore, the channel alignment and dimensions are considered appropriate for passage under given environmental conditions.

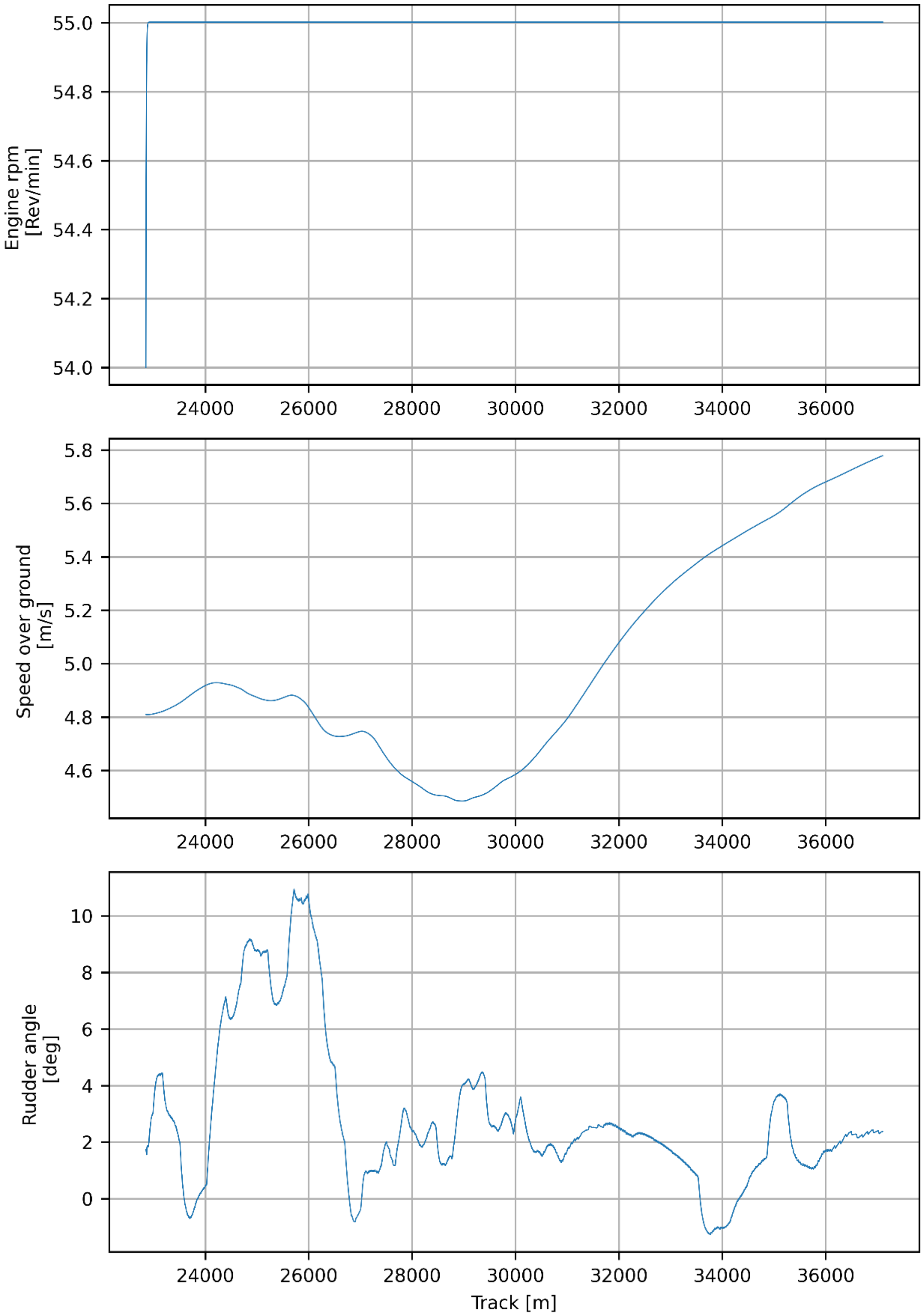

Figure 4-12: A-Dep-N-PF-Swell - RPM, Speed and Rudder Angle

5 Additional Runs

The purpose of the runs discussed in the previous sections was to check whether the channel width is sufficient for the largest vessel, which is described in Section 2.1.5. This vessel, however, is not the only one anticipated to call at the potential future port. Other vessels, smaller in length and beam, but with larger draughts, will also visit the terminal, as explained in PMM report[5]. From the perspective of channel width, those vessels are not governing; in other words, if the largest vessel is able to manoeuvre successfully through the channel under investigated conservative combinations of environmental conditions, then smaller vessels are able, too.

However, larger draught vessels listed in PMM report are governing in determining the channel's depth, which is described in the initial channel concept design report[6]. At concept stage, the depth is determined using coefficients-based method described in PIANC guidelines[7], meaning that the depth values obtained through it are indicative, although highly likely safe for passage, because the method is conservative. In other words, channel depth determined based on PIANC guidelines usually needs to be investigated further using complex mathematical models and detailed representation of environmental conditions as input for them, to confirm that the depth is appropriate for safe passage.

This investigation, called Probabilistic Under Keel Clearance (UKC) study, was performed by RHDHV[8], and it was established that initial minimum required depth in dredged sections of the channel may be safely reduced without causing unacceptable downtime. Initial and optimized channel depth values are shown in Table 5-1.

Table 5-1: Channel Depth Optimization Results

Channel Section	Initial proposed depth	Optimized depth
Section over the bar (entrance section)	-20.5 mCD	-19.0 mCD
Inland section (end section)	-17.7 mCD	-16.0 mCD

In short, reduction of depth is possible because it was demonstrated that the probability of the event where the vessel touches the channel bed is sufficiently low, due to the nature of vessel motion under investigated environmental conditions. An important aspect influencing the vertical component of vessel motion is the speed it travels with: generally, the faster the ship goes, the deeper it will sink into the water. This effect is referred to as squat, and its impact on channel depth was assessed for the speed of 8 knots (4 m/s), which is a typical speed for channel passage. In other words, the probabilistic UKC study demonstrates that larger draught vessels have low probability of touching the bottom while passing through dredged sections of the channel under investigated environmental conditions (meaning that new channel depths are safe), provided that their speed is 8 knots.

While in the main set of simulations (Table 3-3) the passage speed is of no concern due to the fact that the largest ship has smaller draught, giving it an extra margin for bigger squat and thus allowing for flexibility in use of speed, the vessels with larger draughts will have to limit their speed to 8 knots. Adjusting the speed during passage under challenging conditions is one of the ways for mariners to retain or improve control over vessels. Thus, the purpose of additional runs, discussed in this chapter, is to check whether the shorter and narrower ships with deeper draughts can manoeuvre through dredged sections of the channel without exceeding the speed limit of 8 knots.

[5] *"New Zealand Ports and Shipping Overview", PMM (March 2023)*
[6] *"Interim Technical Working Paper. Navigation and Channel Design", RHDHV (June 2023)*
[7] *"Report WG121-2014: Harbour Approach Channels. Design Guidelines", PIANC (2014)*
[8] *"Probabilistic under keel clearance study", RHDHV (December 2023)*

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5.1 Vessel Models

Vessel models used by the modelling software are digital versions of ships that have been comprehensively tested in laboratories to establish coefficients that make it possible to calculate ship's position and response to environmental forces in simulated manoeuvres. Tests are performed for a wide but not limitless range of conditions. One of the variables that affects ship's behaviour in real life and in simulations is the ratio between the vessel's draught and water depth. Thus, each model has a validity range defined by minimum water depth. It means that simulations for passages through water bodies with depth within this range are validated and results are accurate and reliable.

The ship model that is the closest to the design vessel used in the UKC Study has a draught of 14.5m and produces valid results for water depth not less than 17.4m. This model can be used for simulations in channel section A (section over the bar), where the water level is more than 19.56m (channel bed level of -19 mCD with addition of 0.56 mCD water level, see Section 3.1.3) but is outside of its validity range in section C (inland section), where the water depth is 16.56m. The next closest ship model is therefore selected for additional simulations in section C. Its validity range is limited by a minimum water depth of 14.9m, which makes the simulation in section C possible, however, draught of this ship model is 13.5m, which is 0.8m less than the draught of the design vessel used in determining required water depth.

To correct the effect of mismatch between model draught and design vessel draught, ratio of channel bed level and design draught is transferred into the simulated environment:

$$r = \frac{h_a}{T_D} = \frac{16}{14.3} = 1.119$$

Where:

- h_a – water depth of the channel (m), and
- T_D – draught of the design vessel (m).

For simulations with smaller draught ship model to be representative, the ratio should remain the same:

$$h_S = r \times T_M = 1.119 \times 13.5 = 15.1m$$

Where:

- *hs* – water depth of the simulated channel (m), and
- *TM* – draught of the ship model.

In other words, for the behaviour of ship model with smaller draught to be representative, the channel depth in the simulations needs to be adjusted to 15.1m.

Ship models used for additional simulations are described in the following sub-sections.

5.1.1 Ship model used in Channel Section Over the Bar (section A)

The vessel used in the simulations is a partly/fully loaded container vessel with main dimensions LOA x B x T = 347 x 42.91 x 14.5 (SHIPMA Model "con013g2"). Among the available vessel models, the presented model is the closest match in terms of dimensions and manoeuvrability to the design vessel. The vessel model has a single propeller and rudder with 54,860 kW power at 94 RPM. The windage area is 1,540 m^2 frontage and 8,641 m^2 lateral. Vessel speeds for varying telegraph settings are presented in Table 5-2.

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Table 5-2: Telegraph setting of vessel model "con013g2"

Telegraph	RPM	Speed [kn]
Sea full	94	21.2
Harbour full	65	14.6
Half	50	11.2
Slow	35	7.9
Dead slow	25	5.6

5.1.2 Ship model used in Inland Channel Section (section C)

The vessel used in the simulations is a partly/fully loaded container vessel with main dimensions LOA x B x T = 318.2 x 42.80 x 13.5 (SHIPMA Model "con011r4"). Among the available vessel models, the presented model is the closest match in terms of dimensions and manoeuvrability to the design vessel. The vessel model has a single propeller and rudder with 54,860 kW power at 94 RPM. The windage area is 1,417 m^2 frontage and 8,690 m^2 lateral. Vessel speeds for varying telegraph settings are presented in Table 5-3.

Table 5-3: Telegraph setting of vessel model "con011r4"

Telegraph	RPM	Speed [kn]
Sea full	94	24.4
Harbour full	74	19.2
Half	58	15.0
Slow	44	11.4
Dead slow	30	7.8

5.2 Selected Conditions

In total, 12 additional runs are performed for the most adverse conditions in sections A and C:

- Section A: Arrival & Departure with westerly wind and corresponding wind-generated waves, for peak ebb, peak flood, and low water currents, with swell waves present.
- Section C: Arrival & Departure with south-westerly wind and corresponding wind-generated waves, for peak ebb, peak flood, and low water currents, with swell waves present.

Section B is not simulated, as the channel in this section is naturally deep.

Environmental conditions are described in Section 3 in more detail.

5.3 Additional Simulations Case Matrix

In total, 12 simulation runs are performed, 6 for each section of the channel (see Table 5-4, simulations ID follow the same convention as described in Section 3, with "AR" standing for "Additional Runs").

Table 5-4: Simulations Case Matrix – Additional Runs

SN	ID	Direction	Wind (Dir m/s)	Wind Waves (relates to wind conditions)	Water Level & Current	Swell Waves
Channel Section A						
1	AR-A-Arr-W-PF-Swell	Arrival	W 14	ss08	Peak Flood	ss04
2	AR-A-Arr-W-PE-Swell	Arrival	W 14	ss08	Peak Ebb	ss04
3	AR-A-Arr-W-LW-Swell	Arrival	W 14	ss08	Low Water	ss04
4	AR-A-Dep-W-PF-Swell	Departure	W 14	ss08	Peak Flood	ss04
5	AR-A-Dep-W-PE-Swell	Departure	W 14	ss08	Peak Ebb	ss04
6	AR-A-Dep-W-LW-Swell	Departure	W 14	ss08	Low Water	ss04
Channel Section C						
7	AR-C-Arr-SW-PF-Swell	Arrival	SW 14	ss07	Peak Flood	ss04
8	AR-C-Arr-W-PE-Swell	Arrival	SW 14	ss07	Peak Ebb	ss04
9	AR-C-Arr-W-LW-Swell	Arrival	SW 14	ss07	Low Water	ss04
10	AR-C-Dep-W-PF-Swell	Departure	SW 14	ss07	Peak Flood	ss04
11	AR-C-Dep-W-PE-Swell	Departure	SW 14	ss07	Peak Ebb	ss04
12	AR-C-Dep-W-LW-Swell	Departure	SW 14	ss07	Low Water	ss04

5.4 Simulation Results of Additional Runs

Results of all runs listed in Section 5.3 are presented in Appendices A8 – A11. All simulations demonstrated that the ship manoeuvres within the spatial limits defined in Section 2.3.1 and retains good control under the examined conservative combinations of environmental conditions, thus proving that the channel dimensions and alignment allow for safe passage.

For illustration purposes, 2 runs are selected and described in the following sub-sections.

5.4.1 Run "AR-A-Dep-W-PF-Swell"

This additional simulation run is performed for departure through channel section A with westerly wind and corresponding wind-generated wave conditions, during peak flood, with swell waves also present. All section A departure simulations start 850m after the 22,000m mark and end 350m after the 37,000m mark.

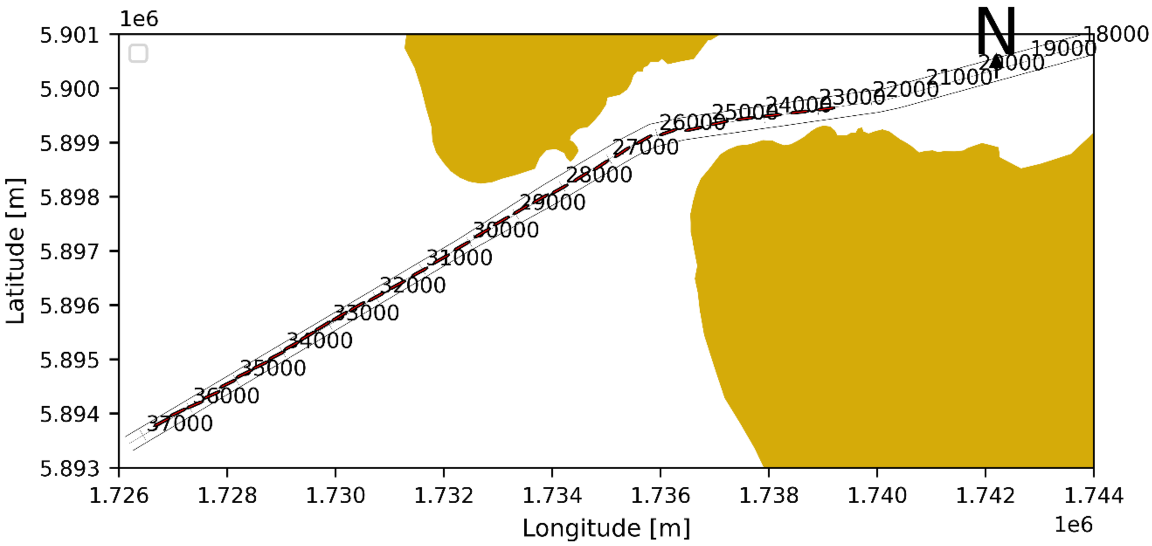

Figure 5-1: AR-A-Dep-W-PF-Swell - Ship's Path

As shown in Figure 5-1, the vessel remains at the channel centre line or is in direct proximity to it. Deviations from the centre line are observed in bends between the 25,000m and 26,000m marks and in the straight section between the 32,000m and 37,000m marks. While the deviation from the track in the bend is usual, deviations in straight sections are caused by the current, swells and wind. Despite adverse environmental conditions, these deviations do not grow, as the vessel is able to correct the course without significant effort.

The propeller speed of the vessel is set at 50 RPM ("half ahead") until the 31,500m mark, after which it decreases to 35 RPM ("slow"), whereas speed of the vessel decreases from 4.2m/s at the beginning to 3.0m/s as the vessel moves towards the exit from the channel (see Figure 5-2). Local speed increase from the 29,000m mark to the 31,500m mark is linked to decreasing current velocity in this channel increment.

Limited rudder action is observed at the beginning of the route, as the ship is correcting course. After that, aside from when the ship is in bends, the rudder remains in an almost straight position.

To conclude, deviations from the track and rudder usage remained well within the set limits. Vessel's speed over ground remains below 8 knots (4m/s) limit for almost entire run, except for between 23,000m and 26,000m marks, where the channel goes through the naturally deep water and therefore bigger squat is of no concern.

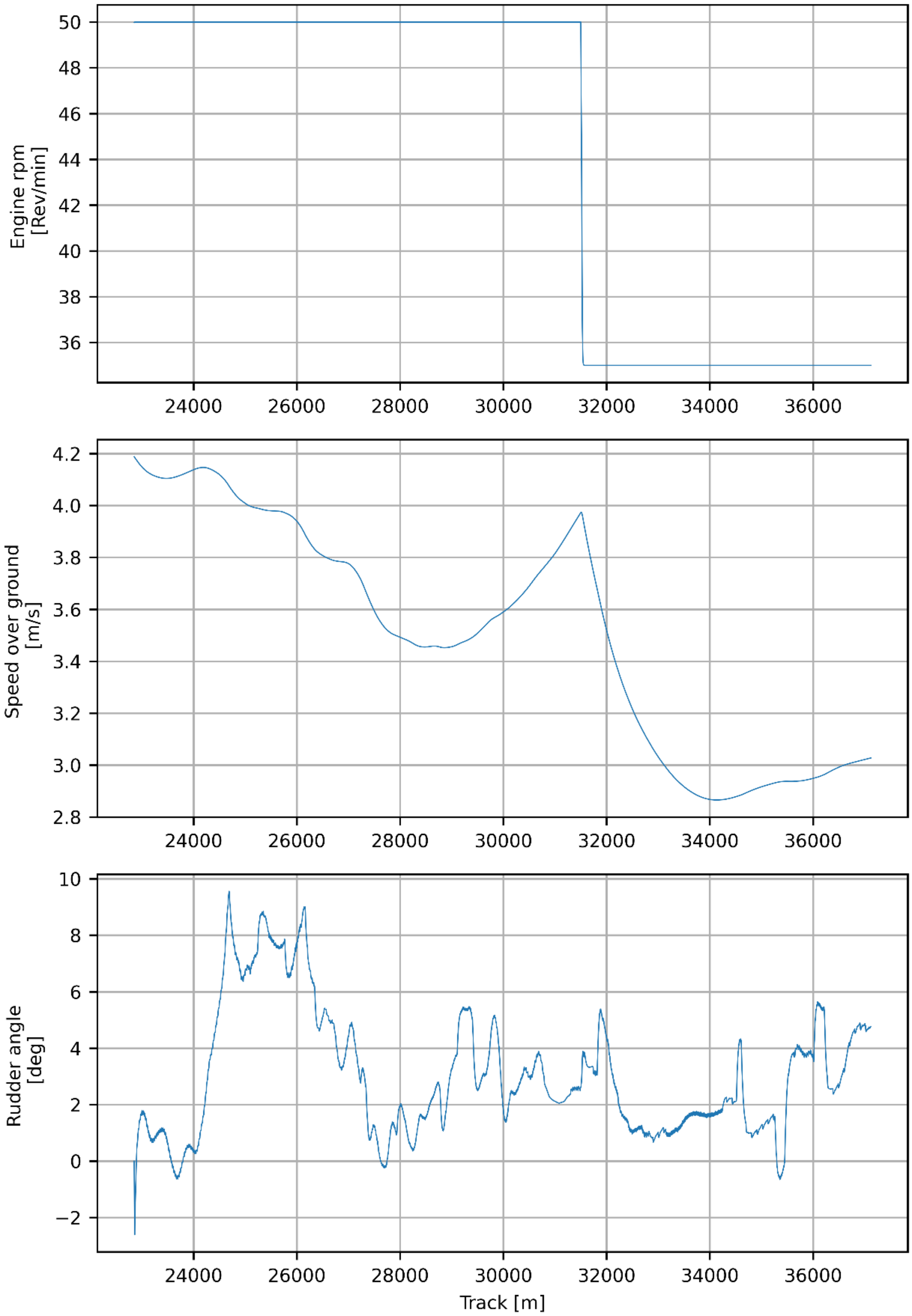

Figure 5-2: AR-A-Dep-W-PF-Swell - RPM, Speed and Rudder Angle

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5.4.2 Run "AR-C-Arr-SW-PF-Swell"

This additional simulation run is performed for arrival through channel section C with south-westerly wind and corresponding wind-generated wave conditions, during peak flood, with swell waves also present. All section C arrival simulations start at the 25,500m mark and end at the 37,350m mark.

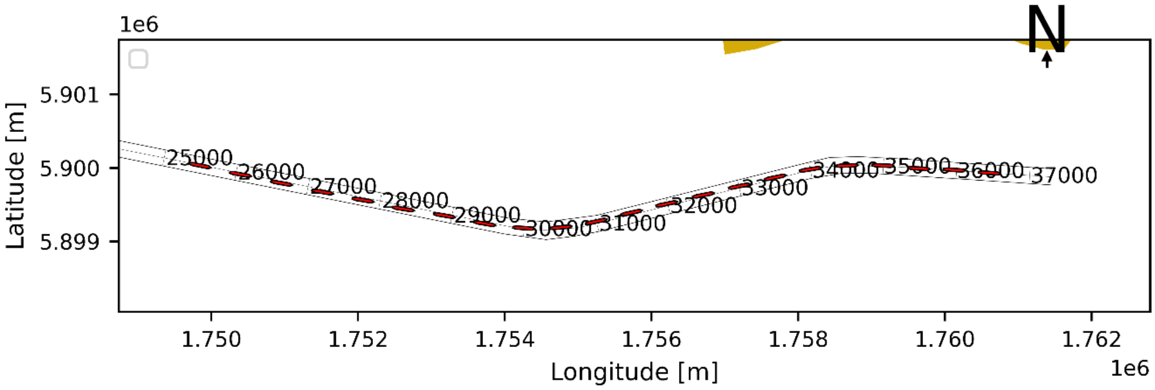


Figure 5-3: AR-C-Arr-SW-PF-Swell - Ship's Path

As shown in Figure 5-3, the vessel slightly deviates from the track for the most part of the simulation. While the deviation from the track in the bend is usual, deviation in the straight sections before and after the first bend (30,000m mark) is caused by the current, wind and bank suction. The ship is nevertheless able to withstand the environmental forces and returns to the track by the 35,000m mark.

The propeller speed is set at 30 RPM ("dead slow") for the whole simulation (see Figure 5-4), whereas speed over ground decreases from 4.7m/s at the start to 3.8m/s at the end, which is caused by weakening current. For the most part of the channel, however, speed remains above 4.0m/s (8 knots), however, this is due to current moving in the same direction as the ship. Current speed in the channel section reaches 1m/s in the area between the 25,000m and 30,000m marks, meaning that vessel's speed in water is around 3.5m/s (7 knots), which follows the set speed limit associated with the squat.

In response to the challenging environmental conditions, the ship heavily relies on rudder use, which is shown in the bottom graph of Figure 5-4: rudder angle reaches the set 70% limit angle of 24.5° in the first bend (around the 30,000m mark). Moreover, except for insignificant fluctuations, the rudder is set at around 10° in straight parts of the section, indicating that correction of deviation from the track is not effortless. Rudder use increases further towards the end of the simulation, as deceleration makes it even more difficult to stay on track.

In conclusion, the simulation demonstrates that the vessel is able to stay within set spatial boundaries and is following the speed limit, however, maneuvering is arguably difficult, as the ship has to resort to the maximum allowed rudder angles.

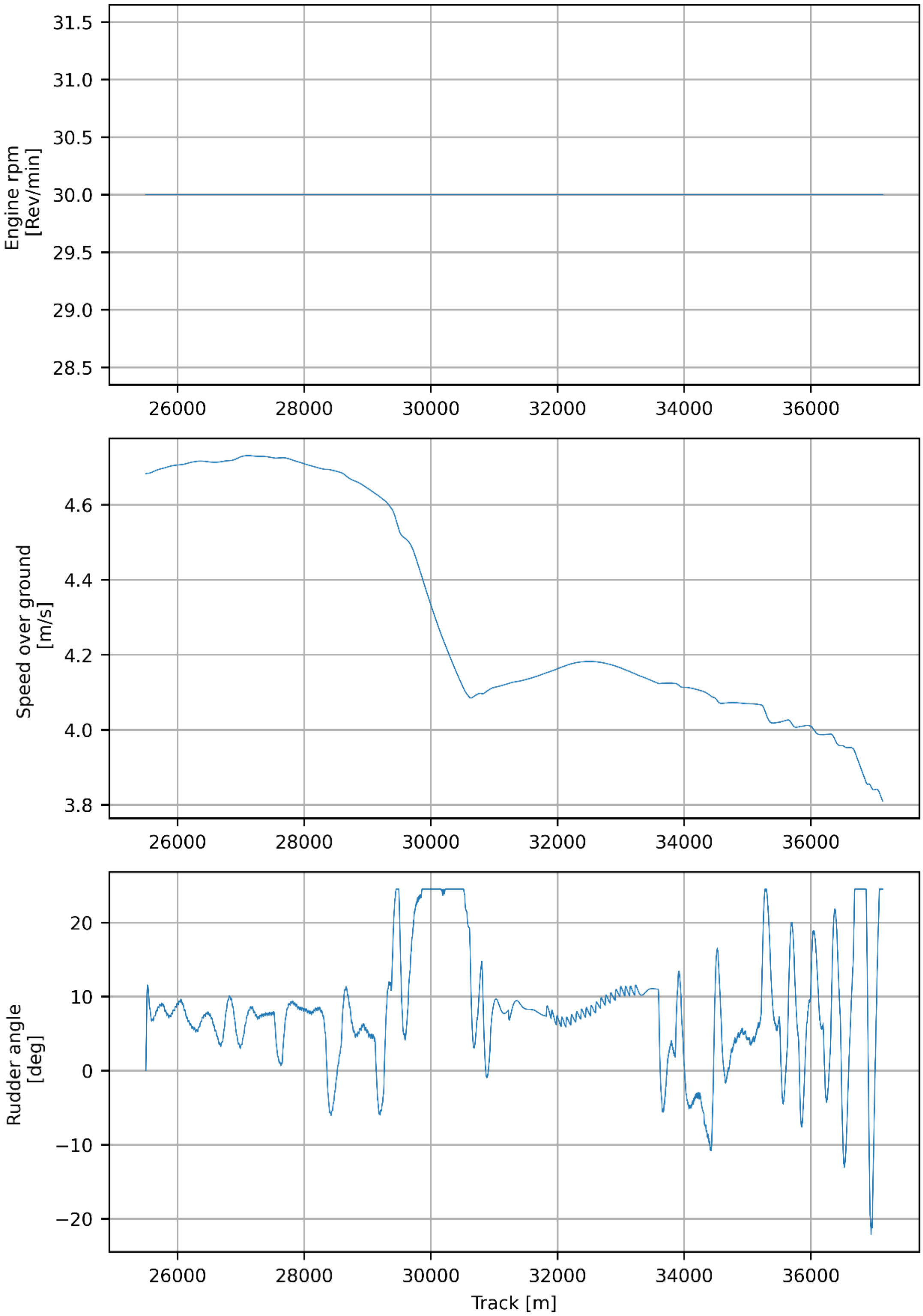


Figure 5-4: AR-C-Arr-SW-PF-Swell - RPM, Speed and Rudder Angle

6 Conclusions and Recommendations

The following conclusions are drawn based on the outcomes of the fast-time simulations:

- Channel dimensions are adequate for the manoeuvres under examined conservative combinations of environmental conditions. The ship leaves the designated path set out in Section 2.3.1 only occasionally and for short periods of time, mostly in bends; the ship is able to return to the intended course swiftly and without significant effort, meaning that the channel width is sufficient. Narrowing the channel, however, is not recommended, as it may lead to greater instability of the ship's track, especially in shallow parts, where influence of bank suction is significant. Channel dimensions optimization may be investigated further during the following design stages, by means of real-time simulations.
- The ship retains sufficient control over its course throughout the entire channel, both during arrival and departure passages, as almost no instances of rudder use exceeding 20° are recorded. Most of the time, rudder angle remains within +10° to -10° range. It is therefore concluded that the channel alignment is appropriate.
- Additional runs with smaller vessels that have deeper draughts in dredged sections demonstrate that vessels are able to retain control with imposed speed limit of 8 knots, however in Section C under some conditions, manoeuvring is arguably difficult, as the ship has to resort to the maximum allowed rudder angles.

A1 Simulation Channel Sections

Main parameter informing the choice of sections and boundaries between them is the period of swell waves (T_P). Over the domain, T_P values reach 15 s at the entrance of the channel and may fall to just 4 s in the area adjacent to the terminal. As described in Section 2.1.3, software's input wave field contains information on wave height and direction at each point of the domain. However, wave period, which also varies over the domain, may only be specified once, and is therefore considered by the software applicable to the entire field. Thus, simulated channel sections must be chosen in such a way that allows for selection of realistic and representative value of wave period. Wave period plots for each wave scenario are presented in figure below, along with selected single wave period values for each simulated channel section.

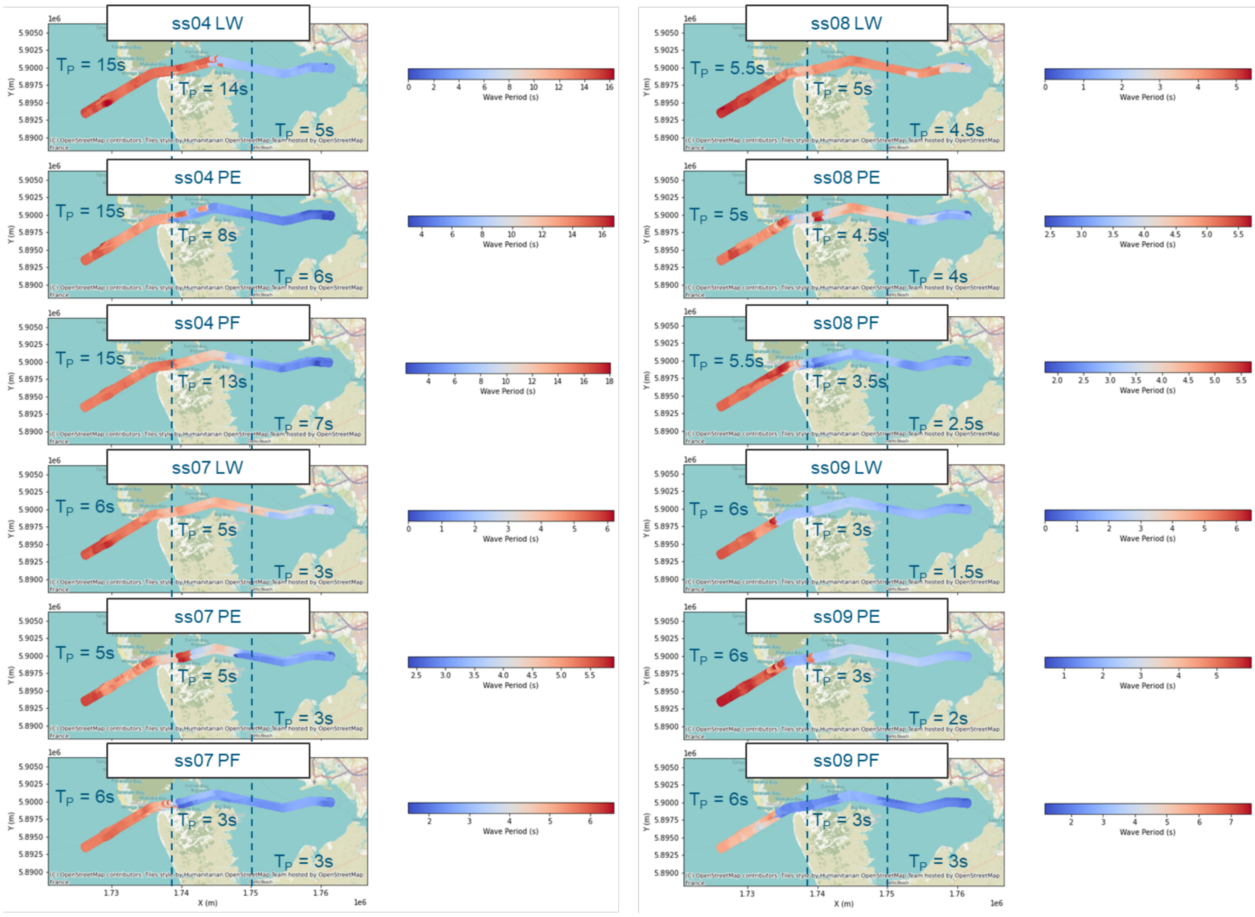


Figure A1-1: Wave Period Plots and Proposed Fixed Wave Period Values (LW – Low Water, PE – Peak Ebb, PF – Peak Flood; case notation "ss0X" follows that described in Section 3.1)

Another consideration that influences the way the sections are chosen is location of the bends. Simulation boundaries should be located at least 2,000 m away from the bends, as investigating behaviour of the vessel in bends is one of the core objectives of the fast-time simulations, therefore, bends should remain well within boundaries of simulated sections.

To ensure continuity, a 2,000 m overlap zones are introduced between simulated sections, meaning that the vessel's track starts at least 1,000 m before the boundary of the section being simulated. This is the case for all simulations except those that start right at the channel's entrance ("A-Arr-…" simulations in Table 3-3) or right at the channel's end ("C-Dep-…" simulations in Table 3-3). Moreover, start position characteristics of the vessel are derived from the finish position characteristics in the previous section. For example, in simulations focusing on arrival through section B ("B-Arr-…" in Table 3-3), the vessel starts with the speed and course values matching those recorded at the end of simulations focusing on arrival through section A.

A2 Arrival Simulations in Section A – Main Runs

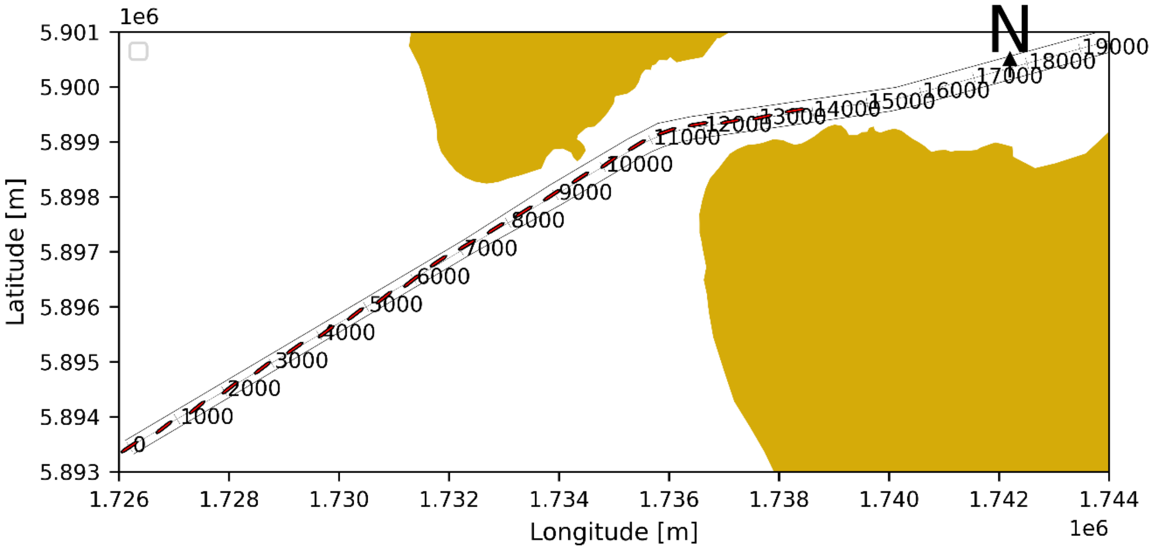
A2.1 Run "A-Arr-N-LW-Swell"

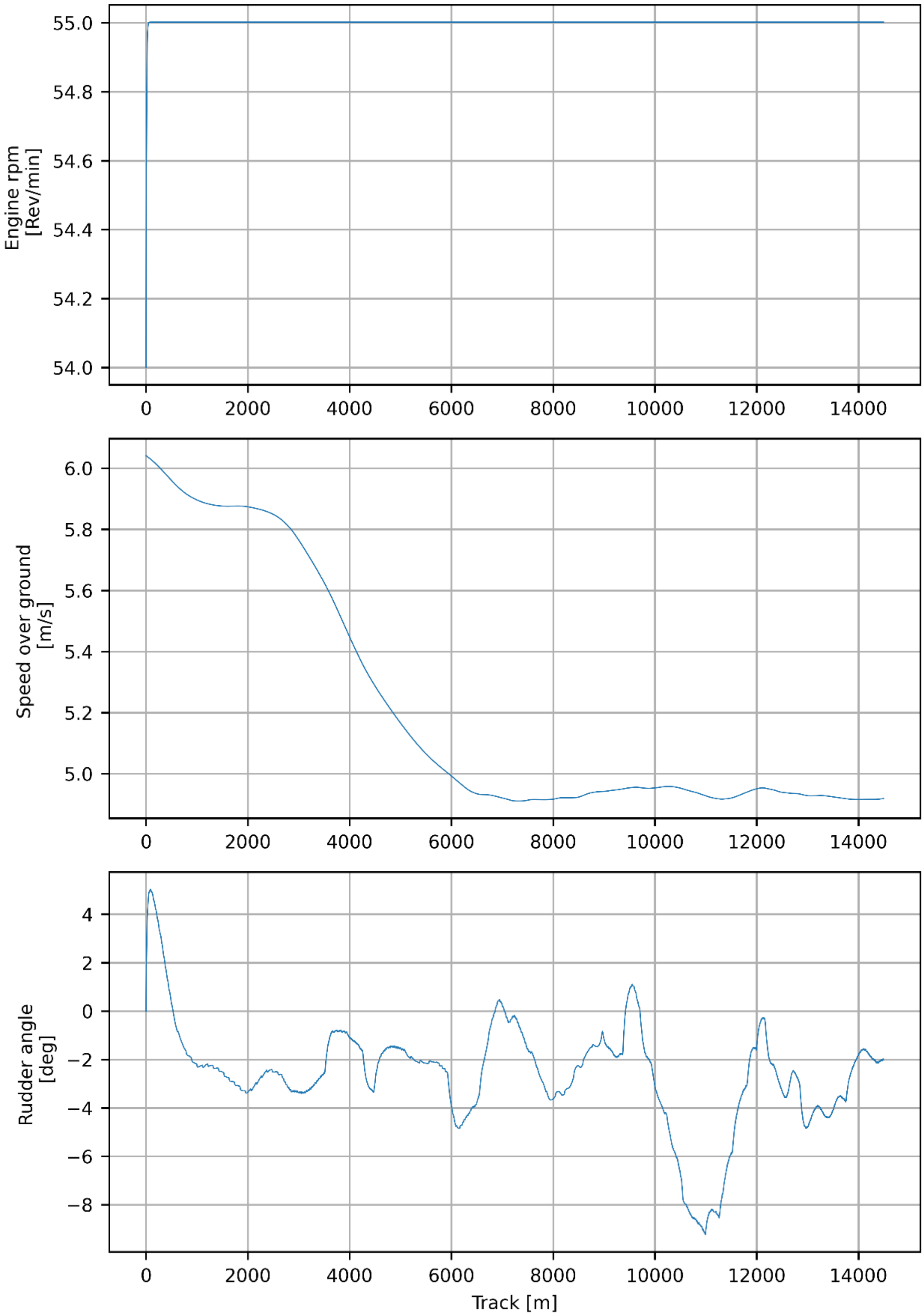
Direction: arrival

Wind: from the north

Current: low water

Swell: present




Engine rpm
[Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
0
2000
4000
6000
8000
10000
12000
14000
Speed over ground
[m/s]
6.0
5.8
5.6
5.4
5.2
5.0
Rudder angle
[deg]
4
2
0
−2
−4
−6
−8
Track [m]

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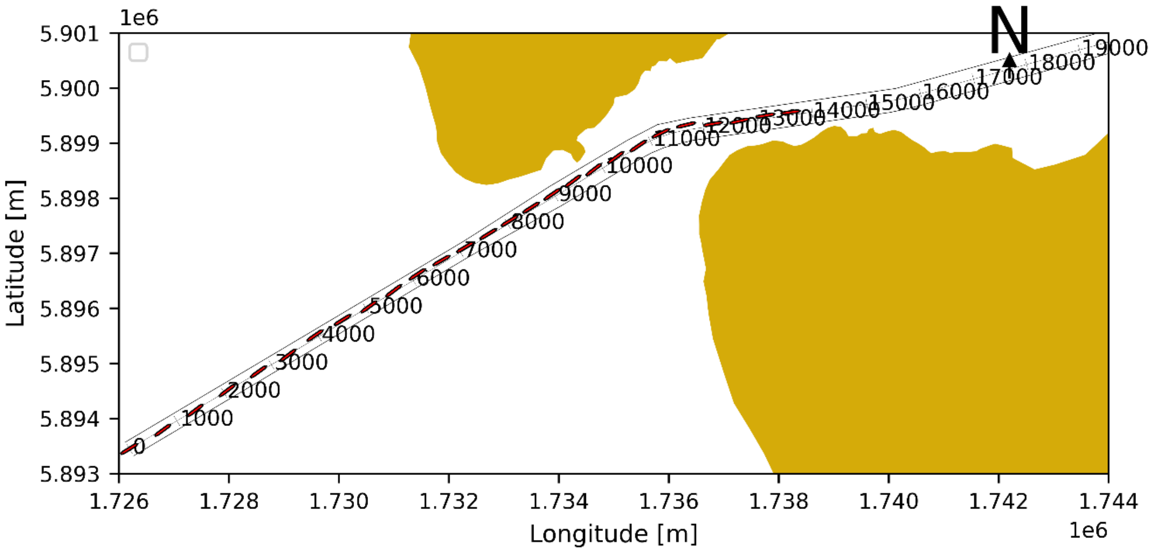
A2.2 Run "A-Arr-N-PE-Swell"

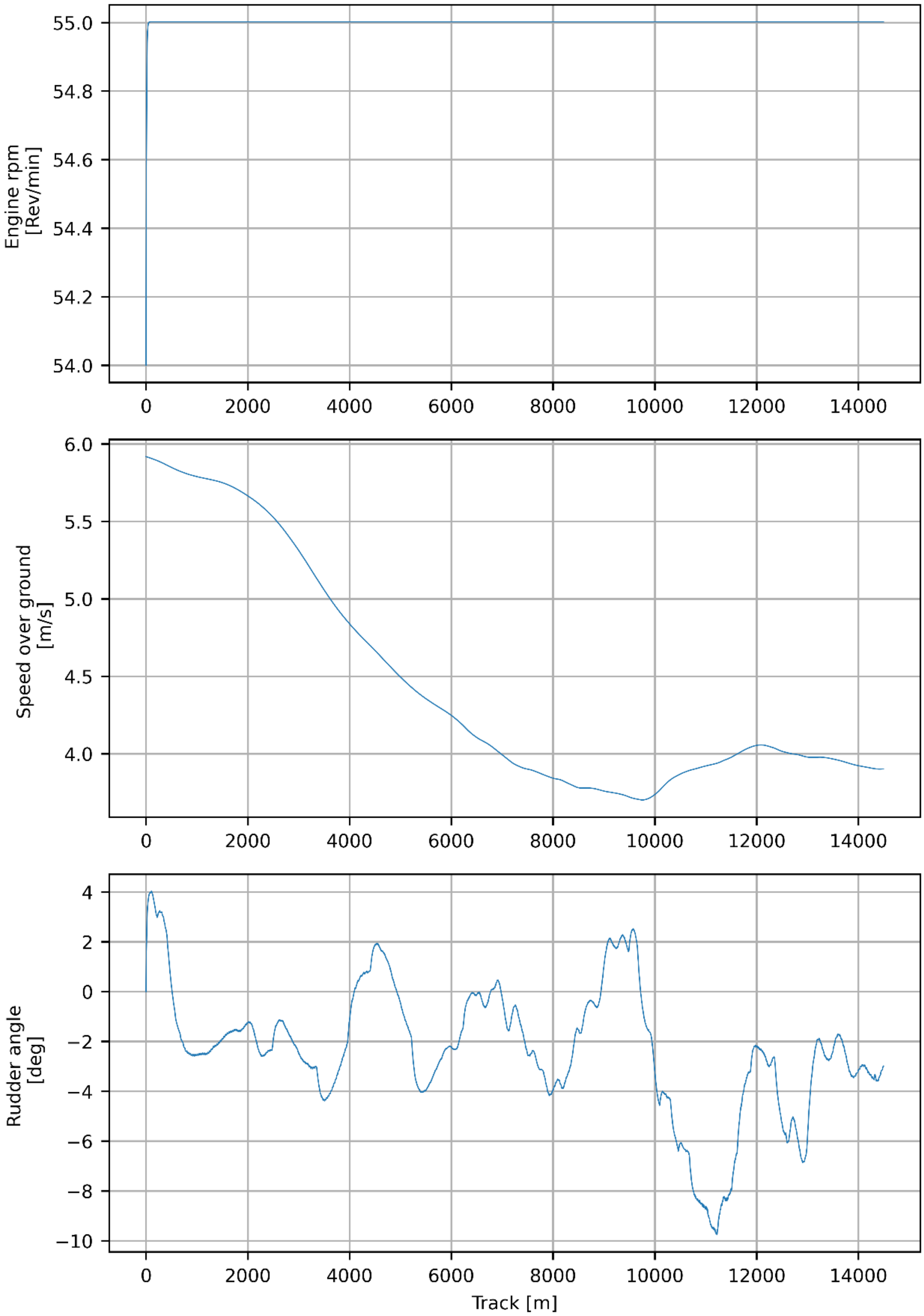
Direction: arrival

Wind: from the north

Current: peak ebb

Swell: present




55.0
54.8
54.6
54.4
54.2
54.0
Engine rpm [Rev/min]
0
2000
4000
6000
8000
10000
12000
14000
6.0
5.5
5.0
4.5
4.0
Speed over ground [m/s]
4
2
0
−2
−4
−6
−8
−10
Rudder angle [deg]
Track [m]

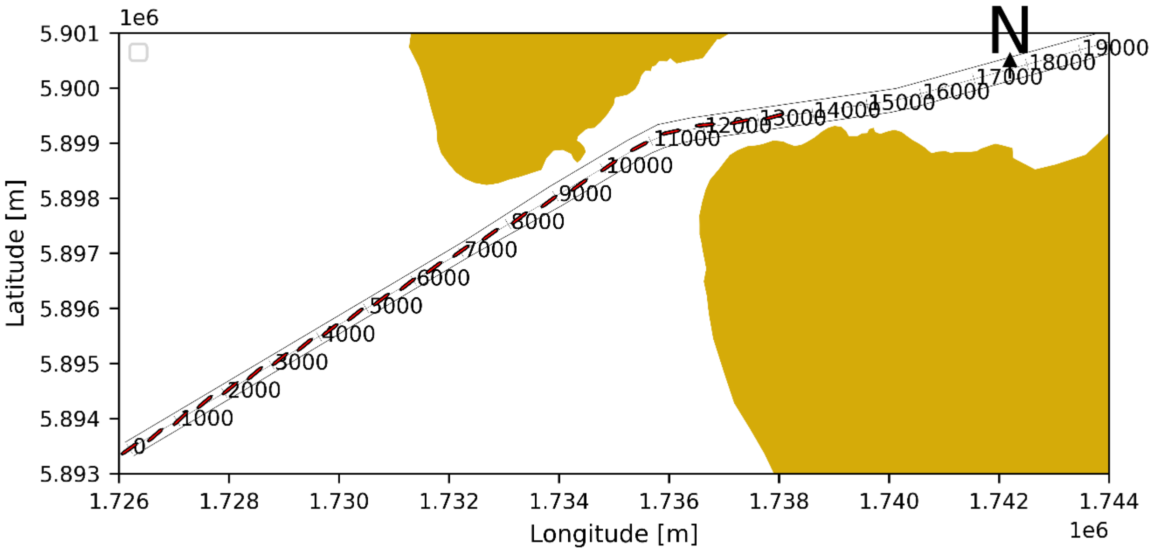
A2.3 Run "A-Arr-N-PF-Swell"

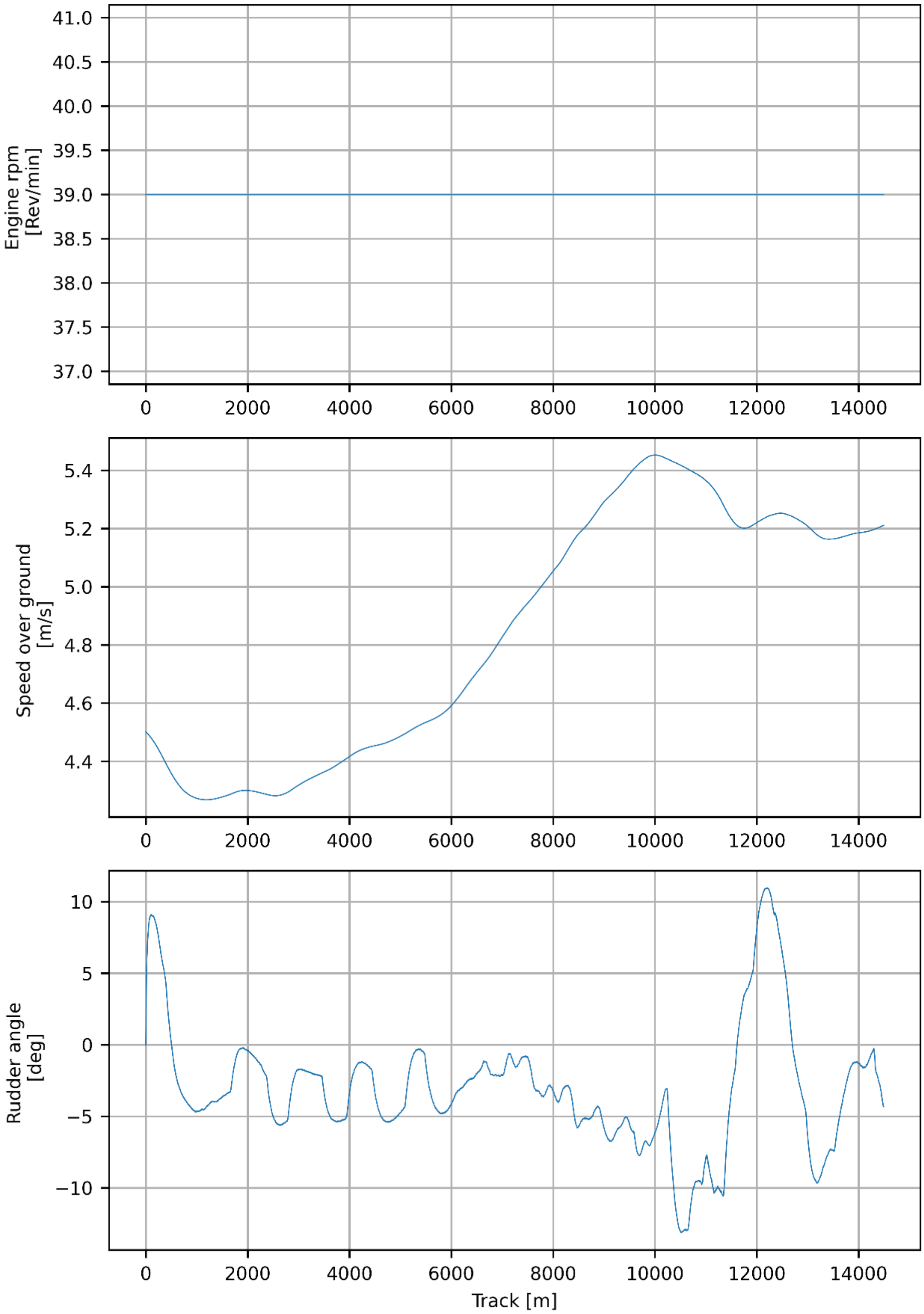
Direction: arrival

Wind: from the north

Current: peak flood

Swell: present





Engine rpm [Rev/min]
41.0
40.5
40.0
39.5
39.0
38.5
38.0
37.5
37.0
0
2000
4000
6000
8000
10000
12000
14000
Speed over ground [m/s]
5.4
5.2
5.0
4.8
4.6
4.4
Rudder angle [deg]
10
5
0
−5
−10
Track [m]

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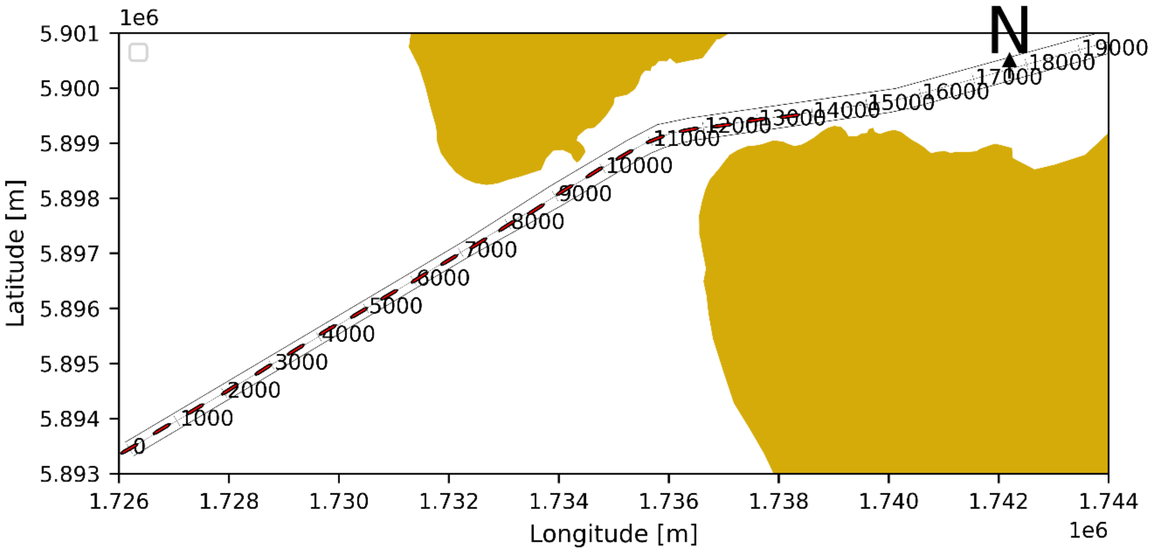
A2.4 Run "A-Arr-SW-LW-Swell"

