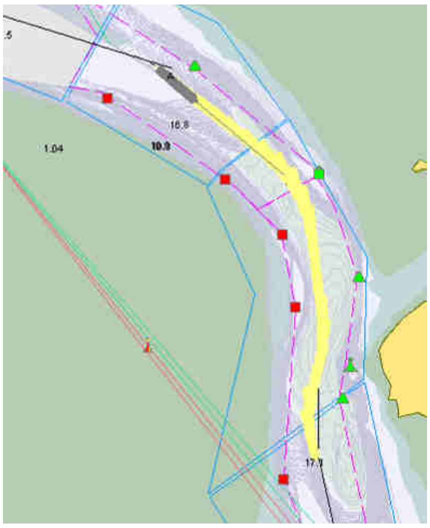

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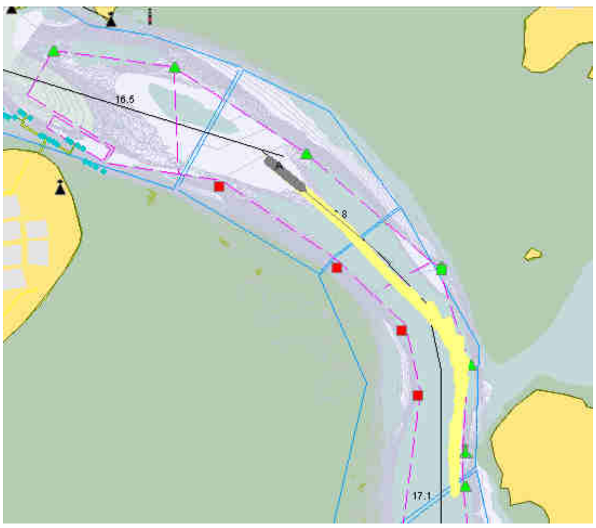

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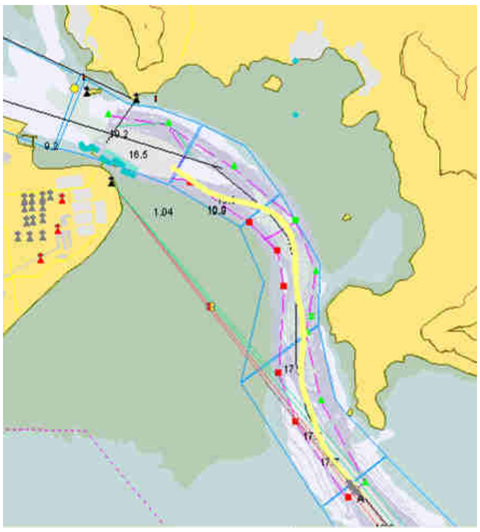

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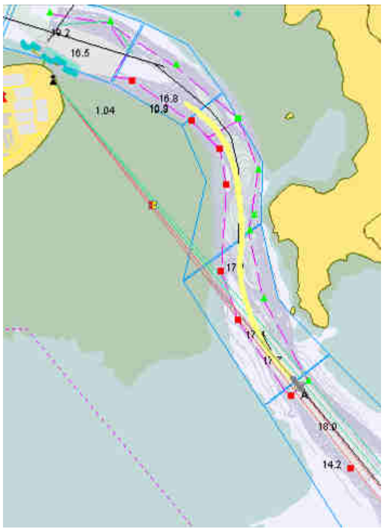

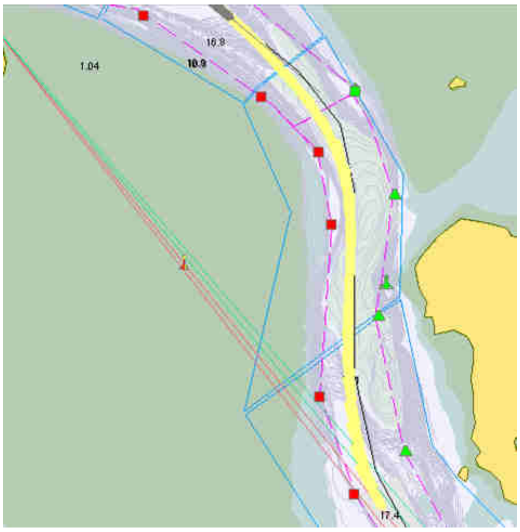

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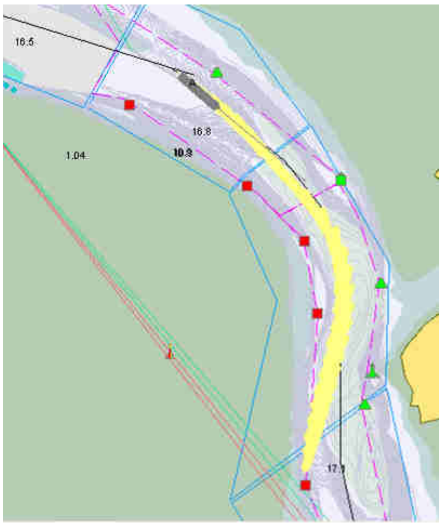

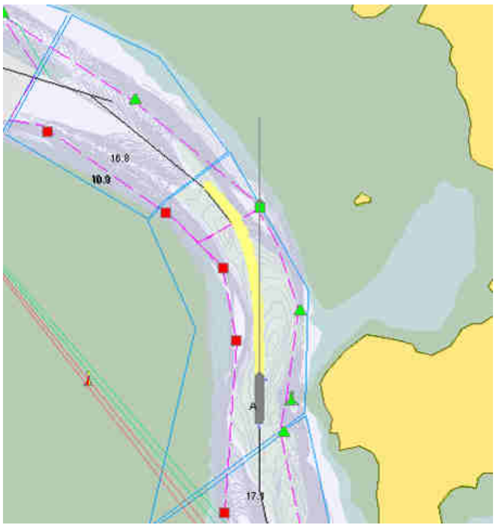

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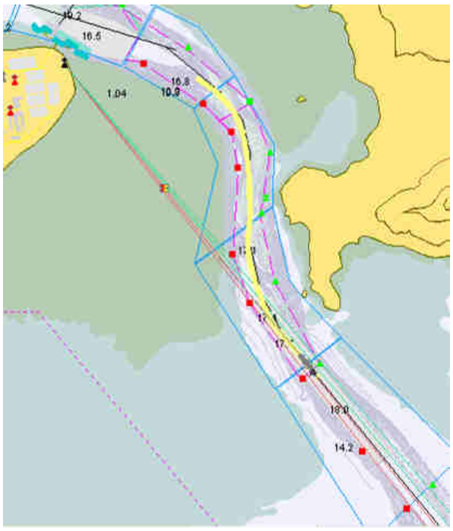

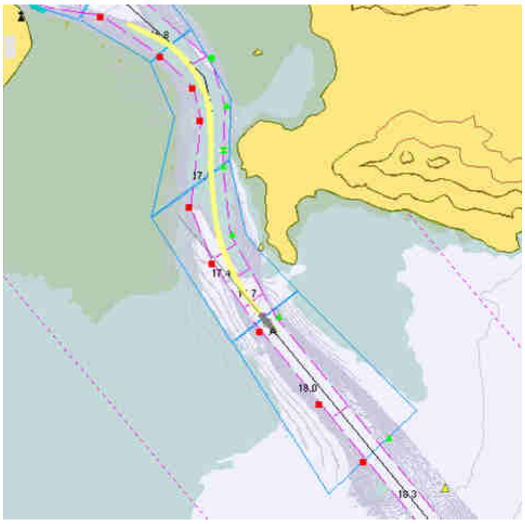

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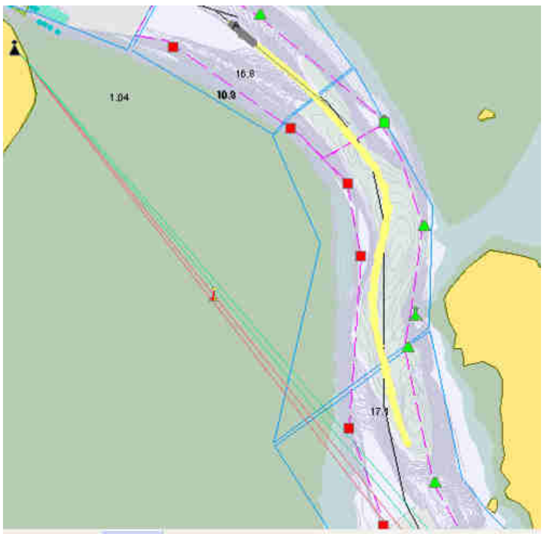

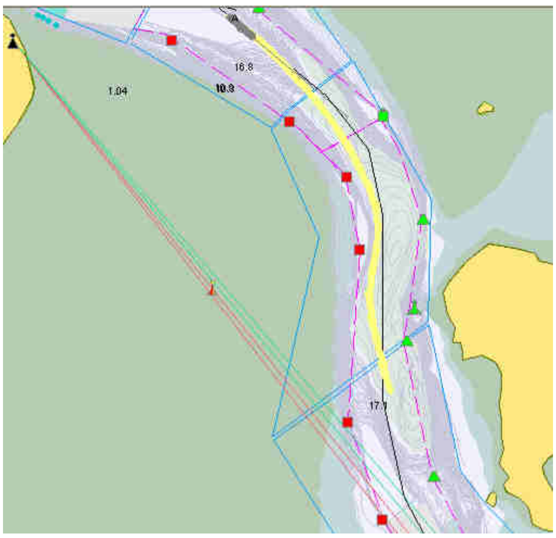

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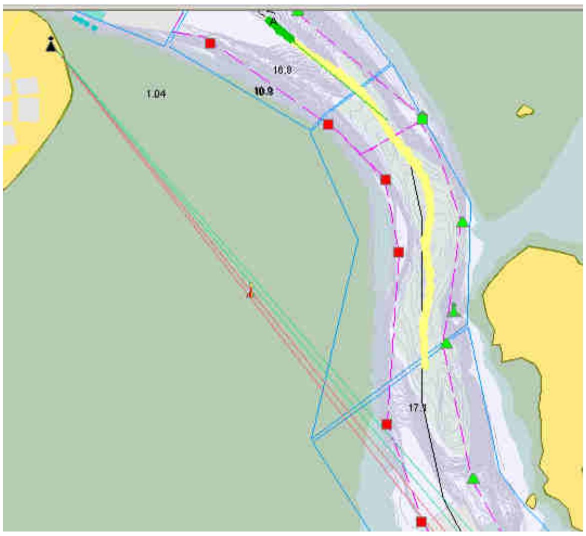

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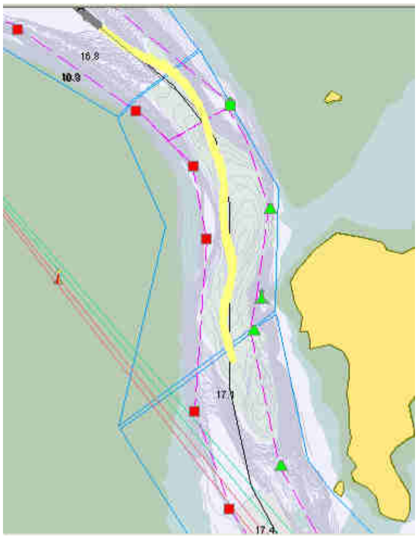

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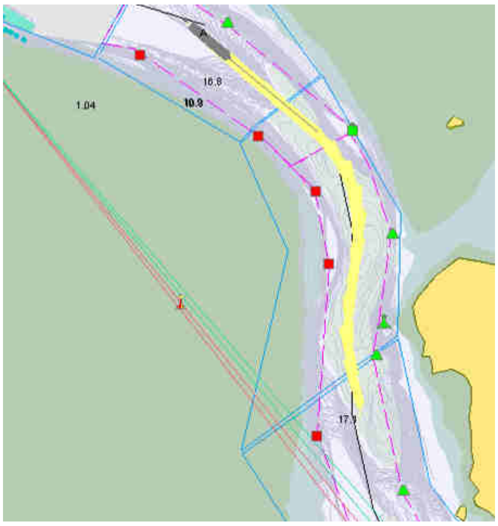

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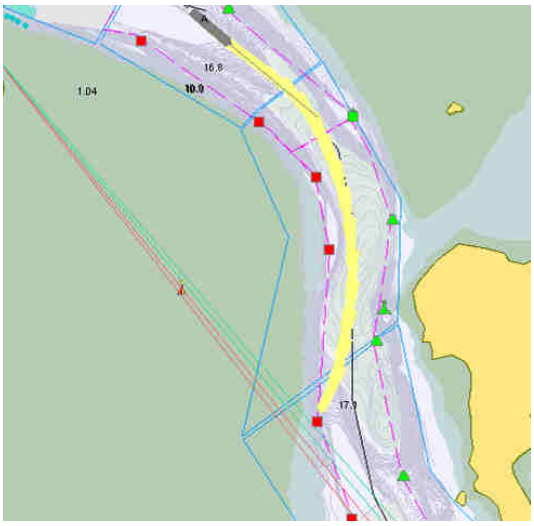

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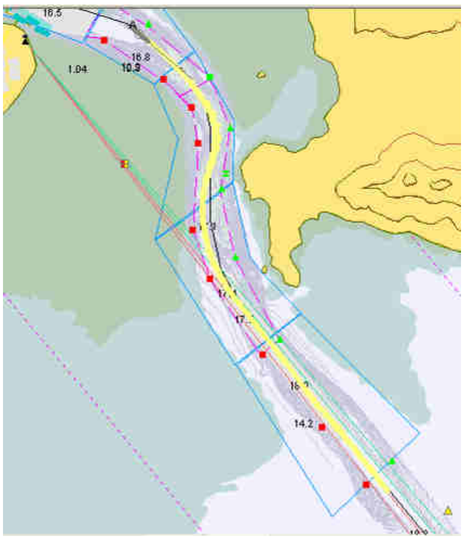

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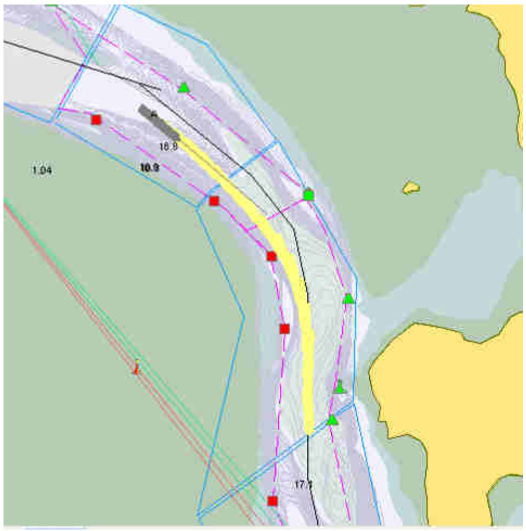

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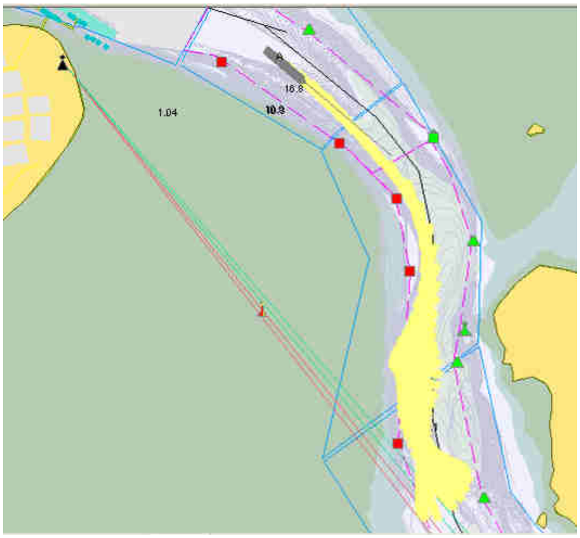

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APPENDIX D: Taurikura Bay Leads Report

FINAL REPORT ON THE PROPOSED TAURIKURA BAY LEADS

Report prepared for Royal HaskoningDHV on behalf of Refining New Zealand Limited

Revision 2.2
June 2016

Prepared by: besoftware Maritime Simulation Solutions

Report Summary

As part of the Desktop Simulation Study prepared for Refining NZ in September 2015, it was proposed to establish a set of Leads in Taurikura Bay to assist with the night time navigation of arriving Suezmax Tankers and other vessels. These leads would define the north south centreline of the proposed Channel Option 4-2 between buoys 3/6 and buoy 14. The requirement for leads only applied to Channel Option 4-2.

These leads were trailed in the simulation study and found to be very useful for the proposed Channel 4-2 as they helped the pilots turning the ship into the approach to the centreline of the channel. The pilots commenced the turn after passing buoys 3\6 and used the leads to align themselves into the centreline of the channel.

The Desktop Simulation study assumed the forward lead will be on the northern edge of Calliope Bank and the rear lead on the foreshore. This report investigates further options to establish Leads. There are four possible Leads options considered here.

(i) A PEL Sector Lead Light (PEL Option 1) established on Calliope Bank.

(ii) Traditional Leads (Low Leads Option 2) established on Calliope Bank (Fore lead) and Taurikura Bay Foreshore (Rea r Lead). This was the option investigated in the previous report revision (Report of Proposed Taurikura Bay Leads, Revision 1).

(iii) Traditional Leads (Water Leads Option 3) established on the Calliope Bank. Both Fore and Rear Lead on Calliope Bank.

(iv) Traditional Leads (High Leads Option 4) established on Calliope Bank (Fore lead) and on the lower southern slopes of Mania overlooking Taurikura Bay (Rear Lead).

This study investigated these proposed Leads options in more detail and the following results were found:

- All four Lead Options are viable but the PEL (Option 1) and the Water Leads (Option 3) will cause the least visual impact on the local community around Taurikura Bay.
- It was considered the PEL (Option 1) will be cheaper than the Water Leads (Option 3).
- Traditional Leads offer the ability to judge the progress of the turn when swinging the ship onto the centreline of the channel. However, Traditional Leads offer little indication of the distance off the centreline when approaching the leading line.
- The PEL (Option 1) can give a precise figure for distance off the centreline and by including an oscillating boundary light option to the PEL; it is possible for the informed mariner to judge the progress of the turn when swinging the ship onto the centreline of the channel.
- The Traditional Leads would be visible in daytime use without lights. The PEL (Option 1) will require daylights if it is to be used during the day. The PEL (Option 1) with daylights has more

power requirements than the Traditional Leads and has a maximum day range out to the vicinity of buoy 3.

- The position of the existing isolated danger buoy in Taurikura Bay will create some interference at night for all Leads Options but it is considered to be not serious. There will also be some interference from shore light in Taurikura Bay for all Leads Options but it is not considered serious. It was considered Buoy 11 should not cause any interference for all Leads Options.
- The program found the minimum heights (above Mean High Water) for the Water Leads (Option 3) are 6 metres for the Front Lead and 13 metres for the Rear Lead.
- The PEL (Option 1) will require a single tower which is 15 metres above MHW. It may be possible to use a lower tower (10 metres) and tilt the PEL light.
- Light intensity for the Traditional Leads options were checked against the IALA Leading Line Design Program V 2.02 E-112-2. The report assumes recommended intensity for traditional lights.
- The report assumes a height of eye of the observer at 8 metres, 15 metres and 25 metres. The lights were found to be usable with all options within the channel from heights of eye above 7 metres.
- It was considered that white lights offered the best visibility by night.
- It is assumed that Calliope Bank is stable enough for establishment of a tower structure. This should be verified.
- It is assumed that approvals can be obtained for the establishment of lead towers in the positions indicated in this report.

1 PEL VERSES TRADITIONAL LEADS

A PEL light (Port Entry Light) uses a single sector light which provides a far greater resolution of sector boundaries than had previously been possible (See **Figure 1**). Using a very fine angled sector light, it is possible to define the centre line of a channel using a single station or tower. A white light indicates the centre of the channel with red and green light sectors either side (See **Figure 2**).

Traditional Leads require two stations to define the centre line of a channel with a light at each station. The PEL light has been available to mariners for over forty years but the traditional leads have been used for much longer. The PEL light has gained acceptance across the world and particularly in New Zealand and Australia, however pilots will often prefer one system over the other.

The following statements were supplied by Captain Ross Nicolls Director and Senior Pilot with Brisbane Marine Pilots:

PEL vs. Lead lights is a subjective one depending on which Pilot you're talking to. This is more prominent when replacing one set of leads with the other and we have been through this in Brisbane and operates with both PEL's and traditional leads.

The PEL certainly provides an indication of distance off the centre course line as the lights (shoulder and centre) are graduated and the Pilot can be educated as to the extremity of the lights visibility. Traditional leads only clearly indicate where the centre line is without any clear appreciation of distance either side.

The primary benefit of the traditional lead is that they are constantly lit or visible as you approach the turn and you can gauge or get a feeling of how the turn is progressing by the aspect of the two leads. This is not as discernible with a PEL. If distance away from the centre line of a course is a critical component then a PEL defines this better.

From the above, if mariners wish to use the PEL during the day then it must be provided with daytime lights which can be a problem if using solar power (as will be required in Taurikura Bay). The manufacturer of PEL lights, Vega of New Zealand http://www.vega.co.nz considers adequate power will be achievable for a PEL light established in Taurikura Bay.

Similarly in order to get a feeling of how the turn is progressing, the PEL needs to be provided with the oscillating boundary option (see **Figure 3**). Vega offer oscillating boundary options which have successfully been used in Cook Strait and Lyttelton. Oscillating boundary is a factory fitted option for any PEL Light. It provides proportional indication of lateral movement within the sectors of the light. In the oscillating sector, the colour oscillates between the colours of the sectors on either side. The signal is easily and intuitively grasped by the mariner. A longer red flash and a shorter white flash means that the mariner is closer to the red sector, and vice versa.

Judging the proportion of time in which each colour is displayed is quite straightforward, and the cycle repeats every three seconds. The oscillating boundary option provides the mariner with a feeling of how the turn is progressing, not as instinctive as the traditional lead but a functional alternative.

Vega of New Zealand has three types of PEL lights (PEL-3, PEL-4 and PEL-6), all of which can provide the oscillating boundary option.

Figure 1 PEL 3 Installation (Courtesy Vega[5])

Figure 2 Light Sectors PEL (Courtesy Vega[5])

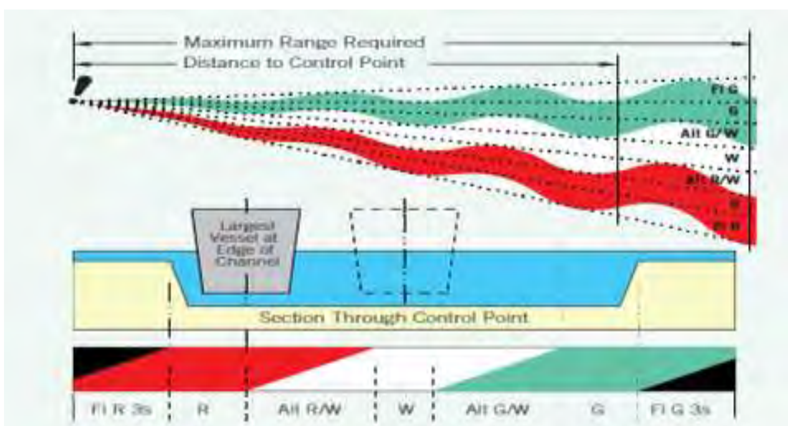


Figure 3 Oscillating Boundary Option (Courtesy Vega[5])

2 CHANNEL DESIGN CRITERIA TO ESTABLISH LEADS

To establish the traditional leads options, the IALA Guideline 1023 *The Design of Leading Lines Edition 1.1 2005* was used. The proposed traditional lead options were tested against this IALA publication in Melbourne by Be-Software. Guideline 1023 uses an excel program Leading Line Design Program V 2.02 E-112-2 (**Table 1**). The PEL (Option 1), where applicable, used the same design channel criteria.

Channel Option 4-2 length	1722 metres
Channel Option 4-2 minimum width	278 metres
Distance between Front and Rear Lead	700 metres Low Leads 1000 metres High Leads 800 metres Water Leads O metres PEL
Distance from Front lead to nearest end of Channel Option 4.2	1352 metres Low Leads 1352 metres High Leads 552 metres Water Leads 552 metres PEL
Mean Range of Tide	2.3 metres
Background Lighting	MINOR
Minimum Visibility	5 nautical miles
Design Visibility	7 nautical miles
Maximum Visibility	10 nautical miles
Safe Height above water	3 metres
Dayshapes Required	YES Low Leads YES High Leads YES Water Leads No PEL
Day Lights Required	YES Low Leads YES High Leads No Water Leads YES PEL
Obstructions	NONE

Table 1

3 PEL (OPTION 1)

The position of the PEL light was tested in this location on the southern edge of Calliope Bank in shallow water shown (See **Figure 4**).

PEL Tower   35 50.375'S   174 31.293'E

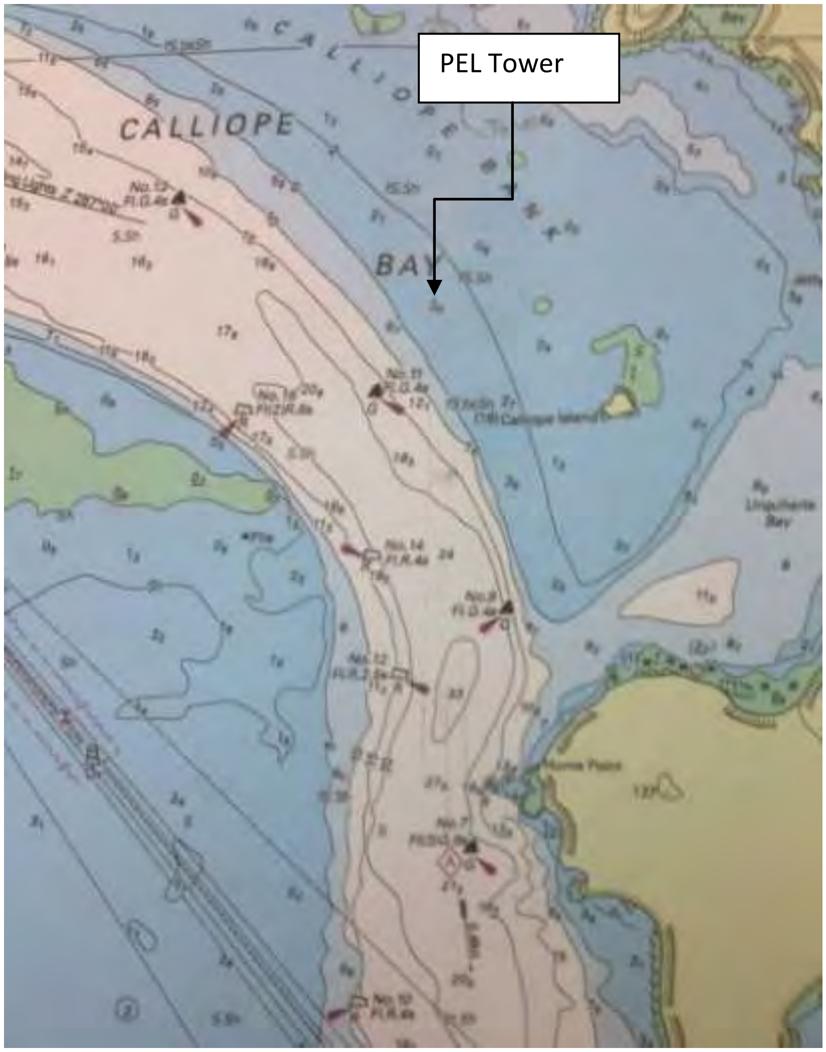


Figure 4

It was assumed the PEL would be mounted on a tower, 15 metres above mean high water.

The PEL can be configured easily to provide for night time operations. To provide daytime operation with a 10 degree arc, the following ranges have been provided by the manufacturer (Vega).

- *PEL-3 10°: about 1.1NM*
- *PEL-4 LED: about 1.7NM*
- *PEL-6 10°: about 1.8NM*

PEL-6 can provide the range coverage just to buoy 3 for daytime operation. Range assumes day ranges T=0.74, with 10kcd/m2 sky luminance (bright cloud and clear sky 1). The atmospheric transmissivity (T) is defined as the transmittance or proportion of light from a source that remains after passing through a specified distance (one nautical mile) through the atmosphere, at sea level [1].

According to the manufacturer, the PEL4 will comfortably be visible at that maximum range.

Power requirements for PEL lights have been provided by the manufacturer Vega:

- *PEL-3: 100W, 12VDC.*
- *PEL-4 LED: about 90W, 12VDC.*
- *PEL-6: 250W, 24VDC.*

It was considered the PEL-4 LED probably represents the best option for PEL if daytime operation is required. The maximum range reaches to halfway between buoy 3 and 5 and is achieved with relatively low power consumption.

Basic sectors were simulated from 173T to 183T and are indicated in the following **Table 2**. The sectors are shown with the ranges (see **Figure 5**).

Sector	Light Colour	Light Characteristic	Significance
173T to 175 T	Green	Fixed	Start of Turn
175T to 177T	Green White	Flashing predominately green	Approach
177T to 179 T	White Green	Flashing predominately white	Close Approach
179T to 181T	White	Fixed	Channel Centreline
181T to 183T	White Red	Flashing predominately white	To west of Centreline

Table 2

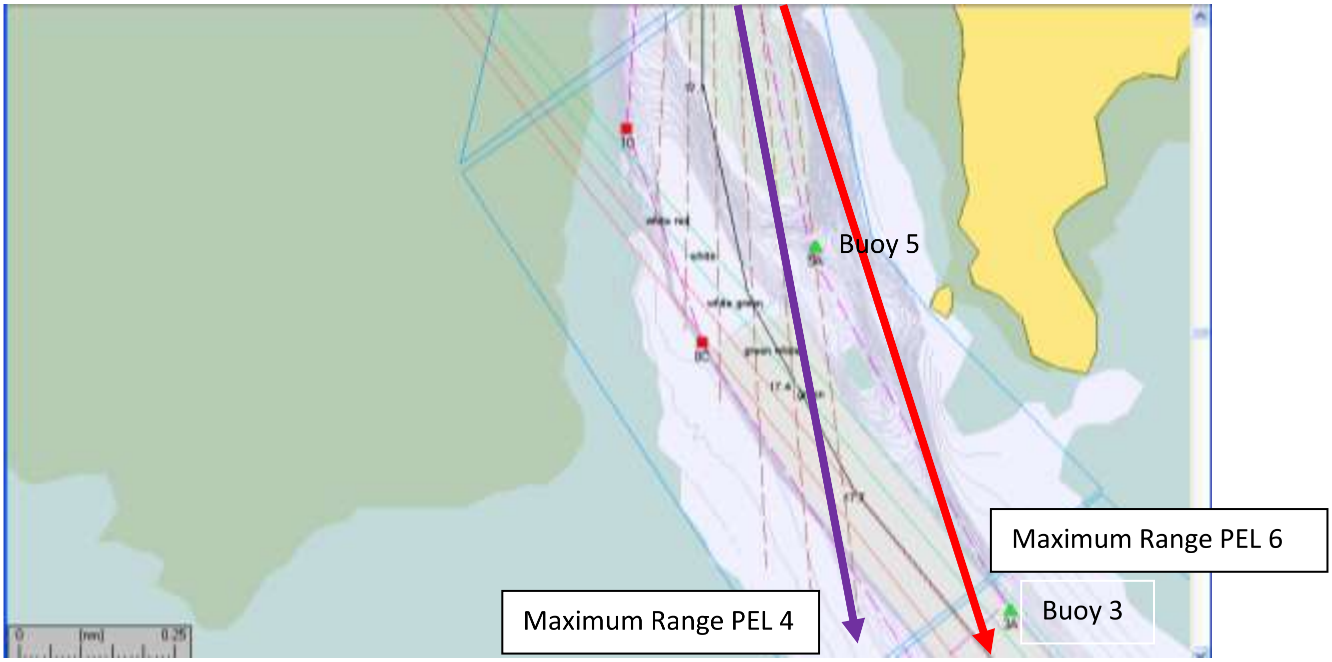


Figure 5

Simulation of the PEL (Option 1) was undertaken for both daytime and night time (See **Figure 6** overleaf, daytime simulation). The simulation showed the ship undertaking the turn from 320T to 000T and the PEL was able to give an indication of the turn progress. Video files of the simulations are included in the electronic version of this report. A PEL 4 light system was simulated.

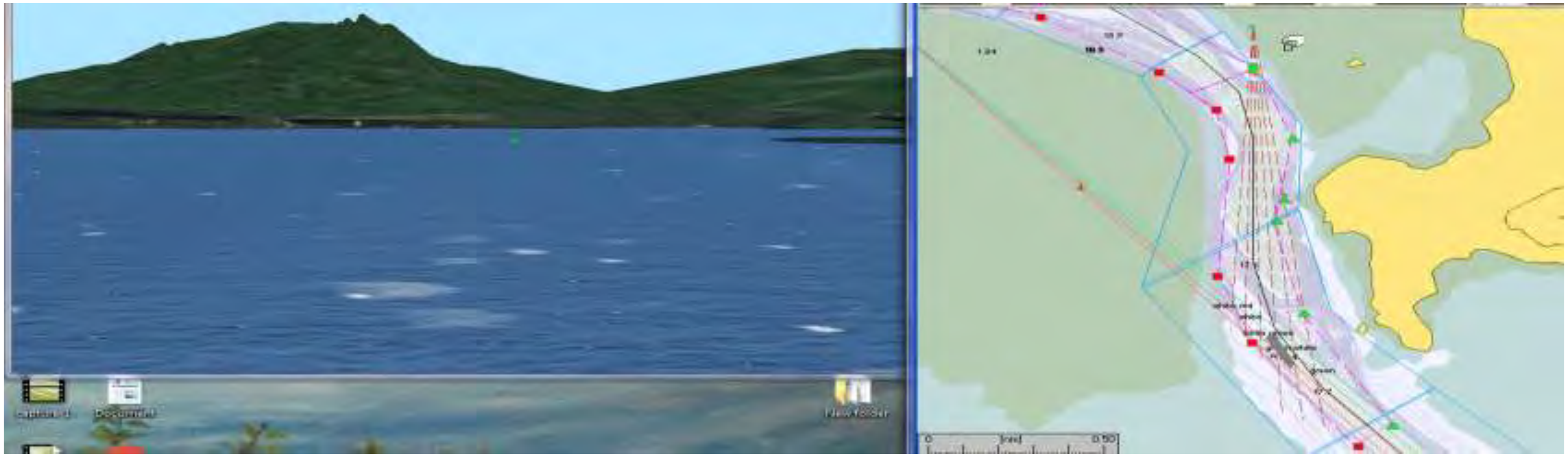


Figure 6

4 LOW LEADS (OPTION 2):

Using the IALA Guideline 1023 The Design of Leading Lines Edition 1.1 2005, the proposed simulated Low Leads (Option 2) were tested against this IALA publication in Melbourne by Be-Software. Guideline 1023 uses an excel program Leading Line Design Program V 2.02 E-112-2 (see detailed results in **Appendix A**). The design criteria were entered into the design program using the following co-ordinates:

Front Lead 35 49.99'S 174 31.293'E

Rear Lead 35 49.63'S 174 31.293'E (see **Figure 7**)

Figure 7

These co-ordinates have the front lead in the shallow water of the Calliope Bank. The rear lead is on the foreshore of Taurikura Bay. This design was tested in detail in the earlier version of this report (*Report of Proposed Taurikura Bay Leads, Revision 1*). The design of the lead lines is viable but it is understood from RNZ that there could be significant concerns with this option in regards to the impact on the community of Taurikura Bay, in particular with the proposed rear lead which is 14 metres in height above MHW on the Taurikura Bay foreshore.

Analysis of Google Earth data (see **Figure 8**) shows the position of the rear lead could be located in front of a set of trees on the foreshore, which may lessen the visual impact. It should be verified by actual survey and, also, to confirm the elevation of the land above Mean High Water. Nevertheless, it is expected there could be community concern with the lead tower in this location.

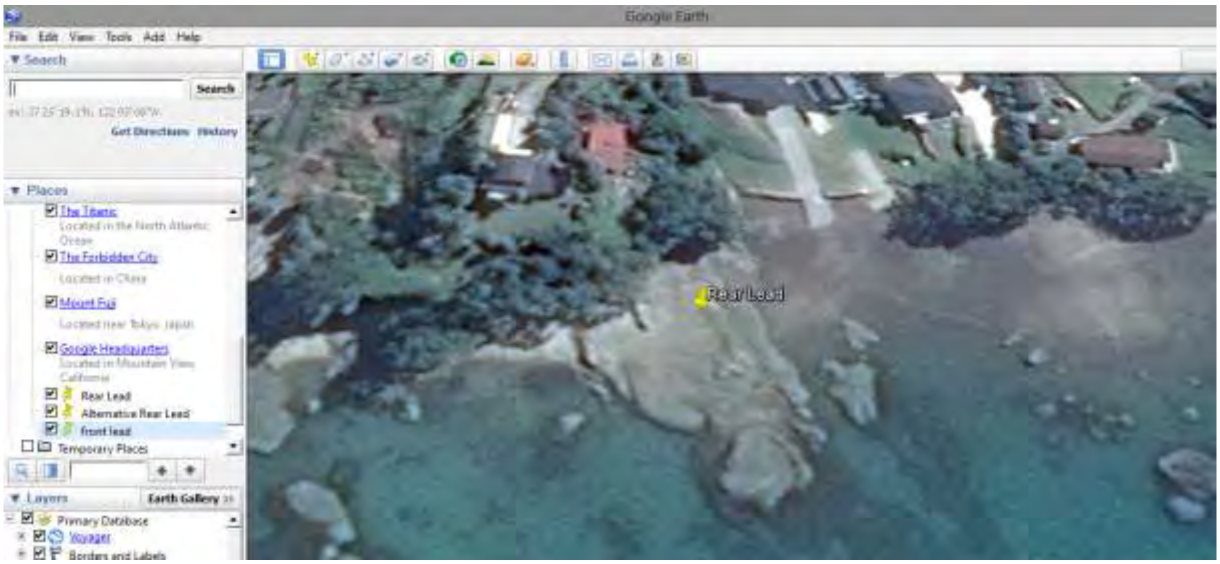
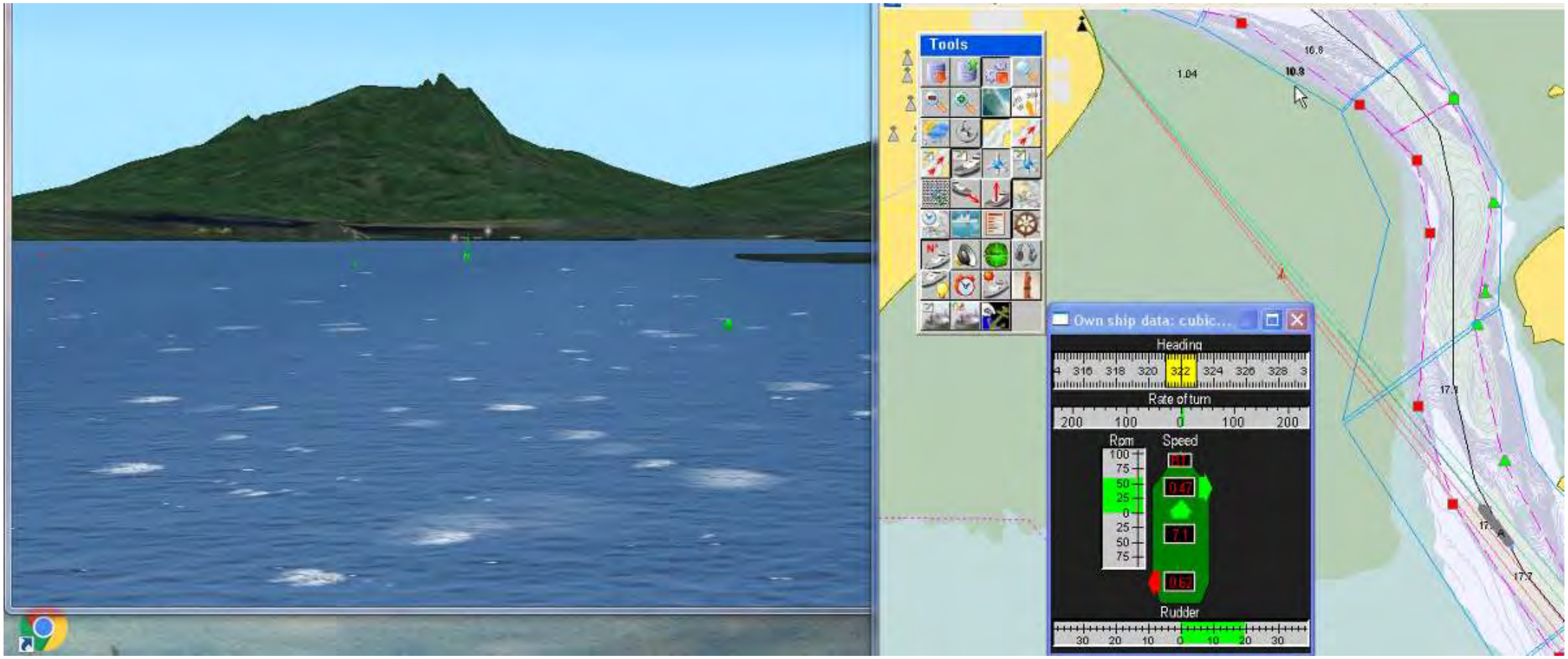


Figure 8

Simulation results for both night time and daylight navigation using the Low Leads were very positive. The daytime navigation simulation is shown (see **Figure 9** overleaf). It was considered that daylights and dayshapes were appropriate and the lights are to be white for both day and night operations.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Heading
Rate of turn
Rpm
Speed
Rudder

Figure 9

5 WATER LEADS (OPTION 3):

An alternative to Low Leads (Option 2) is to establish both the fore and rear lead towers on the Calliope Bank. This may have the advantage of lessening the visual impact on the Taurikura Bay foreshore.

Using the IALA Guideline 1023: *The Design of Leading Lines Edition 1.1 2005*, the proposed simulated leads were tested against this IALA publication in Melbourne by Be-Software. Guideline 1023 uses an excel program Leading Line Design Program V 2.02 E-112-2 (see detailed results in **Appendix A**). The design criteria were entered into the design program using the following co-ordinates:

Front Lead 35 50.375'S 174 31.293'E

Rear Lead 35 49.99'S 174 31.293'E (see **Figure 10**)

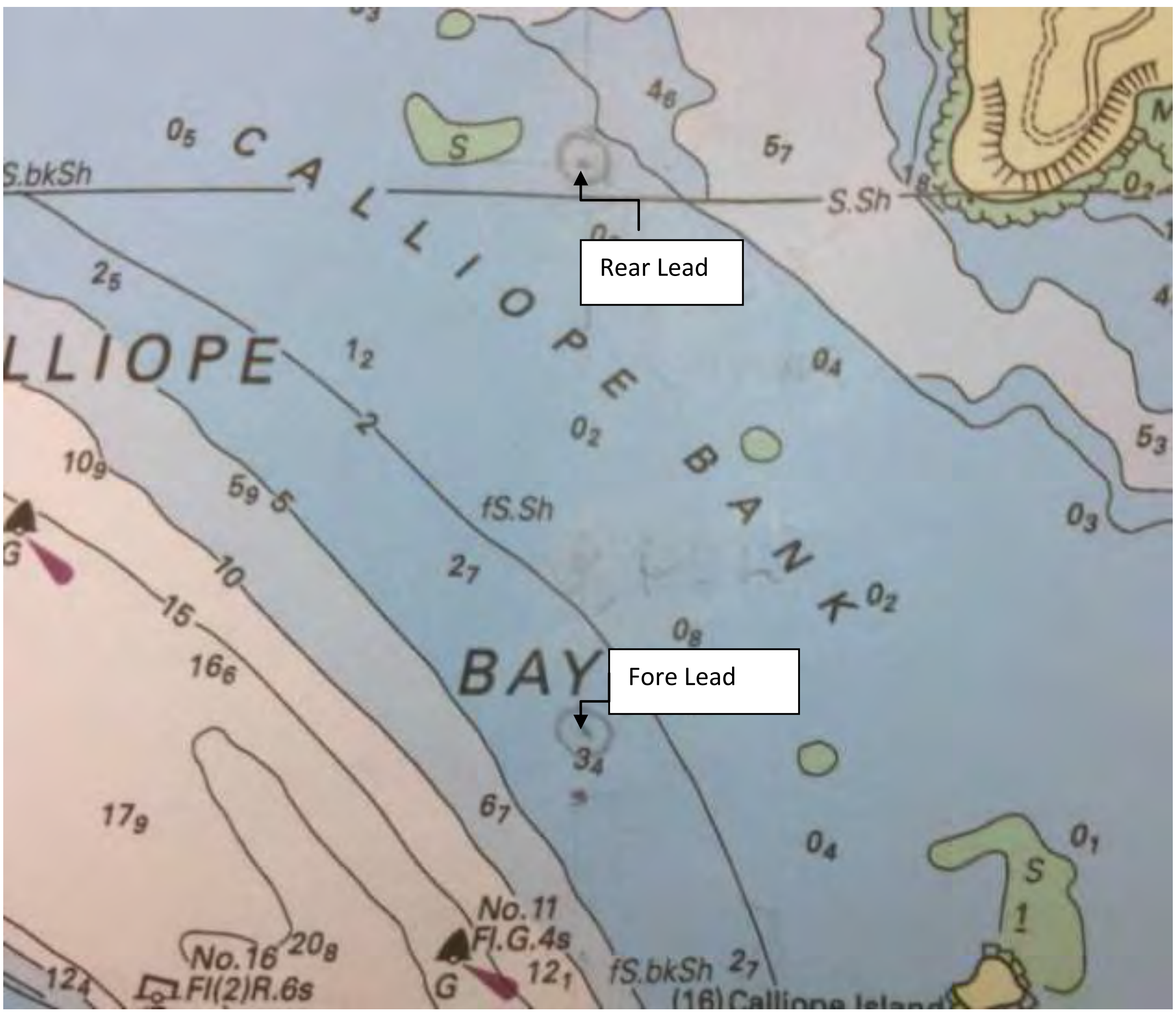


Figure 10

The results of simulation were positive and the leads were found to offer the required sensitivity. The daytime navigation simulation is shown (see **Figure 11** overleaf).

An advantage of having the leads closer to the channel is the possibility to dispense with the daylights and use night lights only. Dayshapes would be required but they would be smaller than for Low Leads (Option 2). Another advantage is the lead towers could be smaller. For the front lead, the tower would be 6 metres above mean high water and the rear lead 13 metres above mean high water. It was considered that buoy 11 would not cause interference with the Leads.

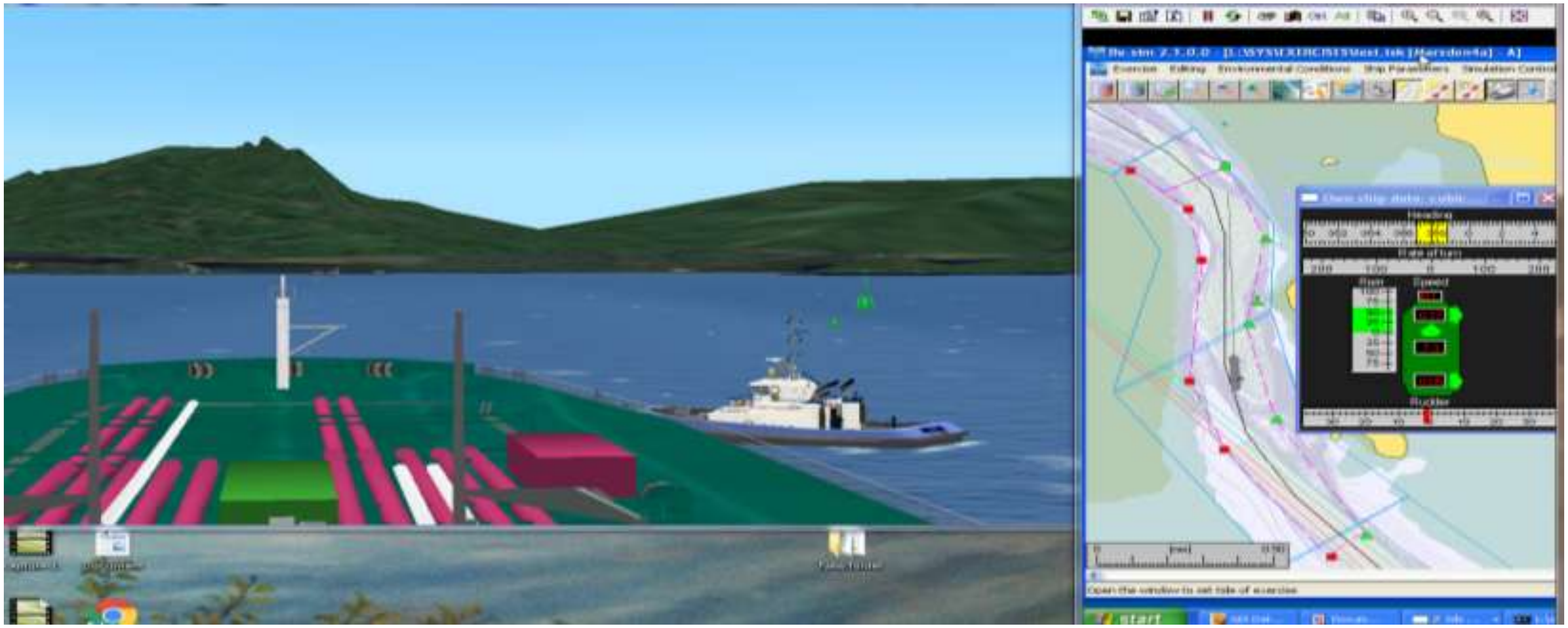


Figure 11

6 HIGH LEADS (OPTION 4):

The final alternative option is to place the rear lead higher up to the north of the housing in Taurikura Bay. Using the IALA Guideline 1023 *The Design of Leading Lines Edition 1.1 2005*, the proposed simulated leads were tested against this IALA publication in Melbourne by Be-Software. Guideline 1023 uses an excel program Leading Line Design Program V 2.02 E-112-2 (see detailed results in **Appendix A**). The design criteria were entered into the design program using the following co-ordinates:

Front Lead 35 49.99'S 174 31.290'E

Rear Lead 35 49.45'S 174 31.290'E (see **Figure 12**)

Figure 12

These co-ordinates have the front lead in the shallow water of the Calliope Bank which is the same for Low Leads (Option 2). The rear lead is on the southern slope of Manaia Mountain, which is an alternative site to that proposed for the rear lead for Low Leads (Option 2).

Analysis of Google Earth data (see **Figure 13**) shows the position of the alternative rear lead could be located in an open area but pushed back against a set of trees which may lessen the visual impact. It should be verified by actual survey in particular the height of the area above mean sea level. From Google Earth, it is assumed the elevation of the location is 35 metres above mean high water. The height of the light was assumed to be 43 metres above mean high water, which gives a tower height of only 8 metres. Nevertheless, it is expected there could still be community concern with the lead tower in this alternative location.

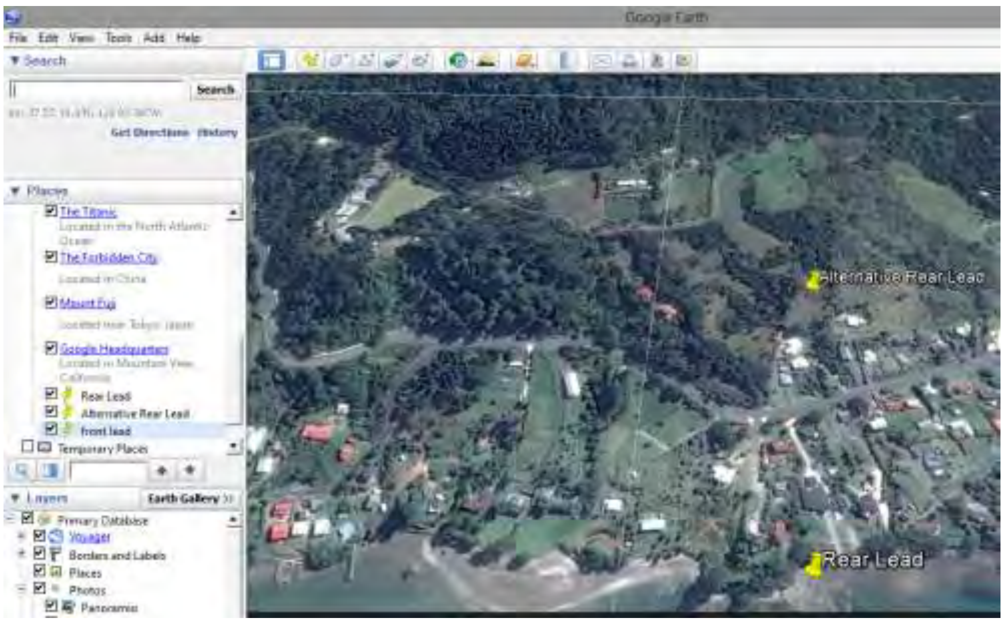
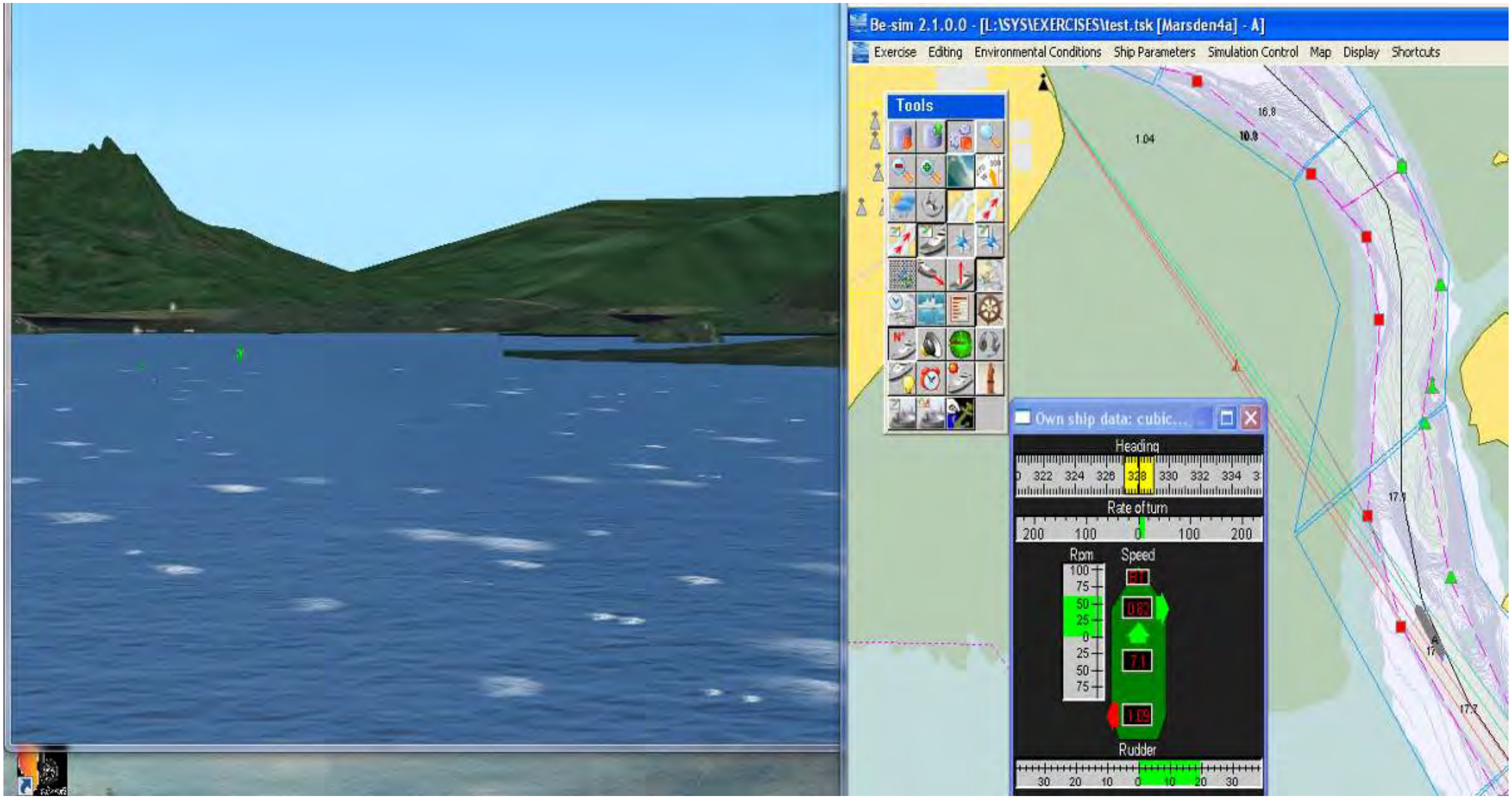


Figure 13

Simulation results for both night time and daylight navigation using the High Leads (Option 4) were positive. The daytime navigation simulation is shown (see **Figure 14** overleaf). It was felt that daylights and dayshapes were appropriate and the lights are to be white for both day and night operations.