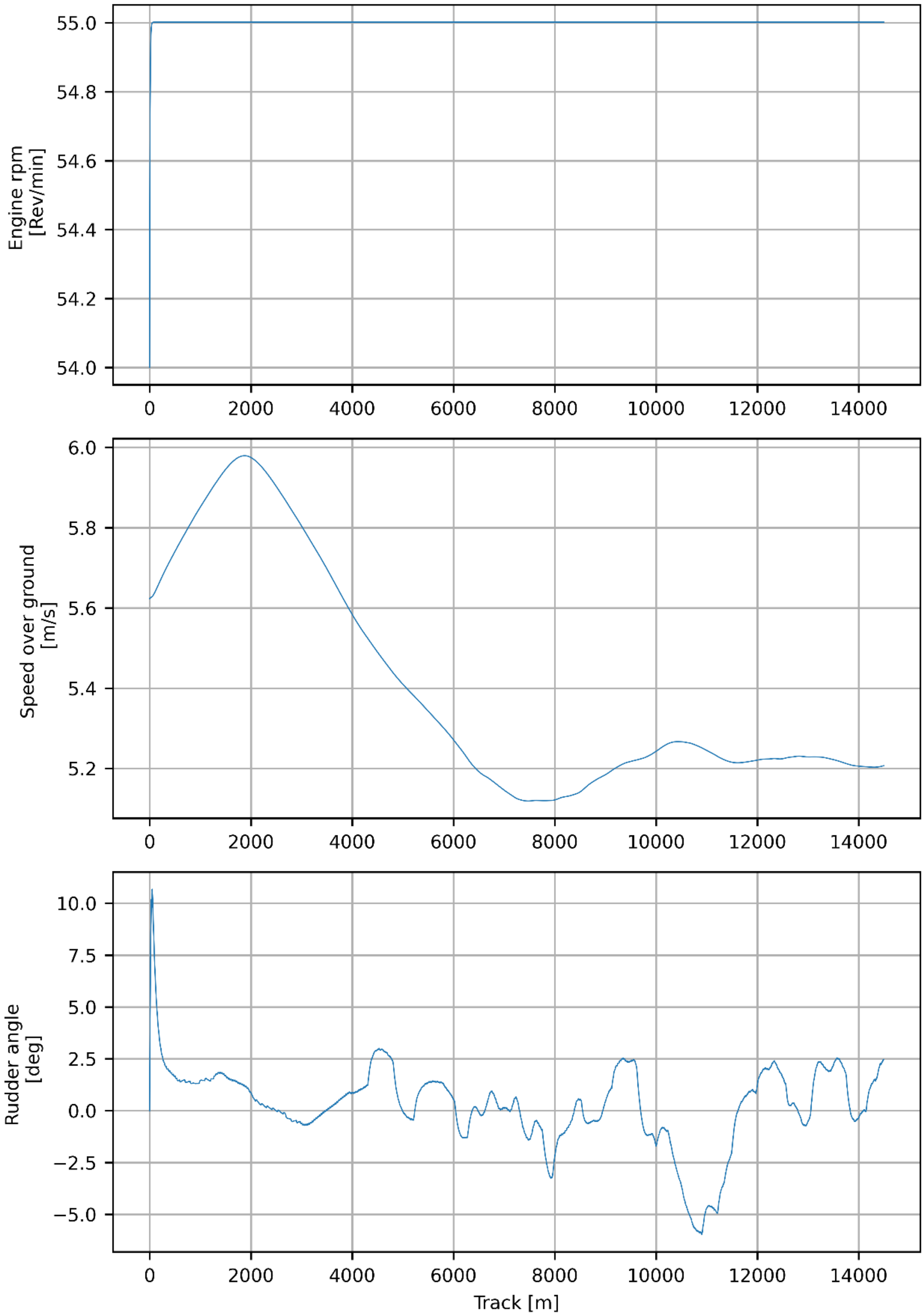
Direction: arrival

Wind: from the southwest

Current: low water

Swell: present




Engine rpm
[Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
0
2000
4000
6000
8000
10000
12000
14000
Speed over ground
[m/s]
6.0
5.8
5.6
5.4
5.2
Rudder angle
[deg]
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
Track [m]

Royal HaskoningDHV

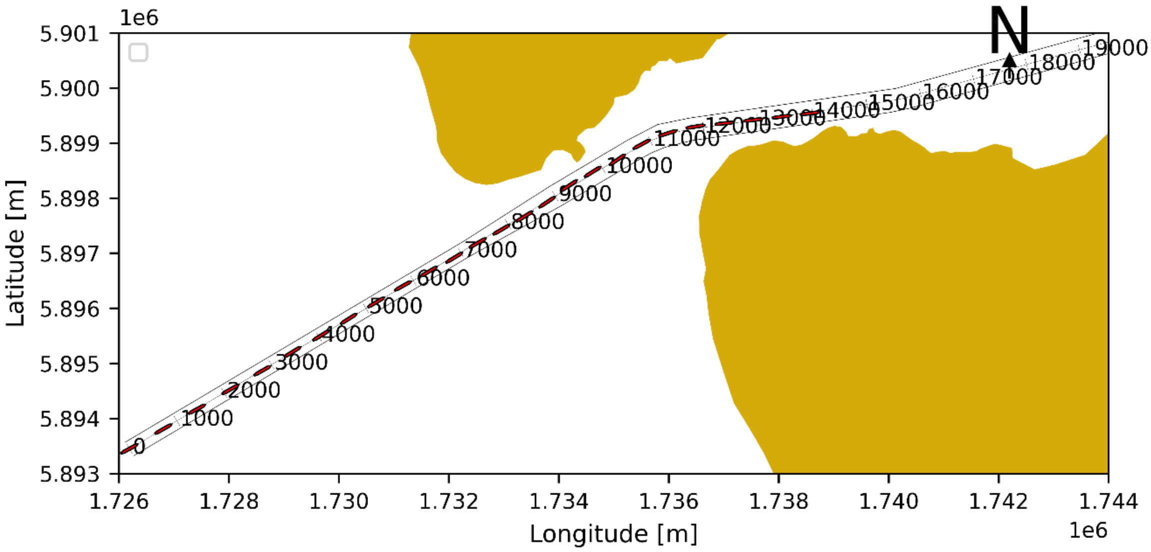
A2.5 Run “A-Arr-SW-PE-Swell”

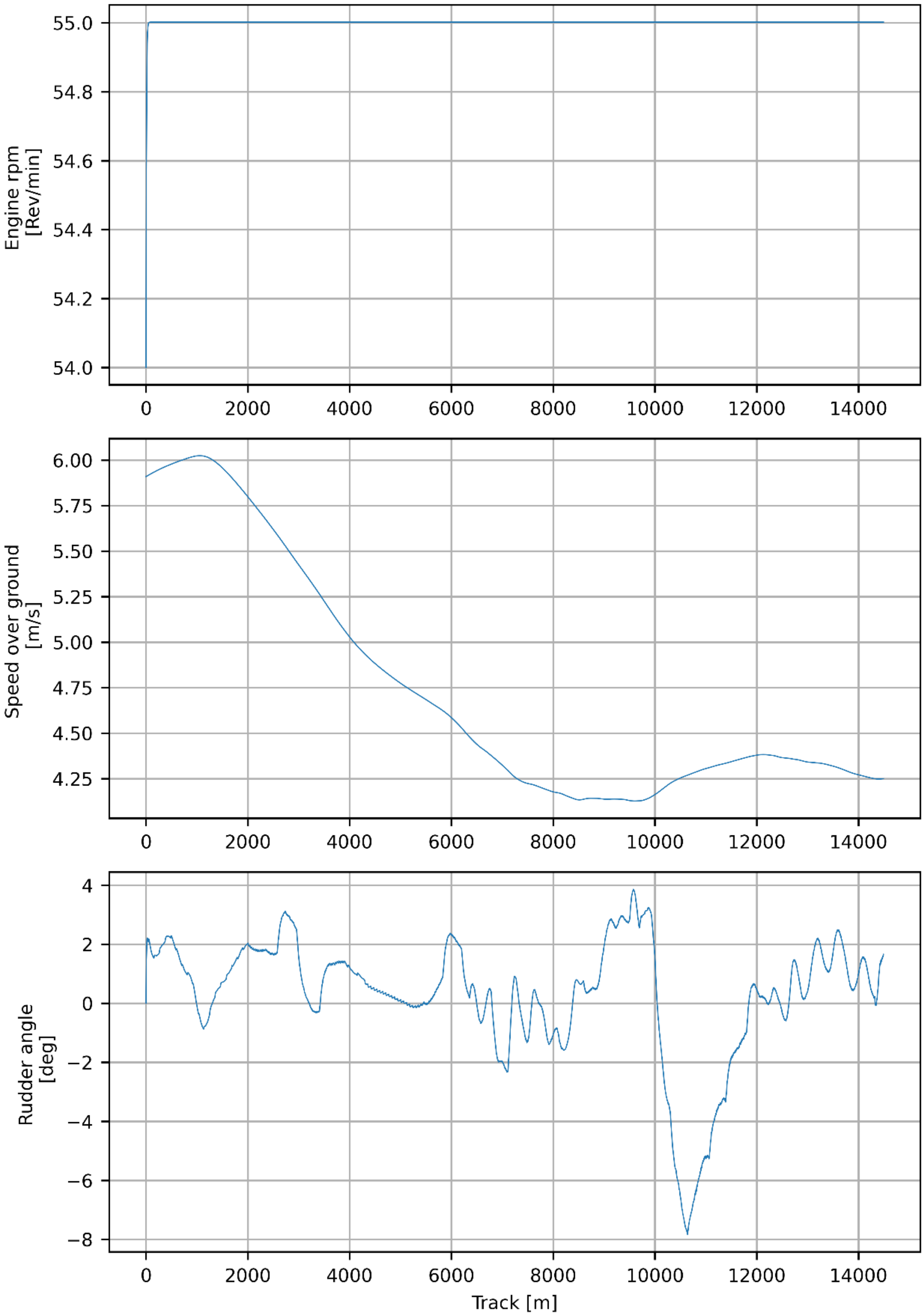
Direction: arrival

Wind: from the southwest

Current: peak ebb

Swell: present




Engine rpm
[Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
Speed over ground
[m/s]
6.00
5.75
5.50
5.25
5.00
4.75
4.50
4.25
Rudder angle
[deg]
4
2
0
−2
−4
−6
−8
0
2000
4000
6000
8000
10000
12000
14000
Track [m]

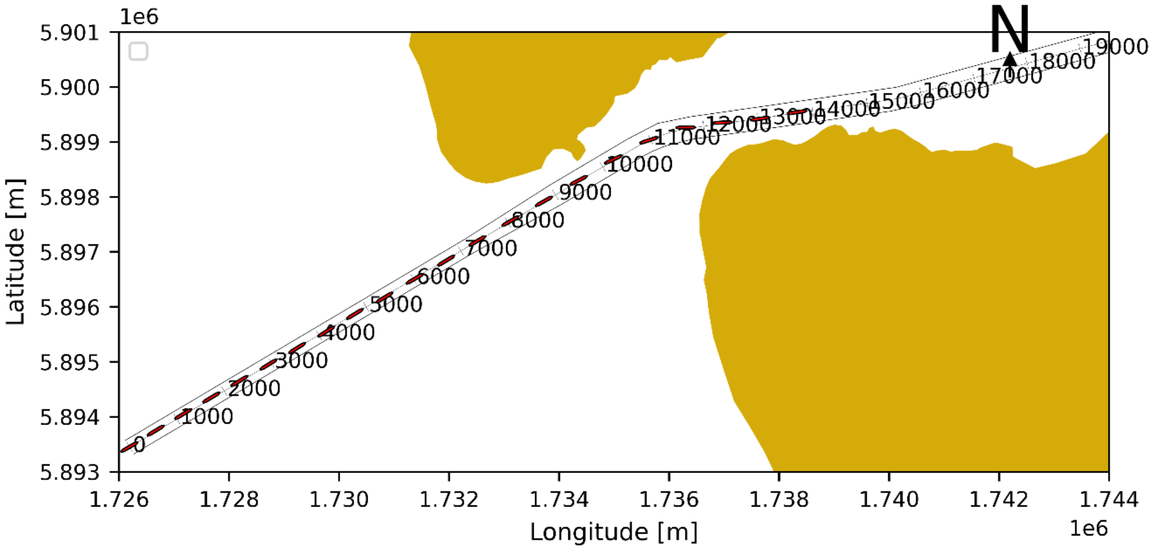
A2.6 Run “A-Arr-SW-PF-Swell”

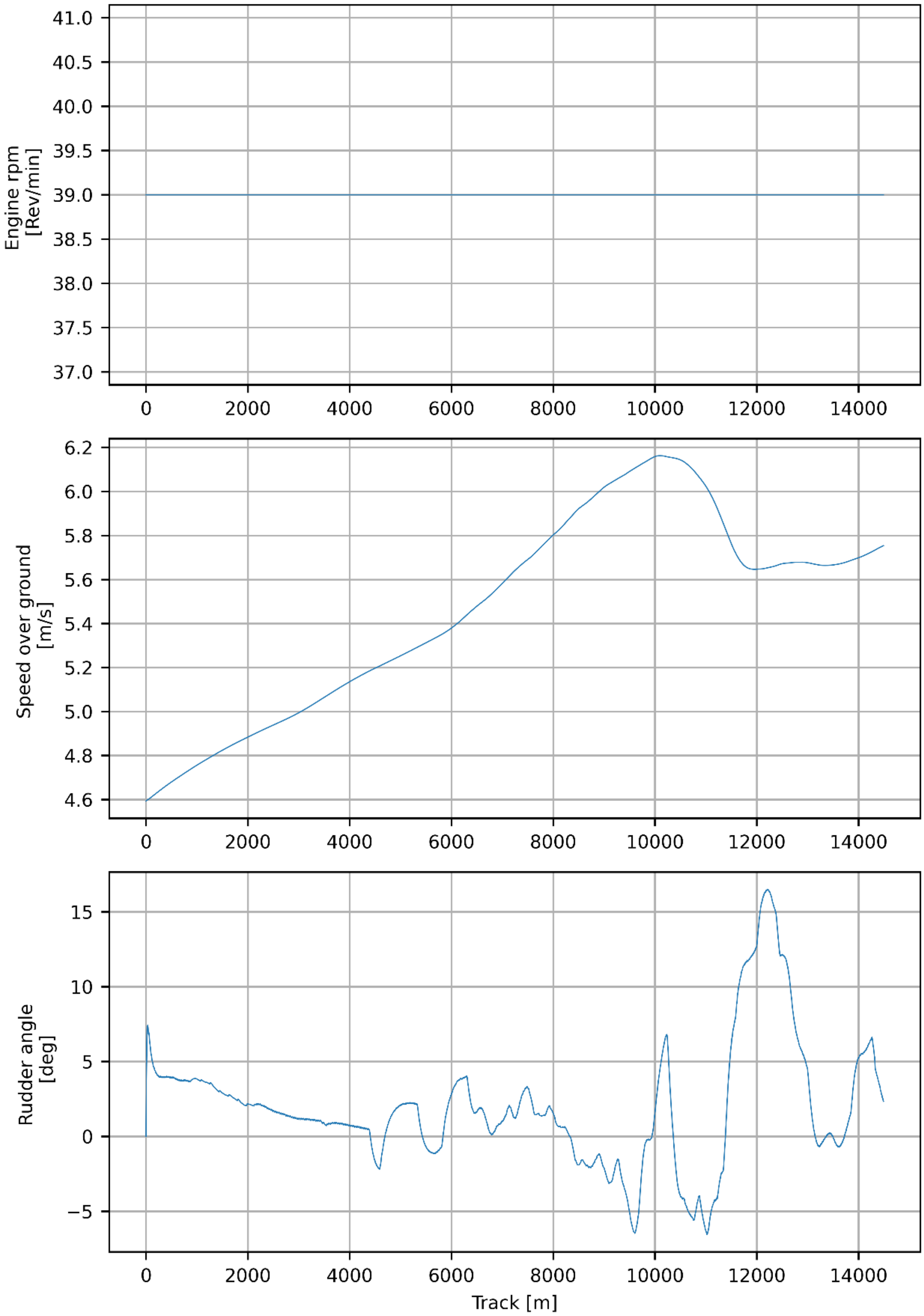
Direction: arrival

Wind: from the southwest

Current: peak flood

Swell: present




41.0
40.5
40.0
39.5
39.0
38.5
38.0
37.5
37.0
Engine rpm
[Rev/min]
0
2000
4000
6000
8000
10000
12000
14000
6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
Speed over ground
[m/s]
15
10
5
0
−5
Rudder angle
[deg]
Track [m]

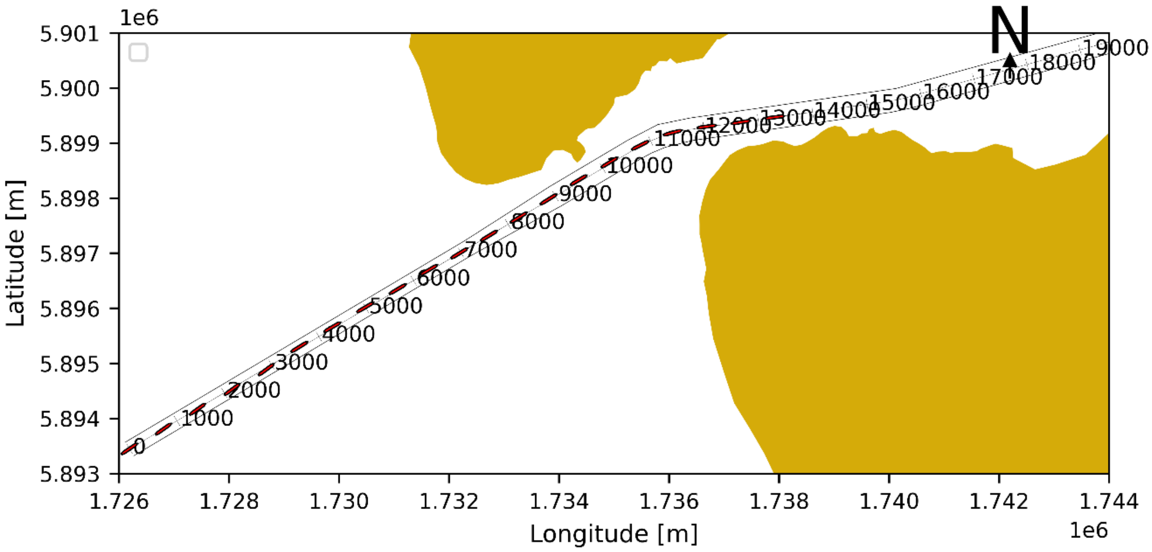
A2.7 Run “A-Arr-W-LW-Swell”

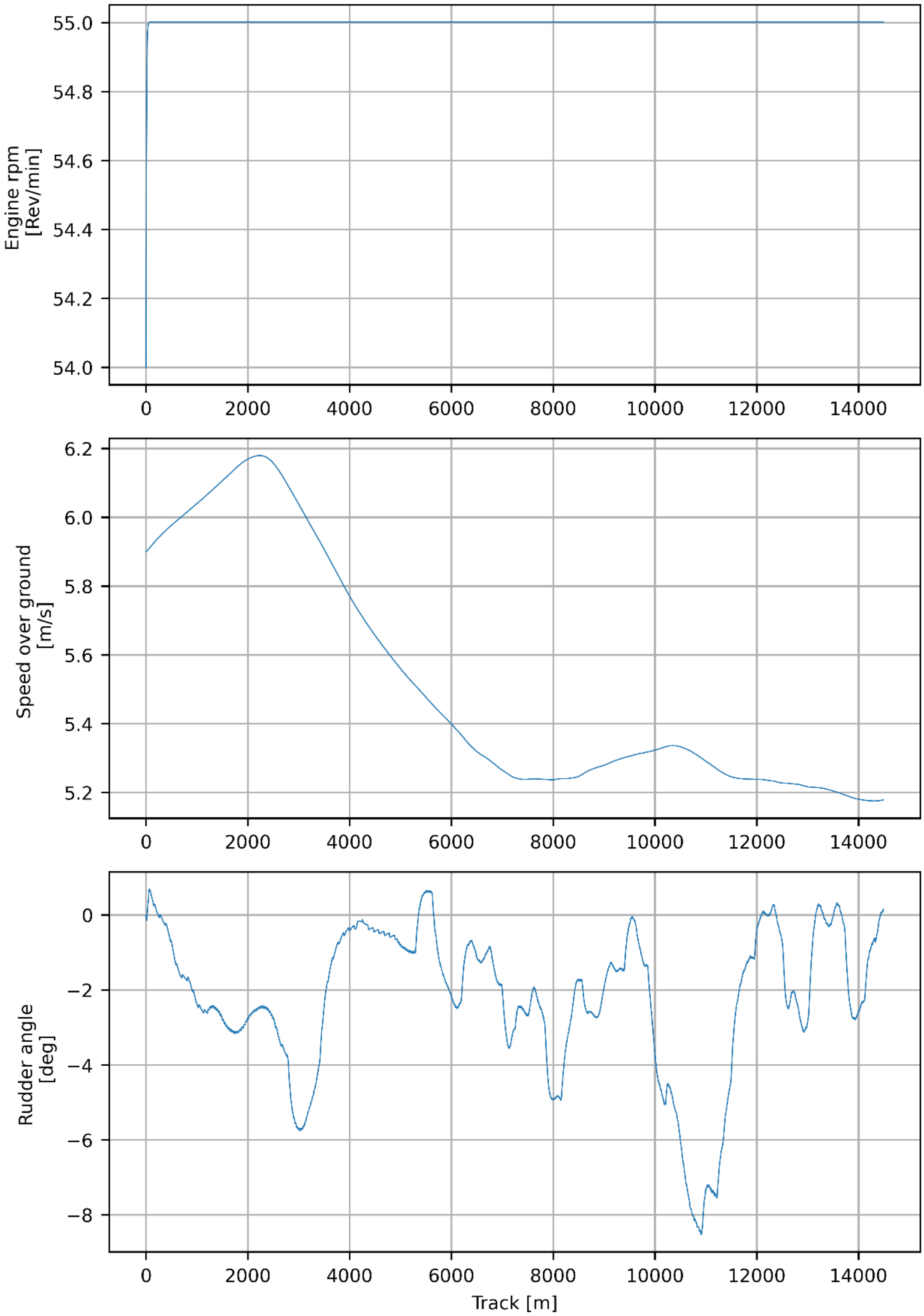
Direction: arrival

Wind: from the west

Current: low water

Swell: present





Engine rpm [Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
Speed over ground [m/s]
6.2
6.0
5.8
5.6
5.4
5.2
Rudder angle [deg]
0
−2
−4
−6
−8
0
2000
4000
6000
8000
10000
12000
14000
Track [m]

Royal HaskoningDHV

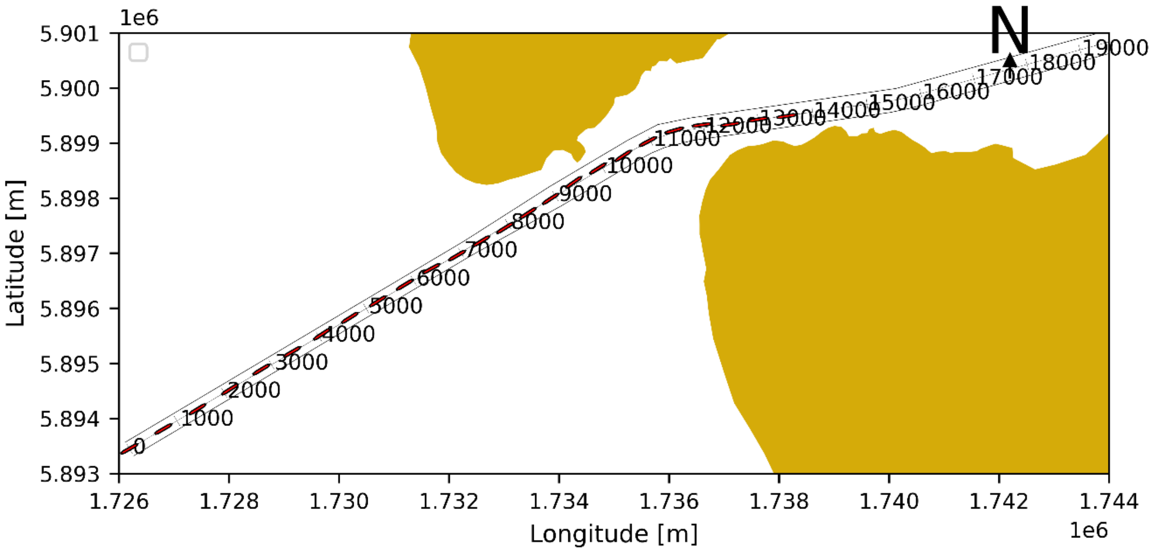
A2.8 Run "A-Arr-W-PE-Swell"

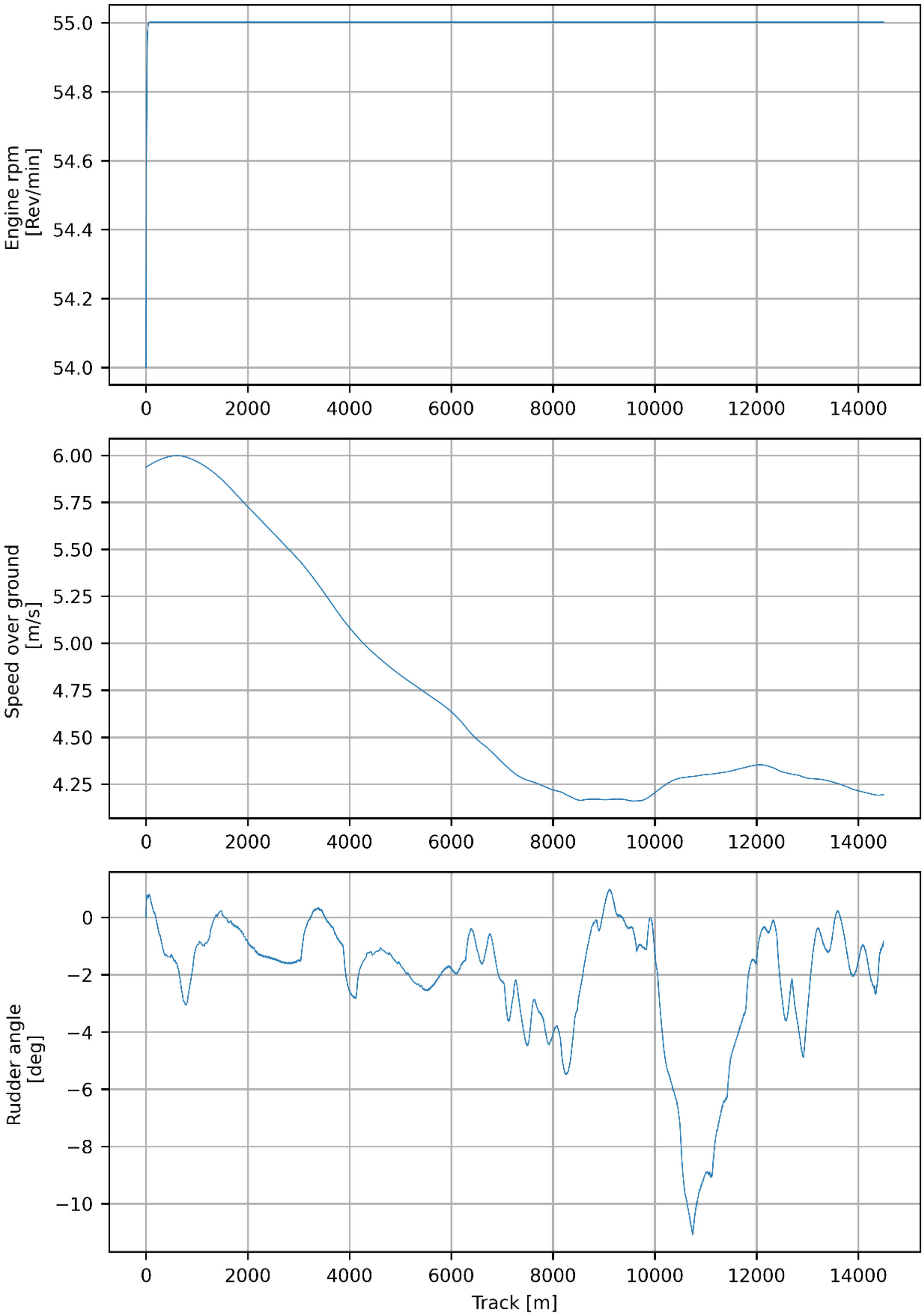
Direction: arrival

Wind: from the west

Current: peak ebb

Swell: present




Engine rpm [Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
0
2000
4000
6000
8000
10000
12000
14000
Speed over ground [m/s]
6.00
5.75
5.50
5.25
5.00
4.75
4.50
4.25
Rudder angle [deg]
0
−2
−4
−6
−8
−10
Track [m]

Royal HaskoningDHV

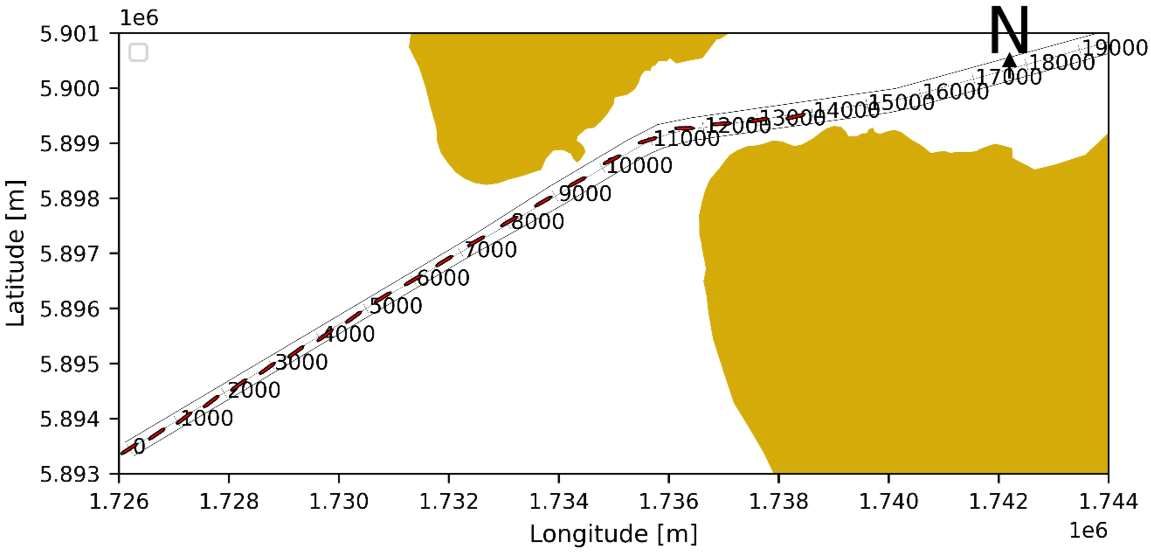
A2.9 Run “A-Arr-W-PF-Swell”

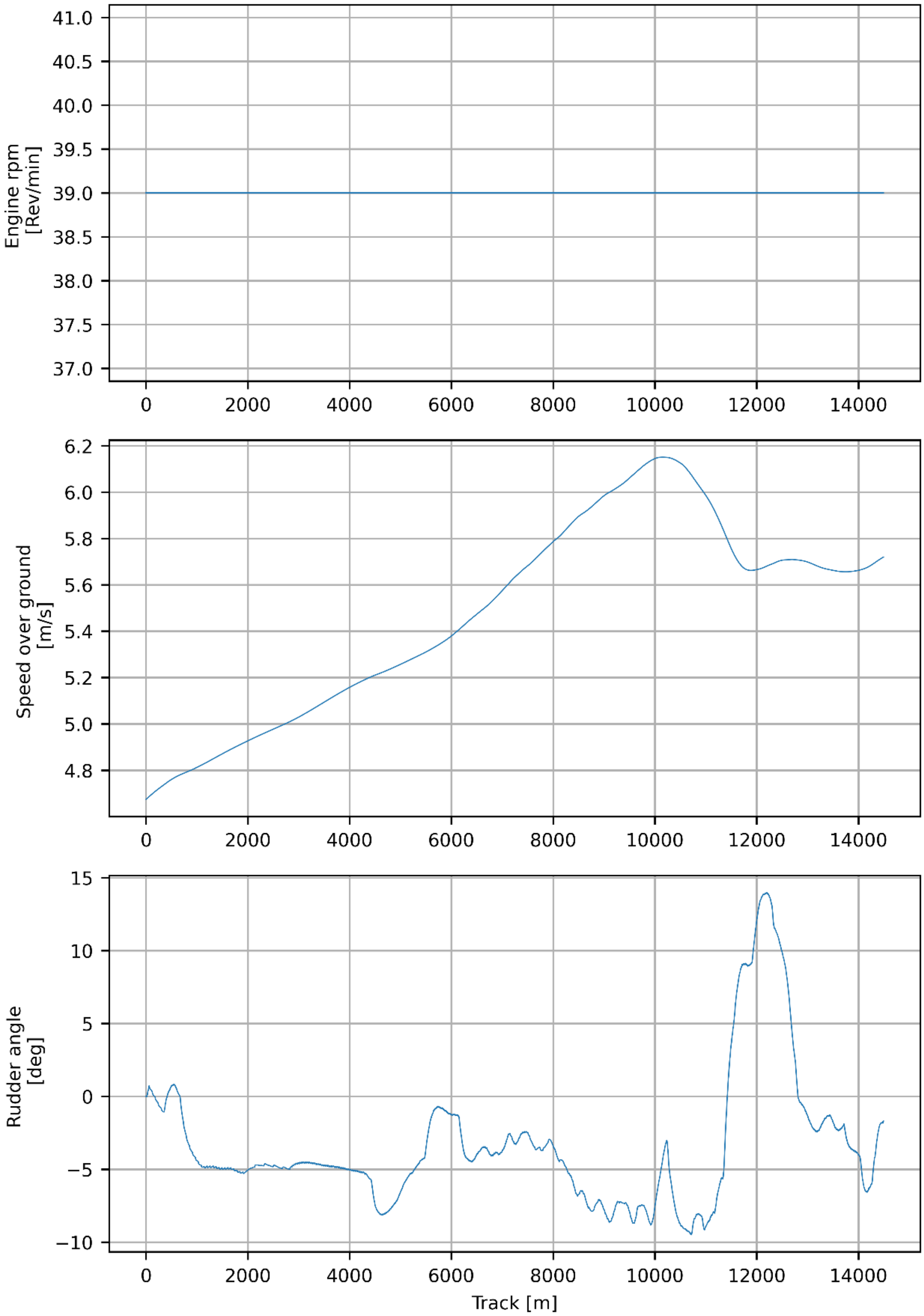
Direction: arrival

Wind: from the west

Current: peak flood

Swell: present




Engine rpm [Rev/min]
41.0
40.5
40.0
39.5
39.0
38.5
38.0
37.5
37.0
Speed over ground [m/s]
6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
Rudder angle [deg]
15
10
5
0
−5
−10
0
2000
4000
6000
8000
10000
12000
14000
Track [m]

Royal HaskoningDHV

A3 Arrival Simulations in Section B – Main Runs

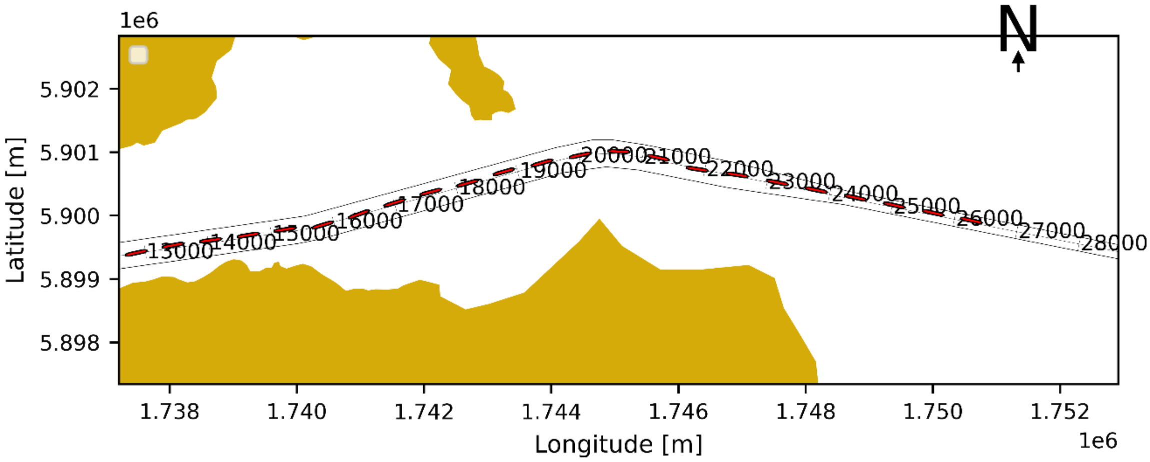
A3.1 Run “B-Arr-N-LW-Swell”

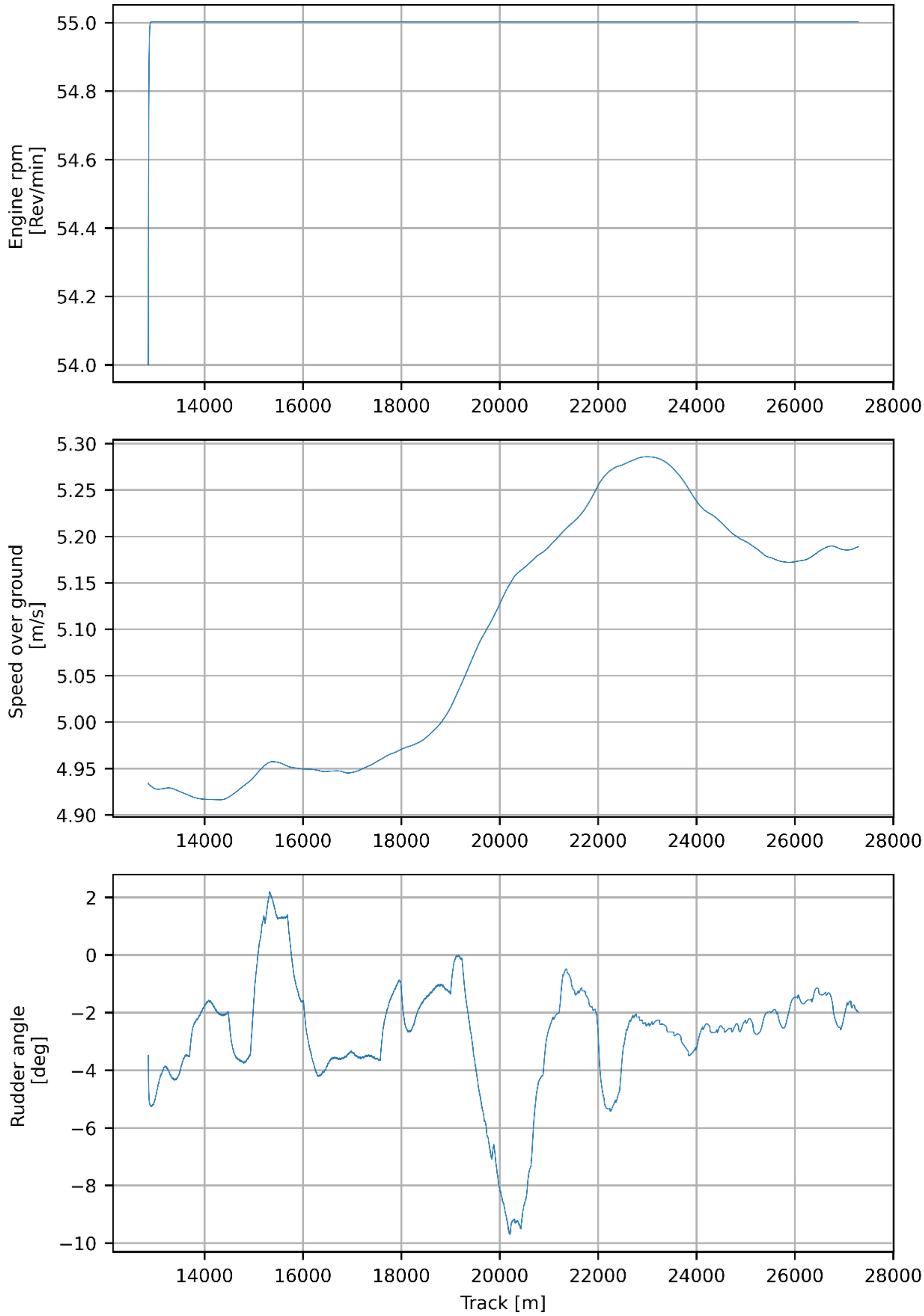
Direction: arrival

Wind: from the north

Current: low water

Swell: present




Engine rpm
[Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
Speed over ground
[m/s]
5.30
5.25
5.20
5.15
5.10
5.05
5.00
4.95
4.90
Rudder angle
[deg]
2
0
−2
−4
−6
−8
−10
14000
16000
18000
20000
22000
24000
26000
28000
Track [m]

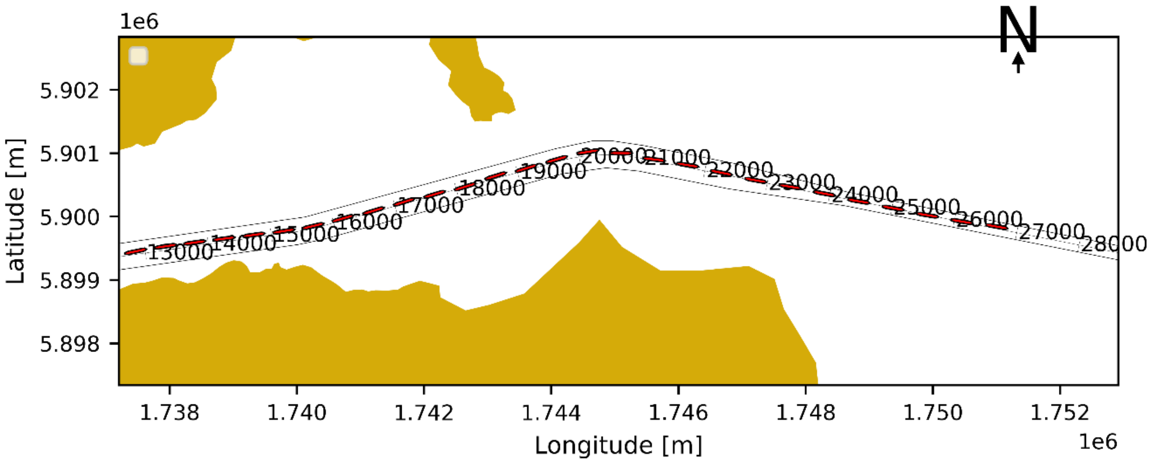
A3.2 Run "B-Arr-N-PE-Swell"

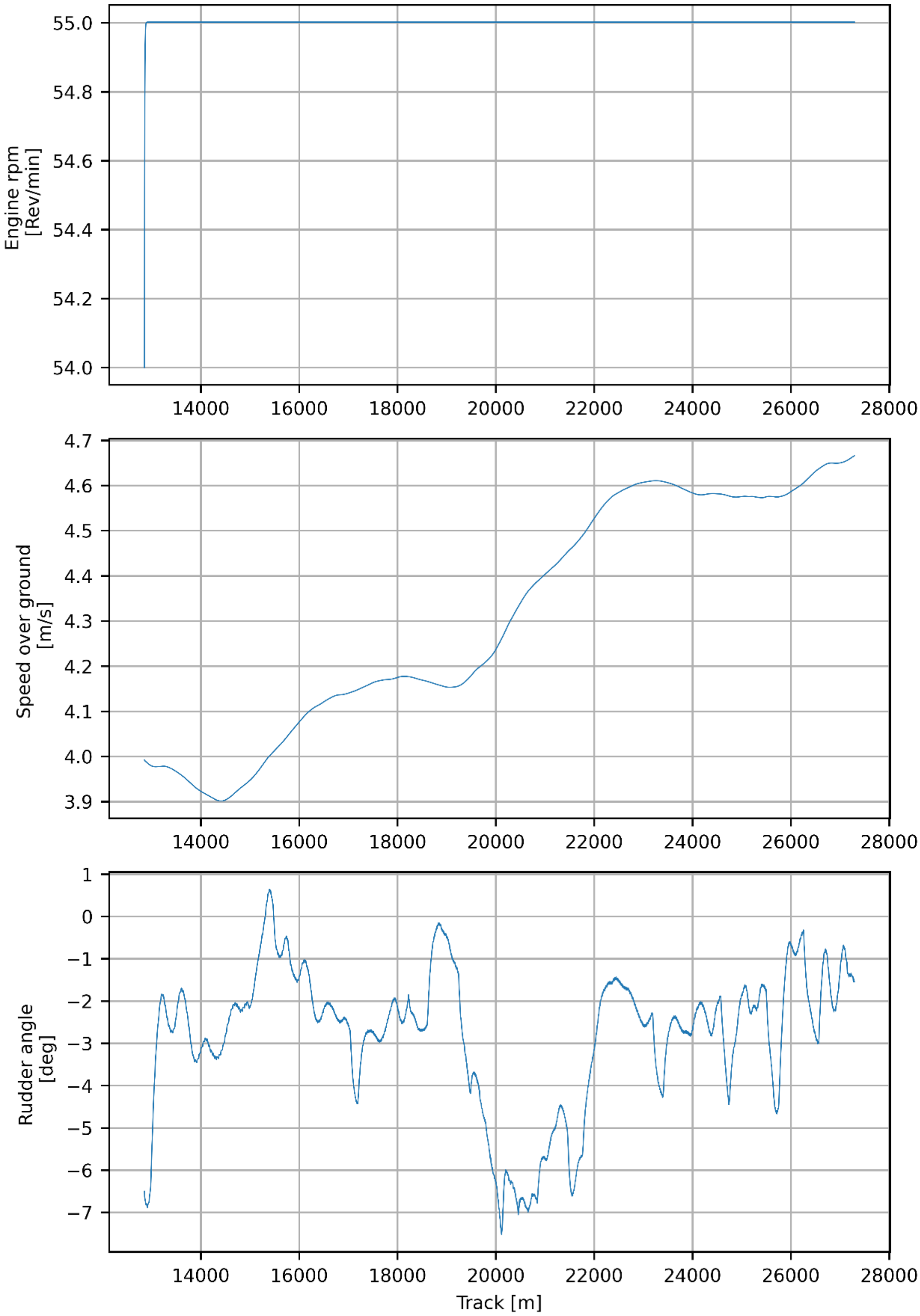
Direction: arrival

Wind: from the north

Current: peak ebb

Swell: present




Engine rpm
[Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
Speed over ground
[m/s]
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4.0
3.9
Rudder angle
[deg]
1
0
−1
−2
−3
−4
−5
−6
−7
14000
16000
18000
20000
22000
24000
26000
28000
Track [m]

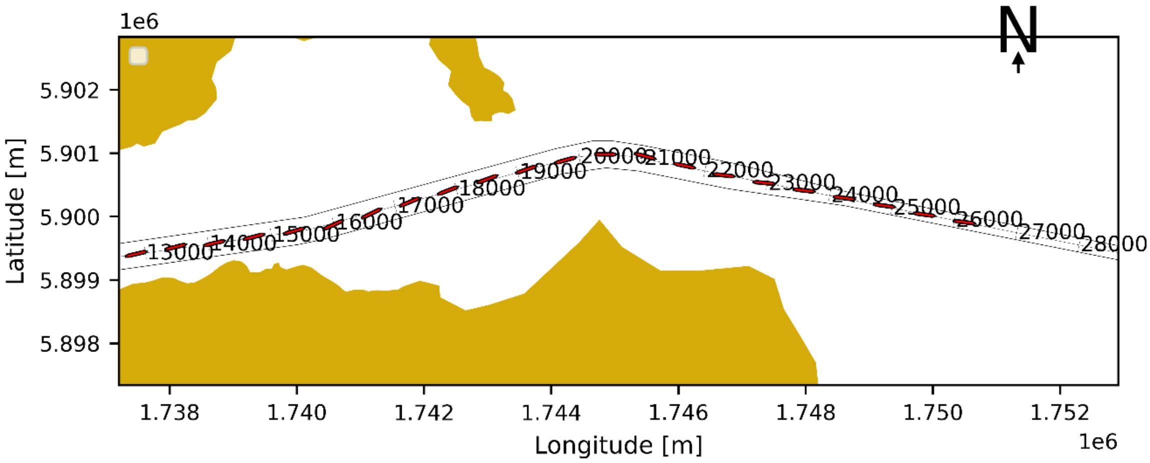
A3.3 Run “B-Arr-N-PF-Swell”

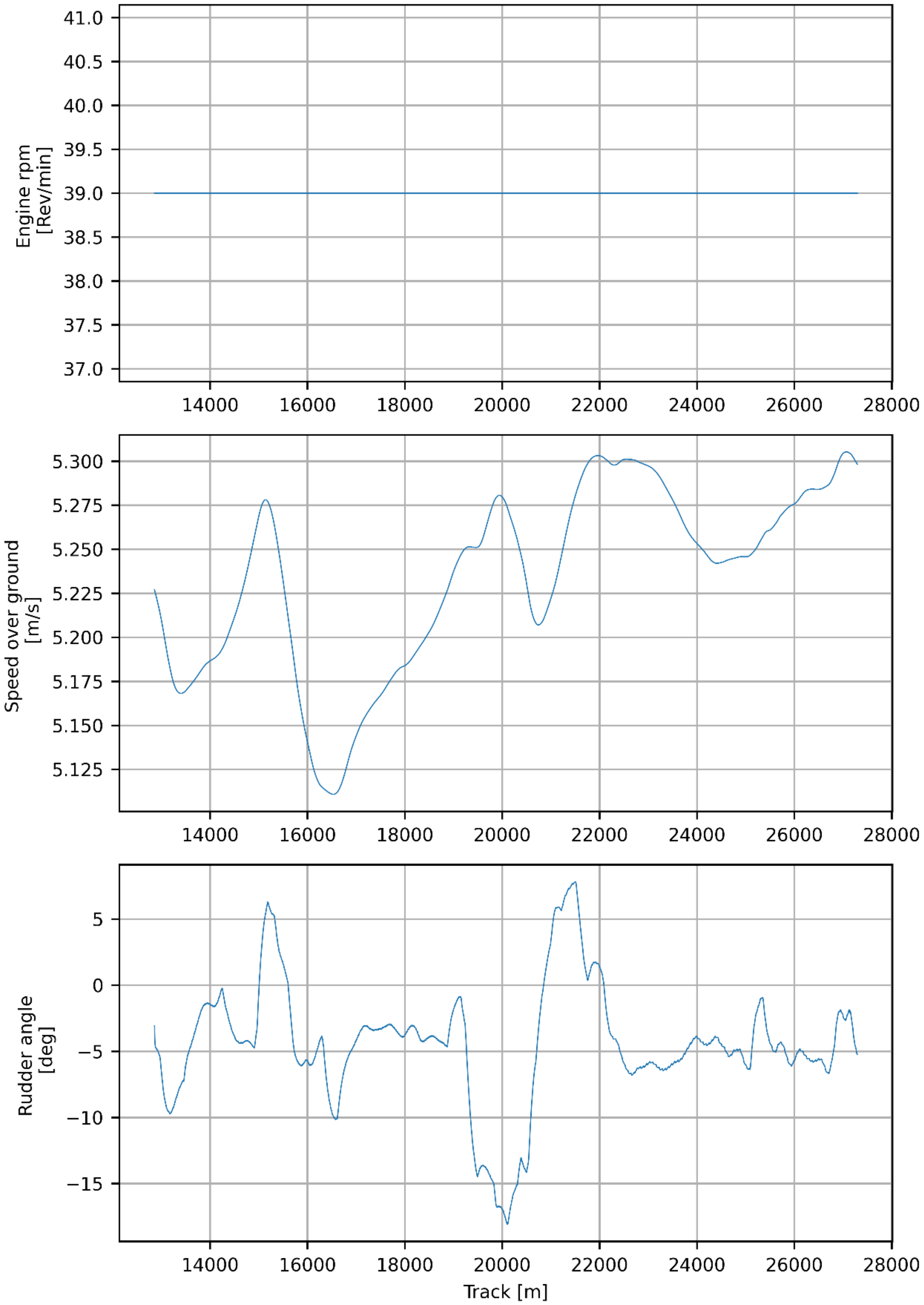
Direction: arrival

Wind: from the north

Current: peak flood

Swell: present





Engine rpm [Rev/min]
41.0
40.5
40.0
39.5
39.0
38.5
38.0
37.5
37.0
Speed over ground [m/s]
5.300
5.275
5.250
5.225
5.200
5.175
5.150
5.125
Rudder angle [deg]
5
0
−5
−10
−15
14000
16000
18000
20000
22000
24000
26000
28000
Track [m]