The dayshape for the rear lead would be larger and also there is a consideration for power at the rear lead to ensure operation of a light. It may require solar power.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Exercise Editing Environmental Conditions Ship Parameters Simulation Control Map Display Shortcuts
Tools
Own ship data: cubic...
Heading
Rate of turn
Rpm
Speed
Rudder

Figure 14

7 SIMULATION RESULTS

The proposed leads were placed in the Be-Software ***Lanterna*** simulator for both night time and daytime simulation of the leads, dayshapes and lights. White, red and blue lights were tested for night time operations. Day time operations were tested with dayshapes only and also with dayshapes and white daylights. A number of video files were produced and are included in the electronic version of this document.

From the simulation for traditional lead options, it was considered the white lights were superior at night but blue or red would also be adequate. Blue or red offer some advantages with some background lights in the vicinity. By day, the dayshapes and daylight (white) were considered superior to dayshapes only.

For the simulation of the PEL (Option 1), a PEL4 system was simulated with an arc of visibility of 10 degrees.

Both day and night time simulations were conducted. A comparison of the lead options that were simulated is as shown in **Table 3**.

Lead Option	Tower Size	Day Shapes Height	Daylights Available	Community Concerns	Power Supply	Distance off centreline available	Indications of progress of turn
PEL Option1	15m or perhaps lower Single	no	Yes	Minimal	Solar	Yes	Adequate with boundary oscillation
Low Leads Option 2	7m FL 14m RL	3m FL 3m RL	Yes	Highly likely	Solar plus Shore	No	Very Good
Water Leads Option 3	6m FL 13m RL	2.1m FL 2.5m RL	May not be required	Less likely	Solar	No	Good
High Leads Option 4	7 m FL 8 m RL needs verifying	3m FL 4m RL	Yes	Likely	Solar Perhaps Shore	No	Good

Table 3

8 RECOMMENDATIONS AND CONCLUSIONS

All the proposed Leads Options are viable. It is recommended that

- The back ground lighting on the foreshore of Taurikura Bay and the isolated danger buoy in Taurikura Bay should be checked at night for intensity. It is assumed the lights are fairly weak however, a nighttime photo or video of the region taken from a ship can verify this.
- It is assumed that Calliope Bank is stable enough for establishment of a tower structure. This should be verified.
- It is assumed that approvals can be obtained for the establishment of lead towers in the positions indicated in this report.
- Final intensity of Traditional Lights should be verified using IALA program Leading Line Design Program V 2.02 E-112-2 to confirm the lights do not merge over the usable segment of the Channel Option 4-2.This report has used light intensities based on recommended values for the night and the day lights.
- The report assumes a height of eye of the observer at 8 metres, 15 metres and 25 metres. The lights were found to be usable from observer heights of eye above 7 metres. Below 7 metres the lights will blur in the channel for the traditional lead options.
- The land based Traditional Lead Options (2 and 4) will need surveying prior to a decision on tower size due to uncertainty in the elevation of the land in the positions proposed in this report.
- Either the PEL (Option 1) using a PEL4 LED system or the Water Leads (Option 3) are the most suitable for covering the mid channel segment of Channel Option 4-2 between buoys 3 /6 and 14.
- The PEL (Option 1) is working at maximum range by day to provide coverage in the critical approach to the channel; however it offers more information to the mariner. Using a PEL6 will marginally increase the range but at greater cost in terms of solar power configuration. According to the manufacturer Vega, the PEL4 will be comfortably visible at the maximum range.
- It was considered that white lights offered the best visibility by night.
- It was considered that buoy 11 would not cause interference with the Leads Option (1) or Leads Option (3) by day or by night.

9 REFERENCES

1. IALA Aids to Navigation Guide

2. IALA Guideline 1023 The Design of Leading Lines

3. IALA Guideline 1041 On Sector Lights

4. IALA Guideline 1043 Light Sources Used in Visual Aids to Navigation

5. Vega PEL Sector Lights

6. Vega PEL 4 Precision LED sector light http://www.vega.co.nz/shop/pel-4/

7. IALA Leading Line Design Programme V2.02 E-112-2

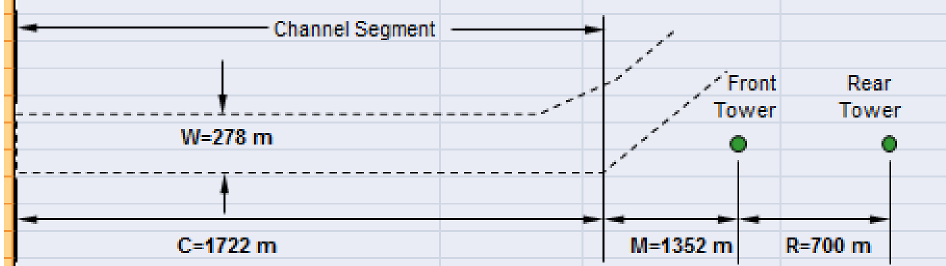
APPENDIX A: IALA PROGRAM LEADING LINE DESIGN PROGRAM V 2.02 E-112-2 OUTPUTS

Low Leads (Option 2) output: Final Configuration IALA program Leading Line Design Program V 2.02 E-112-2.

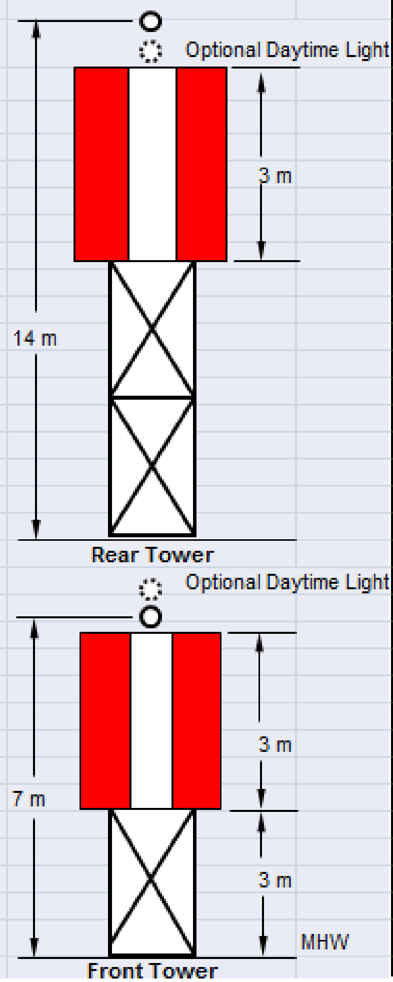
Final Leading Line Configuration

Leading Line Name: **Channel Option 4-2 Marsden Point**

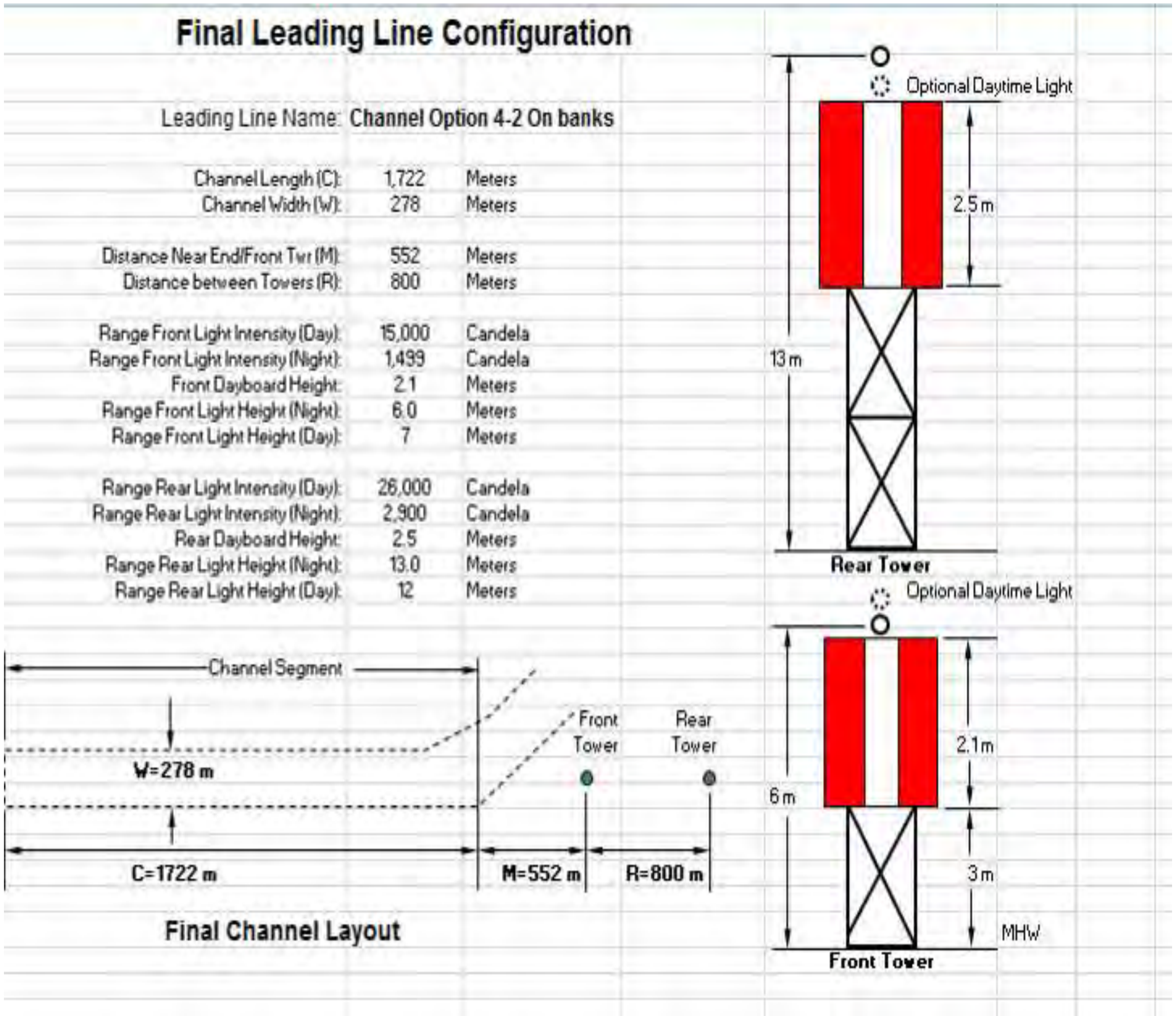
Channel Length (C):	1,722	Meters
Channel Width (W):	278	Meters
Distance Near End/Front Twr (M):	1,352	Meters
Distance between Towers (R):	700	Meters
Range Front Light Intensity (Day):	30,000	Candela
Range Front Light Intensity (Night):	2,555	Candela
Front Dayboard Height:	3.0	Meters
Range Front Light Height (Night):	7.0	Meters
Range Front Light Height (Day):	8	Meters
Range Rear Light Intensity (Day):	50,000	Candela
Range Rear Light Intensity (Night):	5,200	Candela
Rear Dayboard Height:	3.0	Meters
Range Rear Light Height (Night):	14.0	Meters
Range Rear Light Height (Day):	13	Meters



Final Channel Layout



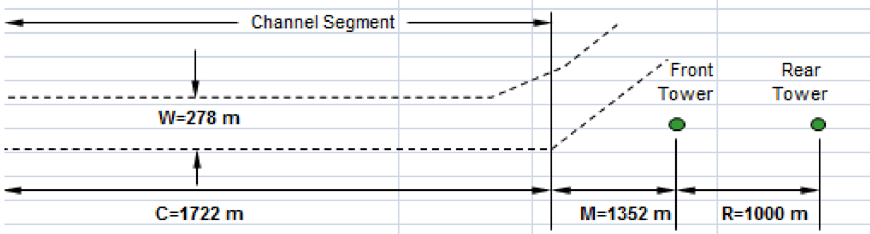
Water Leads (Option 3) output: Final Configuration IALA program Leading Line Design Program V 2.02 E-112-2.



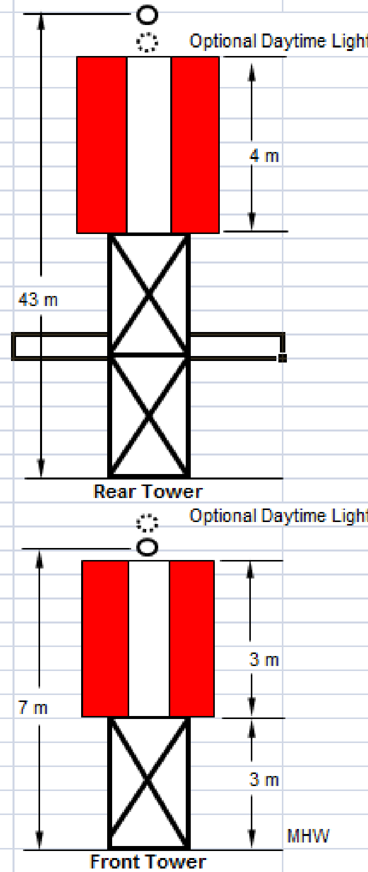
High Leads (Option 4) outputs: Daylights IALA program Leading Line Design Program V 2.02 E-112-2.

Final Leading Line Configuration

Leading Line Name:	**Option 4 High Leads**	
Channel Length (C):	1,722	Meters
Channel Width (W):	278	Meters
Distance Near End/Front Twr (M):	1,352	Meters
Distance between Towers (R):	1,000	Meters
Range Front Light Intensity (Day):	30,000	Candela
Range Front Light Intensity (Night):	2,600	Candela
Front Dayboard Height:	3.0	Meters
Range Front Light Height (Night):	7.0	Meters
Range Front Light Height (Day):	8	Meters
Range Rear Light Intensity (Day):	63,000	Candela
Range Rear Light Intensity (Night):	5,200	Candela
Rear Dayboard Height:	4.0	Meters
Range Rear Light Height (Night):	43.0	Meters
Range Rear Light Height (Day):	42	Meters



Final Channel Layout



APPENDIX E: Revised PIANC Channel Design Calculations

PIANC (2014) CHANNEL WIDTH ASSESSMENT
OPTION 2 CHANNEL DESIGN
REACH 1: Fairway Buoy to Buoy 1/2

INPUT DATA

Parameter	Value	Unit	Comment	Source
Vessel Type	Tanker	n/a		
Vessel Size Class	Suezmax	n/a		OMC, 2015
Vessel Dead Weight Tonnage (DWT)	159,057	tonnes		OMC, 2015
Vessel Beam (B)	50	m		OMC, 2015
Vessel Length Overall (LOA)	276	m		OMC, 2015
Vessel Length Between Perpendiculars (LBP)	264	m		OMC, 2015
Vessel Draft (T)	17.02	m	summer draft	OMC, 2015
Channel Design Level	-18.19	m CD	95% Access, minimum channel design level in Reach 1	OMC, 2015
Mean High Water Neap (MHWN) tide level	2.32	m CD		Tonkin & Taylor, 2015
Channel Type	Outer Channel	n/a	"Outer Channel" = open water, "Inner Channel" = protected water	PIANC, 2014
Passing	One-way	n/a	"Two-way" or One-way"	
Vessel Manoeuvrability	Poor	n/a	"Poor" = tankers/bulk carriers	PIANC, 2014
			"Moderate" = container vessels/car carriers/RoRo vessels/LNG&LPG vessels	PIANC, 2014
			"Good" = twin propeller ships/ferries/cruise vessels	PIANC, 2014
(a) Vessel Speed (V_s)	6.8	knots	"average" speed profile, varies from 6kts at Fairway Buoy to 6.8kts at Buoy 1/2	OMC, 2015
(b) Prevailing cross wind (V_{cw})	20	knots	"Mild" V_{cw}<15 knots, "Moderate" 15 knots <=V_{cw}<33 knots, "Strong" V_{cw}>33 knots	Marsden Point, 5% annual exceedance wind speed 10m/s, MetOcean Solutions measured data
(c) Prevailing cross current (V_{cc})	0.3	knots	"Negligible" V_{cc}<0.2 knots, "Low" 0.2 knots<=V_{cc}<0.5 knots, "Moderate" 0.5 knots<=V_{cc}<1.5 knots, "Strong" V_{cc}>=1.5 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(d) Prevailing longitudinal current (V_{lc})	0.4	knots	"Low" V_{lc}<1.5 knots, "Moderate" 1.5 knots<=V_{lc}<3 knots, "Strong" V_{lc}>=3 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(e) Beam and stern quartering wave height (H_s)	2.4	m	"Hs<=1m", "1m<Hs<3m", "Hs>=3m"	OMC, 2015 99th percentile swell data
(f) Aids to Navigation	Good	n/a	"Excellent" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots, DGPS and Electronic Chart Display and Information System (ECDIS)	PIANC, 2014
			"Good" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots and DGPS	PIANC, 2014
			"Moderate" = anything less than the facilities mentioned above	PIANC, 2014
(g) Bottom Surface	smooth and soft	n/a	"smooth and soft" or "rough and hard"	PIANC, 2014
(h) Depth of waterway (h)	20.51	m	at Mean High Water Neap tide (MHWN)	
Depth to Draft Ratio (h/T)	1.21	n/a		
Channel slope	sloping channel edges and shoals	n/a	"gentle underwater channel slope (1:10 or less steep)" or "sloping channel edges and shoals" or "steep and hard embankments, structures"	PIANC, 2014

CHANNEL WIDTH CALCULATION

Parameter	Beam (B) Multiplier	Category	Comment	Source
Basic Manoeuvring Lane (W_{BM})	1.8	Poor	"Good" = 1.3B, "Moderate" = 1.5B, "Poor" = 1.8B (Table 3.4)	PIANC, 2014
(a) Vessel Speed (V_s)	0.0	Slow	"Fast" V_s>12 = 0.1B, "Moderate" 8<V_s<12 = 0.0B, "Slow" 5<V_s<8 = 0.0B (Table 3.5(a))	PIANC, 2014
(b) Prevailing cross wind (V_{cw})	0.6	Moderate	See Table 3.5(b)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Outer Channel]	0.3	Low	See Table 3.5(c)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Inner Channel]	0.3	Low	See Table 3.5(c)	PIANC, 2014
(d) Prevailing longitudinal current (V_{lc})	0.0	Low	See Table 3.5(d)	PIANC, 2014
(e) Beam and stern quartering wave height (H_s)	0.5	1m<Hs<3m	Hs<=1m = 0.0B, 1m<Hs<3m = 0.5B, Hs>=3m = 1.0B (Table 3.5(e))	PIANC, 2014
(f) Aids to Navigation	0.2	Good	See Table 3.5(f)	PIANC, 2014
(g) Bottom Surface	0.1	h<1.5T	See Table 3.5(g)	PIANC, 2014
(h) Depth of waterway (h) [Outer Channel]	0.2	h<1.25T	See Table 3.5(h)	PIANC, 2014
(h) Depth of waterway (h) [Inner Channel]	0.2	1.15T<=h<1.5T	See Table 3.5(h)	PIANC, 2014
Width for Bank Clearance (W_B)	0.3	sloping channel edges and shoals	See Table 3.6	PIANC, 2014
Additional Width for Channel Passing (W_p)	0.0	Not Required	See Table 3.7	PIANC, 2014

Total Channel Width [Outer Channel]	4.3	B
Total Channel Width [Outer Channel]	**215**	**m**
Total Channel Width [Inner Channel]	4.3	B
Total Channel Width [Inner Channel]	**215**	**m**

PIANC (2014) CHANNEL WIDTH ASSESSMENT
OPTION 2 CHANNEL DESIGN
REACH 2: Buoy 1/2 to Buoy 3/6

INPUT DATA

Parameter	Value	Unit	Comment	Source
Vessel Type	Tanker	n/a		
Vessel Size Class	Suezmax	n/a		OMC, 2015
Vessel Dead Weight Tonnage (DWT)	159,057	tonnes		OMC, 2015
Vessel Beam (B)	50	m		OMC, 2015
Vessel Length Overall (LOA)	276	m		OMC, 2015
Vessel Length Between Perpendiculars (LBP)	264	m		OMC, 2015
Vessel Draft (T)	17.02	m	summer draft	OMC, 2015
Channel Design Level	-17.65	m CD	95% Access, minimum channel design level in Reach 2	OMC, 2015
Mean High Water Neap (MHWN) tide level	2.32	m CD		Tonkin & Taylor, 2015
Channel Type	Outer Channel	n/a	"Outer Channel" = open water, "Inner Channel" = protected water	PIANC, 2014
Passing	One-way	n/a	"Two-way" or One-way"	
Vessel Manoeuvrability	Poor	n/a	"Poor" = tankers/bulk carriers	PIANC, 2014
			"Moderate" = container vessels/car carriers/RoRo vessels/LNG&LPG vessels	PIANC, 2014
			"Good" = twin propeller ships/ferries/cruise vessels	PIANC, 2014
(a) Vessel Speed (V_s)	7.5	knots	"average" speed profile, varies from 6.8kts at Buoy 1/2 to 7.5kts at Buoy 3/6	OMC, 2015
(b) Prevailing cross wind (V_{cw})	20	knots	"Mild" V_{cw}<15 knots, "Moderate" 15 knots <=V_{cw}<33 knots, "Strong" V_{cw}>33 knots	Marsden Point, 5% annual exceedance wind speed 10m/s, MetOcean Solutions measured data
(c) Prevailing cross current (V_{cc})	0.3	knots	"Negligible" V_{cc}<0.2 knots, "Low" 0.2 knots<=V_{cc}<0.5 knots, "Moderate" 0.5 knots<=V_{cc}<1.5 knots, "Strong" V_{cc}>=1.5 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(d) Prevailing longitudinal current (V_{lc})	0.4	knots	"Low" V_{lc}<1.5 knots, "Moderate" 1.5 knots<=V_{lc}<3 knots, "Strong" V_{lc}>=3 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(e) Beam and stern quartering wave height (H_s)	1.9	m	"Hs<=1m", "1m<Hs<3m", "Hs>=3m"	OMC, 2015 99th percentile swell data
(f) Aids to Navigation	Good	n/a	"Excellent" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots, DGPS and Electronic Chart Display and Information System (ECDIS)	PIANC, 2014
			"Good" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots and DGPS	PIANC, 2014
			"Moderate" = anything less than the facilities mentioned above	PIANC, 2014
(g) Bottom Surface	smooth and soft	n/a	"smooth and soft" or "rough and hard"	PIANC, 2014
(h) Depth of waterway (h)	19.97	m	at Mean High Water Neap tide (MHWN)	
Depth to Draft Ratio (h/T)	1.17	n/a		
Channel slope	sloping channel edges and shoals	n/a	"gentle underwater channel slope (1:10 or less steep)" or "sloping channel edges and shoals" or "steep and hard embankments, structures"	PIANC, 2014

CHANNEL WIDTH CALCULATION

Parameter	Beam (B) Multiplier	Category	Comment	Source
Basic Manoeuvring Lane (W_{BM})	1.8	Poor	"Good" = 1.3B, "Moderate" = 1.5B, "Poor" = 1.8B (Table 3.4)	PIANC, 2014
(a) Vessel Speed (V_s)	0.0	Slow	"Fast" V_s>12 = 0.1B, "Moderate" 8<V_s<12 = 0.0B, "Slow" 5<V_s<8 = 0.0B (Table 3.5(a))	PIANC, 2014
(b) Prevailing cross wind (V_{cw})	0.6	Moderate	See Table 3.5(b)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Outer Channel]	0.3	Low	See Table 3.5(c)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Inner Channel]	0.3	Low	See Table 3.5(c)	PIANC, 2014
(d) Prevailing longitudinal current (V_{lc})	0.0	Low	See Table 3.5(d)	PIANC, 2014
(e) Beam and stern quartering wave height (H_s)	0.5	1m<Hs<3m	Hs<=1m = 0.0B, 1m<Hs<3m = 0.5B, Hs>=3m = 1.0B (Table 3.5(e))	PIANC, 2014
(f) Aids to Navigation	0.2	Good	See Table 3.5(f)	PIANC, 2014
(g) Bottom Surface	0.1	h<1.5T	See Table 3.5(g)	PIANC, 2014
(h) Depth of waterway (h) [Outer Channel]	0.2	h<1.25T	See Table 3.5(h)	PIANC, 2014
(h) Depth of waterway (h) [Inner Channel]	0.2	1.15T<=h<1.5T	See Table 3.5(h)	PIANC, 2014
Width for Bank Clearance (W_B)	0.3	sloping channel edges and shoals	See Table 3.6	PIANC, 2014
Additional Width for Channel Passing (W_p)	0.0	Not Required	See Table 3.7	PIANC, 2014

Total Channel Width [Outer Channel]	4.3	B
Total Channel Width [Outer Channel]	**215**	**m**
Total Channel Width [Inner Channel]	4.3	B
Total Channel Width [Inner Channel]	**215**	**m**

PIANC (2014) CHANNEL WIDTH ASSESSMENT
OPTION 2 CHANNEL DESIGN
REACH 3: Buoy 3/6 to Buoy 7

INPUT DATA

Parameter	Value	Unit	Comment	Source
Vessel Type	Tanker	n/a		
Vessel Size Class	Suezmax	n/a		OMC, 2015
Vessel Dead Weight Tonnage (DWT)	159,057	tonnes		OMC, 2015
Vessel Beam (B)	50	m		OMC, 2015
Vessel Length Overall (LOA)	276	m		OMC, 2015
Vessel Length Between Perpendiculars (LBP)	264	m		OMC, 2015
Vessel Draft (T)	17.02	m	summer draft	OMC, 2015
Channel Design Level	-16.87	m CD	95% Access, minimum channel design level in Reach 3	OMC, 2015
Mean High Water Neap (MHWN) tide level	2.32	m CD		Tonkin & Taylor, 2015
Channel Type	Outer Channel	n/a	"Outer Channel" = open water, "Inner Channel" = protected water	PIANC, 2014
Passing	One-way	n/a	"Two-way" or One-way"	
Vessel Manoeuvrability	Poor	n/a	"Poor" = tankers/bulk carriers	PIANC, 2014
			"Moderate" = container vessels/car carriers/RoRo vessels/LNG&LPG vessels	PIANC, 2014
			"Good" = twin propeller ships/ferries/cruise vessels	PIANC, 2014
(a) Vessel Speed (V_s)	7.5	knots	"average" speed profile, varies from 7.5kts at Buoy 3/6 to 7.3kts at Buoy 7	OMC, 2015
(b) Prevailing cross wind (V_{cw})	20	knots	"Mild" V_{cw}<15 knots, "Moderate" 15 knots <=V_{cw}<33 knots, "Strong" V_{cw}>33 knots	Marsden Point, 5% annual exceedance wind speed 10m/s, MetOcean Solutions measured data
(c) Prevailing cross current (V_{cc})	0.3	knots	"Negligible" V_{cc}<0.2 knots, "Low" 0.2 knots<=V_{cc}<0.5 knots, "Moderate" 0.5 knots<=V_{cc}<1.5 knots, "Strong" V_{cc}>=1.5 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(d) Prevailing longitudinal current (V_{lc})	1.3	knots	"Low" V_{lc}<1.5 knots, "Moderate" 1.5 knots<=V_{lc}<3 knots, "Strong" V_{lc}>=3 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(e) Beam and stern quartering wave height (H_s)	0.9	m	"Hs<=1m", "1m<Hs<3m", "Hs>=3m"	OMC, 2015 99th percentile swell data
(f) Aids to Navigation	Good	n/a	"Excellent" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots, DGPS and Electronic Chart Display and Information System (ECDIS)	PIANC, 2014
			"Good" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots and DGPS	PIANC, 2014
			"Moderate" = anything less than the facilities mentioned above	PIANC, 2014
(g) Bottom Surface	smooth and soft	n/a	"smooth and soft" or "rough and hard"	PIANC, 2014
(h) Depth of waterway (h)	19.19	m	at Mean High Water Neap tide (MHWN)	
Depth to Draft Ratio (h/T)	1.13	n/a		
Channel slope	sloping channel edges and shoals	n/a	"gentle underwater channel slope (1:10 or less steep)" or "sloping channel edges and shoals" or "steep and hard embankments, structures"	PIANC, 2014

CHANNEL WIDTH CALCULATION

Parameter	Beam (B) Multiplier	Category	Comment	Source
Basic Manoeuvring Lane (W_{BM})	1.8	Poor	"Good" = 1.3B, "Moderate" = 1.5B, "Poor" = 1.8B (Table 3.4)	PIANC, 2014
(a) Vessel Speed (V_s)	0.0	Slow	"Fast" V_s>12 = 0.1B, "Moderate" 8<V_s<12 = 0.0B, "Slow" 5<V_s<8 = 0.0B (Table 3.5(a))	PIANC, 2014
(b) Prevailing cross wind (V_{cw})	0.6	Moderate	See Table 3.5(b)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Outer Channel]	0.3	Low	See Table 3.5(c)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Inner Channel]	0.3	Low	See Table 3.5(c)	PIANC, 2014
(d) Prevailing longitudinal current (V_{lc})	0.0	Low	See Table 3.5(d)	PIANC, 2014
(e) Beam and stern quartering wave height (H_s)	0.0	Hs<=1	Hs<=1m = 0.0B, 1m<Hs<3m = 0.5B, Hs>=3m = 1.0B (Table 3.5(e))	PIANC, 2014
(f) Aids to Navigation	0.2	Good	See Table 3.5(f)	PIANC, 2014
(g) Bottom Surface	0.1	h<1.5T	See Table 3.5(g)	PIANC, 2014
(h) Depth of waterway (h) [Outer Channel]	0.2	h<1.25T	See Table 3.5(h)	PIANC, 2014
(h) Depth of waterway (h) [Inner Channel]	0.4	h<1.15T	See Table 3.5(h)	PIANC, 2014
Width for Bank Clearance (W_B)	0.3	sloping channel edges and shoals	See Table 3.6	PIANC, 2014
Additional Width for Channel Passing (W_p)	0.0	Not Required	See Table 3.7	PIANC, 2014

Total Channel Width [Outer Channel]	3.8	B
Total Channel Width [Outer Channel]	**190**	**m**
Total Channel Width [Inner Channel]	4.0	B
Total Channel Width [Inner Channel]	**200**	**m**

PIANC (2014) CHANNEL WIDTH ASSESSMENT
OPTION 2 CHANNEL DESIGN
REACH 4: Buoy 7 to Buoy 14

INPUT DATA

Parameter	Value	Unit	Comment	Source
Vessel Type	Tanker	n/a		
Vessel Size Class	Suezmax	n/a		OMC, 2015
Vessel Dead Weight Tonnage (DWT)	159,057	tonnes		OMC, 2015
Vessel Beam (B)	50	m		OMC, 2015
Vessel Length Overall (LOA)	276	m		OMC, 2015
Vessel Length Between Perpendiculars (LBP)	264	m		OMC, 2015
Vessel Draft (T)	17.02	m	summer draft	OMC, 2015
Channel Design Level	-16.86	m CD	95% Access, minimum channel design level in Reach 4	OMC, 2015
Mean High Water Neap (MHWN) tide level	2.32	m CD		Tonkin & Taylor, 2015
Channel Type	Inner Channel	n/a	"Outer Channel" = open water, "Inner Channel" = protected water	PIANC, 2014
Passing	One-way	n/a	"Two-way" or One-way"	
Vessel Manoeuvrability	Poor	n/a	"Poor" = tankers/bulk carriers	PIANC, 2014
			"Moderate" = container vessels/car carriers/RoRo vessels/LNG&LPG vessels	PIANC, 2014
			"Good" = twin propeller ships/ferries/cruise vessels	PIANC, 2014
(a) Vessel Speed (V_s)	7.3	knots	"average" speed profile, varies from 7.3kts at Buoy 7 to 6.8kts at Buoy 14	OMC, 2015
(b) Prevailing cross wind (V_{cw})	20	knots	"Mild" V_{cw}<15 knots, "Moderate" 15 knots <=V_{cw}<33 knots, "Strong" V_{cw}>33 knots	Marsden Point, 5% annual exceedance wind speed 10m/s, MetOcean Solutions measured data
(c) Prevailing cross current (V_{cc})	0.5	knots	"Negligible" V_{cc}<0.2 knots, "Low" 0.2 knots<=V_{cc}<0.5 knots, "Moderate" 0.5 knots<=V_{cc}<1.5 knots, "Strong" V_{cc}>=1.5 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(d) Prevailing longitudinal current (V_{lc})	1.5	knots	"Low" V_{lc}<1.5 knots, "Moderate" 1.5 knots<=V_{lc}<3 knots, "Strong" V_{lc}>=3 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(e) Beam and stern quartering wave height (H_s)	0.6	m	"Hs<=1m", "1m<Hs<3m", "Hs>=3m"	OMC, 2015 99th percentile swell data
(f) Aids to Navigation	Good	n/a	"Excellent" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots, DGPS and Electronic Chart Display and Information System (ECDIS)	PIANC, 2014
			"Good" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots and DGPS	PIANC, 2014
			"Moderate" = anything less than the facilities mentioned above	PIANC, 2014
(g) Bottom Surface	smooth and soft	n/a	"smooth and soft" or "rough and hard"	PIANC, 2014
(h) Depth of waterway (h)	19.18	m	at Mean High Water Neap tide (MHWN)	
Depth to Draft Ratio (h/T)	1.13	n/a		
Channel slope	sloping channel edges and shoals	n/a	"gentle underwater channel slope (1:10 or less steep)" or "sloping channel edges and shoals" or "steep and hard embankments, structures"	PIANC, 2014

CHANNEL WIDTH CALCULATION

Parameter	Beam (B) Multiplier	Category	Comment	Source
Basic Manoeuvring Lane (W_{BM})	1.8	Poor	"Good" = 1.3B, "Moderate" = 1.5B, "Poor" = 1.8B (Table 3.4)	PIANC, 2014
(a) Vessel Speed (V_s)	0.0	Slow	"Fast" V_s>12 = 0.1B, "Moderate" 8<V_s<12 = 0.0B, "Slow" 5<V_s<8 = 0.0B (Table 3.5(a))	PIANC, 2014
(b) Prevailing cross wind (V_{cw})	0.6	Moderate	See Table 3.5(b)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Outer Channel]	0.3	Low	See Table 3.5(c)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Inner Channel]	0.3	Low	See Table 3.5(c)	PIANC, 2014
(d) Prevailing longitudinal current (V_{lc})	0.2	Moderate	See Table 3.5(d)	PIANC, 2014
(e) Beam and stern quartering wave height (H_s)	0.0	Hs<=1	Hs<=1m = 0.0B, 1m<Hs<3m = 0.5B, Hs>=3m = 1.0B (Table 3.5(e))	PIANC, 2014
(f) Aids to Navigation	0.2	Good	See Table 3.5(f)	PIANC, 2014
(g) Bottom Surface	0.1	h<1.5T	See Table 3.5(g)	PIANC, 2014
(h) Depth of waterway (h) [Outer Channel]	0.2	h<1.25T	See Table 3.5(h)	PIANC, 2014
(h) Depth of waterway (h) [Inner Channel]	0.4	h<1.15T	See Table 3.5(h)	PIANC, 2014
Width for Bank Clearance (W_B)	0.3	sloping channel edges and shoals	See Table 3.6	PIANC, 2014
Additional Width for Channel Passing (W_p)	0.0	Not Required	See Table 3.7	PIANC, 2014

Total Channel Width [Outer Channel]	4.0	B
Total Channel Width [Outer Channel]	**200**	**m**
Total Channel Width [Inner Channel]	4.2	B
Total Channel Width [Inner Channel]	**210**	**m**

PIANC (2014) CHANNEL WIDTH ASSESSMENT
OPTION 2 CHANNEL DESIGN
REACH 5: Buoy 14 to Buoy 16

INPUT DATA

Parameter	Value	Unit	Comment	Source
Vessel Type	Tanker	n/a		
Vessel Size Class	Suezmax	n/a		OMC, 2015
Vessel Dead Weight Tonnage (DWT)	159,057	tonnes		OMC, 2015
Vessel Beam (B)	50	m		OMC, 2015
Vessel Length Overall (LOA)	276	m		OMC, 2015
Vessel Length Between Perpendiculars (LBP)	264	m		OMC, 2015
Vessel Draft (T)	17.02	m	summer draft	OMC, 2015
Channel Design Level	-16.69	m CD	95% Access, minimum channel design level in Reach 5	OMC, 2015
Mean High Water Neap (MHWN) tide level	2.32	m CD		Tonkin & Taylor, 2015
Channel Type	Inner Channel	n/a	"Outer Channel" = open water, "Inner Channel" = protected water	PIANC, 2014
Passing	One-way	n/a	"Two-way" or One-way"	
Vessel Manoeuvrability	Poor	n/a	"Poor" = tankers/bulk carriers	PIANC, 2014
			"Moderate" = container vessels/car carriers/RoRo vessels/LNG&LPG vessels	PIANC, 2014
			"Good" = twin propeller ships/ferries/cruise vessels	PIANC, 2014
(a) Vessel Speed (V_s)	6.8	knots	"average" speed profile, varies from 6.8kts at Buoy 14 to 5.8kts at Buoy 16	OMC, 2015
(b) Prevailing cross wind (V_{cw})	20	knots	"Mild" V_{cw}<15 knots, "Moderate" 15 knots <=V_{cw}<33 knots, "Strong" V_{cw}>33 knots	Marsden Point, 5% annual exceedance wind speed 10m/s, MetOcean Solutions measured data
(c) Prevailing cross current (V_{cc})	0.7	knots	"Negligible" V_{cc}<0.2 knots, "Low" 0.2 knots<=V_{cc}<0.5 knots, "Moderate" 0.5 knots<=V_{cc}<1.5 knots, "Strong" V_{cc}>=1.5 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(d) Prevailing longitudinal current (V_{lc})	1.5	knots	"Low" V_{lc}<1.5 knots, "Moderate" 1.5 knots<=V_{lc}<3 knots, "Strong" V_{lc}>=3 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(e) Beam and stern quartering wave height (H_s)	0.6	m	"Hs<=1m", "1m<Hs<3m", "Hs>=3m"	OMC, 2015 99th percentile swell data
(f) Aids to Navigation	Good	n/a	"Excellent" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots, DGPS and Electronic Chart Display and Information System (ECDIS)	PIANC, 2014
			"Good" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots and DGPS	PIANC, 2014
			"Moderate" = anything less than the facilities mentioned above	PIANC, 2014
(g) Bottom Surface	smooth and soft	n/a	"smooth and soft" or "rough and hard"	PIANC, 2014
(h) Depth of waterway (h)	19.01	m	at Mean High Water Neap tide (MHWN)	
Depth to Draft Ratio (h/T)	1.12	n/a		
Channel slope	sloping channel edges and shoals	n/a	"gentle underwater channel slope (1:10 or less steep)" or "sloping channel edges and shoals" or "steep and hard embankments, structures"	PIANC, 2014

CHANNEL WIDTH CALCULATION

Parameter	Beam (B) Multiplier	Category	Comment	Source
Basic Manoeuvring Lane (W_{BM})	1.8	Poor	"Good" = 1.3B, "Moderate" = 1.5B, "Poor" = 1.8B (Table 3.4)	PIANC, 2014
(a) Vessel Speed (V_s)	0.0	Slow	"Fast" V_s>12 = 0.1B, "Moderate" 8<V_s<12 = 0.0B, "Slow" 5<V_s<8 = 0.0B (Table 3.5(a))	PIANC, 2014
(b) Prevailing cross wind (V_{cw})	0.6	Moderate	See Table 3.5(b)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Outer Channel]	1.0	Moderate	See Table 3.5(c)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Inner Channel]	0.8	Moderate	See Table 3.5(c)	PIANC, 2014
(d) Prevailing longitudinal current (V_{lc})	0.2	Moderate	See Table 3.5(d)	PIANC, 2014
(e) Beam and stern quartering wave height (H_s)	0.0	Hs<=1	Hs<=1m = 0.0B, 1m<Hs<3m = 0.5B, Hs>=3m = 1.0B (Table 3.5(e))	PIANC, 2014
(f) Aids to Navigation	0.2	Good	See Table 3.5(f)	PIANC, 2014
(g) Bottom Surface	0.1	h<1.5T	See Table 3.5(g)	PIANC, 2014
(h) Depth of waterway (h) [Outer Channel]	0.2	h<1.25T	See Table 3.5(h)	PIANC, 2014
(h) Depth of waterway (h) [Inner Channel]	0.4	h<1.15T	See Table 3.5(h)	PIANC, 2014
Width for Bank Clearance (W_B)	0.3	sloping channel edges and shoals	See Table 3.6	PIANC, 2014
Additional Width for Channel Passing (W_p)	0.0	Not Required	See Table 3.7	PIANC, 2014

Total Channel Width [Outer Channel]	4.7	B
Total Channel Width [Outer Channel]	**235**	**m**
Total Channel Width [Inner Channel]	4.7	B
Total Channel Width [Inner Channel]	**235**	**m**

PIANC (2014) CHANNEL WIDTH ASSESSMENT
OPTION 2 CHANNEL DESIGN
REACH 6: Buoy 16 to Buoy 17

INPUT DATA

Parameter	Value	Unit	Comment	Source
Vessel Type	Tanker	n/a		
Vessel Size Class	Suezmax	n/a		OMC, 2015
Vessel Dead Weight Tonnage (DWT)	159,057	tonnes		OMC, 2015
Vessel Beam (B)	50	m		OMC, 2015
Vessel Length Overall (LOA)	276	m		OMC, 2015
Vessel Length Between Perpendiculars (LBP)	264	m		OMC, 2015
Vessel Draft (T)	17.02	m	summer draft	OMC, 2015
Channel Design Level	-16.31	m CD	95% Access, minimum channel design level in Reach 6	OMC, 2015
Mean High Water Neap (MHWN) tide level	2.32	m CD		Tonkin & Taylor, 2015
Channel Type	Inner Channel	n/a	"Outer Channel" = open water, "Inner Channel" = protected water	PIANC, 2014
Passing	One-way	n/a	"Two-way" or One-way"	
Vessel Manoeuvrability	Poor	n/a	"Poor" = tankers/bulk carriers	PIANC, 2014
			"Moderate" = container vessels/car carriers/RoRo vessels/LNG&LPG vessels	PIANC, 2014
			"Good" = twin propeller ships/ferries/cruise vessels	PIANC, 2014
(a) Vessel Speed (V_s)	5.8	knots	"average" speed profile, varies from 5.8kts at Buoy 16 to 2kts at Buoy 17	OMC, 2015
(b) Prevailing cross wind (V_{cw})	20	knots	"Mild" V_{cw}<15 knots, "Moderate" 15 knots <=V_{cw}<33 knots, "Strong" V_{cw}>33 knots	Marsden Point, 5% annual exceedance wind speed 10m/s, MetOcean Solutions measured data
(c) Prevailing cross current (V_{cc})	0.7	knots	"Negligible" V_{cc}<0.2 knots, "Low" 0.2 knots<=V_{cc}<0.5 knots, "Moderate" 0.5 knots<=V_{cc}<1.5 knots, "Strong" V_{cc}>=1.5 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(d) Prevailing longitudinal current (V_{lc})	1.5	knots	"Low" V_{lc}<1.5 knots, "Moderate" 1.5 knots<=V_{lc}<3 knots, "Strong" V_{lc}>=3 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(e) Beam and stern quartering wave height (H_s)	0.6	m	"Hs<=1m", "1m<Hs<3m", "Hs>=3m"	OMC, 2015 99th percentile swell data
(f) Aids to Navigation	Good	n/a	"Excellent" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots, DGPS and Electronic Chart Display and Information System (ECDIS)	PIANC, 2014
			"Good" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots and DGPS	PIANC, 2014
			"Moderate" = anything less than the facilities mentioned above	PIANC, 2014
(g) Bottom Surface	smooth and soft	n/a	"smooth and soft" or "rough and hard"	PIANC, 2014
(h) Depth of waterway (h)	18.63	m	at Mean High Water Neap tide (MHWN)	
Depth to Draft Ratio (h/T)	1.09	n/a		
Channel slope	sloping channel edges and shoals	n/a	"gentle underwater channel slope (1:10 or less steep)" or "sloping channel edges and shoals" or "steep and hard embankments, structures"	PIANC, 2014

CHANNEL WIDTH CALCULATION

Parameter	Beam (B) Multiplier	Category	Comment	Source
Basic Manoeuvring Lane (W_{BM})	1.8	Poor	"Good" = 1.3B, "Moderate" = 1.5B, "Poor" = 1.8B (Table 3.4)	PIANC, 2014
(a) Vessel Speed (V_s)	0.0	Slow	"Fast" V_s>12 = 0.1B, "Moderate" 8<V_s<12 = 0.0B, "Slow" 5<V_s<8 = 0.0B (Table 3.5(a))	PIANC, 2014
(b) Prevailing cross wind (V_{cw})	0.6	Moderate	See Table 3.5(b)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Outer Channel]	1.0	Moderate	See Table 3.5(c)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Inner Channel]	0.8	Moderate	See Table 3.5(c)	PIANC, 2014
(d) Prevailing longitudinal current (V_{lc})	0.2	Moderate	See Table 3.5(d)	PIANC, 2014
(e) Beam and stern quartering wave height (H_s)	0.0	Hs<=1	Hs<=1m = 0.0B, 1m<Hs<3m = 0.5B, Hs>=3m = 1.0B (Table 3.5(e))	PIANC, 2014
(f) Aids to Navigation	0.2	Good	See Table 3.5(f)	PIANC, 2014
(g) Bottom Surface	0.1	h<1.5T	See Table 3.5(g)	PIANC, 2014
(h) Depth of waterway (h) [Outer Channel]	0.2	h<1.25T	See Table 3.5(h)	PIANC, 2014
(h) Depth of waterway (h) [Inner Channel]	0.4	h<1.15T	See Table 3.5(h)	PIANC, 2014
Width for Bank Clearance (W_B)	0.3	sloping channel edges and shoals	See Table 3.6	PIANC, 2014
Additional Width for Channel Passing (W_p)	0.0	Not Required	See Table 3.7	PIANC, 2014

Total Channel Width [Outer Channel]	4.7	B
Total Channel Width [Outer Channel]	**235**	**m**
Total Channel Width [Inner Channel]	4.7	B
Total Channel Width [Inner Channel]	**235**	**m**

BEND GEOMETRY

OPTION 2 CHANNEL DESIGN

Bend No.	Entry Channel Heading	Exit Channel Heading	Bearing Change (S)	Vessel Beam	Vessel LOA	Bend Radius*	Entry Channel Width	Draft Angle Width^	Response Time Width"	Bend Width	Exit Channel Width
	(deg. from North)	(deg. from North)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
1	321	345	24	50	276	1400	215	12.1	20.0	245	200
2	345	369	24	50	276	1400	200	12.1	20.0	230	200
3	369	309	60	50	276	800	200	21.2	20.0	275	235

* 5 x LOA recommended, Table 3.8 PIANC 2014

^ Eqn. 3-5 PIANC 2014

" Eqn. 3-6 PIANC 2014

PIANC (2014) CHANNEL WIDTH ASSESSMENT
OPTION 4 CHANNEL DESIGN
REACH 1: Fairway Buoy to Buoy 1/2

INPUT DATA

Parameter	Value	Unit	Comment	Source
Vessel Type	Tanker	n/a		
Vessel Size Class	Suezmax	n/a		OMC, 2015
Vessel Dead Weight Tonnage (DWT)	159,057	tonnes		OMC, 2015
Vessel Beam (B)	50	m		OMC, 2015
Vessel Length Overall (LOA)	276	m		OMC, 2015
Vessel Length Between Perpendiculars (LBP)	264	m		OMC, 2015
Vessel Draft (T)	17.02	m	summer draft	OMC, 2015
Channel Design Level	-18.19	m CD	95% Access, minimum channel design level in Reach 1	OMC, 2015
Mean High Water Neap (MHWN) tide level	2.32	m CD		Tonkin & Taylor, 2015
Channel Type	Outer Channel	n/a	"Outer Channel" = open water, "Inner Channel" = protected water	PIANC, 2014
Passing	One-way	n/a	"Two-way" or One-way"	
Vessel Manoeuvrability	Poor	n/a	"Poor" = tankers/bulk carriers	PIANC, 2014
			"Moderate" = container vessels/car carriers/RoRo vessels/LNG&LPG vessels	PIANC, 2014
			"Good" = twin propeller ships/ferries/cruise vessels	PIANC, 2014
(a) Vessel Speed (V_s)	6.8	knots	"average" speed profile, varies from 6kts at Fairway Buoy to 6.8kts at Buoy 1/2	OMC, 2015
(b) Prevailing cross wind (V_{cw})	20	knots	"Mild" V_{cw}<15 knots, "Moderate" 15 knots <=V_{cw}<33 knots, "Strong" V_{cw}>33 knots	Marsden Point, 5% annual exceedance wind speed 10m/s, MetOcean Solutions measured data
(c) Prevailing cross current (V_{cc})	0.3	knots	"Negligible" V_{cc}<0.2 knots, "Low" 0.2 knots<=V_{cc}<0.5 knots, "Moderate" 0.5 knots<=V_{cc}<1.5 knots, "Strong" V_{cc}>=1.5 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(d) Prevailing longitudinal current (V_{lc})	0.4	knots	"Low" V_{lc}<1.5 knots, "Moderate" 1.5 knots<=V_{lc}<3 knots, "Strong" V_{lc}>=3 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(e) Beam and stern quartering wave height (H_s)	2.4	m	"Hs<=1m", "1m<Hs<3m", "Hs>=3m"	OMC, 2015 99th percentile swell data
(f) Aids to Navigation	Good	n/a	"Excellent" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots, DGPS and Electronic Chart Display and Information System (ECDIS)	PIANC, 2014
			"Good" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots and DGPS	PIANC, 2014
			"Moderate" = anything less than the facilities mentioned above	PIANC, 2014
(g) Bottom Surface	smooth and soft	n/a	"smooth and soft" or "rough and hard"	PIANC, 2014
(h) Depth of waterway (h)	20.51	m	at Mean High Water Neap tide (MHWN)	
Depth to Draft Ratio (h/T)	1.21	n/a		
Channel slope	sloping channel edges and shoals	n/a	"gentle underwater channel slope (1:10 or less steep)" or "sloping channel edges and shoals" or "steep and hard embankments, structures"	PIANC, 2014

CHANNEL WIDTH CALCULATION

Parameter	Beam (B) Multiplier	Category	Comment	Source
Basic Manoeuvring Lane (W_{BM})	1.8	Poor	"Good" = 1.3B, "Moderate" = 1.5B, "Poor" = 1.8B (Table 3.4)	PIANC, 2014
(a) Vessel Speed (V_s)	0.0	Slow	"Fast" V_s>12 = 0.1B, "Moderate" 8<V_s<12 = 0.0B, "Slow" 5<V_s<8 = 0.0B (Table 3.5(a))	PIANC, 2014
(b) Prevailing cross wind (V_{cw})	0.6	Moderate	See Table 3.5(b)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Outer Channel]	0.3	Low	See Table 3.5(c)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Inner Channel]	0.3	Low	See Table 3.5(c)	PIANC, 2014
(d) Prevailing longitudinal current (V_{lc})	0.0	Low	See Table 3.5(d)	PIANC, 2014
(e) Beam and stern quartering wave height (H_s)	0.5	1m<Hs<3m	Hs<=1m = 0.0B, 1m<Hs<3m = 0.5B, Hs>=3m = 1.0B (Table 3.5(e))	PIANC, 2014
(f) Aids to Navigation	0.2	Good	See Table 3.5(f)	PIANC, 2014
(g) Bottom Surface	0.1	h<1.5T	See Table 3.5(g)	PIANC, 2014
(h) Depth of waterway (h) [Outer Channel]	0.2	h<1.25T	See Table 3.5(h)	PIANC, 2014
(h) Depth of waterway (h) [Inner Channel]	0.2	1.15T<=h<1.5T	See Table 3.5(h)	PIANC, 2014
Width for Bank Clearance (W_B)	0.3	sloping channel edges and shoals	See Table 3.6	PIANC, 2014
Additional Width for Channel Passing (W_p)	0.0	Not Required	See Table 3.7	PIANC, 2014