Royal HaskoningDHV

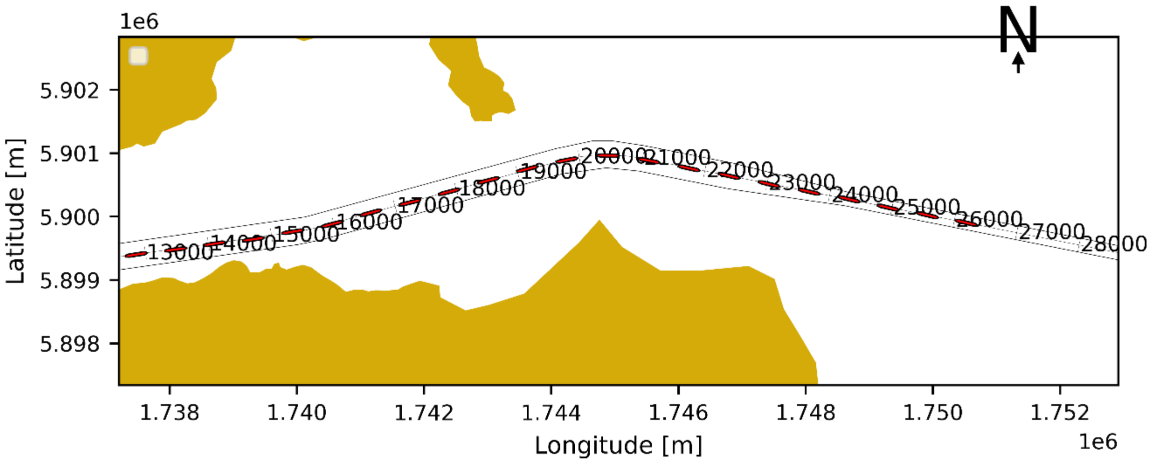
A3.4 Run "B-Arr-SW-LW-Swell"

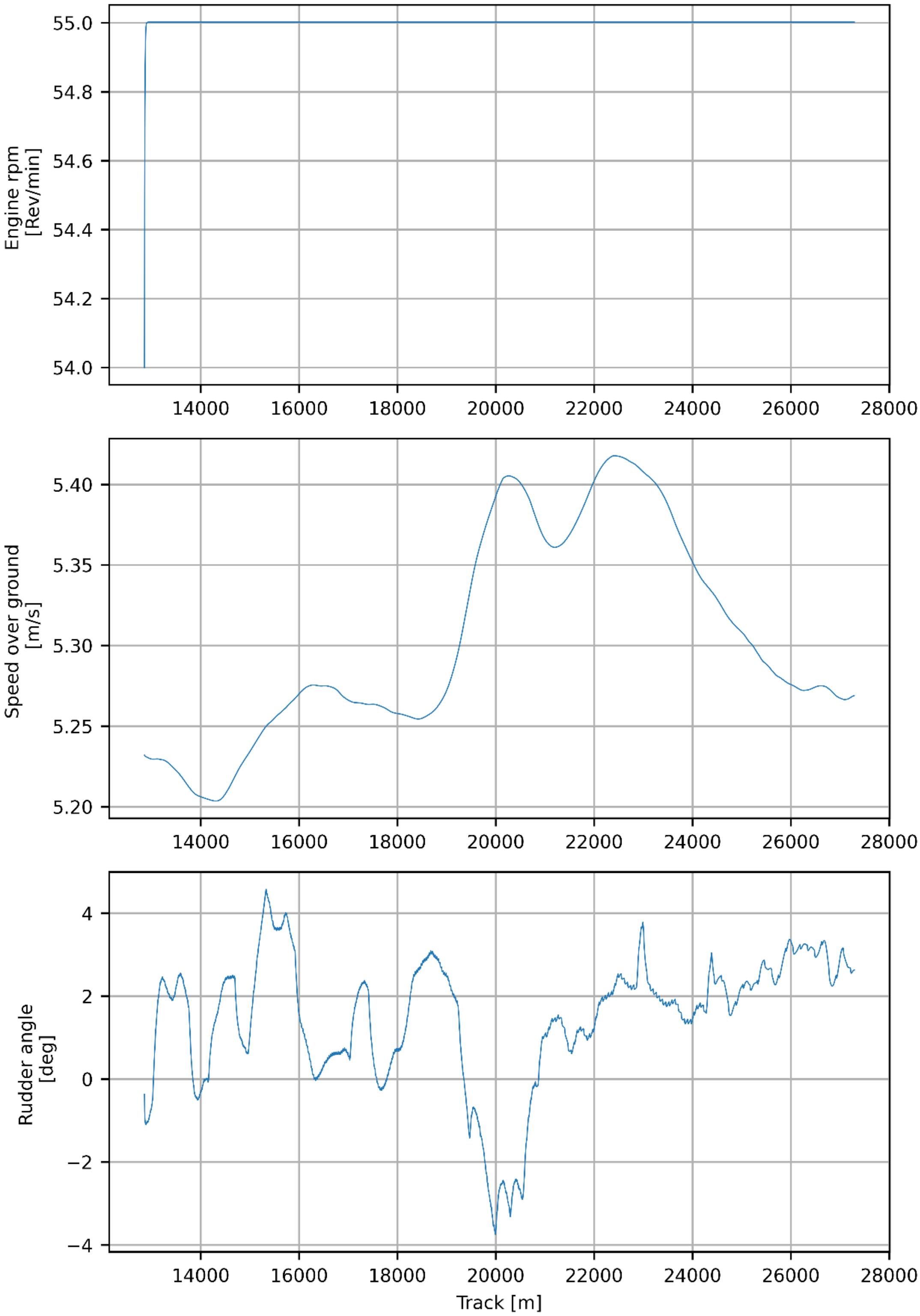
Direction: arrival

Wind: from the southwest

Current: low water

Swell: present




Engine rpm
[Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
Speed over ground
[m/s]
5.40
5.35
5.30
5.25
5.20
Rudder angle
[deg]
4
2
0
−2
−4
14000
16000
18000
20000
22000
24000
26000
28000
Track [m]

Royal HaskoningDHV

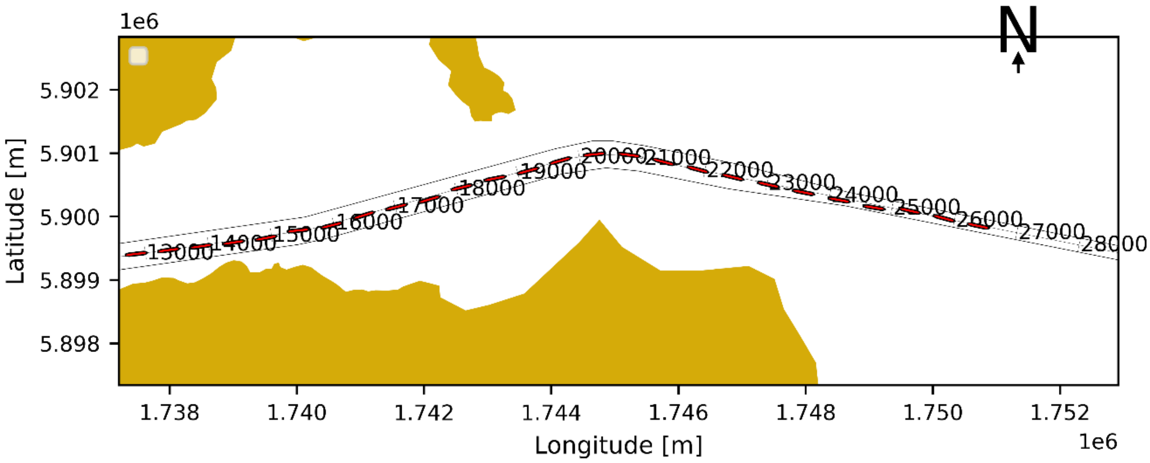
A3.5 Run "B-Arr-SW-PE-Swell"

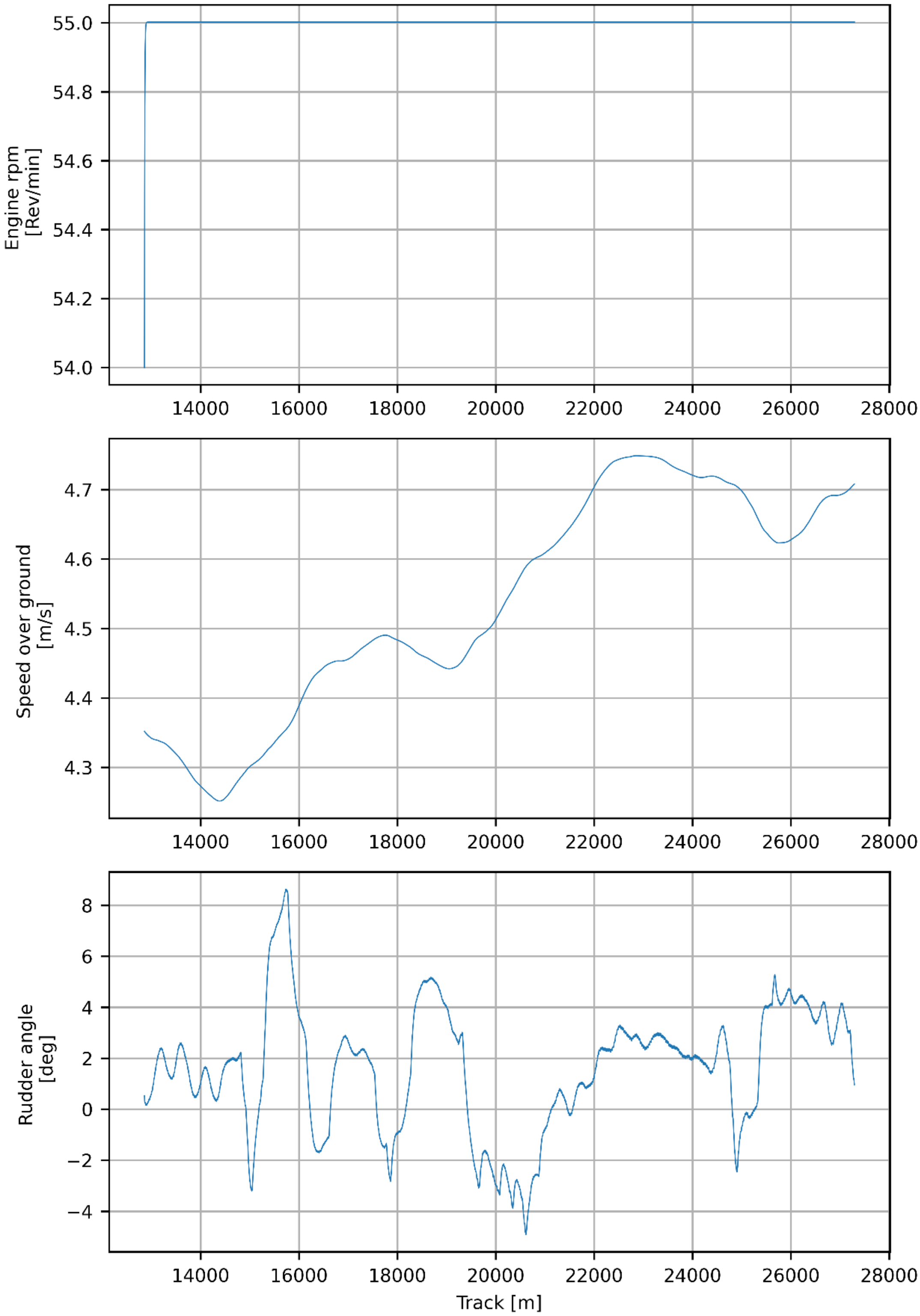
Direction: arrival

Wind: from the southwest

Current: peak ebb

Swell: present




55.0
54.8
54.6
54.4
54.2
54.0
Engine rpm [Rev/min]
4.7
4.6
4.5
4.4
4.3
Speed over ground [m/s]
8
6
4
2
0
−2
−4
Rudder angle [deg]
14000
16000
18000
20000
22000
24000
26000
28000
Track [m]

Royal HaskoningDHV

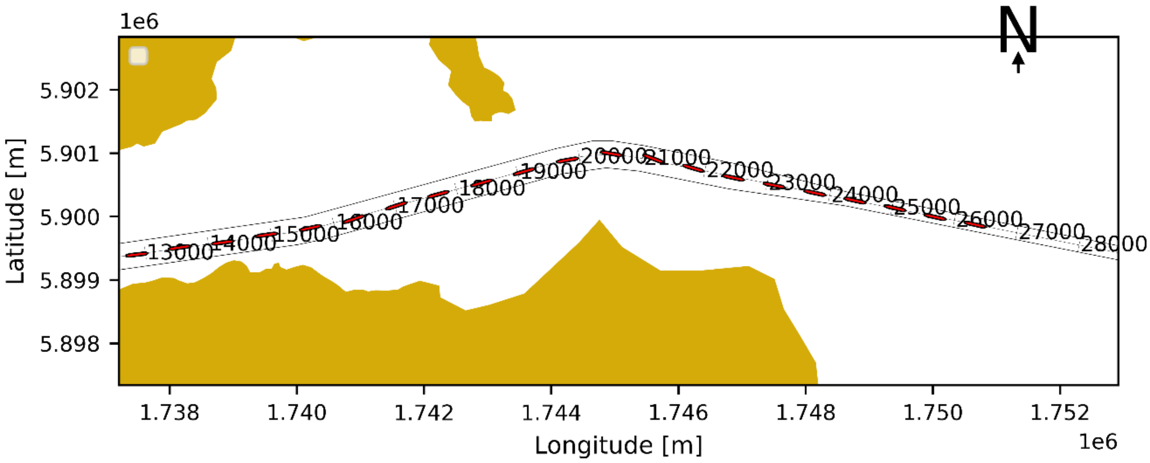
A3.6 Run "B-Arr-SW-PF-Swell"

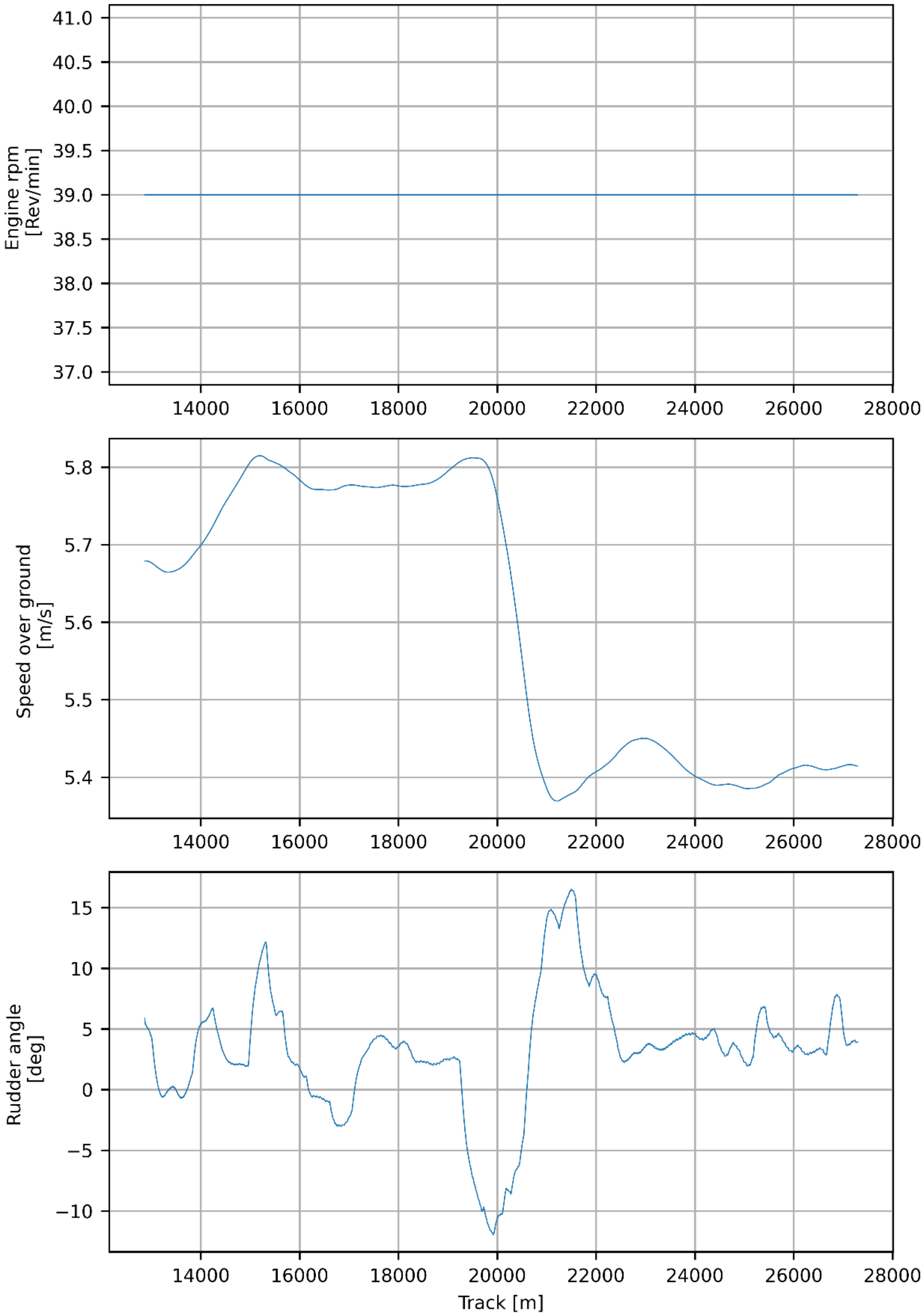
Direction: arrival

Wind: from the southwest

Current: peak flood

Swell: present





41.0
40.5
40.0
39.5
39.0
38.5
38.0
37.5
37.0
Engine rpm [Rev/min]
14000
16000
18000
20000
22000
24000
26000
28000
5.8
5.7
5.6
5.5
5.4
Speed over ground [m/s]
15
10
5
0
−5
−10
Rudder angle [deg]
Track [m]

Royal HaskoningDHV

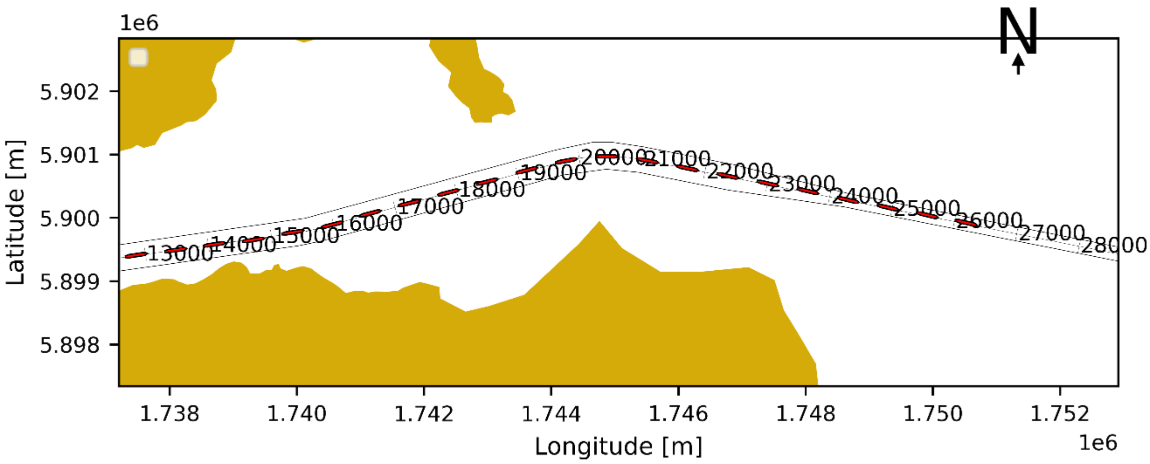
A3.7 Run "B-Arr-W-LW-Swell"

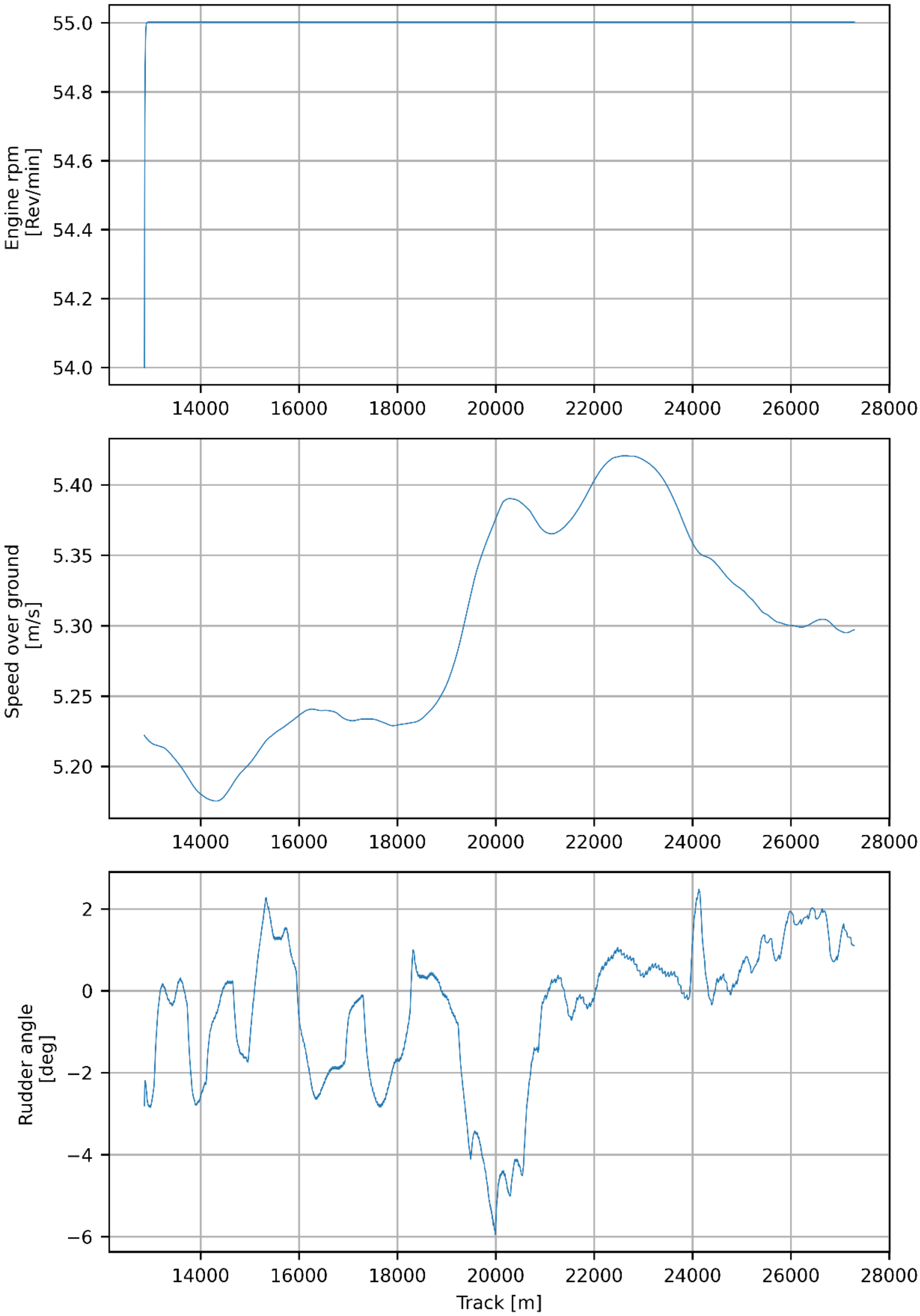
Direction: arrival

Wind: from the west

Current: low water

Swell: present





55.0
54.8
54.6
54.4
54.2
54.0
Engine rpm
[Rev/min]
14000
16000
18000
20000
22000
24000
26000
28000
5.40
5.35
5.30
5.25
5.20
Speed over ground
[m/s]
2
0
−2
−4
−6
Rudder angle
[deg]
Track [m]

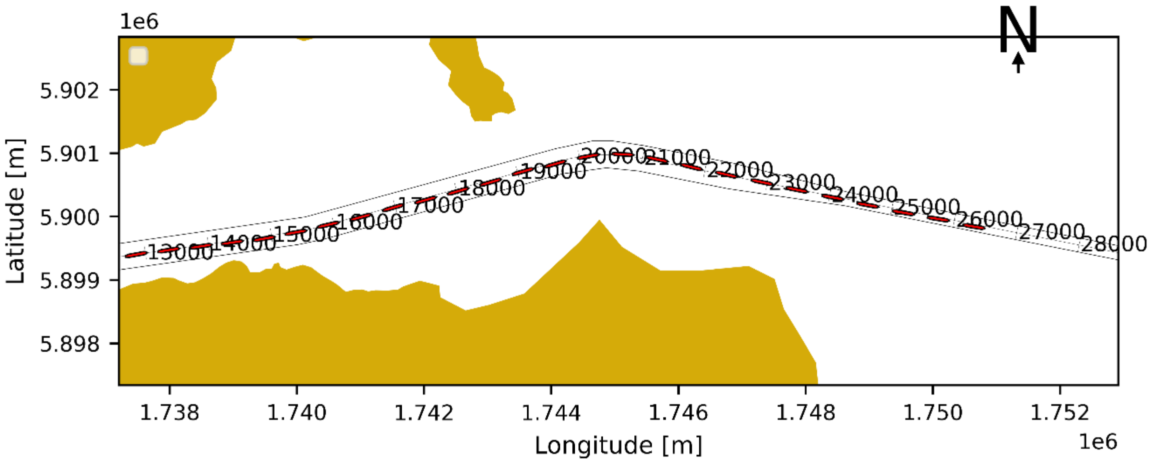
A3.8 Run "B-Arr-W-PE-Swell"

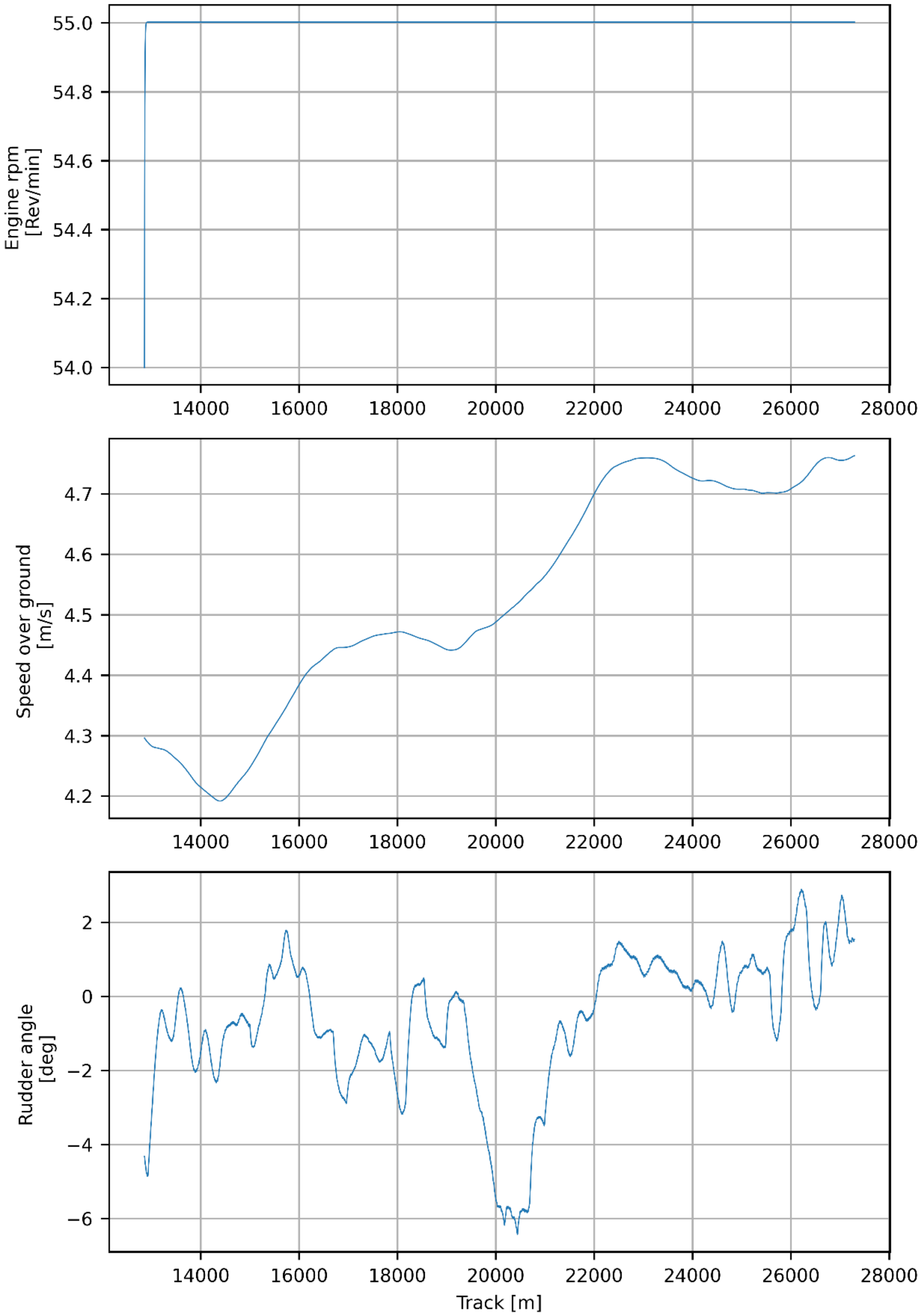
Direction: arrival

Wind: from the west

Current: peak ebb

Swell: present





55.0
54.8
54.6
54.4
54.2
54.0
Engine rpm
[Rev/min]
4.7
4.6
4.5
4.4
4.3
4.2
Speed over ground
[m/s]
2
0
−2
−4
−6
Rudder angle
[deg]
14000
16000
18000
20000
22000
24000
26000
28000
Track [m]

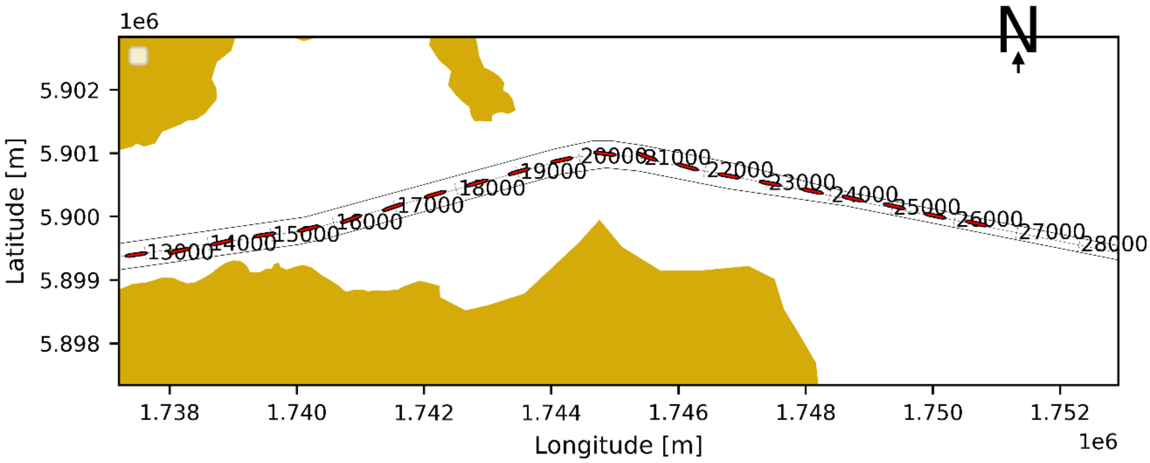
A3.9 Run "B-Arr-W-PF-Swell"

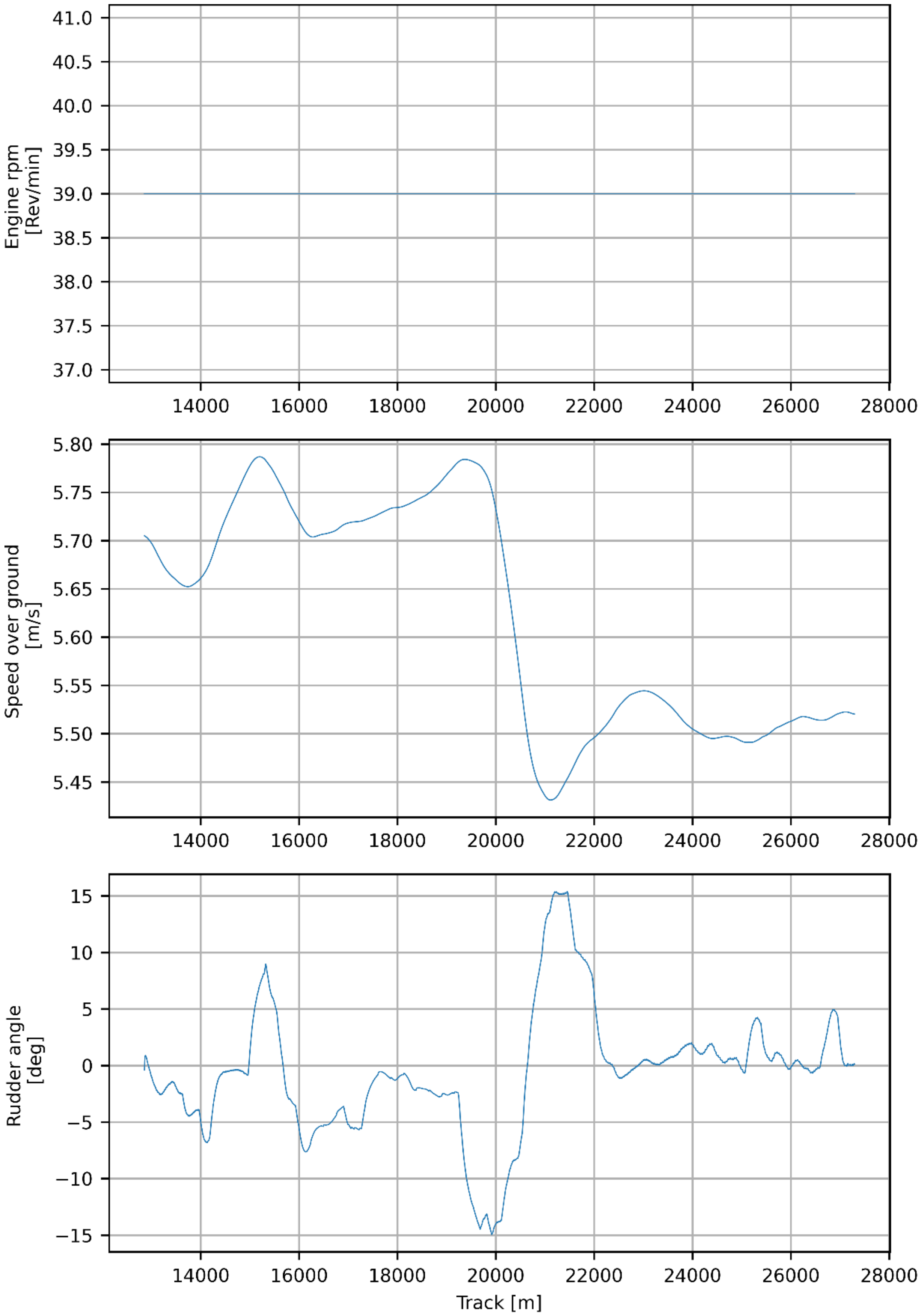
Direction: arrival

Wind: from the west

Current: peak flood

Swell: present





Engine rpm
[Rev/min]
41.0
40.5
40.0
39.5
39.0
38.5
38.0
37.5
37.0
Speed over ground
[m/s]
5.80
5.75
5.70
5.65
5.60
5.55
5.50
5.45
Rudder angle
[deg]
15
10
5
0
−5
−10
−15
14000
16000
18000
20000
22000
24000
26000
28000
Track [m]

A4 Arrival Simulations in Section C – Main Runs

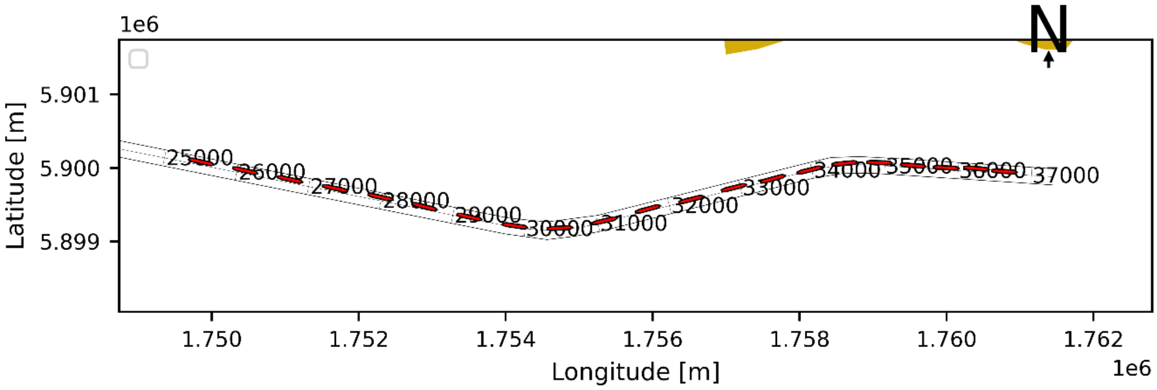
A4.1 Run "C-Arr-N-LW-Swell"

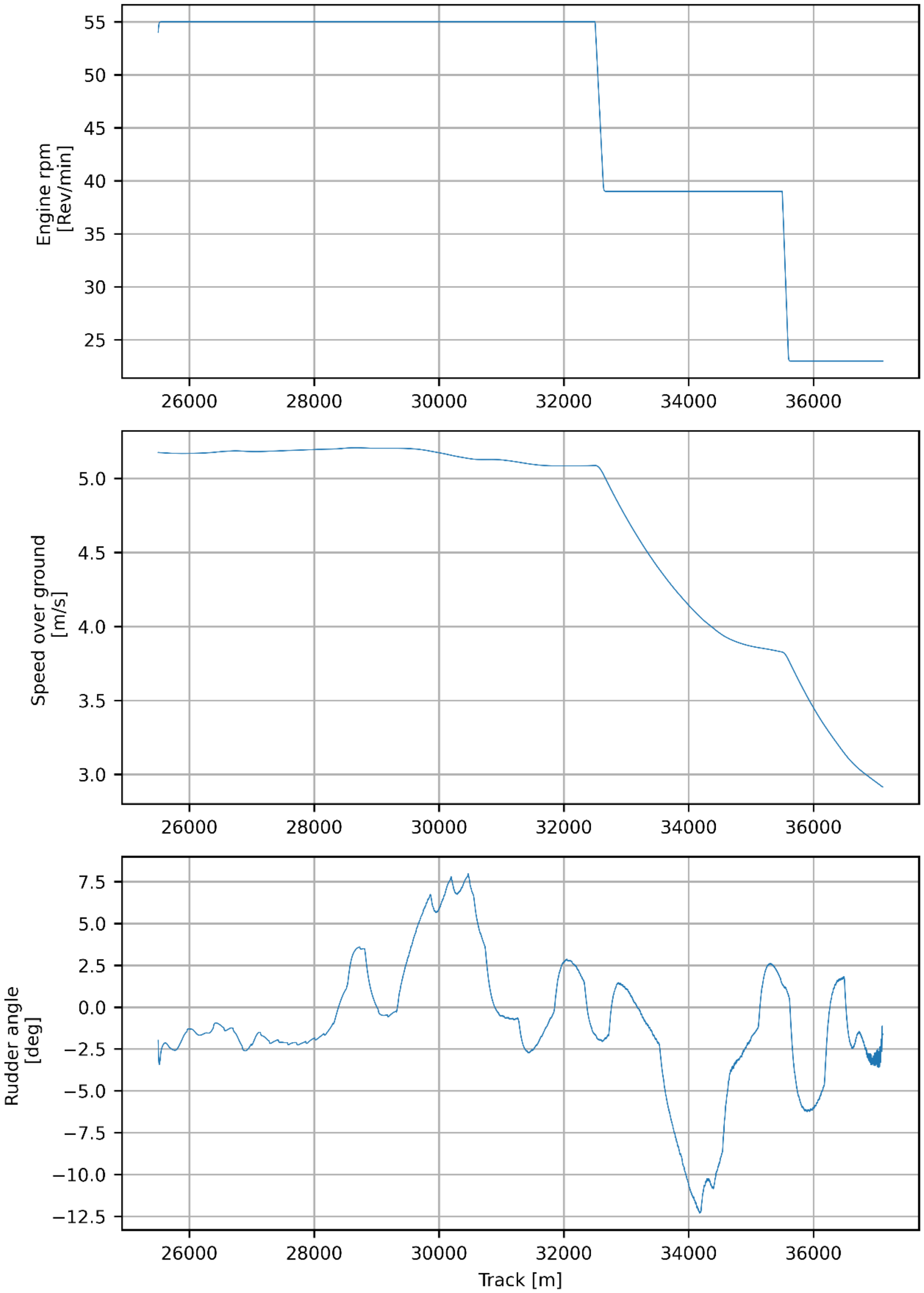
Direction: arrival

Wind: from the north

Current: low water

Swell: present





Engine rpm
[Rev/min]
55
50
45
40
35
30
25
Speed over ground
[m/s]
5.0
4.5
4.0
3.5
3.0
Rudder angle
[deg]
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
−12.5
26000
28000
30000
32000
34000
36000
Track [m]

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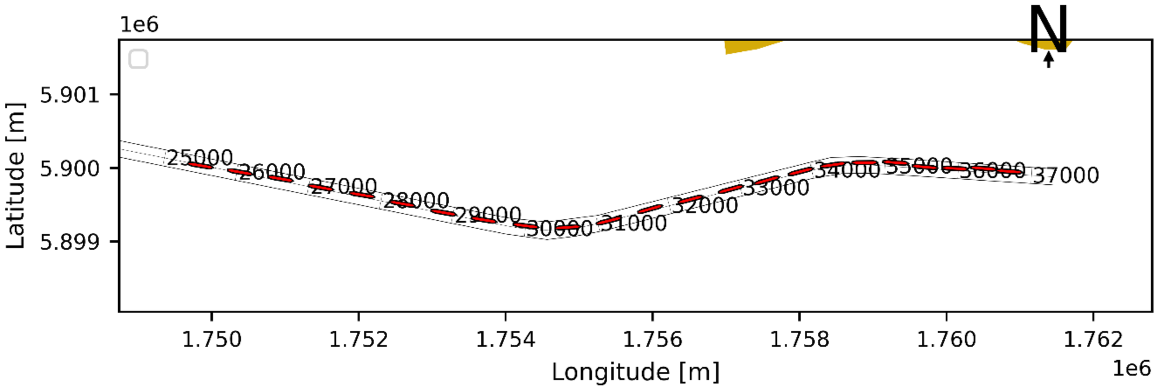
A4.2 Run “C-Arr-N-PE-Swell”

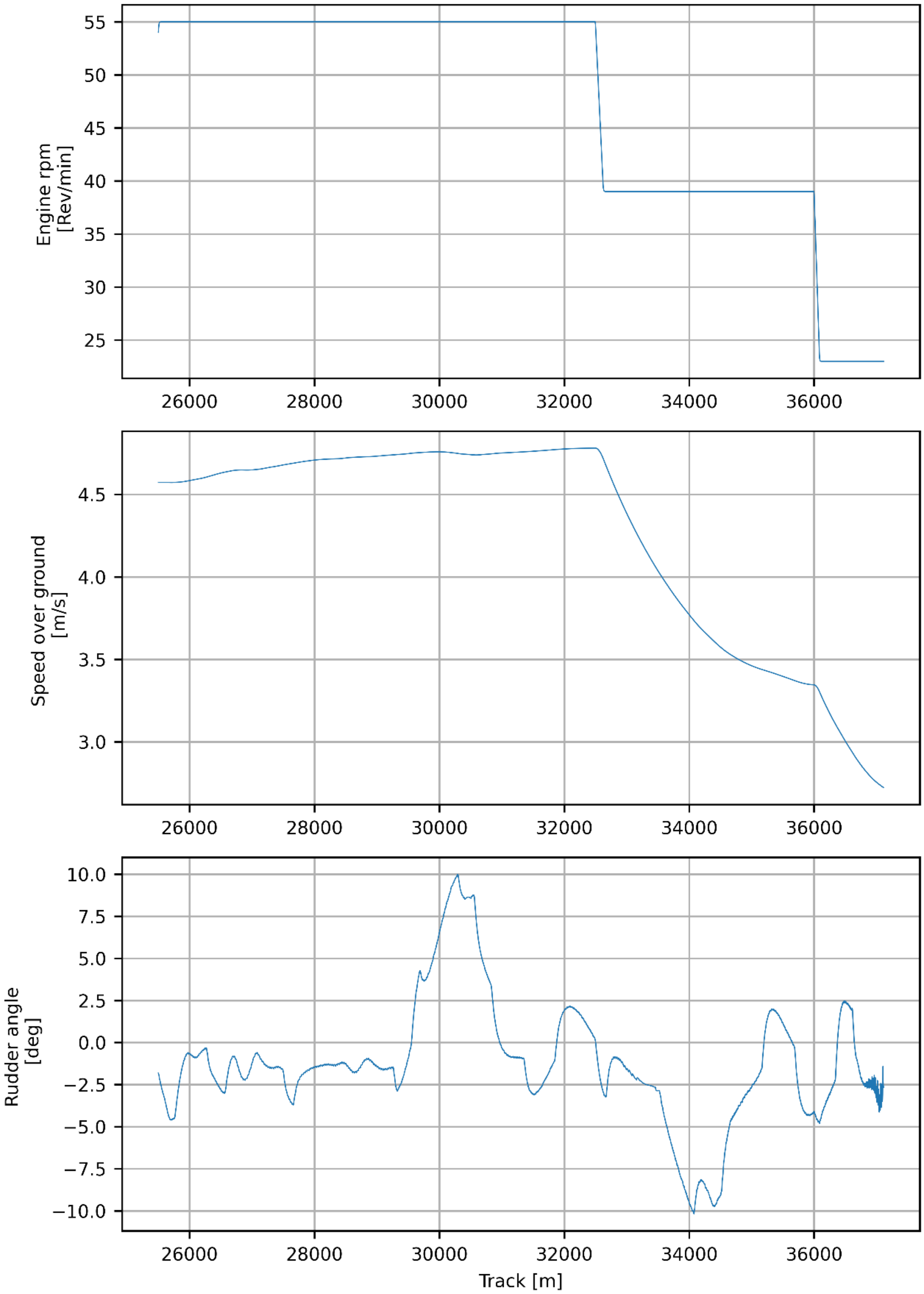
Direction: arrival

Wind: from the north

Current: peak ebb

Swell: present




Engine rpm
[Rev/min]
Speed over ground
[m/s]
Rudder angle
[deg]
Track [m]

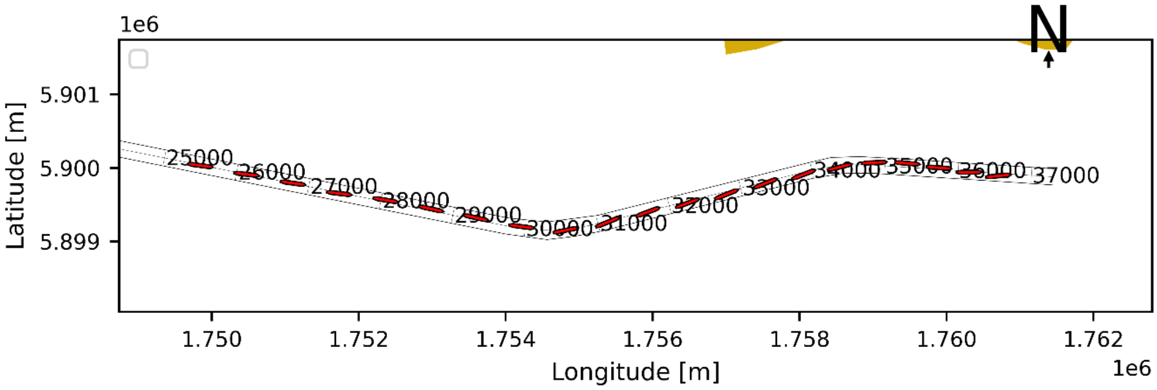
A4.3 Run “C-Arr-N-PF-Swell”

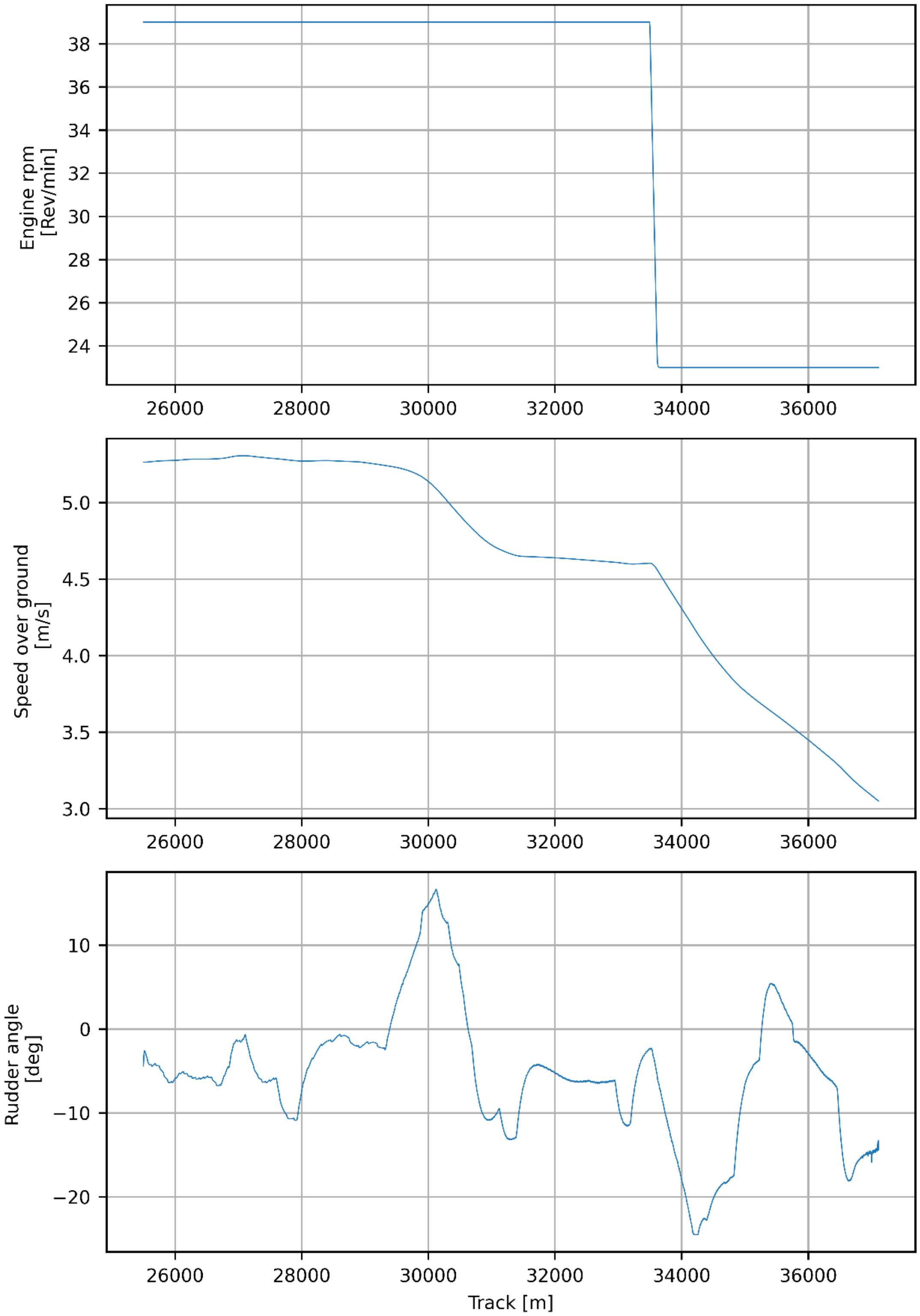
Direction: arrival

Wind: from the north

Current: peak flood

Swell: present





38
36
34
32
30
28
26
24
Engine rpm
[Rev/min]
26000
28000
30000
32000
34000
36000
5.0
4.5
4.0
3.5
3.0
Speed over ground
[m/s]
10
0
−10
−20
Rudder angle
[deg]
Track [m]

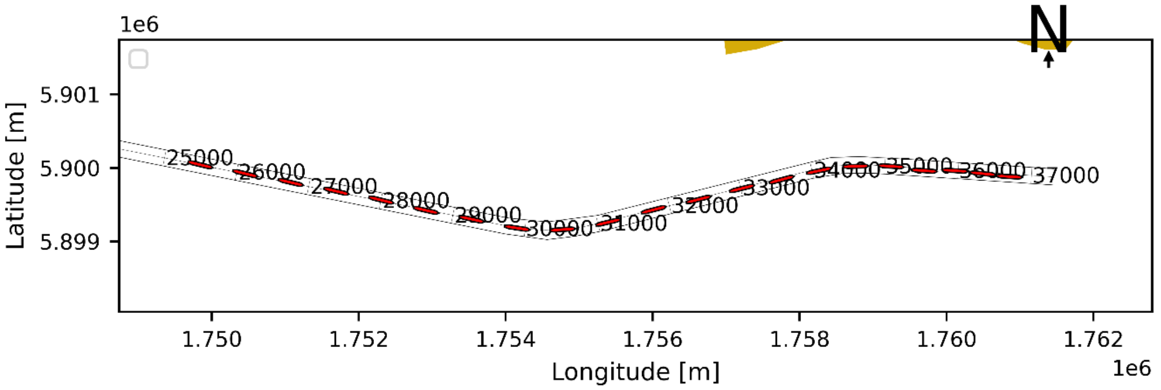
A4.4 Run “C-Arr-SW-LW-Swell”

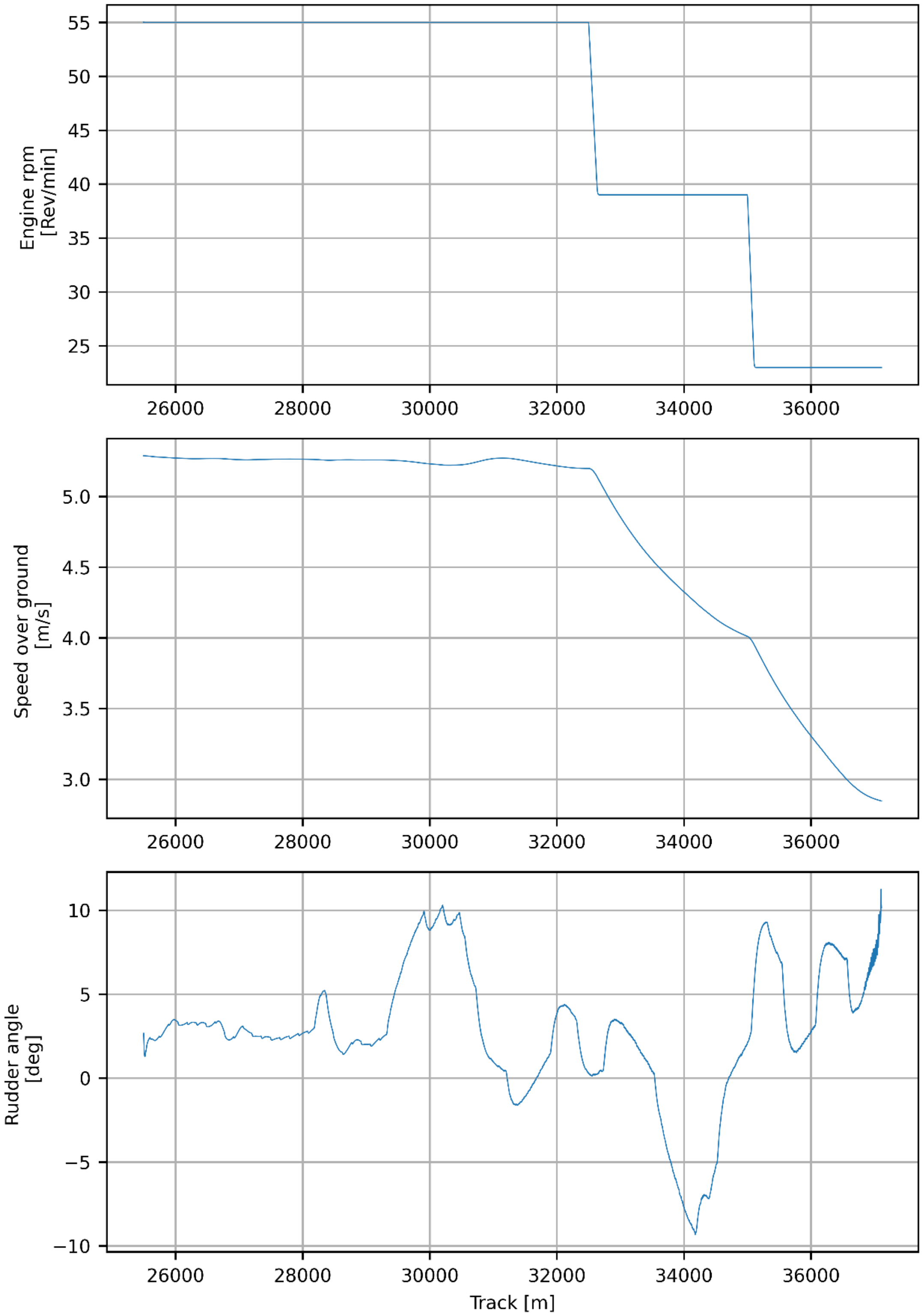
Direction: arrival

Wind: from the southwest

Current: low water

Swell: present





55
50
45
40
35
30
25
Engine rpm
[Rev/min]
26000
28000
30000
32000
34000
36000
5.0
4.5
4.0
3.5
3.0
Speed over ground
[m/s]
10
5
0
−5
−10
Rudder angle
[deg]
Track [m]

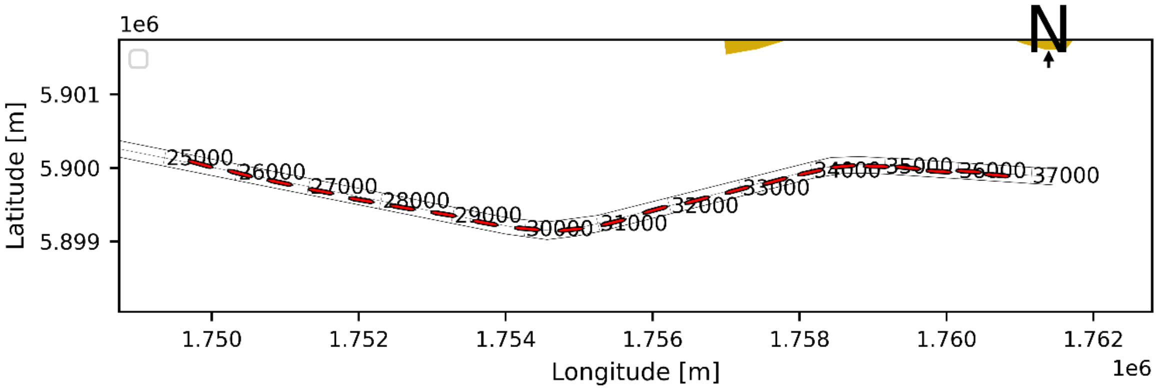
A4.5 Run "C-Arr-SW-PE-Swell"

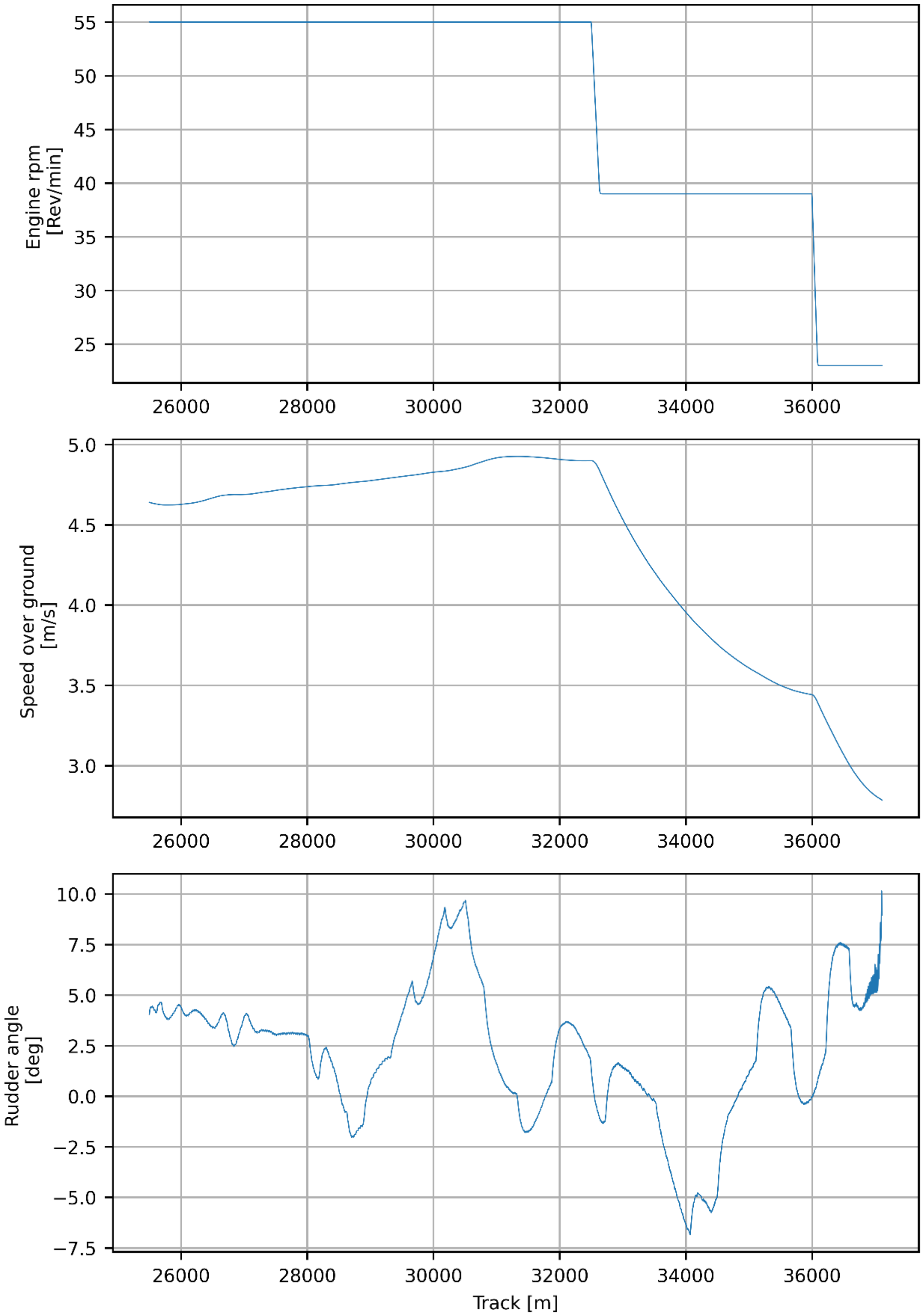
Direction: arrival

Wind: from the southwest

Current: peak ebb

Swell: present





Engine rpm
[Rev/min]
55
50
45
40
35
30
25
26000
28000
30000
32000
34000
36000
Speed over ground
[m/s]
5.0
4.5
4.0
3.5
3.0
Rudder angle
[deg]
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
Track [m]

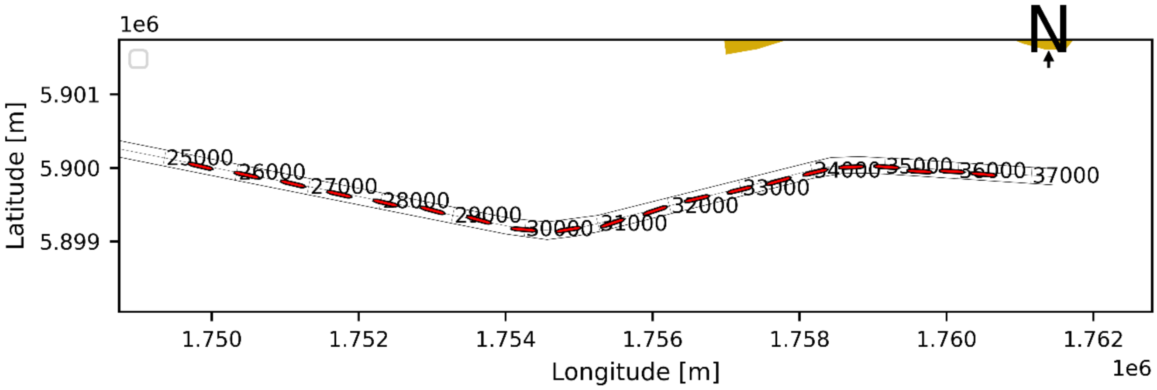
A4.6 Run "C-Arr-SW-PF-Swell"

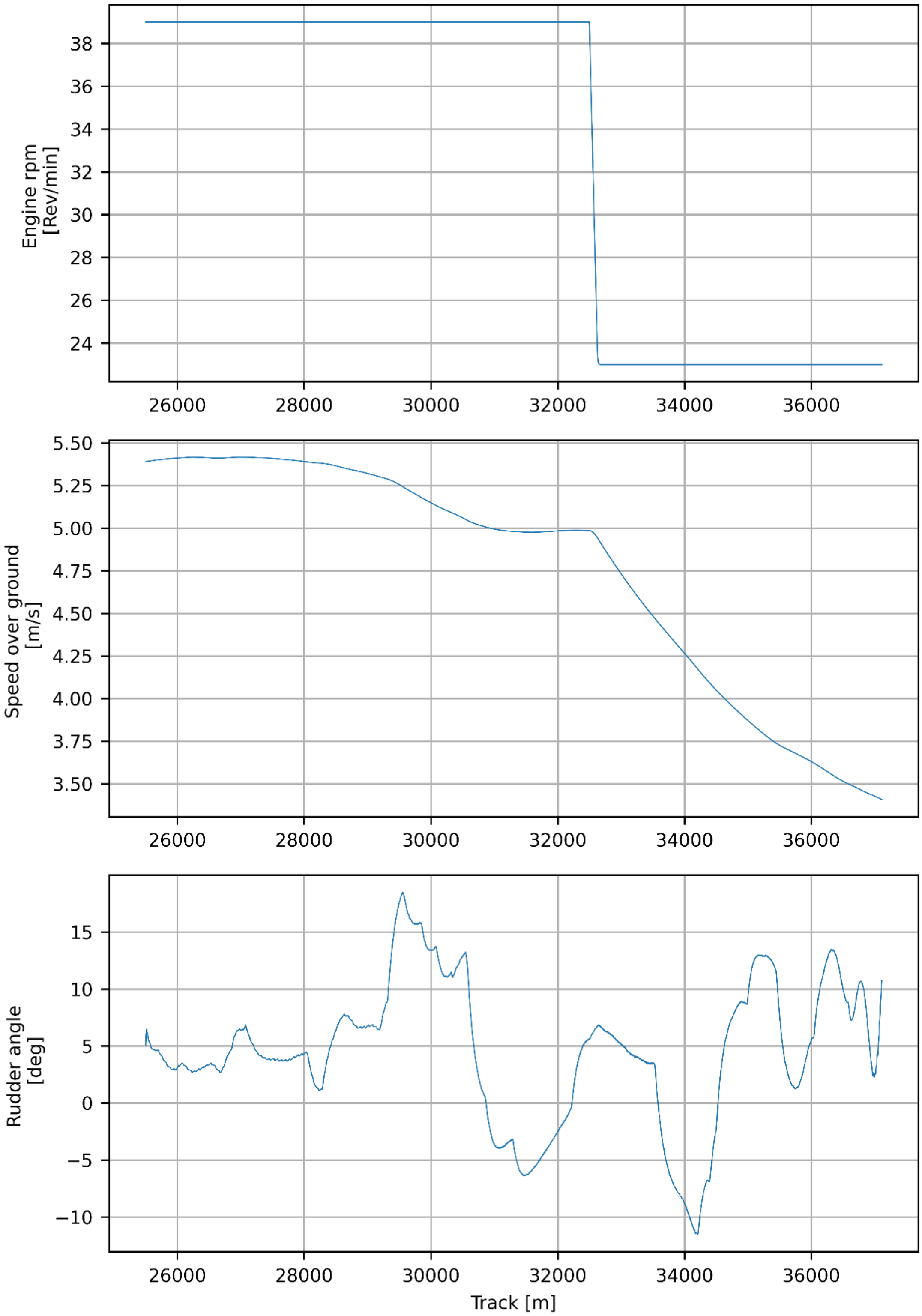
Direction: arrival

Wind: from the southwest

Current: peak flood

Swell: present




Engine rpm
[Rev/min]
38
36
34
32
30
28
26
24
26000
28000
30000
32000
34000
36000
Speed over ground
[m/s]
5.50
5.25
5.00
4.75
4.50
4.25
4.00
3.75
3.50
Rudder angle
[deg]
15
10
5
0
−5
−10
Track [m]

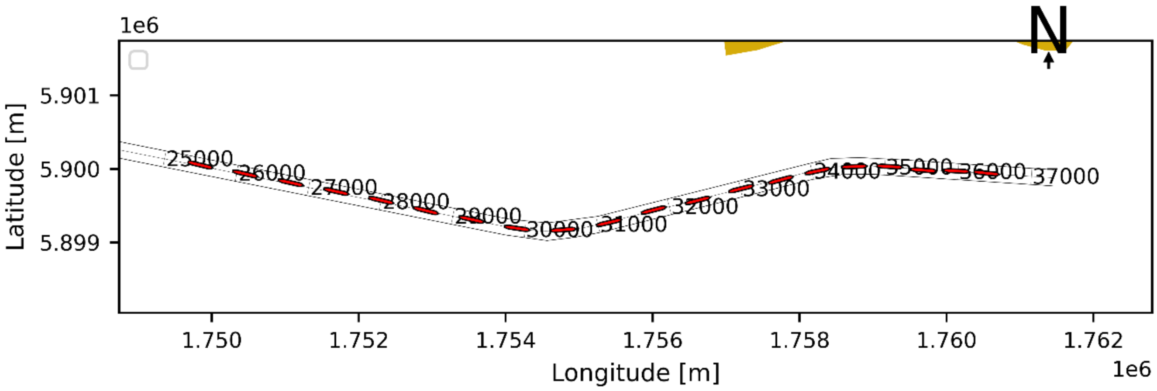
A4.7 Run “C-Arr-W-LW-Swell”

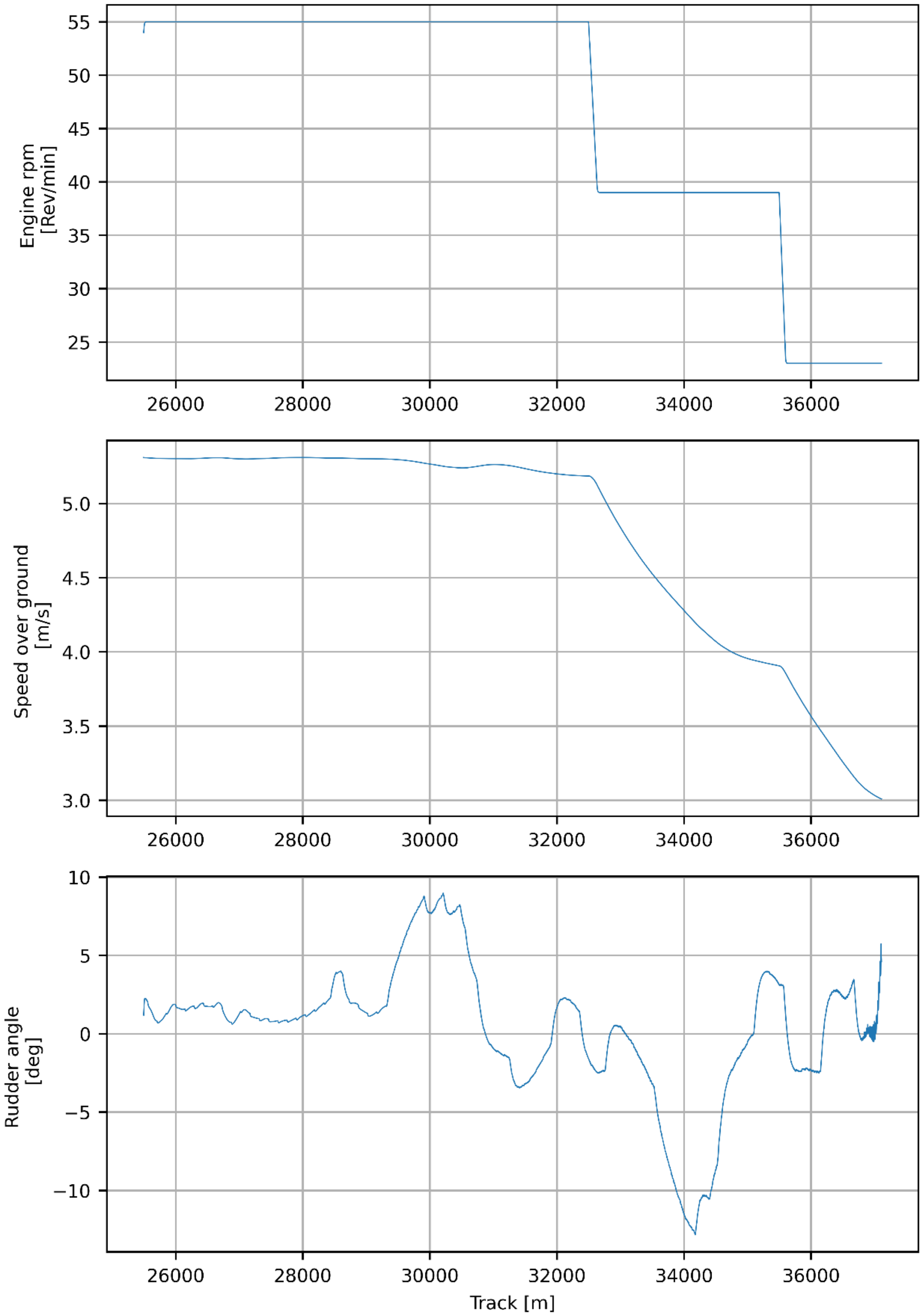
Direction: arrival

Wind: from the west

Current: low water

Swell: present




55
50
45
40
35
30
25
Engine rpm
[Rev/min]
26000
28000
30000
32000
34000
36000
5.0
4.5
4.0
3.5
3.0
Speed over ground
[m/s]
26000
28000
30000
32000
34000
36000
10
5
0
−5
−10
Rudder angle
[deg]
26000
28000
30000
32000
34000
36000
Track [m]

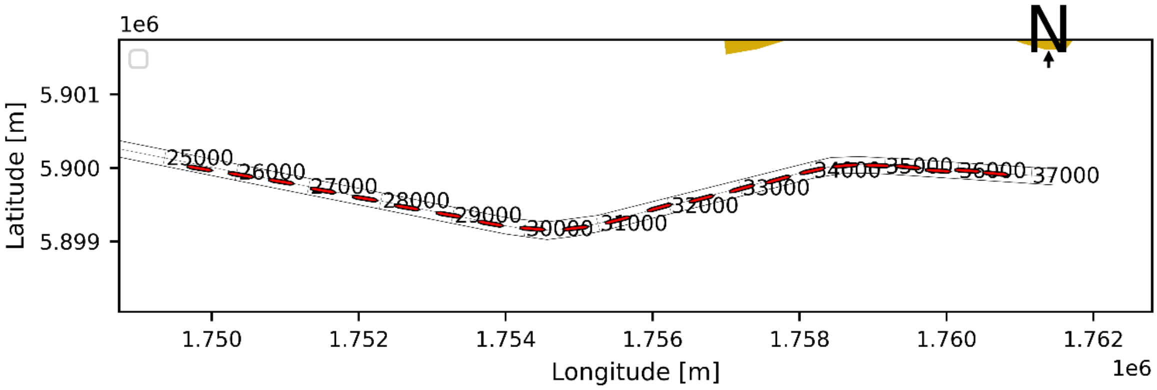
A4.8 Run "C-Arr-W-PE-Swell"

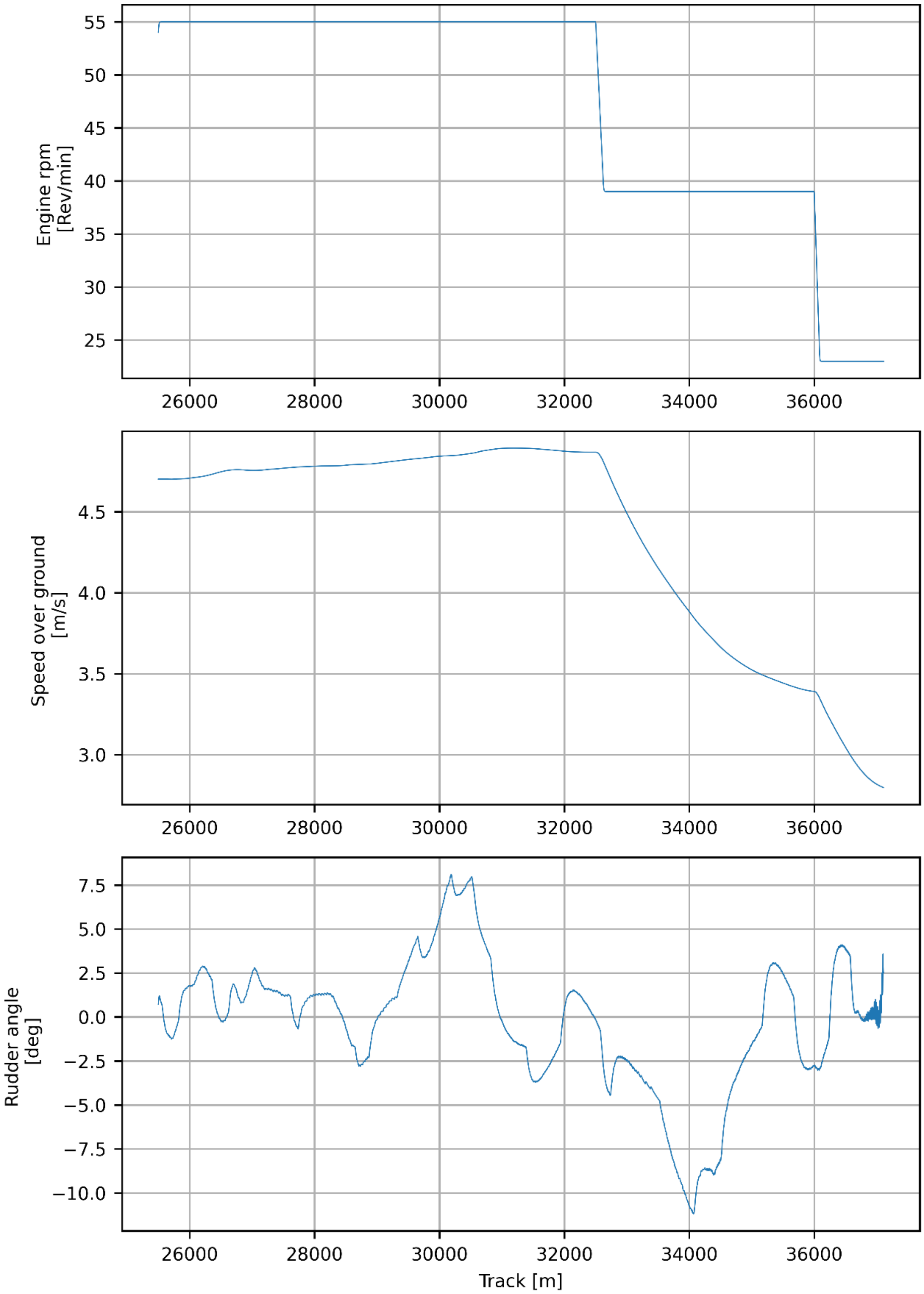
Direction: arrival

Wind: from the west

Current: peak ebb

Swell: present





55
50
45
40
35
30
25
Engine rpm
[Rev/min]
26000
28000
30000
32000
34000
36000
4.5
4.0
3.5
3.0
Speed over ground
[m/s]
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
Rudder angle
[deg]
Track [m]

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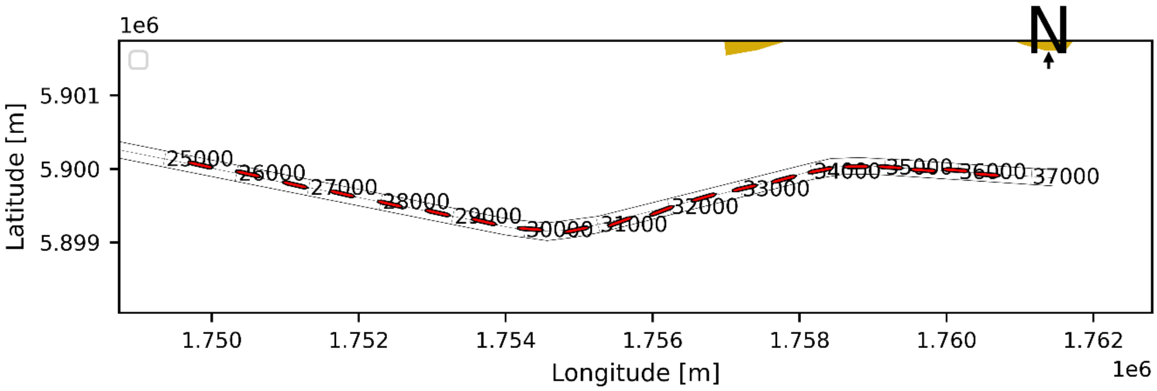
A4.9 Run “C-Arr-W-PF-Swell”

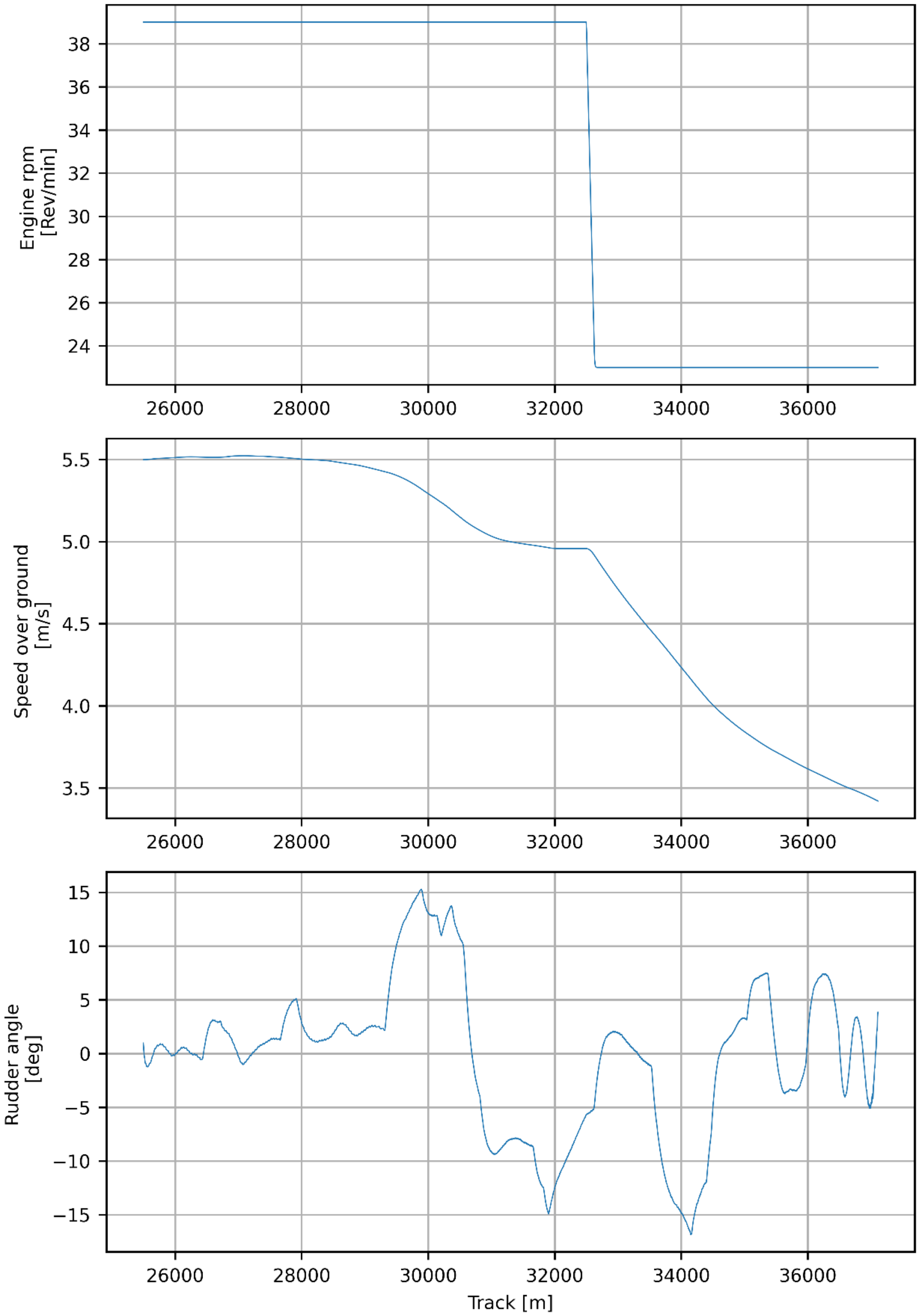
Direction: arrival

Wind: from the west

Current: peak flood

Swell: present





Engine rpm
[Rev/min]
38
36
34
32
30
28
26
24
Speed over ground
[m/s]
5.5
5.0
4.5
4.0
3.5
Rudder angle
[deg]
15
10
5
0
−5
−10
−15
26000
28000
30000
32000
34000
36000
Track [m]

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A5 Departure Simulations in Section C – Main Runs

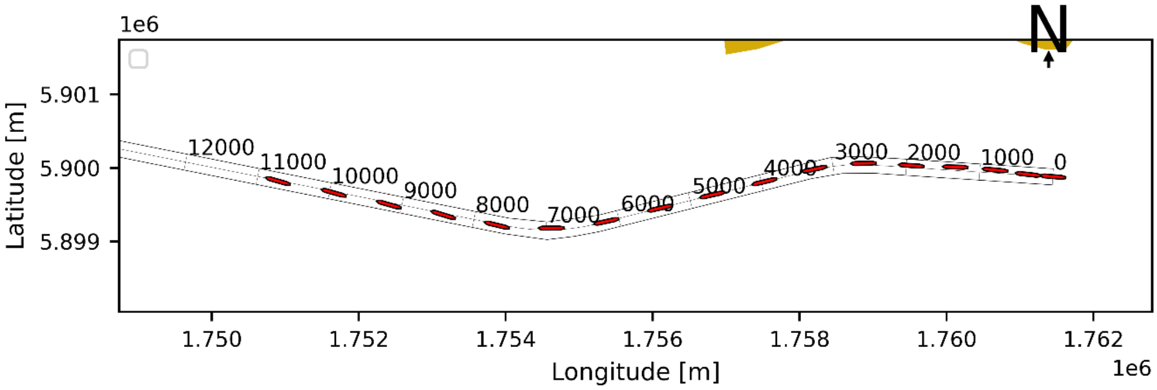
A5.1 Run "C-Dep-N-LW-Swell"

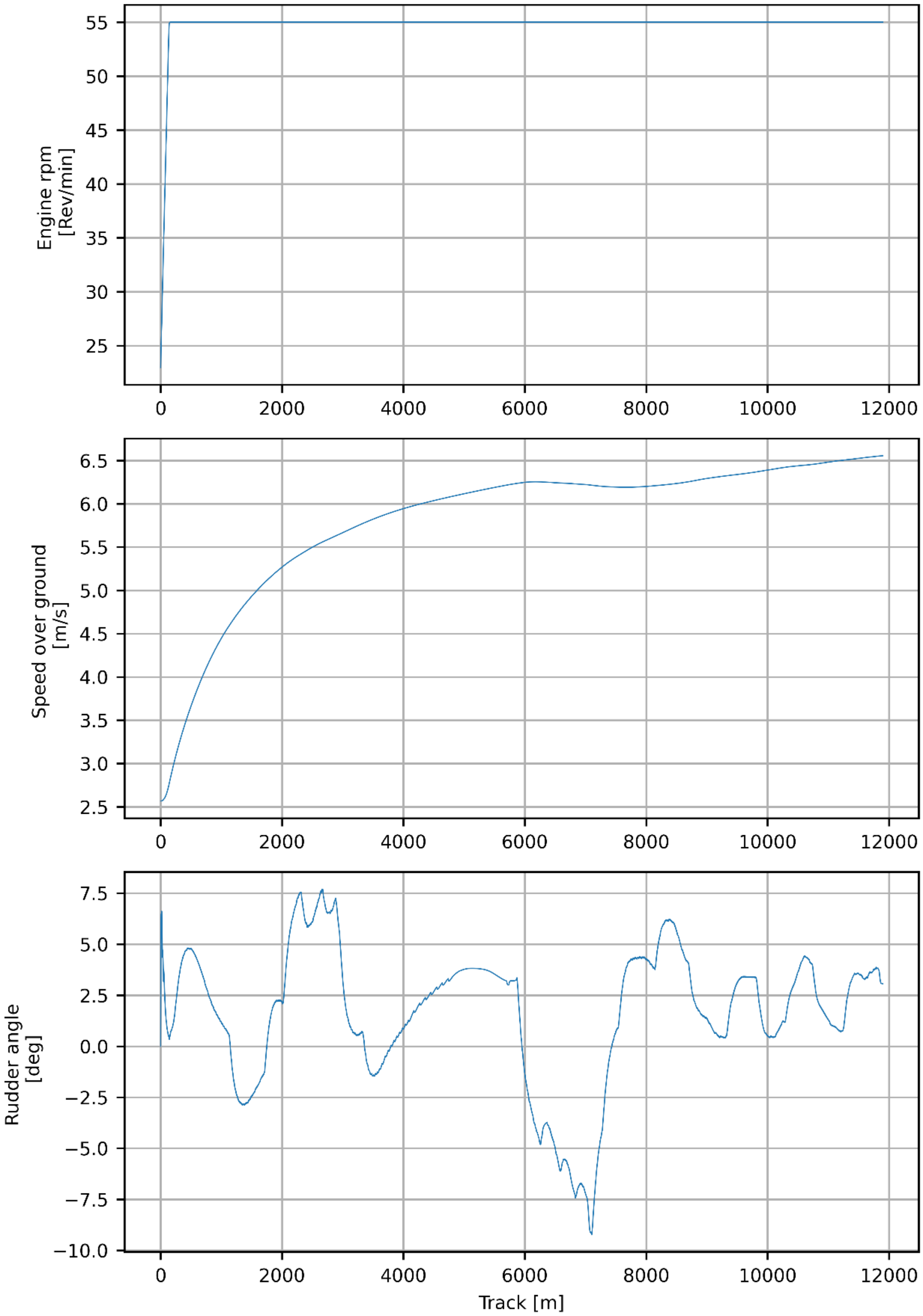
Direction: departure

Wind: from the north

Current: low water

Swell: present




55
50
45
40
35
30
25
Engine rpm
[Rev/min]
0
2000
4000
6000
8000
10000
12000
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
Speed over ground
[m/s]
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
Rudder angle
[deg]
Track [m]

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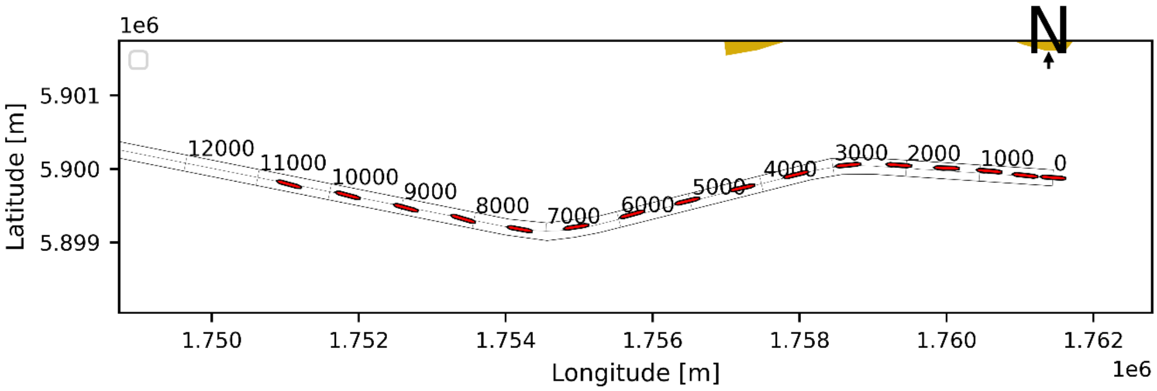
A5.2 Run "C-Dep-N-PE-Swell"

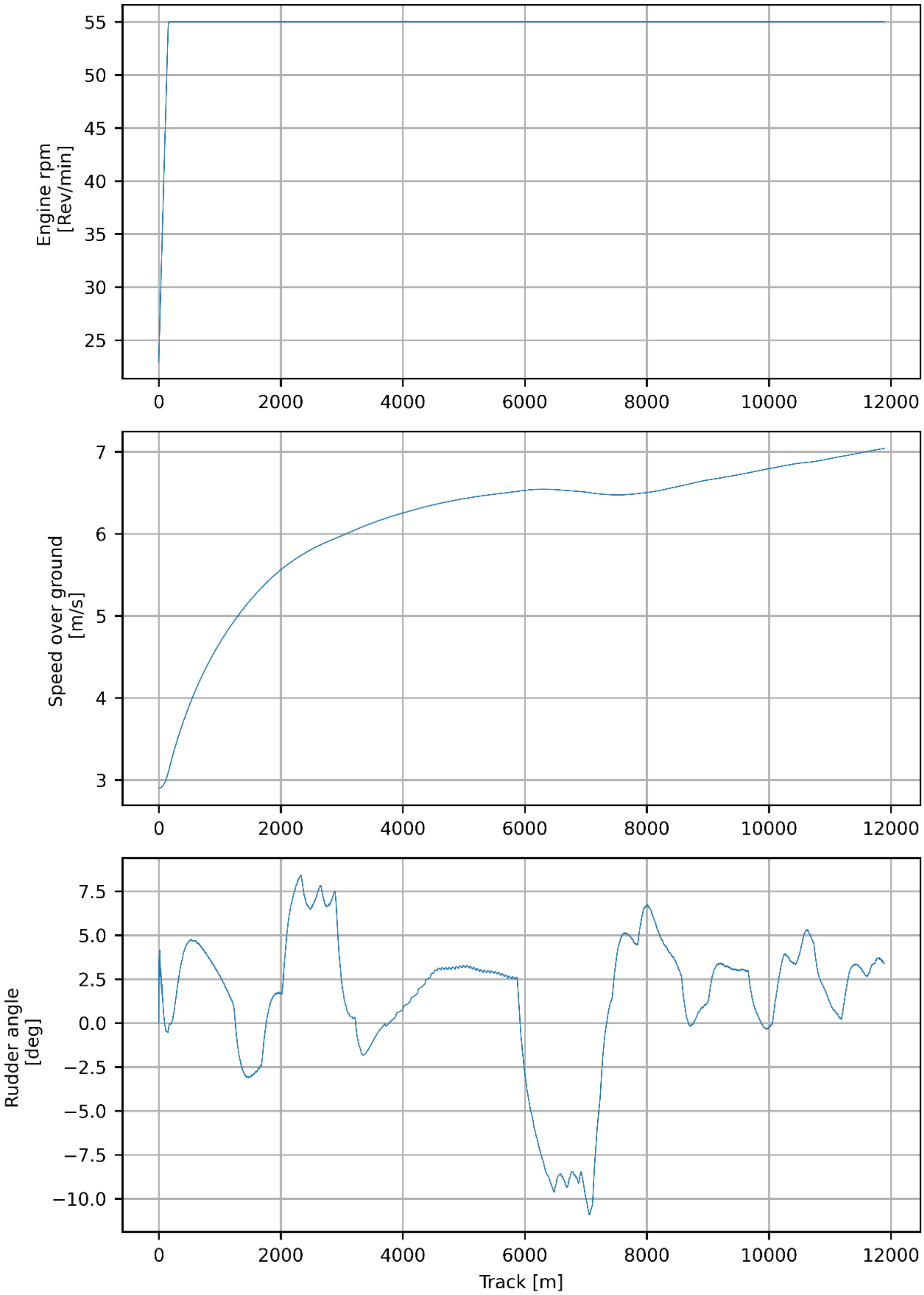
Direction: departure

Wind: from the north

Current: peak ebb

Swell: present




Engine rpm
[Rev/min]
55
50
45
40
35
30
25
Speed over ground
[m/s]
7
6
5
4
3
Rudder angle
[deg]
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
0
2000
4000
6000
8000
10000
12000
Track [m]

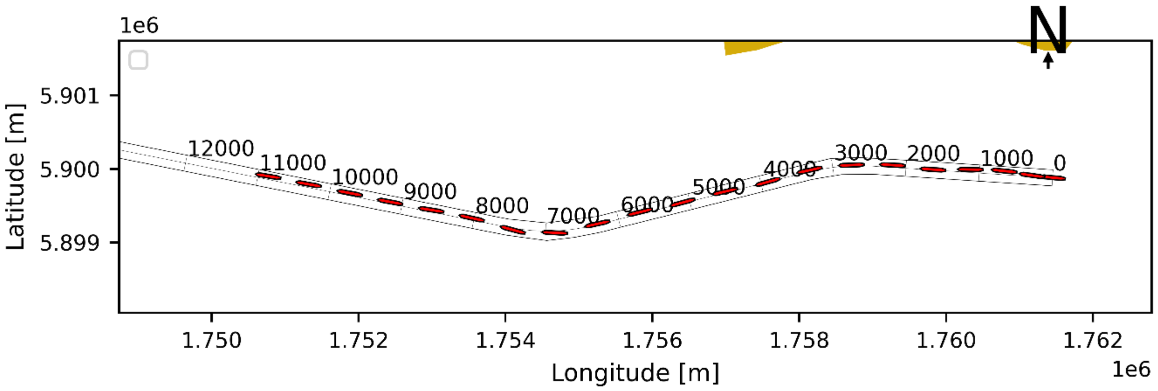
A5.3 Run "C-Dep-N-PF-Swell"

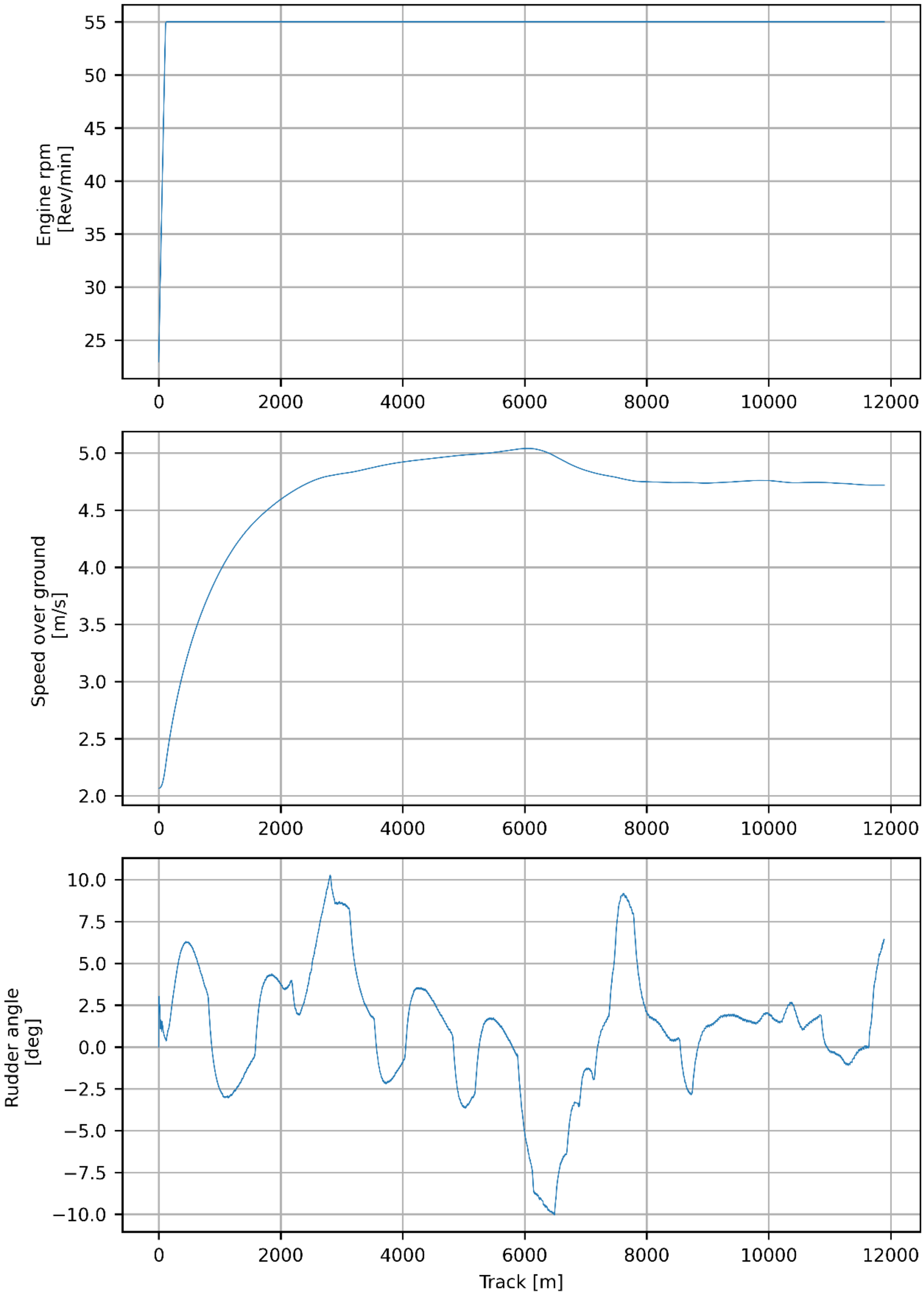
Direction: departure

Wind: from the north

Current: peak flood

Swell: present





Engine rpm
[Rev/min]
55
50
45
40
35
30
25
0
2000
4000
6000
8000
10000
12000
Speed over ground
[m/s]
5.0
4.5
4.0
3.5
3.0
2.5
2.0
Rudder angle
[deg]
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
Track [m]

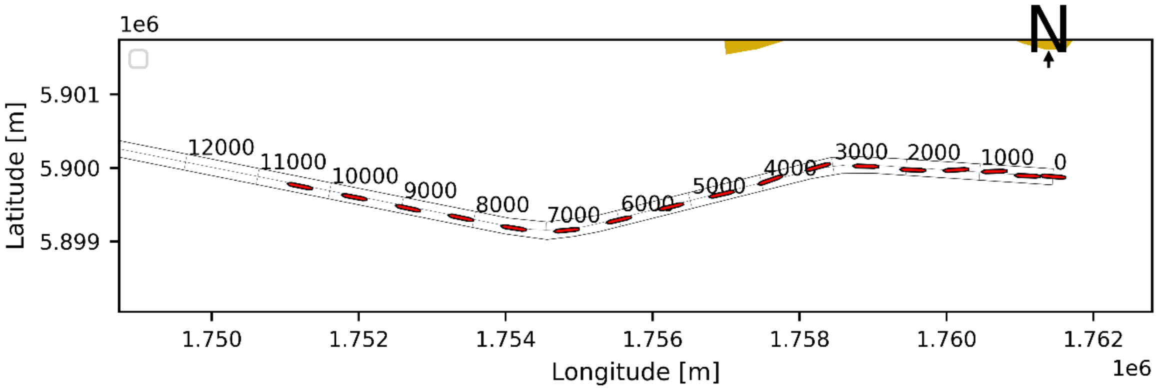
A5.4 Run “C-Dep-SW-LW-Swell”

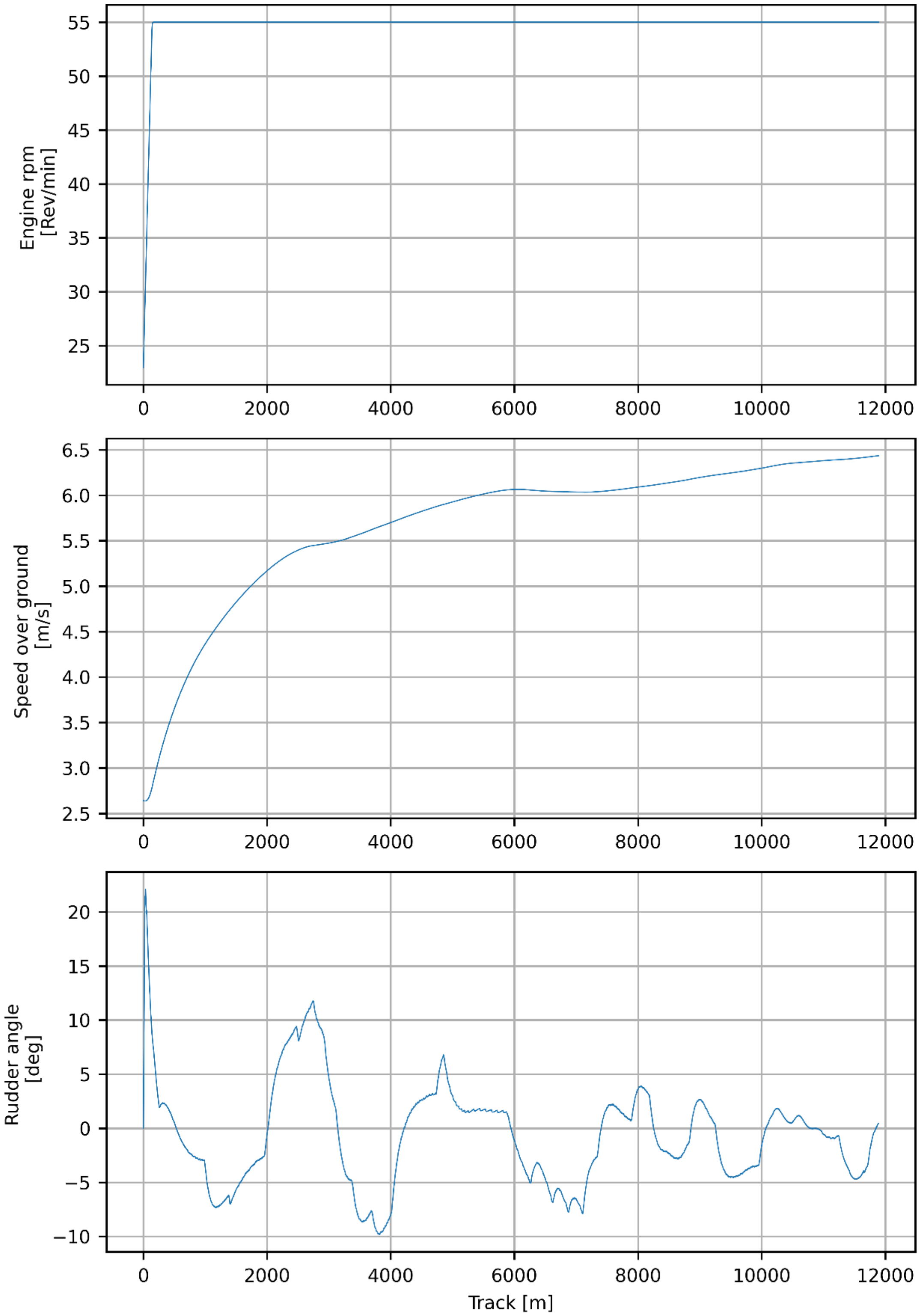
Direction: departure

Wind: from the southwest

Current: low water

Swell: present





Engine rpm
[Rev/min]
55
50
45
40
35
30
25
0
2000
4000
6000
8000
10000
12000
Speed over ground
[m/s]
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
Rudder angle
[deg]
20
15
10
5
0
−5
−10
Track [m]