Total Channel Width [Outer Channel]	4.3	B
Total Channel Width [Outer Channel]	**215**	**m**
Total Channel Width [Inner Channel]	4.3	B
Total Channel Width [Inner Channel]	**215**	**m**

PIANC (2014) CHANNEL WIDTH ASSESSMENT
OPTION 4 CHANNEL DESIGN
REACH 2: Buoy 1/2 to Buoy 3/6

INPUT DATA

Parameter	Value	Unit	Comment	Source
Vessel Type	Tanker	n/a		
Vessel Size Class	Suezmax	n/a		OMC, 2015
Vessel Dead Weight Tonnage (DWT)	159,057	tonnes		OMC, 2015
Vessel Beam (B)	50	m		OMC, 2015
Vessel Length Overall (LOA)	276	m		OMC, 2015
Vessel Length Between Perpendiculars (LBP)	264	m		OMC, 2015
Vessel Draft (T)	17.02	m	summer draft	OMC, 2015
Channel Design Level	-17.65	m CD	95% Access, minimum channel design level in Reach 2	OMC, 2015
Mean High Water Neap (MHWN) tide level	2.32	m CD		Tonkin & Taylor, 2015
Channel Type	Outer Channel	n/a	"Outer Channel" = open water, "Inner Channel" = protected water	PIANC, 2014
Passing	One-way	n/a	"Two-way" or One-way"	
Vessel Manoeuvrability	Poor	n/a	"Poor" = tankers/bulk carriers	PIANC, 2014
			"Moderate" = container vessels/car carriers/RoRo vessels/LNG&LPG vessels	PIANC, 2014
			"Good" = twin propeller ships/ferries/cruise vessels	PIANC, 2014
(a) Vessel Speed (V_s)	7.5	knots	"average" speed profile, varies from 6.8kts at Buoy 1/2 to 7.5kts at Buoy 3/6	OMC, 2015
(b) Prevailing cross wind (V_{cw})	20	knots	"Mild" V_{cw}<15 knots, "Moderate" 15 knots <=V_{cw}<33 knots, "Strong" V_{cw}>33 knots	Marsden Point, 5% annual exceedance wind speed 10m/s, MetOcean Solutions measured data
(c) Prevailing cross current (V_{cc})	0.3	knots	"Negligible" V_{cc}<0.2 knots, "Low" 0.2 knots<=V_{cc}<0.5 knots, "Moderate" 0.5 knots<=V_{cc}<1.5 knots, "Strong" V_{cc}>=1.5 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(d) Prevailing longitudinal current (V_{lc})	0.4	knots	"Low" V_{lc}<1.5 knots, "Moderate" 1.5 knots<=V_{lc}<3 knots, "Strong" V_{lc}>=3 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(e) Beam and stern quartering wave height (H_s)	1.9	m	"Hs<=1m", "1m<Hs<3m", "Hs>=3m"	OMC, 2015 99th percentile swell data
(f) Aids to Navigation	Good	n/a	"Excellent" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots, DGPS and Electronic Chart Display and Information System (ECDIS)	PIANC, 2014
			"Good" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots and DGPS	PIANC, 2014
			"Moderate" = anything less than the facilities mentioned above	PIANC, 2014
(g) Bottom Surface	smooth and soft	n/a	"smooth and soft" or "rough and hard"	PIANC, 2014
(h) Depth of waterway (h)	19.97	m	at Mean High Water Neap tide (MHWN)	
Depth to Draft Ratio (h/T)	1.17	n/a		
Channel slope	sloping channel edges and shoals	n/a	"gentle underwater channel slope (1:10 or less steep)" or "sloping channel edges and shoals" or "steep and hard embankments, structures"	PIANC, 2014

CHANNEL WIDTH CALCULATION

Parameter	Beam (B) Multiplier	Category	Comment	Source
Basic Manoeuvring Lane (W_{BM})	1.8	Poor	"Good" = 1.3B, "Moderate" = 1.5B, "Poor" = 1.8B (Table 3.4)	PIANC, 2014
(a) Vessel Speed (V_s)	0.0	Slow	"Fast" V_s>12 = 0.1B, "Moderate" 8<V_s<12 = 0.0B, "Slow" 5<V_s<8 = 0.0B (Table 3.5(a))	PIANC, 2014
(b) Prevailing cross wind (V_{cw})	0.6	Moderate	See Table 3.5(b)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Outer Channel]	0.3	Low	See Table 3.5(c)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Inner Channel]	0.3	Low	See Table 3.5(c)	PIANC, 2014
(d) Prevailing longitudinal current (V_{lc})	0.0	Low	See Table 3.5(d)	PIANC, 2014
(e) Beam and stern quartering wave height (H_s)	0.5	1m<Hs<3m	Hs<=1m = 0.0B, 1m<Hs<3m = 0.5B, Hs>=3m = 1.0B (Table 3.5(e))	PIANC, 2014
(f) Aids to Navigation	0.2	Good	See Table 3.5(f)	PIANC, 2014
(g) Bottom Surface	0.1	h<1.5T	See Table 3.5(g)	PIANC, 2014
(h) Depth of waterway (h) [Outer Channel]	0.2	h<1.25T	See Table 3.5(h)	PIANC, 2014
(h) Depth of waterway (h) [Inner Channel]	0.2	1.15T<=h<1.5T	See Table 3.5(h)	PIANC, 2014
Width for Bank Clearance (W_B)	0.3	sloping channel edges and shoals	See Table 3.6	PIANC, 2014
Additional Width for Channel Passing (W_p)	0.0	Not Required	See Table 3.7	PIANC, 2014

Total Channel Width [Outer Channel]	4.3	B
Total Channel Width [Outer Channel]	**215**	**m**
Total Channel Width [Inner Channel]	4.3	B
Total Channel Width [Inner Channel]	**215**	**m**

PIANC (2014) CHANNEL WIDTH ASSESSMENT
OPTION 4 CHANNEL DESIGN
REACH 3: Buoy 3/6 to Buoy 7

INPUT DATA

Parameter	Value	Unit	Comment	Source
Vessel Type	Tanker	n/a		
Vessel Size Class	Suezmax	n/a		OMC, 2015
Vessel Dead Weight Tonnage (DWT)	159,057	tonnes		OMC, 2015
Vessel Beam (B)	50	m		OMC, 2015
Vessel Length Overall (LOA)	276	m		OMC, 2015
Vessel Length Between Perpendiculars (LBP)	264	m		OMC, 2015
Vessel Draft (T)	17.02	m	summer draft	OMC, 2015
Channel Design Level	-16.87	m CD	95% Access, minimum channel design level in Reach 3	OMC, 2015
Mean High Water Neap (MHWN) tide level	2.32	m CD		Tonkin & Taylor, 2015
Channel Type	Outer Channel	n/a	"Outer Channel" = open water, "Inner Channel" = protected water	PIANC, 2014
Passing	One-way	n/a	"Two-way" or One-way"	
Vessel Manoeuvrability	Poor	n/a	"Poor" = tankers/bulk carriers	PIANC, 2014
			"Moderate" = container vessels/car carriers/RoRo vessels/LNG&LPG vessels	PIANC, 2014
			"Good" = twin propeller ships/ferries/cruise vessels	PIANC, 2014
(a) Vessel Speed (V_s)	7.5	knots	"average" speed profile, varies from 7.5kts at Buoy 3/6 to 7.3kts at Buoy 7	OMC, 2015
(b) Prevailing cross wind (V_{cw})	20	knots	"Mild" V_{cw}<15 knots, "Moderate" 15 knots <=V_{cw}<33 knots, "Strong" V_{cw}>33 knots	Marsden Point, 5% annual exceedance wind speed 10m/s, MetOcean Solutions measured data
(c) Prevailing cross current (V_{cc})	0.7	knots	"Negligible" V_{cc}<0.2 knots, "Low" 0.2 knots<=V_{cc}<0.5 knots, "Moderate" 0.5 knots<=V_{cc}<1.5 knots, "Strong" V_{cc}>=1.5 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(d) Prevailing longitudinal current (V_{lc})	1.3	knots	"Low" V_{lc}<1.5 knots, "Moderate" 1.5 knots<=V_{lc}<3 knots, "Strong" V_{lc}>=3 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(e) Beam and stern quartering wave height (H_s)	0.9	m	"Hs<=1m", "1m<Hs<3m", "Hs>=3m"	OMC, 2015 99th percentile swell data
(f) Aids to Navigation	Good	n/a	"Excellent" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots, DGPS and Electronic Chart Display and Information System (ECDIS)	PIANC, 2014
			"Good" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots and DGPS	PIANC, 2014
			"Moderate" = anything less than the facilities mentioned above	PIANC, 2014
(g) Bottom Surface	smooth and soft	n/a	"smooth and soft" or "rough and hard"	PIANC, 2014
(h) Depth of waterway (h)	19.19	m	at Mean High Water Neap tide (MHWN)	
Depth to Draft Ratio (h/T)	1.13	n/a		
Channel slope	sloping channel edges and shoals	n/a	"gentle underwater channel slope (1:10 or less steep)" or "sloping channel edges and shoals" or "steep and hard embankments, structures"	PIANC, 2014

CHANNEL WIDTH CALCULATION

Parameter	Beam (B) Multiplier	Category	Comment	Source
Basic Manoeuvring Lane (W_{BM})	1.8	Poor	"Good" = 1.3B, "Moderate" = 1.5B, "Poor" = 1.8B (Table 3.4)	PIANC, 2014
(a) Vessel Speed (V_s)	0.0	Slow	"Fast" V_s>12 = 0.1B, "Moderate" 8<V_s<12 = 0.0B, "Slow" 5<V_s<8 = 0.0B (Table 3.5(a))	PIANC, 2014
(b) Prevailing cross wind (V_{cw})	0.6	Moderate	See Table 3.5(b)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Outer Channel]	1.0	Moderate	See Table 3.5(c)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Inner Channel]	0.8	Moderate	See Table 3.5(c)	PIANC, 2014
(d) Prevailing longitudinal current (V_{lc})	0.0	Low	See Table 3.5(d)	PIANC, 2014
(e) Beam and stern quartering wave height (H_s)	0.0	Hs<=1	Hs<=1m = 0.0B, 1m<Hs<3m = 0.5B, Hs>=3m = 1.0B (Table 3.5(e))	PIANC, 2014
(f) Aids to Navigation	0.2	Good	See Table 3.5(f)	PIANC, 2014
(g) Bottom Surface	0.1	h<1.5T	See Table 3.5(g)	PIANC, 2014
(h) Depth of waterway (h) [Outer Channel]	0.2	h<1.25T	See Table 3.5(h)	PIANC, 2014
(h) Depth of waterway (h) [Inner Channel]	0.4	h<1.15T	See Table 3.5(h)	PIANC, 2014
Width for Bank Clearance (W_B)	0.3	sloping channel edges and shoals	See Table 3.6	PIANC, 2014
Additional Width for Channel Passing (W_p)	0.0	Not Required	See Table 3.7	PIANC, 2014

Total Channel Width [Outer Channel]	4.5	B
Total Channel Width [Outer Channel]	**225**	**m**
Total Channel Width [Inner Channel]	4.5	B
Total Channel Width [Inner Channel]	**225**	**m**

PIANC (2014) CHANNEL WIDTH ASSESSMENT
OPTION 4 CHANNEL DESIGN
REACH 4: Buoy 7 to Buoy 14

INPUT DATA

Parameter	Value	Unit	Comment	Source
Vessel Type	Tanker	n/a		
Vessel Size Class	Suezmax	n/a		OMC, 2015
Vessel Dead Weight Tonnage (DWT)	159,057	tonnes		OMC, 2015
Vessel Beam (B)	50	m		OMC, 2015
Vessel Length Overall (LOA)	276	m		OMC, 2015
Vessel Length Between Perpendiculars (LBP)	264	m		OMC, 2015
Vessel Draft (T)	17.02	m	summer draft	OMC, 2015
Channel Design Level	-16.86	m CD	95% Access, minimum channel design level in Reach 4	OMC, 2015
Mean High Water Neap (MHWN) tide level	2.32	m CD		Tonkin & Taylor, 2015
Channel Type	Inner Channel	n/a	"Outer Channel" = open water, "Inner Channel" = protected water	PIANC, 2014
Passing	One-way	n/a	"Two-way" or One-way"	
Vessel Manoeuvrability	Poor	n/a	"Poor" = tankers/bulk carriers	PIANC, 2014
			"Moderate" = container vessels/car carriers/RoRo vessels/LNG&LPG vessels	PIANC, 2014
			"Good" = twin propeller ships/ferries/cruise vessels	PIANC, 2014
(a) Vessel Speed (V_s)	7.3	knots	"average" speed profile, varies from 7.3kts at Buoy 7 to 6.8kts at Buoy 14	OMC, 2015
(b) Prevailing cross wind (V_{cw})	20	knots	"Mild" V_{cw}<15 knots, "Moderate" 15 knots <=V_{cw}<33 knots, "Strong" V_{cw}>33 knots	Marsden Point, 5% annual exceedance wind speed 10m/s, MetOcean Solutions measured data
(c) Prevailing cross current (V_{cc})	0.3	knots	"Negligible" V_{cc}<0.2 knots, "Low" 0.2 knots<=V_{cc}<0.5 knots, "Moderate" 0.5 knots<=V_{cc}<1.5 knots, "Strong" V_{cc}>=1.5 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(d) Prevailing longitudinal current (V_{lc})	1.5	knots	"Low" V_{lc}<1.5 knots, "Moderate" 1.5 knots<=V_{lc}<3 knots, "Strong" V_{lc}>=3 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(e) Beam and stern quartering wave height (H_s)	0.6	m	"Hs<=1m", "1m<Hs<3m", "Hs>=3m"	OMC, 2015 99th percentile swell data
(f) Aids to Navigation	Good	n/a	"Excellent" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots, DGPS and Electronic Chart Display and Information System (ECDIS)	PIANC, 2014
			"Good" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots and DGPS	PIANC, 2014
			"Moderate" = anything less than the facilities mentioned above	PIANC, 2014
(g) Bottom Surface	smooth and soft	n/a	"smooth and soft" or "rough and hard"	PIANC, 2014
(h) Depth of waterway (h)	19.18	m	at Mean High Water Neap tide (MHWN)	
Depth to Draft Ratio (h/T)	1.13	n/a		
Channel slope	sloping channel edges and shoals	n/a	"gentle underwater channel slope (1:10 or less steep)" or "sloping channel edges and shoals" or "steep and hard embankments, structures"	PIANC, 2014

CHANNEL WIDTH CALCULATION

Parameter	Beam (B) Multiplier	Category	Comment	Source
Basic Manoeuvring Lane (W_{BM})	1.8	Poor	"Good" = 1.3B, "Moderate" = 1.5B, "Poor" = 1.8B (Table 3.4)	PIANC, 2014
(a) Vessel Speed (V_s)	0.0	Slow	"Fast" V_s>12 = 0.1B, "Moderate" 8<V_s<12 = 0.0B, "Slow" 5<V_s<8 = 0.0B (Table 3.5(a))	PIANC, 2014
(b) Prevailing cross wind (V_{cw})	0.6	Moderate	See Table 3.5(b)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Outer Channel]	0.3	Low	See Table 3.5(c)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Inner Channel]	0.3	Low	See Table 3.5(c)	PIANC, 2014
(d) Prevailing longitudinal current (V_{lc})	0.2	Moderate	See Table 3.5(d)	PIANC, 2014
(e) Beam and stern quartering wave height (H_s)	0.0	Hs<=1	Hs<=1m = 0.0B, 1m<Hs<3m = 0.5B, Hs>=3m = 1.0B (Table 3.5(e))	PIANC, 2014
(f) Aids to Navigation	0.2	Good	See Table 3.5(f)	PIANC, 2014
(g) Bottom Surface	0.1	h<1.5T	See Table 3.5(g)	PIANC, 2014
(h) Depth of waterway (h) [Outer Channel]	0.2	h<1.25T	See Table 3.5(h)	PIANC, 2014
(h) Depth of waterway (h) [Inner Channel]	0.4	h<1.15T	See Table 3.5(h)	PIANC, 2014
Width for Bank Clearance (W_B)	0.3	sloping channel edges and shoals	See Table 3.6	PIANC, 2014
Additional Width for Channel Passing (W_p)	0.0	Not Required	See Table 3.7	PIANC, 2014

Total Channel Width [Outer Channel]	4.0	B
Total Channel Width [Outer Channel]	**200**	**m**
Total Channel Width [Inner Channel]	4.2	B
Total Channel Width [Inner Channel]	**210**	**m**

PIANC (2014) CHANNEL WIDTH ASSESSMENT
OPTION 4 CHANNEL DESIGN
REACH 5: Buoy 14 to Buoy 16

INPUT DATA

Parameter	Value	Unit	Comment	Source
Vessel Type	Tanker	n/a		
Vessel Size Class	Suezmax	n/a		OMC, 2015
Vessel Dead Weight Tonnage (DWT)	159,057	tonnes		OMC, 2015
Vessel Beam (B)	50	m		OMC, 2015
Vessel Length Overall (LOA)	276	m		OMC, 2015
Vessel Length Between Perpendiculars (LBP)	264	m		OMC, 2015
Vessel Draft (T)	17.02	m	summer draft	OMC, 2015
Channel Design Level	-16.69	m CD	95% Access, minimum channel design level in Reach 5	OMC, 2015
Mean High Water Neap (MHWN) tide level	2.32	m CD		Tonkin & Taylor, 2015
Channel Type	Inner Channel	n/a	"Outer Channel" = open water, "Inner Channel" = protected water	PIANC, 2014
Passing	One-way	n/a	"Two-way" or One-way"	
Vessel Manoeuvrability	Poor	n/a	"Poor" = tankers/bulk carriers	PIANC, 2014
			"Moderate" = container vessels/car carriers/RoRo vessels/LNG&LPG vessels	PIANC, 2014
			"Good" = twin propeller ships/ferries/cruise vessels	PIANC, 2014
(a) Vessel Speed (V_s)	6.8	knots	"average" speed profile, varies from 6.8kts at Buoy 14 to 5.8kts at Buoy 16	OMC, 2015
(b) Prevailing cross wind (V_{cw})	20	knots	"Mild" V_{cw}<15 knots, "Moderate" 15 knots <=V_{cw}<33 knots, "Strong" V_{cw}>33 knots	Marsden Point, 5% annual exceedance wind speed 10m/s, MetOcean Solutions measured data
(c) Prevailing cross current (V_{cc})	0.7	knots	"Negligible" V_{cc}<0.2 knots, "Low" 0.2 knots<=V_{cc}<0.5 knots, "Moderate" 0.5 knots<=V_{cc}<1.5 knots, "Strong" V_{cc}>=1.5 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(d) Prevailing longitudinal current (V_{lc})	1.5	knots	"Low" V_{lc}<1.5 knots, "Moderate" 1.5 knots<=V_{lc}<3 knots, "Strong" V_{lc}>=3 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(e) Beam and stern quartering wave height (H_s)	0.6	m	"Hs<=1m", "1m<Hs<3m", "Hs>=3m"	OMC, 2015 99th percentile swell data
(f) Aids to Navigation	Good	n/a	"Excellent" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots, DGPS and Electronic Chart Display and Information System (ECDIS)	PIANC, 2014
			"Good" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots and DGPS	PIANC, 2014
			"Moderate" = anything less than the facilities mentioned above	PIANC, 2014
(g) Bottom Surface	smooth and soft	n/a	"smooth and soft" or "rough and hard"	PIANC, 2014
(h) Depth of waterway (h)	19.01	m	at Mean High Water Neap tide (MHWN)	
Depth to Draft Ratio (h/T)	1.12	n/a		
Channel slope	sloping channel edges and shoals	n/a	"gentle underwater channel slope (1:10 or less steep)" or "sloping channel edges and shoals" or "steep and hard embankments, structures"	PIANC, 2014

CHANNEL WIDTH CALCULATION

Parameter	Beam (B) Multiplier	Category	Comment	Source
Basic Manoeuvring Lane (W_{BM})	1.8	Poor	"Good" = 1.3B, "Moderate" = 1.5B, "Poor" = 1.8B (Table 3.4)	PIANC, 2014
(a) Vessel Speed (V_s)	0.0	Slow	"Fast" V_s>12 = 0.1B, "Moderate" 8<V_s<12 = 0.0B, "Slow" 5<V_s<8 = 0.0B (Table 3.5(a))	PIANC, 2014
(b) Prevailing cross wind (V_{cw})	0.6	Moderate	See Table 3.5(b)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Outer Channel]	1.0	Moderate	See Table 3.5(c)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Inner Channel]	0.8	Moderate	See Table 3.5(c)	PIANC, 2014
(d) Prevailing longitudinal current (V_{lc})	0.2	Moderate	See Table 3.5(d)	PIANC, 2014
(e) Beam and stern quartering wave height (H_s)	0.0	Hs<=1	Hs<=1m = 0.0B, 1m<Hs<3m = 0.5B, Hs>=3m = 1.0B (Table 3.5(e))	PIANC, 2014
(f) Aids to Navigation	0.2	Good	See Table 3.5(f)	PIANC, 2014
(g) Bottom Surface	0.1	h<1.5T	See Table 3.5(g)	PIANC, 2014
(h) Depth of waterway (h) [Outer Channel]	0.2	h<1.25T	See Table 3.5(h)	PIANC, 2014
(h) Depth of waterway (h) [Inner Channel]	0.4	h<1.15T	See Table 3.5(h)	PIANC, 2014
Width for Bank Clearance (W_B)	0.3	sloping channel edges and shoals	See Table 3.6	PIANC, 2014
Additional Width for Channel Passing (W_p)	0.0	Not Required	See Table 3.7	PIANC, 2014

Total Channel Width [Outer Channel]	4.7	B
Total Channel Width [Outer Channel]	**235**	**m**
Total Channel Width [Inner Channel]	4.7	B
Total Channel Width [Inner Channel]	**235**	**m**

PIANC (2014) CHANNEL WIDTH ASSESSMENT
OPTION 4 CHANNEL DESIGN
REACH 6: Buoy 16 to Buoy 17

INPUT DATA

Parameter	Value	Unit	Comment	Source
Vessel Type	Tanker	n/a		
Vessel Size Class	Suezmax	n/a		OMC, 2015
Vessel Dead Weight Tonnage (DWT)	159,057	tonnes		OMC, 2015
Vessel Beam (B)	50	m		OMC, 2015
Vessel Length Overall (LOA)	276	m		OMC, 2015
Vessel Length Between Perpendiculars (LBP)	264	m		OMC, 2015
Vessel Draft (T)	17.02	m	summer draft	OMC, 2015
Channel Design Level	-16.31	m CD	95% Access, minimum channel design level in Reach 6	OMC, 2015
Mean High Water Neap (MHWN) tide level	2.32	m CD		Tonkin & Taylor, 2015
Channel Type	Inner Channel	n/a	"Outer Channel" = open water, "Inner Channel" = protected water	PIANC, 2014
Passing	One-way	n/a	"Two-way" or One-way"	
Vessel Manoeuvrability	Poor	n/a	"Poor" = tankers/bulk carriers	PIANC, 2014
			"Moderate" = container vessels/car carriers/RoRo vessels/LNG&LPG vessels	PIANC, 2014
			"Good" = twin propeller ships/ferries/cruise vessels	PIANC, 2014
(a) Vessel Speed (V_s)	5.8	knots	"average" speed profile, varies from 5.8kts at Buoy 16 to 2kts at Buoy 17	OMC, 2015
(b) Prevailing cross wind (V_{cw})	20	knots	"Mild" V_{cw}<15 knots, "Moderate" 15 knots <=V_{cw}<33 knots, "Strong" V_{cw}>33 knots	Marsden Point, 5% annual exceedance wind speed 10m/s, MetOcean Solutions measured data
(c) Prevailing cross current (V_{cc})	0.7	knots	"Negligible" V_{cc}<0.2 knots, "Low" 0.2 knots<=V_{cc}<0.5 knots, "Moderate" 0.5 knots<=V_{cc}<1.5 knots, "Strong" V_{cc}>=1.5 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(d) Prevailing longitudinal current (V_{lc})	1.5	knots	"Low" V_{lc}<1.5 knots, "Moderate" 1.5 knots<=V_{lc}<3 knots, "Strong" V_{lc}>=3 knots	Max. ebb or flood current velocity +/-1hr from HW, Auckland Ports ADCP Data 2015
(e) Beam and stern quartering wave height (H_s)	0.6	m	"Hs<=1m", "1m<Hs<3m", "Hs>=3m"	OMC, 2015 99th percentile swell data
(f) Aids to Navigation	Good	n/a	"Excellent" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots, DGPS and Electronic Chart Display and Information System (ECDIS)	PIANC, 2014
			"Good" = paired lighted buoys with radar deflectors/lighted leading lines with availability of Pilots and DGPS	PIANC, 2014
			"Moderate" = anything less than the facilities mentioned above	PIANC, 2014
(g) Bottom Surface	smooth and soft	n/a	"smooth and soft" or "rough and hard"	PIANC, 2014
(h) Depth of waterway (h)	18.63	m	at Mean High Water Neap tide (MHWN)	
Depth to Draft Ratio (h/T)	1.09	n/a		
Channel slope	sloping channel edges and shoals	n/a	"gentle underwater channel slope (1:10 or less steep)" or "sloping channel edges and shoals" or "steep and hard embankments, structures"	PIANC, 2014

CHANNEL WIDTH CALCULATION

Parameter	Beam (B) Multiplier	Category	Comment	Source
Basic Manoeuvring Lane (W_{BM})	1.8	Poor	"Good" = 1.3B, "Moderate" = 1.5B, "Poor" = 1.8B (Table 3.4)	PIANC, 2014
(a) Vessel Speed (V_s)	0.0	Slow	"Fast" V_s>12 = 0.1B, "Moderate" 8<V_s<12 = 0.0B, "Slow" 5<V_s<8 = 0.0B (Table 3.5(a))	PIANC, 2014
(b) Prevailing cross wind (V_{cw})	0.6	Moderate	See Table 3.5(b)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Outer Channel]	1.0	Moderate	See Table 3.5(c)	PIANC, 2014
(c) Prevailing cross current (V_{cc}) [Inner Channel]	0.8	Moderate	See Table 3.5(c)	PIANC, 2014
(d) Prevailing longitudinal current (V_{lc})	0.2	Moderate	See Table 3.5(d)	PIANC, 2014
(e) Beam and stern quartering wave height (H_s)	0.0	Hs<=1	Hs<=1m = 0.0B, 1m<Hs<3m = 0.5B, Hs>=3m = 1.0B (Table 3.5(e))	PIANC, 2014
(f) Aids to Navigation	0.2	Good	See Table 3.5(f)	PIANC, 2014
(g) Bottom Surface	0.1	h<1.5T	See Table 3.5(g)	PIANC, 2014
(h) Depth of waterway (h) [Outer Channel]	0.2	h<1.25T	See Table 3.5(h)	PIANC, 2014
(h) Depth of waterway (h) [Inner Channel]	0.4	h<1.15T	See Table 3.5(h)	PIANC, 2014
Width for Bank Clearance (W_B)	0.3	sloping channel edges and shoals	See Table 3.6	PIANC, 2014
Additional Width for Channel Passing (W_p)	0.0	Not Required	See Table 3.7	PIANC, 2014

Total Channel Width [Outer Channel]	4.7	B
Total Channel Width [Outer Channel]	**235**	**m**
Total Channel Width [Inner Channel]	4.7	B
Total Channel Width [Inner Channel]	**235**	**m**

BEND GEOMETRY

OPTION 4 CHANNEL DESIGN

Bend No.	Entry Channel Heading	Exit Channel Heading	Bearing Change (S)	Vessel Beam	Vessel LOA	Bend Radius*	Entry Channel Width	Exit Channel Width	Draft Angle Width^	Response Time Width"	Bend Width
	(deg. from North)	(deg. from North)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
1	321	360	39	50	276	1800	215	225	9.4	20.0	255
2	360	309	51	50	276	800	225	235	21.2	20.0	275

* 5 x LOA recommended, Table 3.8 PIANC 2014

^ Eqn. 3-5 PIANC 2014

" Eqn. 3-6 PIANC 2014

APPENDIX F: Full Bridge Simulation Study Report

RNZ FULL BRIDGE SIMULATION STUDY
Final Report prepared for Royal HaskoningDHV on behalf of Refining New Zealand Limited

Prepared by:

besoftware
Maritime Simulation Solutions

Executive Summary

This full bridge simulation study was undertaken from 7th July to 13th July 2016 in support of the proposed approach channel realignment and deepening to accept up to a 16.6 metre draft vessels on arrival at Marsden Point for Refining New Zealand Limited (RNZ).

The study was conducted to verify the earlier portable and remote link simulation studies (Final Report RNZ Desktop Simulation Study. Be-Software December 2015) which looked at the feasibility of four different channel designs (denoted Option 2, Option 4, Option 4-2 and Option 5) for a number of typical vessels that currently utilise the port, in addition to the design ship, being a Suezmax Class Oil Tanker having a length overall (LOA) of 274m, beam of 48m and draft of 16.8 m. The full bridge simulation study focussed on the two preferred channel designs, Option 2 and Option 4-2. The design ship for the full bridge simulation study was a Suezmax Class Oil Tanker having a length overall (LOA) of 276m, beam of 50m and draft of 16.6m.

This study found that:

- The results of the two earlier portable and remote link simulation studies were validated. This study used a different simulation system and different sets of mathematical equations but the results were the same as obtained from the previous simulation studies.
- Both channel designs were feasible with operational limitations up to a 30 knot wind and slack tide high water arrival of the design ship, following current operational procedures for the port.
- The Option 4.2 channel design is preferred by the pilots as it provides a simpler approach through the critical turn area in the vicinity of buoy 14. This allows the pilots to execute a constant radius turn which is easily monitored using a Portable Pilotage Unit (PPU). It also provides more sea room for all departing vessels to clear the rocky outcrop at Home Point safely, particularly during ebb tides and strong offshore winds. Simulated scenarios used current operational procedures with the design ship in ballast and loaded condition.
- The design ship was considered to manoeuvre at below average standard for a vessel of her class. However, the pilots were able to use existing tug capability and PPU to consistently navigate safely within the confines of both channel designs. Of the two designs, the Option 4-2 was considered the optimum as it allows the most sea room for the arriving vessel and has a larger radius of turn in the channel alignment for both arrival and departure vessels. Greater sea room and improved bend radius significantly improves existing channel safety margins, especially under adverse weather conditions and with a difficult ship to manoeuvre.
- An alternative design ship was used in the full bridge simulation study as an additional check to manoeuvring capability. The alternative design ship study was a Suezmax Class Oil Tanker having a length overall (LOA) of 280m, beam of 50m and draft of 16.6m. The alternative design ship was considered to be of average manoeuvring standard and this ship was consistently navigated safely in both channel designs.
- Minimal realignment of existing navigational buoys is necessary with both channel designs.

- An improvement in the existing leading sector light and buoy lights will be necessary to properly indicate navigable water in the approach channel from the fairway buoy to buoys 3/6.
- Existing tugs are capable of handling the design ship under normal operational conditions.
- Existing operational tug procedures for departing vessels need to be reinforced for all channel designs.
- Existing tugs under the simulated emergency scenarios in this study raise some potential issues which may require further investigation /analysis as part of separate risk /safety review.
- The proposed channel design alignments will potentially assist in an emergency scenario by providing more searoom.

Table of Contents

1 INTRODUCTION

This full bridge simulation study was conducted in Auckland in the Marine Simulation Centre of the New Zealand Maritime School over five days.

The study was required to validate two earlier portable and remote link simulation studies for the proposed expansion of the port to receive deeper draft Suezmax Oil Tankers, to 16.6 metres draft. The proposed expansion will involve dredging and buoyage realignment in the approach channel to Northport and the oil berths at the RNZ Marsden Point facility. The design ship for this study is a Suezmax Oil Tanker with an LOA of 276m and a beam of 50m and a draft of 16.6m, noting that this class of ship periodically visits Marsden Point but is part loaded with a maximum 14.7m draft.

The first two days of the full bridge simulation study were used to simulate manoeuvring with the two channel designs (denoted as Option 2 and Option 4-2), by a group of pilots which included the Marsden Point Harbourmaster, the Northtugz Pilot Manager and a senior Auckland Pilot. The next three days utilized a different group of pilots including the senior pilots for Marsden Point and a senior Tugmaster. This second group were used to also simulate manoeuvring with the two different channel designs (Option 2 and Option 4-2) in particular the emergency scenarios and the use of existing tug capability for the port.

The full bridge simulation study used a completely different simulation system and mathematical models to the portable and remote link simulation studies. Although the design ship for all the studies was a Suezmax of very similar dimensions, displacement and power, the mathematical models used in the simulations were quite different. Nevertheless, the results of the studies (portable, remote link and full bridge) match in terms of the suitability of both channel designs for this Suezmax class of vessel and also the response of the design ship under the emergency scenarios.

The Option 2 channel alignment closely matched the current channel alignment to Marsden Point, keeping within the existing navigation buoys, except at buoy No 11 which was slightly relocated to accommodate the recommended channel design guidelines. This Option 2 channel alignment was, hence, validated in the full bridge and the earlier portable and remote link simulation studies.

The Option 4 channel alignment also matched, in general, the current alignment except with the purpose of reducing the number of alignments and bends, again in order to meet preferred design standards. This required the relocation of the existing No 8, No 12 and No 11 buoys. This alignment was tested in the portable and remote link simulation studies but was considered inferior to Option 4.2 channel alignment.

The Option 4-2 channel alignment is similar to Option 4 but takes advantage of some deeper water on the inside of Buoy No 14 and also the possibility to move the N-S channel alignment slightly to the east so as the eastern edge of the dredge channel coincided with Buoy No 7. By making these amendments, a Radius=800m bend around the (now relocated) No 14 buoy is possible. This is a significant improvement in the radius of bend available in Option 4 (Radius=580m). This alignment also eliminates the need for any dredging along the edge of the bank between Buoy 16 and 18. To achieve the Option 4-2 alignment, the relocation of the existing No 3, No 8, No18, No 14, No 12 and No 11 buoys was required. This Option4-2 channel alignment was validated in the full bridge and the earlier portable and remote link simulation studies.

The Option 5 channel alignment involved a movement of the N-S channel alignment further to the east. This will require dredging in the vicinity of Home Point. It was designed to eliminate all dredging adjacent on the western side of the channel at the expense of dredging on the eastern side at Home Point. This required the relocation of the existing No 7 and No 12 buoys. This alignment was tested in the portable simulation studies but was considered inferior to Option 4-2 and Option 2 channel alignments. The Option 5 channel alignment was not tested in the full bridge simulation study.

2 AIMS OF THE STUDY

The full bridge simulation study aimed to:

- Validate the earlier portable and remote link simulation studies of the preferred channel alignment designs (Option 4-2 and Option 2)

- Investigate the implications for navigation safety and changes to buoyage necessary for the arrival of a Suezmax class vessel of draft 16.6 metres utilising the channel designs Option 2 and Option 4-2 in the proposed realignment and deepening of the approach channel to RNZ Marsden Point Crude Oil Berth.

- Confirm that other current shipping to Refining NZ and Northport facilities would be able to continue to safely navigate the channel design options.

3 STUDY PARTICIPANTS

Refining New Zealand RNZ:
Dave Martin (Business Opportunities Manager)

Harbourmaster:
Jim Lyle

NorthTugz Pilots:
George Walkinshaw
Kirit Barot
Tom Greig

NorthTugz Tugmaster:
Simon Noakes

Auckland Pilots
Wayne Mills

Tauranga Pilots
Troy Evans

NZ Maritime School
Kees Buckens

Royal HaskoningDHV:
Richard Mocke
Julian Cross

Be Software:
Bruce Goodchild

In addition, other representatives from Northport, NorthTugz, and COLL together with the Deputy Harbourmaster also attended some of the simulation. There was also representatives of Northland Tangata Whenua who attended on Friday 8th July for some of the simulation.

4 SIMULATOR OVERVIEW

New Zealand Maritime School provided the use of a full mission simulator with integrated tug simulator at their simulation centre in Auckland.

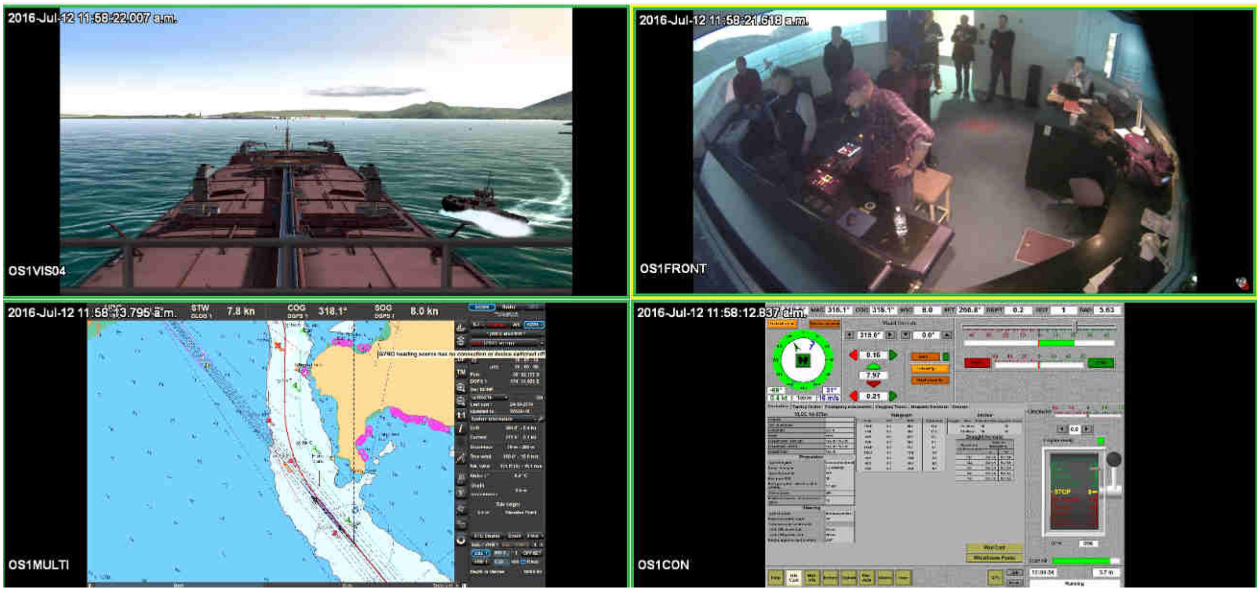
The full mission simulator on the main bridge incorporated a number of instrument consoles and vision displays covering 300 degrees of horizontal field of view displayed on large projector screens. A separate tug bridge was available with 360 degrees of broken horizontal field of view on large 50 inch monitors.

The main bridge instrument consoles incorporated ARPA radar, ECDIS and manoeuvring displays showing speeds, engine RPM, rudder angle and rate of turn. Real instrumentation was provided for most of the bridge equipment. Similar real tug instrumentation was available on the tug bridge.

The separate instructor station was able to fully control and monitors the main bridge and also the tug bridge. The instructor station was used for recording of simulation runs and editing of hydrodynamic, visual and environmental models.

The software used for the project was a Transas 5000 Integrated Ship and Tug simulator. Details on the simulation software are available on the website www.transas.com

NorthTugz Pilots attending the Full bridge Simulation in Auckland.



Displays from the Simulation Centre Auckland

Tangata Whenua attending Simulation 8th July

5 AREA MODEL AND CHANNEL DESIGNS

A basic Marsden Point area model was developed to provide a visual scene and incorporate the new channel designs. The new channel designs were titled Option 2 and Option 4-2.

From the base Marsden model, new area models were constructed for the full bridge simulation as follows:

MODEL ID	DESCRIPTION	CHANNEL ID
Marsden	Existing Approach Channel	Existing
Marsden2	Option 2 alignment within existing buoyage	Option 2
Marsden4.2.1	Revised Option 4-2 alignment with Traditional Leads (Water Leads Option 3) on Middle Reach of Channel	Option 4-2.1
Marsden4.2.2	Revised Option 4-2 alignment with PEL Leads (PEL Leads Option 1) on Middle Reach of Channel	Option 4-2.2

Throughout the Report, for ease of reference, each channel design will be identified by the names in the third column (i.e. Channel ID).

Channels Marsden 4-2.1 and Marsden 4-2.2 are identical except for the type of Leads installed for the 000\180T Centreline in the Middle Reach of the Channel. The types of Leads are fully described in the Taurikura Bay Leads Report (Report of Proposed Taurikura Bay Leads Revision 2.2. Be-Software June 2016)

6 ENVIRONMENTAL DATA

Environmental data inputs for the simulation were provided by Ross Venell (currents) and Royal HaskoningDHV.

6.1 Tidal Streams

Tidal stream patterns were based on Acoustic Doppler Current Profiler (ADCP) current measurements.

Tidal streams were modelled on the basis of a 25 metre grid spacing with an updated tidal vector provided for every 15 minutes. The simulator was able to interpret the tidal stream at six minutes intervals over the operational area from the Fairway buoy to the Crude Berth. Tidal stream data was identical through the channel designs - Existing, Option 2, Option 4-2.1, Option 4-2.2.

6.2 Wave Models

Wave data was obtained from the underkeel clearance modelling previously undertaken by OMC International (2015) and comprised wave percentile data from the Alpha waverider buoy and estimated wave attenuation factors at different points along the approach channel alignment.

Each simulation was carried out in a multiple wave environment. Swell waves varied from 2.0 m Hs with a 22 second period to 1.0 m Hs with a 13 second period at the wave rider buoy. Wave direction was uniformly at a bearing of 090 (i.e. East). Swell height varied within the model area based upon OMC wave attenuation data. Swell waves progressively diminished into the inner harbour as per the OMC model to a minimum of 0.24 of the value at the wave rider buoy.

6.3 Wind Forces

Winds were stipulated as steady or gusting for each simulated run. Wind speeds varied from 15 to 30 knots. Gusts varied in intensity by 50% with a 30 degree spread in direction. Wind shadow effects were incorporated where appropriate. Wind shadowing dropped the wind speed by over 50%. For example, a wind speed of 25 knots was decreased to 10 knots in a shadow area behind Home Point.

7 SHIP MODELS

The design vessel for this study was a Suezmax Oil Tanker with a LOA of 276m, a beam of 50m and a draft of 16.6m which was represented in the simulation by the VLCC1A which had a LOA of 275 m, a beam of 48m and a draft of 16.6m. The ballasted version of this design ship VLCCB had a LOA of 262m, a beam of 48m and draft of 9m. An alternative simulated design ship was provided VLCC7 which had a LOA of 280 m, a beam of 50m and a draft of 16.6m. There was no ballast condition for VLCC7.

Design Ship draft conditions:

ID	SHIP	CONDITION	DRAFT FORWARD	DRAFT AFT
VLCC1A	VLCC1A	Loaded	16.6m	16.6m
VLCC7	VLCC7	Loaded	16.6m	16.6m
VLCCB	VLCCB	In - ballast	6.0m	9.0m

At Marsden Point, Suezmax Tankers of these dimensions are currently handled in both the ballast and part loaded conditions. The loaded Suezmax to 16.6 metres has not been handled to date due to insufficient water in the existing channel at some locations. The full loaded vessel is more difficult to handle in strong tidal streams due to its deeper draft. It also has a larger turning diameter and is more prone to overshooting a turn due to the larger displacement in comparison to the partly loaded ship.

VLCC1A was considered to have below average manoeuvring capability and VLCC7 was considered to have average manoeuvring capability but above average engine power. The Simulated design vessel (SML) in the portable and remote link simulation studies was considered to have average manoeuvring capability. At the present time, the Suezmax vessels in ballast condition are restricted to flood tide only and the part loaded conditions are only handled at slack water when tidal streams are at their lowest velocity.

It should be noted that all references to load conditions refer to the ship model used in the simulation.

A log vessel was represented by the handy max bulk carrier, Bulk1, with an LOA of 183m, a beam of 22.6m, which was provided in one loaded draft condition:

ID	SHIP	CONDITION	DRAFT FORWARD	DRAFT AFT
Bulk1	Bulk1	Loaded	10.1m	10.7m

Tugs used in the simulation exercises were based on data sheets available on the Northport's website. Four tugs were nominated for use and are summarised below:

ID	SHIP	BOLLARD PULL	TYPE	SKEG	ESCORT Designated
BB	Bream Bay	70	ASD	Docking with extended closed forward skeg [1]	No
T	Takahiwai	50	ASD	No	No
K	Kemp	14	Twin Screw	No	No
MB	Marsden Bay	28	Twin Kort	No	No

Kemp and Marsden Bay were only used in Run 50 of this simulation study.

An Aframax class oil tanker was available for simulation. The Aframax vessel LOA 243m Beam 43m was provided at two draft conditions:

ID	SHIP	CONDITION	DRAFT FORWARD	DRAFT AFT
AML	AfraMax Oil	Loaded	12.5m	12.5m
AMB	AfraMax Oil B	In ballast	6.0m	7.0m

Details of ship models used are contained in the pilot cards of the vessels provided in **Appendix 1.**

Reference:

1. *Tug Use in Port A Practical Guide Henk Hensen Second Edition pp169-172 Section 10.1.3*

8 SIMULATION RUNS SUMMARY

This section provides a summary of the simulation runs, organised according to day. Further details on simulation runs and debriefing run notes are provided in **Appendix 3 and 4**. Run plots are provided separately to this report (**see Marsden Point Full Bridge Simulation Run Plots : Be-Software July 2016**).

8.1 Day One

Run 1 was an arrival exercise using the existing channel with the loaded AfraMax Oil Tanker. The objective of this run was to prove the validity of the current model and visual database. The current model and visual model was considered correct. Run Number 2 used the new channel design 4-2.1 with the loaded Suezmax VLCC1. The objective of this run was to check the depth databases particularly in the outer channel reach. An error was discovered in the depth database model which required a change in the simulation.

Runs 3 – 5 were arrival exercises using the VLCC1A from Fairway Buoy to Buoy 18 using the channel design 4-2.1. Underkeel clearance was much more realistic and the Pilots were able to control the ship but it was not easy in 20 knots of wind. The VLCC1 was considered by the pilots below average in terms of manoeuvring capability which confirmed the earlier assessment of that ship based on the supplied manoeuvring data. Existing tug capability was sufficient to assist in the arrival particularly for the deceleration required between Buoy 14 and Buoy 18. The stern tug was required to eliminate any residual rate of turn after the swing around buoy 14. The traditional leads on the 000\180 T centre line of the mid channel reach were considered a useful guide for the arriving design ship.

Run 6 and 7 used channel design 2 with the loaded Suezmax VLCC1A and VLCC7. Wind speeds were maintained at 20 knots and it was considered VLCC7 was much easier to control and more indicative of the Suezmax class of ship in terms of manoeuvrability. VLCC7 was classed as average and VLCC1A was classed as below average by the Pilots in terms of steering capability. The new position of the Fairway buoy on the starboard side of the channel was considered to be in a good position in relation to the entrance of the new channel. The entrance PEL light was not visible due to a simulation fault so it was not possible to comment on its effectiveness.

8.2 Day Two

Runs 8 and 9 were night time arrival runs with both VLCC1A and VLCC7 with wind speeds up to 30 knots. The channel design 4-2.2 was used for these runs .With the winds from the ENE it was expected that there would be some wind shadowing effects as the ship transited between buoy 3\6 and buoy 12. This was not simulated and it was very difficult to control VLCC1A. Thus run 8 was considered an unrealistic situation because of no wind shadowing.

Using VLCC7 in run 9, the ship could be controlled in the higher wind speed. In run 9 the wind shadowing was realistic. The PEL Lead Option 1 for the 000\180T centreline of the mid channel reach was considered not as effective as the traditional leads (Water Leads Option

3). The pilots felt it was more difficult to interpret their position using the PEL option when swinging onto the 000\180T centreline.

Run 10 was a daytime departure using channel design 4-2.2. The loaded logship was used for this departure under slack tidal conditions. It was not possible to simulate full ebb tidal conditions due to a problem with the tidal database. No difficulties were experienced with the departure. An alternative fairway buoy position on the port side of the channel was simulated and this was considered acceptable. The group of pilots had no real preference for the position of the fairway buoy either to port or starboard of the new entrance channel.

Run 11 was another nighttime arrival using VLCC7 with channel design 4-2.2. Ship was easier to control but not positioned well for the turn round buoy 14. As a consequence, there was a danger of grounding. Run 12 was a departure logship with channel design 4-2.2 under full ebb tide conditions. Tidal database was realistic and the departure successful, however it was considered that the logship model could accelerate too quickly.

Runs 13 to 17 were daylight arrival runs using channel design 4-2.1 with VLCC1A under limiting environmental conditions with wind speeds up to 30 knots. Using the portable pilot unit (PPU), the pilots were able to control the ship much better and in particular get real advantage from the traditional leads (Water Leads Option 3). A mistaken impression of the actual position of buoy 8 on the PPU had made the pilots initiate the turn from buoys 3\6 to buoy 7 earlier than was necessary. Once the position of buoy 8 was adjusted on the PPU, the pilots could use the traditional leads (Water Leads Option 3) much more effectively and more control was exercised when passing Home Point and initiating the turn round buoy 14. The pilots still needed to use the tugs to help control the residual rate of turn and deceleration once the arriving ship swings around buoy 14.

A short progress meeting was held at the end of the day to discuss the findings of the two days of simulation. The following points were raised.

- Channel design Option 4-2.1 with the traditional leads was considered superior to Option 2. There was more room to manoeuvre around buoy 14 and the advantage of the 000\180T centreline in passing Home Point were both considered advantageous.

- The PEL lead in Option 4-2.2 was not considered as effective in delineating the 000\180T centreline in the middle reach of the channel. The traditional leads (Water Leads Option 3) were considered better.

- The main PEL light on the outer entrance channel should be supplemented by a forward traditional lead which would be fitted with a single daylight on a simple structure. A single day shape was considered not required. The PEL sectors should be adjusted to reflect the new channel width dimensions accurately to give good warning when off the centreline and before reaching the toeline of the channel.

- The position of the Fairway buoy had no preference either side of the channel would be ok.

- The lights on the channel buoys should all be synchronized

- The ship VLCC1A represented a below average manoeuvring capability which was very difficult to control with wind speeds up to 30 knots. Such vessels are considered to be not commonly encountered. A system of vetting such ships before arrival was considered, to ensure appropriate procedures are in place before the ship enters the port. Such procedures could include daylight only and wind speed limited to 20 knots. VLCC7 was considered more realistic in terms of manoeuvring capability and more indicative of the class of vessels which had already visited the port. VLCC7 had above average engine power.

8.3 Day 3

A new group of pilots participated in the simulation from day three.

Runs 18 to 19 involved arrival runs using channel design 4-2.1, with the VLCC7, under average to limiting environmental conditions. Wind speeds up to 30 knots were simulated. Both runs demonstrated good control of the ship with minimal use of tugs. Both runs were very successful and both pilots were happy with the position of the tradition leads (Water Leads Option 3) for the 000\180T centreline of the middle reach of the channel.

Runs 20 and 21 introduced the arrival of VLCC1A under limiting environmental conditions of winds speeds up to 30 knots. Both pilots had difficulty in controlling the ship and called for tug assistance. The degree of difficulty in manoeuvring the ship was outside the pilots experience for this class of vessel.

Runs 22 and 23 were again with VLCC1A under limiting environmental conditions wind speeds up to 30 knots but both pilots were able to better control the ship with careful control of speed and use of tugs. The runs were very difficult but manageable.

Runs 24 and 25 were daylight departures of the logship under full flood and ebb tide with limiting environmental conditions, wind speeds up to 30 knots. The departures were completed successfully and both pilots were able to verify the port and starboard hand options for the fairway buoy. Both pilots preferred the fairway buoy on the starboard side.

The final run of the day was run 26. This was a nighttime arrival of the VLCC1A using channel design 4-2.1. Environment conditions were simulated with wind speeds to 20 knots. This was managed successfully using tug power opposed to engine power to control speed when approaching buoy 16 and provide effective flow of water over the rudder to control the rate of turn.

8.4 Day 4

Run 27 was conducted in channel design 4-2.1 with an arrival of VLCC1A. Environmental conditions were simulated with wind speeds up to 20 knots. The stern tug was prepositioned to assist when required and the PPU set up to use the predictor function. The ship was controlled very well and the run was successful.

Runs 28 to 35 were all arrival runs in channel design 2.0 using VLCC1A. Environmental conditions were simulated with wind speeds up to 25 knots. Both daytime and nighttime arrivals were simulated and wind directions varied. Careful navigation and use of the PPU, with stern tug prepositioned resulted in all runs being successful.

Runs 34 and 35 used the simulated tug Bream Bay operated from the tug simulator with a Northtugz Tugmaster. The integrated simulation performed very well under nighttime conditions and both runs were successful.

The final three runs 36 to 38 were departure runs using the logship and VLCCB in ballast. Channel design used was 4-2.1 and environmental conditions were varied up to wind speeds of 30 knots with full ebb tides. All runs were successful and were also used to check the options for placement of the Fairway Buoy on either the port side or starboard side of the channel. It was considered by the pilots that the best position for the fairway buoy was in its original position on the starboard hand side of the channel with an additional red port lateral buoy positioned across from the fairway buoy marking the port hand extremity of the channel.

8.5 Day Five

Run 39 tested the agreed position of the fairway buoy and an abort point was established six cables from the fairway buoy in the approach to the entrance of the channel. The VLCC1A was used to test the abort point and the ship passed clear of the fairway buoy by 140 metres.

Run 40 tested a power blackout on the VLCC1A when arriving and transiting the outer channel reach. Bream Bay was driven by Tugmaster Simon Noakes of Northtugz with assistance from training tugmaster and Pilot Troy Evans of the Port of Tauranga. The tugs were able to reach the VLCC1 in time to prevent grounding despite environmental conditions with cross winds up to 25 knots. With the ship safe in the channel, the decision was made to run the ship astern back out of the channel. This was successfully controlled using only the two tugs Bream Bay and Takahiwai. Runs 39 and 40 used channel design 2.

Runs 41 and 42 tested arrival emergencies with a black out and then a rudder jam to port. The existing tug capability was able to control both situations. Using a direct tow method the tug model Bream Bay was able to generate a line force of up to 100 tons at an angle of 50 degrees from the centreline. Both runs used channel design 4-2.1.

Run 43 used channel design 4-2.2 with the VLCCB on departure in a current operational scenario. Operational environmental conditions were simulated. The ship departed at one hour before high water on the last of the flood tide. Winds were up to 25 knots from the west. The ship was not escorted past buoy 16. A power blackout and rudder jam full to port resulted in the ship running aground bow first at a speed of 5 knots in the vicinity of Home Point. The tugs although called could not reach the ship before the grounding occurred.

Runs 44 to 46 then used an identical operational departing scenario with active and passive escorting. The passive escorting was successful in keeping the ship in the channel to the south of Home Point. Passively escorting the Bream Bay and Takahiwai were able to keep pace with the ship and remain at a distance of 100 metres off the ship. The active escorting was also successful but it was found a second tug was necessary to prevent the bow from grounding south of Home Point. From the results, it was found that some deficiencies in the use of tugs and available tug designs could impact on the ability to prevent the ship from grounding in certain operational cases specifically rudder jams and power blackouts involving a steering failure.

Runs 47 and 48 were arrival scenarios with channel design 4-2.2. The VLCC1A was used in limiting environmental conditions with wind speeds up to 30 knots. In run 47, after turning around buoy 14 and exiting the turn, the stern tug was used to brake the speed of the ship in the final approach to the berth. A towline breakage on the stern tug was controlled by astern power on the ship. Speed of the ship when the towline broke was about 6 knots. Run 48 continued run 47 and went on to berth the ship. Berthing velocities were controllable with the existing operational tug power.

Run 49 was an arrival with channel design 2. VLCC1A was under limiting environmental conditions with wind speeds up to 30 knots. Passing buoy 12 with a 2 degree rate of turn to port, the rudder jammed 25 degrees to starboard. Using the Bream Bay tug model driven by Simon Noakes, the Bream Bay model was able to get at least 50 degrees out from the centreline on the starboard quarter and deliver a direct pull of 100 tons with the ship speed over ground at 6 knots. This was sufficient to overcome the rudder jam to starboard and keep the ship within the channel.

The final run 50 was a VLCC1A deadship berthing from emergency anchorage to berth using all four tugs available in the port. Bream Bay 70 ton, Takahiwai 50 ton, Marsden Bay 28 ton and Kemp 14 ton. Operating with a wind speed of 30 knots from the south and from HW to just the start of the ebb tide, the deadship was controlled and moved to the berth. It was considered berthing could be safely achieved.

Following Run 50, there was a final washup meeting. The meeting reiterated points raised in the meeting on Friday 08\07\16, including:

- Channel Option 4-2 was the preferred channel design over Option 2 because it offered more searoom for the arriving and departing vessels and included a set of leads available to day and night time navigation which would assist particularly with arriving ships difficult to manoeuvre such as VLCC1A.

- Use of the PPU with the predictor function provided a great advantage particularly with arriving ships difficult to manoeuvre such as VLCC1A.
  The predictor allows for more precise navigation when turning onto the 000\180T leads in the middle reach of the channel and also for the turn round Buoy 14.

- The traditional Leads were preferred (Water Leads Option 3) to a PEL (PEL Leads Option 1) for the 000\180T centreline in the middle reach of the channel. The Leads should be fitted with daylights and nightlights. No day shapes were considered necessary and coloured lights were preferred.

- It was considered by the pilots that the Fairway buoy remain in its present position and an additional red port hand lateral buoy be placed abeam of the Fairway buoy to mark the port hand limit of the new entrance channel.

- The main PEL light on the outer entrance channel should be supplemented by a forward traditional lead which would be fitted with a single daylight on a simple structure. A single day shape was not required. The PEL sectors should be adjusted to reflect the new channel width dimensions accurately to give good warning when off the centreline and before reaching the toeline of the channel.

- The ship VLCC1A represented a below average manoeuvring capability which would be very difficult to control under limiting environmental conditions with wind speeds up to 30 knots. Such vessels are considered to be not commonly encountered. A system of vetting such ships before arrival should be considered, to ensure appropriate procedures are in place before the ship enters the port. VLCC7 and the SML used in the earlier portable and remote simulation studies, were considered more commonly encountered with this Suezmax class of vessels.

- Existing tug power was considered to be adequate for most emergencies between buoys 3\6 and the Crude Berth. However it was discussed to investigate tug procedures and design as part of an independent review.

9 FINDINGS

9.2.1 Channel dimensions

The channels: Option 2 and Option 4-2 were re tested against the earlier work done in the portable and remote link simulation studies. Testing in this full bridge study was done using current operational scenarios. From the Fairway buoy to buoys 3 and 6, the options are the same with a channel width of 215 metres. This was considered to be adequate for the design ship and existing ships provided there were improvements in the navigation aids.

Swell conditions could be simulated up to 2 metres Hs and period 22 seconds. However, it was considered by the Pilots that the DUKC system would cut out any arrivals if the swell height was above 1m Hs, based on the current DUKC operation. Swell accessibility may change in the future subject to the final channel design. Some plots of minimum UKC under differing swell conditions, vessel speed and ship stability are provided in **Appendix 2**.

Most of the full bridge simulation activity was performed between Fairway Buoy and buoy 18 near the RNZ berth. In this area, channel Option 2 and Option 4-2 would support the arrival of the design vessel VLCC1A. However, there was a clear preference amongst the pilots for Option 4-2 as it simplified the arrival approach around the critical area at buoy 14. The westward move of buoy 12 and the north westward move of buoy 14 in Channel Option 4-2 provided more searoom for the arriving ship in this area and increased the radius of the turn to 800m. The increase in radius of the turn and increase in searoom in the area bounded by buoy 14 to 12 to 11 to SM2, makes Channel Option 4-2 superior to Channel Option 2. (See: Table 1 in **Section 10.2**. Final Report RNZ Desktop Simulation Study Be-Software December 2015)

These are improvements over the existing channel and Option 2 because the simplification of the turn and more searoom will improve execution and monitoring of the turn on the part of the pilot. This full bridge simulation study found the provision of the traditional Leads (Water Leads Option 3) and also the use of the predictor function of the PPU improved execution and monitoring. This simulation study verified the results of the earlier portable and remote link simulation studies (Final Report RNZ Desktop Simulation Study Be-Software December 2015)

Option 4-2 improvements also are of benefit for the same reasons of simplification of the turn in the departure cases for existing vessels. It also provides more sea room in the area bounded by Buoy 7 to 12 to 14 to 9 for the clearing of the rocky outcrop off Home Point than the existing channel and Option 2. (See: Table 1 in **Section 10.2**. Final Report RNZ Desktop Simulation Study Be-Software December 2015) All the simulations demonstrated that vessels were able to successfully execute the turn rounding buoy 14.

9.2.2 Arrivals

Both the channels: Option 2 and Option 4-2 simulations demonstrated that the design ship could navigate this arrival turn at buoy 14 adequately. Tug assistance under non-emergency conditions can be used to brake the ship in the approach to the berth and also with a below average manoeuvrability Suezmax, the stern tug can be prepositioned to control the residual rate of turn when the ship exits the turn. It was found from simulation that with full rudder and half tug power applied at an offset angle of 20 degrees was sufficient to overcome any residual rate of turn. This is only necessary with a below average manoeuvrability SuezMax Oil Tanker

In Option 4-2, a set of leads was introduced in Taurikura Bay to define the north south centreline. These were found particularly helpful by both day and night. The preferred leads (Water Leads Option 3) are a traditional set of leads with daylights and nightlights (refer : Report of Proposed Taurikura Bay Leads Revision 2.2 Be-Software June 2016)

From the simulation it was found that both channel designs were adequate and the design ship could be safely manoeuvred for arrivals. In all cases, it was found that the pilot must:

- Be alert to commence the turn in the optimal position.
- Control the rate of turn of the ship carefully.
- Maintain an adequate speed through the turn to ensure the ship will exit the turn in a stable condition but can also be slowed in time for arrival off the berth.
- Use the PPU with the predictor function.
- Preposition the stern tug in case of difficulty in steering.

9.2.3 Departures

Using the existing ships which currently depart the port, it was found that both channel designs were adequate. Limited departure runs were run in this full bridge simulation study however there was a clear preference from the pilots for channel Option 4-2.. Option 4-2 offers a single turn around buoy 14 whilst Option 2 is a linked turn, which is more difficult to complete. The position of buoy 12 (shifted to the west) with Option 4-2 gives the pilot more room to keep to the west and avoid the dangers of shallow water off Home Point. This also has the effect of widening the channel for the pilot at a critical area.

The area in the close vicinity of buoy 7 and Home Point is considered risky and an area to be avoided due to the presence of strong tidal streams and hard rock. Option 4-2 was considered to be preferred to Option 2 as it allows the pilot to manoeuvre the ship further west in the departure case and clear the dangerous area around Home Point.

The table below shows the percentage of runs from all three simulation studies, which resulted in the safe passing of the area around Home Point. This table includes both arrival and departure non-emergency scenarios.

Channel Option	West of Centreline or on the Centreline of the channel	East of Centreline Of Channel	Well east of Centreline of Channel (One Beamwidth or less of HomePoint Special Marker)
2	46	43	11
4-2	86	12	2

This table clearly shows that Option 4-2 was significantly safer by being able to maintain the vessel west of centreline or on the centreline of the channel and away from Home Point.

Once clear of buoy 7, all options are adequate to proceed outwards to buoys 3/6 and then hence outward to the Fairway Buoy.

9.2.4 Swell conditions

For arrivals of the design ship VLCC1A, swell heights up to 2m were manageable. The pilots, however, considered that a 1m swell was all the DUKC would accept and that the new DUKC parameters will be critical with respect to the rolling and squat in a large swell.

9.2.5 Tidal streams

Good information was available on the tidal streams in the vicinity of buoys 3/6 up to the area off the Crude Berth. The portable, remote link and full bridge simulation studies used the same tidal data. In all cases the design ship could be controlled under the tidal streams simulated in the operational area using current operational procedures.

It should be noted that the ADCP data used to represent tidal stream was obtained during a 2.5m spring tide range and would be considered to be representative of the upper limit of tidal streams experienced in the port.

9.2.6 Wind conditions

Winds of up to 30 knots were simulated and the ships were controllable. VLCC1A was more comfortably managed at 25 knots. Wind directions were varied to create the least optimal conditions but were all managed adequately.

9.2.7 Navigation aids

Buoys are used to mark the extents of the existing channel and the existing buoys will be utilised throughout to mark the extents of the proposed Option 2 and Option 4-2 channels. The existing buoys were considered to be inadequately lighted (too weak) by some of the pilots.

Between the Fairway buoy and buoys 3/6, the buoys should remain in position (in particular the starboard hand buoys) or be moved outside the toeline as is required at buoy 3. It was important to maintain the existing wider buoyed channel for shallower draft vessels. The buoys should be lighted with a synchronized pattern, however this was not simulated. A new red port hand buoy was added to the start of the narrower deep outer channel and be positioned abreast of the existing Fairway buoy. This was tested and found extremely useful by the pilots.

The existing lead light marking the offshore approach channel was considered to be too insensitive by the pilots and this was demonstrated in all the simulations. The sectors of the main lead should adequately show the navigation limits of the new channel and be bright enough to support operations in adverse environmental conditions. Additionally a forward lead should be added to the main PEL lead to provide a traditional lead. This forward lead must be lit with a day and night light and was considered by the pilots not to require a day shape. This was simulated and found useful.

In the area from buoys 3/6 to the Crude Berth it was important that no buoys be moved inwards from their present positions so that the extent of the existing buoyed navigation area is not reduced.

Buoys 11 and 8 were aligned to provide a north-south centreline for the Option 4-2 channel. It was considered that these buoys should have a distinctive light characteristic. Additionally the traditional Leads (Water Leads Option 3) were found to be extremely valuable by all the pilots.

Buoy 5 was moved inwards in option 2 and option 4-2, to minimise dredging, and its position found to be acceptable. Buoy 7 remained in position in both the channel options to show the limit of the navigable water but an additional beacon SM2 positioned directly off the Home Point rock outcrop was added and found extremely useful by the Pilots.

9.2.8 Tugs

For the arrivals with design ship in all the simulation studies, it was considered that the available existing tug capability was adequate for both channels Option 2 and Option 4-2 under normal operations, including berthing.

In an emergency situation, there is a question whether the existing tugs would be able to provide emergency support for the arriving design ship. Simulations showed that the critical area was the turn at buoy 14 for the arrivals and clearing Home Point for the departures. The simulations were intended only as a feasibility exercise for channel design and navigational safety, rather than a risk assessment. Where there are possible risk issues which have arisen, they should be subject to a risk assessment and if necessary any consequential consideration by relevant stakeholders.

- The operational scenario simulations for the design ship arriving, found that in the event of a rudder jam to port or main engine failure or a power blackout, the existing tugs should be able to control that situation. This covers the majority of possible incidents.
- The operational scenario simulations for the design ship arriving, also found that the existing tugs may not be able to control the design ship in the event of a rudder jam

hard to starboard. In the full bridge simulation study it was found the model of the Bream Bay could provide a direct pull of up to 100 tons at an angle of four points on the quarter at a speed over ground of six knots. This could be verified by a live test on the actual Tug Bream Bay using a load cell on the tow rope.

- From the departure scenarios simulated, it was evident from the simulation that if tugs were not in the immediate vicinity of the ship and could not assist within two to three minutes, the departing vessel was highly likely to run aground or hit a buoy. This was evident specifically in the case of rudder jams and power blackouts involving steering failures. These were considered worst case scenarios but are largely directly related to the speed of ship and velocity of tidal stream, so are applicable to any ship type. This was tested in the area from buoy 14 to buoy 7 in all simulation studies.

10 CONCLUSIONS AND RECOMMENDATIONS

From the simulation study the following conclusions and recommendations are offered:

10.2.1 Channels and the design vessel Suezmax

- The channel designs Option 2 and Option 4-2 are all suitable for the design ship in wind conditions up to 30 knots and swell conditions up to 2 metre at the wave rider buoy. Arrival transits should only be attempted at slack water following the current operational procedures for the port.

- Both channel designs are suitable for day and night arrivals.

- The Option 4-2 Channel is the preferred channel – (refer: Table 1 **Section 10.2** in Final Report RNZ Desktop Simulation Study Be-Software December 2015) for a navigational comparison of the channel options.

- The positions of the buoys from the Fairway buoy to buoys 3/6 should be maintained in their current positions unless they are located inside the proposed channel toeline, as is the case with buoy 3. Buoy 3 needs to be moved north eastward to conform to the Option 4-2 design. An additional red port hand buoy should be placed abreast of the Fairway buoy. A majority of pilots preferred the Fairway buoy to remain a safe water buoy however it is recommended that it be replaced by a lit starboard hand lateral mark in accordance with IALA guidelines. The buoys between buoy 3/6 to the Crude Berth should generally remain in their present positions as they are used by the pilots to mark an acceptable channel width and provide the indications for the initiation of turns. Buoys 8 and 11 can be moved and lighted with a distinctive flash pattern to provide a north-south transit line up with the Option 4-2 approach to buoy 14.However the set of Leads on this leg were considered more useful. It is important to move buoy 11 to the new designed position east of its current location. Buoy 14 should be moved north westward and buoy 12 should be moved westward to conform to the Option 4-2 design. Buoy 5 can be moved in slightly to minimise dredging, if required. Buoy 7 should remain in its current position and a new beacon established to mark the extent of the navigable water off the Home Point rock outcrop. Buoys 10, 13, 14, 15, and 16 should all remain in their current positions. Buoy 18 should be moved eastward to conform to the Option 4-2 design. It was considered that by dredging further north to in line with buoys 11, 13 and 15, a suitable area would be available as an emergency anchorage and that this would provide an escape route if there was an emergency (i.e. loss of rudder control or engine power) when rounding buoy 14.

- The daylight leads on the offshore approach channel between the Fairway buoy and buoys 3/6 should be made more sensitive to adequately show the navigation limits of the new channel and be bright enough to support operations in adverse environmental conditions. An additional front lead should be established with day and night lights in the current front lead position. The existing front lead should be replaced with a simple day\night light lead with no day shape.

10.2.2 Tugs

The existing tugs Bream Bay and Takahiwai were considered to be adequate for an arriving design ship for normal operations from buoys 3/6 to the Crude Berth using channel Option 2 and Option 4-2. The existing tugs could assist in decelerating the ship in the approach to the berth and to put the vessel alongside the berth for a normal berthing operation at slack water. Additionally the aft tug can be prepositioned to provide additional steering forces operating no more than twenty degrees off the centreline. The Bream Bay is the most capable of the tugs and it is recommended to be tethered on the centre lead aft. Prepositioning of the tug to assist in the case of steering difficulties is recommended.

The existing tugs would be able to deal with the majority of emergency situations for the arriving ship. However, in the event of a rudder jam full to starboard in the vicinity of buoy 14 with an arriving ship, the existing tugs could have difficulty in providing sufficient tug forces to prevent the ship grounding. It is a consideration to be resolved independently of this work.

Shifting a dead ship from emergency anchorage to berth was simulated and considered possible using all four tugs.

Departing vessels were simulated with tug assistance located more than five minutes away. In the event of an emergency (specifically rudder jams and power blackouts involving a steering failure), that was too late for the tugs to provide any assistance to prevent grounding in the area between buoy 14 to buoys 8/10. This is applicable to all the channel designs.

It is recommended that the procedure in place by Northtugz for departing vessels should be reinforced to ensure that tugs attend in the immediate vicinity of the departing vessel as a minimum, until the ship has cleared the dangerous area at buoy 7 and the pilot is comfortable with the approach to buoys 3/6.

10.2.3 PPUs

Use of PPUs with a predictor function is recommended for both arrivals and departures for all vessels over 500 GRT.

10.2.4 Vetting of Manoeuvrability of Ships

VLCC1 was vetted prior to the full bridge simulation using manoeuvrability data supplied by the Simulation provider. The vessel was classed as below average manoeuvrability based on information for the tactical diameter and zig zag tests. During the simulation, the pilots verified this assessment. The alternative design ship VLCC7 and the SML used for the previous portable and remote link simulation studies were both classed as average in terms of manoeuvring capability and verified by the Pilots. It would be recommended to vet Suezmax vessels for manoeuvrability prior to acceptance into the port to ensure adequate preparation and procedures are in place for ships of below average manoeuvring capability.

Vetting of ships is possible by reference to dimensions and manoeuvring characteristics provided on the wheelhouse poster and result of sea trails hull part booklet.

References:

1. *Tug Use in Port A Practical Guide HenkHensen Second Edition pp169-172 Section 10.1.3*
2. *http://www.towingsolutionsinc.com/technology-escort_tugs.html et al*
3. *Tug Use in Port A Practical Guide HenkHensen Second Edition p 152 pp137-140 Section 9.4.1*
4. *Hydrodynamic Aspects of Ship Handling Tugs Brandner 1994 et al http://www.rina.org.uk/hres/1994-2%20Brandner%20-%20Hydrodynamic%20Aspects%20of%20Shiphandling%20Tugs.pdf*
5. *Review of New Zealand's Oil Pollution Preparedness and Response Capability Maritime New Zealand February 2011 pg 25 Section 7.1.1 https://www.maritimenz.govt.nz/Publications-and-forms/Environmental-protection/OPPRC-Review-February-2011.pdf*
6. *Rating-Based Maneuverability Standards. ABS Technical Papers United States October 2006 et al*

11 APPENDIX 1: PILOT CARDS and Maneuvering Data for SUEXMAX TANKERS and (LOGSHIP)

1. GENERAL DESCRIPTION

1.1. Ship's particulars

Ships name	VLCC 1m (Dis 165958t) TRANSAS version 2.311.0		
Displacement	165958 t	Deadweight	-
LOA	275 m	Breadth (Moulded)	48 m
LBP	259.1 m	Depth (Moulded)	25.1 m
Extreme height of the ships structure (measured from keel)	77.1 m	Draft middle	16.6 m
		Hull coefficient	0.78
Longitudinal metacenter height	336.6 m	Distance from middle frame to gravity center in stern	0 m
Transverse metacenter height	4 m	Distance from base plane to gravity center	14.4 m

1.2. Main Engine(s)

Type	Low speed diesel	Number of units	1	Power output	16520 kW

Remote control system modes: Harbour, Normal, Emergency, FPP

1.3. Propeller(s)

Type	FPP	Diameter	7.5 m
Number of units	1	Propeller immersion	11.4 m
Direction of rotation	Right	Pitch ratio	0.8

1.4. Rudder(s)

Type	Semisuspended	
Number of units	1	Rudder area ratio: 100 %
Number of pumps	2	(Effect. rudder area / Total rudder area)*100
Total rudder area	71.7 m2	
Max. rudder angle	45°	
Neutral rudder angle for Full Sea Ahead	0.34°	

1.5. Bow and Stern Thrusters

Type			
Number of units (bow)	0	Number of units (stern)	0
Bow thruster capacity	-	Stern thruster capacity	-
Bow thruster location	-	Stern thruster location	-

1.8. Characteristics of Main Engine

Engine order	Propeller RPM	Speed, Knots	Power, kW	Pitch ratio
FSAH	90.0	14.7	16002.0	0.8
FAH	75.0	12.2	9347.0	0.8
HAH	57.0	9.3	4168.0	0.8
SAH	38.1	6.2	1301.0	0.8
DSAH	27.0	4.4	495.0	0.8
DSAS	-27.8	-2.5	545.0	0.8
SAS	-40.0	-3.8	1497.0	0.8
HAS	-55.3	-4.3	3868.0	0.8
FAS	-65.0	-5.0	6180.0	0.8

Deep water, Water depth 1000 m

Min Stable RPM: 20 Speed at min RPM: 3.27 knots

ET Regime: Const RPM
Maximum No. of consecutive starts (diesel engine): 12

Time to get the specified propeller RPM for models with Fixed Pitch Propeller(s) or specified propeller pitch for models with Controllable Pitch Propeller(s)

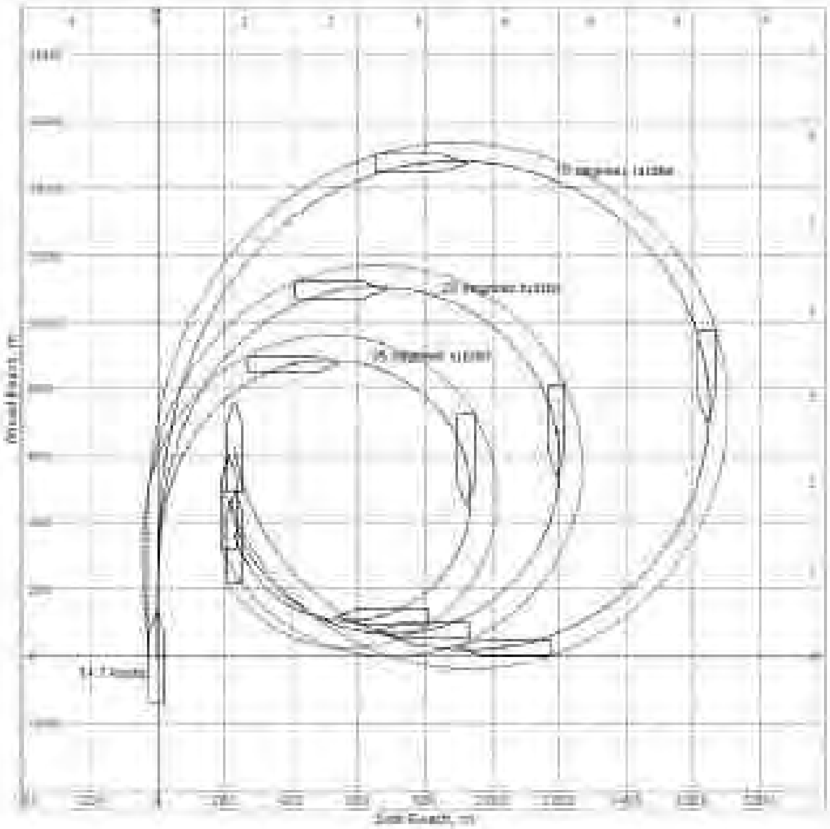
	Time Taken (min-s)	
Change in Engine Telegraph Settings	**Normal**	**Emergency**
From FSAH to FAS	6-32	1-44
From FAH to FAS	0-39	0-29
From HAH to FAS	0-34	0-26
From SAH to FAS	0-32	0-24
From DSAH to FAS	6-14	6-09
From FSAH to STOP	10-01	6-37
From FAH to STOP	3-44	3-44
From HAH to STOP	0-15	0-15
From SAH to STOP	0-07	0-07
From DSAH to STOP	0-05	0-05

2. MANOEUVRING CHARACTERISTICS IN DEEP WATER

2.1. Course change performance

FSAH ET

Initial turning test results



Environment conditions during test

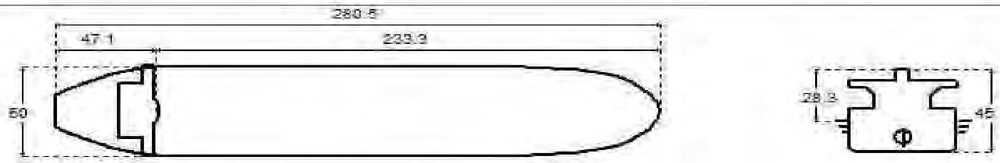
Wind direction	Wind speed, m/s	Sea state	Depth of water, m
0.0	0.0	Calm Sea	Deep Water (1000 Draft(s))

PILOT CARD

Ship name	VLCC 7 3.0.4.0 *			Date	29.04.2014
IMO Number	9316127	Call Sign	A8LY6	Year built	N/A
Load Condition	Full load				
Displacement	189406 tons		Draft forward	16.62 m / 54 ft 8 in	
Deadweight	163545.3 tons		Draft forward extreme	16.62 m / 54 ft 8 in	
Capacity			Draft after	16.62 m / 54 ft 8 in	
Air draft	28.38 m / 93 ft 4 in		Draft after extreme	16.62 m / 54 ft 8 in	

Ship's Particulars

Length overall	280.5 m	Type of bow	Bulbous
Breadth	50 m	Type of stern	V-shaped
Anchor(s) (No./types)	2 (PortBow / StbdBow)		
No. of shackles	14 / 13		(1 shackle =27.5 m / 15 fathoms)
Max. rate of heaving, m/min	18 / 18		



Steering characteristics

Steering device(s) (type/No.)	Semisuspended / 1	Number of bow thrusters	1
Maximum angle	35	Power	1500 kW
Rudder angle for neutral effect	0.33 degrees	Number of stern thrusters	N/A
Hard over to over(2 pumps)	14 seconds	Power	N/A
Flanking Rudder(s)	0	Auxiliary Steering Device(s)	N/A

Stopping

Description	Full Time	Head reach
FAH to FAS	553.6 s	10.23 cbls
HAH to HAS	598.6 s	9.77 cbls
SAH to SAS	678.6 s	9.16 cbls

Turning circle

Ordered Engine: 100%, Ordered rudder: 35 degrees	
Advance	4.77 cbls
Transfer	1.91 cbls
Tactical diameter	4.93 cbls

Main Engine(s)

Type of Main Engine	Low speed diesel	Number of propellers	1
Number of Main Engine(s)	1	Propeller rotation	Right
Maximum power per shaft	1 x 21770 kW	Propeller type	CPP
Astern power	80 % ahead	Min. RPM	45
Time limit astern	N/A	Emergency FAH to FAS	28.2 seconds

Engine Telegraph Table

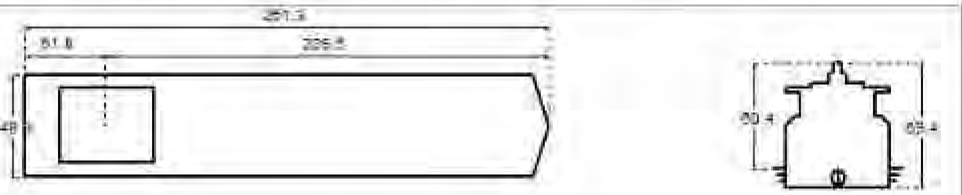
Engine order	Speed, knots	Engine power, kW	RPM	Pitch ratio
"FSAH"	16.1	19809	90.7	0.69
"FAH"	14.6	15321	82.8	0.69
"HAH"	13.2	11573	74.8	0.69
"SAH"	11	7756	64	0.69
"DSAH"	6	3066	62	0.35
"DSAS"	-3	3475	62	-0.35
"SAS"	-4.4	8433	64	-0.69
"HAS"	-5.3	13077	75	-0.69

PILOT CARD

Ship name	VLCC1 (Dis.63430t) bl. TRANSAS 2.31.33.0 *			Date	12.12.2012
IMO Number	N/A	Call Sign	N/A	Year built	N/A
Load Condition	Ballast				
Displacement	63430 tones	Draft forward		5.85 m / 19 ft 2 in	
Deadweight	N/A tonnes	Draft forward extreme		5.85 m / 19 ft 2 in	
Capacity		Draft after		9 m / 29 ft 7 in	
Air draft	60.48 m / 198 ft 11 in	Draft after extreme		9 m / 29 ft 7 in	

Ship's Particulars

Length overall	261.3 m	Type of bow	Bulbous
Breadth	48.3 m	Type of stern	V-shaped
Anchor Chain(Port)	15 shackles		
Anchor Chain(Starboard)	15 shackles		
Anchor Chain(Stern)	N/A shackles	(1 shackle=27.5 m / 15 fathoms)	



Steering characteristics

Steering device(s) (type/No.)	Semisuspended 1	Number of bow thrusters	N/A
Maximum angle	45	Power	N/A
Rudder angle for neutral effect	0.26 degrees	Number of stern thrusters	N/A
Hard over to over(2 pumps)	34 seconds	Power	N/A
Flanking Rudder(s)	0	Auxiliary Steering Device(s)	Auxiliary Steering Device(s): N/A

Stopping			Turning circle	
Description	Full Time	Head reach	Ordered Engine: 100%, Ordered rudder: 35 degrees	
FAH to FAS	479.6 s	8.13 cbls	Advance	3.62 cbls
HAH to HAS	525.6 s	6.92 cbls	Transfer	1.69 cbls
SAH to SAS	715.6 s	6.25 cbls	Tactical diameter	4.33 cbls

Main Engine(s)

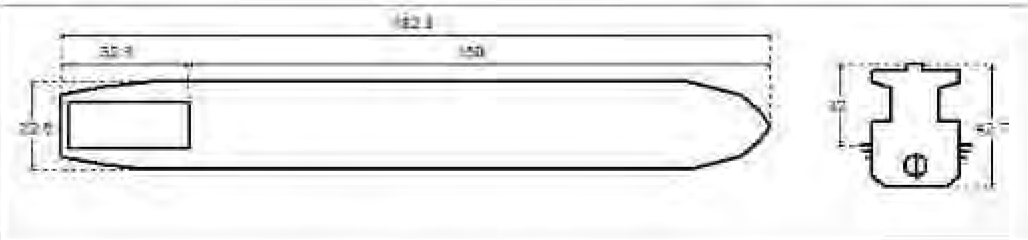
Type of Main Engine	Low speed diesel	Number of propellers	1
Number of Main Engine(s)	1	Propeller rotation	Right
Maximum power per shaft	1 x 15500 kW	Propeller type	FPP
Astern power	40 % ahead	Min. RPM	27.32
Time limit astern	N/A	Emergency FAH to FAS	1.1 seconds

Engine Telegraph Table

Engine order	Speed, knots	Engine power, kW	RPM	Pitch ratio
"FSAH"	16.3	15400	90.6	0.8
"FAH"	13.5	8845	75	0.8
"HAH"	10.3	3982	57.1	0.8
"SAH"	6.9	1246	38.1	0.8
"DSAH"	4.9	500	27.3	0.8
"DSAS"	-1.9	598	-28.3	0.8
"SAS"	-2.9	1592	-40.2	0.8
"HAS"	-4.5	4581	-57	0.8
"FAS"	-5.4	7175	-67	0.8

PILOT CARD					
Ship name	Bulk carrier 1 (Dis 330896 TRANSAS 2.31.44.0 *			Date	27.12.2011
IMO Number	N/A	Call Sign	N/A	Year built	1976
Load Condition	Full load				
Displacement	33089 tonnes	Draft forward		10.1 m / 33 ft 2 in	
Deadweight	N/A tonnes	Draft forward extreme		10.1 m / 33 ft 2 in	
Capacity		Draft after		10.7 m / 35 ft 2 in	
Air draft	32 m / 105 ft 3 in	Draft after extreme		10.7 m / 35 ft 2 in	

Ship's Particulars			
Length overall	182.88 m	Type of bow	Bulbous
Breadth	22.60 m	Type of stern	V-shaped
Anchor Chain(Port)	14 shackles		
Anchor Chain(Starboard)	14 shackles		
Anchor Chain(Stern)	N/A shackles	(1 shackle =27.5 m / 15 fathoms)	



Steering characteristics			
Steering device(s) (type No.)	Normal balance rudder 1	Number of bow thrusters	N/A
Maximum angle	35	Power	N/A
Rudder angle for neutral effect	1.4 degrees	Number of stern thrusters	N/A
Hard over to over(2 pumps)	17 seconds	Power	N/A
Flanking Rudder(s)	0		

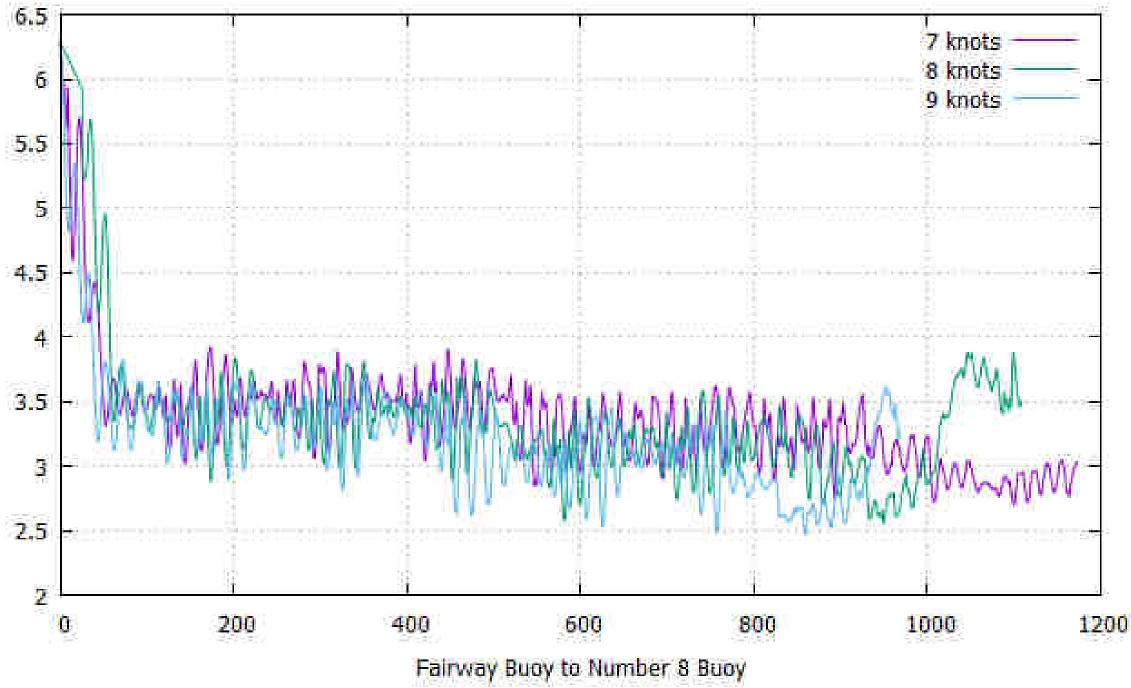
Stopping			Turning circle	
Description	Full Time	Head reach	Ordered Engine: 100%, Ordered rudder: 35 degrees	
FAH to FAS	238 s	3.46 cbls	Advance	2.96 cbls
HAH to HAS	401.6 s	3.44 cbls	Transfer	1.44 cbls
SAH to SAS	494.6 s	3.42 cbls	Tactical diameter	3.48 cbls

Main Engine(s)			
Type of Main Engine	Slow speed diesel	Number of propellers	1
Number of Main Engine(s)	1	Propeller rotation	Right
Maximum power per shaft	1 x 8827 kW	Propeller type	FPP
Astern power	80 % ahead	Min. RPM	29.7
Time limit astern	N/A	Emergency FAH to FAS	9.6 seconds

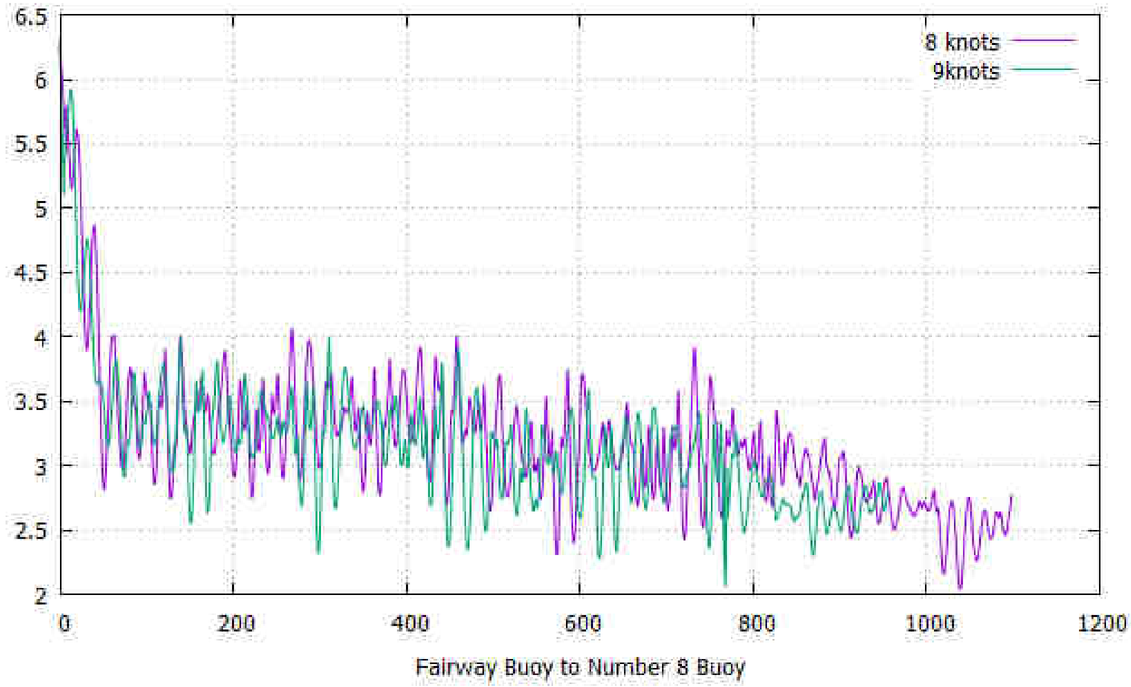
Engine Telegraph Table

Engine order	Speed, knots	Engine power, kW	RPM	Pitch ratio
Full Sea Ahead	14	8562	115	0.71
Full Ahead	10.3	3566	85.1	0.71
Half Ahead	6.5	935	54.4	0.71
Slow Ahead	5.3	504	44.2	0.71
Dead Slow Ahead	3.5	163	30.1	0.71
Dead Slow Astern	-1.5	195	-30	0.71
Slow Astern	-2.3	599	-44	0.71
Half Astern	-3.9	1199	-55	0.71
Full Astern	-4.8	4991	-86	0.71

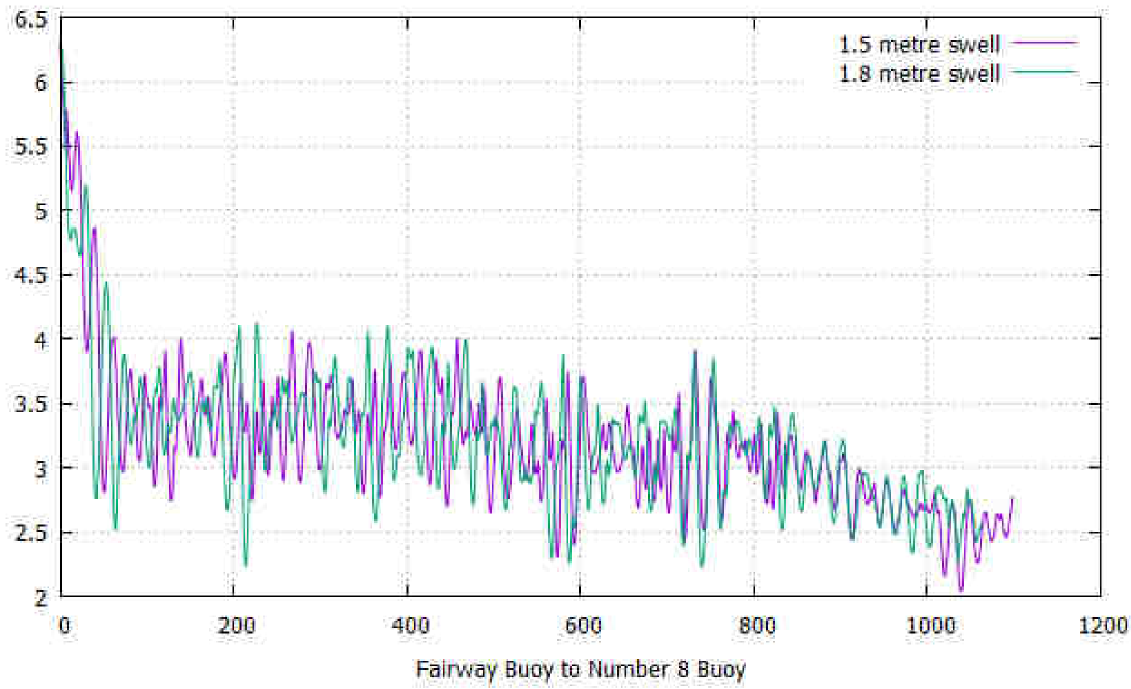
APPENDIX 2 Minimum UKC Plots



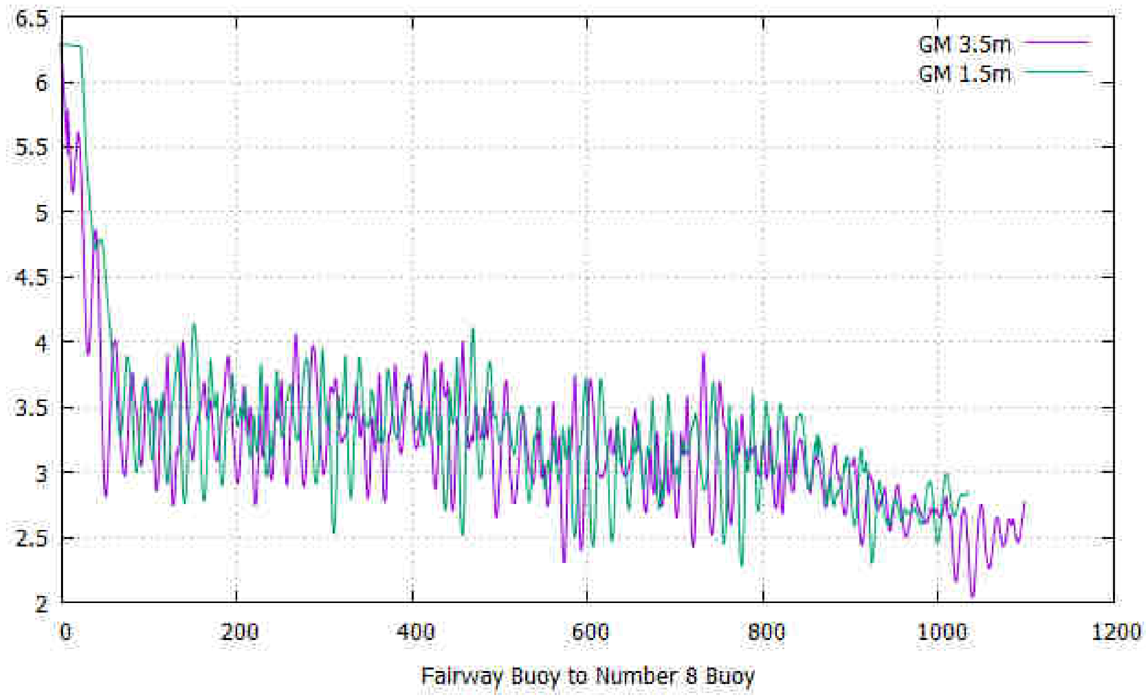
Minimum UKC experienced by SuezmaxL (Final Report RNZ Desktop Simulation Study: Be-Software December 2015) in swell 1.0 metres 13 second period. Winds cross channel 30 knots and gusting from SW.



Minimum UKC experienced by SuezmaxL (Final Report RNZ Desktop Simulation Study: Be-Software December 2015)in swell 1.5 metres 15 second period. Winds cross channel 30 knots and gusting from SW.



Minimum UKC experienced by SuezmaxL (Final Report RNZ Desktop Simulation Study: Be-Software December 2015) at 8 knots in swells 1.5m 15 seconds to 1.8m 20 seconds. Winds cross channel 30 knots and gusting from SW.



Minimum UKC experienced by SuezmaxL (Final Report RNZ Desktop Simulation Study: Be-Software December 2015) in swell 1.5 metres 15 second period in different stability cases. Winds cross channel 30 knots and gusting from SW.

APPENDIX 3 Runs Summary

SIMULATION SUMMARY:- MARSDEN POINT FULL BRIDGE SIMULATION STUDY

	Run No.	Date Channel	Time Simulator Local Start	Time Simulator Local Finish	Run Time (min)	Ship	Pilot	Start Position	Finish Position	Arrival / Departure	Vessel Start Directn (deg) Speed (kts)	Wind and Swell Directn (deg)	Wind and Swell Speed Height	Tide Flood/Ebb Rate (kts)
Day 1	**1**	7.7.16 Existing	7:00	7:31	31min	AlphamaxL	Tom	Fairway Existing	Buoy 16	Arrival	321.0 8.2	90 10	1m, 11s	1 hour before HW
	2	7.7.16 4.2.1	7:00	7:31	31min	SuezmaxL	Tom	Fairway	Buoy 16	Arrival	321.0 6.0	270 20	1m, 11s	1 hour before HW
	3	7.7.16 4.2.1	7:00	7:40	40min	SuezmaxL	Tom	Fairway	Buoy 18	Arrival	321.0 6.0	90 20	1m 11s	1 hour before HW
	4	7.7.16 4.2.1	7:30	8:10	40min	SuezmaxL	Wayne	Fairway	Buoy 18	Arrival	321.0 6.0	90 20	1m 11s	1 hour before HW
	5	7.7.16 4.2.1	7:30	8:10	40min	SuezmaxL	Jim	Fairway	Buoy 18	Arrival	321.0 6.0	90 20	1m11s	1 hour HW
	6	7.7.16 2.0.0	12:00	12:54	54mins	SuezmaxL	Tom	1.5 nms from Fairway Fairway	Buoy 18	Arrival	270.0 6.0	270 20	1m 13 s	1.25 before HW
	7	7.7.16 2.0.0	7:30	8:27	57 mins	Suezmax7L	Wayne	1.5 nms from Fairway	Buoy 18	Arrival	270.0	270	1m 13 s	1.25 before HW

								Fairway			6.0	20		
Day 2	**8**	8.7.16 4.2.2	22:00	22:31	31mins	SuezmaxL	Tom	Fairway	Buoy 11	Arrival	321.0 7.0	70 30	1m 13s	1 Hour before HW
	9	8.7.16 4.2.2	22:00	22:30	30mins	Suezmax7L	Jim	Fairway	Buoy 11	Arrival	321.0 7.0	70 30	1m 13s	1 Hour before HW
	10	8.7.16 4.2.2	7:30	8:00	30 mins	Logship	Tom	Buoy 18	Fairway	Departure	120.0 6.5	180 15	1m 13s	HW
	11	8.7.16 4.2.2	22:00	22:31	31mins	Suezmax7L	Wayne	Fairway	Buoy 16	Arrival	321.0 7.0	70 30	1m 13s	1 Hr before HW
	12	8..7.16 4.2.2	7:30	7:40	10mins	Logship	Tom	Buoy 8	Fairway	Departure	120.0 6.5	180 30	1m 13s	3 hour after HW
	13	8.7.16 4.2.1	3:00	3:40	40mins	SuezmaxL	Wayne	Buoy4	No. 18 Buoy	Arrival	320.0 6.5	250 30	1m 13s	0.8 hr before HW
	14	8.7.16 4.2.1	7:30	7:51	21mins	Suezmax7L	Wayne	Buoy 8	Buoy 16	Arrival	320.0 6.5	250 30	1m 13s	0.8 hr before HW
	15	8.7.16 4.2.1	7:30	7:51	21mins	Suezmax7L	Jim	Buoy 8	Buoy 14/16	Arrival	320.0 6.5	225 30	1m 13s	0.8 hr before HW
	16	8.7.16 4.2.1	7:30	7:55	25mins	SuezmaxL	Wayne	Buoy 8	Buoy 16	Arrival	320.0 6.5	225 30	1m 13s	0.8 hr before HW
	17	8.7.16 4.2.1	7:30	7:50	20mins	SuezmaxL	Wayne	Buoy 3/6	Buoy 16	Arrival	320.0 6.5	225 30	1m 13s	0.8 hr before HW
Day 3	**18**	11.7.16 4.2.1	7:30	8:04	34mins	Suezmax7L	Kirit	Fairway	Buoy 16	Arrival	320.0 6.5	225 20	1m 13s	1hr before HW
	19	11.7.16 4.2.1	7:30	8:05	35mins	Suezmax7L	George	Fairway	Buoy 16\18	Arrival	320.0 6.5	270 30	1m 13s	1hr before HW

	20	11.7.16 4.2.1	7:30	8:04	30mins	SuezmaxL	Kirit	Fairway	Buoy 16	Arrival	320.0 6.5	270 30	1m 13s	1hr before HW
	21	11.7.16 4.2.1	7:30	7:53	23mins	SuezmaxL	George	Buoy4	Buoy 16	Arrival	320.0 6.5	225 30	1m 13s	1hr before HW
	22	11.7.16 4.2.1	7:30	7:55	25mins	SuezmaxL	Kirit	Buoy4	Buoy 18	Arrival	320.0 6.5	45 30	1m 13s	1hr before HW
	23	11.7.16 4.2.1	7:30	7:55	25mins	SuezmaxL	George	Buoy4	Buoy 18	Arrival	320.0 6.5	225 30 g	1m 13s	1hr before HW
	24	11.7.16 4.2.1 FWBy Stb	7:30	7:51	21mins	Logship	Kirit	Buoy 16	Buoy 1	Departure	120.0 3.5	225 30	1m 13s	3hr before HW
	25	11.7.16 4.2.1 FWBy Port	7:30	7:50	20mins	Logship	George	Buoy 16	Buoy 1	Departure	120.0 3.5	225 30	1m 13s	3hr before HW
	26	11.7.16 4.2.1	22:00	22:38	38mins	SuezmaxL	George	Buoy4	Buoy 18	Arrival	320.0 6.5	225 20	1m 13s	1hr before HW
Day 4	**27**	12.7.16 4.2.1	7:30	7:53	23mins	SuezmaxL	Kirit	Buoy3/6	Buoy 18	Arrival	320.0 6.5	215 20	1m 13s	0.7hr before HW
	28	12.7.16 2.0.0	7:30	7:53	23mins	SuezmaxL	George	Buoy3/6	Buoy 18	Arrival	320.0 6.5	215 20	1m 13s	0.7hr before HW
	29	12.7.16 2.0.0	12:00	12::21	21 mins	SuezmaxL	Kirit	Buoy3/6	Buoy 18	Arrival	320.0 6.5	45 20	1m 13s	0.7hr before HW
	30	12.7.16 2.0.0	12:00	12:21	21mins	SuezmaxL	George	Buoy3/6	Buoy 18	Arrival	320.0 8knots	225 25	1m 13s	0.7hr before HW
	31	12.7.16 2.0.0	12:00	12:24	24mins	SuezmaxL	Kirit	Buoy3/6	Buoy 18	Arrival	320.0 8knots	270 25	1m 13s	0.7hr before HW

	32	12.7.16 2.0.0	12:00	12:21	21 mins	SuezmaxL	George	Buoy3/6	Buoy 18	Arrival	320.0 8knots	180 25	1m 13s	0.7hr before HW
	33	12.7.16 2.0.0	12:00	12:27	27mins	SuezmaxL	Kirit	Buoy3/6	Buoy 18	Arrival	320.0 8knots	0 25	1m 13s	0.7hr before HW
	34	12.7.16 2.0.0	22:00	22:25	25mins	SuezmaxL	George	Buoy3/6	Buoy 18	Arrival	320.0 8knots	225 25	1m 13s	0.7hr before HW
	35	12.7.16 2.0.0	22:00	5:31	23mins	SuezmaxL	Kirit	Buoy3/6	Buoy 18	Arrival	320.0 8knots	180 25	1m 13s	0.7hr before HW
	36	12.7.16 4.2.1	7:30	7:55	25mins	Logship	George	Buoy 18	Fairway	Departure	120.0 6 knots	225 30	1m 13s	3hrs after HW
	37	12.7.16 4.2.1	7:30	7:52	22mins	Logship	Kirit	Buoy 18	New Buoy 1A	Arrival	120.0 6 knots	225 30	1m 13s	3 hrs after HW
	38	12.7.16 4.2.1	7:30	7:49	19mins	VLCC1B	George	Buoy 18	New Buoy 1A	Arrival	120.0 6 knots	45 20	1m 13s	3hr before HW
Day 5	**39**	13.7.16 2.00.0	7:30	7:45	15mins	VLCC1A	George	1.5 nms off Fairway Buoy	0.6nms off Fairway	Arrival	320.0 3knots	225 10	1m 13s	1hr before HW
	40	13.7.16 2.0.0	7:30	7:52	22mins	VLCC1A	Kirit	1.5 nms off Fairway Buoy	Buoys 1\2	Arrival	320.0 6 knots	225 25	1m 13s	1hr before HW
	41	13.7.16 4.2.1	7:30	7:53	23mins	VLCC1A	George	Buoys 3\6	Buoy 16	Arrival	320.0 6 knots	270 25 to 30 k	1m 13s	0.7hr before HW
	42	13.7.16 4.2.1	7:30	7:49	19mins	VLCC1A	Kirit	Buoys 3\6	Buoy 16	Arrival	320.0 6 knots	180 25 to 30 k	1m 13s	0.7hr before HW
		12.7.16									120.0	270	1m 13s	