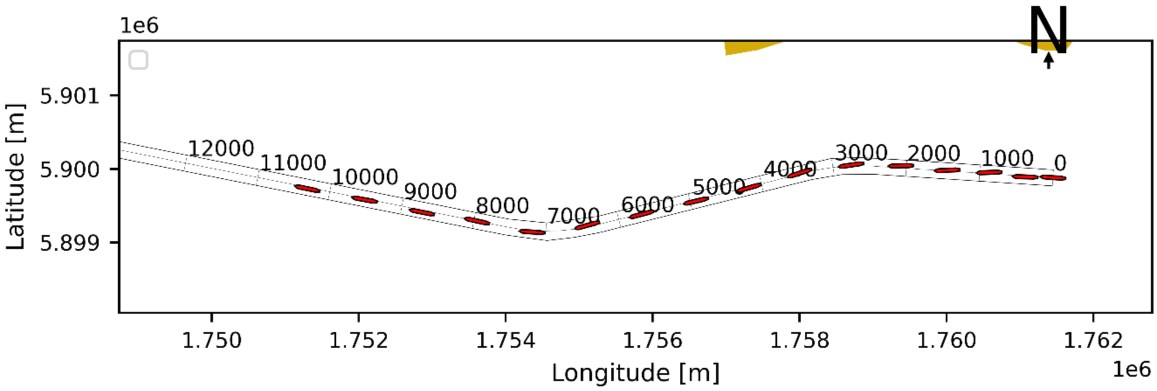
A5.5 Run "C-Dep-SW-PE-Swell"

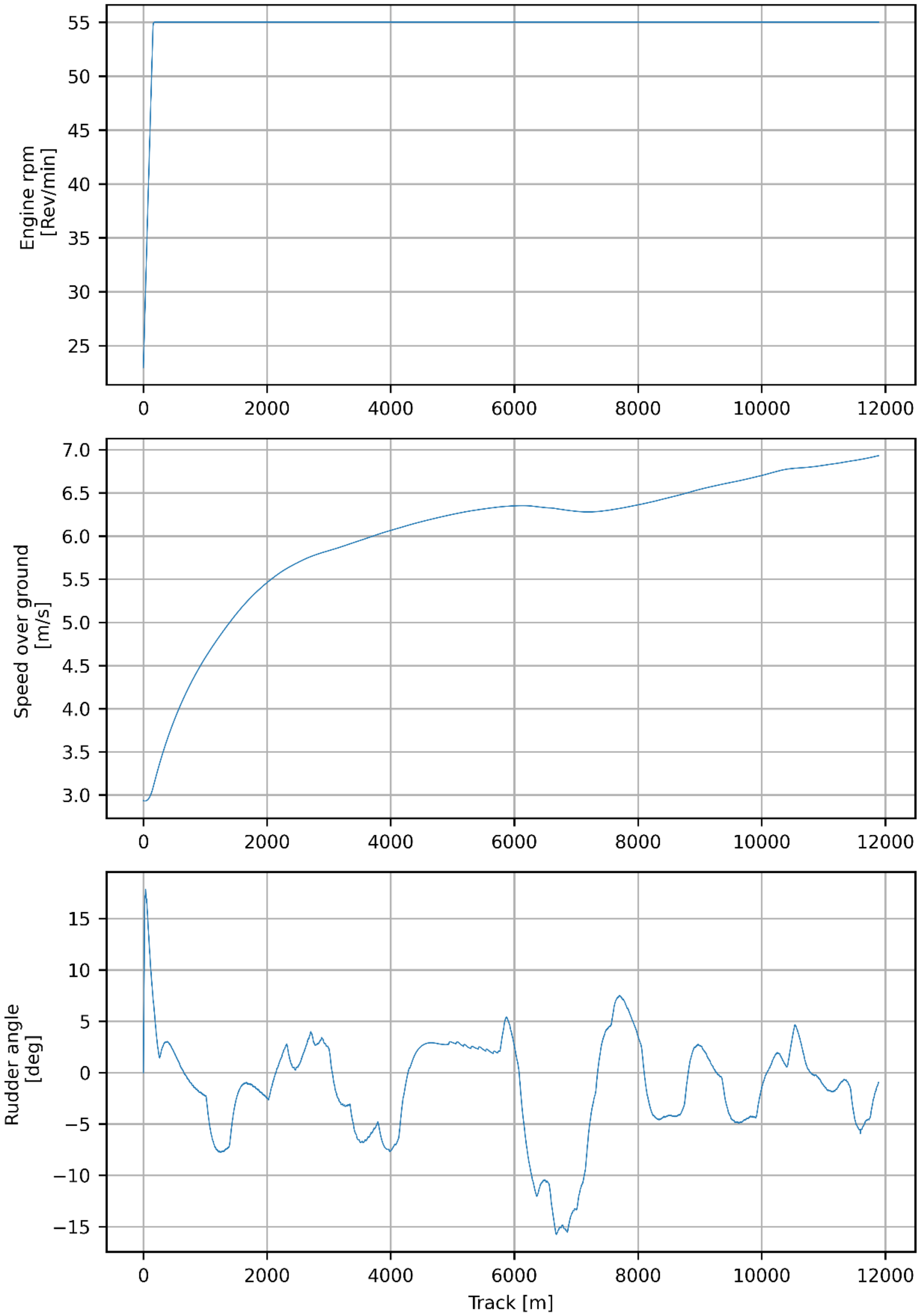
Direction: departure

Wind: from the southwest

Current: peak ebb

Swell: present





55
50
45
40
35
30
25
Engine rpm
[Rev/min]
0
2000
4000
6000
8000
10000
12000
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
Speed over ground
[m/s]
15
10
5
0
−5
−10
−15
Rudder angle
[deg]
Track [m]

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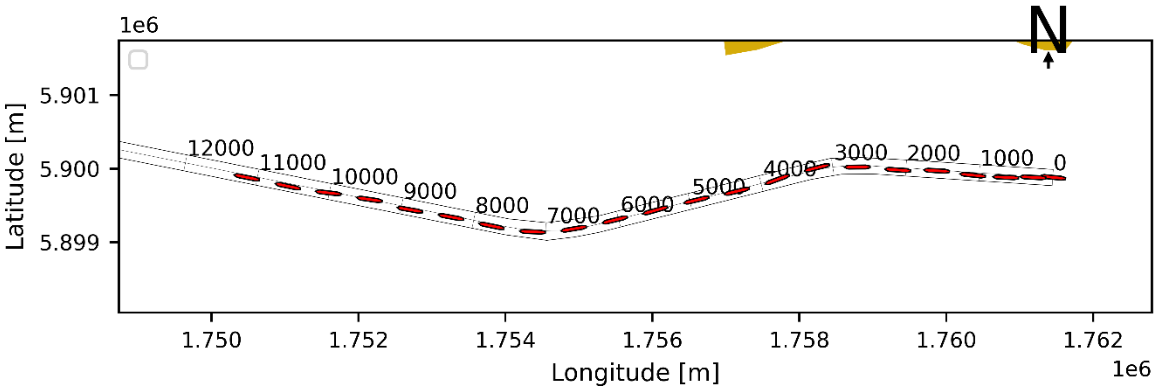
A5.6 Run “C-Dep-SW-PF-Swell”

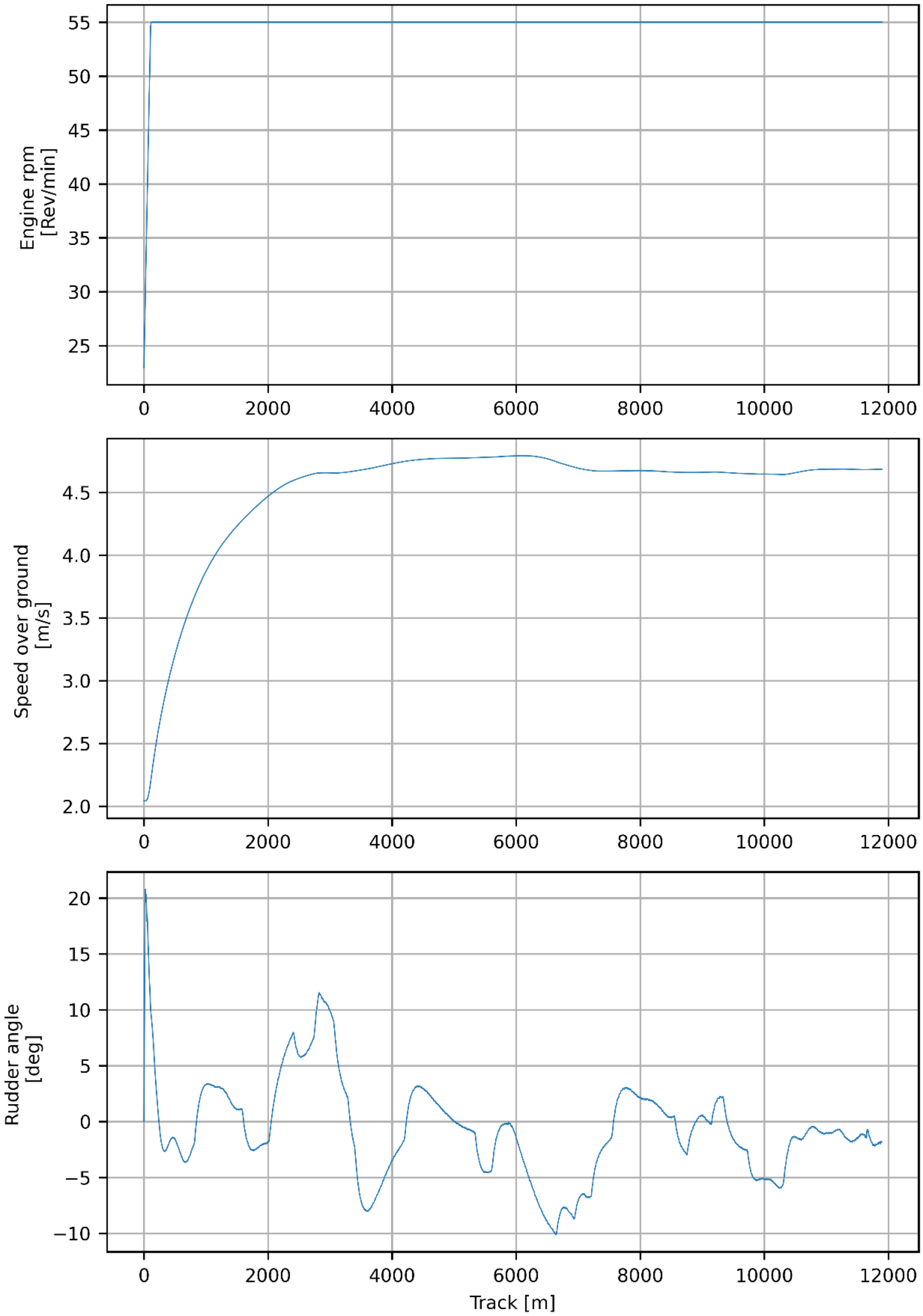
Direction: departure

Wind: from the southwest

Current: peak flood

Swell: present




Engine rpm
[Rev/min]
55
50
45
40
35
30
25
0
2000
4000
6000
8000
10000
12000
Speed over ground
[m/s]
4.5
4.0
3.5
3.0
2.5
2.0
Rudder angle
[deg]
20
15
10
5
0
−5
−10
Track [m]

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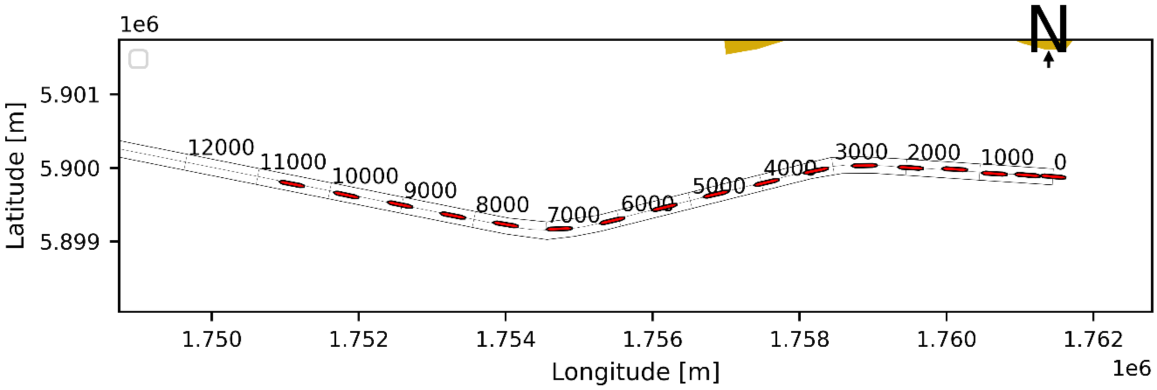
A5.7 Run “C-Dep-W-LW-Swell”

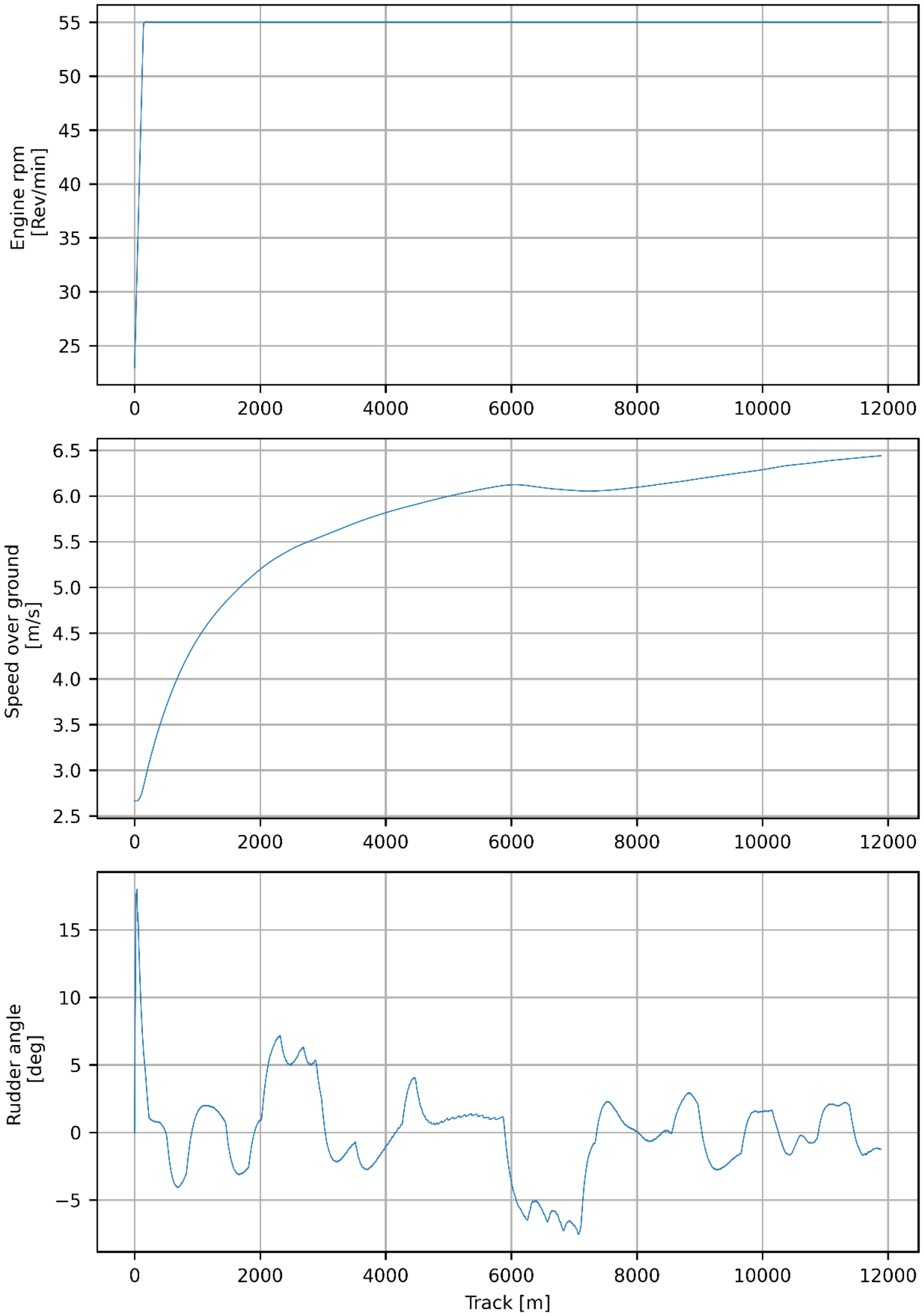
Direction: departure

Wind: from the west

Current: low water

Swell: present




55
50
45
40
35
30
25
Engine rpm
[Rev/min]
0
2000
4000
6000
8000
10000
12000
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
Speed over ground
[m/s]
15
10
5
0
−5
Rudder angle
[deg]
Track [m]

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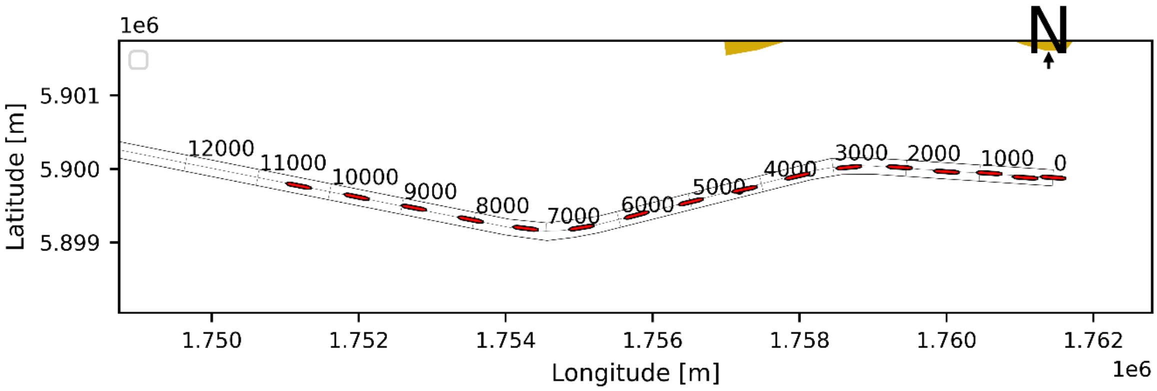
A5.8 Run "C-Dep-W-PE-Swell"

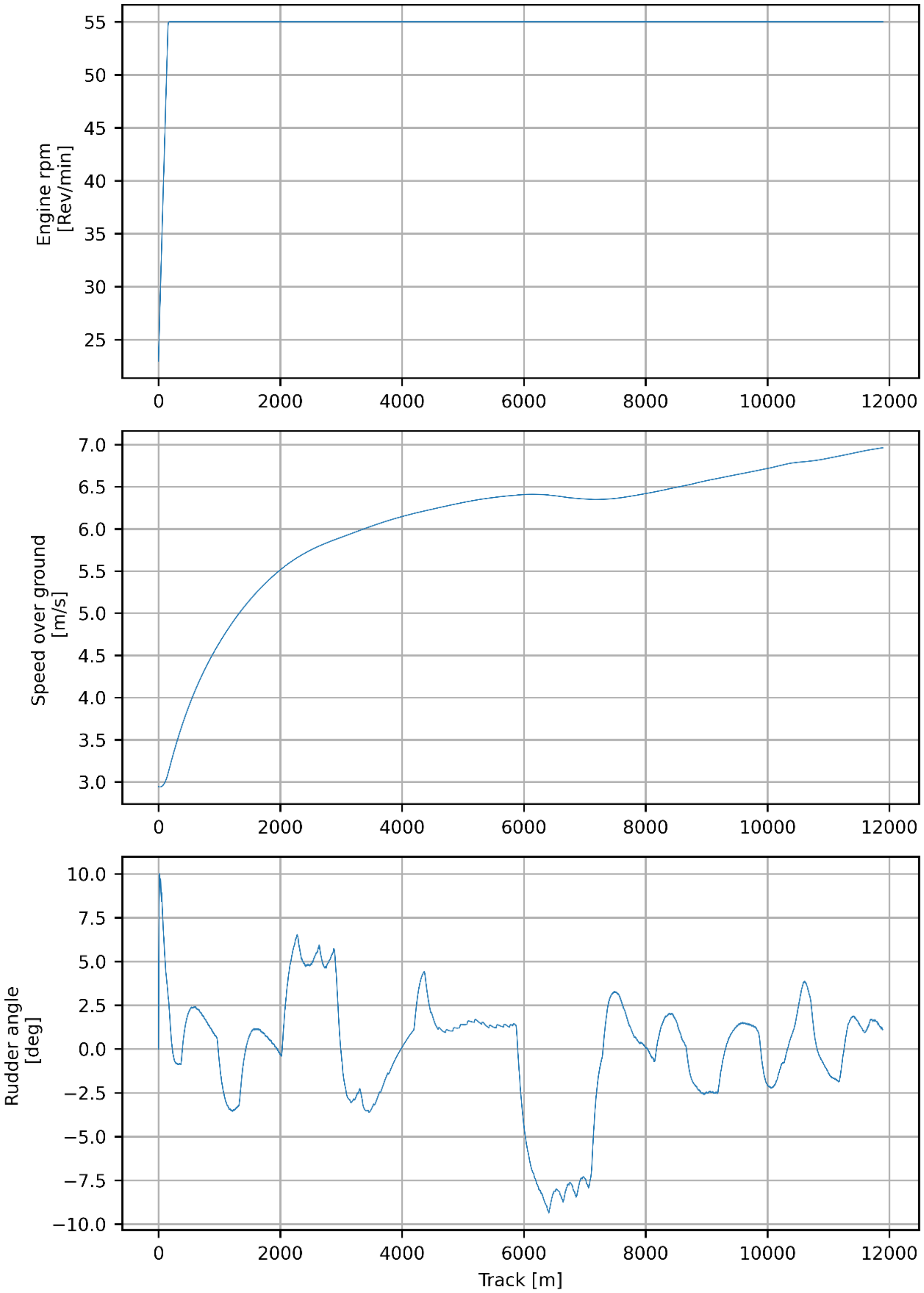
Direction: departure

Wind: from the west

Current: peak ebb

Swell: present




Engine rpm
[Rev/min]
55
50
45
40
35
30
25
0
2000
4000
6000
8000
10000
12000
Speed over ground
[m/s]
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
Rudder angle
[deg]
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
Track [m]

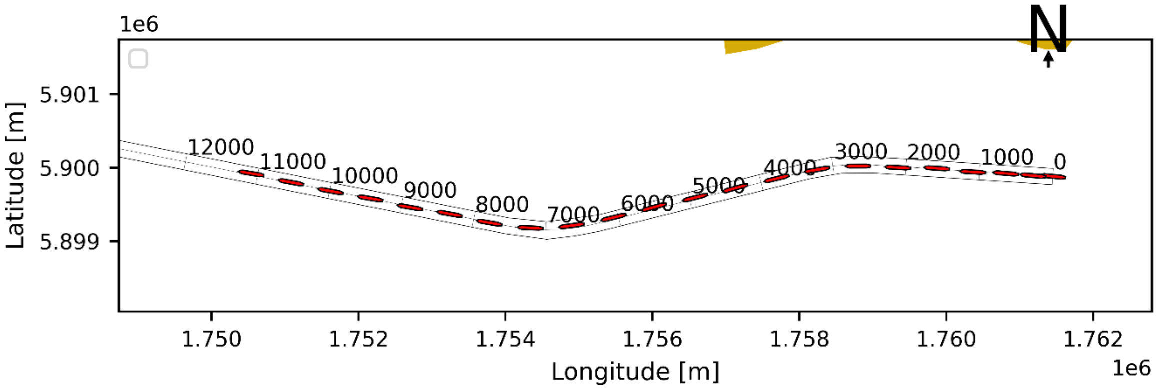
A5.9 Run “C-Dep-W-PF-Swell”

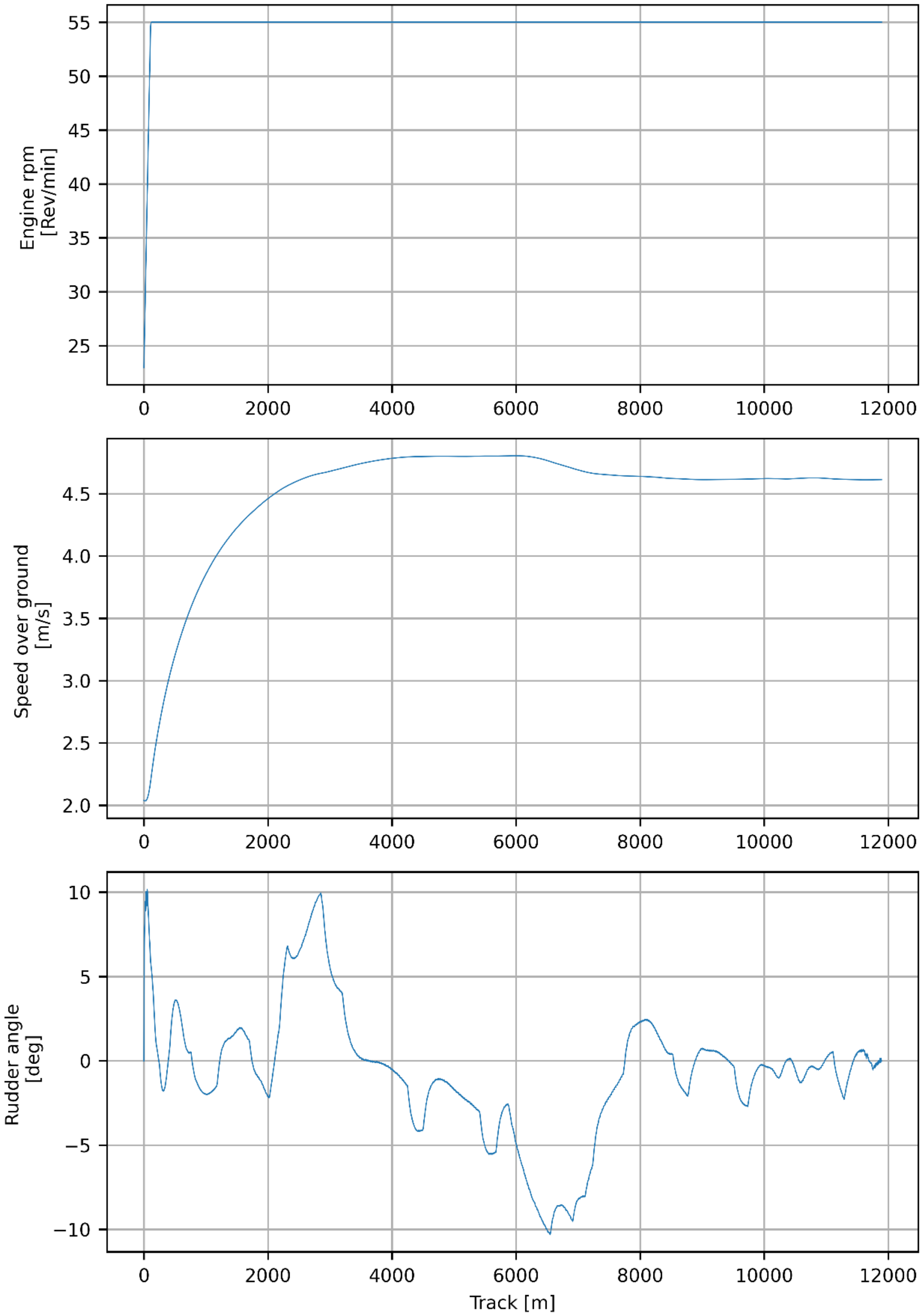
Direction: departure

Wind: from the west

Current: peak flood

Swell: present




Engine rpm
[Rev/min]
55
50
45
40
35
30
25
0
2000
4000
6000
8000
10000
12000
Speed over ground
[m/s]
4.5
4.0
3.5
3.0
2.5
2.0
Rudder angle
[deg]
10
5
0
−5
−10
Track [m]

A6 Departure Simulations in Section B – Main Runs

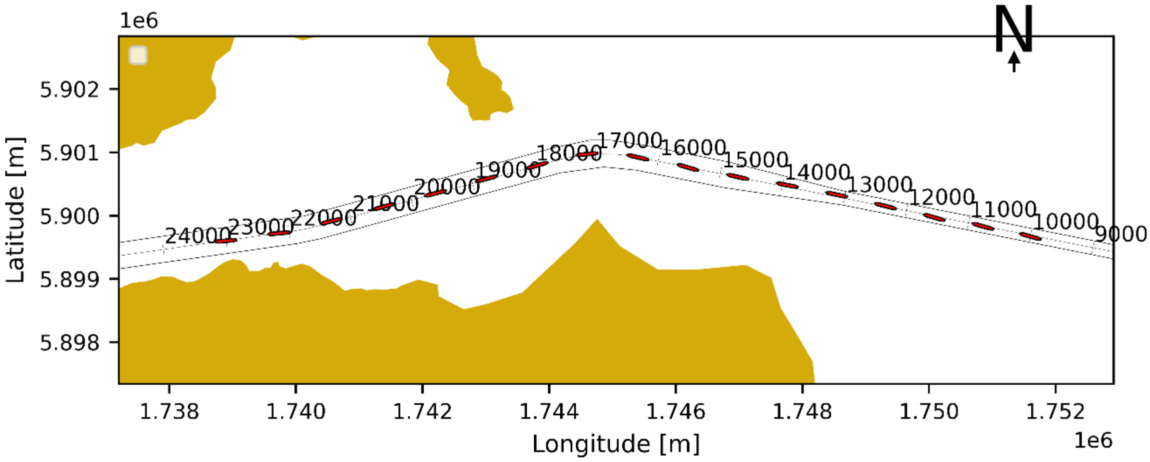
A6.1 Run "B-Dep-N-LW-Swell"

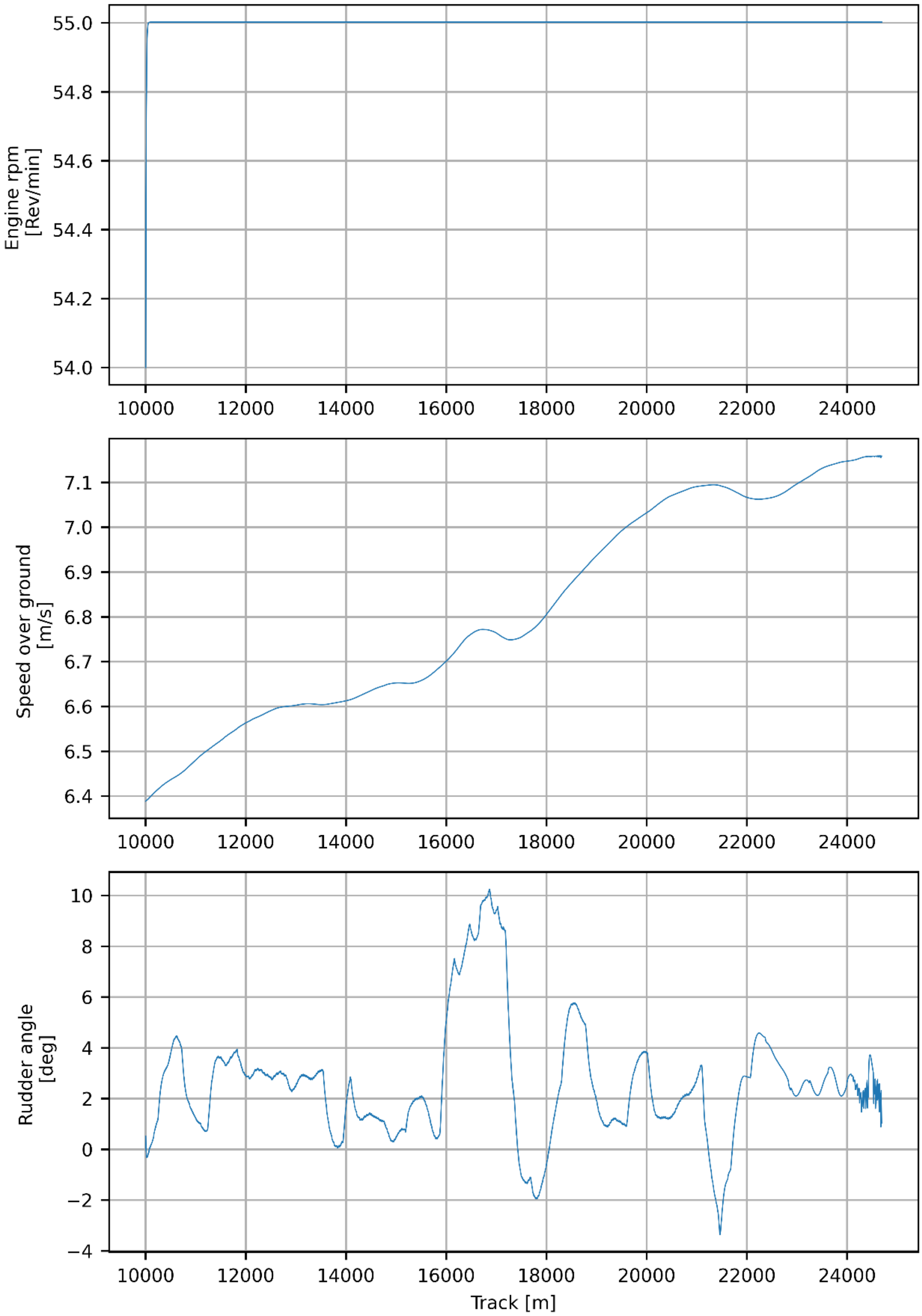
Direction: departure

Wind: from the north

Current: low water

Swell: present




Engine rpm
[Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
Speed over ground
[m/s]
7.1
7.0
6.9
6.8
6.7
6.6
6.5
6.4
Rudder angle
[deg]
10
8
6
4
2
0
−2
−4
10000
12000
14000
16000
18000
20000
22000
24000
Track [m]

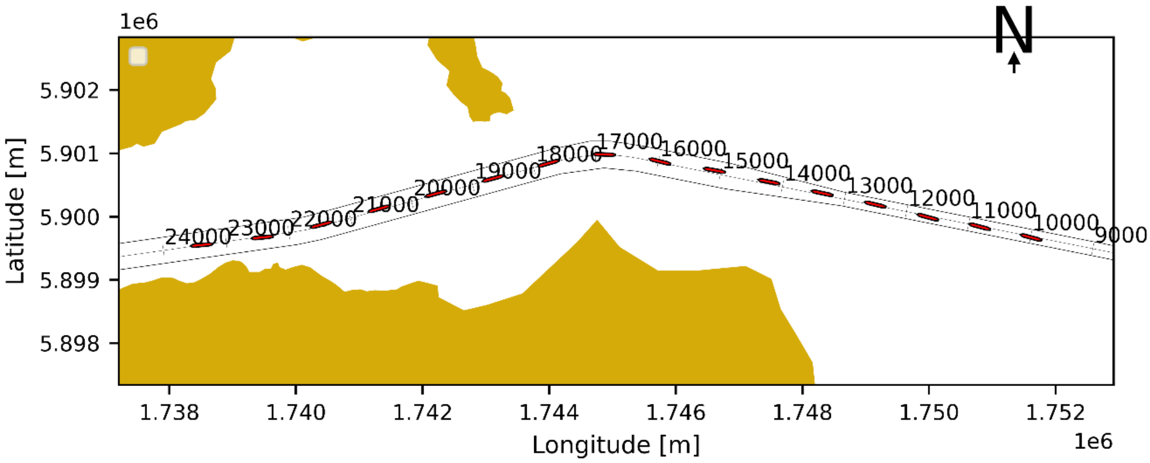
A6.2 Run "B-Dep-N-PE-Swell"

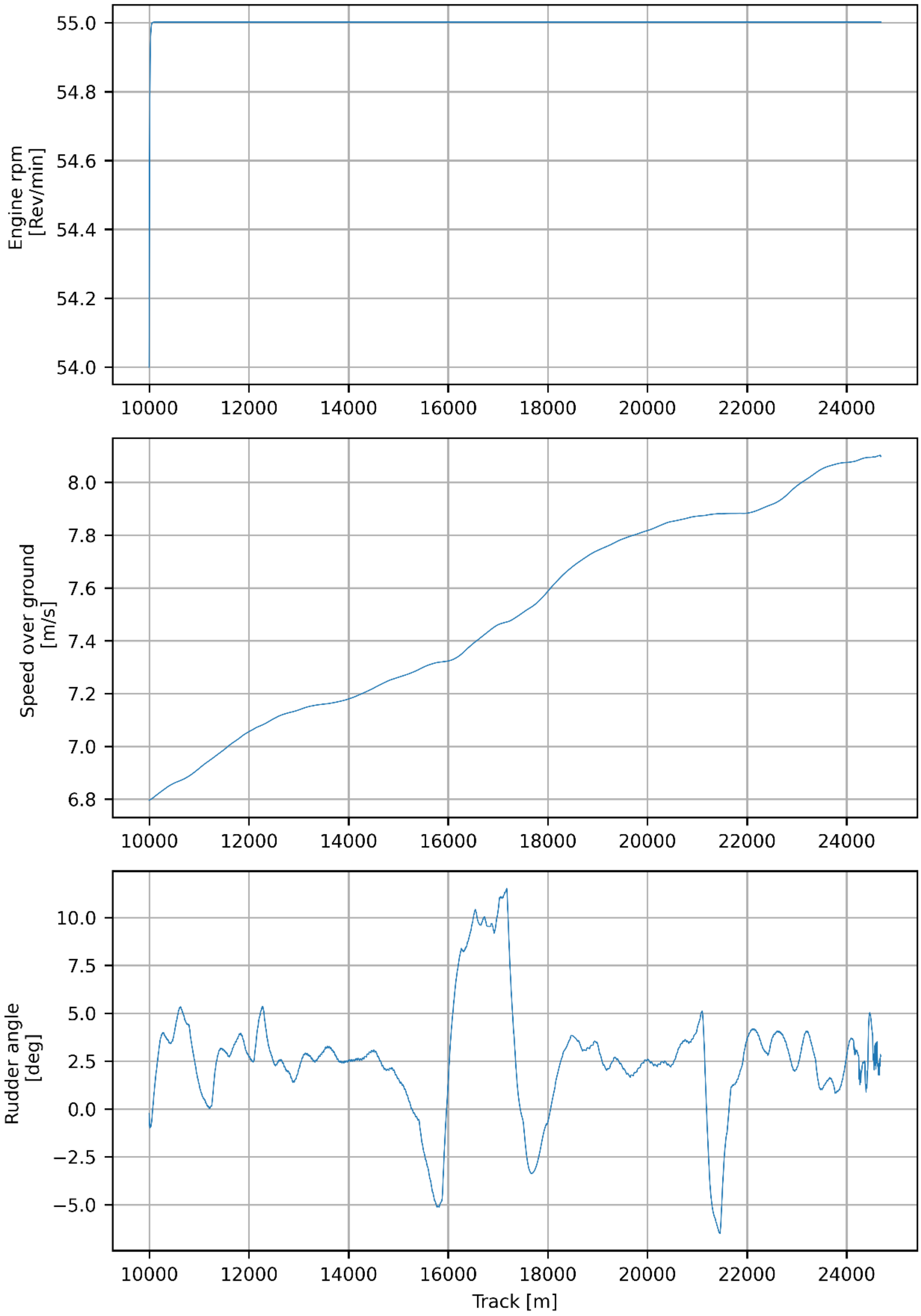
Direction: departure

Wind: from the north

Current: peak ebb

Swell: present





Engine rpm
[Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
Speed over ground
[m/s]
8.0
7.8
7.6
7.4
7.2
7.0
6.8
Rudder angle
[deg]
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
10000
12000
14000
16000
18000
20000
22000
24000
Track [m]

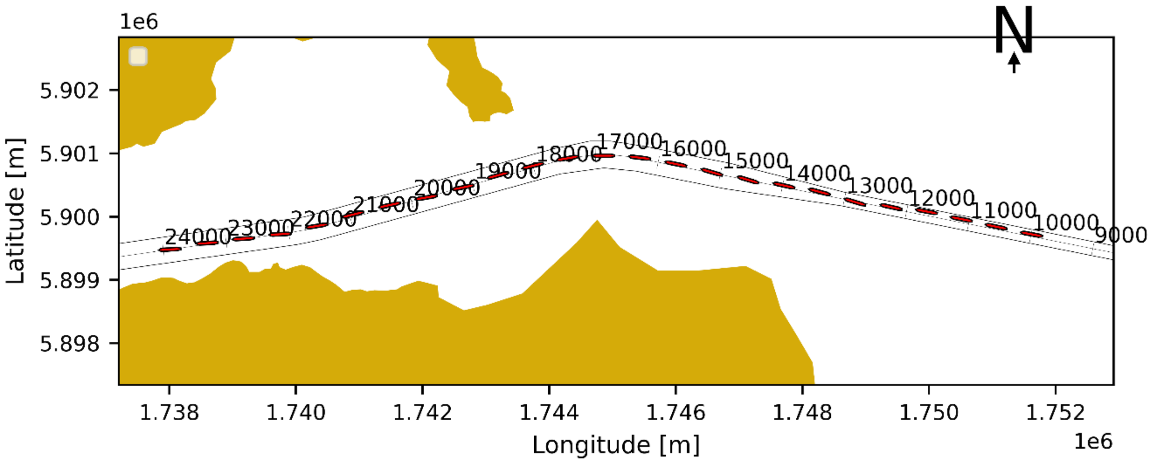
A6.3 Run “B-Dep-N-PF-Swell”

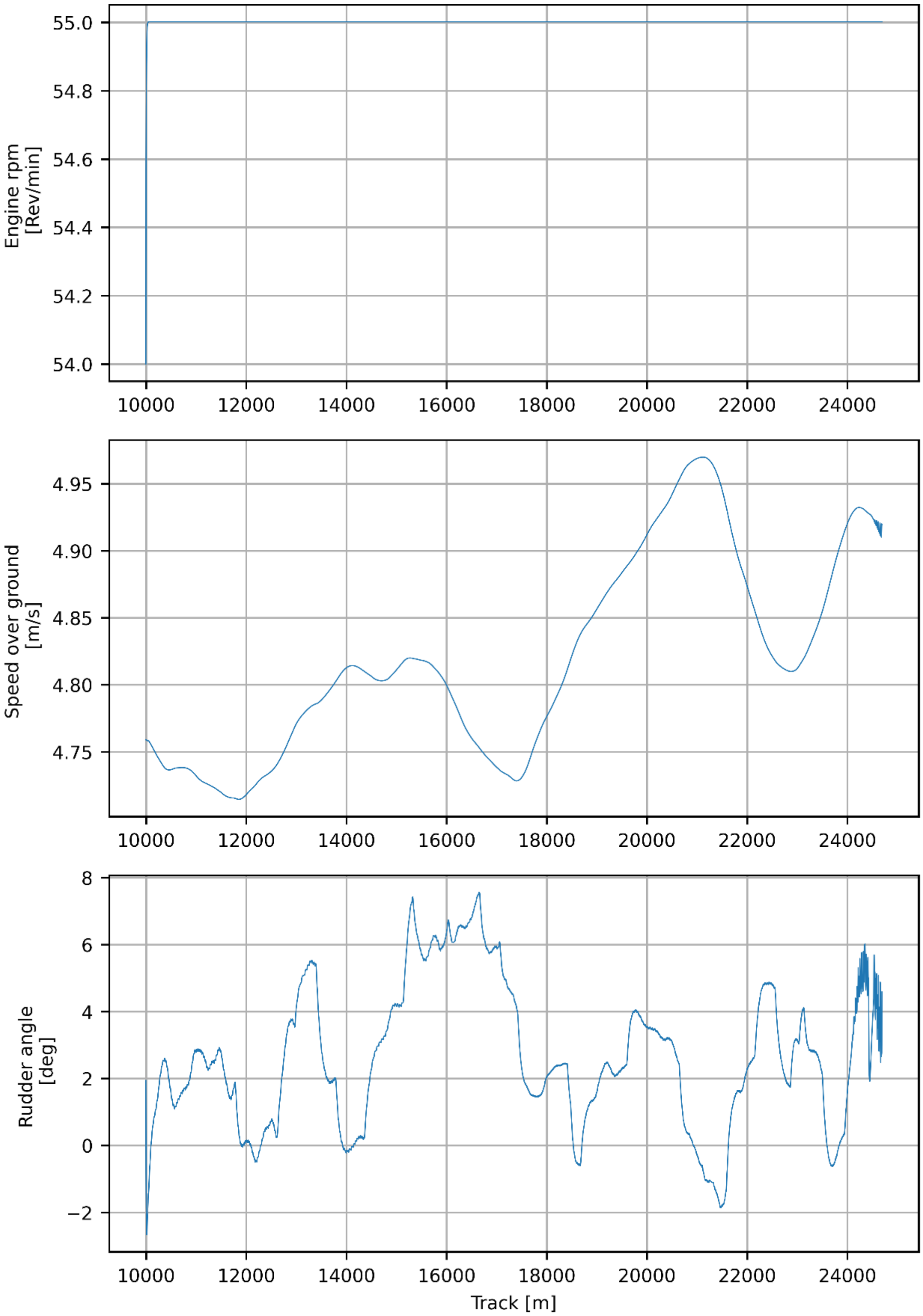
Direction: departure

Wind: from the north

Current: peak flood

Swell: present




55.0
54.8
54.6
54.4
54.2
54.0
Engine rpm
[Rev/min]
4.95
4.90
4.85
4.80
4.75
Speed over ground
[m/s]
8
6
4
2
0
−2
Rudder angle
[deg]
10000
12000
14000
16000
18000
20000
22000
24000
Track [m]

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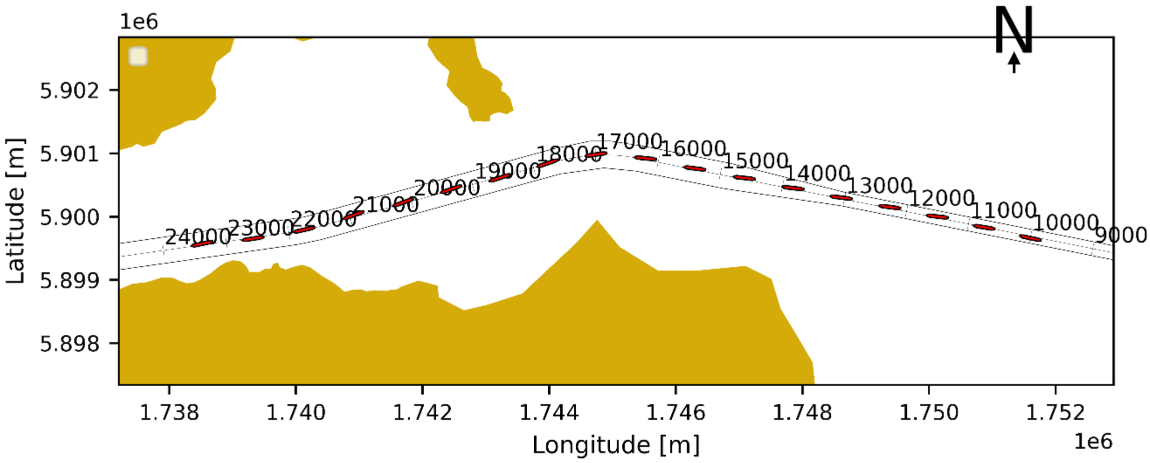
A6.4 Run "B-Dep-SW-LW-Swell"

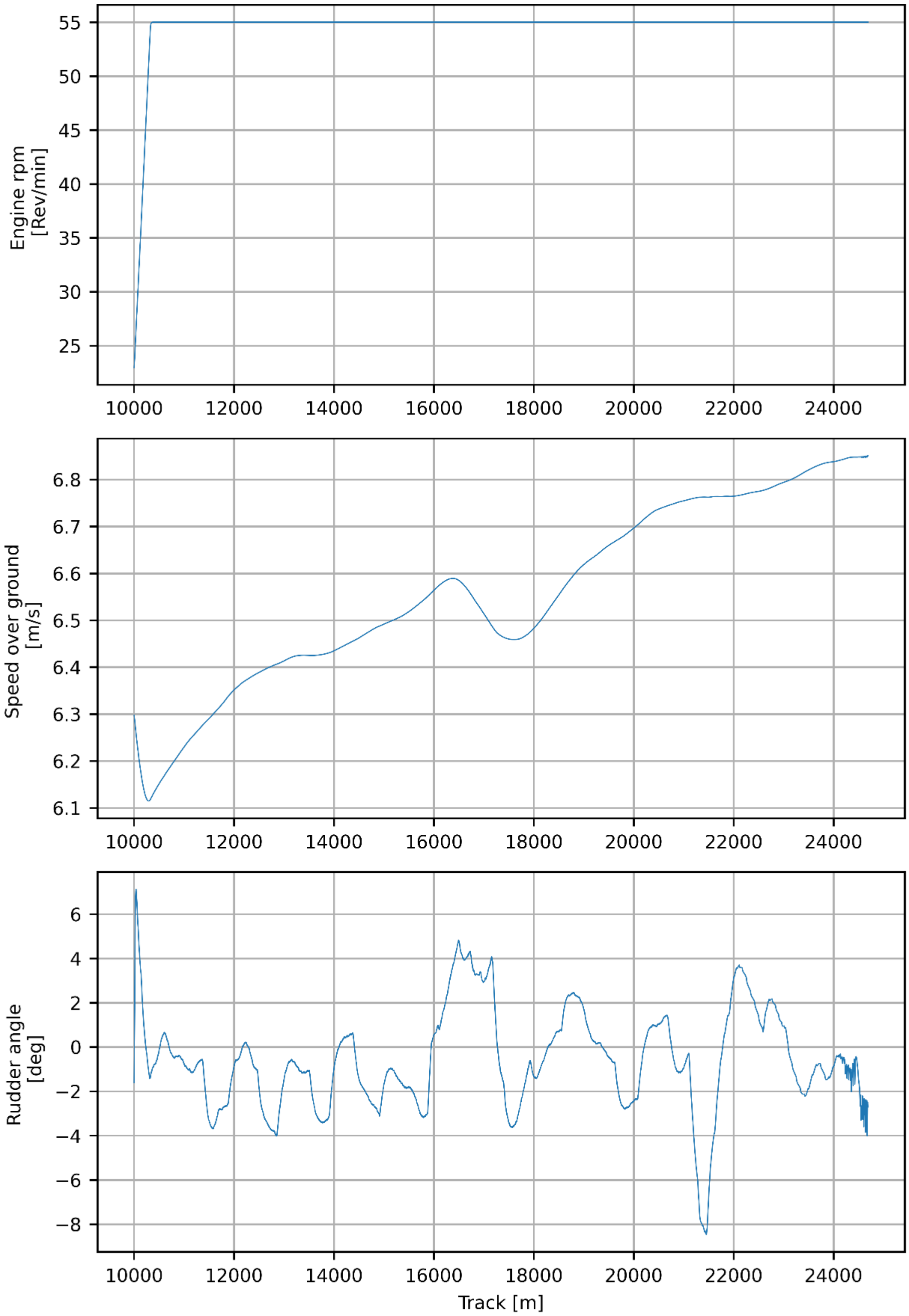
Direction: departure

Wind: from the southwest

Current: low water

Swell: present




Engine rpm
[Rev/min]
55
50
45
40
35
30
25
10000
12000
14000
16000
18000
20000
22000
24000
Speed over ground
[m/s]
6.8
6.7
6.6
6.5
6.4
6.3
6.2
6.1
Rudder angle
[deg]
6
4
2
0
−2
−4
−6
−8
Track [m]

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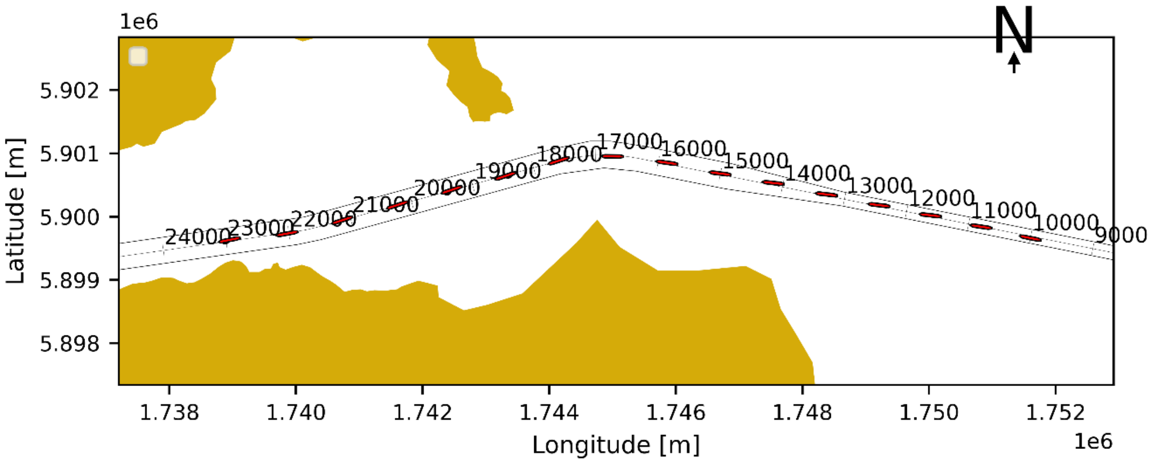
A6.5 Run “B-Dep-SW-PE-Swell”

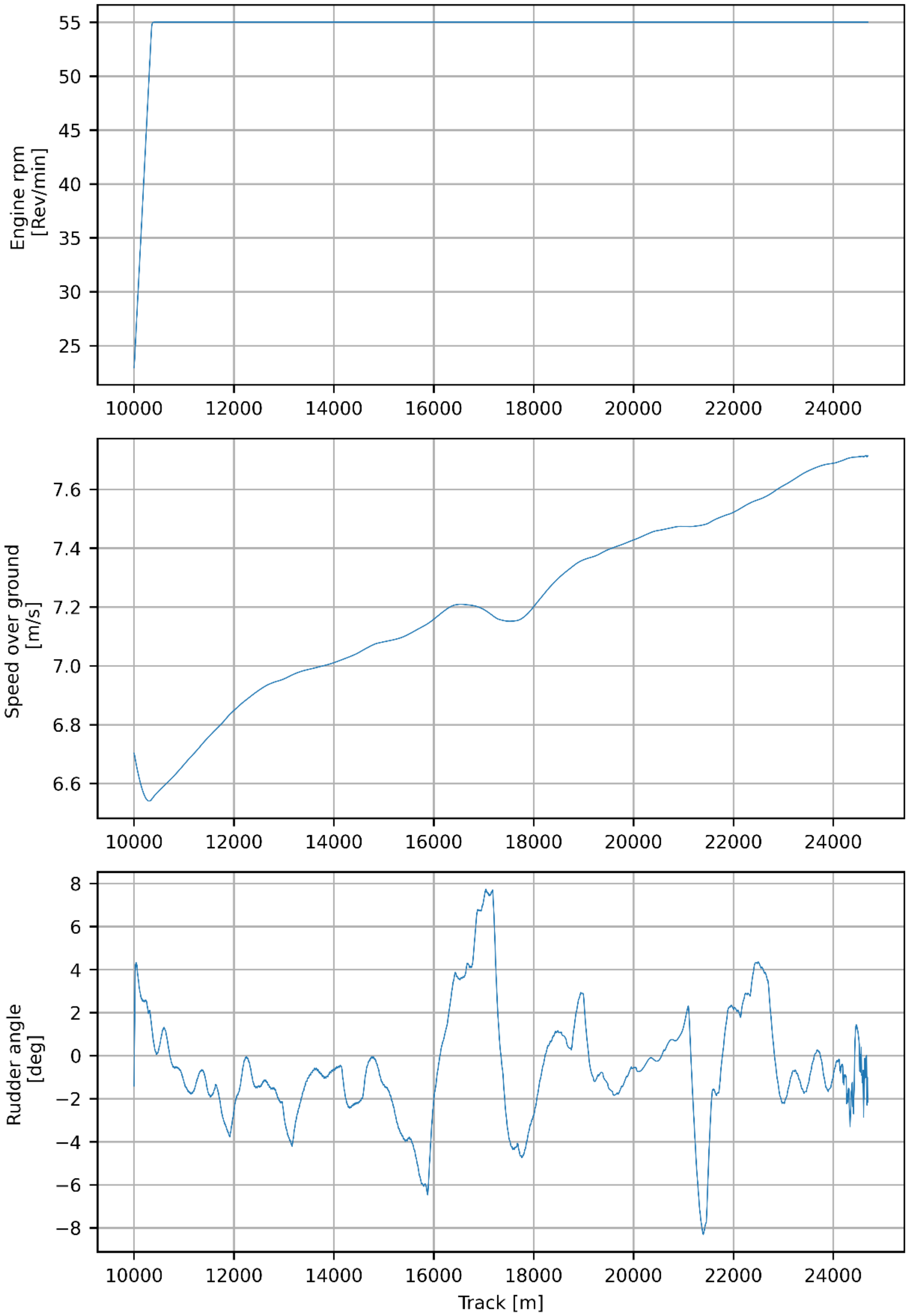
Direction: departure

Wind: from the southwest

Current: peak ebb

Swell: present




Engine rpm
[Rev/min]
Speed over ground
[m/s]
Rudder angle
[deg]
Track [m]

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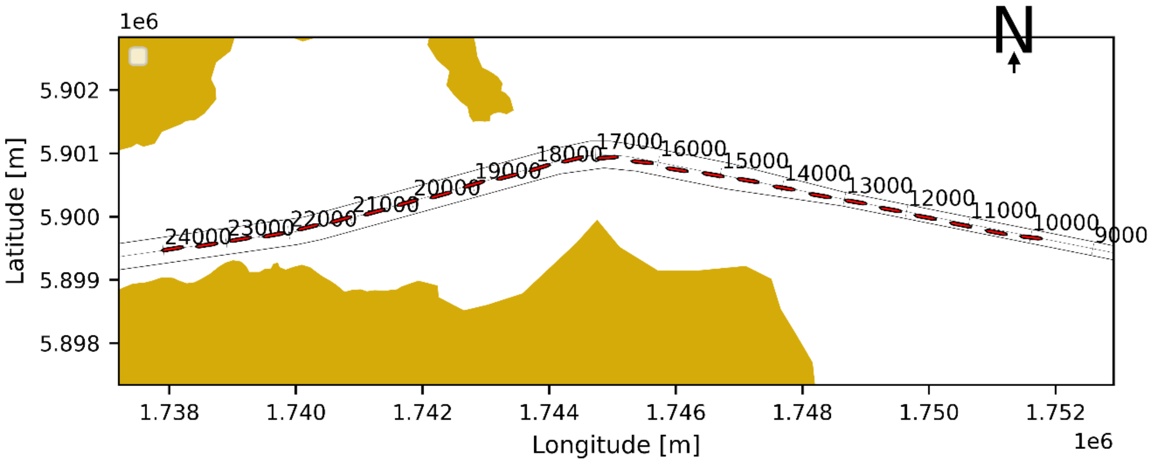
A6.6 Run “B-Dep-SW-PF-Swell”

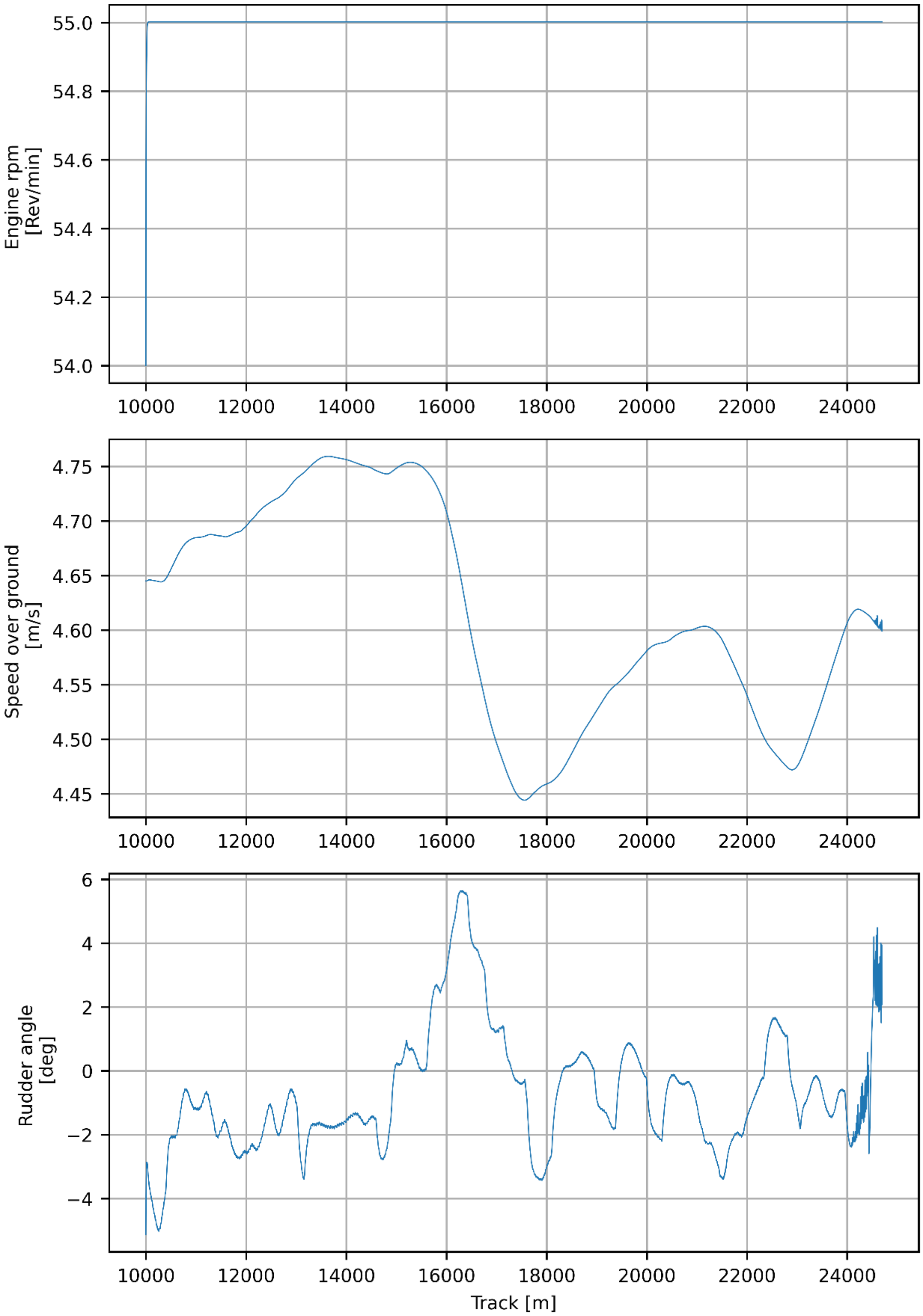
Direction: departure

Wind: from the southwest

Current: peak flood

Swell: present




55.0
54.8
54.6
54.4
54.2
54.0
Engine rpm
[Rev/min]
4.75
4.70
4.65
4.60
4.55
4.50
4.45
Speed over ground
[m/s]
6
4
2
0
−2
−4
Rudder angle
[deg]
10000
12000
14000
16000
18000
20000
22000
24000
Track [m]

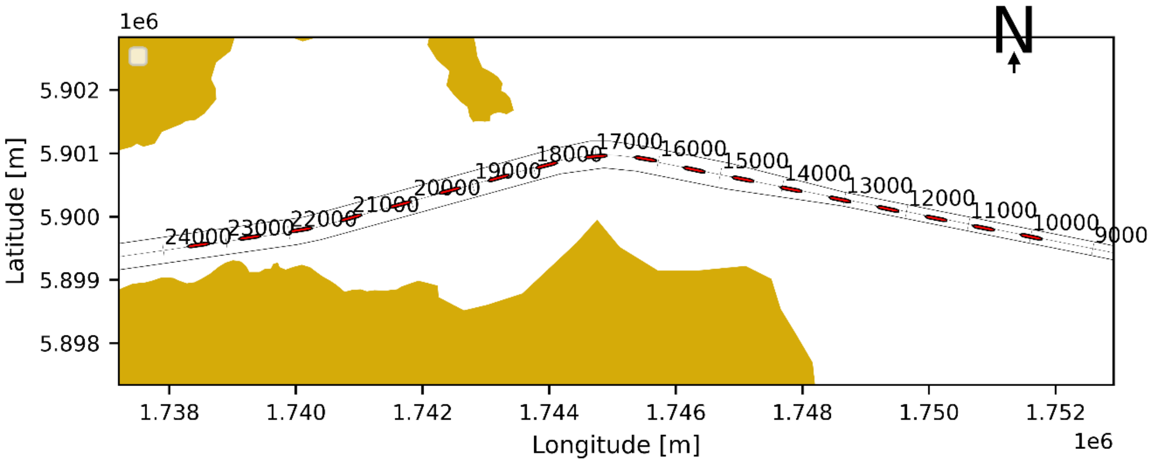
A6.7 Run "B-Dep-W-LW-Swell"

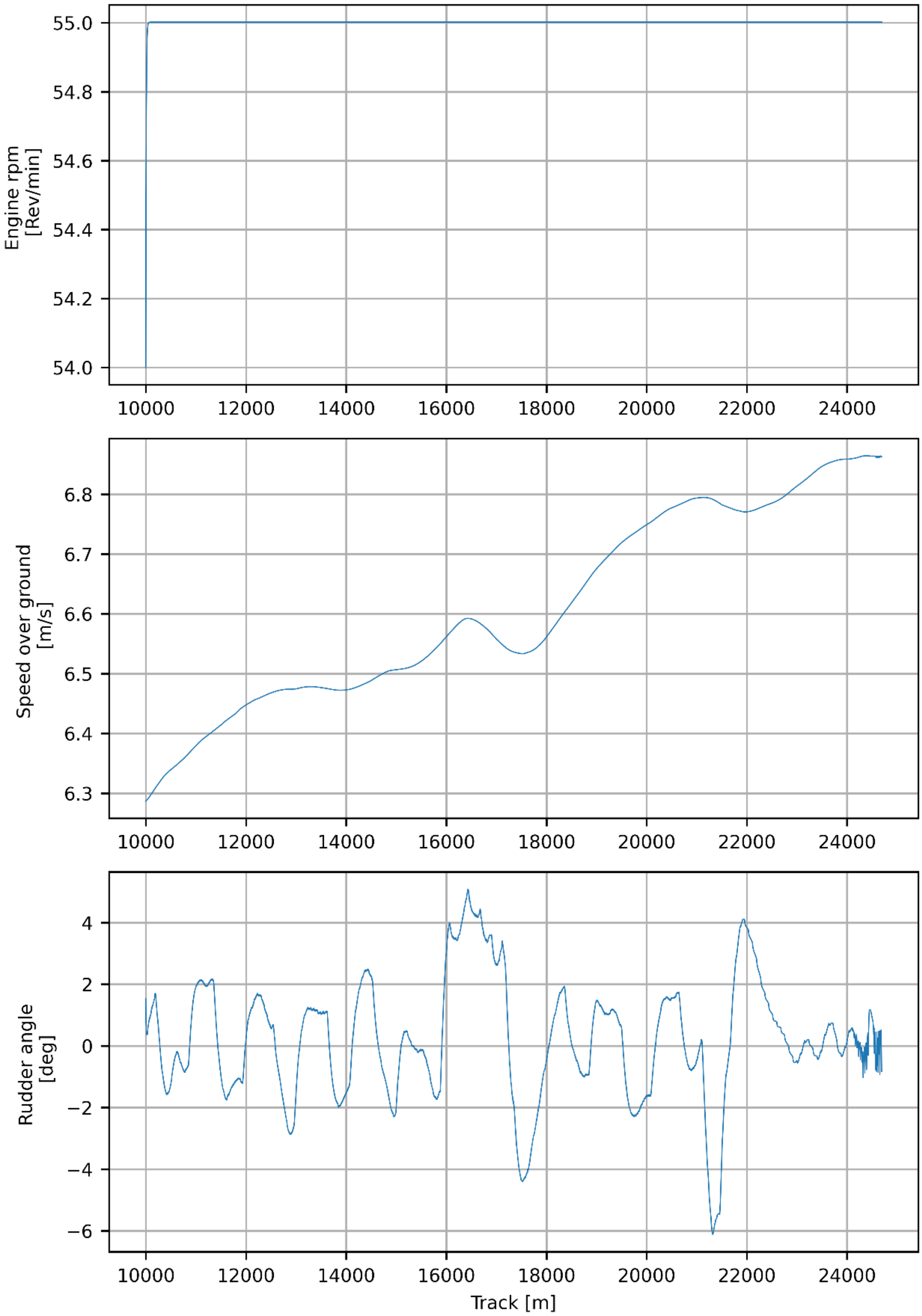
Direction: departure

Wind: from the west

Current: low water

Swell: present




55.0
54.8
54.6
54.4
54.2
54.0
Engine rpm
[Rev/min]
10000
12000
14000
16000
18000
20000
22000
24000
6.8
6.7
6.6
6.5
6.4
6.3
Speed over ground
[m/s]
4
2
0
−2
−4
−6
Rudder angle
[deg]
Track [m]

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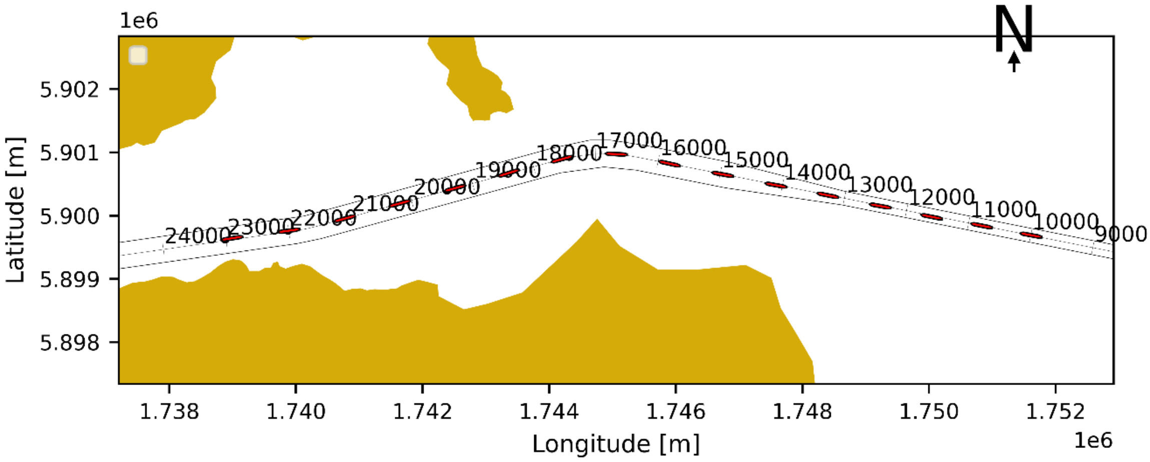
A6.8 Run "B-Dep-W-PE-Swell"

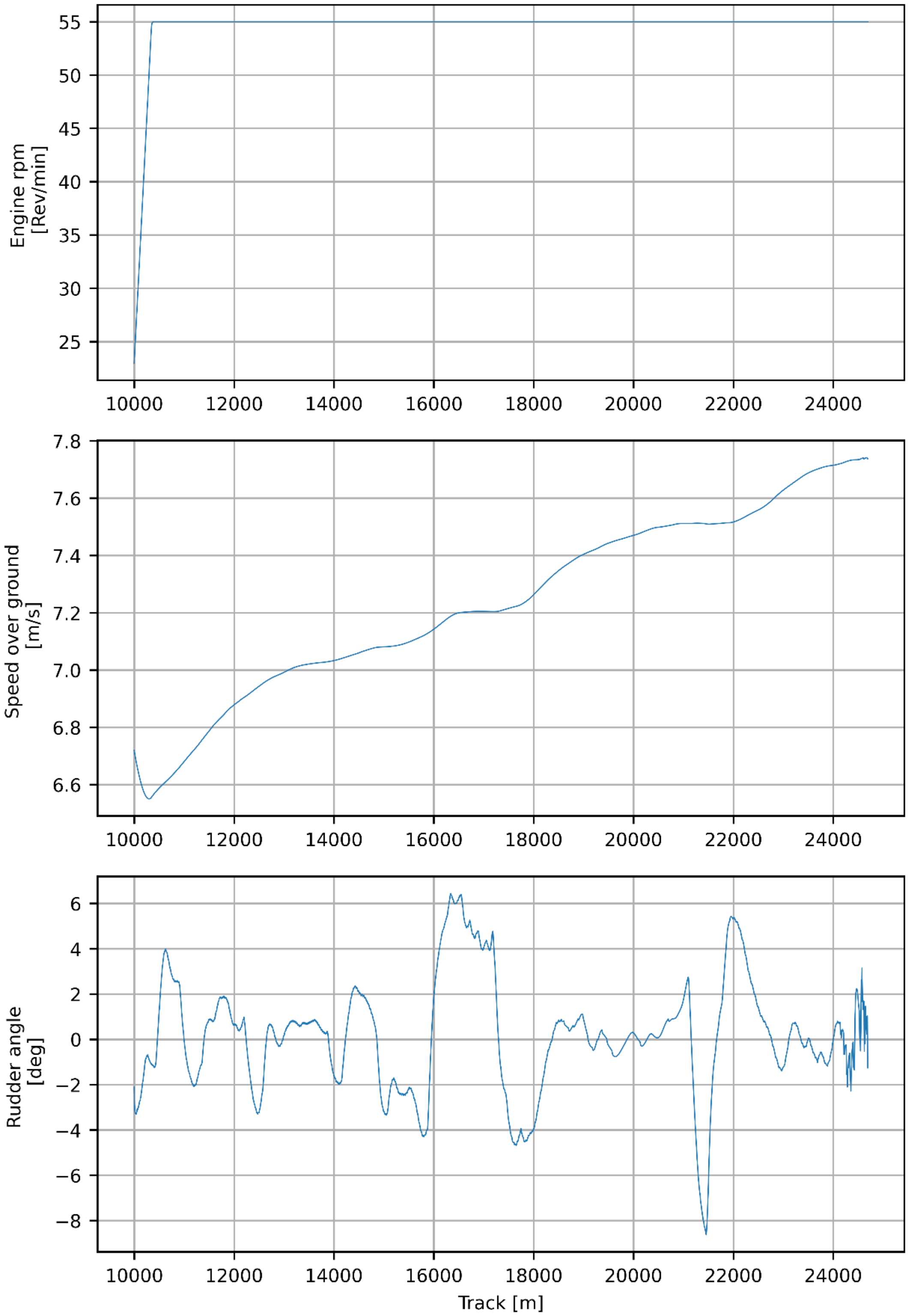
Direction: departure

Wind: from the west

Current: peak ebb

Swell: present




Engine rpm [Rev/min]
55
50
45
40
35
30
25
10000
12000
14000
16000
18000
20000
22000
24000
Speed over ground [m/s]
7.8
7.6
7.4
7.2
7.0
6.8
6.6
Rudder angle [deg]
6
4
2
0
−2
−4
−6
−8
Track [m]

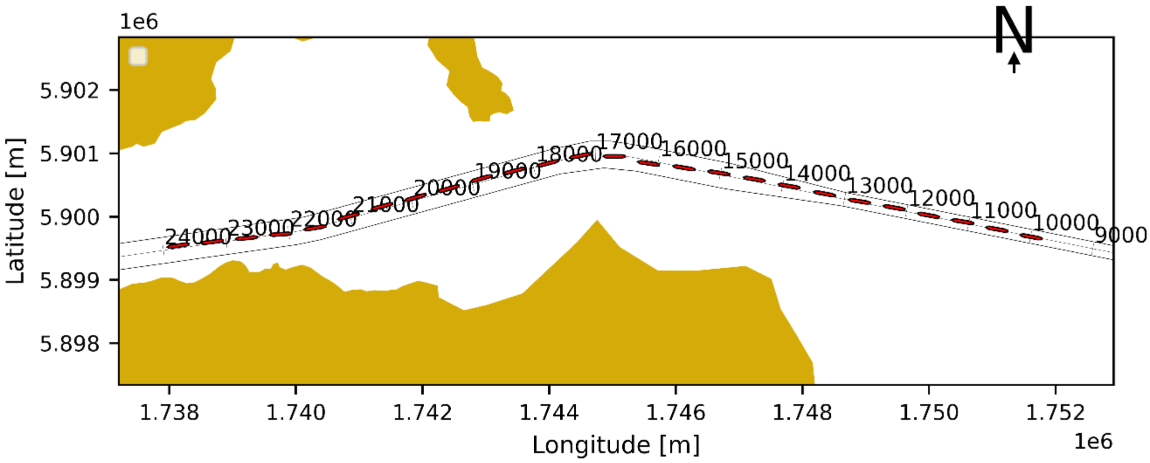
A6.9 Run “B-Dep-W-PF-Swell”

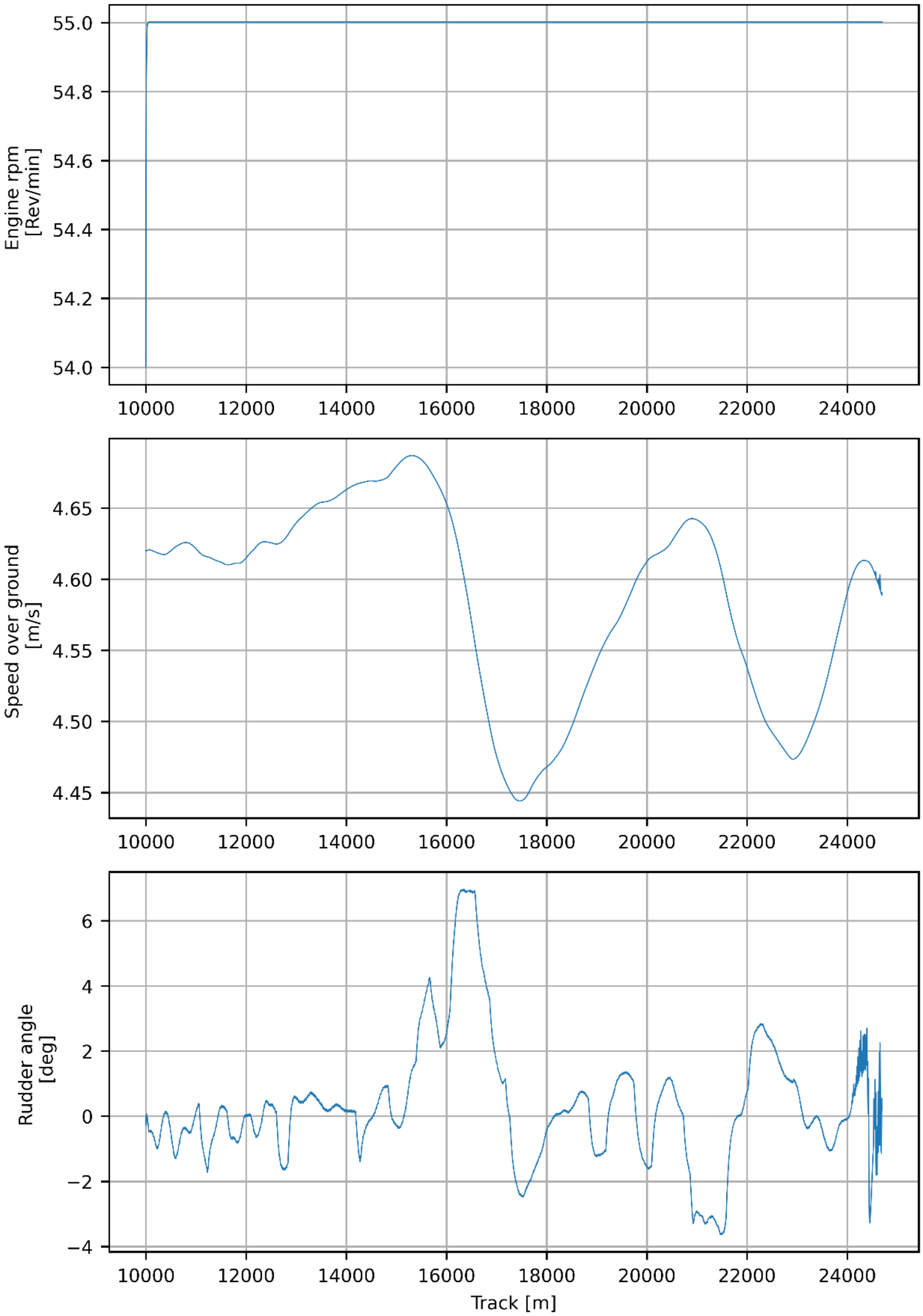
Direction: departure

Wind: from the west

Current: peak flood

Swell: present




55.0
54.8
54.6
54.4
54.2
54.0
Engine rpm
[Rev/min]
4.65
4.60
4.55
4.50
4.45
Speed over ground
[m/s]
6
4
2
0
−2
−4
Rudder angle
[deg]
10000
12000
14000
16000
18000
20000
22000
24000
Track [m]

Royal HaskoningDHV

A7 Departure Simulations in Section A – Main Runs

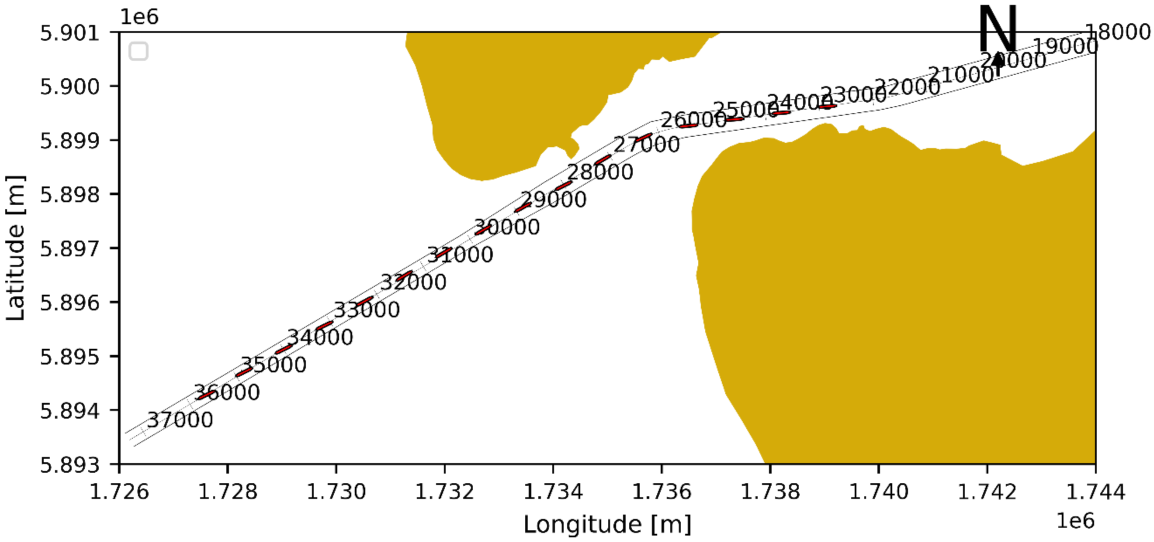
A7.1 Run "A-Dep-N-LW-Swell"

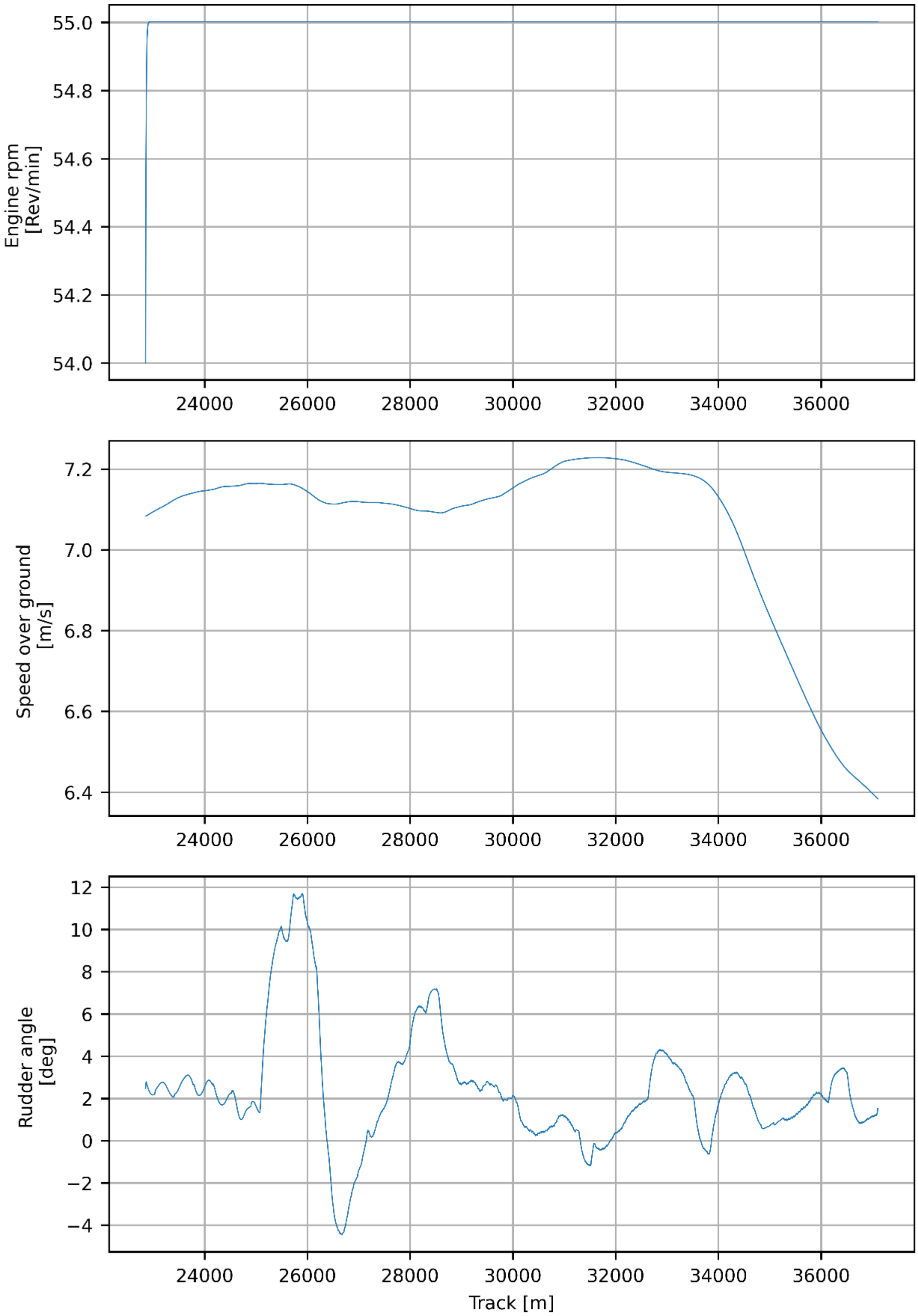
Direction: departure

Wind: from the north

Current: low water

Swell: present




Engine rpm
[Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
24000
26000
28000
30000
32000
34000
36000
Speed over ground
[m/s]
7.2
7.0
6.8
6.6
6.4
Rudder angle
[deg]
12
10
8
6
4
2
0
−2
−4
Track [m]

Royal HaskoningDHV

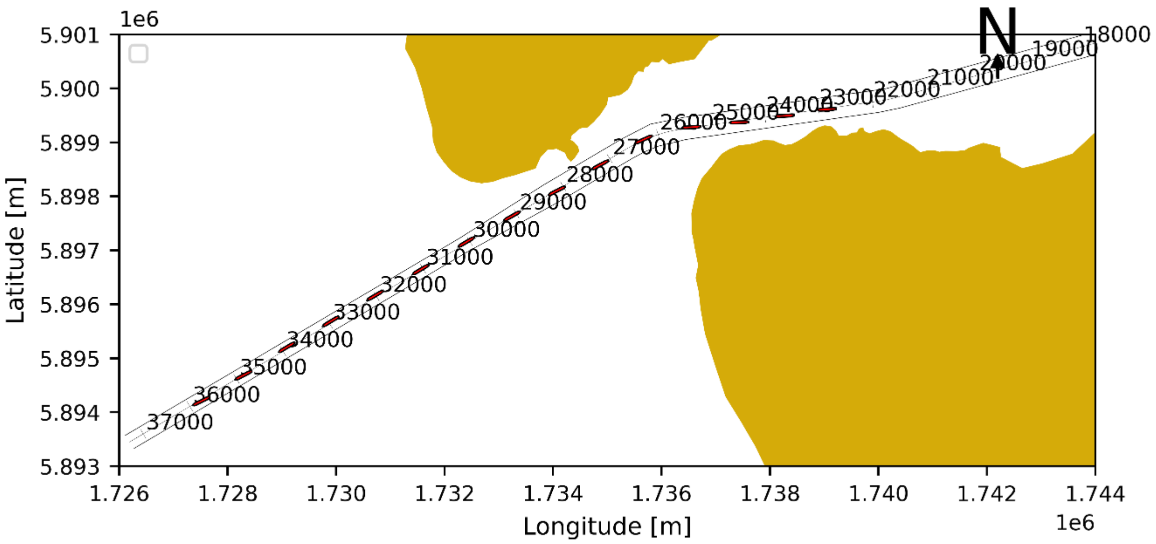
A7.2 Run "A-Dep-N-PE-Swell"

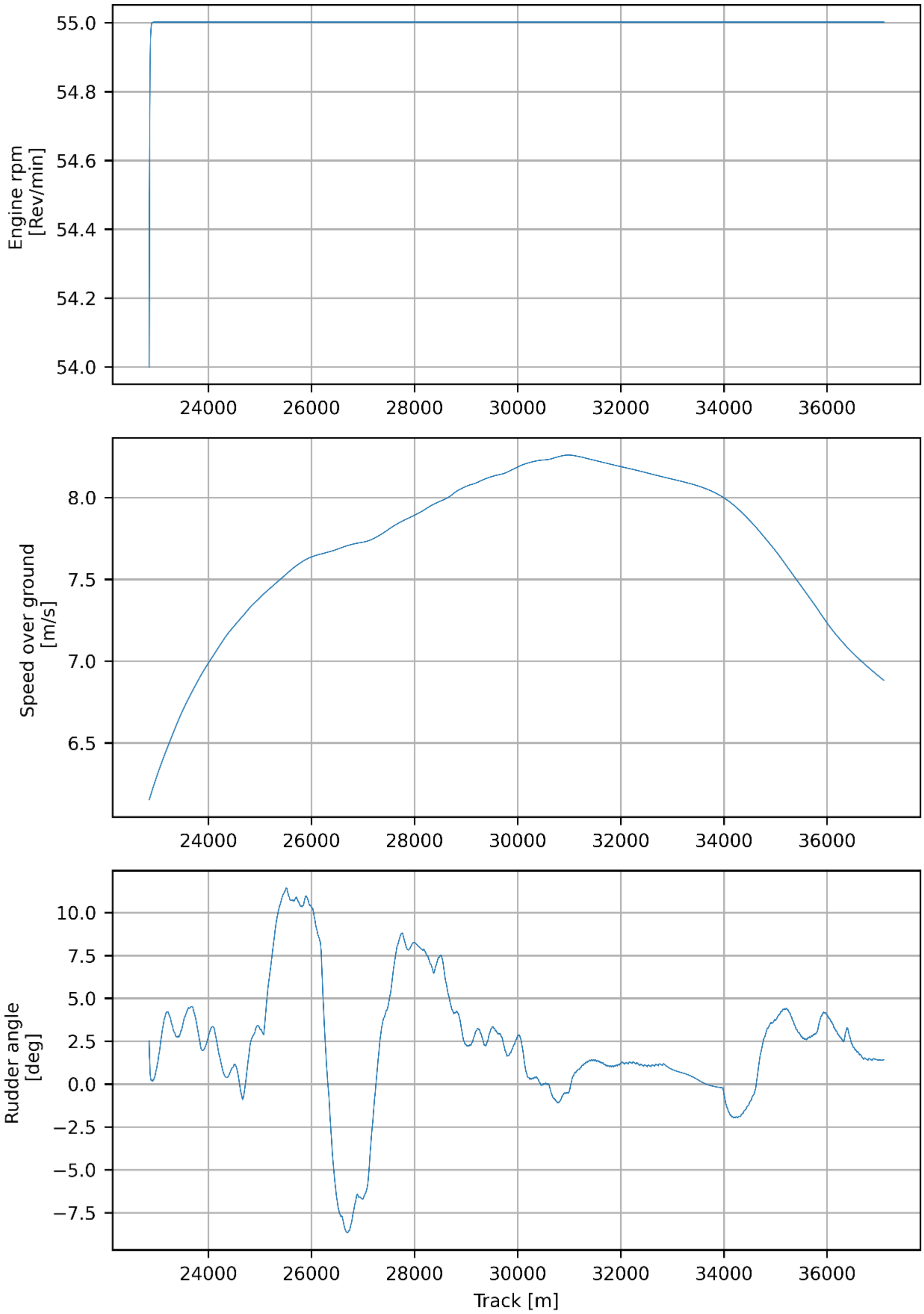
Direction: departure

Wind: from the north

Current: peak ebb

Swell: present




55.0
54.8
54.6
54.4
54.2
54.0
Engine rpm
[Rev/min]
24000
26000
28000
30000
32000
34000
36000
8.0
7.5
7.0
6.5
Speed over ground
[m/s]
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
Rudder angle
[deg]
Track [m]

Royal HaskoningDHV

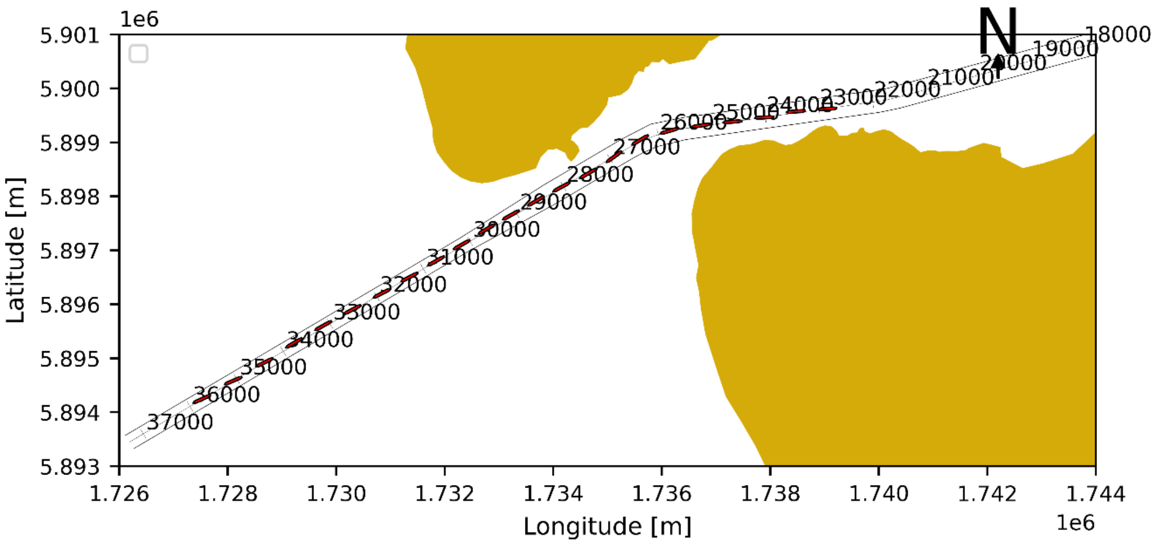
A7.3 Run “A-Dep-N-PF-Swell”

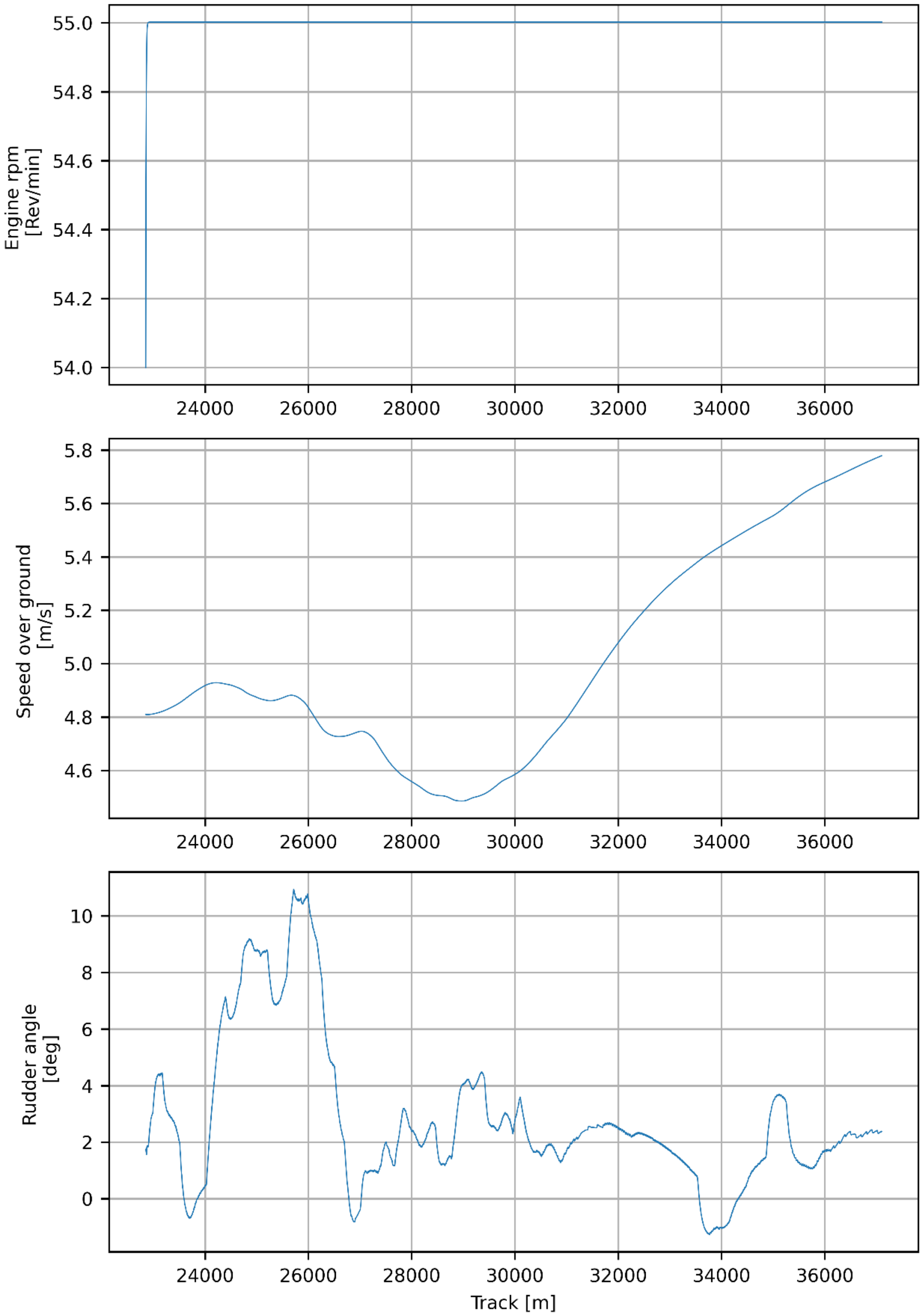
Direction: departure

Wind: from the north

Current: peak flood

Swell: present




Engine rpm
[Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
24000
26000
28000
30000
32000
34000
36000
Speed over ground
[m/s]
5.8
5.6
5.4
5.2
5.0
4.8
4.6
24000
26000
28000
30000
32000
34000
36000
Rudder angle
[deg]
10
8
6
4
2
0
24000
26000
28000
30000
32000
34000
36000
Track [m]

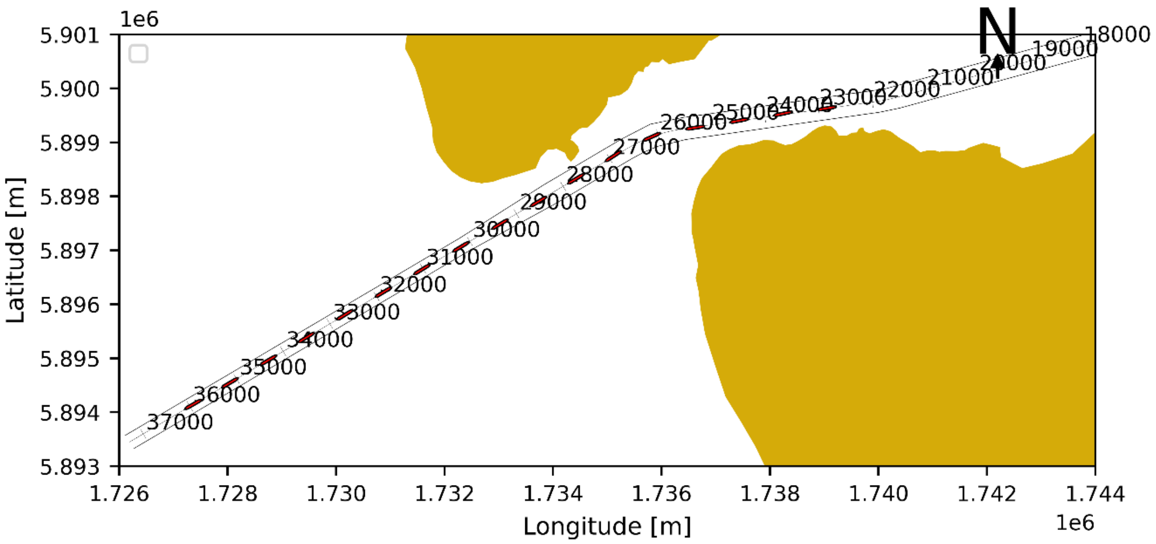
A7.4 Run "A-Dep-SW-LW-Swell"

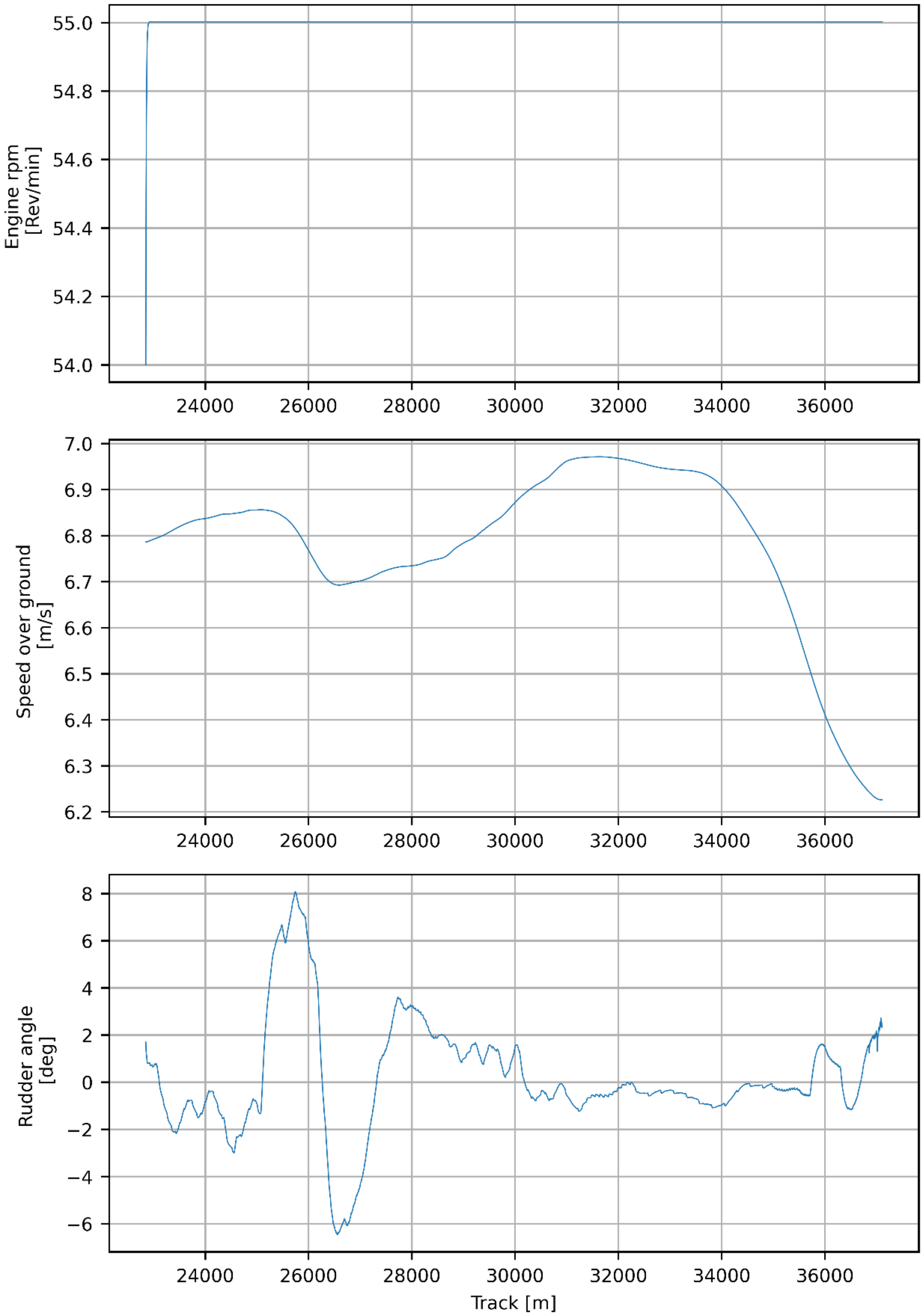
Direction: departure

Wind: from the southwest

Current: low water

Swell: present





Engine rpm [Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
Speed over ground [m/s]
7.0
6.9
6.8
6.7
6.6
6.5
6.4
6.3
6.2
Rudder angle [deg]
8
6
4
2
0
−2
−4
−6
24000
26000
28000
30000
32000
34000
36000
Track [m]

Royal HaskoningDHV

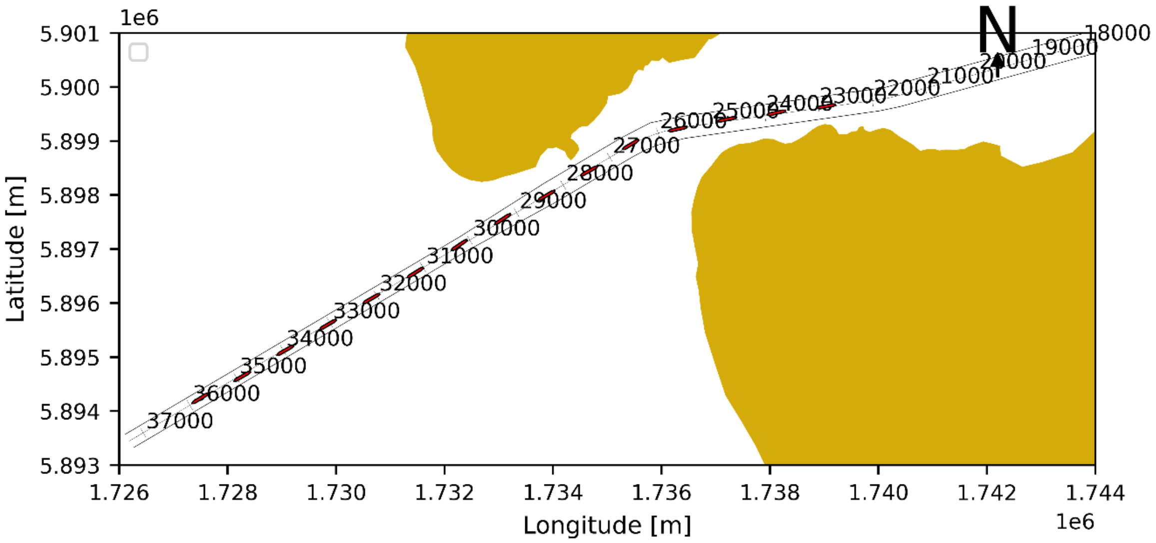
A7.5 Run "A-Dep-SW-PE-Swell"