43	2.0.0	7:30	7:40	10mins	VLCC1B	George	Buoy 16	Buoy 7	Departure	4 knots	25		1 Hr before HW
44	12.7.16 4.2.1	7:30	7:45	15mins	VLCC1B	Kirit	Buoy 16	Buoy 7	Departure	120.0 4 knots	270 25	1m 13s	1 Hr before HW
45	12.7.16 4.2.1	7:30	7:45	15mins	VLCC1B	George	Buoy 16	Buoy 7	Departure	120.0 4 knots	270 25	1m 13s	1 Hr before HW
46	12.7.16 4.2.1	7:30	7:45	15mins	VLCC1B	Kirit	Buoy 16	Buoy 7	Departure	120.0 4 knots	270 25	1m 13s	1 Hr before HW
47	13.7.16 4.2.1	7:30	7:52	22mins	VLCC1A	George	Buoy 3/6	Buoy 18	Arrival	320.0 6knots	60 25-30	1m 13s	1 Hr before HW
48	13.7.16 4.2.1	7:30	7:58	28mins	VLCC1A	George	Buoy 18	Berth	Arrival	292.0 4.2knots	60 25-30	1m 13s	10mins before HW
49	13.7.16 2.0.0	7:30	7:54	24mins	VLCC1A	Kirit	Buoy 3\6	Buoy 16	Arrival	320.0 6knots	180 30	1m 13s	40mins before HW
50	13.7.16 4.2.1	12:00	12:28	28mins	VLCC1A	Tom	Buoy 15	Off Berth	Arrival	270.0 0 knots	180 30	1m 13s	HW

APPENDIX 4 Debriefing Notes Full Bridge Simulation Study

RUN NUMBER	SPEED	RUDDER COMMANDS	ENGINE COMMANDS	SHIP POSITION	VESSEL CONTROL	ANY CHANGES REQUIRED TO SIMULATION?	PILOT COMMENTS	SIMULATOR OPERATOR COMMENTS
1	Controlled	Very Responsive	Good	Good	Good	No	Tom Pilot Currents look correct Ship over responsive to helm	Existing Channel Currents are correct
2	Fast	High	High	Adequate	Poor in Outer Reach	Yes Depth	Tom Pilot Response not good in outer reaches. Response is ok in the deep water Leads not particularl helpful. Guide only	Channel 4.2.1 Depth data not correct for Dredged channel.
3	Controlled	High	Ok	Good	Good	No	Tom Pilot Response is better in outer reach Handling as expected middle reach. Turn around buoy 14 needed tug to assist in controlling swing	Channel 4.2.1 Underkeel clearance more realistic Tug used at full power three points to port. Swell too high in inner harbour
4	Controlled	High	Good	Ok	Good	Yes Leads	Wayne Pilot Outer reach need to not get up too much speed . Needed to carefully reduce the speed after buoy 14	Channel 4.2.1 Traditional leads look in wrong position. Rear Lead out of position. Not saved run. Controlled ship rounding buoy 14 using rudder ok
5	Controlled	Excessive	Good	Well to east in Middle Reach	Average	No	Jim Pilot When reducing engine rpm noticable effect on steering. Using tug to reduce speed after passing buoy 14 Needed tug to control swing	Channel 4.2.1 Appeared to need much more helm this run. Need tug to reduce ROT when exiting turn around Buoy 14
6	Controlled	Excessive	Good	OK	Average	Yes Leads and UKC	Tom Pilot Test of new starboard fairway buoy	Channel 2.0 Error in UKC at start of exercise with tide incorrectly applied but corrected ok. Channel PEL not visible

							No problem with position of new starboard fairway buoy	Ship took long time to take off port swing
7	Very Responsive	Very Responsive	Very Good	Good	Good	No	Wayne Pilot Vessel much more responsive. Helm and engines. Able to control ship without tugs quite easily. No logic to placement of buoys in this channel Control of speed so critical in the approach to berth. Tugs essential	Channel 2.0 No problem in outer reach. Swung onto middle reach all ok. Swung around buoy 14 wider but all ok.
8	Slow	Excessive	Good	Very Poor	No	Yes Wind Shadowing	Tom Pilot Nighttime run. Outer Reaches Wind too high no shadowing Could not control ship at 7 knots with full port helm	Channel 4.2.2 PEL Option Wind unrealistic Ship in danger of grounding
9	Good	Very Good	Good	Poor	Poor	No	Jim Pilot Night time run. Ship not positioned well for the turn around of buoy 14	Channel 4.2.2 PEL Option Wind shadowing 10knots in Middle Reach. Ship not positioned well in the middle reach Ship in danger of grounding
10	Good	Very Good	Good	Good	Good	Yes Current	Tom Pilot No problem with position of new port fairway buoy No preference port or starboard side for new fairway buoy	Channel 4.2.2 PEL Option Current wrong. Running at HW
11	Good	Very Good	Good	Poor	Poor	Yes Position of Buoys	Jim Pilot Night time run. Ship not positioned well for the turn around of buoy 14	Channel 4.2.2 PEL Option Wind shadowing 10knots in Middle Reach Ship in danger of grounding. Need to check position of buoys 12 and 14
12	Excessive	OK	Too Much	OK	Good	No	Wayne Pilot Unrealistic ship for acceleration due to engine power Able to control quite ok.	Channel 4.2.2 PEL Option Currents working. Ship unrealistic for a logship due to engine power. But some logships are more powerful. Requested Bulk22 for this ship.
							Wayne Pilot	Channel 4.2.1 Traditional Option

13	Good	Excessive	OK	Good	Poor	Yes Position of Buoys	Close to buoy 7 needed to take off turn earlier. Needed tug to help control turn to take off residual Rate of Turn.	Very Close to Buoy 7 and then poorly positioned for turn around Buoy 14. Overswung in the turn. Need to check position of buoys 12 and 14
14	Good	Good	Good	Very Good	Very Good	No	Wayne Pilot No problem. Leads very good Controlled wind effects on ship all ok	Channel 4.2.1 Traditional Option Good control. Mistaken impression of position of buoy to be started too early 8 caused initial turn to be too early. Value of leads clearly seen. Position of buoys checked.
15	Good	Good	Good	Very Good	Very Good	No	Jim Pilot No problem and Leads very good	Channel 4.2.1 Traditional Option Good Control and value of Leads clearly seen.
16	Fast	Ok	Ok	OK	OK	No	Wayne Pilot Used tug to assist in turn. Used leads to pass Home Point safely. Very difficult ship to control	Channel 4.2.1 Traditional Option Need to control swing to stbd before buoy 14 otherwise will be to the north on exiting the turn
17	Fast	Ok	Ok	OK	OK	No	Wayne Pilot Used tug to assist in turn. Used leads to pass Home Point and they were very useful. Very difficult ship to control but achievable. Preference to have leads to supplement buoys.	Channel 4.2.1 Traditional Option Need to control swing to stabd before buoy 14. Better result this run and value of leads clearly seen in keeping ship off Home Point.
18	Fast	Good	fast	good	ok	no	KIrit Pilot Good control Yes no problem. Powerful ship	Channel 4.2.1 Traditional Option Good Control. Fast in Middle reach 8 knots Tugs not used in turn at all.
19	Good	Good	OK	Very Good	Good	No	George Pilot Good control	Channel 4.2.1 Traditional Option Good Control. Fast in Middle reach 8 knots

							Yes no problem. Powerful ship	Tugs not used in turn but to decelerate ship
20	Very Fast	Too much	High	poor	Very Poor	No	Kirit Pilot Unrealistic response on rudder Never experienced before such difficulty in controlling residual rate of turn when exiting around buoy 14. Used high speed to try to control ship.	Channel 4.2.1 Traditional Option Overshot around buoy 8 . Too fast, speed was approaching 9 knots .Tried to use tugs but speed too high. Ship in danger of going aground
21	Good	Ok	OK	OK	Poor	No	George Pilot Asked for indirect tow from stern tug as passing Home Point. Used tugs to assist when exiting turn to assist in steering.	Channel 4.2.1 Traditional Option Overshot around buoy 8 . Good Speed .Tried to use tugs but speed too high. Ship in danger of going aground
22	Good	Good	Good	Good	Good	No	KIrit Pilot Much better control this time but still difficult.	Channel 4.2.1 Traditional Option Much better control Good speed. Turned ok . Used tug astern and engine ahead to control port swing
23	Good	Good	Good	Good	Good	No	George Pilot Much better control as anticipated ship response Bit fast near Buoy 18	Channel 4.2.1 Traditional Option Much better control Good speed. Turned ok . Used tug astern and engine ahead to control port swing
24	Good	Good	Good	Good	Good	No	KIrit Pilot Present position is good on starboard side	Channel 4.2.1 Traditional Option No problem with Fairway Buoy in this position.
25	Good	Good	Good	Good	Good	No	George Pilot Pilot Present position on starboard side is better than port. Simulate two entrance buoys as well	Channel 4.2.1 Traditional Option No problem with position of fairway buoy
26	Fast	Good	Good	Good	Good	No	George Pilot Pilot Did not use tug to turn	Channel 4.2.1 Traditional Option Controlled ok

							Used engine against tug to reduce ROT to port	Speed excessive at 18 Buoy 4.9 kns.
27	Good	Good	Good	Good	Very good	No	Kirit Pilot Much better control with less wind. Sluggish but controllable.	Channel 4.2.1 Traditional Option Preposition tugs 50t pull back. One point port quarter increased to two points It was found that controlling the RoT was more effective at two points off the centerline of the ship
28	Good	Good	Good	Good	Very Good	Yes(UKC)	George Pilot Using PPU Less wind was good. Missed having Leads.	Channel Option 2.0 Error in UKC due to incorrect tide input at start of exercise but corrected ok. Preposition Tugs Started port swing with 2.5 deg\min ROT. Controlling ROT ok
29	Very Good	Good	Good	Very Good	Very Good	No	Kirit Pilot Using PPU Controlled all ok. Less wind was much better	Channel Option 2.0 Preposition Tugs Controlling ROT ok
30	Very Good	Good	Good	Very Good	Very Good	No	George Pilot Using PPU No problem controlling ship	Channel Option 2.0 Preposition Tugs Used less ROT and able to control turn very well
31	Very Good	Good	Good	Very Good	Very Good	No	Kirit Pilot Using PPU Able to control ship quite OK	Channel Option 2.0 Preposition Tugs To the north with wind from south. No problem to control ship
32	Very Good	Good	Good	Very Good	Very Good	No	George Pilot Using PPU Able to control ship quite OK	Channel Option 2.0 Preposition Tugs To the north with wind from south. No problem to control ship
33	Very Good	Good	Good	Very Good	Very Good	No	Kirit Pilot Using PPU Controlled ship very well	Channel Option 2.0 Preposition Tugs Very well controlled
34	Faster	Good	Good	Very Good	Very Good	No	George Pilot Using PPU Night time	Channel Option 2.0 Live Tugs

							Controlled situation well.	Up to 85 tons transverse arrest. Parted line for 2 mins Unrealistic time to rig an alternative towrope but recovered situation
35	Good	Good	Good	Very Good	Very Good	No	Kirit Pilot Using PPU Night time No problem controlling ship	Channel Option 2.0 Live Tugs Maximum pull up to 100 tons. All controlled well
36	Good	Good	Slower	Very good	Very Good	No	George Pilot No problem to take ship out and between new 1A and New Fairway buoy to depart north.	Channel Option 4.2.1 Live tugs Bream Bay Passive Escort and maintained station with departing ship.
37	Controlled	Good	OK	Very Good	Very Good	No	Kirit Pilot Preference is buoys in line with fairway buoy. No apparent issues with this ship in this exercise.	Channel Option 4.2.1 Looked at removing Fairway buoy and green buoys in alignment with toeline of channel Live Tugs Bream Bay Passive Escort tug and maintained station with departing ship.
38	Good	Good	OK	To West Good	OK	No	George Pilot Ballasted Suezmax out under max operational conditions. Full Flood tide Vessel sluggish. Need extra searoom around 12 and 7 to keep away from Home Point. Discussion with Pilots concluded the best navigation aids configuration is with the Fairway buoy in the original position with the green buoys offset from the toeline and with the addition of an addition red buoy	Channel Option 4.2.1 Flood tide maximum. Passing close to number 12 Extra sea room with Option 4-2 was beneficial in this case
39	Good	Good	OK	Good	OK	No	George Pilot Tested Abort Point 6 cables off Fairway Buoy Speed 7knots when aborted	Channel Option 2 Swung to starboard cleared by Fairway by 140 metres
							Kirit Pilot Emergency	Channel Option 2

40	Good	Good	lost	Good	OK	No	7:33:00 AM Main Engine Failure as part of blackout. 07:44 Main Engines available. Ship to be taken out of channel astern. TK moved from Port to Sbd Shoulder Was considered able to move ship out of channel astern	Called Tug assistance. BB onto stern. Tk port shoulder. BB fast 07:39. Tk pushes BB pulls back. Port shoulder on edge of Channel. Controlled movement astern.
41	Good	Good	Lost	to East	OK	Yes Need to be able to measure push effect by tugs.	George Emergency 07:39:00 Blackout. Lost Steering and Engines 07:42 Emergency Steering. Cleared Home Point by one beam width. Controlled ROT with Tugs around 14 and then used BB to push up on transom	Channel Option 4.2 Controlled emergency well around HomePoint with emergency steering and tugs. Did turn around By14 using tugs and controlled ROT well. Used BB to push on transom to move ship past buoy 16. Unable to measure tug push tonnage. Used BB to attempt to steer from Transom
42	Good	Good	Lost	Good	OK	No	Kirit Pilot Emergency Controlled port rudder jam ok with BB on stern . Direct tow 100 tons at four points Troy pleasantly surprised at weight on line	Channel Option 4.2.1 Controlled emergency well. Use live tug and got up to 100tons direct pull at four points
43	Good	Lost	Lost	Emergency	Lost	No	George Pilot Emergency Black out occurred after buoy12 Hard port rudder jam and Black out	Channel Option 4.2.2 Unable to control BB at Buoy 14 when running aground
44	Good	Lost	Lost	Emergency	Poor	No	Kirit Pilot Emergency Black out occurred after buoy12 Hard port rudder jam and Black out	Channel Option 4-2.2 Able to control with active escort Needed second tug to control bow
45	Good	Lost	Lost	Emergency	Good	No	George Pilot Emergency Black out occurred after buoy12 Small jam to stbd	Channel Option 4.2.2 Passive Escort Able to control
46	Good	Lost	Lost	Emergency	Good	No	KIrit Pilot Emergency Black out occurred after buoy12 Rudder jam Hard a Port. Controlled	Channel Option 4.2.2 Passive Escort Controlled with large push on starboard quarter

47	Good	Ok	OK	Emergency	OK	No	George Pilot Emergency 07:45 TK on Centre lead aft and broke towline 7:52:00 AM Recovered but simulation lost	Channel Option 4.2.2 Winds gusting 30k Able to decelerate ship ok
48	Good	Good	Good	OK	Very Good	No	George Pilot Emergency Decelerate before berth TK Centre lead aft Berthed ok	Channel Option 4.2.2 Berthing Winds gusting 30k Unable to have bridgewing view
49	Good	Good	Good	Good	Very Good	No	Kirit Pilot Emergency Rudder jam 25 degrees to stbd. Speed 6.5kns Engine stopped immediately	Channel Option 2.0 Winds steady 30 knots Speed slower and stopped engine immediately. BB up to 100 tons at 4 points on the starboard quarter. Controlled
50	Slow but OK	NA	NA	Good	Good	No	Tom Pilot Emergency Four Tugs. Start of Ebb .TK Centrelead forrard BB Stbd Quarter. Kempt\Marsden Bay free as required. Manageable. Comfortable that can control	Channel Option 4.2 Berthing Dead Ship move to berth. Slow but OK

RNZ Full Bridge Simulation Study Final Run Plots

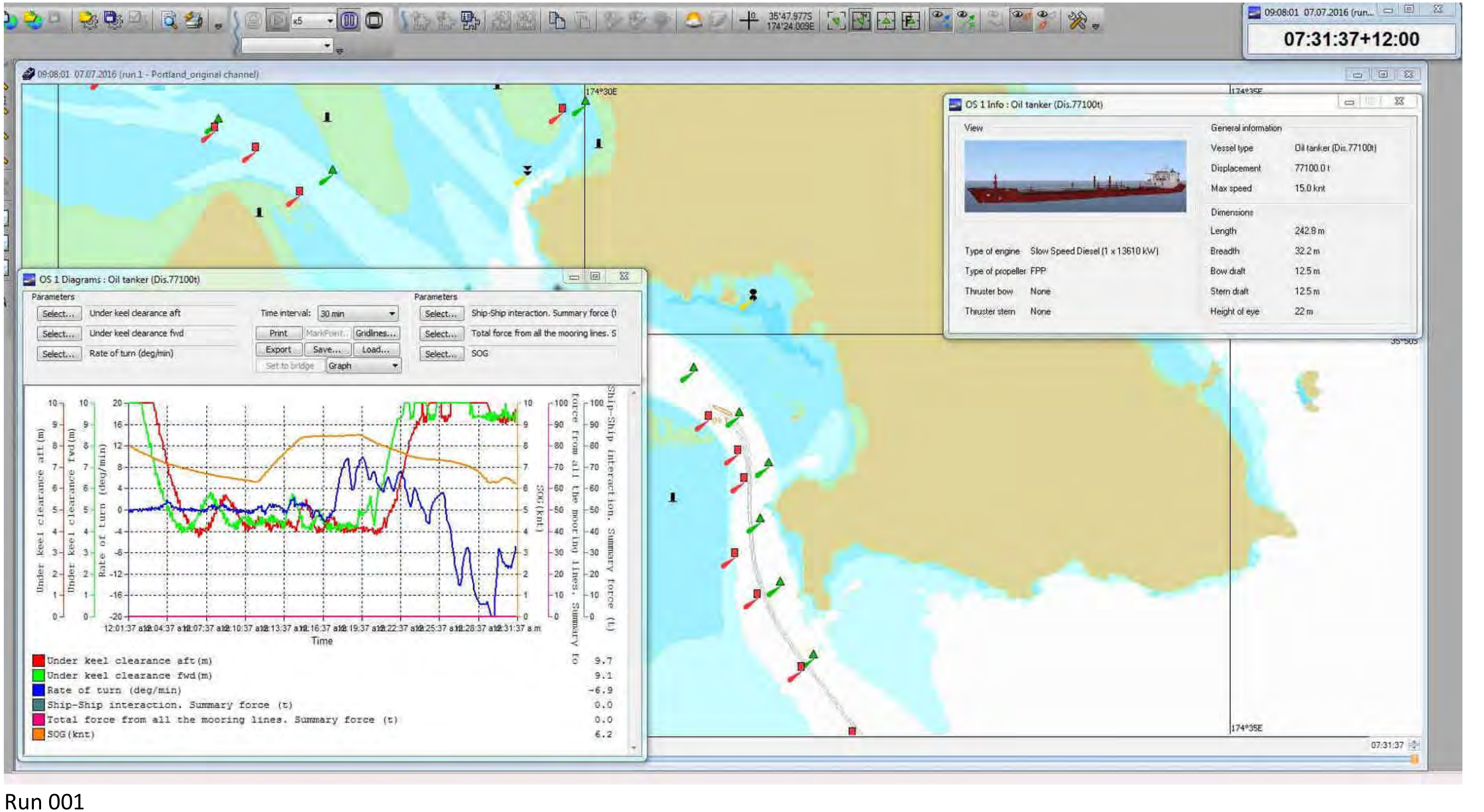
August 2016

In association with the report : RNZ Full Bridge Simulation Study Final Report August 2016 Be-Software

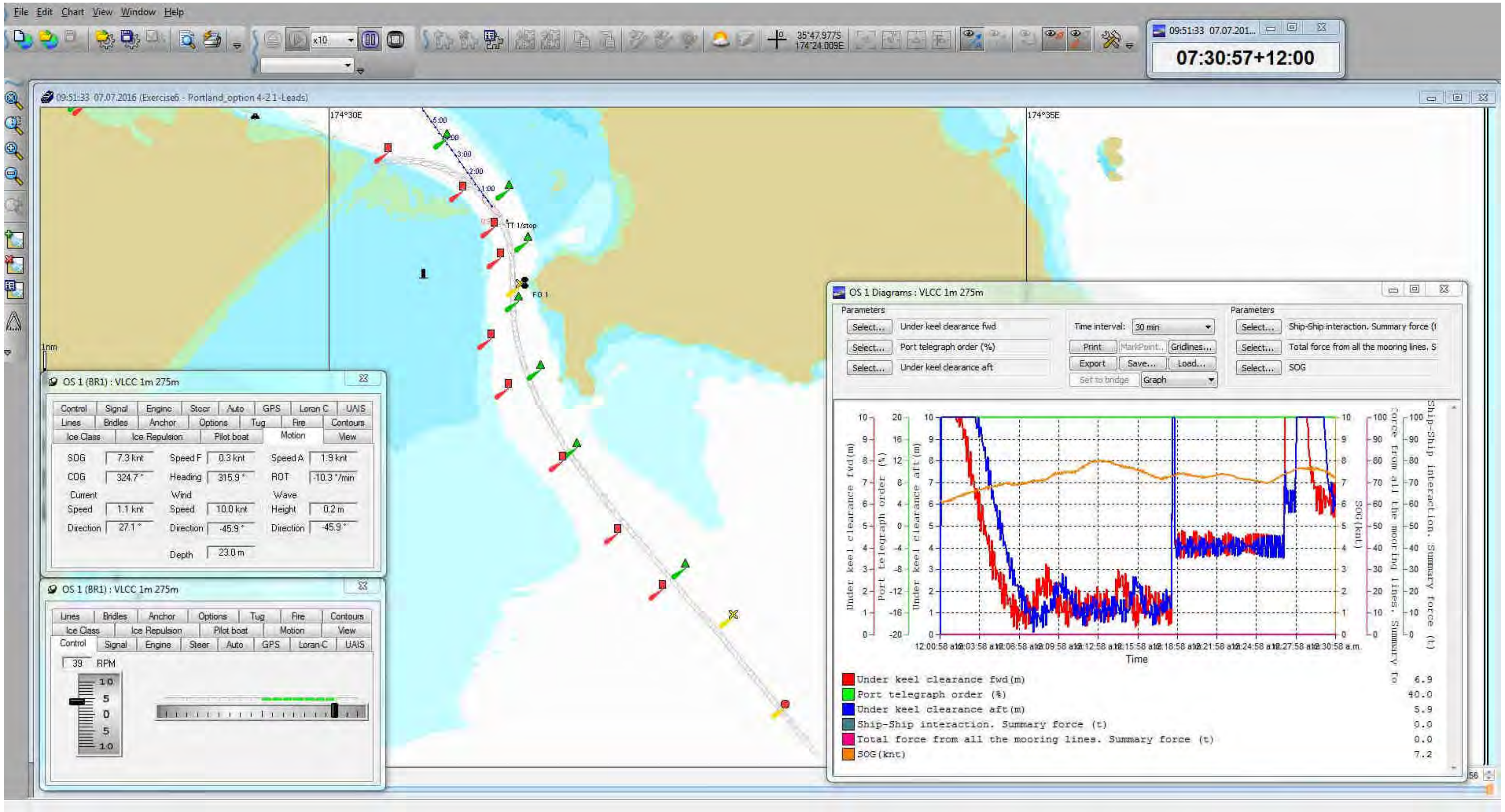
Prepared by:

besoftware
Maritime Simulation Solutions

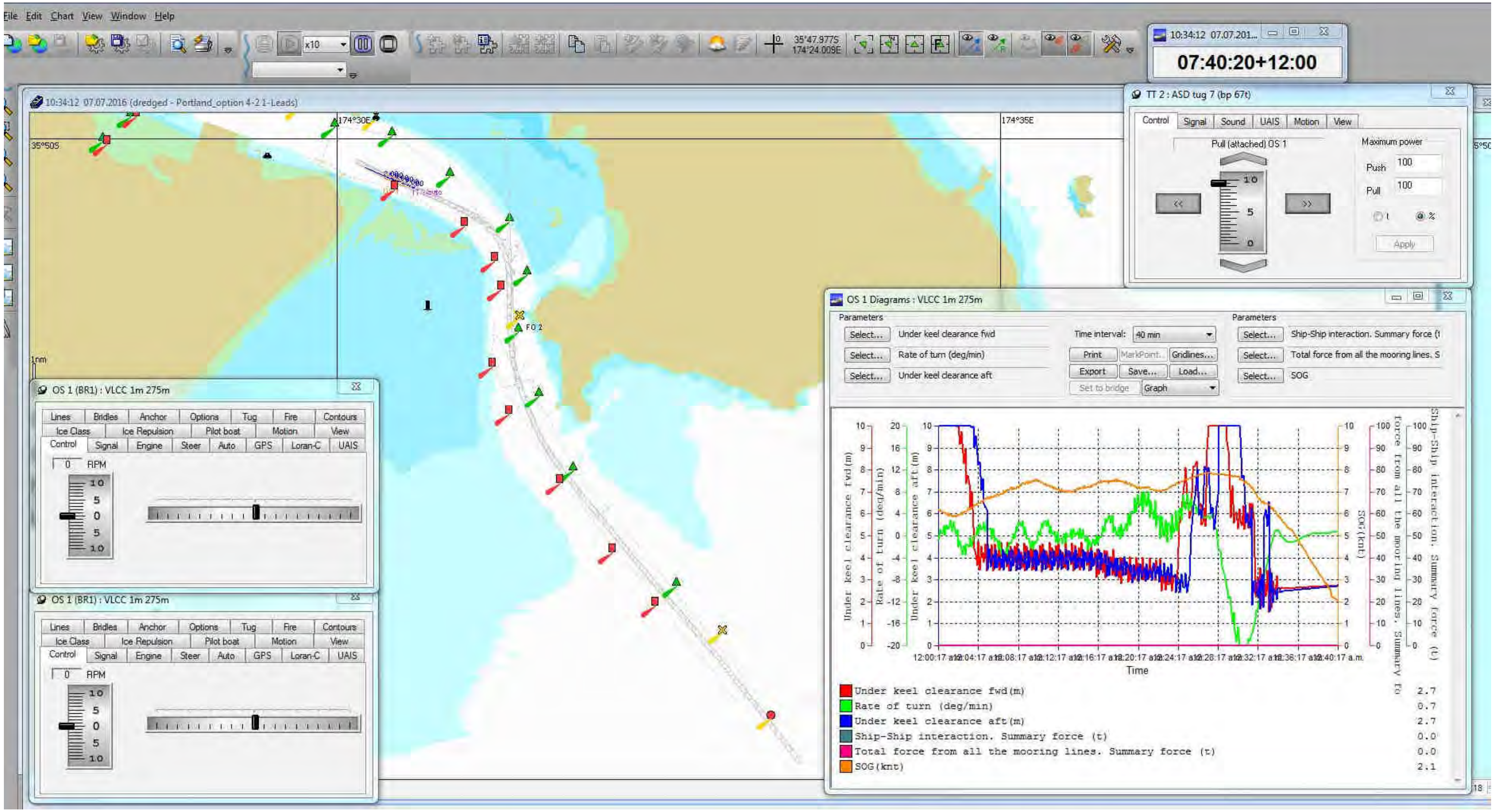
RNZ Full Bridge Simulation Study Final Run Plots July 2016



Run 001



Run 002 (Note: Error in UKC in this exercise)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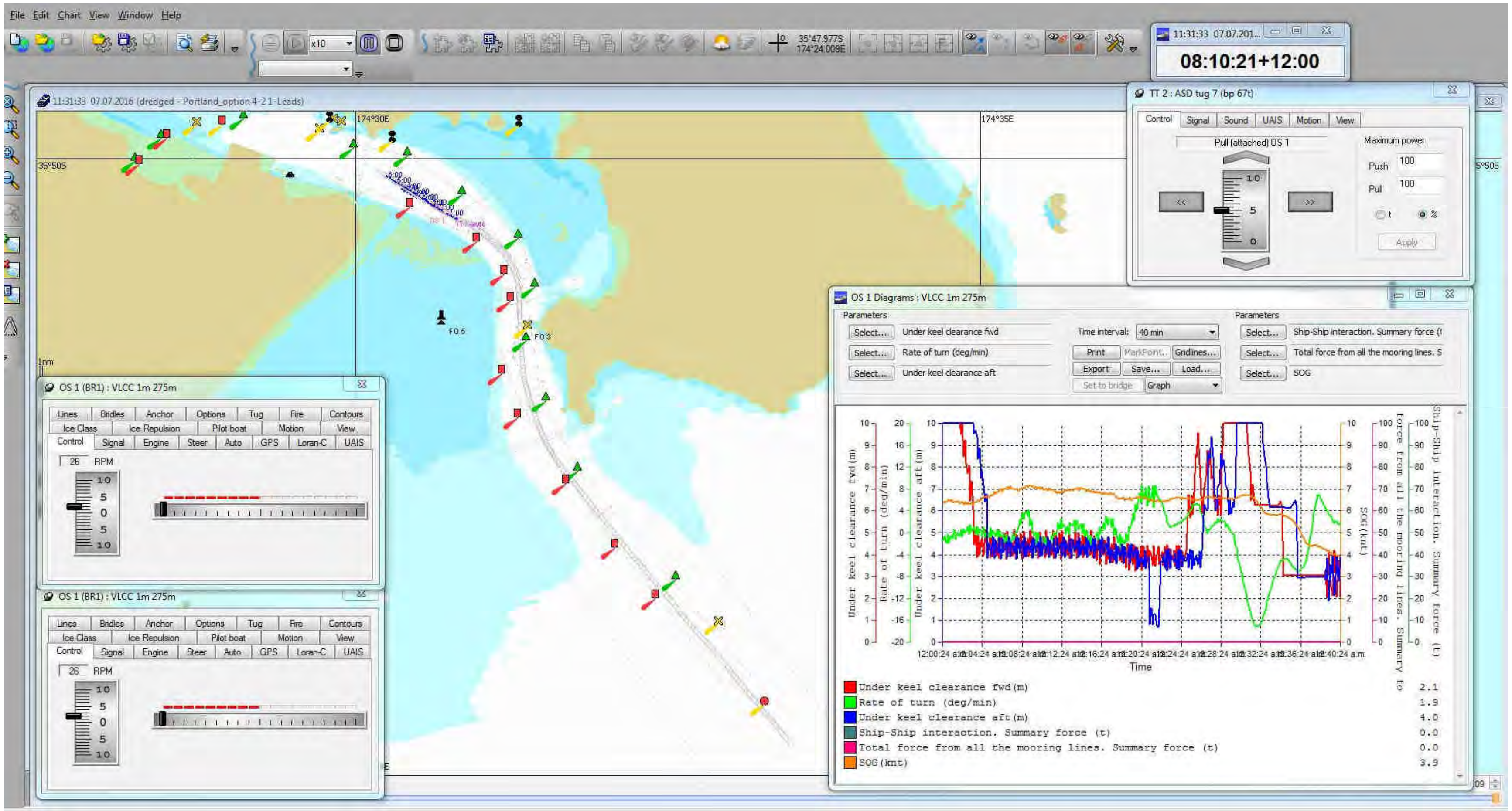
10:34:12 07.07.2016 (dredged - Portland_option 4-2 1-Leads)
TT 2 : ASD tug 7 (bp 67t)
OS 1 (BR1) : VLCC 1m 275m
OS 1 Diagrams : VLCC 1m 275m
Under keel clearance fwd (m)
Rate of turn (deg/min)
Under keel clearance aft (m)
Ship-Ship interaction. Summary force (t)
Total force from all the mooring lines. Summary force (t)
SOG (knt)
Time

Run 003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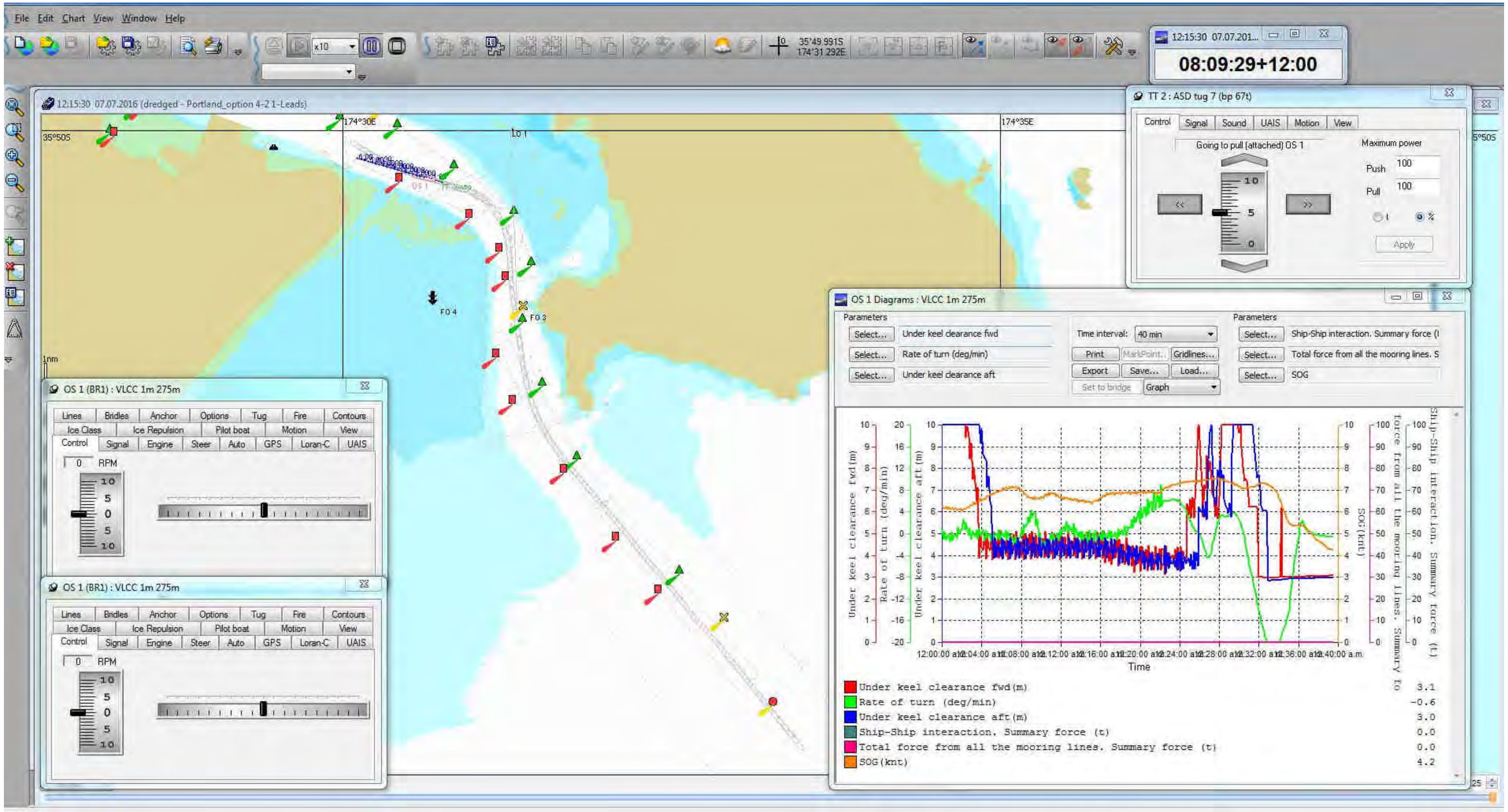
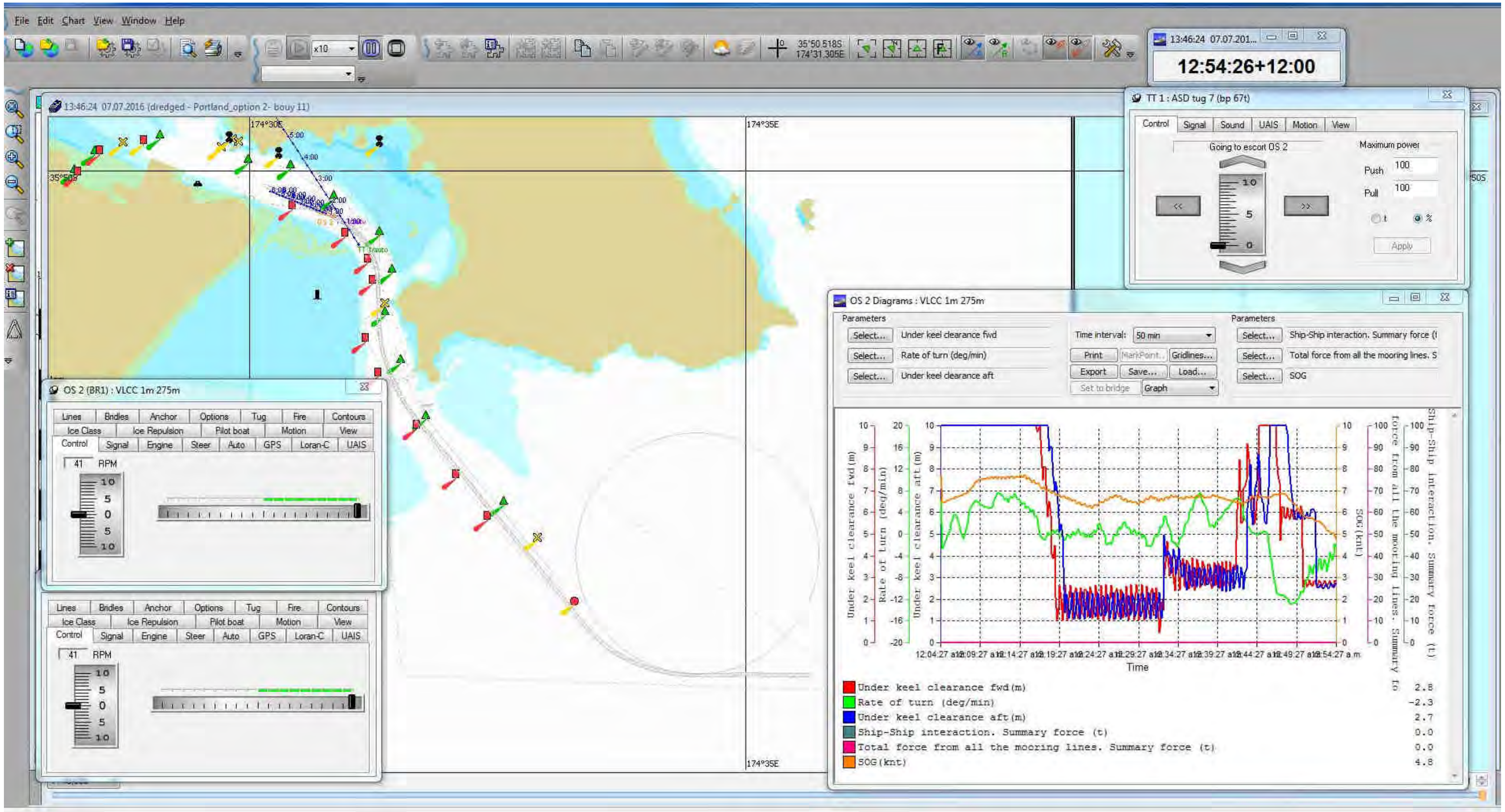
11:31:33 07.07.2016 (dredged - Portland_option 4-2 1-Leads)
08:10:21+12:00
TT 2 : ASD tug 7 (bp 67t)
Control Signal Sound UAIS Motion View
Pull (attached) OS 1
Maximum power
Push 100
Pull 100
Apply
OS 1 (BR1) : VLCC 1m 275m
Lines Bridles Anchor Options Tug Fire Contours
Ice Class Ice Repulsion Pilot boat Motion View
Control Signal Engine Steer Auto GPS Loran-C UAIS
26 RPM
OS 1 (BR1) : VLCC 1m 275m
OS 1 Diagrams : VLCC 1m 275m
Parameters
Under keel clearance fwd
Rate of turn (deg/min)
Under keel clearance aft
Time interval: 40 min
Print Gridlines... Export Save... Load...
Set to bridge Graph
Ship-Ship interaction. Summary force (t)
Total force from all the mooring lines. Summary force (t)
SOG
Time
Under keel clearance fwd(m) 2.1
Rate of turn (deg/min) 1.9
Under keel clearance aft(m) 4.0
Ship-Ship interaction. Summary force (t) 0.0
Total force from all the mooring lines. Summary force (t) 0.0
SOG(knt) 3.9

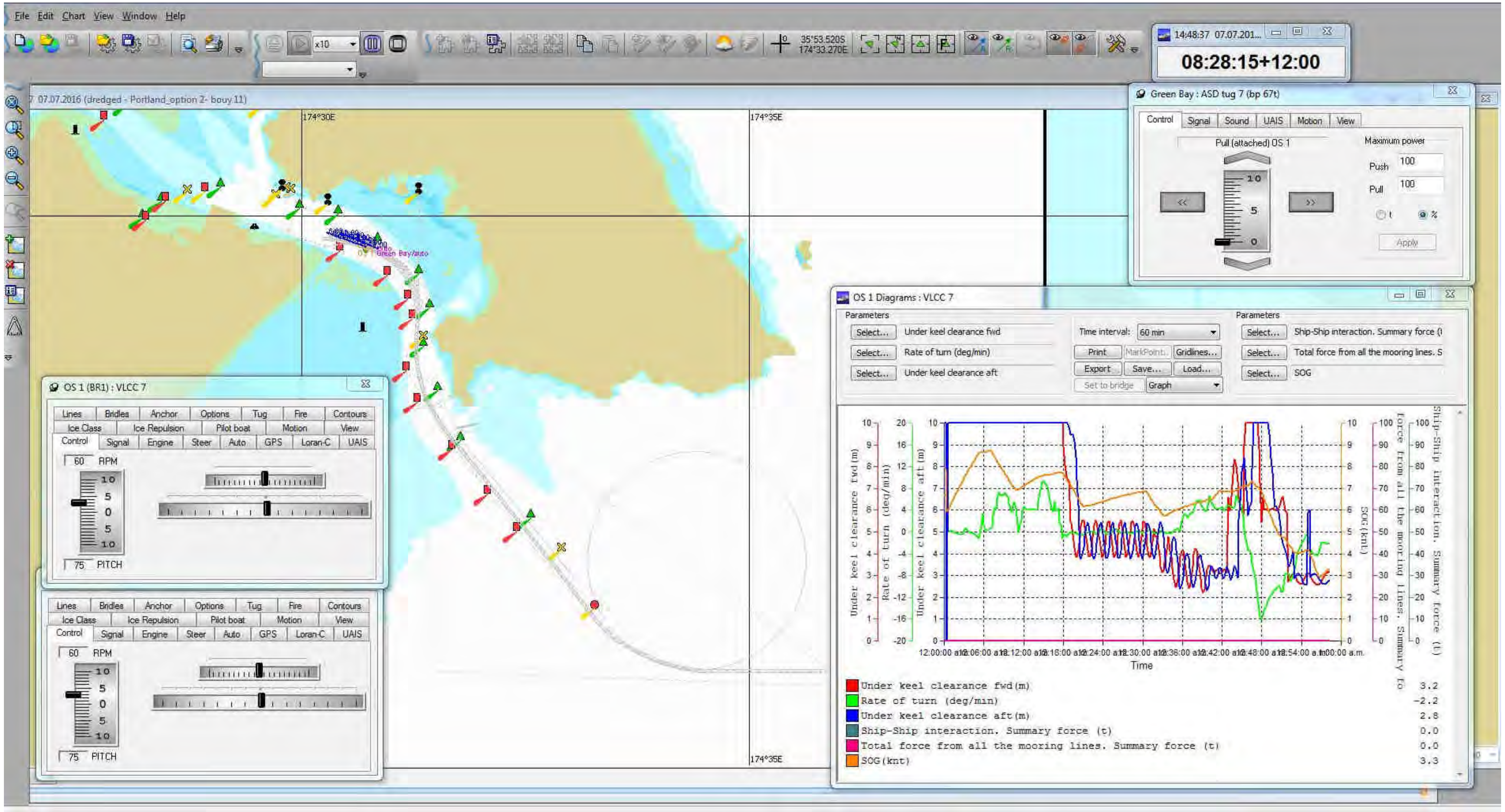
Run 004


08:09:29+12:00
TT 2 : ASD tug 7 (bp 67t)
OS 1 Diagrams : VLCC 1m 275m
Under keel clearance fwd(m)
Rate of turn (deg/min)
Under keel clearance aft(m)
Ship-Ship interaction. Summary force (t)
Total force from all the mooring lines. Summary force (t)
SOG(knt)

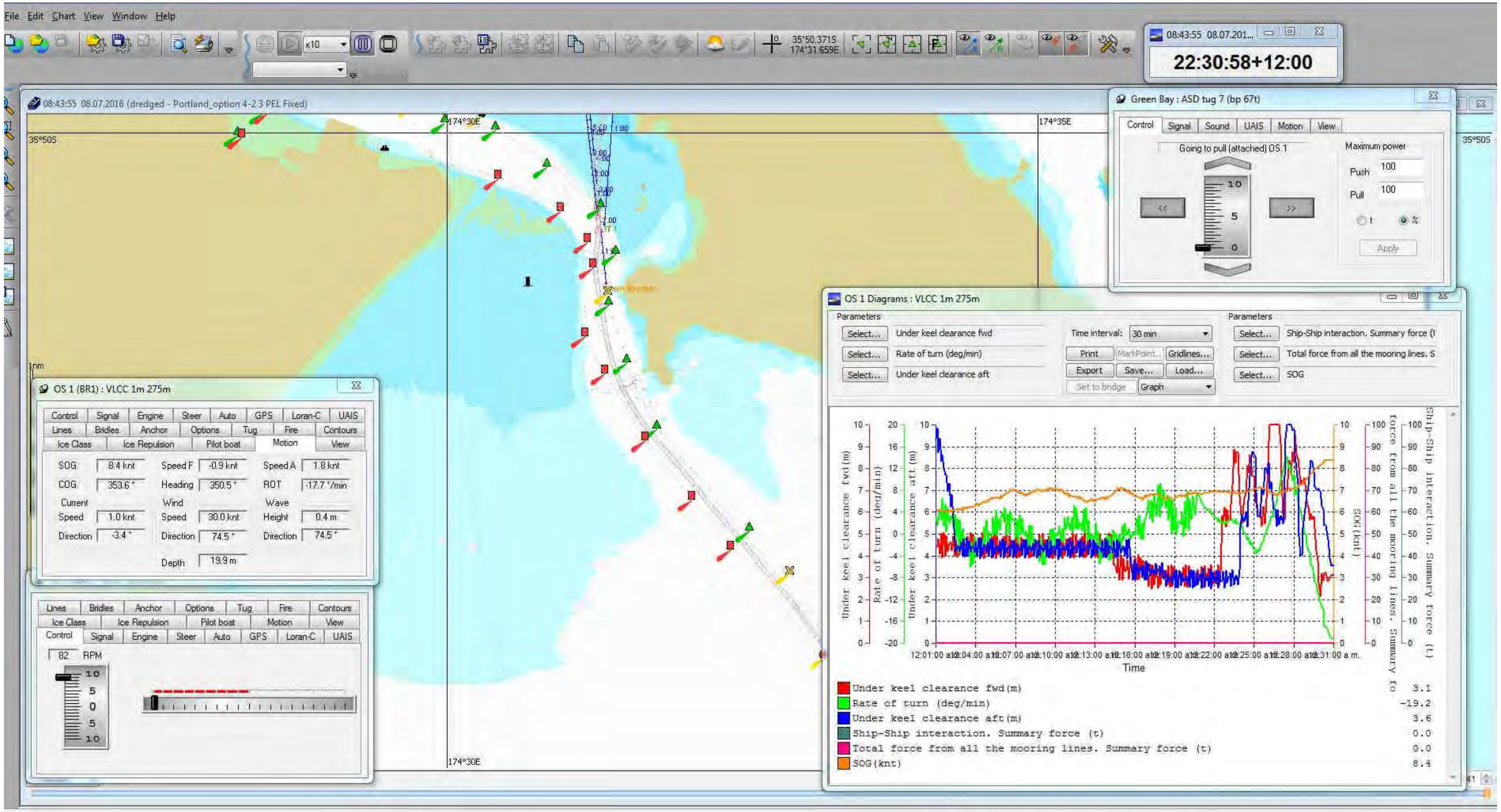
Run005



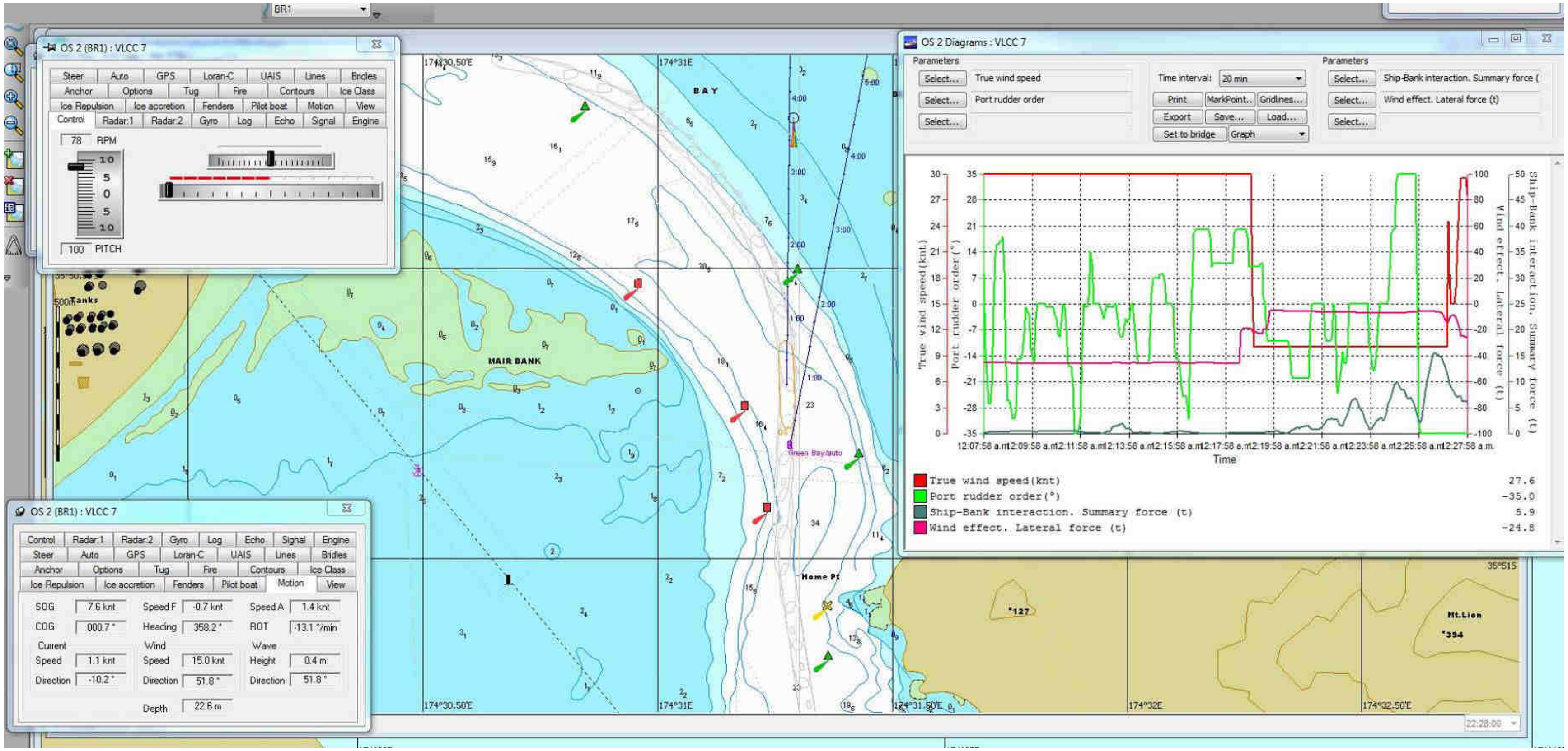
Run 006 (Note: Error in UKC with incorrect tide input. Corrected ok)


08:28:15+12:00
Green Bay : ASD tug 7 (bp 67t)
OS 1 Diagrams : VLCC 7
OS 1 (BR1) : VLCC 7
Under keel clearance fwd(m) 3.2
Rate of turn (deg/min) -2.2
Under keel clearance aft(m) 2.8
Ship-Ship interaction. Summary force (t) 0.0
Total force from all the mooring lines. Summary force (t) 0.0
SOG(knt) 3.3

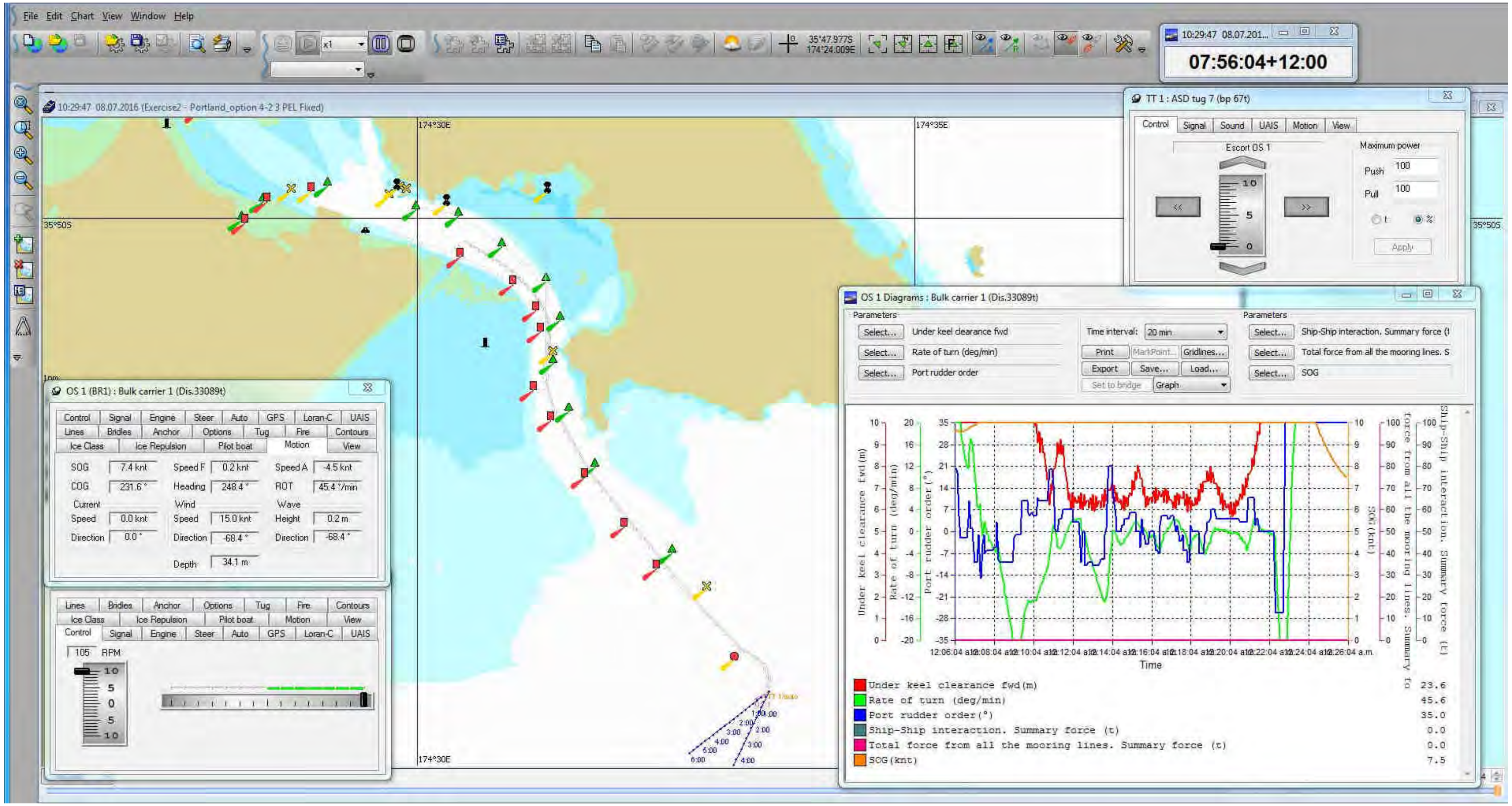
Run 007



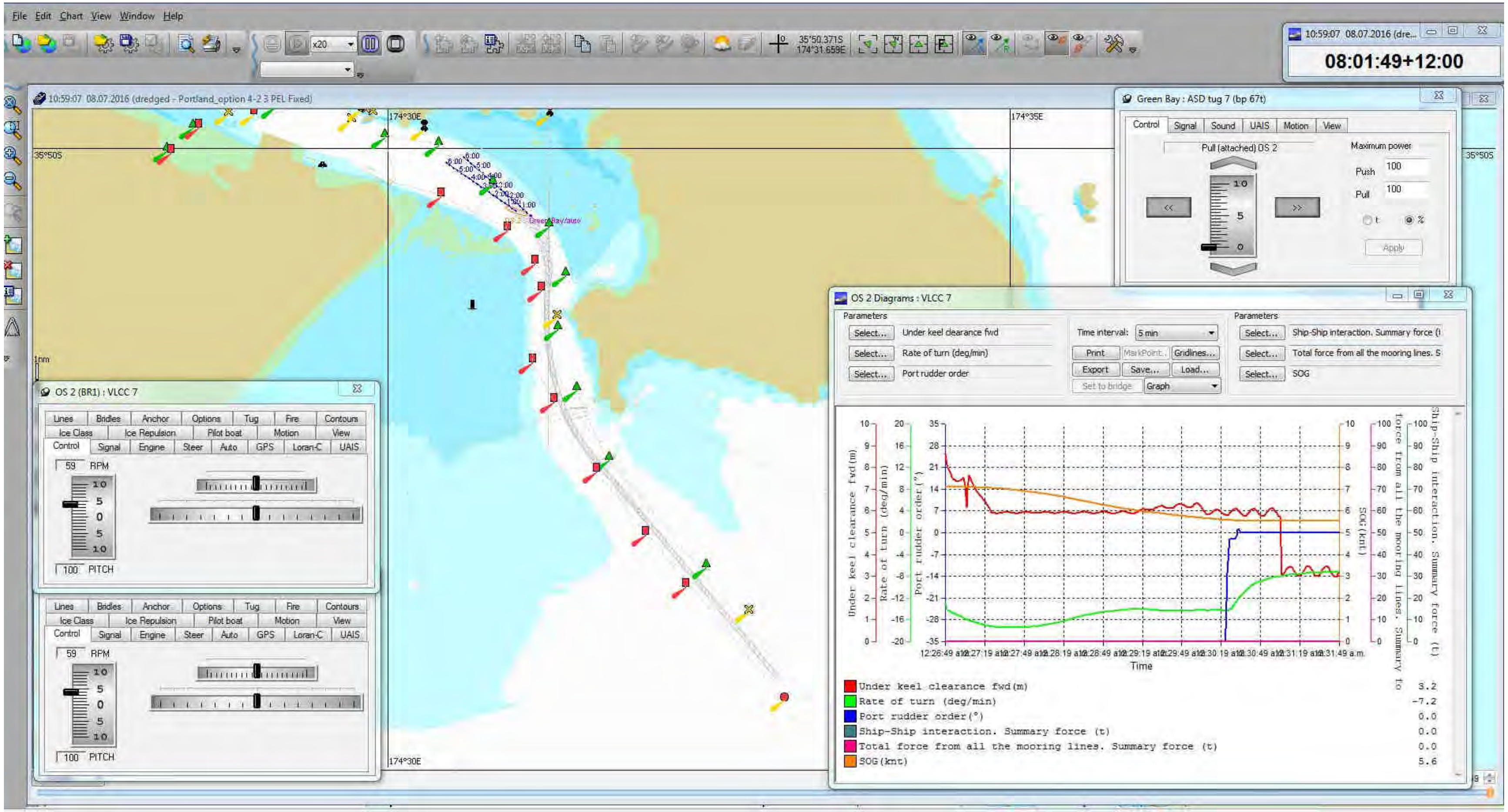
Run 008



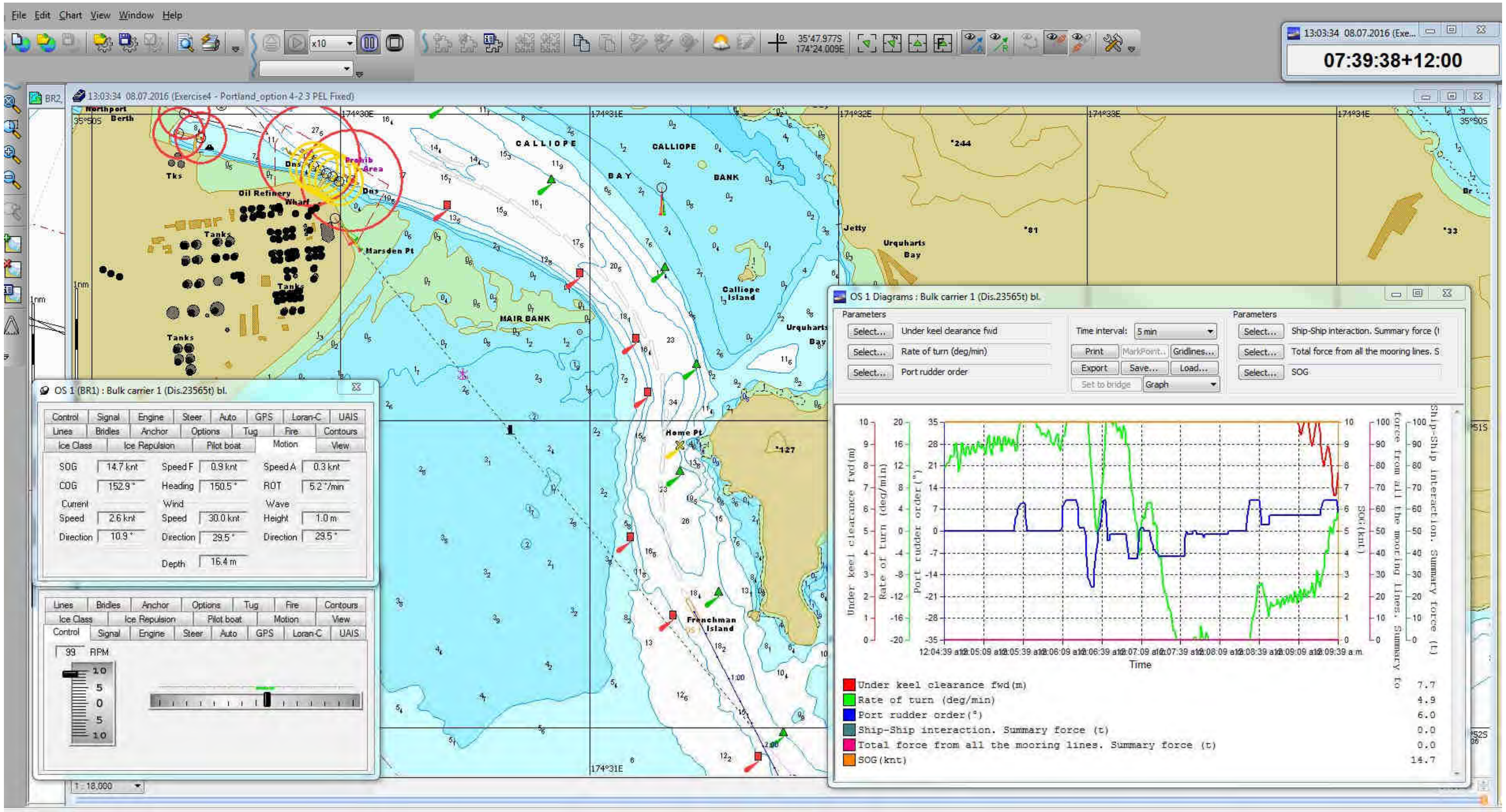
Run009


07:56:04+12:00
TT 1 : ASD tug 7 (bp 67t)
OS 1 (BR1) : Bulk carrier 1 (Dis.33089t)
OS 1 Diagrams : Bulk carrier 1 (Dis.33089t)
Under keel clearance fwd (m) 23.6
Rate of turn (deg/min) 45.6
Port rudder order (°) 35.0
Ship-Ship interaction. Summary force (t) 0.0
Total force from all the mooring lines. Summary force (t) 0.0
SOG (knt) 7.5

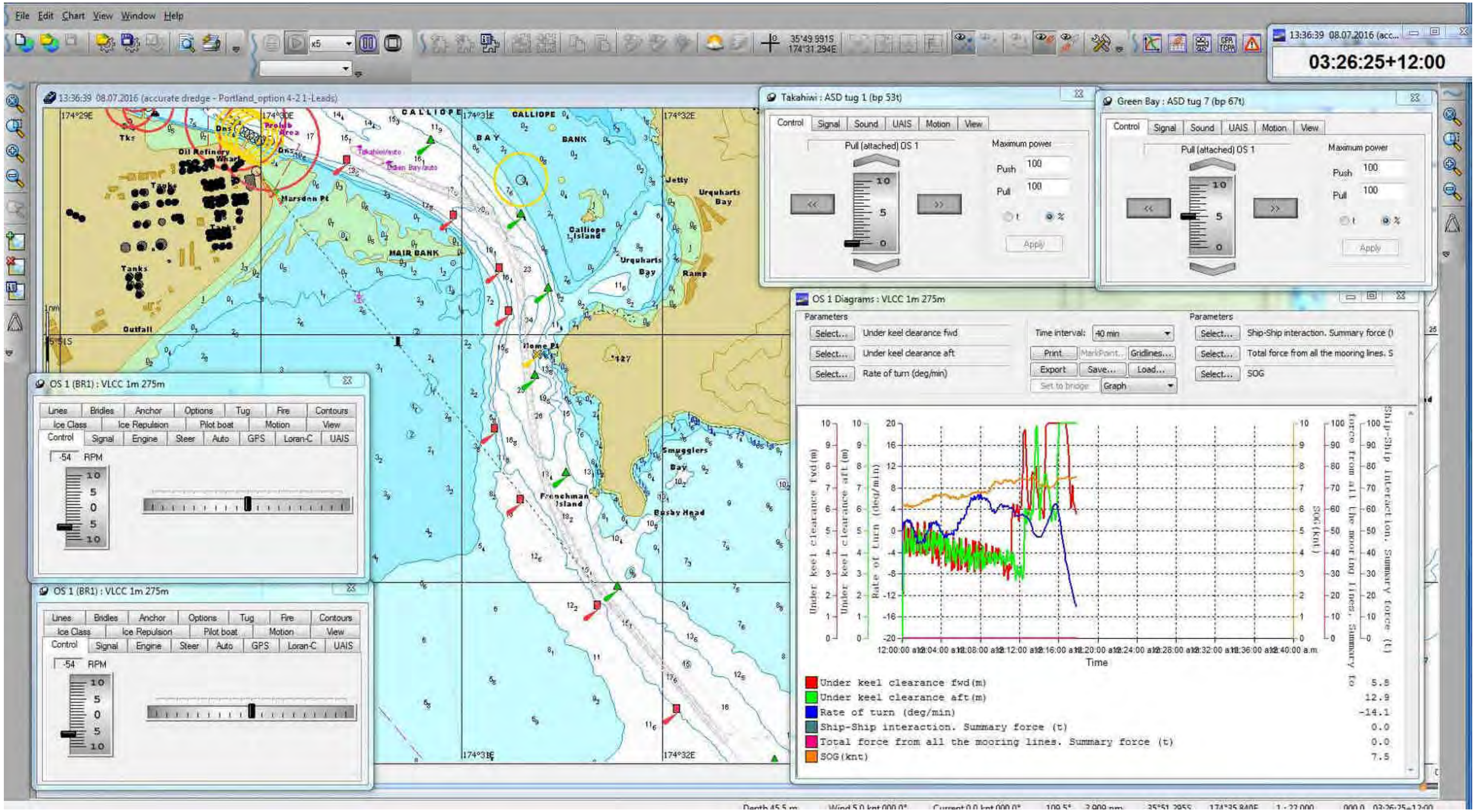
Run010


10:59:07 08.07.2016 (dredged - Portland_option 4-2 3 PEL Fixed)
08:01:49+12:00
Green Bay : ASD tug 7 (bp 67t)
OS 2 (BR1) : VLCC 7
OS 2 Diagrams : VLCC 7
Under keel clearance fwd(m)
Rate of turn (deg/min)
Port rudder order(°)
Ship-Ship interaction. Summary force (t)
Total force from all the mooring lines. Summary force (t)
SOG(knt)

Run011



Run012



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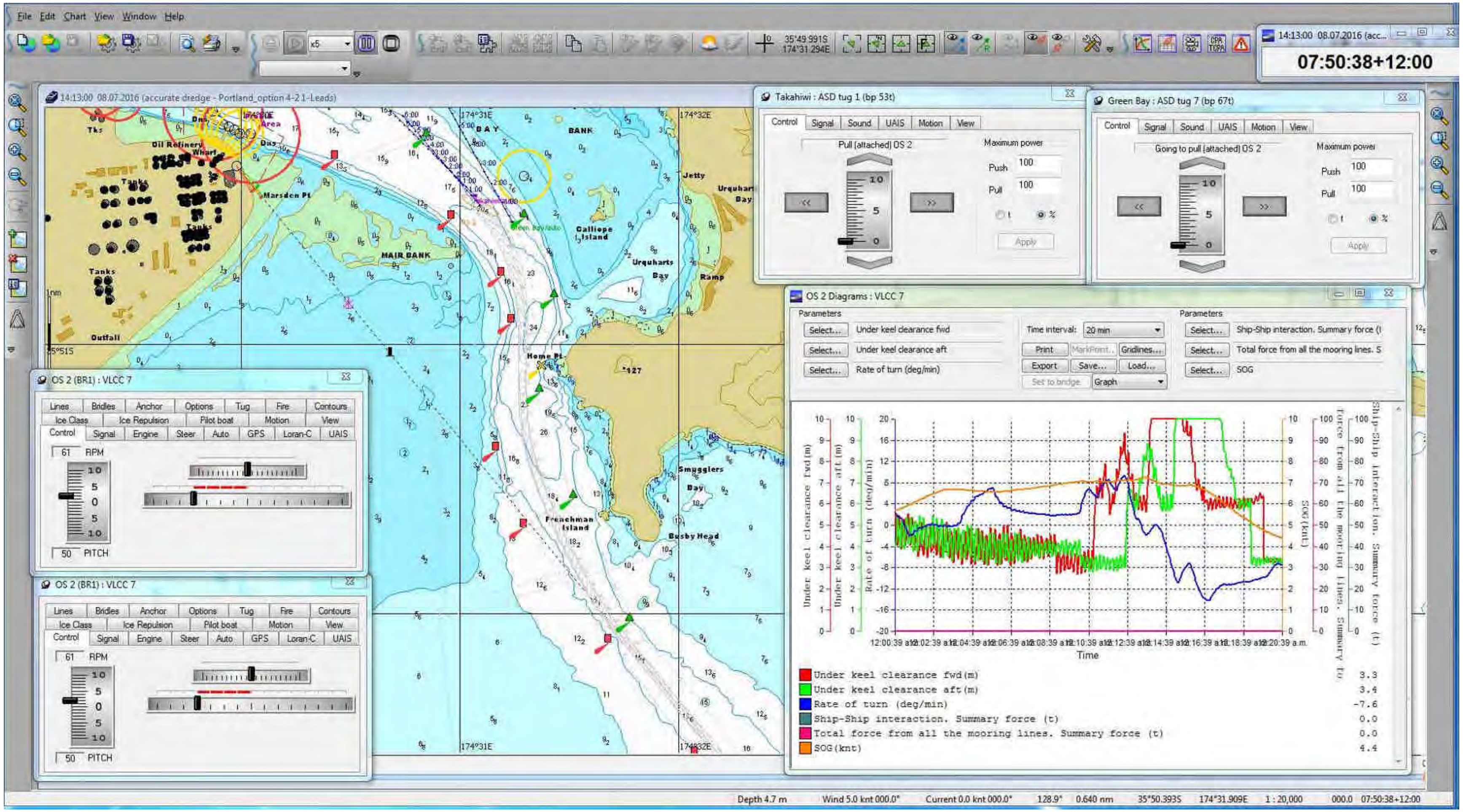
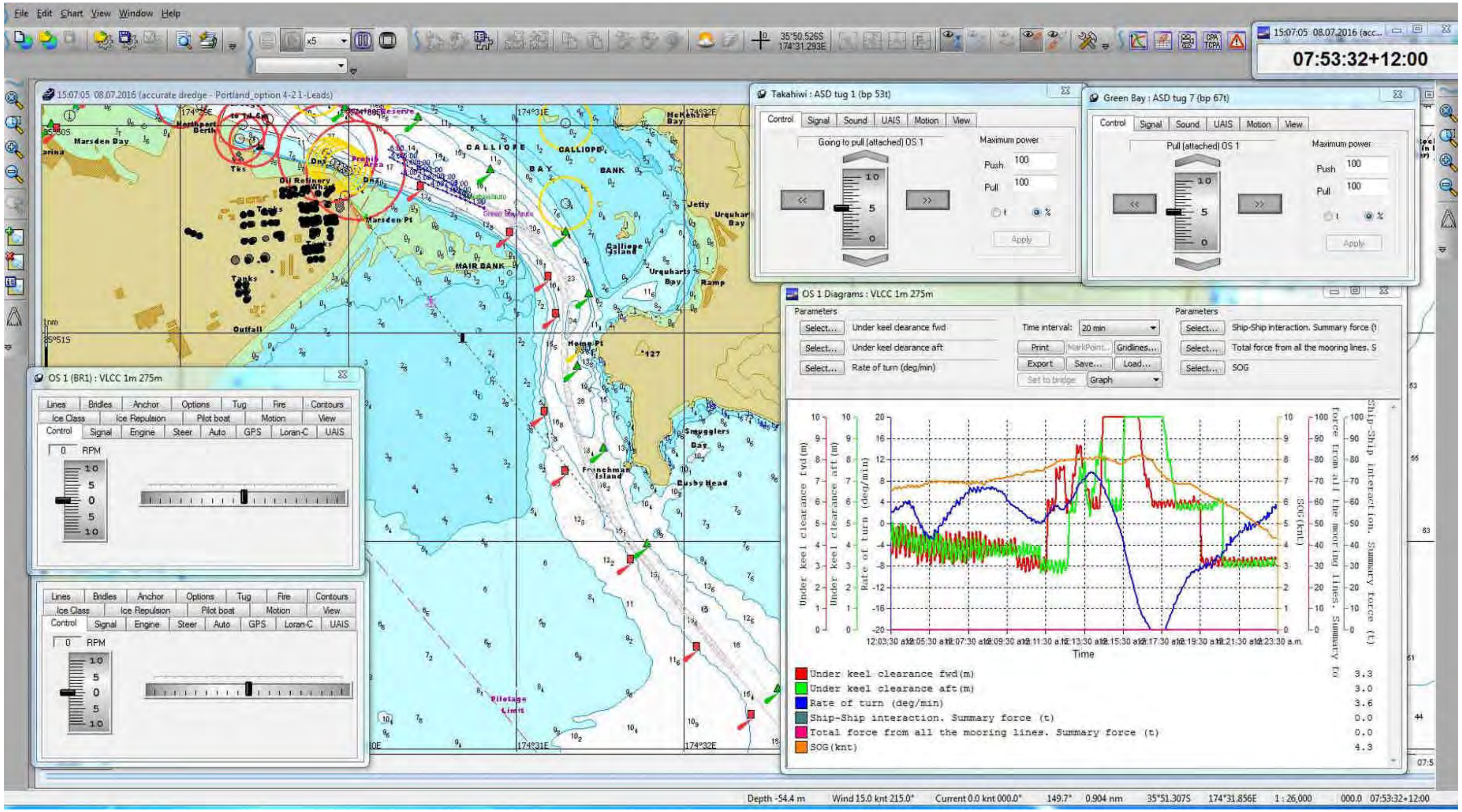
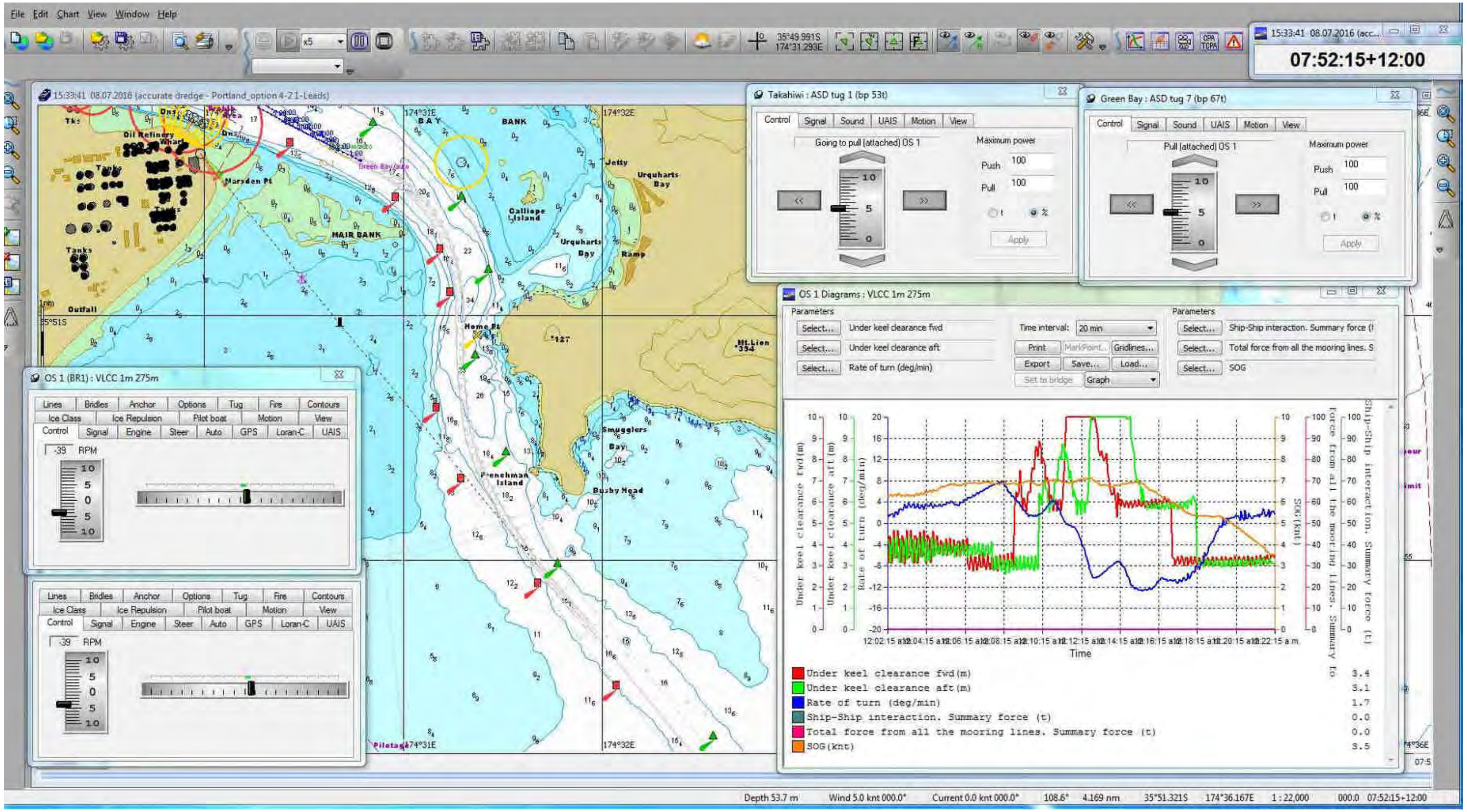


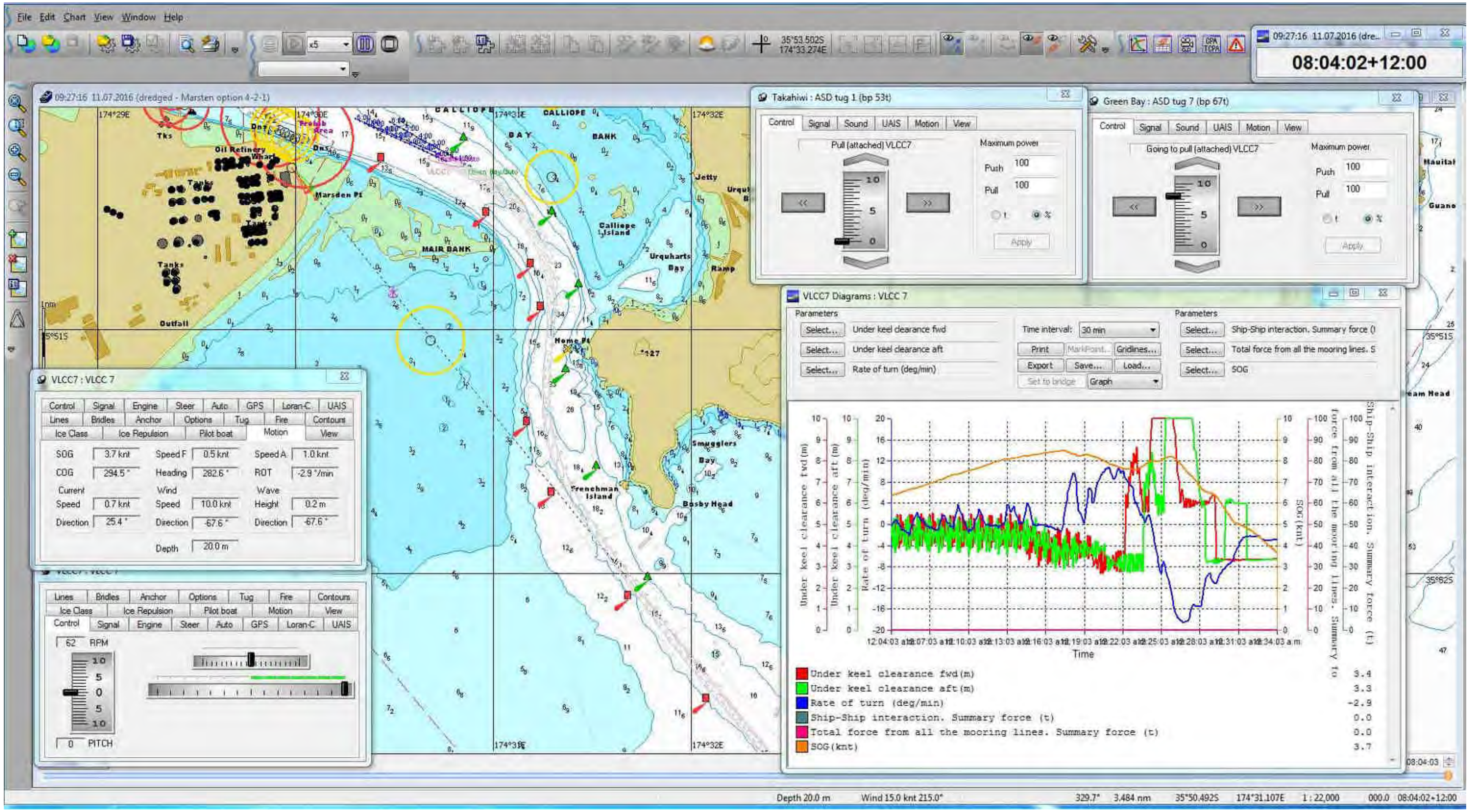
Run015



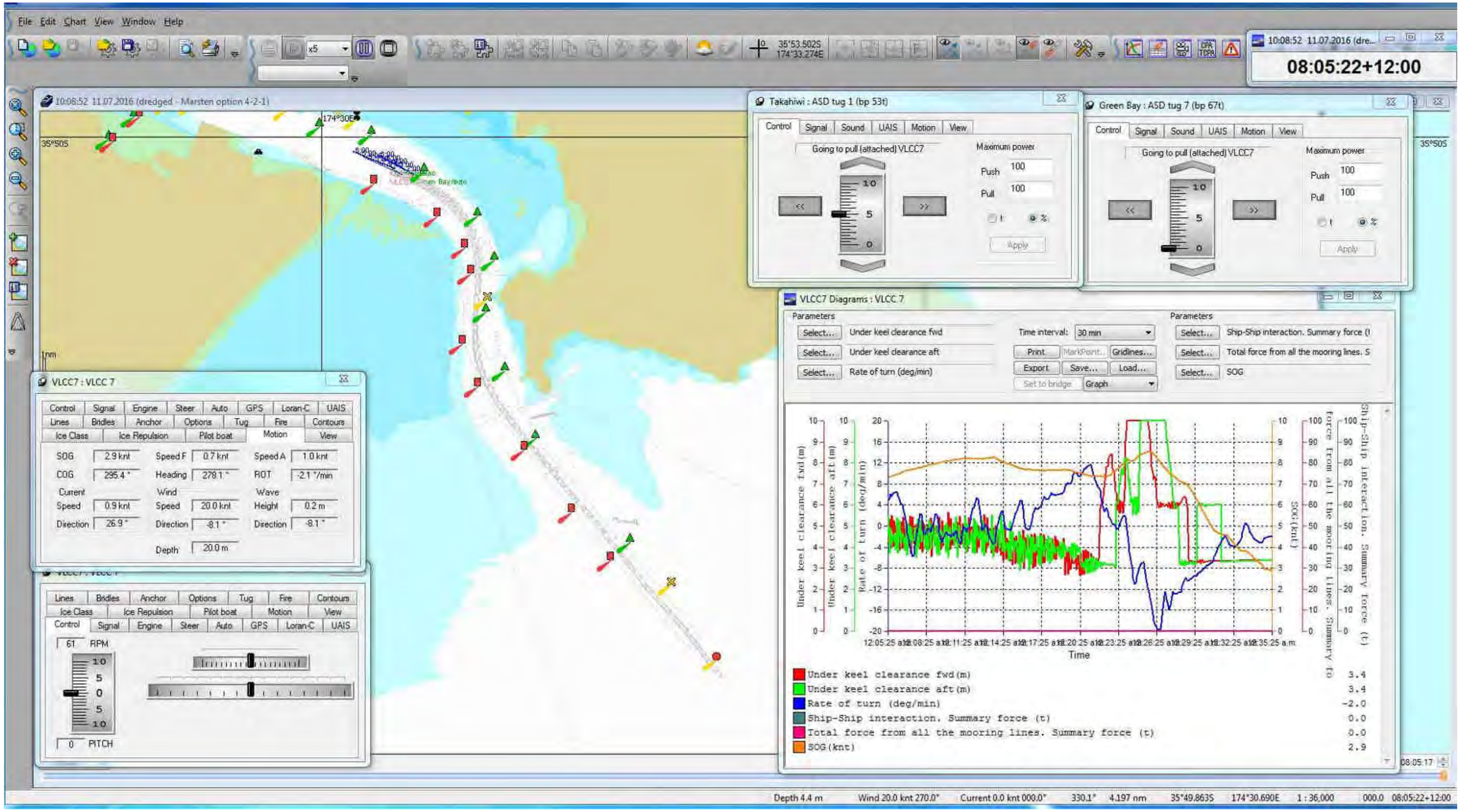
Run016



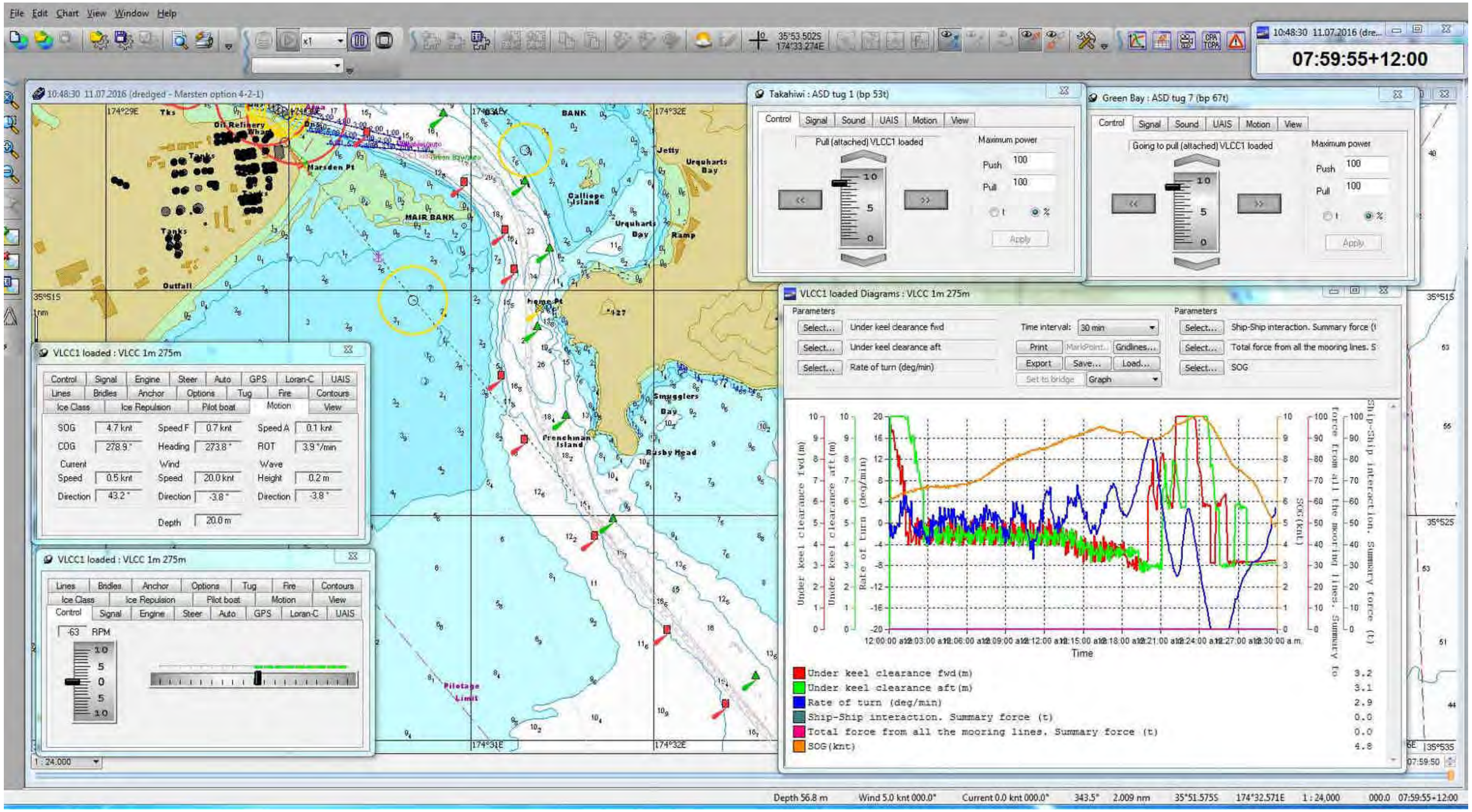
Run017



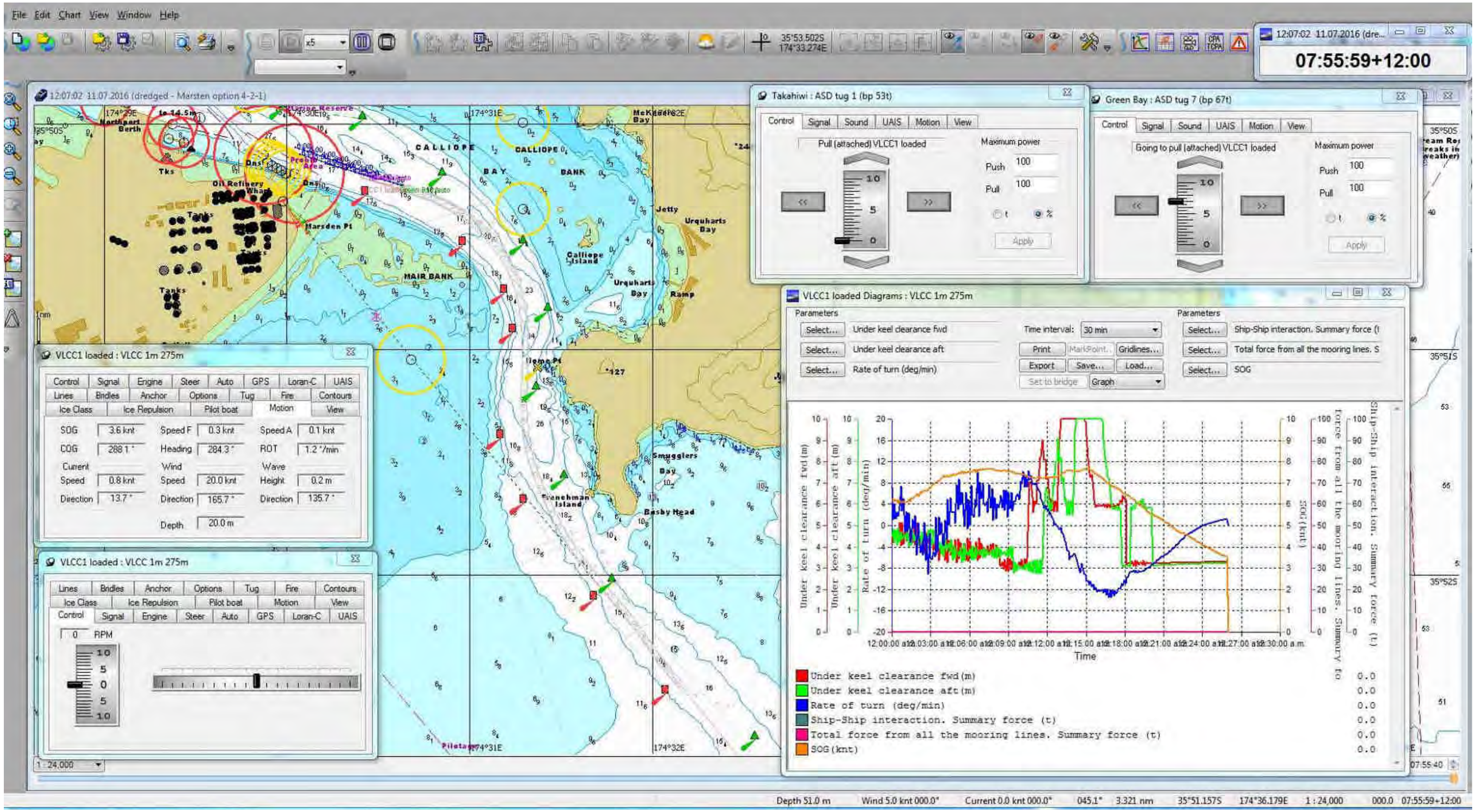
Run018


08:05:22+12:00
Takahiwi : ASD tug 1 (bp 53t)
Green Bay : ASD tug 7 (bp 67t)
VLCC7 : VLCC 7
VLCC7 Diagrams : VLCC 7
Under keel clearance fwd(m)
Under keel clearance aft(m)
Rate of turn (deg/min)
Ship-Ship interaction. Summary force (t)
Total force from all the mooring lines. Summary force (t)
SOG(knt)
Time