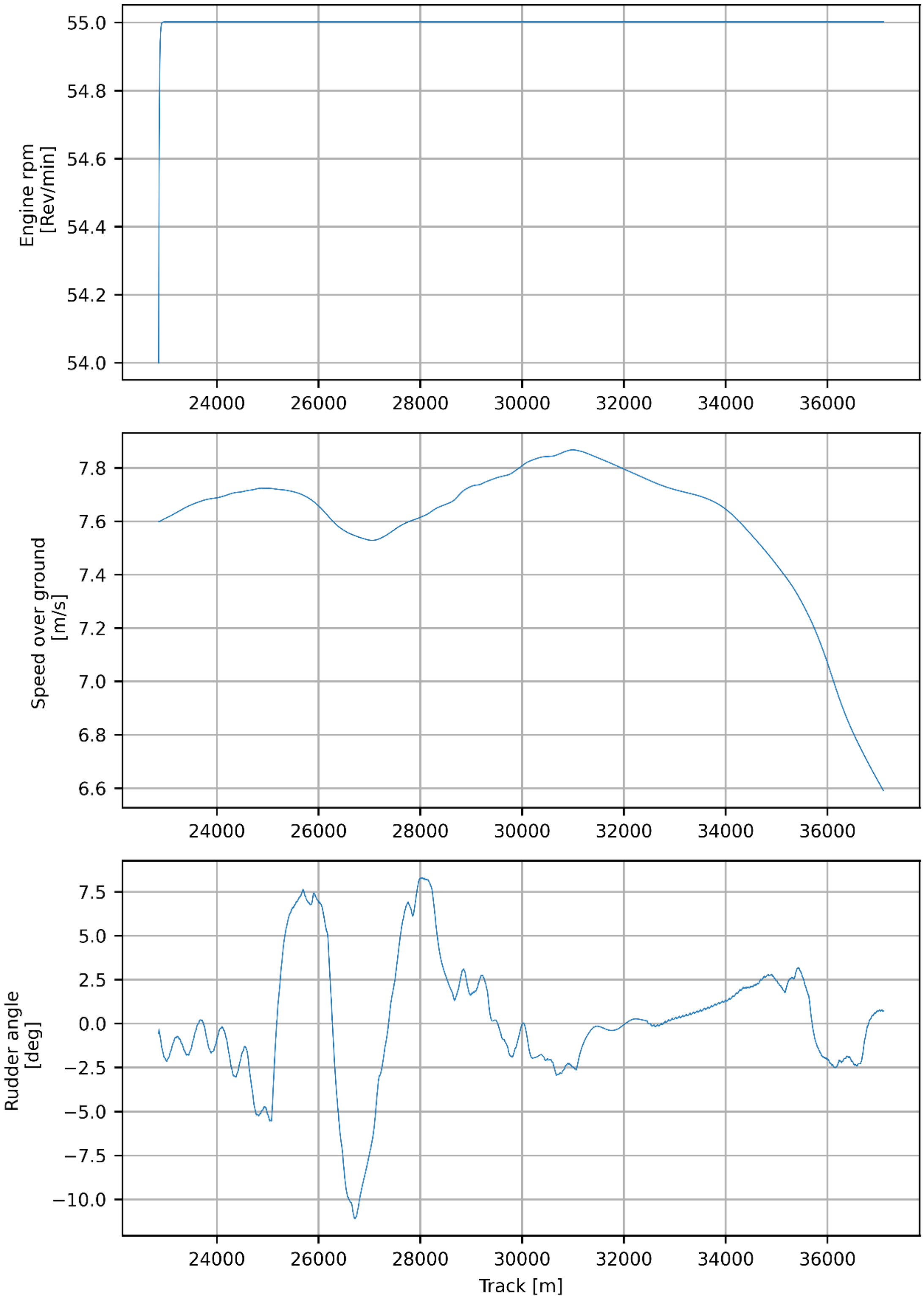
Direction: departure

Wind: from the southwest

Current: peak ebb

Swell: present





55.0
54.8
54.6
54.4
54.2
54.0
Engine rpm [Rev/min]
24000
26000
28000
30000
32000
34000
36000
7.8
7.6
7.4
7.2
7.0
6.8
6.6
Speed over ground [m/s]
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
Rudder angle [deg]
Track [m]

Royal HaskoningDHV

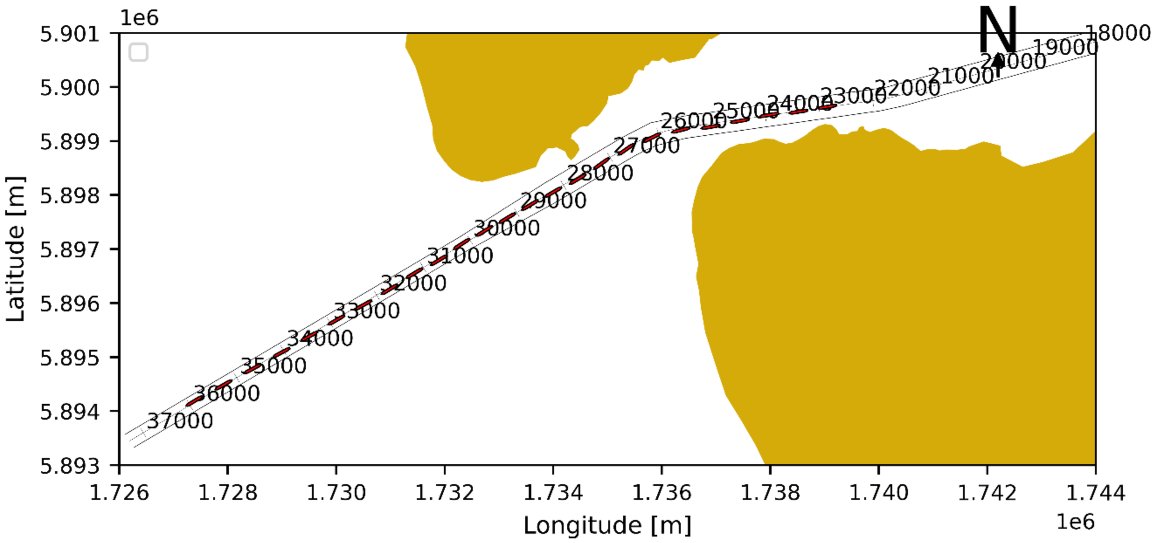
A7.6 Run "A-Dep-SW-PF-Swell"

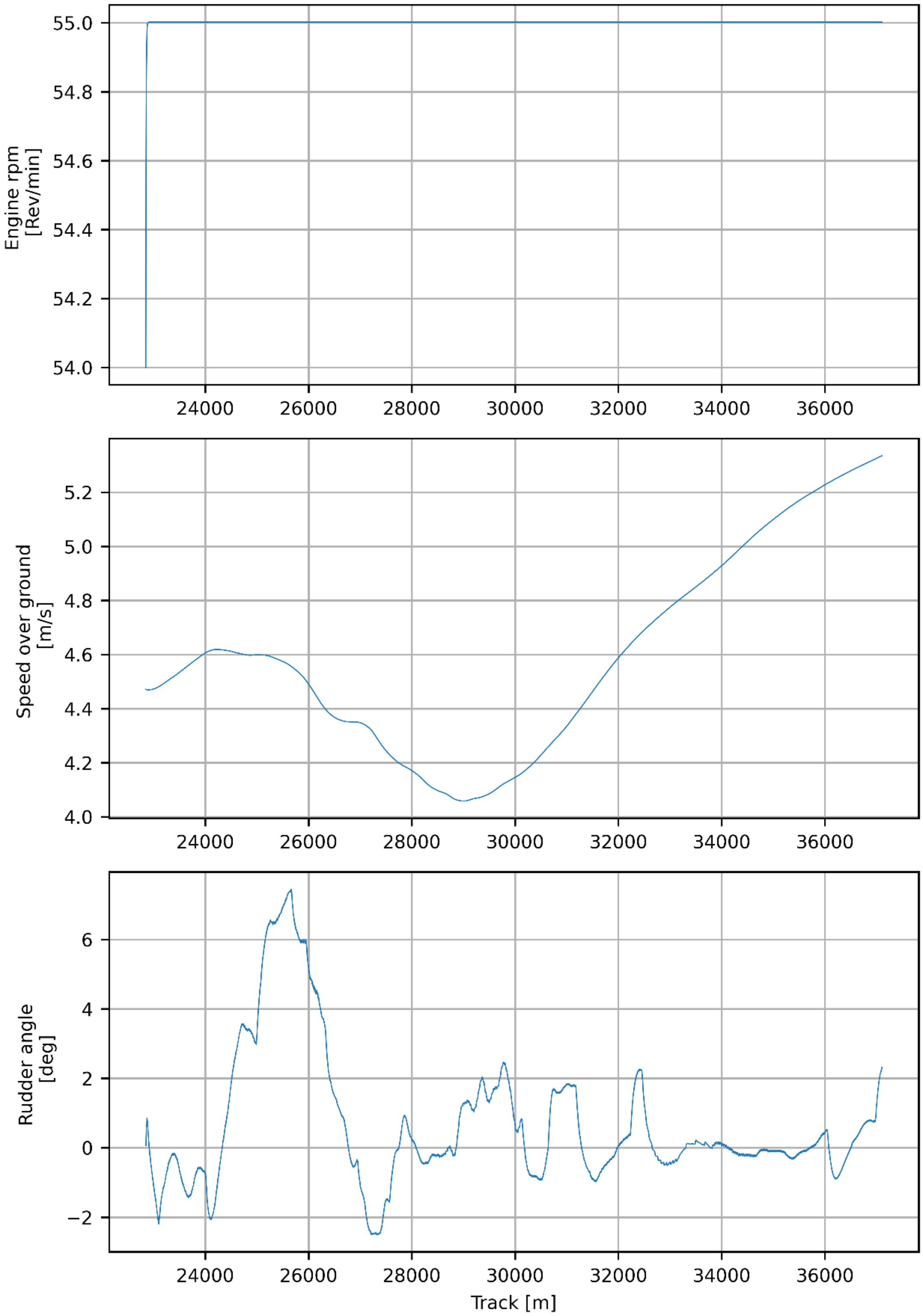
Direction: departure

Wind: from the southwest

Current: peak flood

Swell: present





Engine rpm
[Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
24000
26000
28000
30000
32000
34000
36000
Speed over ground
[m/s]
5.2
5.0
4.8
4.6
4.4
4.2
4.0
Rudder angle
[deg]
6
4
2
0
−2
Track [m]

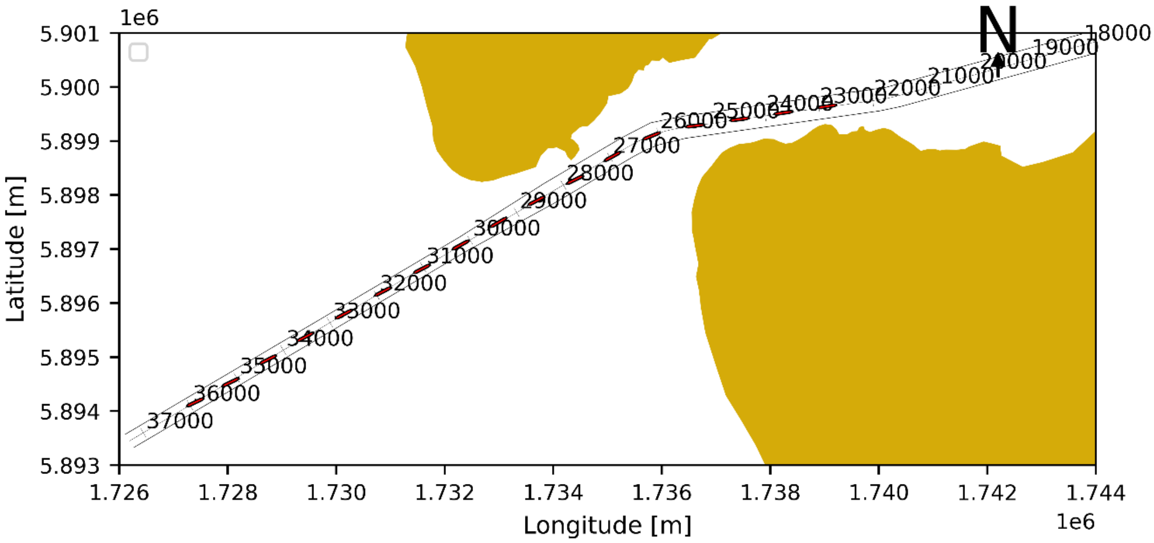
A7.7 Run “A-Dep-W-LW-Swell”

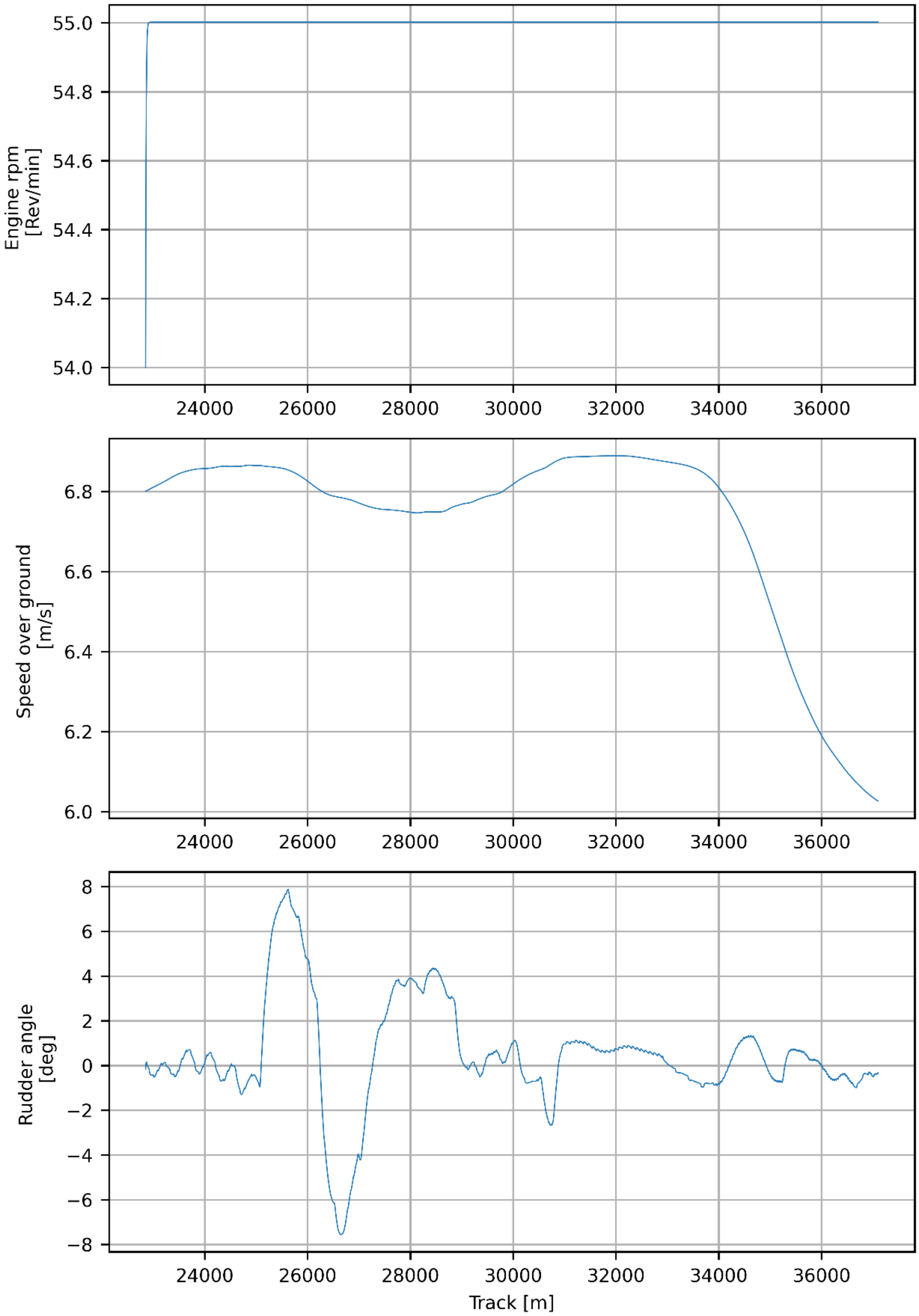
Direction: departure

Wind: from the west

Current: low water

Swell: present




Engine rpm
[Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
Speed over ground
[m/s]
6.8
6.6
6.4
6.2
6.0
Rudder angle
[deg]
8
6
4
2
0
−2
−4
−6
−8
24000
26000
28000
30000
32000
34000
36000
Track [m]

Royal HaskoningDHV

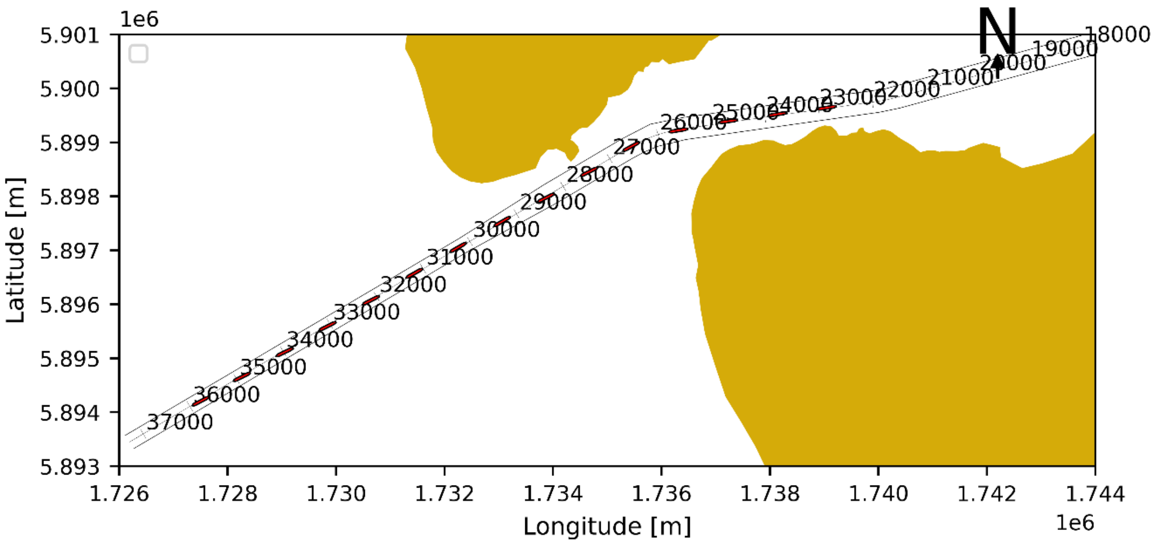
A7.8 Run "A-Dep-W-PE-Swell"

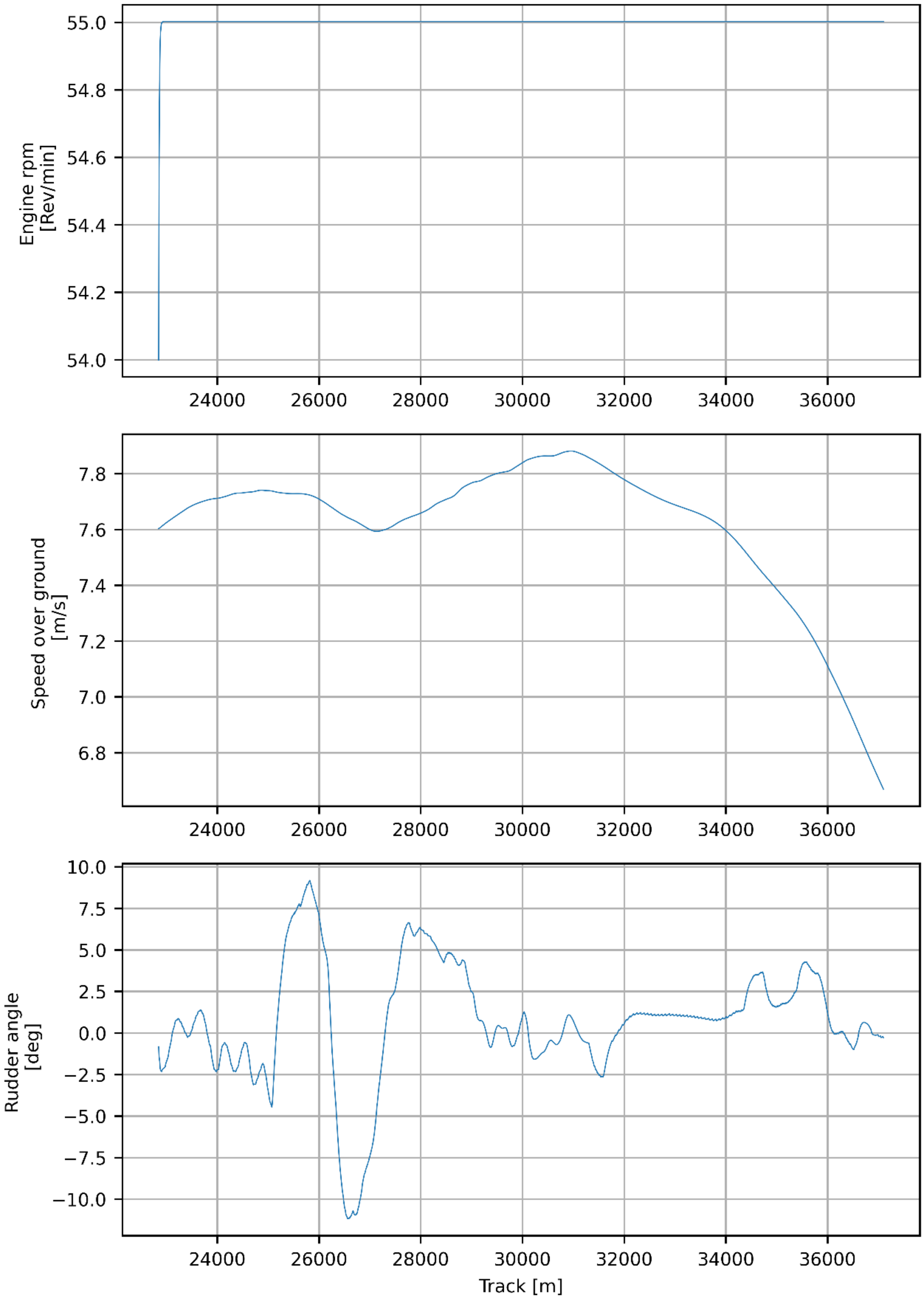
Direction: departure

Wind: from the west

Current: peak ebb

Swell: present




Engine rpm
[Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
Speed over ground
[m/s]
7.8
7.6
7.4
7.2
7.0
6.8
Rudder angle
[deg]
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
24000
26000
28000
30000
32000
34000
36000
Track [m]

Royal HaskoningDHV

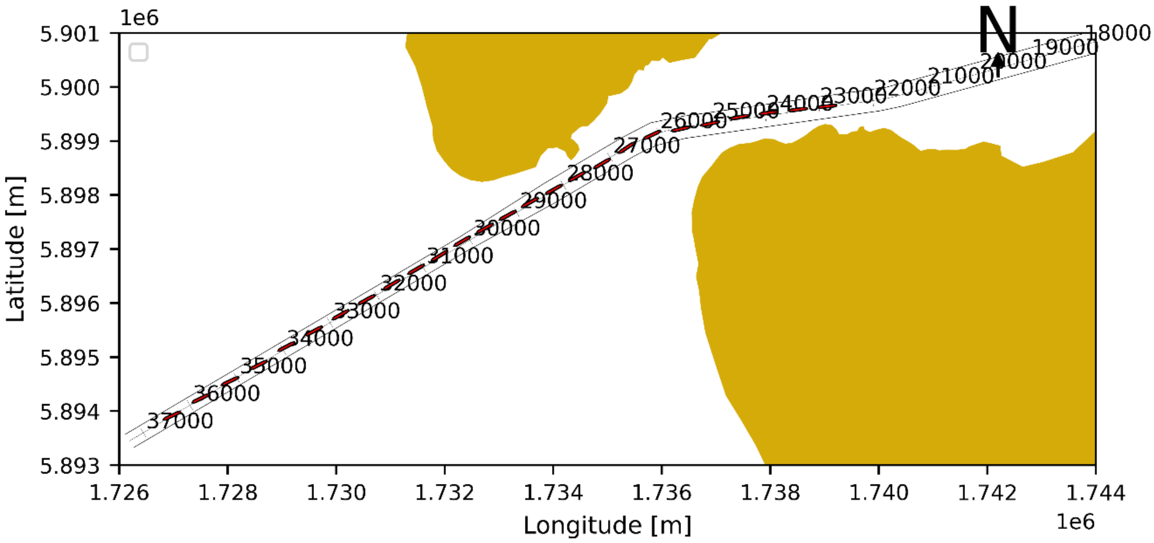
A7.9 Run "A-Dep-W-PF-Swell"

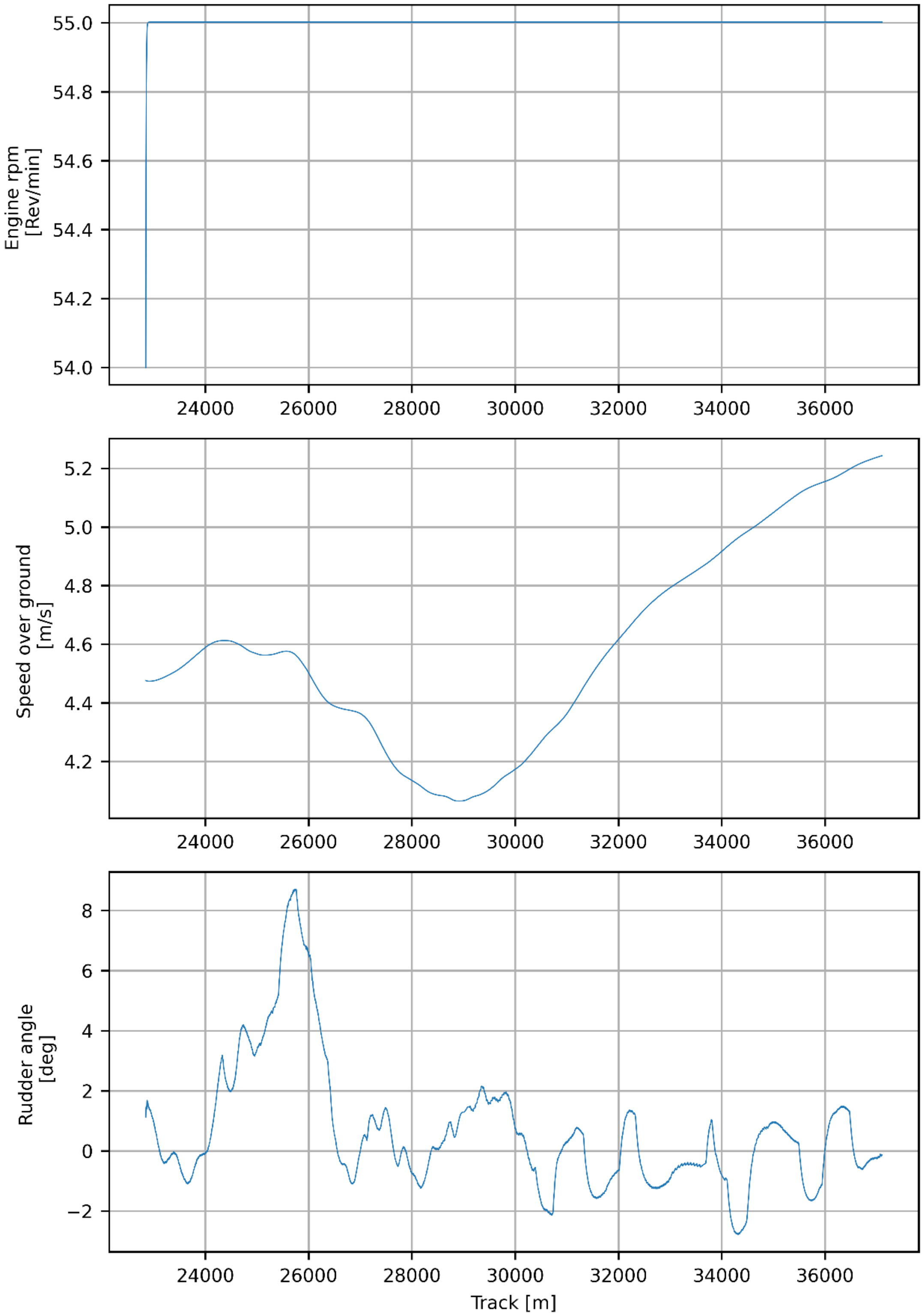
Direction: departure

Wind: from the west

Current: peak flood

Swell: present




Engine rpm
[Rev/min]
55.0
54.8
54.6
54.4
54.2
54.0
24000
26000
28000
30000
32000
34000
36000
Speed over ground
[m/s]
5.2
5.0
4.8
4.6
4.4
4.2
Rudder angle
[deg]
8
6
4
2
0
−2
Track [m]

A8 Arrival Simulations in Section A – Additional Runs (AR)

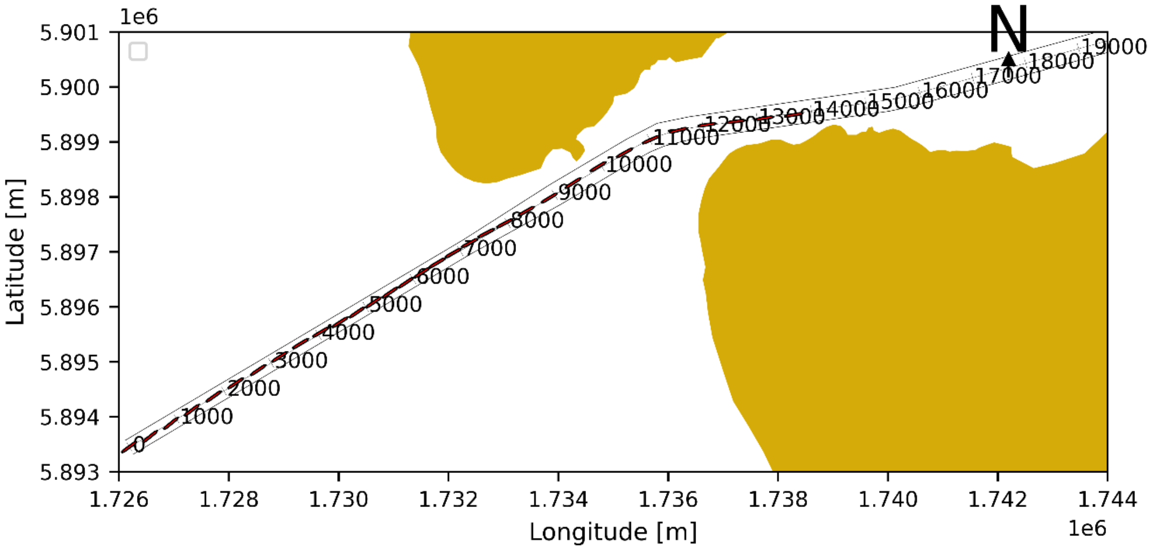
A8.1 Run "AR-A-Arr-W-LW-Swell"

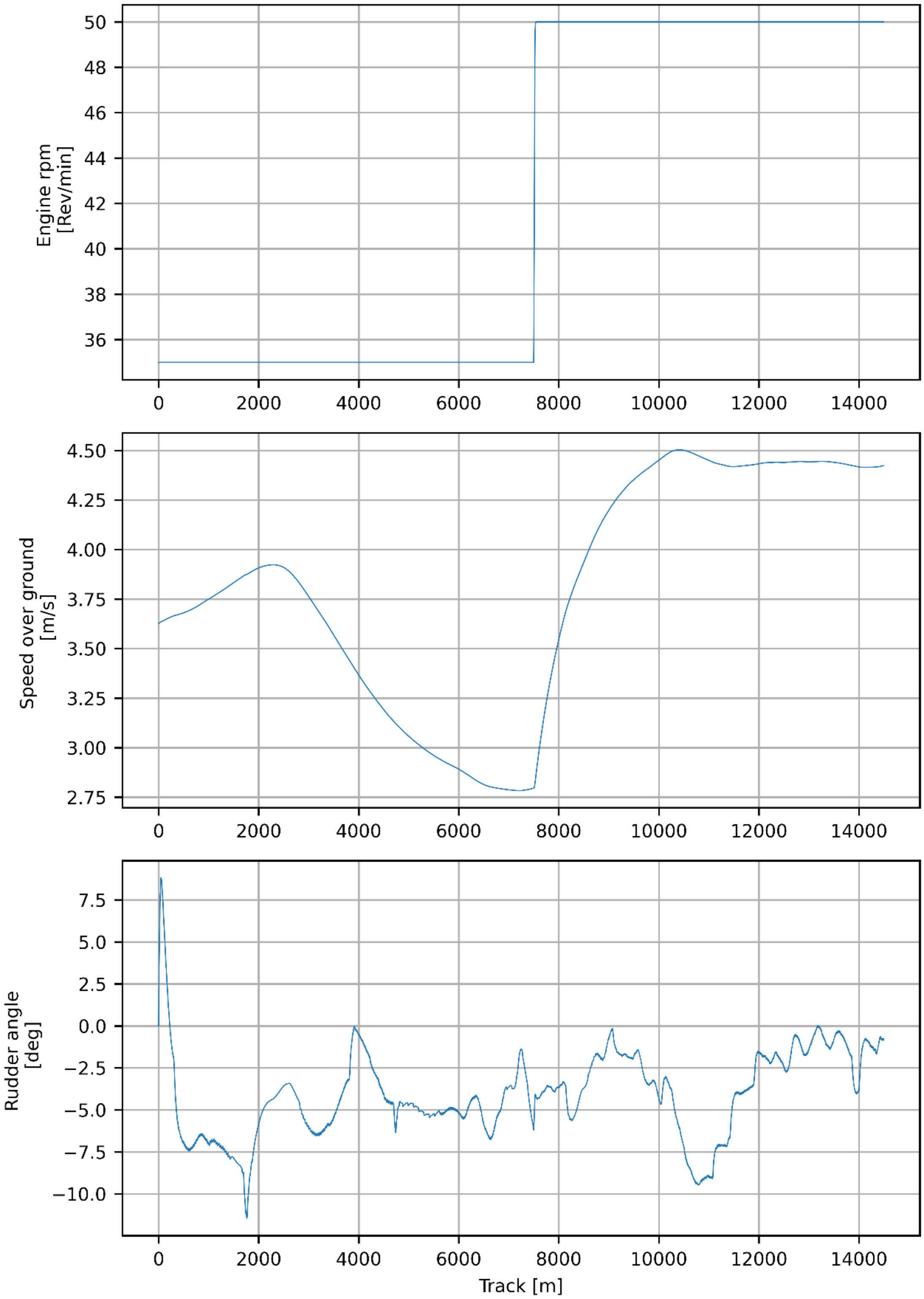
Direction: arrival

Wind: from the west

Current: low water

Swell: present





Engine rpm [Rev/min]
50
48
46
44
42
40
38
36
Speed over ground [m/s]
4.50
4.25
4.00
3.75
3.50
3.25
3.00
2.75
Rudder angle [deg]
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
0
2000
4000
6000
8000
10000
12000
14000
Track [m]

Royal HaskoningDHV

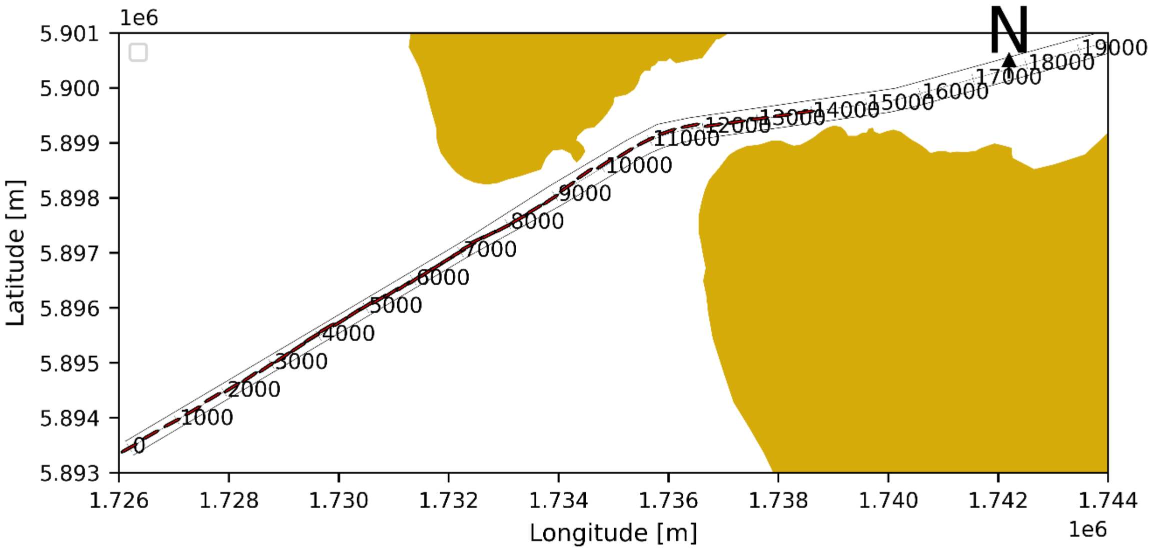
A8.2 Run "AR-A-Arr-W-PE-Swell"

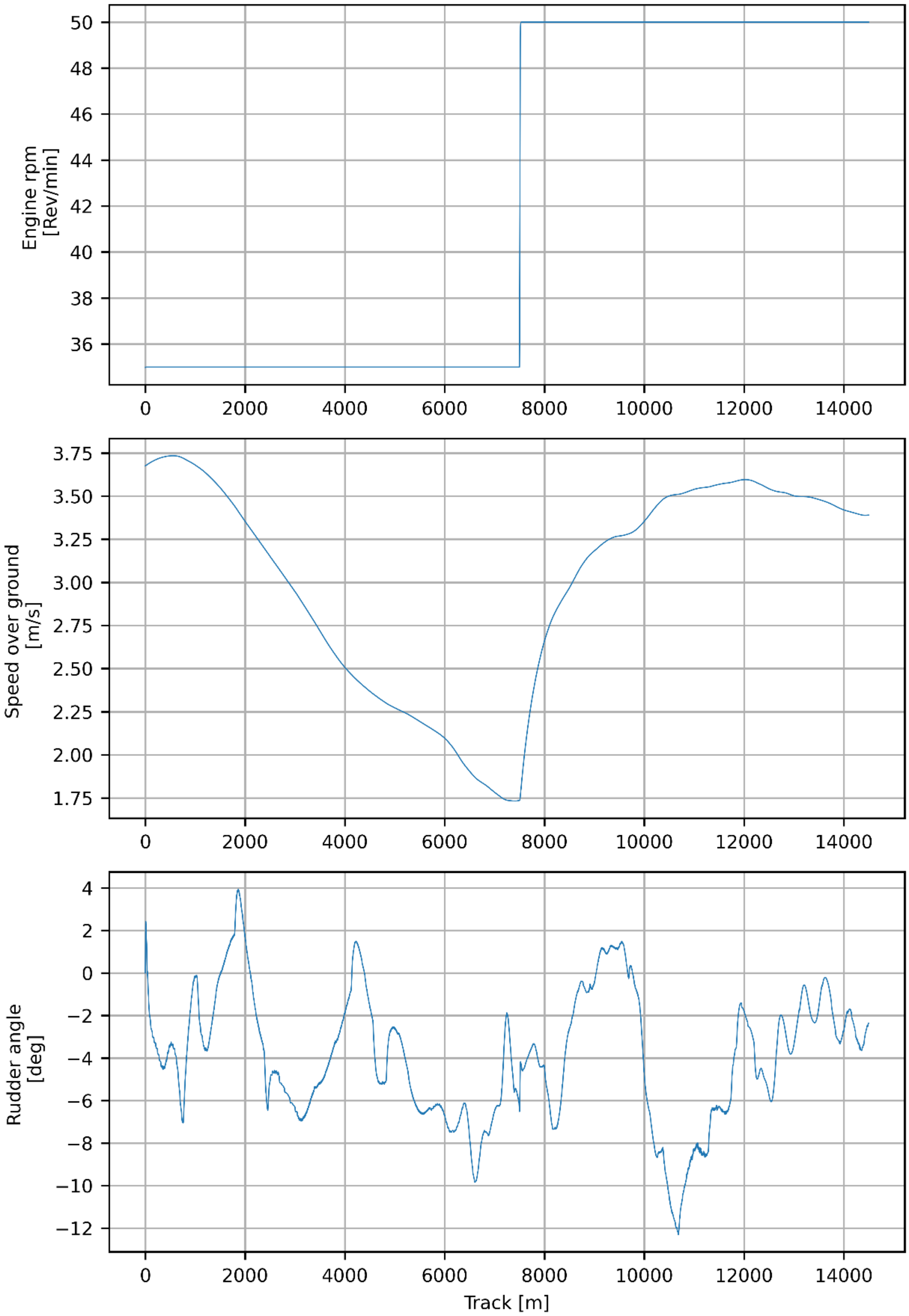
Direction: arrival

Wind: from the west

Current: peak ebb

Swell: present




Engine rpm
[Rev/min]
50
48
46
44
42
40
38
36
0
2000
4000
6000
8000
10000
12000
14000
Speed over ground
[m/s]
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
Rudder angle
[deg]
4
2
0
−2
−4
−6
−8
−10
−12
Track [m]

Royal HaskoningDHV

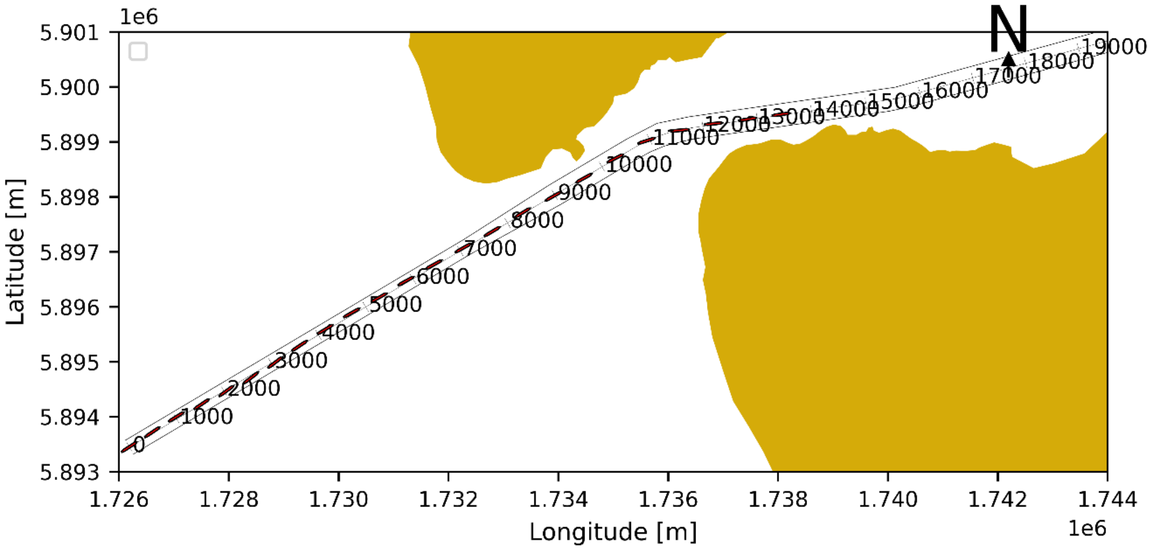
A8.3 Run “AR-A-Arr-W-PF-Swell”

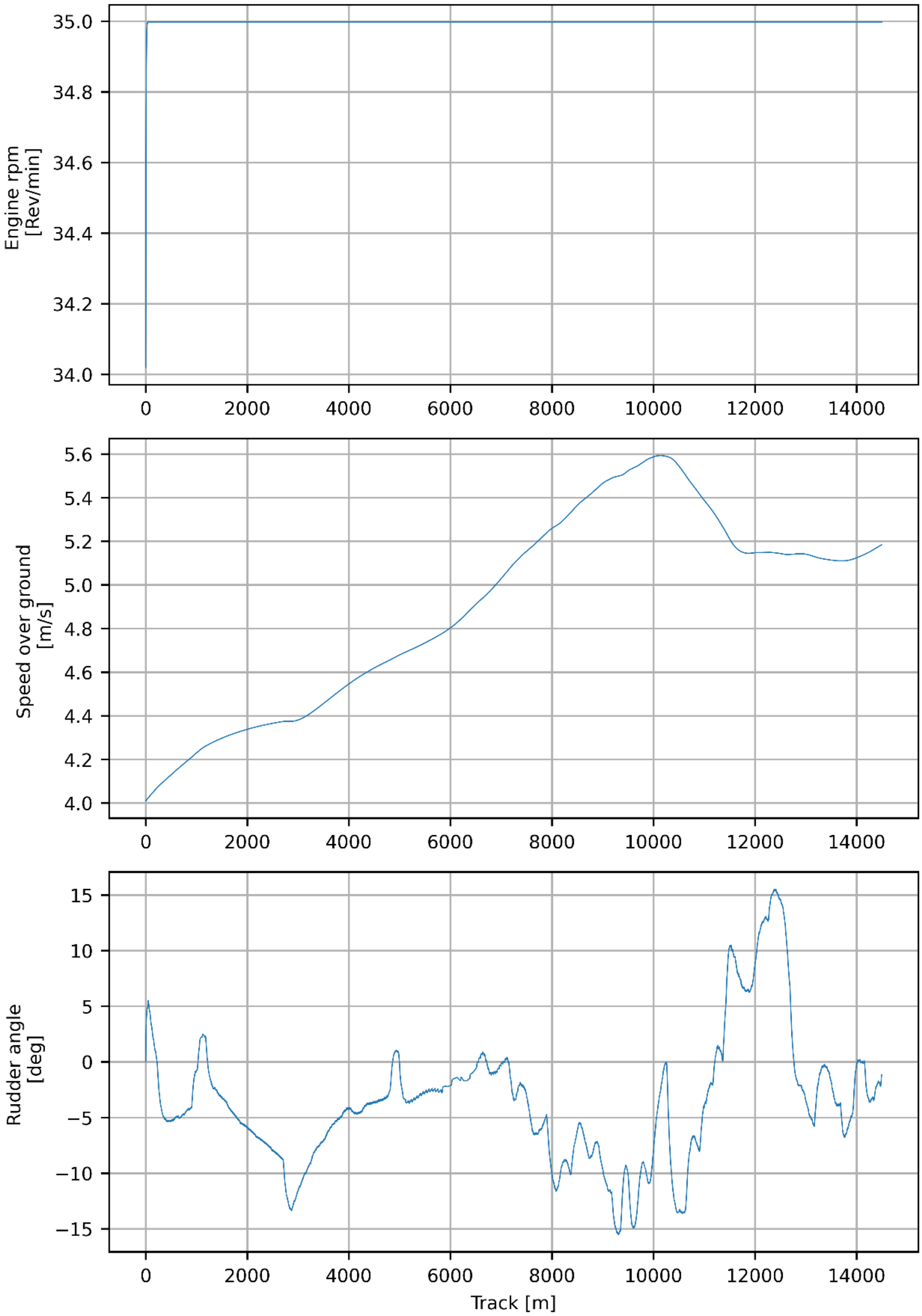
Direction: arrival

Wind: from the west

Current: peak flood

Swell: present





35.0
34.8
34.6
34.4
34.2
34.0
Engine rpm [Rev/min]
0
2000
4000
6000
8000
10000
12000
14000
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
Speed over ground [m/s]
0
2000
4000
6000
8000
10000
12000
14000
15
10
5
0
−5
−10
−15
Rudder angle [deg]
0
2000
4000
6000
8000
10000
12000
14000
Track [m]

A9 Arrival Simulations in Section C – Additional Runs (AR)

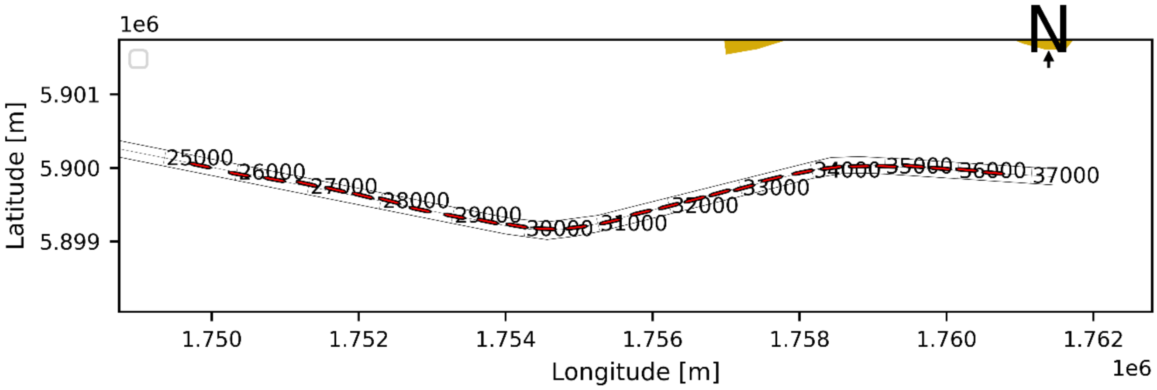
A9.1 Run "AR-C-Arr-SW-PF-Swell"

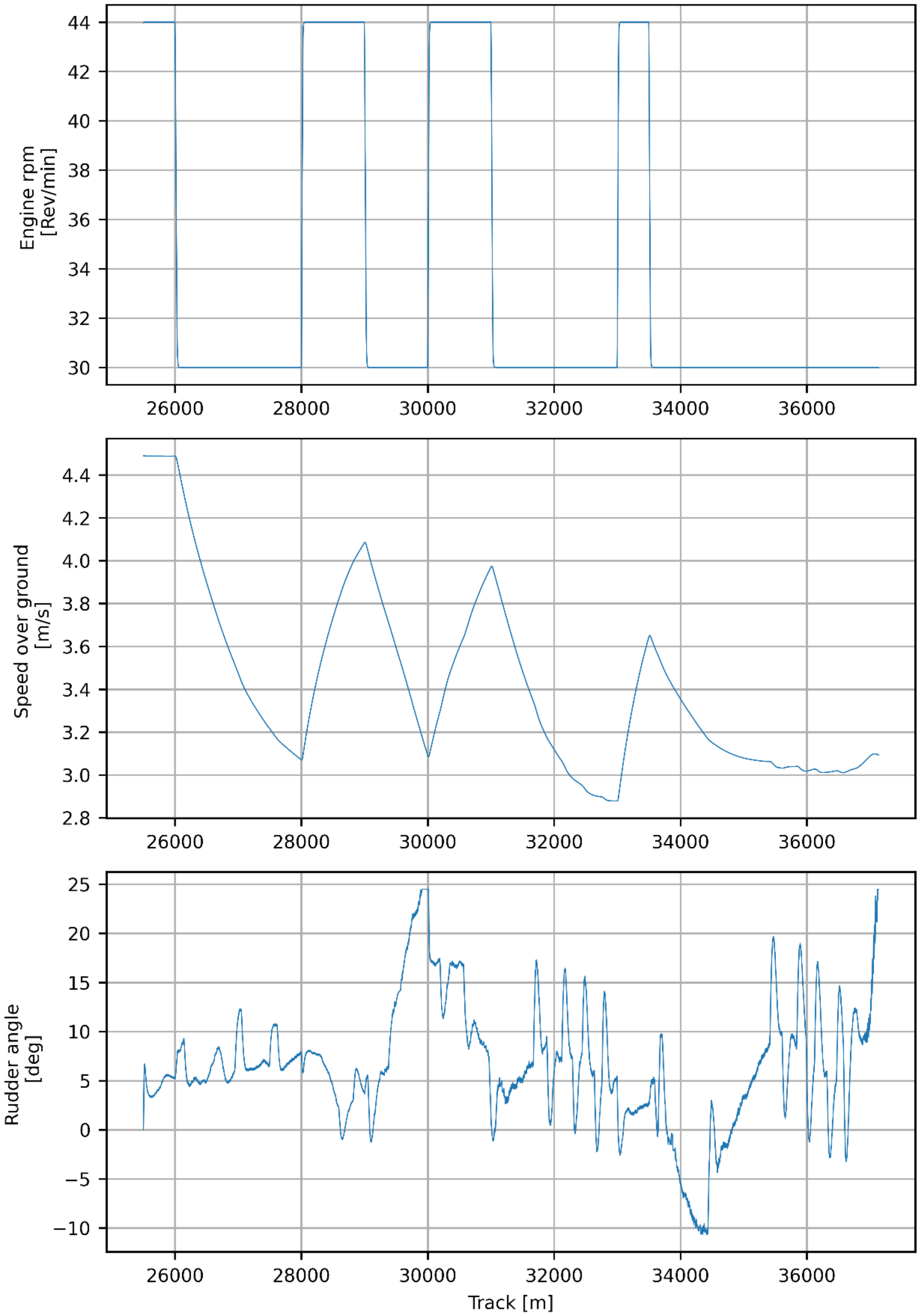
Direction: arrival

Wind: from the southwest

Current: peak flood

Swell: present




Engine rpm [Rev/min]
44
42
40
38
36
34
32
30
Speed over ground [m/s]
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
Rudder angle [deg]
25
20
15
10
5
0
−5
−10
26000
28000
30000
32000
34000
36000
Track [m]

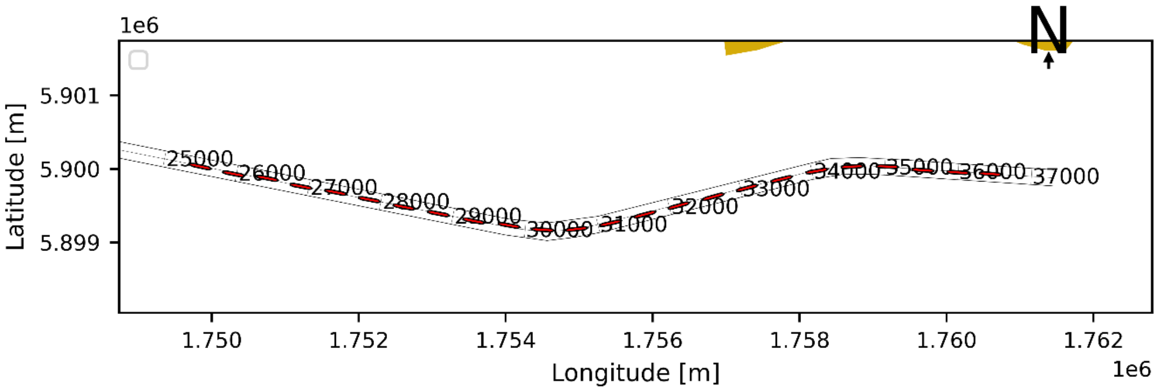
A9.2 Run “AR-C-Arr-W-LW-Swell”

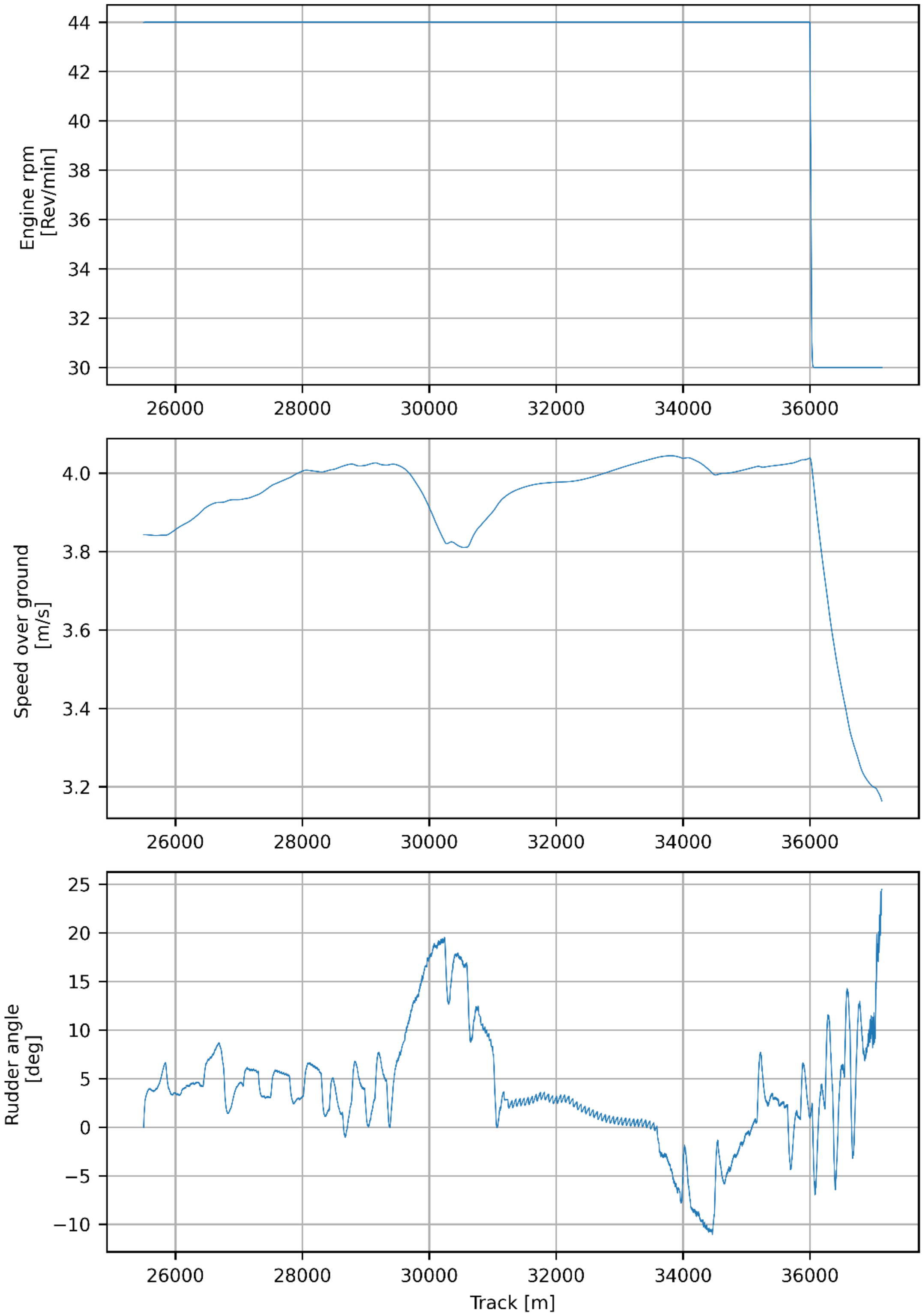
Direction: arrival

Wind: from the west

Current: low water

Swell: present




44
42
40
38
36
34
32
30
Engine rpm
[Rev/min]
26000
28000
30000
32000
34000
36000
4.0
3.8
3.6
3.4
3.2
Speed over ground
[m/s]
26000
28000
30000
32000
34000
36000
25
20
15
10
5
0
−5
−10
Rudder angle
[deg]
26000
28000
30000
32000
34000
36000
Track [m]

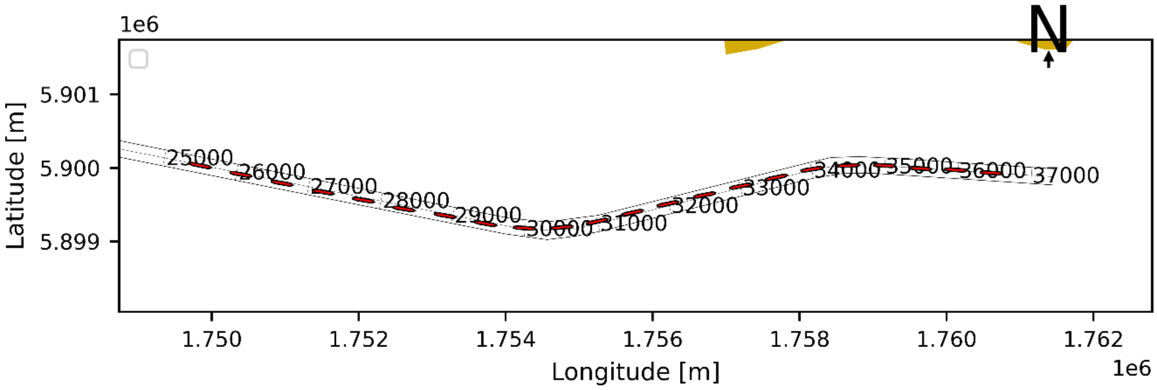
A9.3 Run “AR-C-Arr-W-PE-Swell”

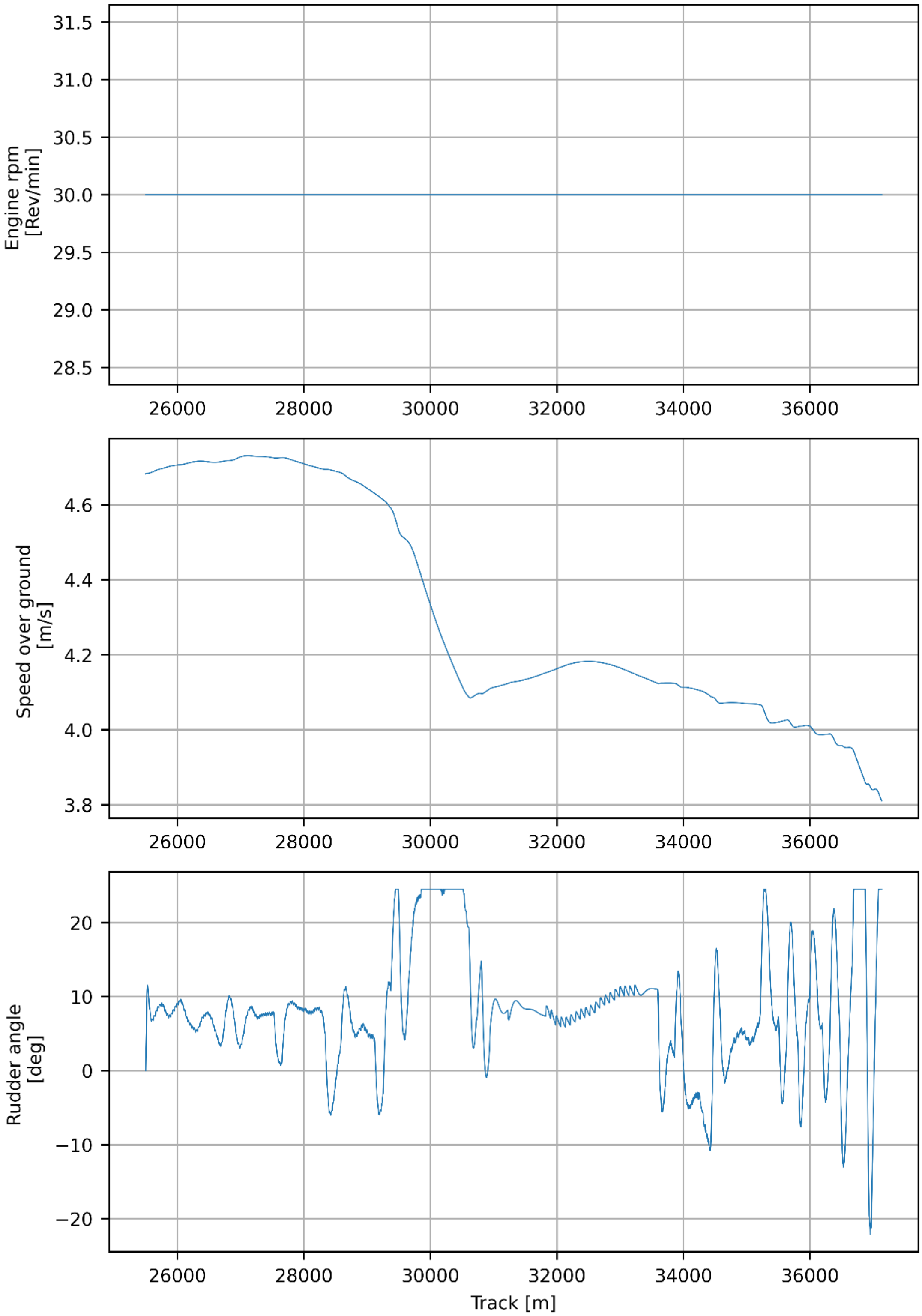
Direction: arrival

Wind: from the west

Current: peak ebb

Swell: present





31.5
31.0
30.5
30.0
29.5
29.0
28.5
Engine rpm [Rev/min]
26000
28000
30000
32000
34000
36000
4.6
4.4
4.2
4.0
3.8
Speed over ground [m/s]
26000
28000
30000
32000
34000
36000
20
10
0
−10
−20
Rudder angle [deg]
26000
28000
30000
32000
34000
36000
Track [m]

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A10 Departure Simulations in Section C – Additional Runs (AR)

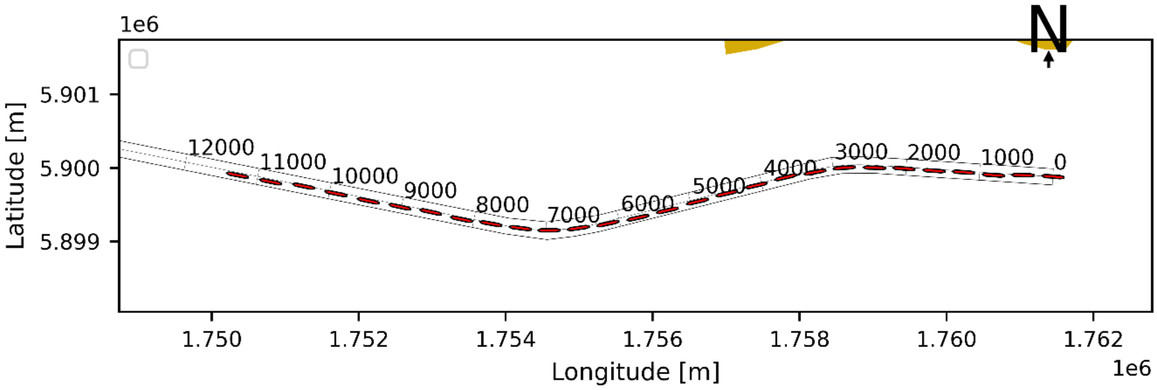
A10.1 Run “AR-C-Dep-SW-LW-Swell”

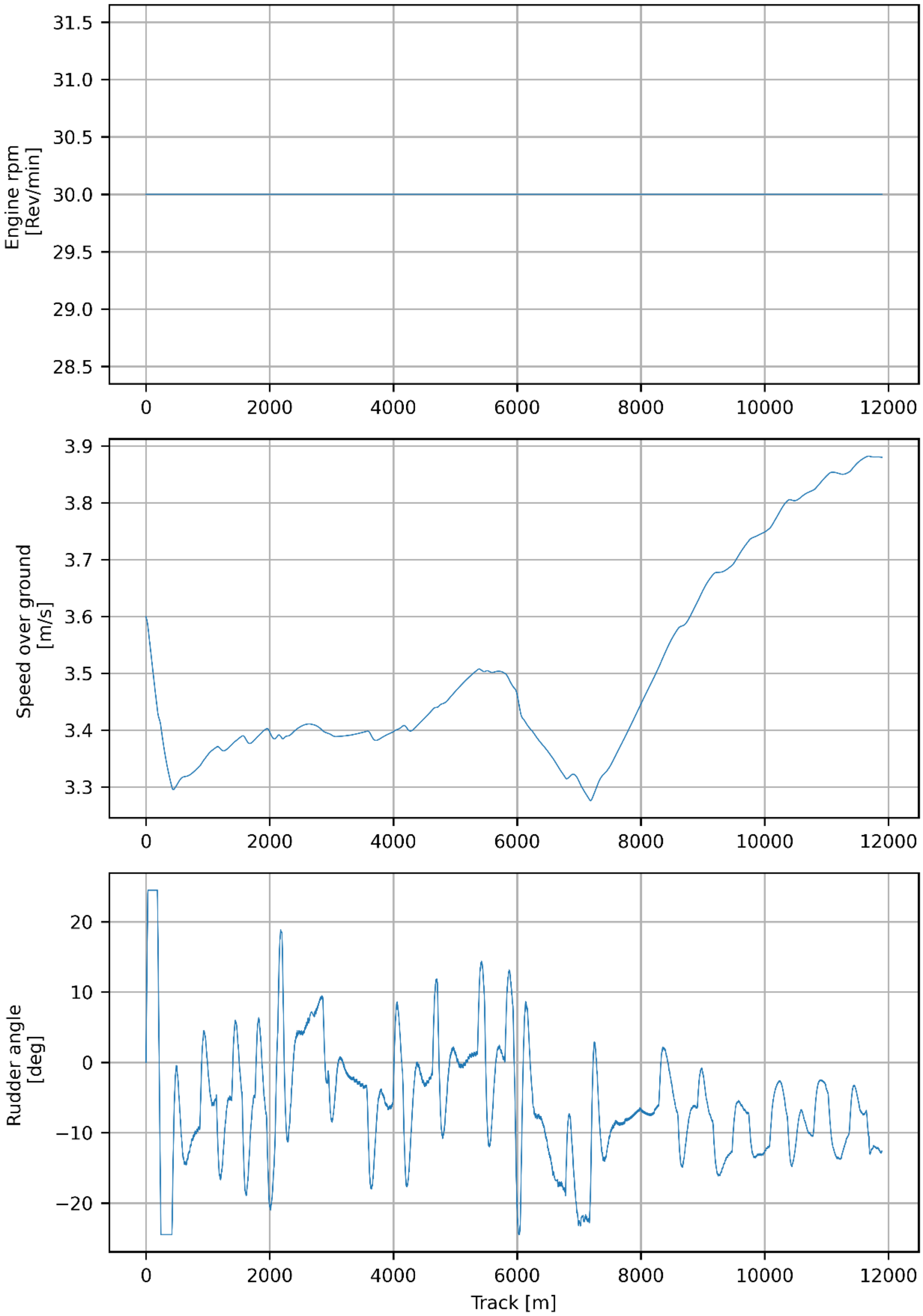
Direction: departure

Wind: from the southwest

Current: low water

Swell: present





Engine rpm
[Rev/min]
31.5
31.0
30.5
30.0
29.5
29.0
28.5
0
2000
4000
6000
8000
10000
12000
Speed over ground
[m/s]
3.9
3.8
3.7
3.6
3.5
3.4
3.3
Rudder angle
[deg]
20
10
0
−10
−20
Track [m]

Royal HaskoningDHV

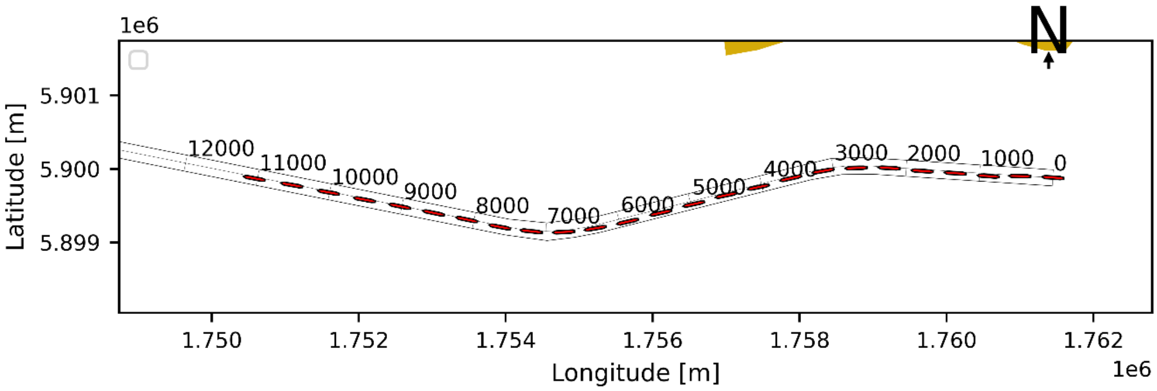
A10.2 Run “AR-C-Dep-SW-PE-Swell”

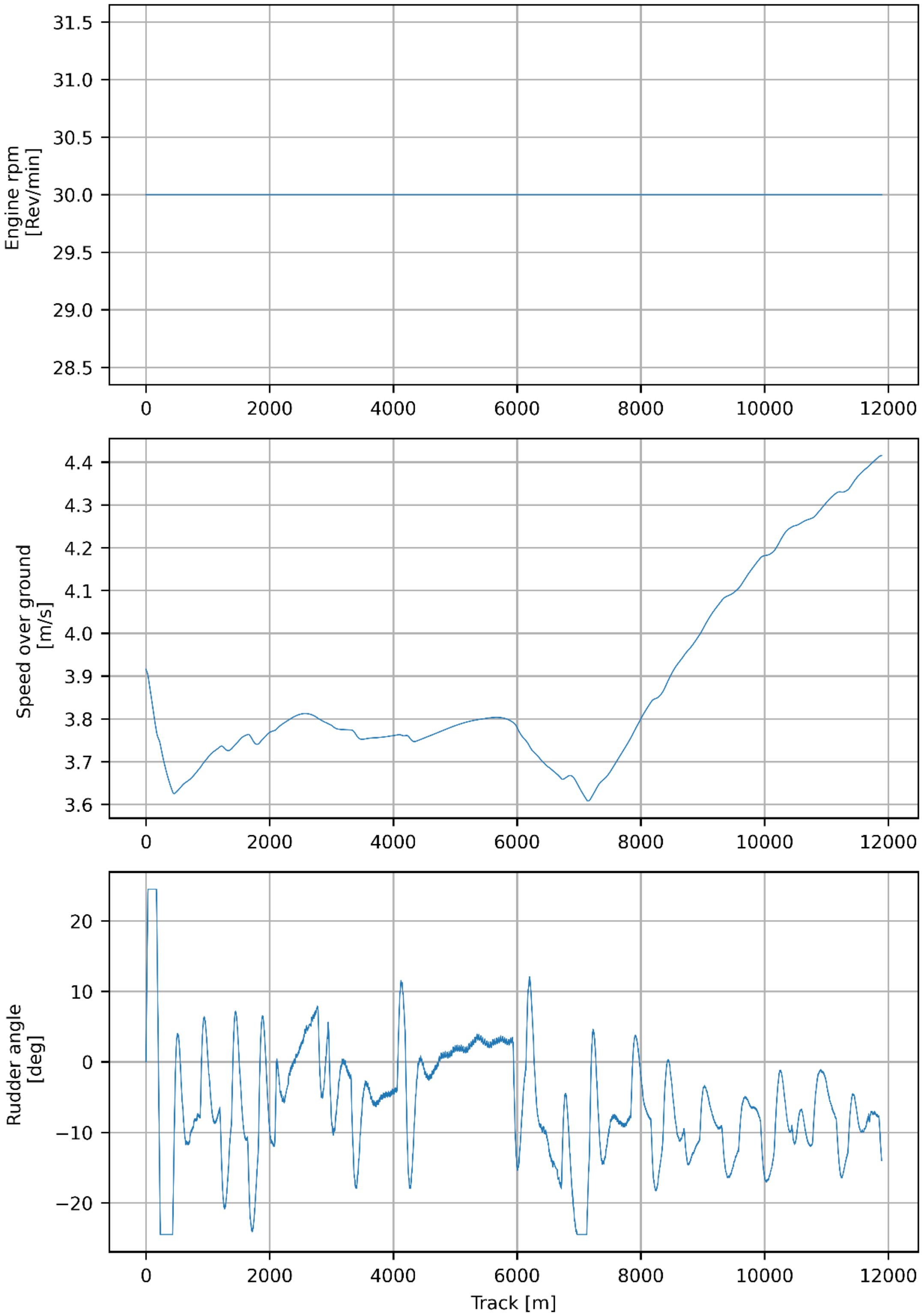
Direction: departure

Wind: from the southwest

Current: peak ebb

Swell: present




Engine rpm
[Rev/min]
31.5
31.0
30.5
30.0
29.5
29.0
28.5
Speed over ground
[m/s]
4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
Rudder angle
[deg]
20
10
0
−10
−20
0
2000
4000
6000
8000
10000
12000
Track [m]

Royal HaskoningDHV

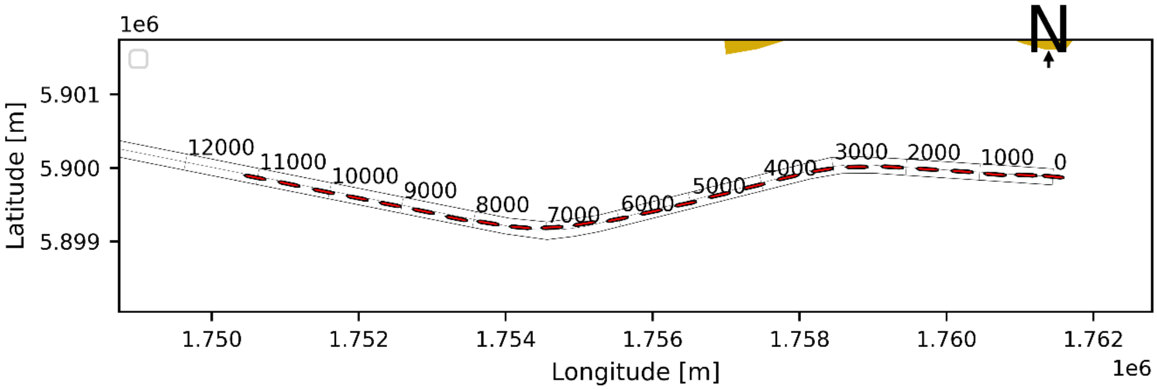
A10.3 Run “AR-C-Dep-SW-PF-Swell”

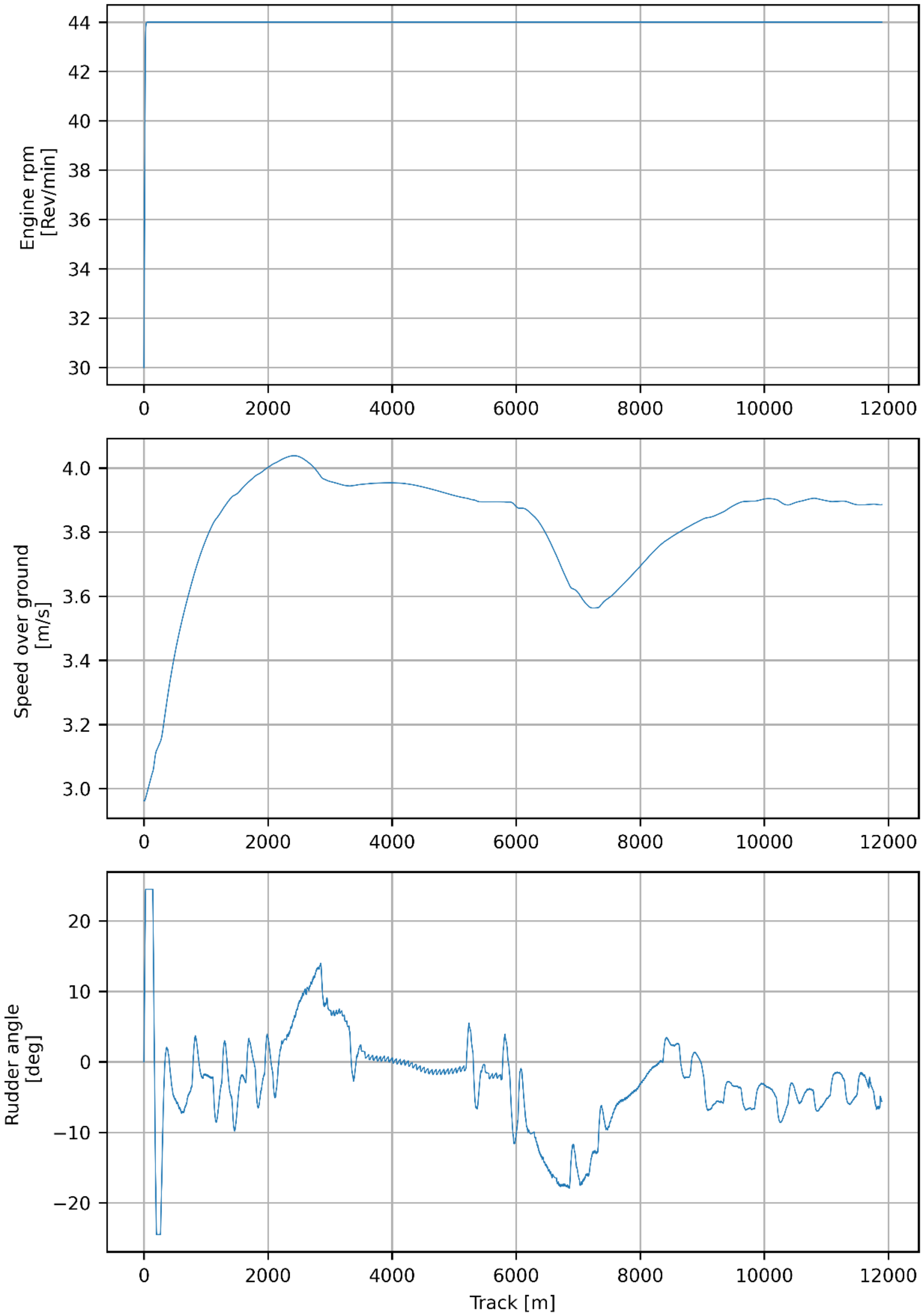
Direction: departure

Wind: from the southwest

Current: peak flood

Swell: present




Engine rpm [Rev/min]
44
42
40
38
36
34
32
30
0
2000
4000
6000
8000
10000
12000
Speed over ground [m/s]
4.0
3.8
3.6
3.4
3.2
3.0
Rudder angle [deg]
20
10
0
−10
−20
Track [m]

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A11 Departure Simulations in Section A – Additional Runs (AR)

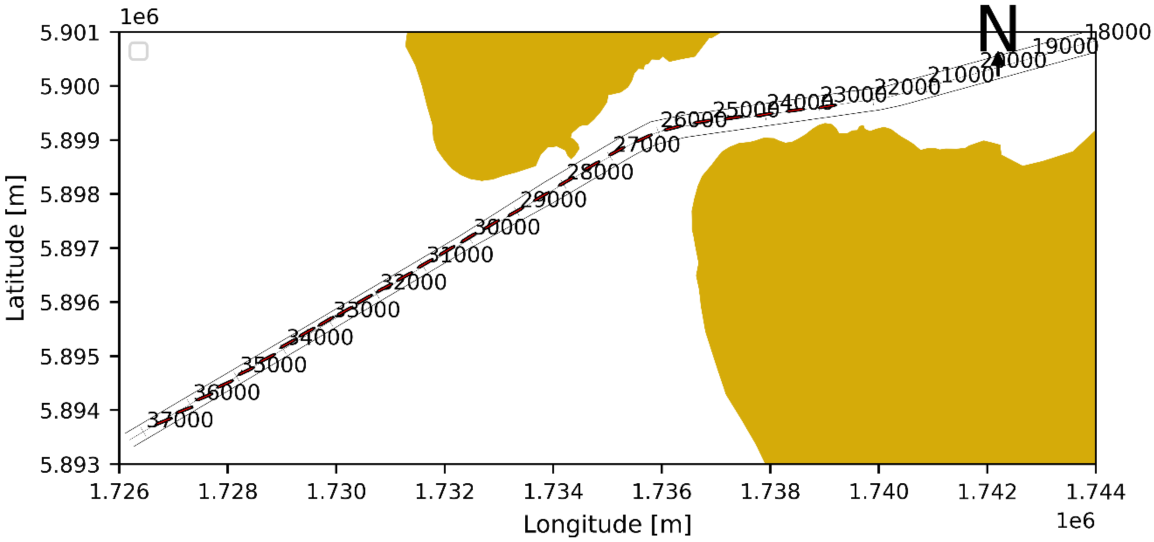
A11.1 Run "AR-A-Dep-W-LW-Swell"

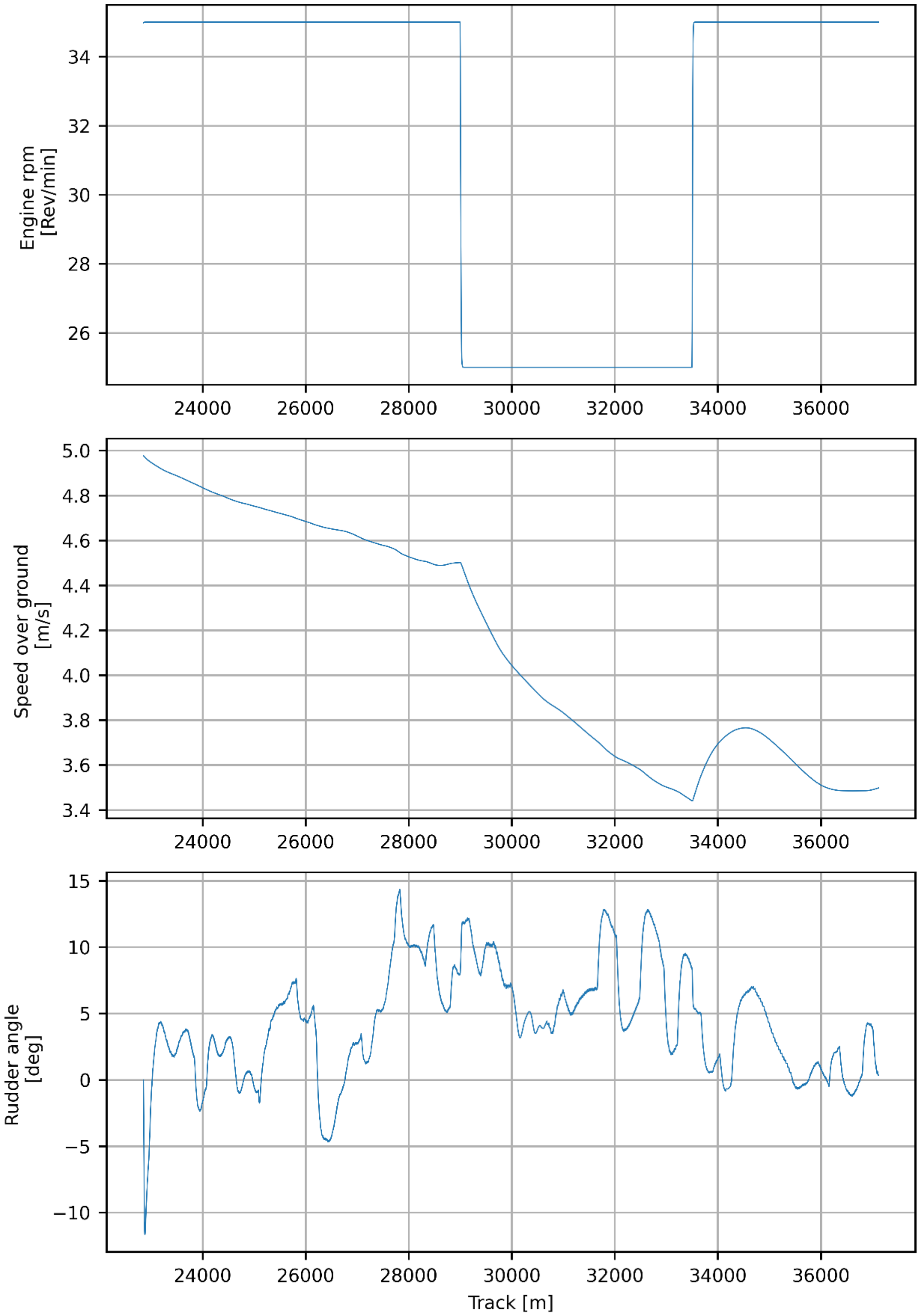
Direction: departure

Wind: from the west

Current: low water

Swell: present




Engine rpm
[Rev/min]
Speed over ground
[m/s]
Rudder angle
[deg]
Track [m]

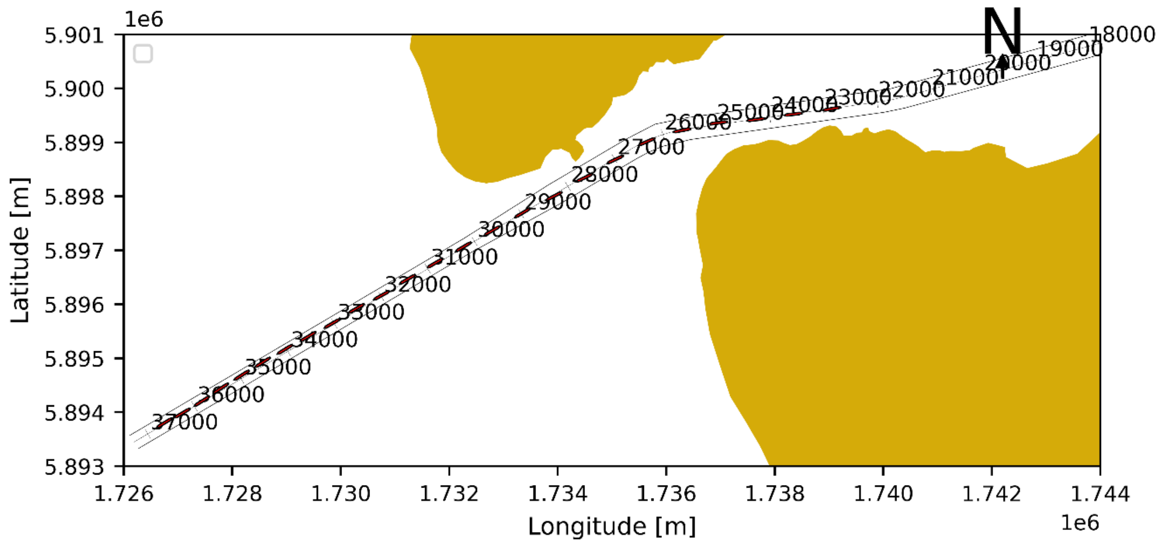
A11.2 Run "AR-A-Dep-W-PE-Swell"

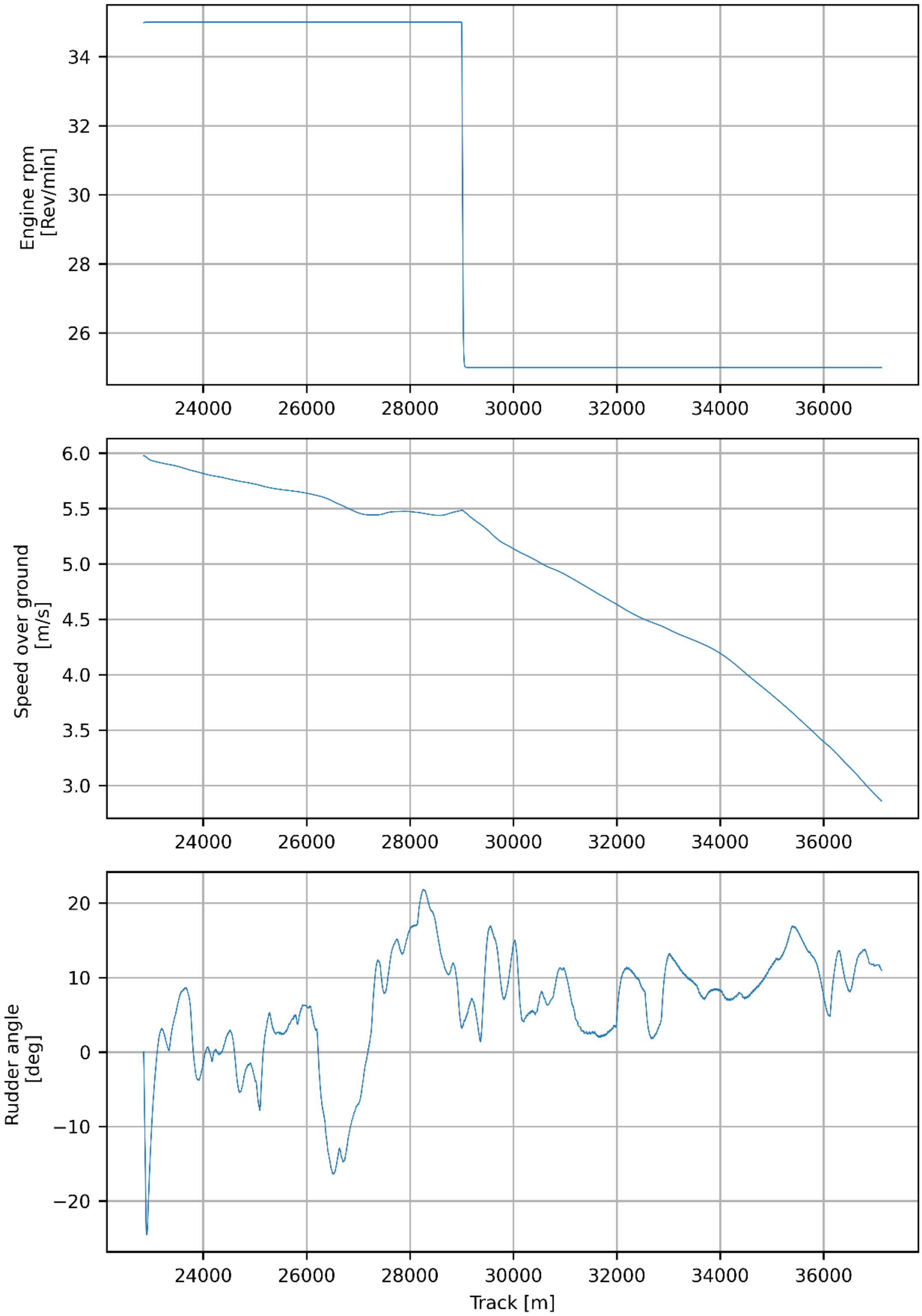
Direction: departure

Wind: from the west

Current: peak ebb

Swell: present




Engine rpm
[Rev/min]
34
32
30
28
26
24000
26000
28000
30000
32000
34000
36000
Speed over ground
[m/s]
6.0
5.5
5.0
4.5
4.0
3.5
3.0
Rudder angle
[deg]
20
10
0
−10
−20
Track [m]

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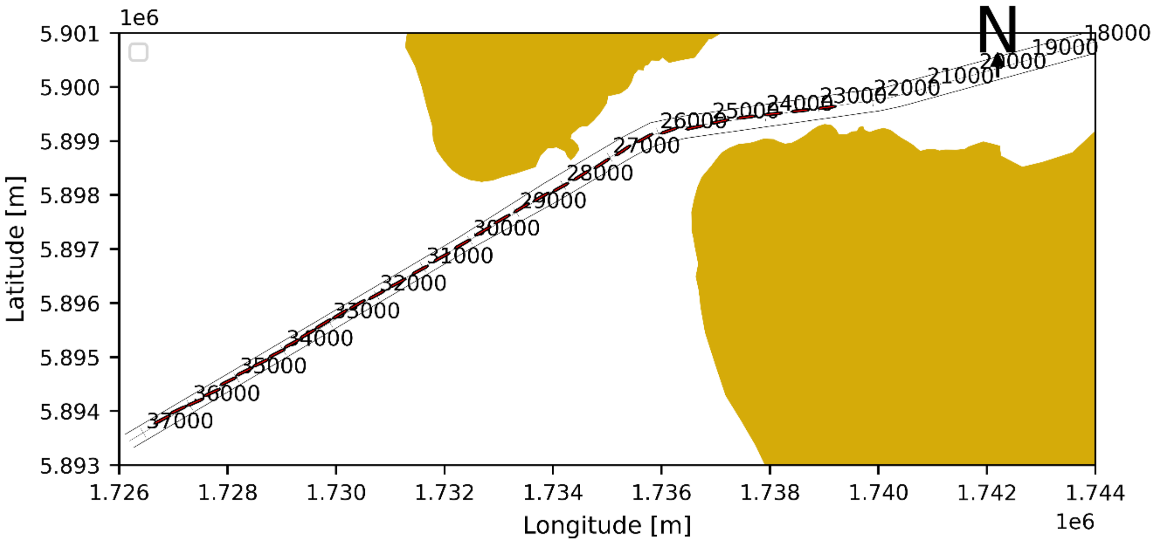
A11.3 Run “AR-A-Dep-W-PF-Swell”

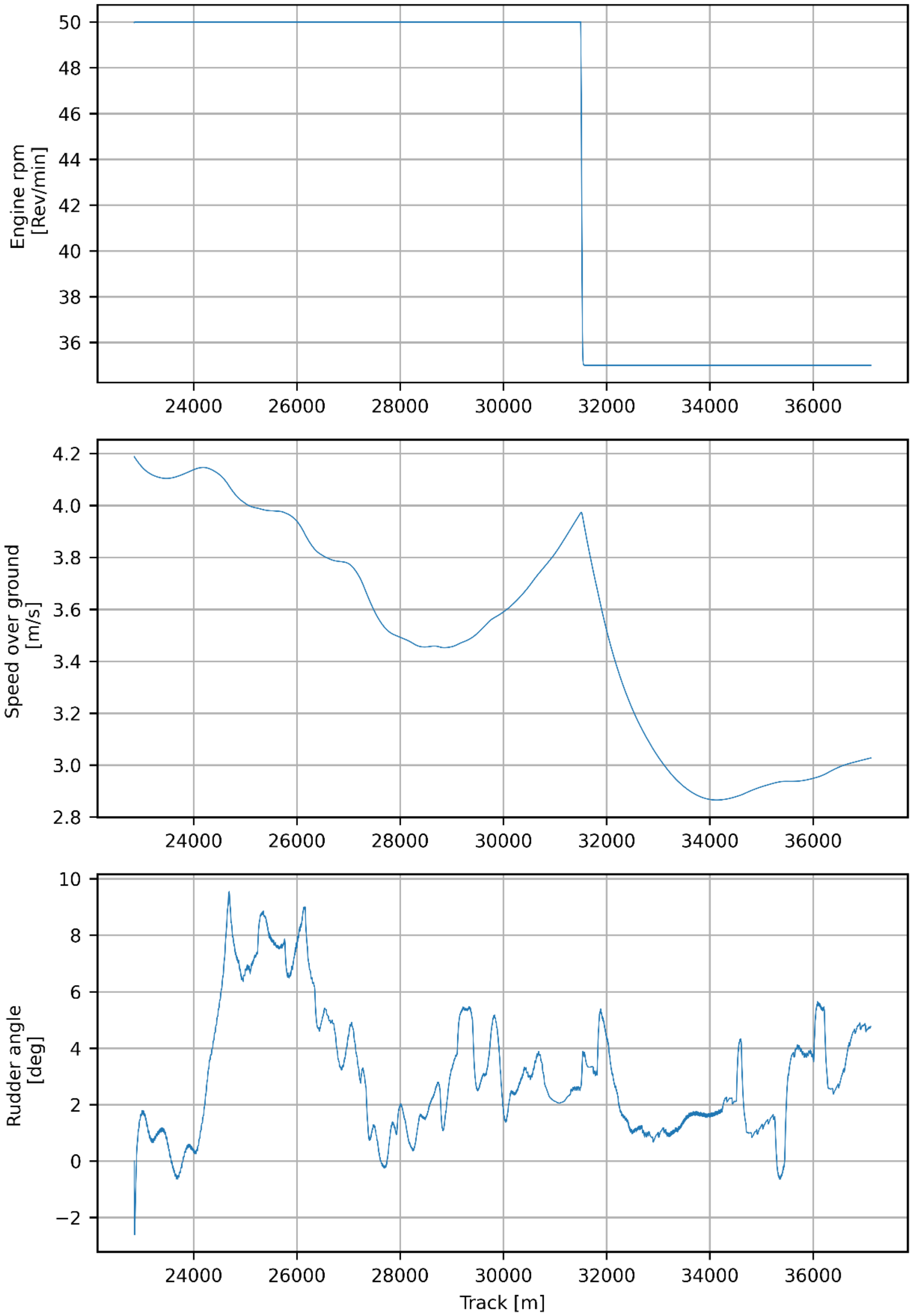
Direction: departure

Wind: from the west

Current: peak flood

Swell: present



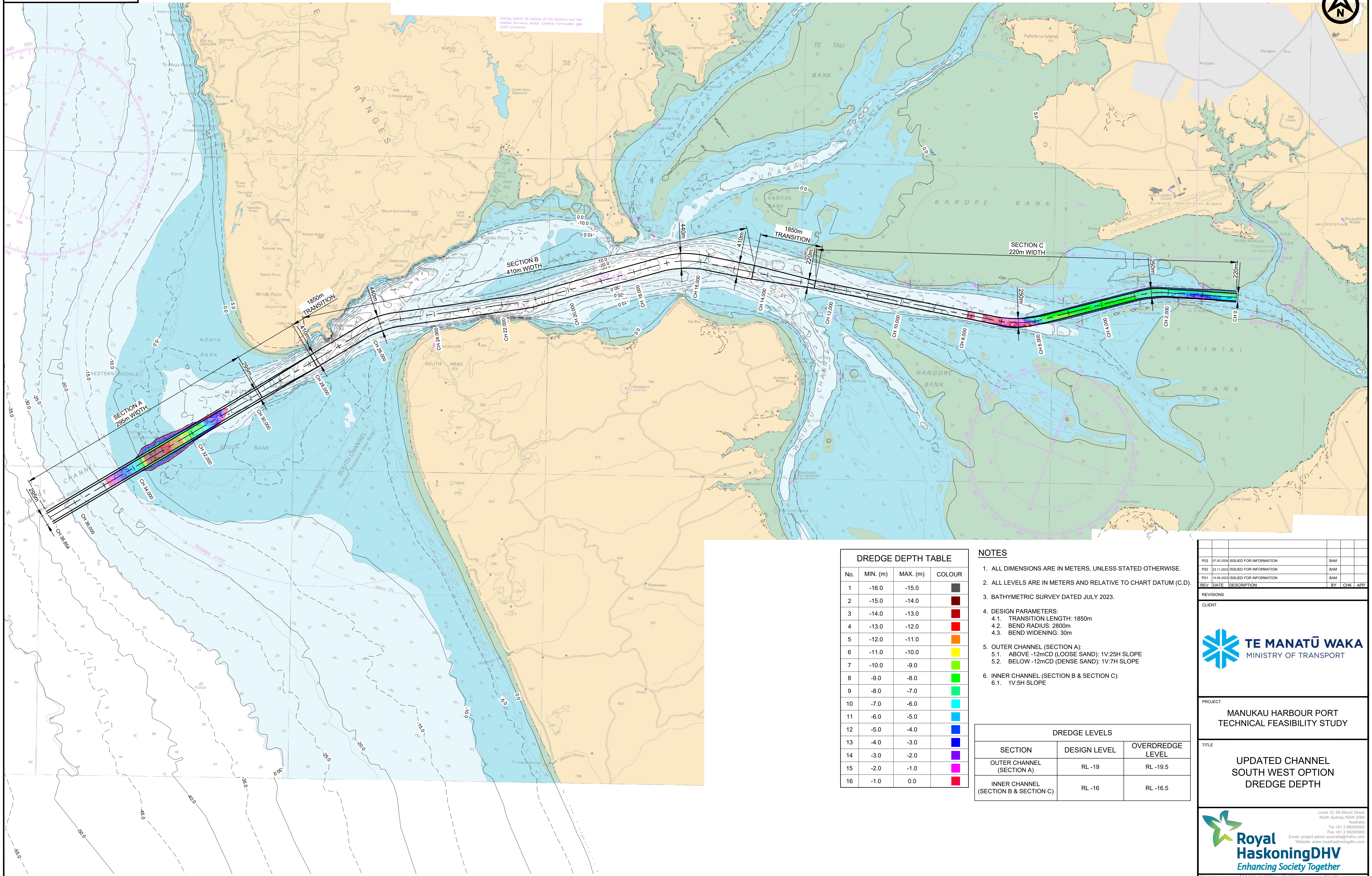


Engine rpm [Rev/min]
50
48
46
44
42
40
38
36
24000
26000
28000
30000
32000
34000
36000
Speed over ground [m/s]
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
Rudder angle [deg]
10
8
6
4
2
0
−2
Track [m]

D. Final Channel Concept Design (South West Channel)

DRAWING No.
PA3148-RHD-00-XX-DR-ME-0112

DO NOT SCALE



NOTES

1. ALL DIMENSIONS ARE IN METERS, UNLESS STATED OTHERWISE.
2. ALL LEVELS ARE IN METERS AND RELATIVE TO CHART DATUM (C.D).
3. BATHYMETRIC SURVEY DATED JULY 2023.
4. DESIGN PARAMETERS:
   - 4.1. TRANSITION LENGTH: 1850m
   - 4.2. BEND RADIUS: 2800m
   - 4.3. BEND WIDENING: 30m
5. OUTER CHANNEL (SECTION A):
   - 5.1. ABOVE -12mCD (LOOSE SAND): 1V:25H SLOPE
   - 5.2. BELOW -12mCD (DENSE SAND): 1V:7H SLOPE
6. INNER CHANNEL (SECTION B & SECTION C):
   - 6.1. 1V:5H SLOPE

DREDGE DEPTH TABLE

No.	MIN. (m)	MAX. (m)	COLOUR
1	-16.0	-15.0	
2	-15.0	-14.0	
3	-14.0	-13.0	
4	-13.0	-12.0	
5	-12.0	-11.0	
6	-11.0	-10.0	
7	-10.0	-9.0	
8	-9.0	-8.0	
9	-8.0	-7.0	
10	-7.0	-6.0	
11	-6.0	-5.0	
12	-5.0	-4.0	
13	-4.0	-3.0	
14	-3.0	-2.0	
15	-2.0	-1.0	
16	-1.0	0.0	

DREDGE LEVELS

SECTION	DESIGN LEVEL	OVERDREDGE LEVEL
OUTER CHANNEL (SECTION A)	RL -19	RL -19.5
INNER CHANNEL (SECTION B & SECTION C)	RL -16	RL -16.5

CHART DATUM

NOT FOR CONSTRUCTION

S0 WORK IN PROGRESS

REV	DATE	DESCRIPTION	BY	CHK	APP
P03	07.02.2024	ISSUED FOR INFORMATION	BAM		
P02	23.11.2023	ISSUED FOR INFORMATION	BAM		
P01	14.08.2023	ISSUED FOR INFORMATION	BAM		

REVISIONS

CLIENT

TE MANATŪ WAKA
MINISTRY OF TRANSPORT

PROJECT

MANUKAU HARBOUR PORT
TECHNICAL FEASIBILITY STUDY

TITLE

UPDATED CHANNEL SOUTH WEST OPTION DREDGE DEPTH

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Website: www.royalhaskoningdhv.com

DRAWN	COORD. SYSTEM	DATUM	DATE
BAM	NZTM2000	CHART DATUM	07.02.2024
SCALE AS SHOWN	REF. PA3148-RHD-00-00-M3-UPDATED CHANNEL [P03]		

DRAWING No.	SUITABILITY	REVISION
PA3148-RHD-00-XX-DR-ME-0112	S2	P03

C:\USERS\220025\ROYAL HASKONINGDHV\PROJECT-PA3148-MANAKAU-HARBOUR-PFS - TEAM\WORK IN PROGRESS\02_CAD\PA3148-RHD-00-00-M3-UPDATED CHANNEL [P03]