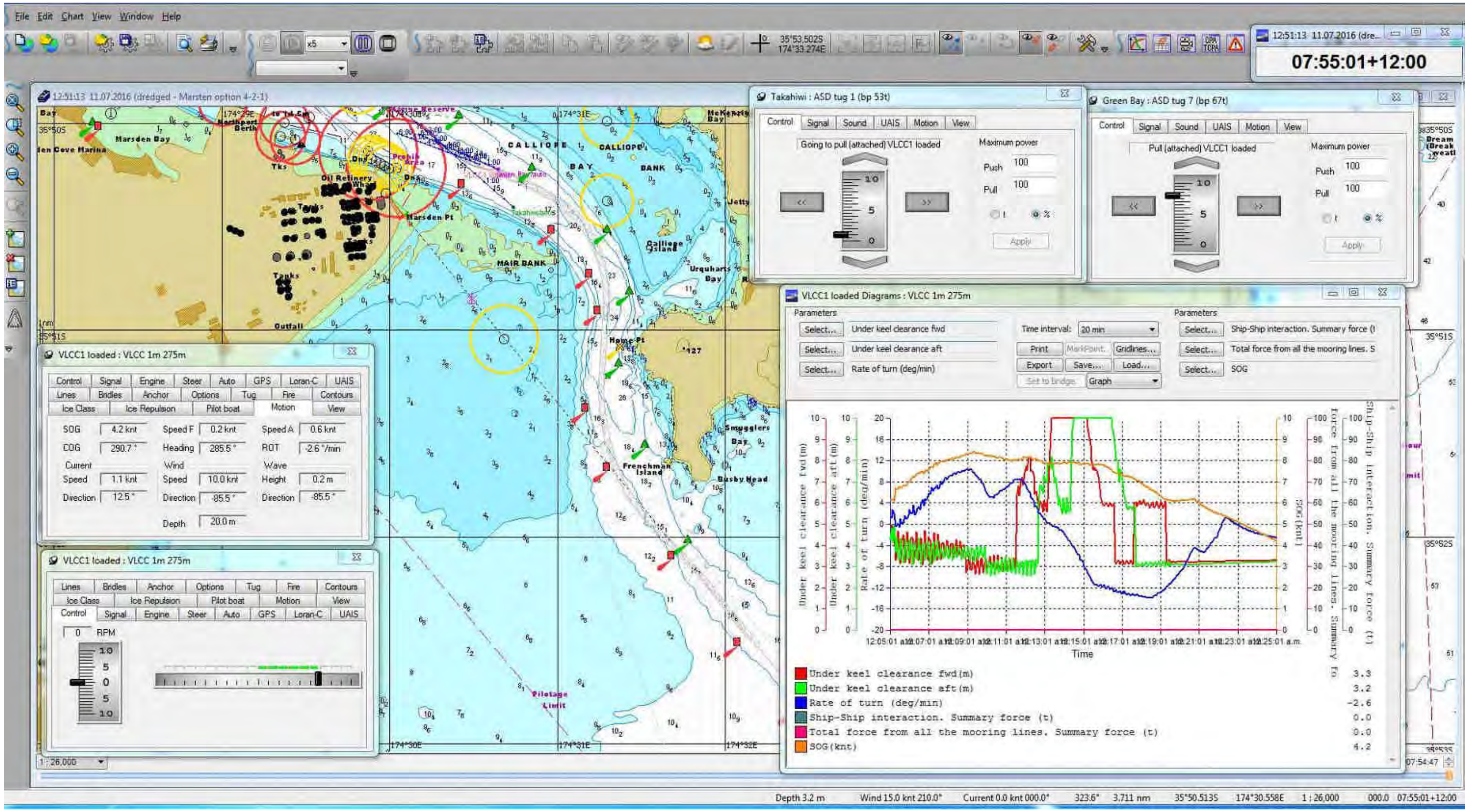
Run019



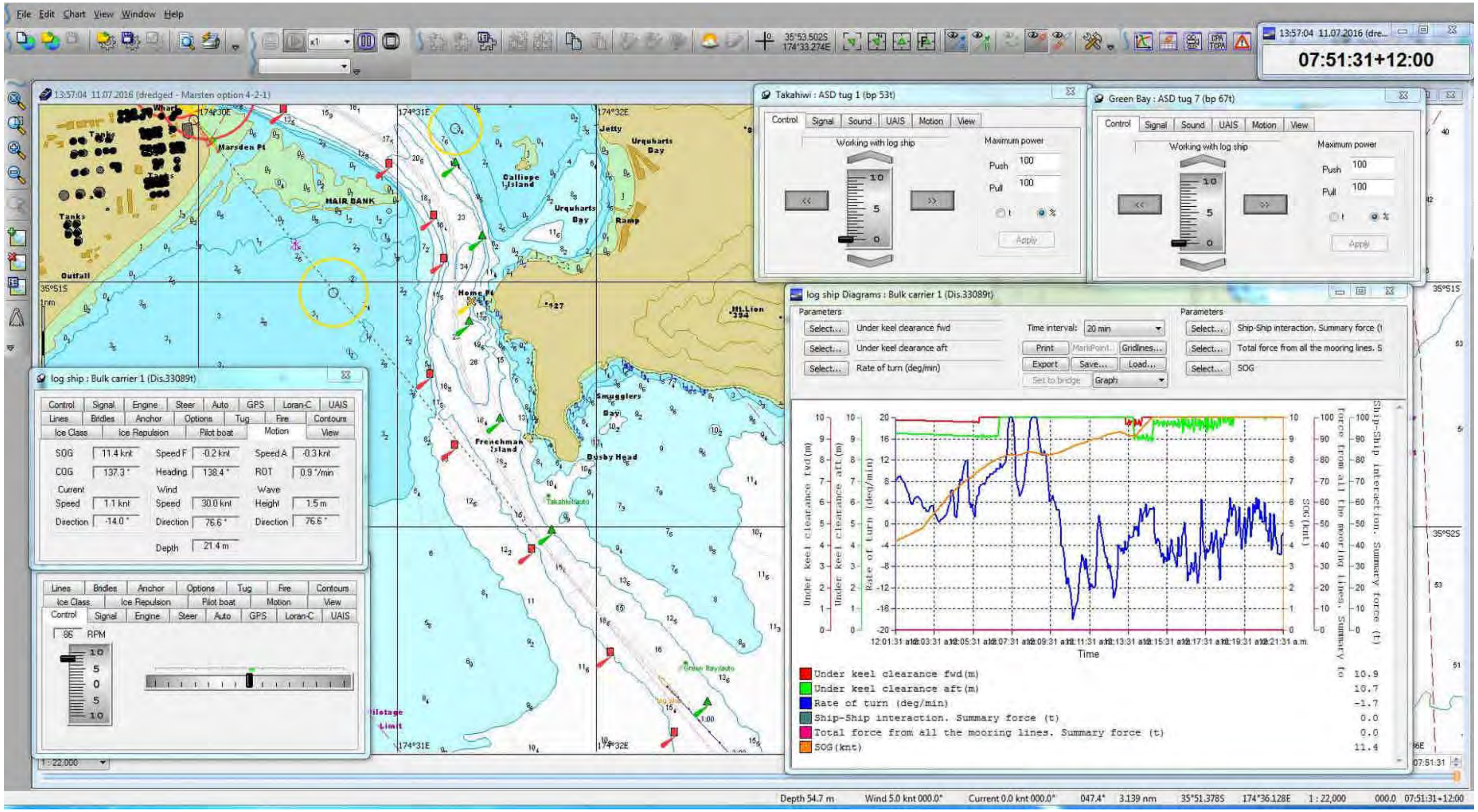
Run020



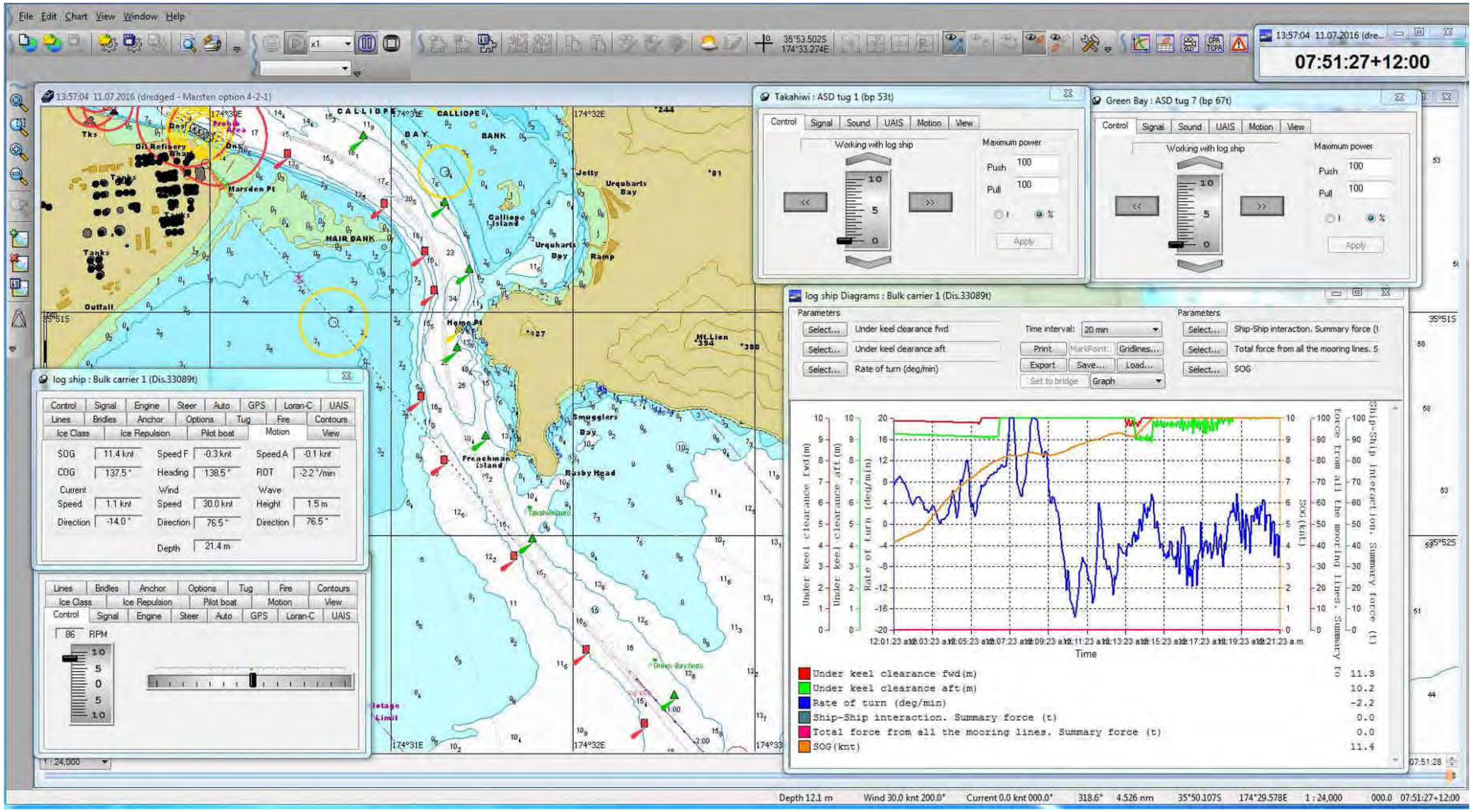
Run021



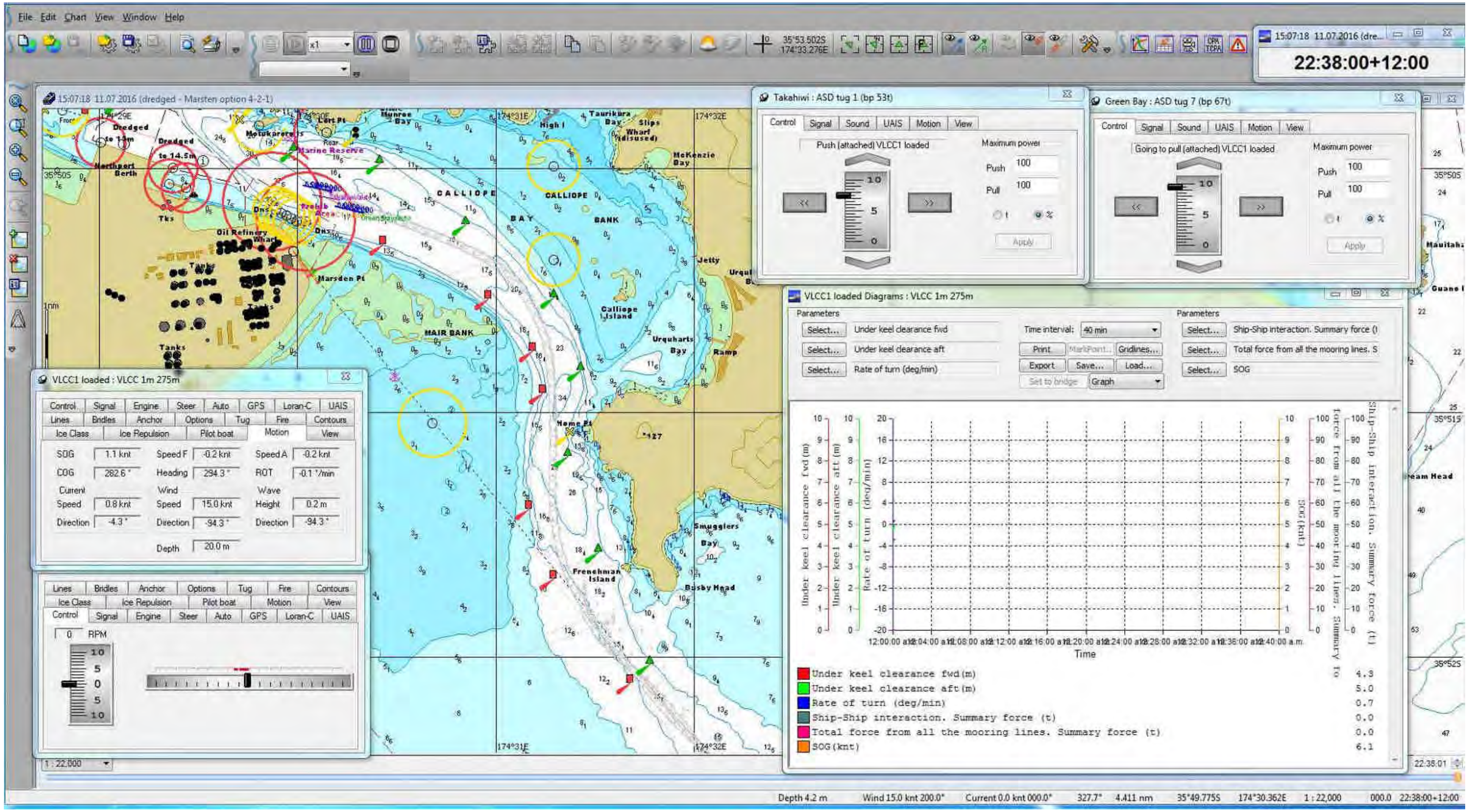
Run22



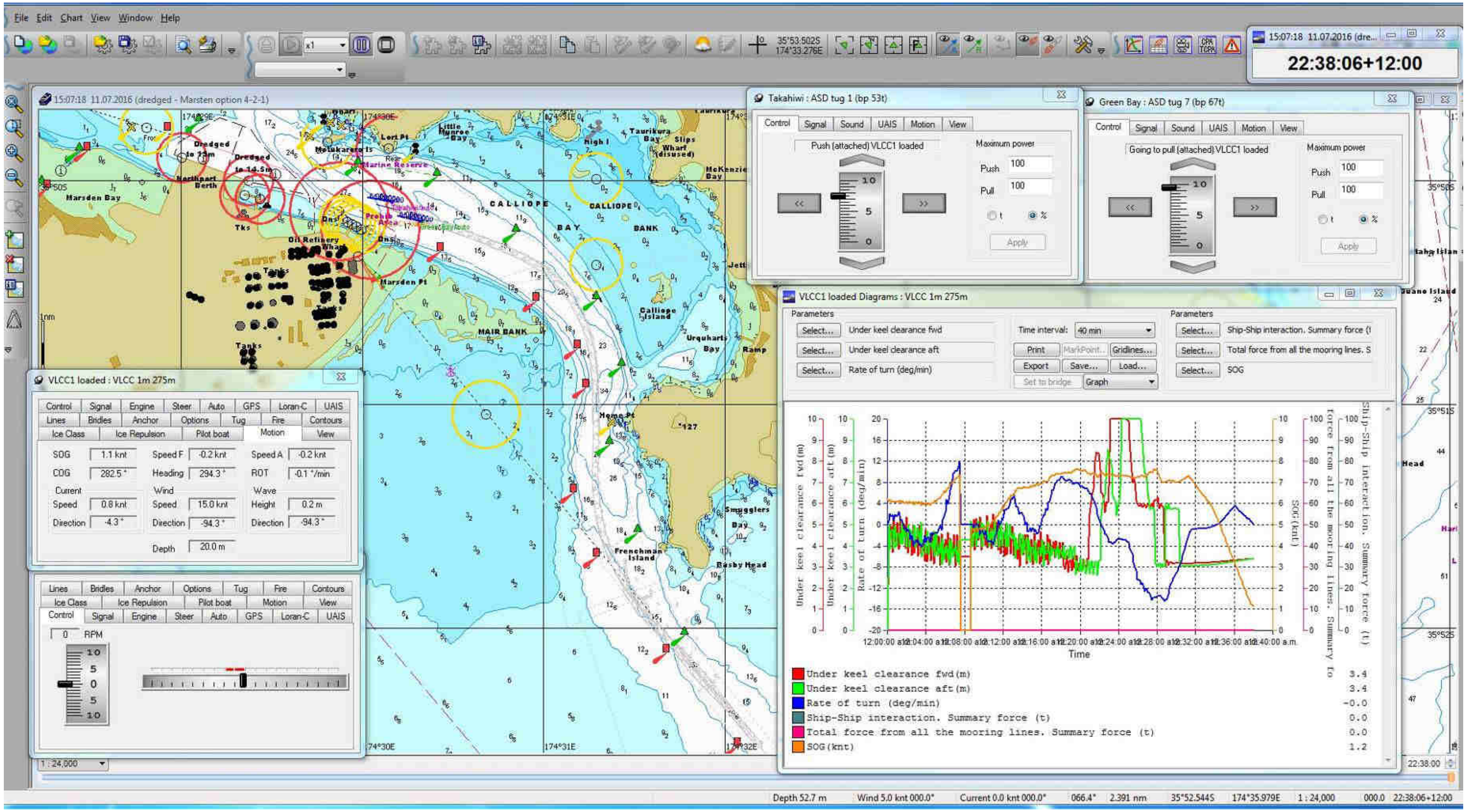
Run023



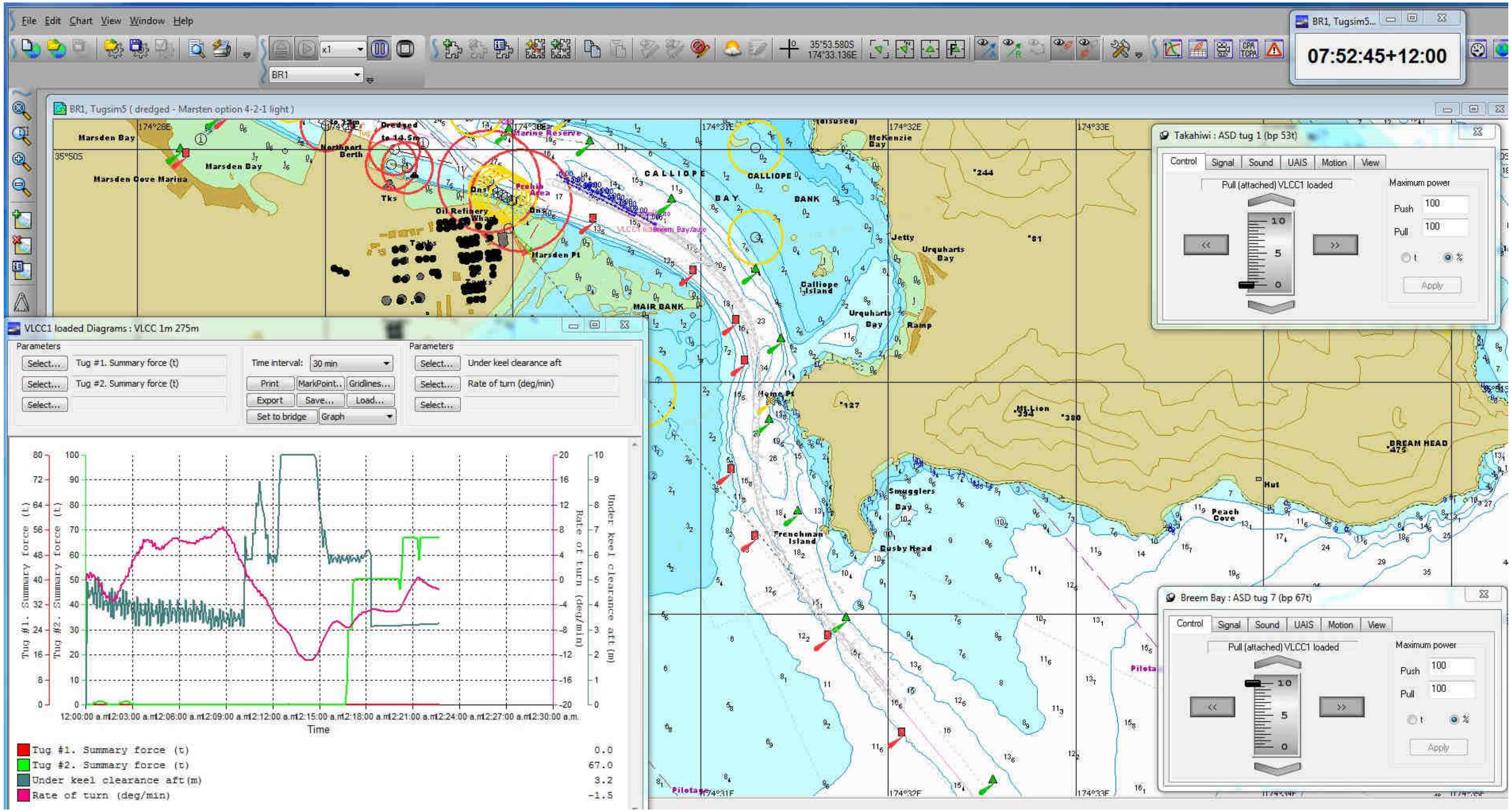
Run024



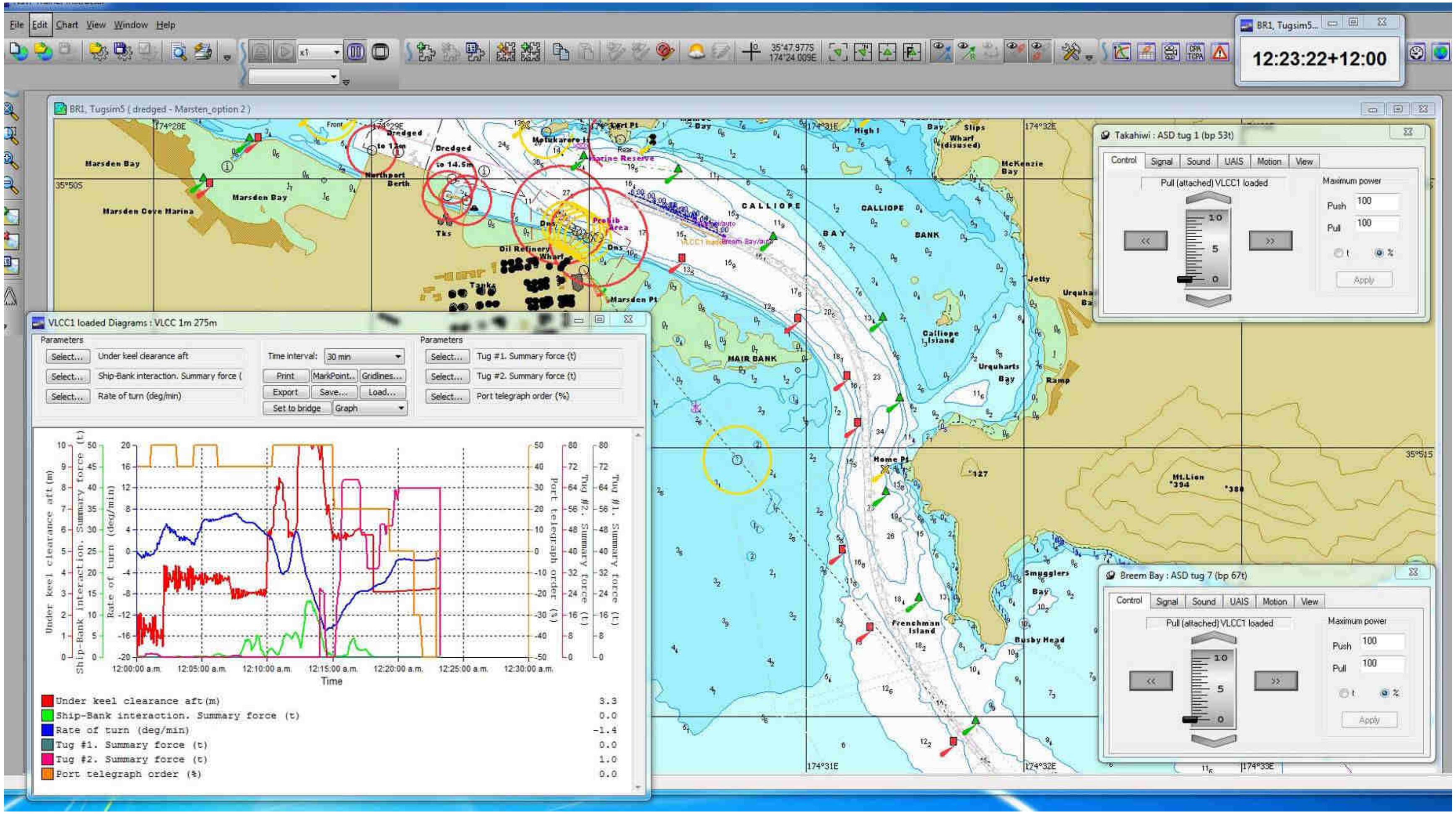
Run025



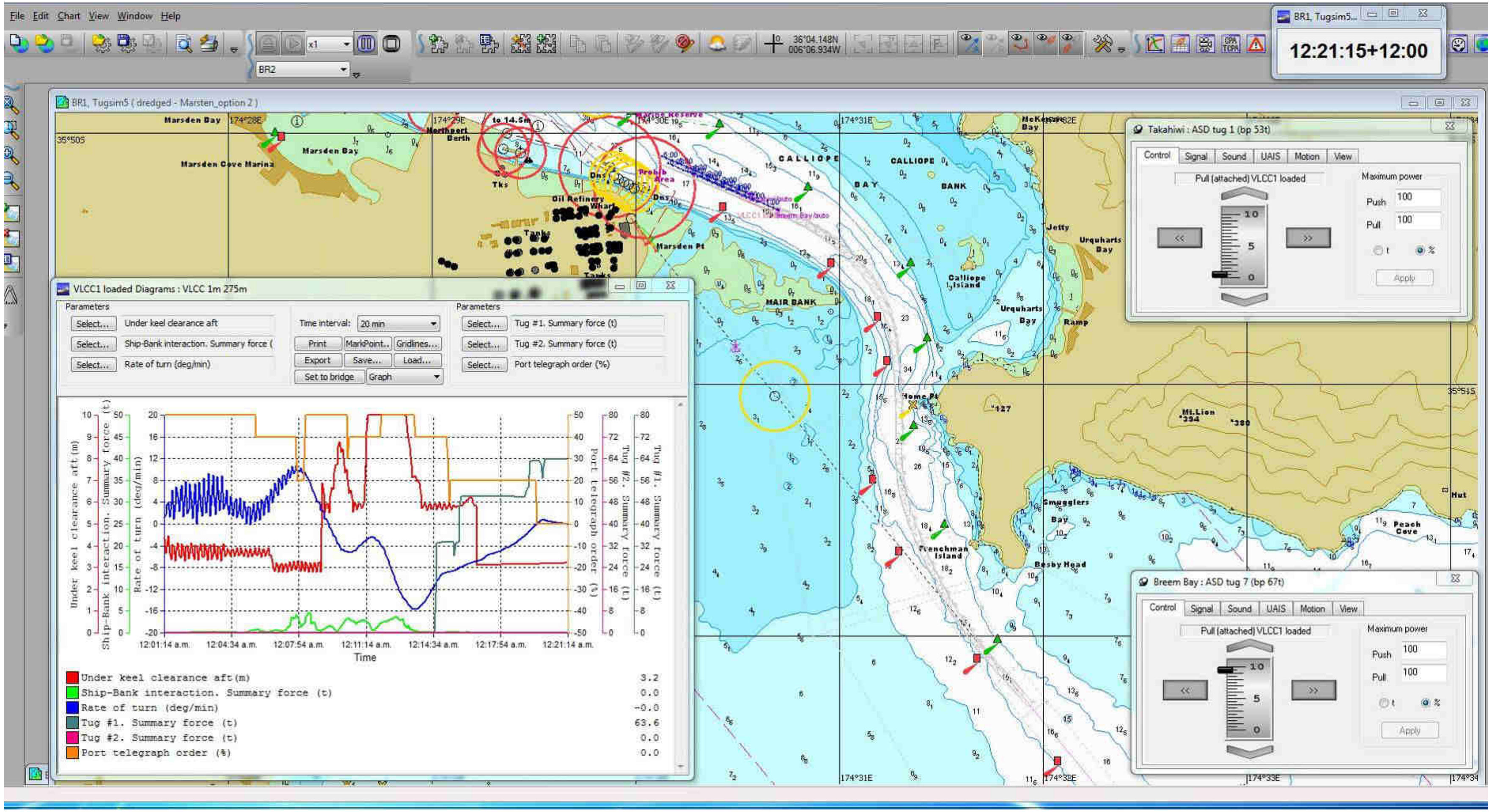
Run026


BR1, Tugsim5 (dredged - Marsten option 4-2-1 light)
07:52:45+12:00
Takahiwi : ASD tug 1 (bp 53t)
Pull (attached) VLCC1 loaded
Breem Bay : ASD tug 7 (bp 67t)
VLCC1 loaded Diagrams : VLCC 1m 275m
Tug #1. Summary force (t) 0.0
Tug #2. Summary force (t) 67.0
Under keel clearance aft (m) 3.2
Rate of turn (deg/min) -1.5

Run 027

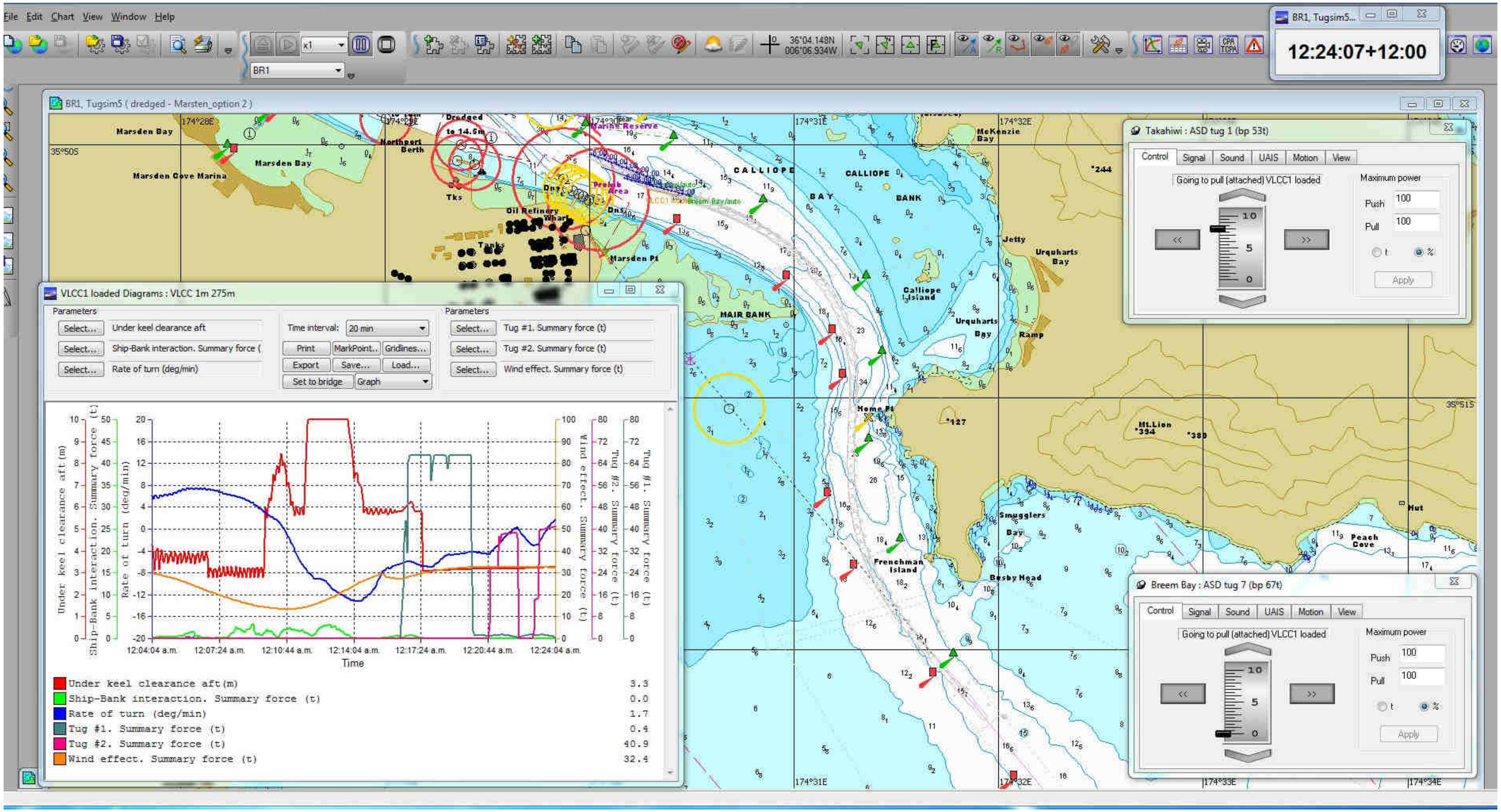


Run 028 (Note: error in UKC at start of exercise due incorrect tide input then corrected ok.)

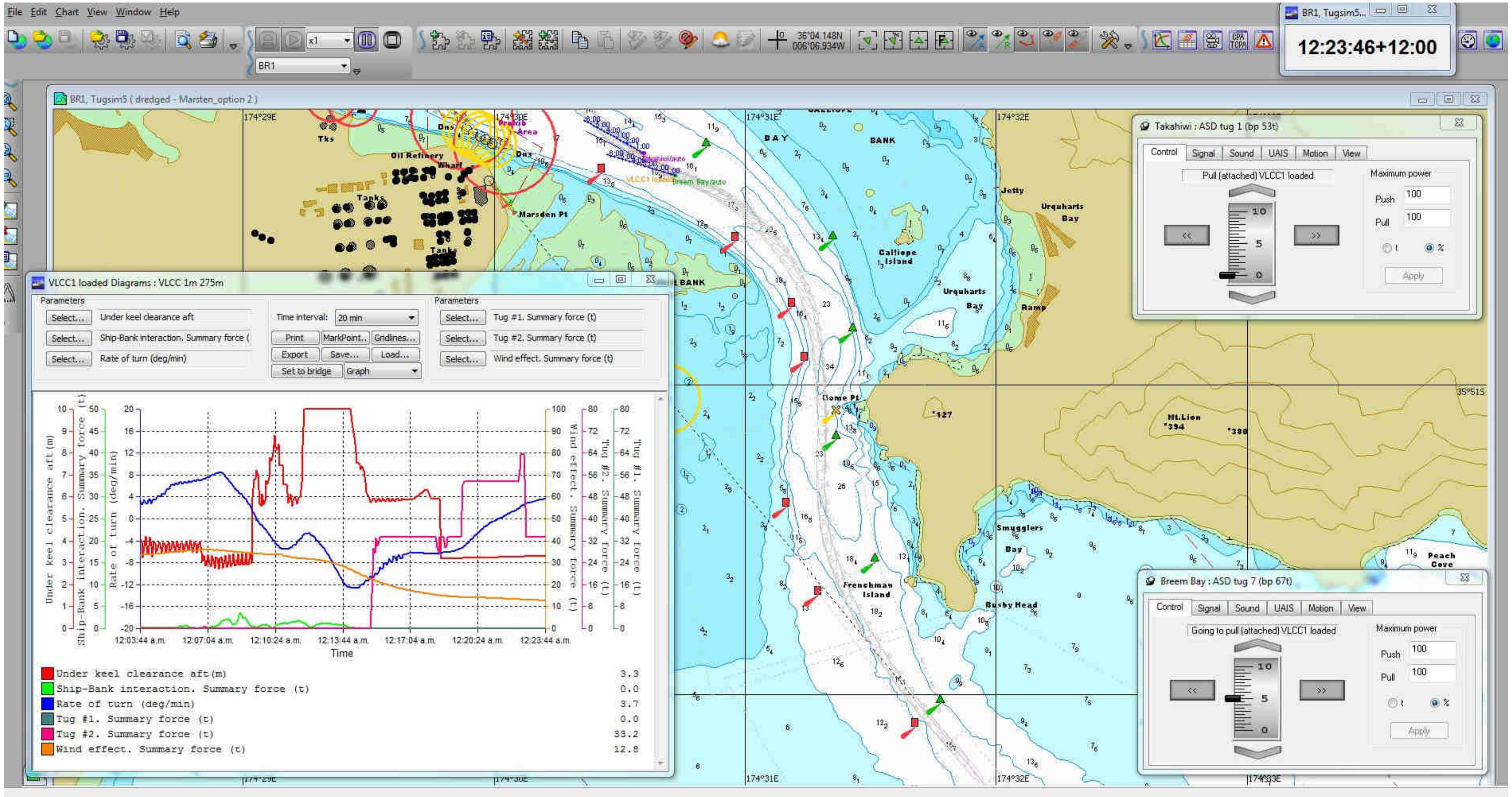


12:21:15+12:00
VLCC1 loaded Diagrams : VLCC 1m 275m
Under keel clearance aft (m) 3.2
Ship-Bank interaction. Summary force (t) 0.0
Rate of turn (deg/min) -0.0
Tug #1. Summary force (t) 63.6
Tug #2. Summary force (t) 0.0
Port telegraph order (%) 0.0
Takahiwi : ASD tug 1 (bp 53t)
Breem Bay : ASD tug 7 (bp 67t)

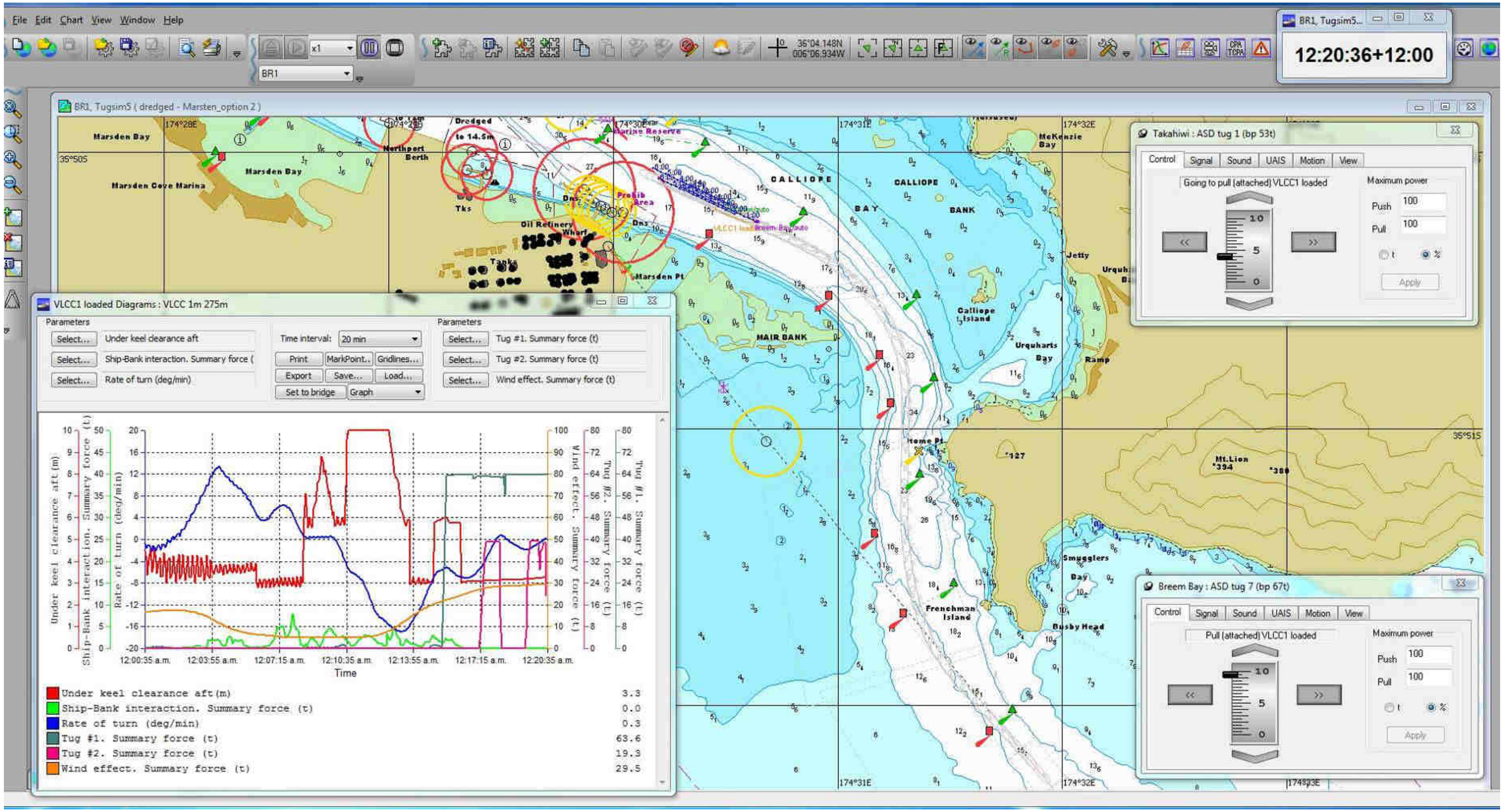
Run 029


BR1, Tugsim5 (dredged - Marsten_option 2)
12:24:07+12:00
VLCC1 loaded Diagrams : VLCC 1m 275m
Takahiwi : ASD tug 1 (bp 53t)
Going to pull (attached) VLCC1 loaded
Breem Bay : ASD tug 7 (bp 67t)
Going to pull (attached) VLCC1 loaded
Under keel clearance aft (m) 3.3
Ship-Bank interaction. Summary force (t) 0.0
Rate of turn (deg/min) 1.7
Tug #1. Summary force (t) 0.4
Tug #2. Summary force (t) 40.9
Wind effect. Summary force (t) 32.4
Time

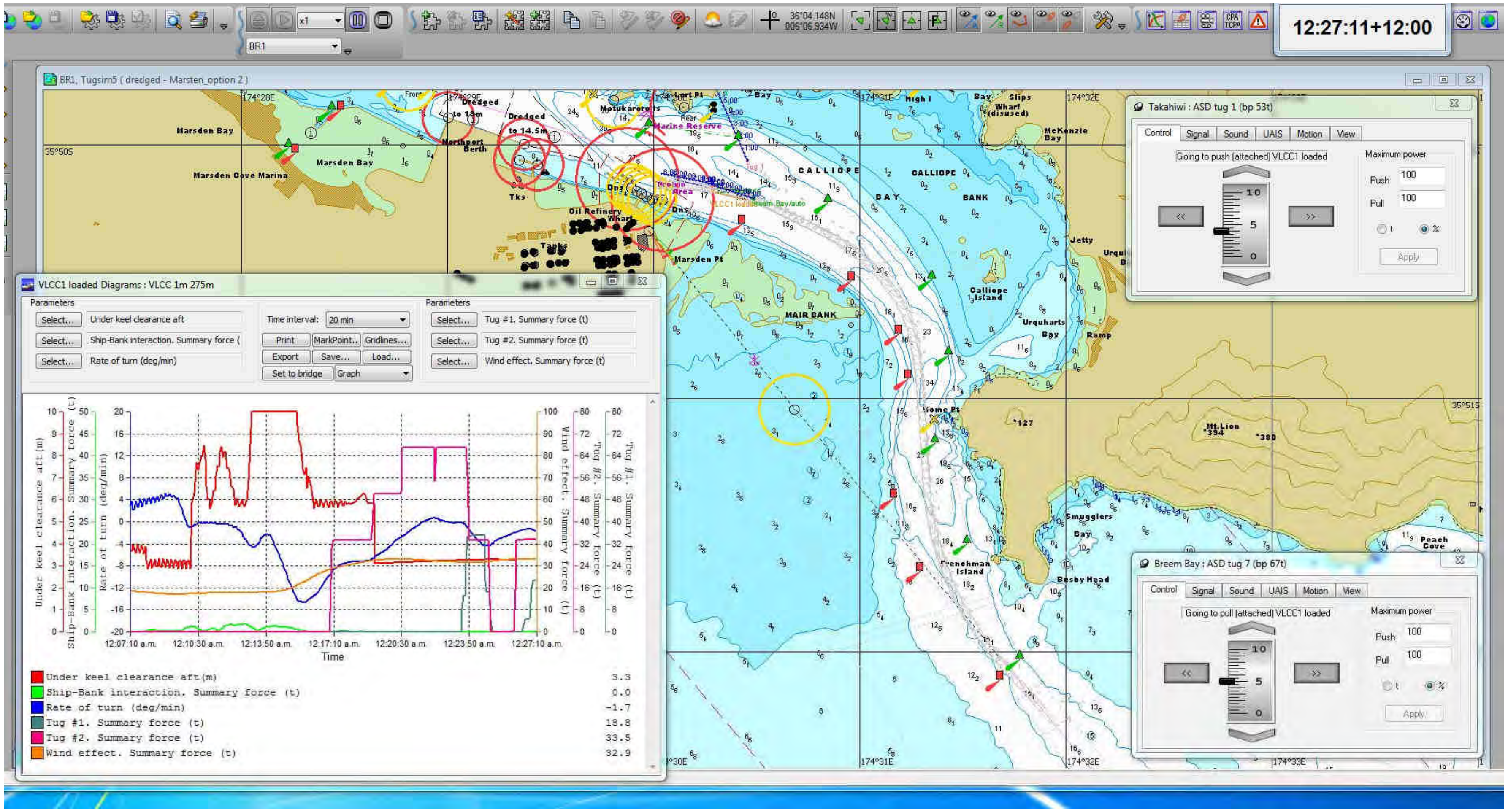
Run 030


BR1, Tugsim5 (dredged - Marsten_option 2)
12:23:46+12:00
VLCC1 loaded Diagrams : VLCC 1m 275m
Takahiwi : ASD tug 1 (bp 53t)
Breem Bay : ASD tug 7 (bp 67t)
Under keel clearance aft (m) 3.3
Ship-Bank interaction. Summary force (t) 0.0
Rate of turn (deg/min) 3.7
Tug #1. Summary force (t) 0.0
Tug #2. Summary force (t) 33.2
Wind effect. Summary force (t) 12.8
Time

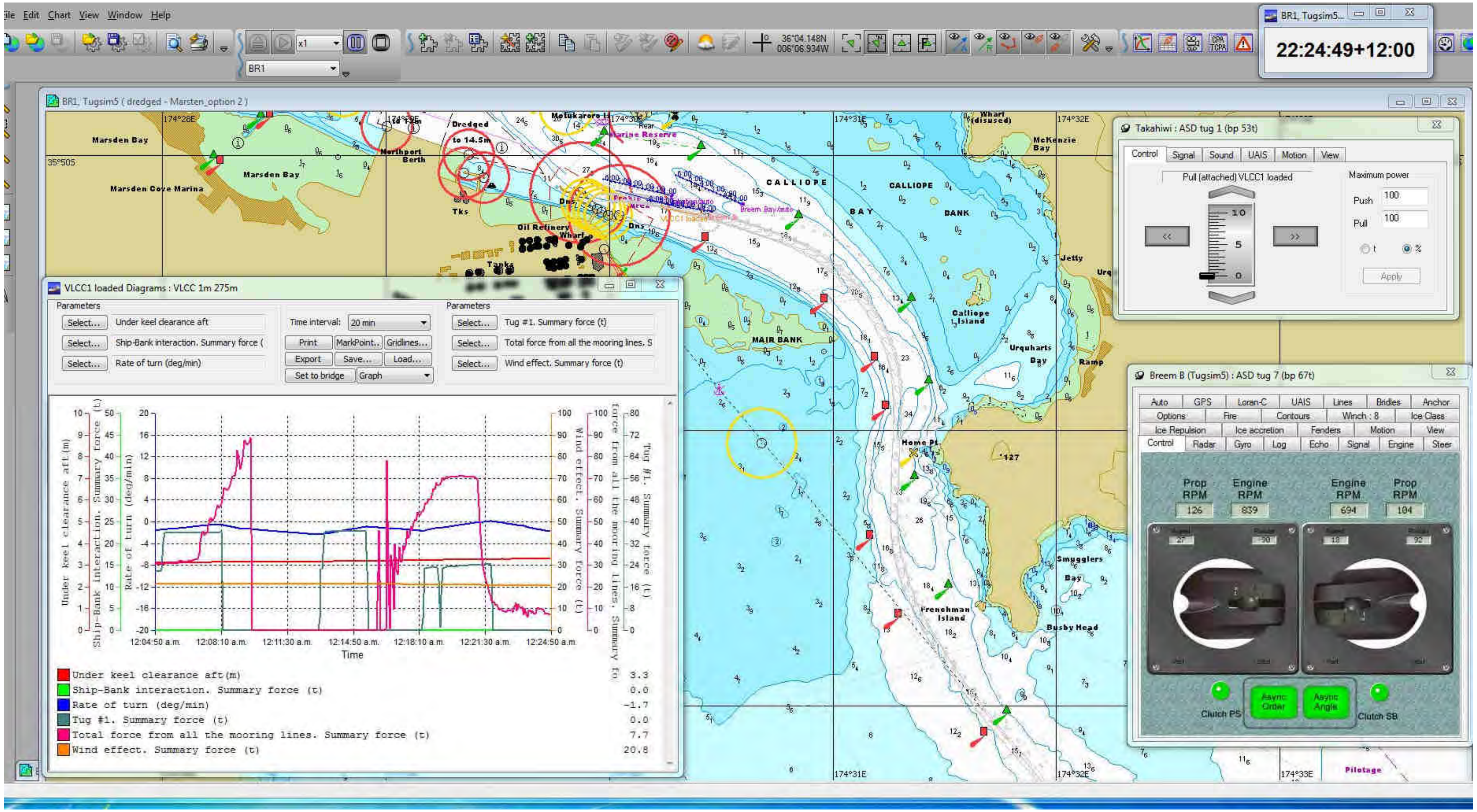
Run 031


12:20:36+12:00
VLCC1 loaded Diagrams : VLCC 1m 275m
Takahiwi : ASD tug 1 (bp 53t)
Breem Bay : ASD tug 7 (bp 67t)
Under keel clearance aft (m) 3.3
Ship-Bank interaction. Summary force (t) 0.0
Rate of turn (deg/min) 0.3
Tug #1. Summary force (t) 63.6
Tug #2. Summary force (t) 19.3
Wind effect. Summary force (t) 29.5

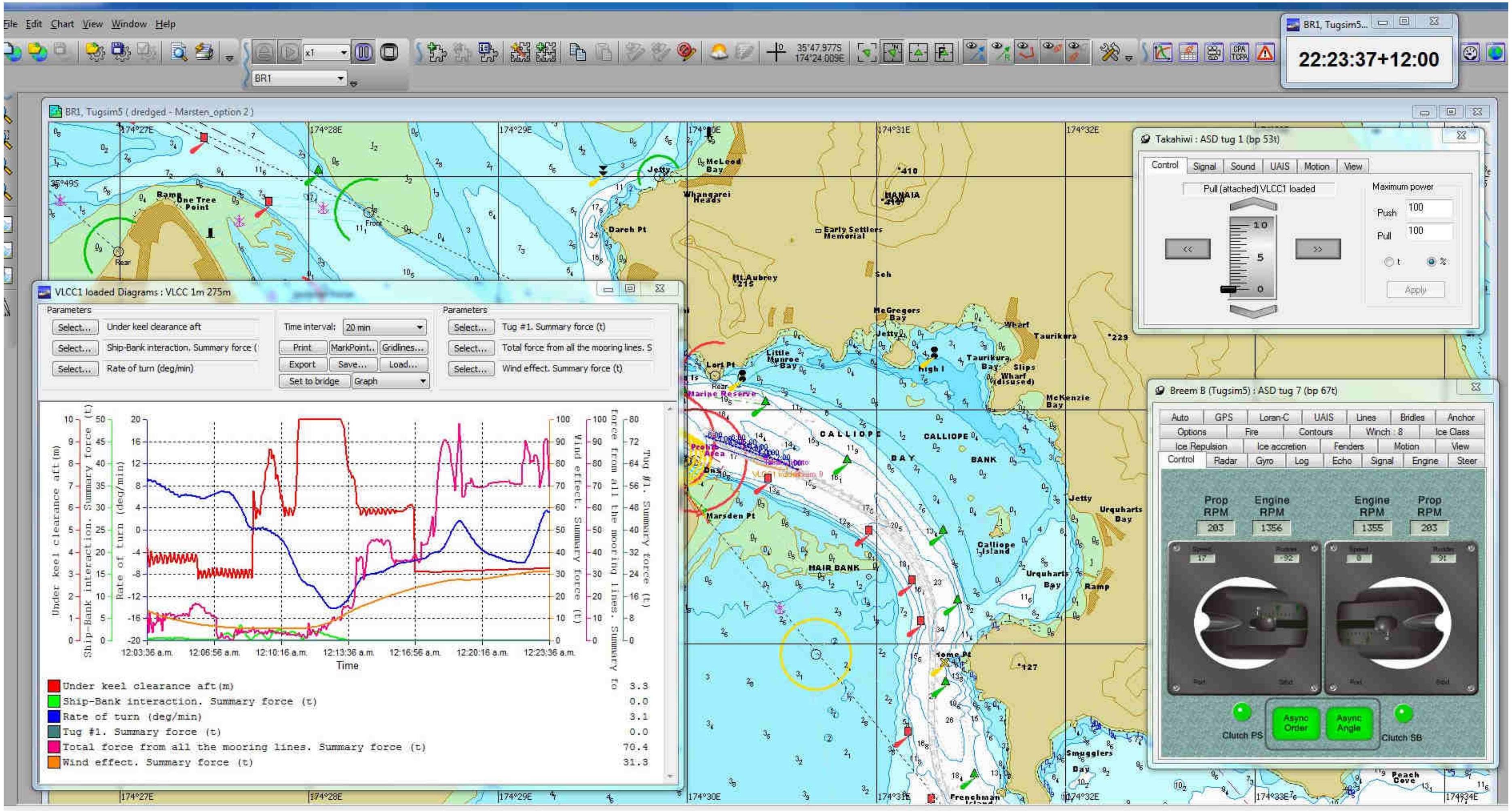
Run 032



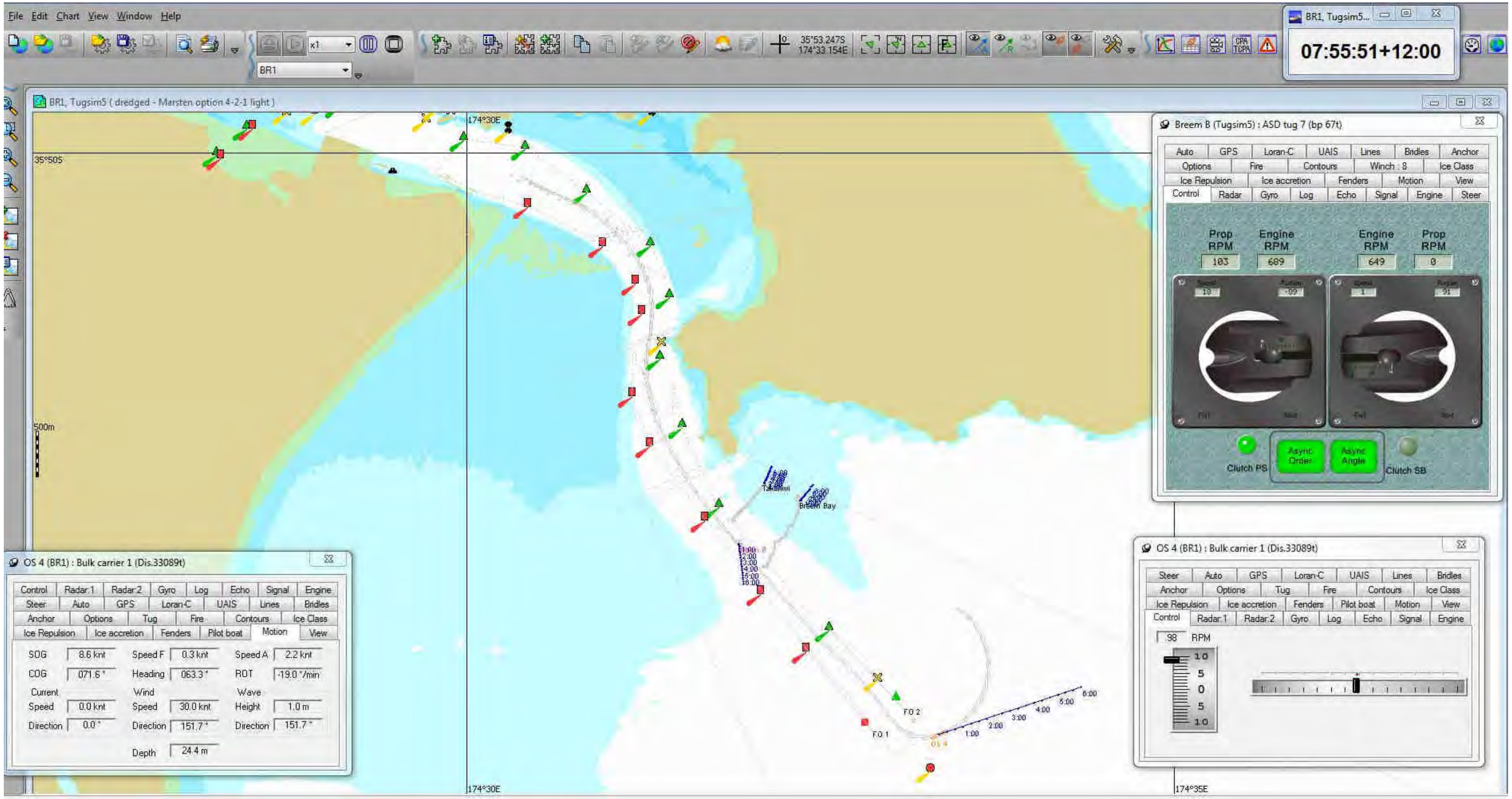
Run 033



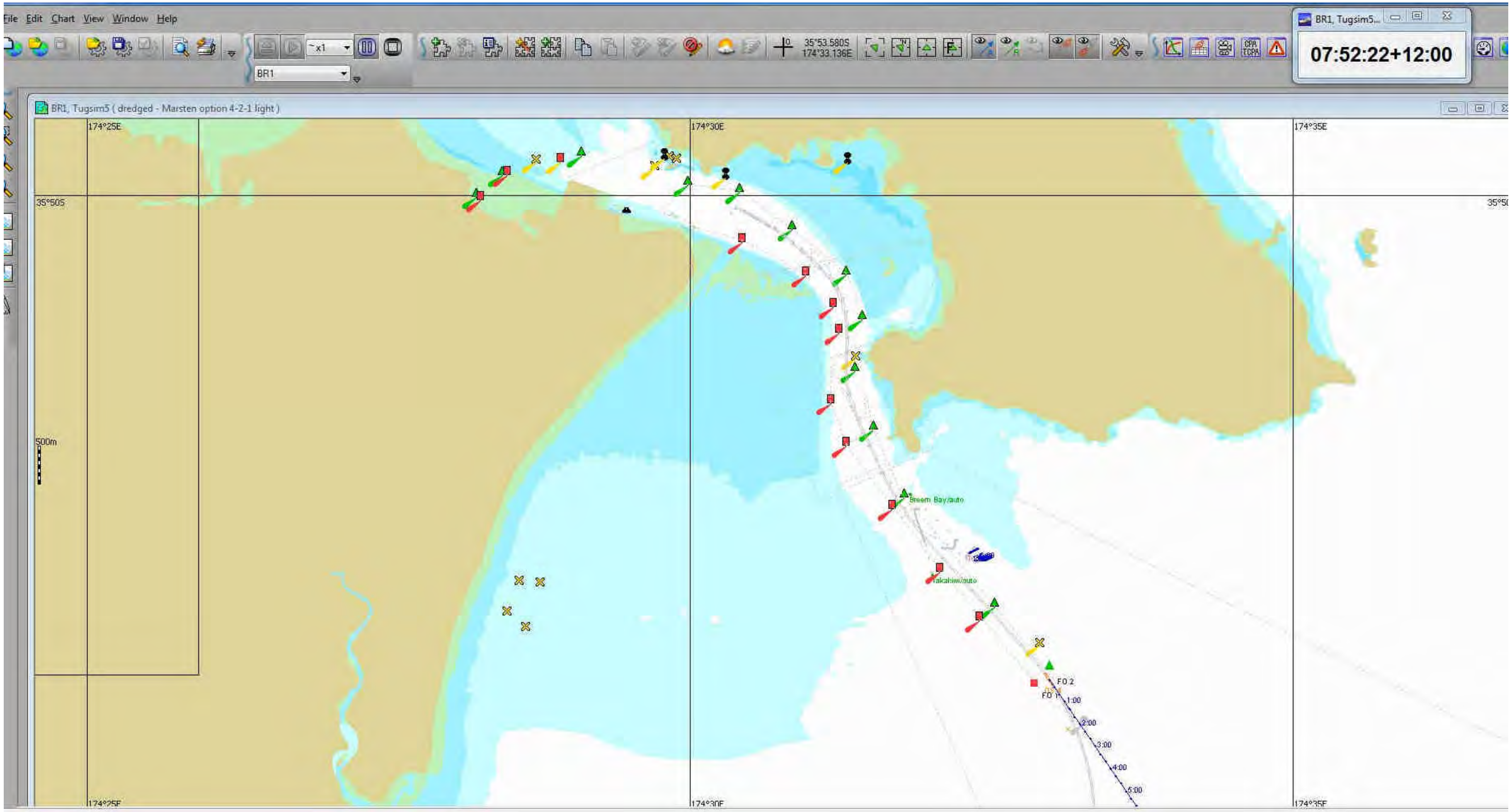
Run 034


BR1, Tugsim5 (dredged - Marsten_option 2)
22:23:37+12:00
VLCC1 loaded Diagrams : VLCC 1m 275m
Takahiwi : ASD tug 1 (bp 53t)
Breem B (Tugsim5) : ASD tug 7 (bp 67t)
Under keel clearance aft (m) 3.3
Ship-Bank interaction. Summary force (t) 0.0
Rate of turn (deg/min) 3.1
Tug #1. Summary force (t) 0.0
Total force from all the mooring lines. Summary force (t) 70.4
Wind effect. Summary force (t) 31.3

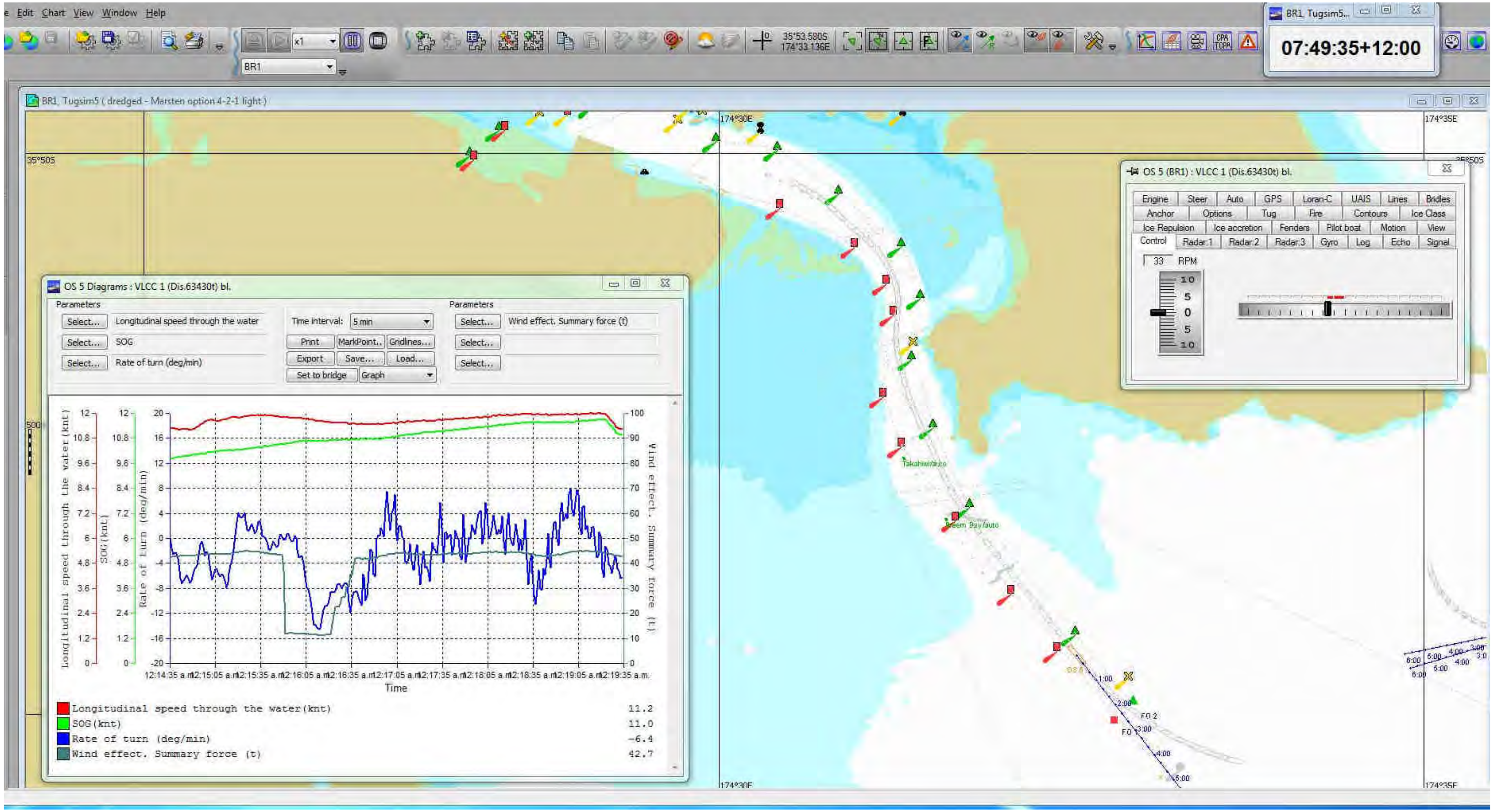
Run 035


BR1, Tugsim5 (dredged - Marsten option 4-2-1 light)
07:55:51+12:00
Breem B (Tugsim5) : ASD tug 7 (bp 67t)
OS 4 (BR1) : Bulk carrier 1 (Dis.33089t)
SOG 8.6 knt
COG 071.6 °
Heading 063.3 °
ROT -19.0 °/min
Depth 24.4 m
OS 4 (BR1) : Bulk carrier 1 (Dis.33089t)

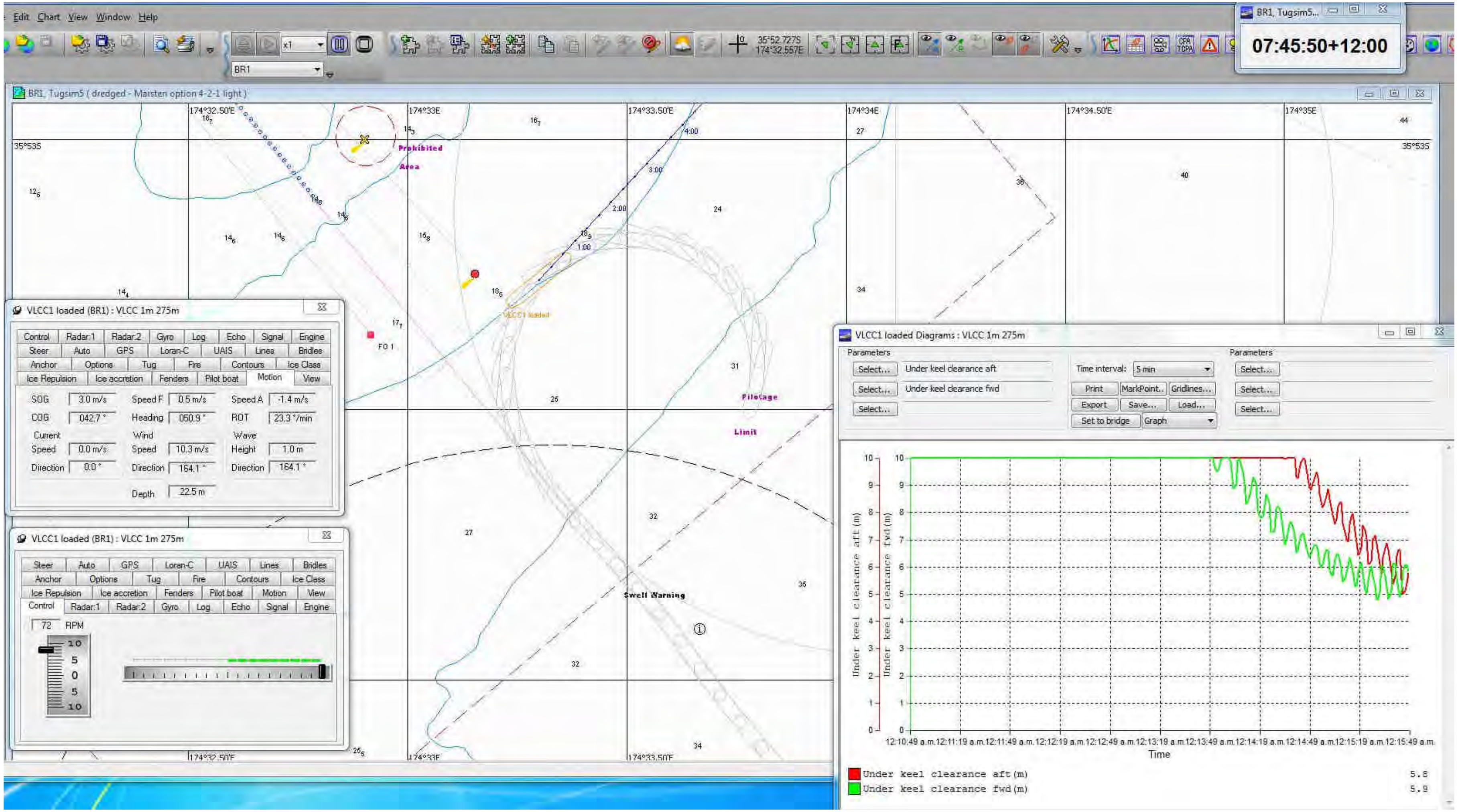
Run 036


File Edit Chart View Window Help
BR1, Tugsim5 (dredged - Marsten option 4-2-1 light)
07:52:22+12:00
174°25E
174°30E
174°35E
35°50S
500m
Bream Bay/auto

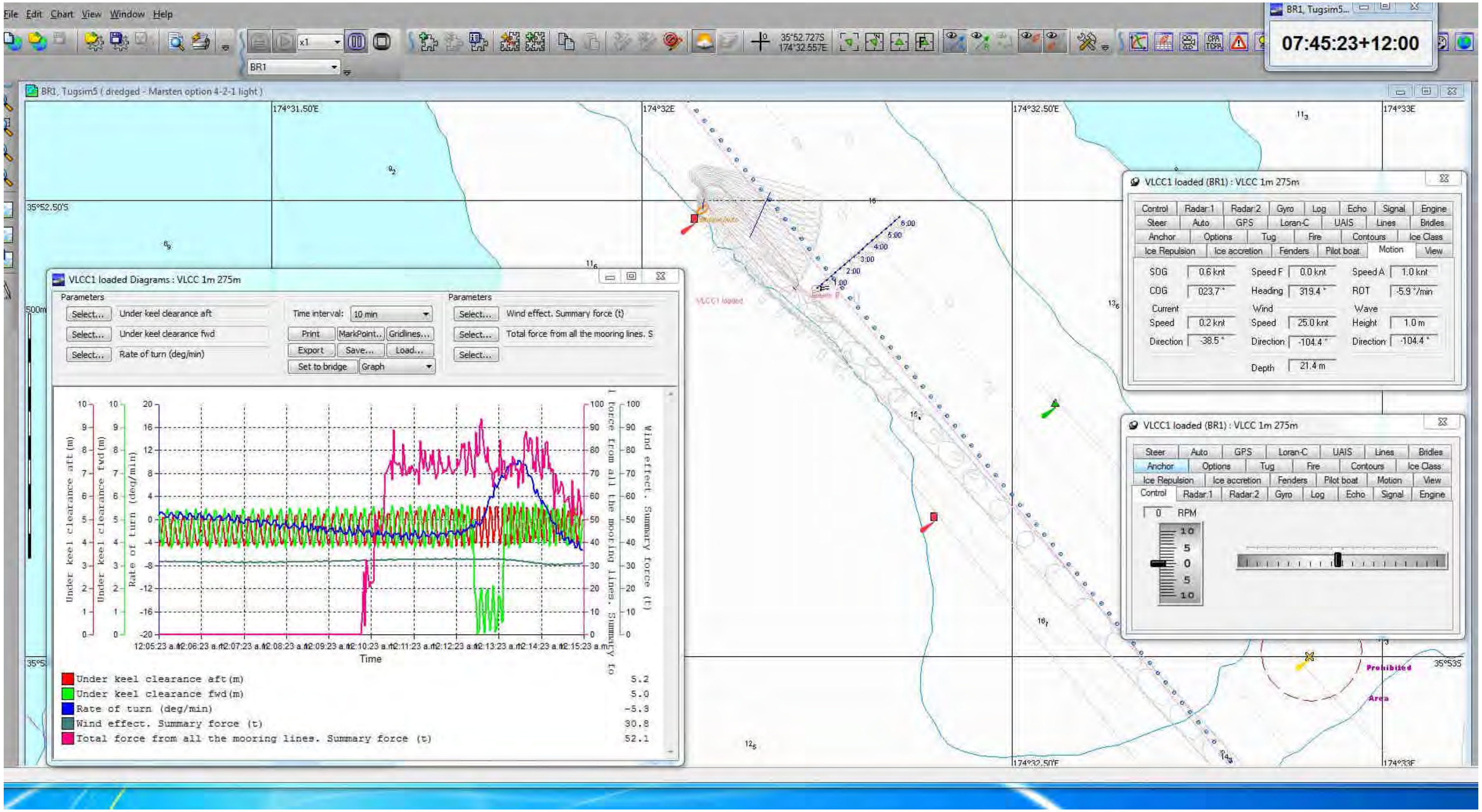
Run 37


OS 5 Diagrams : VLCC 1 (Dis.63430t) bl.
Longitudinal speed through the water
SOG
Rate of turn (deg/min)
Wind effect. Summary force (t)
Time interval: 5 min
Time
Longitudinal speed through the water(knt) 11.2
SOG(knt) 11.0
Rate of turn (deg/min) -6.4
Wind effect. Summary force (t) 42.7
BR1, Tugsim5 (dredged - Marsden option 4-2-1 light)
OS 5 (BR1) : VLCC 1 (Dis.63430t) bl.
07:49:35+12:00

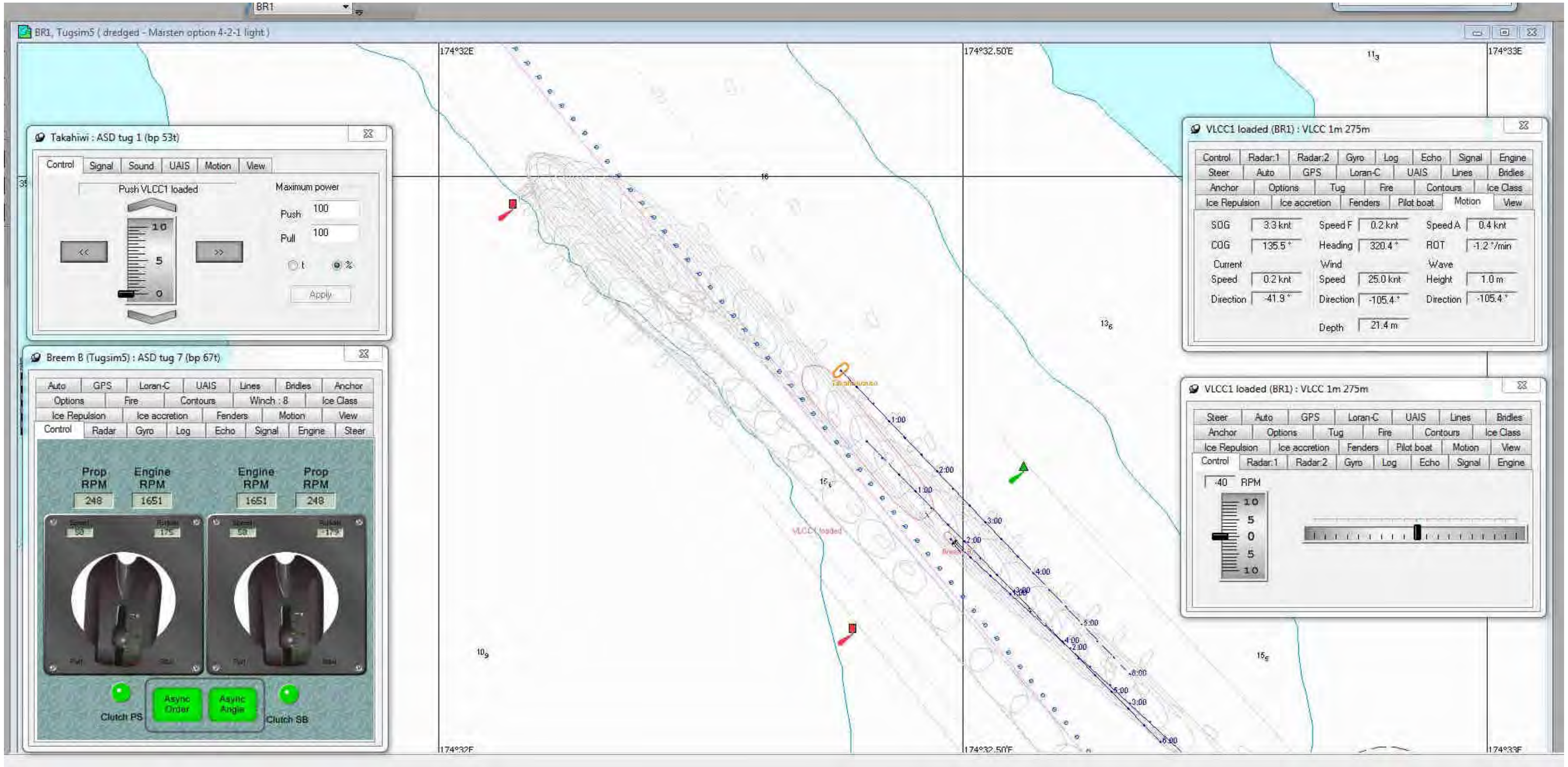
Run 038



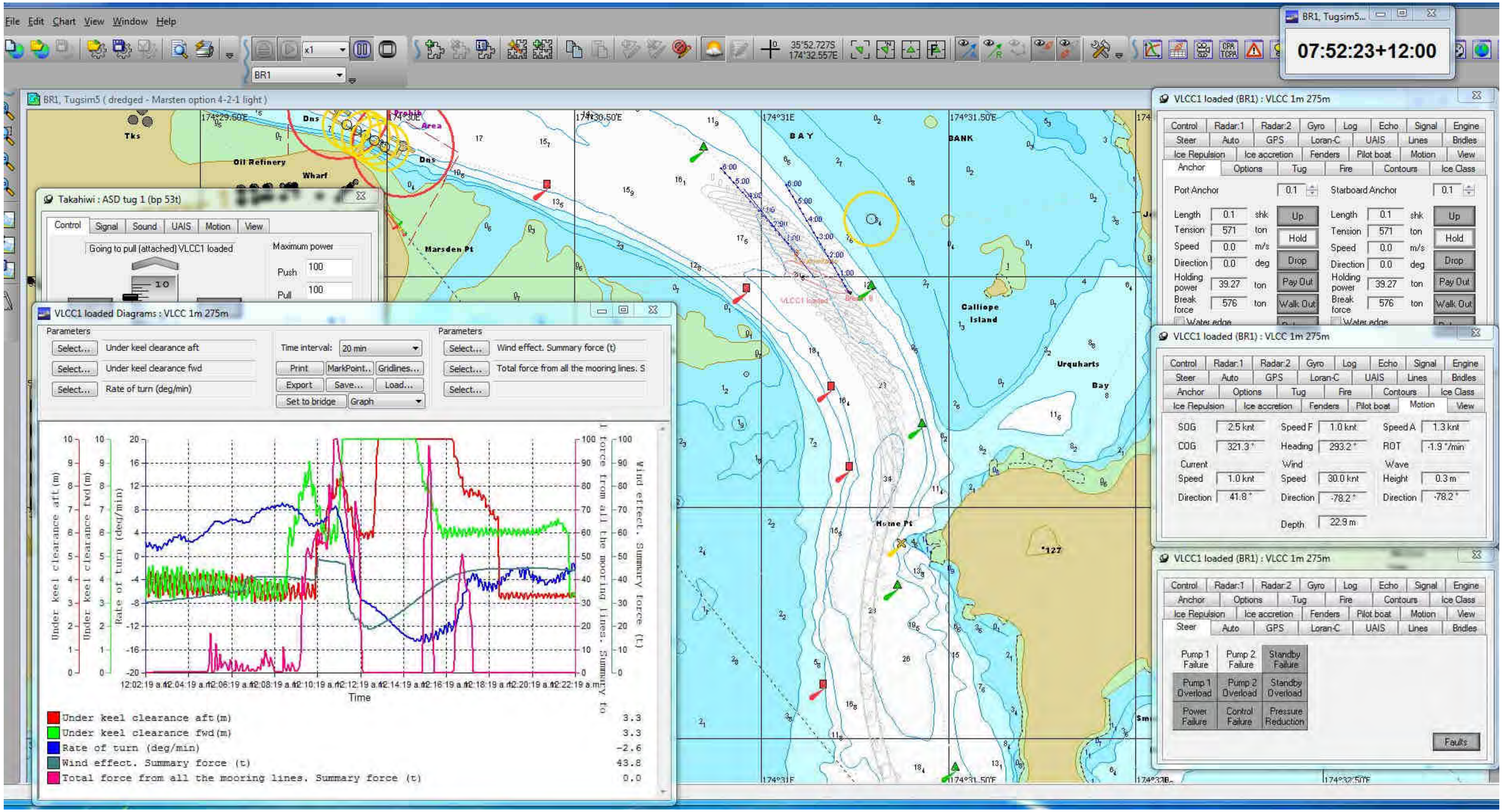
Run 039



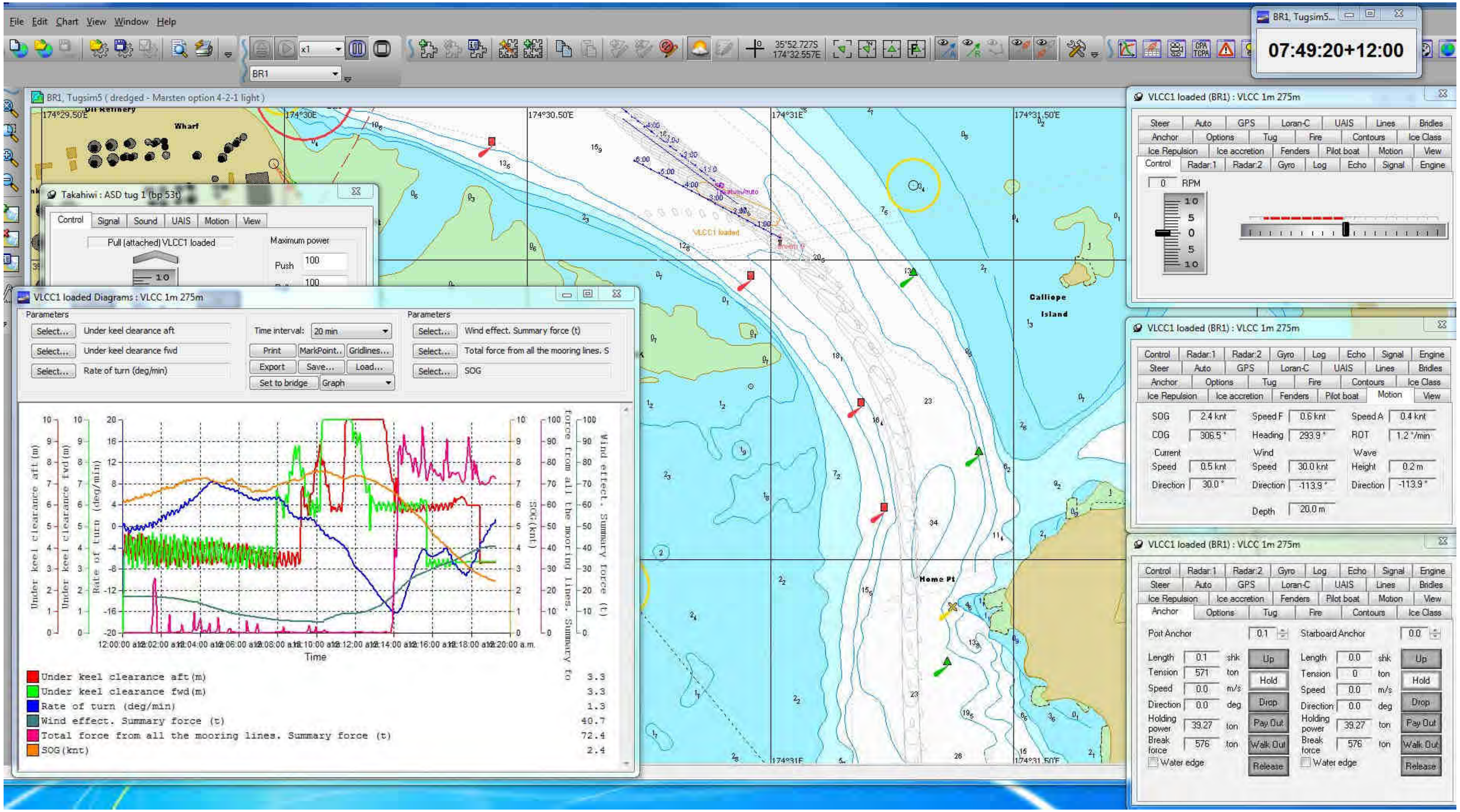
Run 040



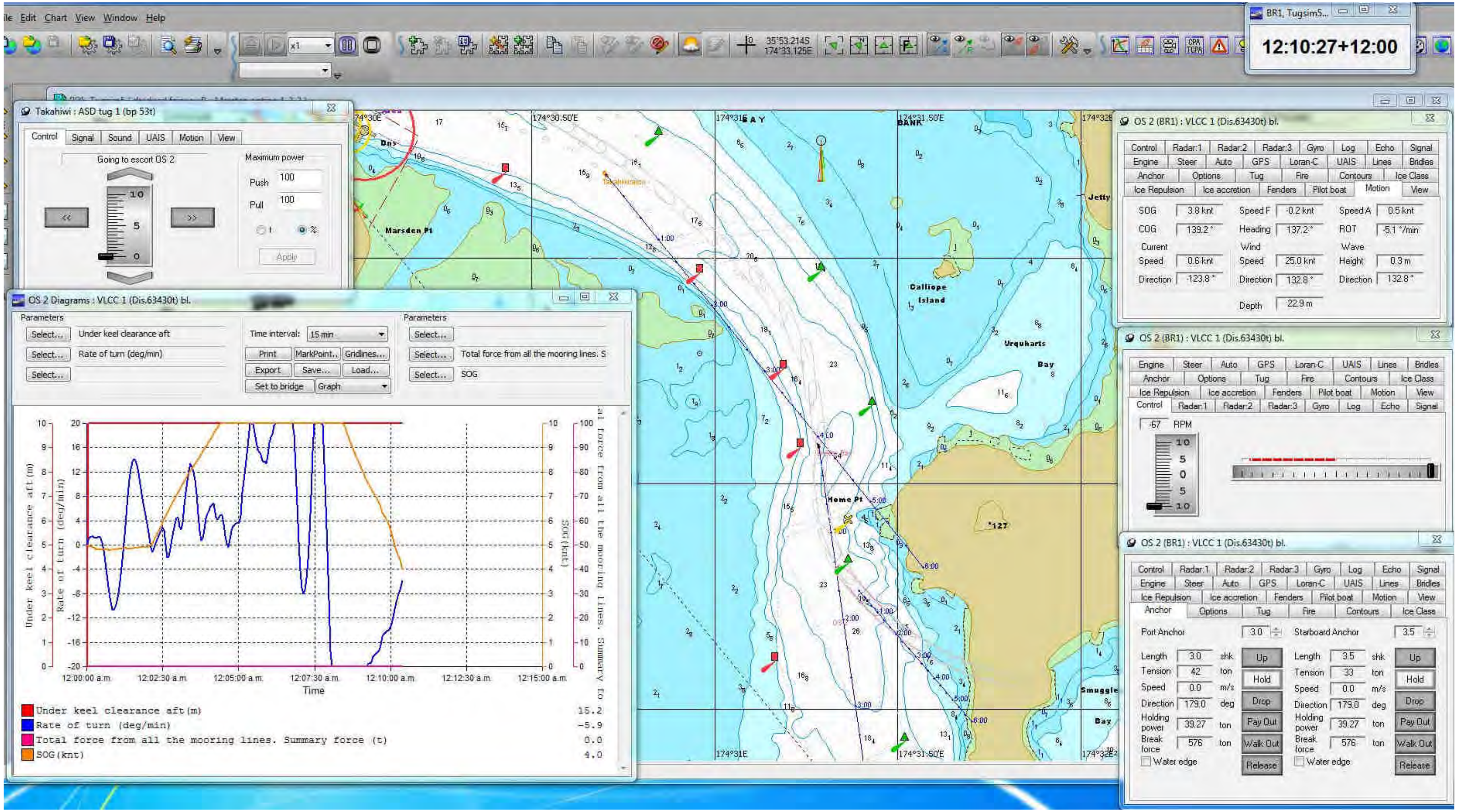
Run 040A



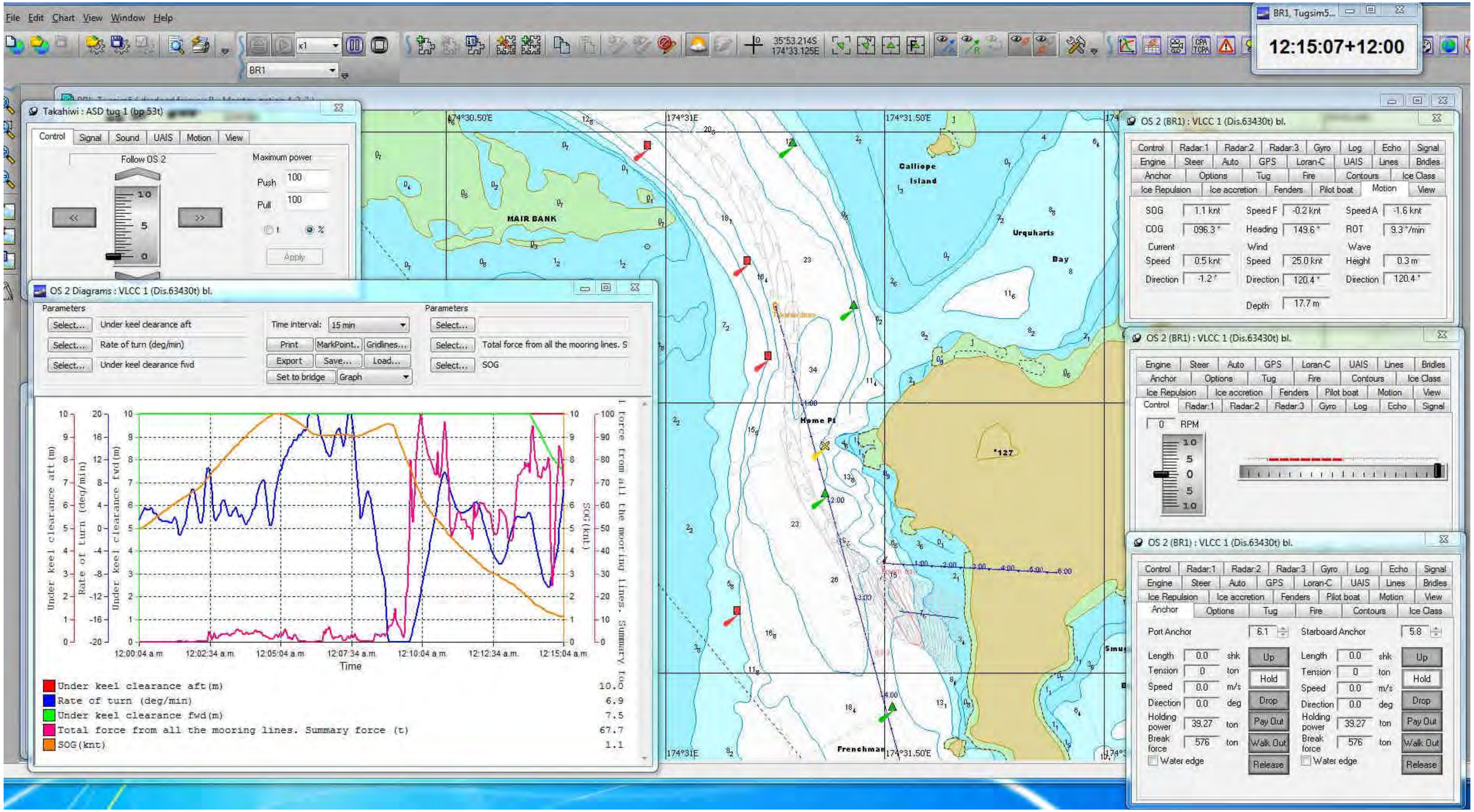
Run 041



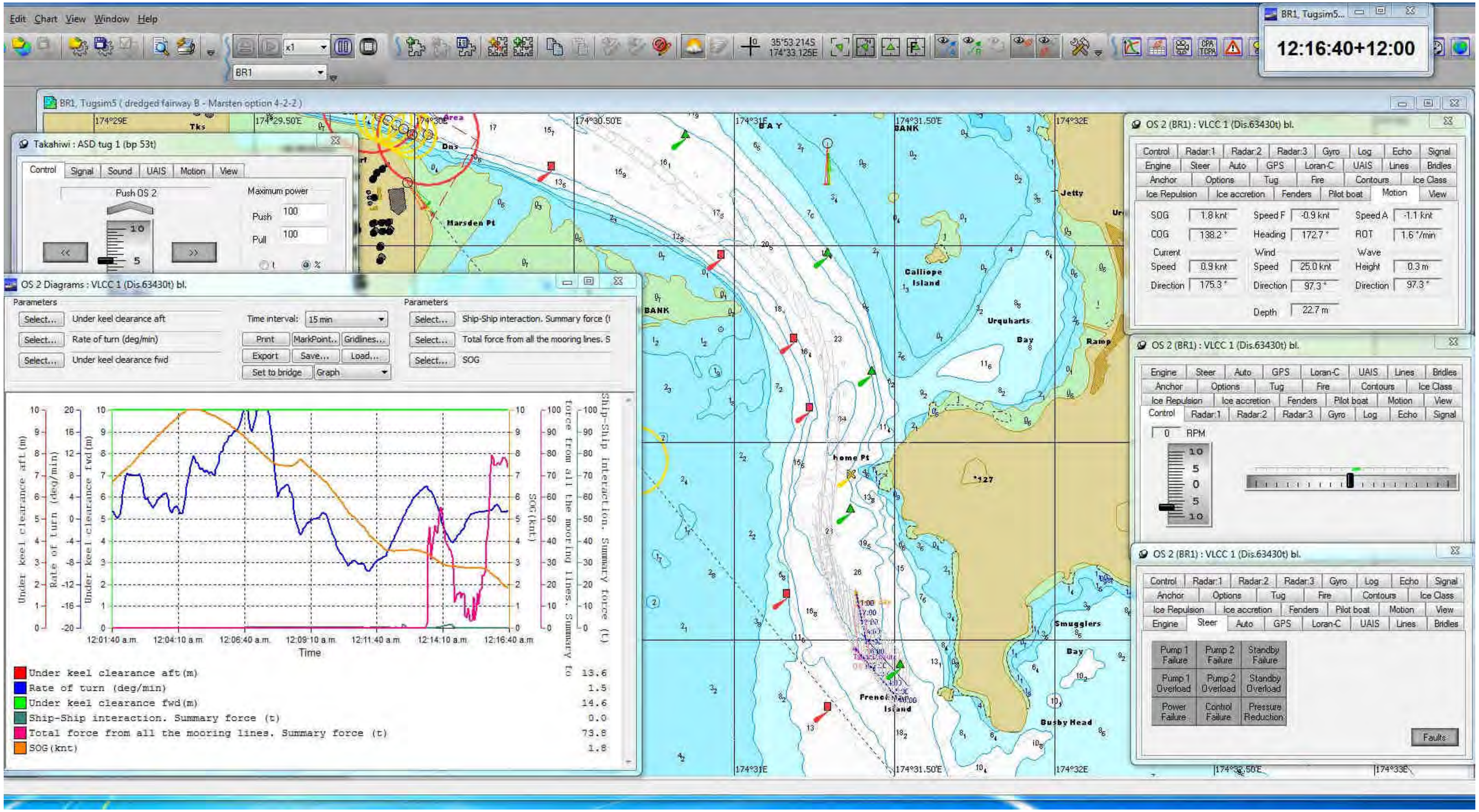
Run 042



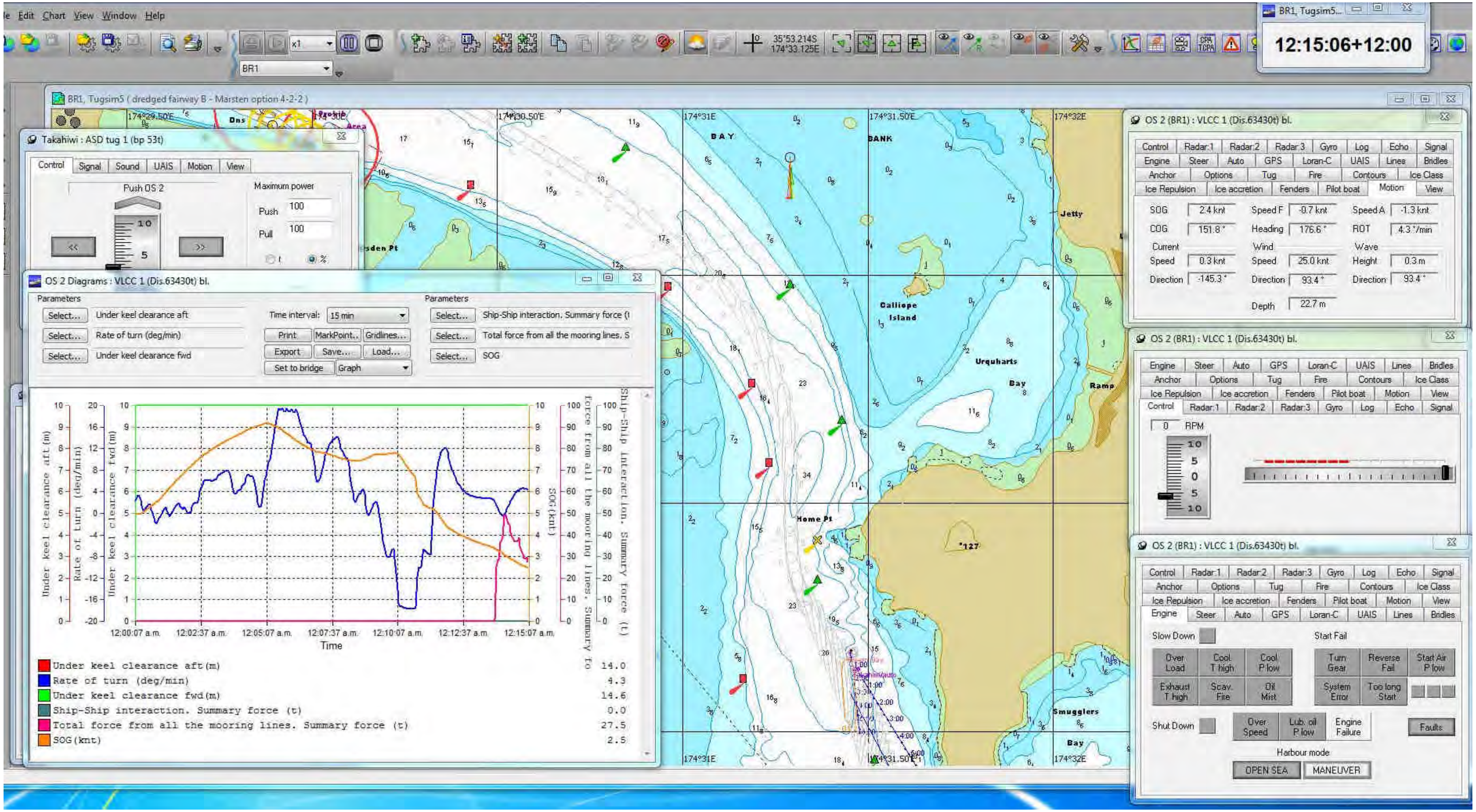
Run 043


12:15:07+12:00
OS 2 Diagrams : VLCC 1 (Dis.63430t) bl.
Under keel clearance aft (m)
Rate of turn (deg/min)
Under keel clearance fwd (m)
Total force from all the mooring lines. Summary force (t)
SOG (knt)
Time
Calliope Island
Urquharts Bay
MAIR BANK
Home Pt
Frenchman

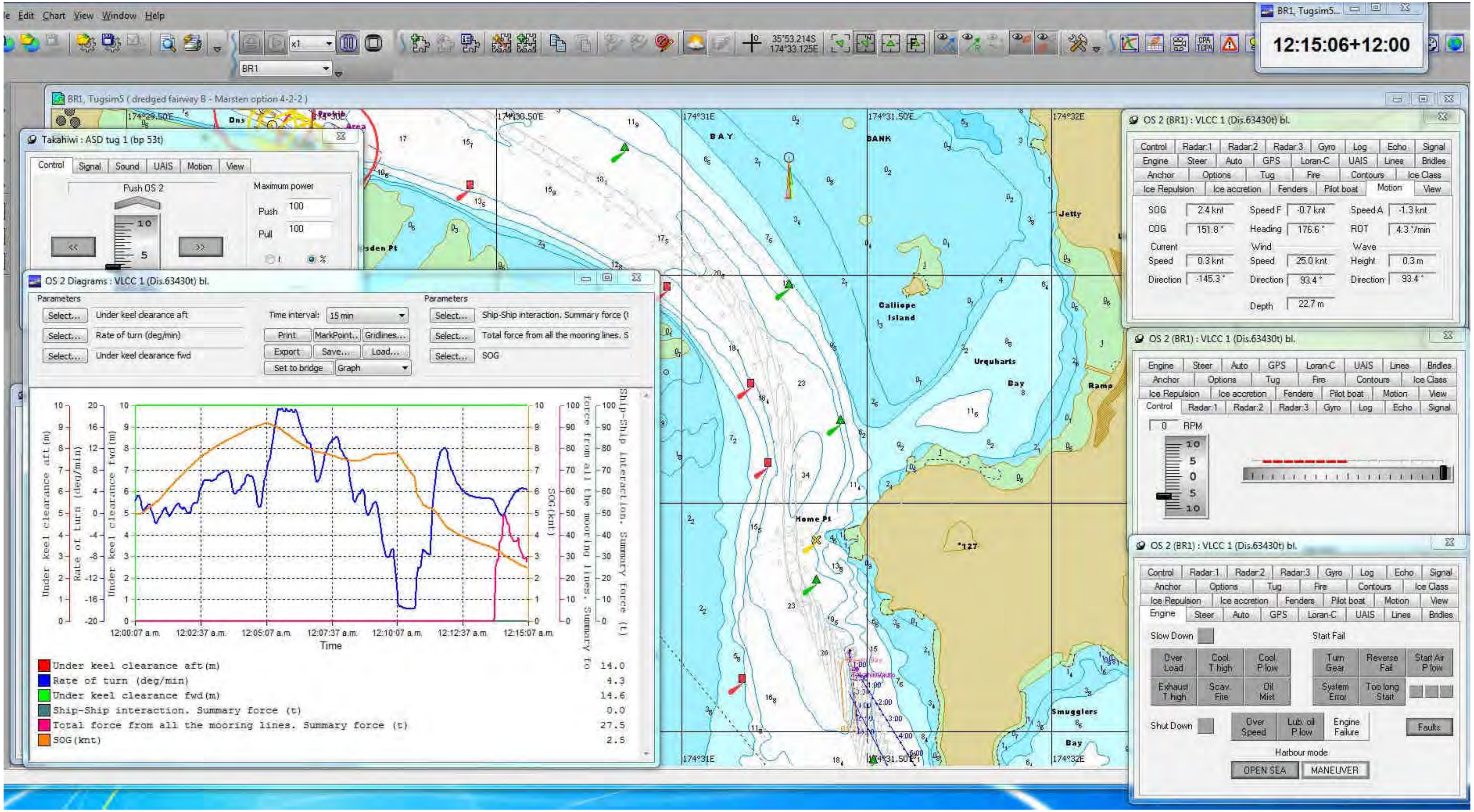
Run 044



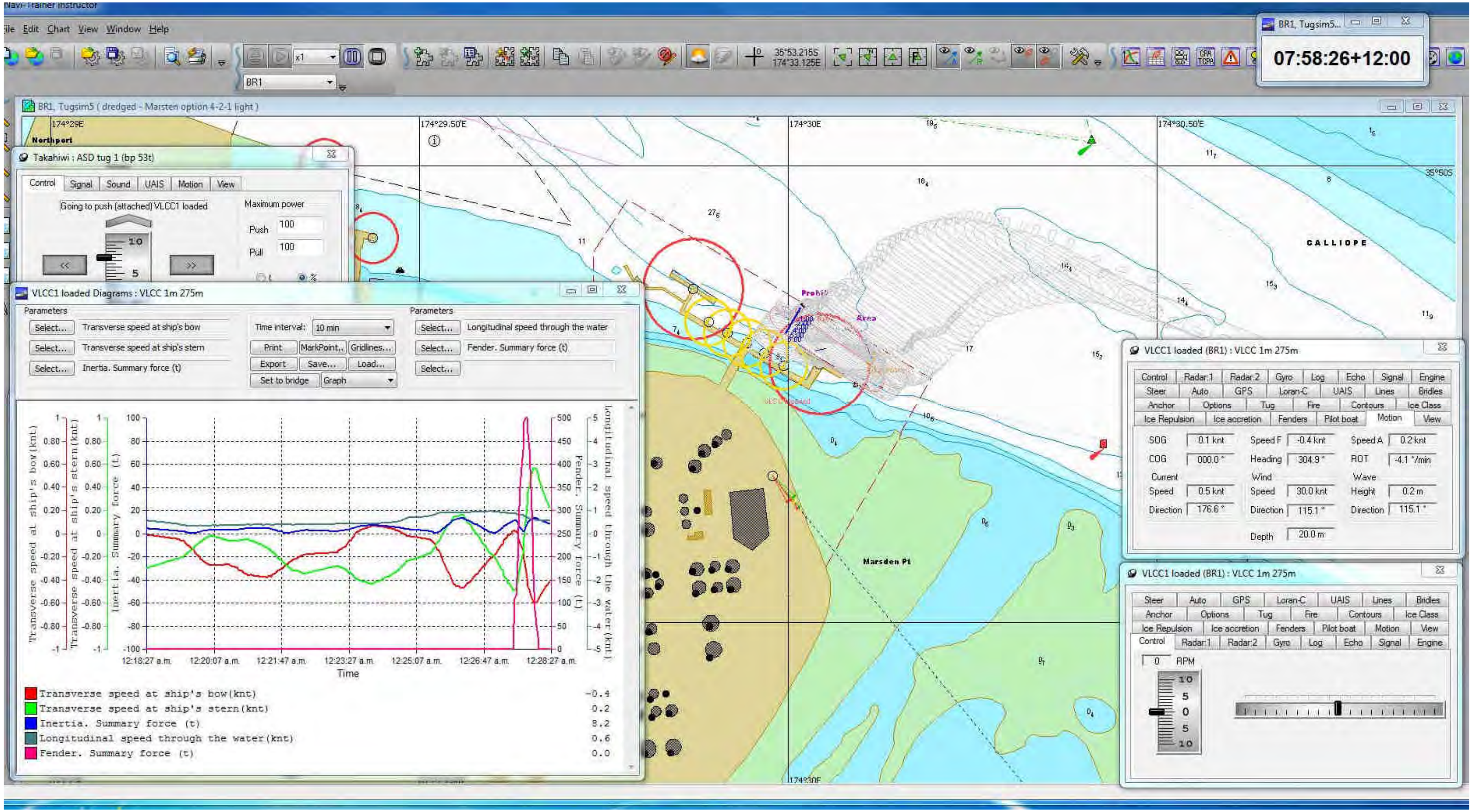
Run 045



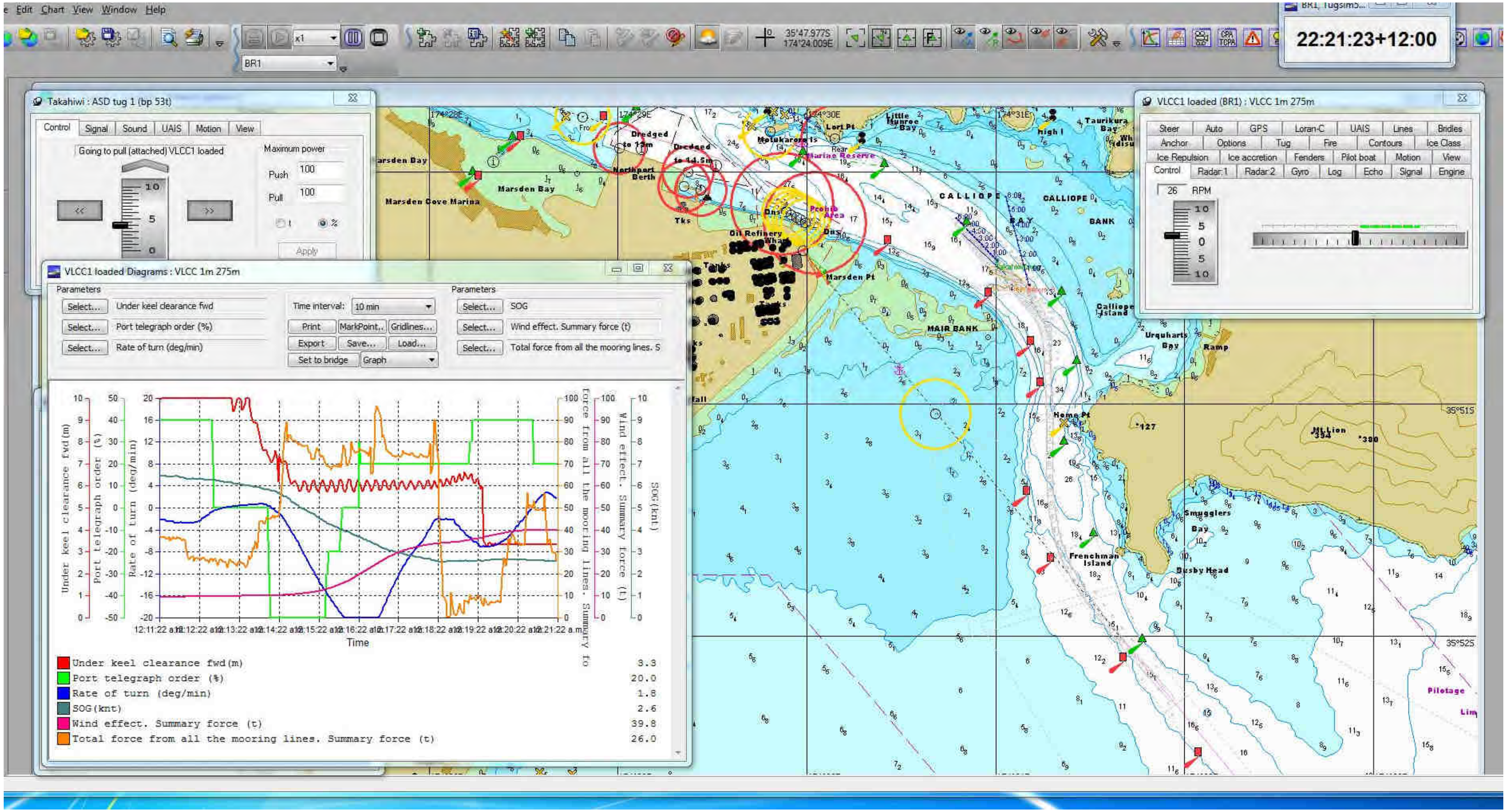
Run 046



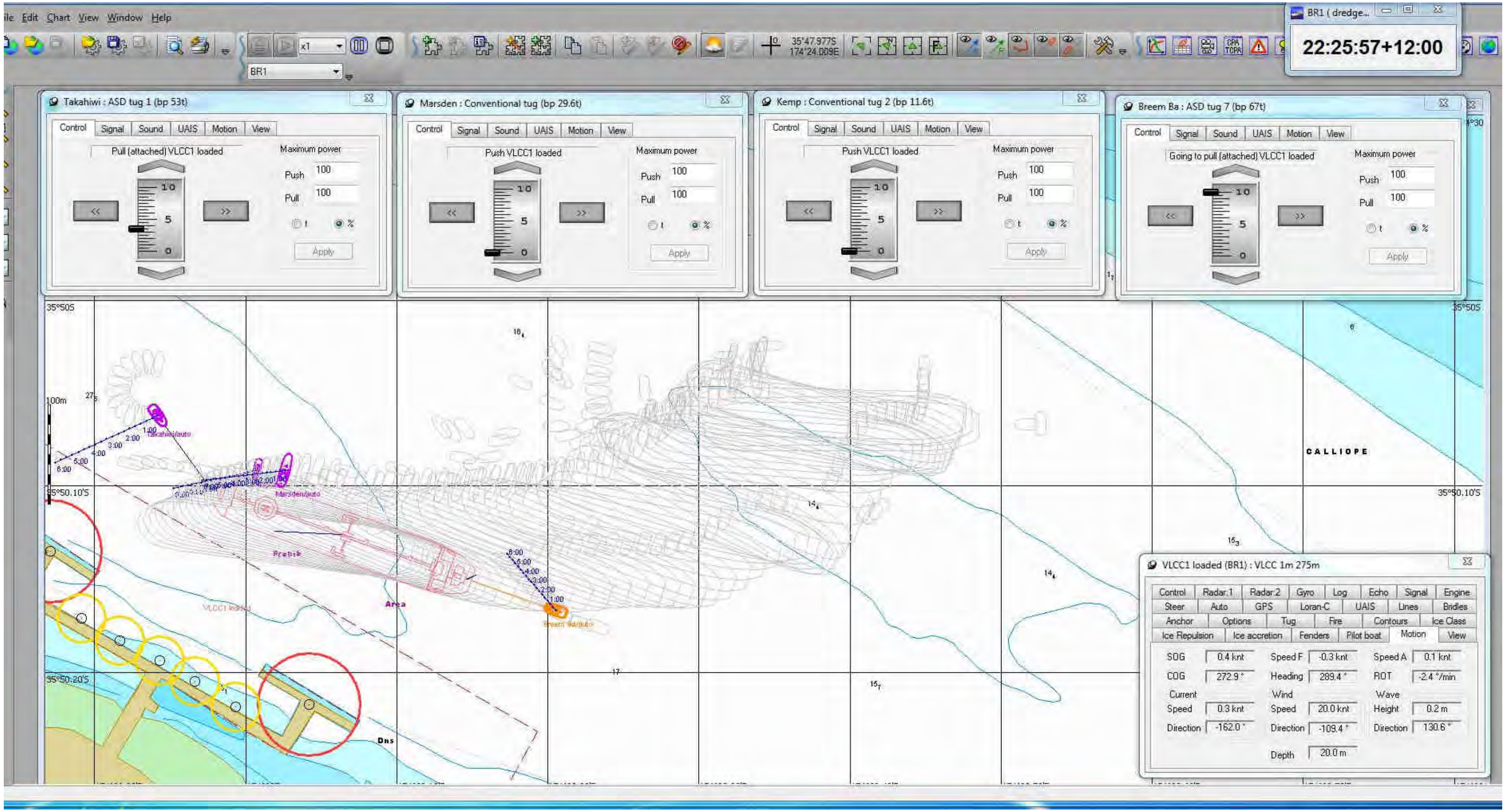
Run 047



Run 048



Run 049



Takahiwi : ASD tug 1 (bp 53t)
Pull (attached) VLCC1 loaded
Marsden : Conventional tug (bp 29.6t)
Push VLCC1 loaded
Kemp : Conventional tug 2 (bp 11.6t)
Push VLCC1 loaded
Breem Ba : ASD tug 7 (bp 67t)
Going to pull (attached) VLCC1 loaded
VLCC1 loaded (BR1) : VLCC 1m 275m
22:25:57+12:00
CALLIOPE

Run 050

Appendix C: Memo on side slope stability assessment (T+T)

Tonkin+Taylor

Memo

To:	Chris Simmons	Job No:	30488
From:	Eric Torvelainen and Richard Reinen-Hamill	Date:	16 August 2016
Subject:	Refining NZ Channel Deepening Project - Side slope stability assessment. Rev. 2		

1 Stable dredge slope angles

1.1 Purpose

This memo outlines the assessment of side slope stability. The accepted best practice for the design of stable dredged slopes is generally based on Raaijmakers (2005):

- Physical observation of existing natural slopes along the channel entrance
- Results of geotechnical investigations in the area concerned
- Observed slopes during trial dredging and maintenance dredging (i.e. from the dredging carried out at Marsden Point).

1.2 Executive summary

The existing natural slopes range from 1V:2.2H to 1V to 10:2H with an average slope of 1V:5.2H showing the existing slopes are stable at relatively steep angles. Micro-stability analysis shows a stability factor of 2 for slopes flatter than 1V:3.5H.

The boreholes and vibro-cores along the channel alignment indicate a layer of loose sand (up to 2.0m thick in the areas of the Crude Oil Terminal Wharf and 1.5m in the outer channel) over a profile of typically medium dense to dense sand.

The assessment of liquefaction indicates it is unlikely (less than 0.04% chance per year) that liquefaction will be triggered causing instability in the medium dense to dense soil material below 1.5m to 2.0m depth.

There is a possibility that the thin mantle of overlying loose soil could experience liquefaction. This could result from a low intensity of earthquake shaking or wave loading from a large tropical cyclone. This could be from earthquake shaking with a return period less than 500 years or a tropical cyclone with a return period of around 100 years.

The consequence of this liquefaction is likely a flow type failure of the upper layer of loose soil and to fully mitigate against the likelihood of flow liquefaction a slope grade of 1V:10H would be required for the upper layer.

The present channel design with sides slopes of 1V:4H and with a benched slope at the berth that provides a composite slope of 1V:5.1H, or an effective upper slope above the 4.2 m CD bench of 1V:7.8H therefore has a low risk of instability. Increased stability could be achieved by forming a flatter slope of the upper layer of soft sediment. Alternatively it is likely to naturally occur in the localised areas of softer material and be managed by the initial maintenance dredging regime.

If an earthquake did occur causing strong shaking (Peak Ground Acceleration of 0.1g of greater) at Marsden Point, or after a significant tropical cyclone, it would be prudent to inspect the channel for slope failures before further passage by ships.

2 Theory and design guidance

Slope development is dependent on macro-stability, micro-stability and morphology. Macro-stability is the overall stability of the slope and this is controlled by macro-shear failure, flow slide/liquefaction and breaching. Micro-stability is the internal stability of the particles that is a function of micro shear failure, seepage and pressure gradients. The morphological control relates to changes in shear stress and the threshold of motion of the particles.

2.1 No loading

In areas of no loading by waves and currents, as long as the soil is non-cohesive, the unloaded stability is governed by micro-stability (i.e. the friction angle of the sand, Φ). Slip circle analysis for a range of soil types showed that macro-stability is not likely to occur, unless weaker soil layers or a water level somewhere through the slope are present. In these situations the slop circle is attracted to these local weaknesses (Raaimakers, 2005). Breaching is only likely to occur in slopes of medium to densely packed sand that are steeper than the angle of internal friction. For 10 m high slopes the following design rules are often used (Raaijmakers, 2005):

Coarse sand slopes	2.5(H):1(V)
Medium sand slopes	3(H):1(V)
Fine sand slopes	3.5(H):1(V).

Based on the typical sand being predominantly medium to coarse, this suggests slopes could be reasonably steep if no loading was present.

2.2 Wave loads

Waves can affect the water pressure and loading on the seabed affecting effective stresses. While there is no practical means for evaluating this effect engineering practice suggests that where slope design is not governed by micro-stability and the slopes are in the range of 3(H):1(V) or flatter, the risk of wave induced slope failure is implicitly accounted for in the safety factor provided the indirect effect does not cause failure (Raaijmakers, 2005).

Indirect effects are a function of the load (represented by the wave height, wave period, storm duration and water-depth) and the strength represented by the consolidated properties (hydraulic conductivity, k and the coefficient of vertical compression, m_v) and the relative density (RD – the ratio of the minimum and maximum void ratio). Typically coarse, permeable dense soils will have such good consolidation properties that they will not experience wave pressure build-up. Laboratory testing of representative sediments have shown that if wave induced shear stresses are in the order of 0.1 or larger there is the potential risk of cyclic liquefaction. Sediments with a relative density (RD) of 0.8 are unconditionally stable under depth limited waves of 5 m, while loosely packed soils (RD = 0.2) will fail with very mild wave climates (H less than 1.75 m).

The wave climate in the vicinity to the harbour entrance is relatively mild, with generally low wave heights. *Figure 2-1* shows wave propagation modelling over the ebb tide delta and into the harbour. Even for the extreme situation wave heights are less than 5 m offshore from the delta and reduce to less than 0.5 m at Marsden Point. Even with the proposed channel dredging wave heights are not expected to increase by more than 0.25 m, with generally changes being ±0.05 m (refer *Figure 2-2*). Wave loading is therefore not anticipated to have a significant effect on side slope angles.

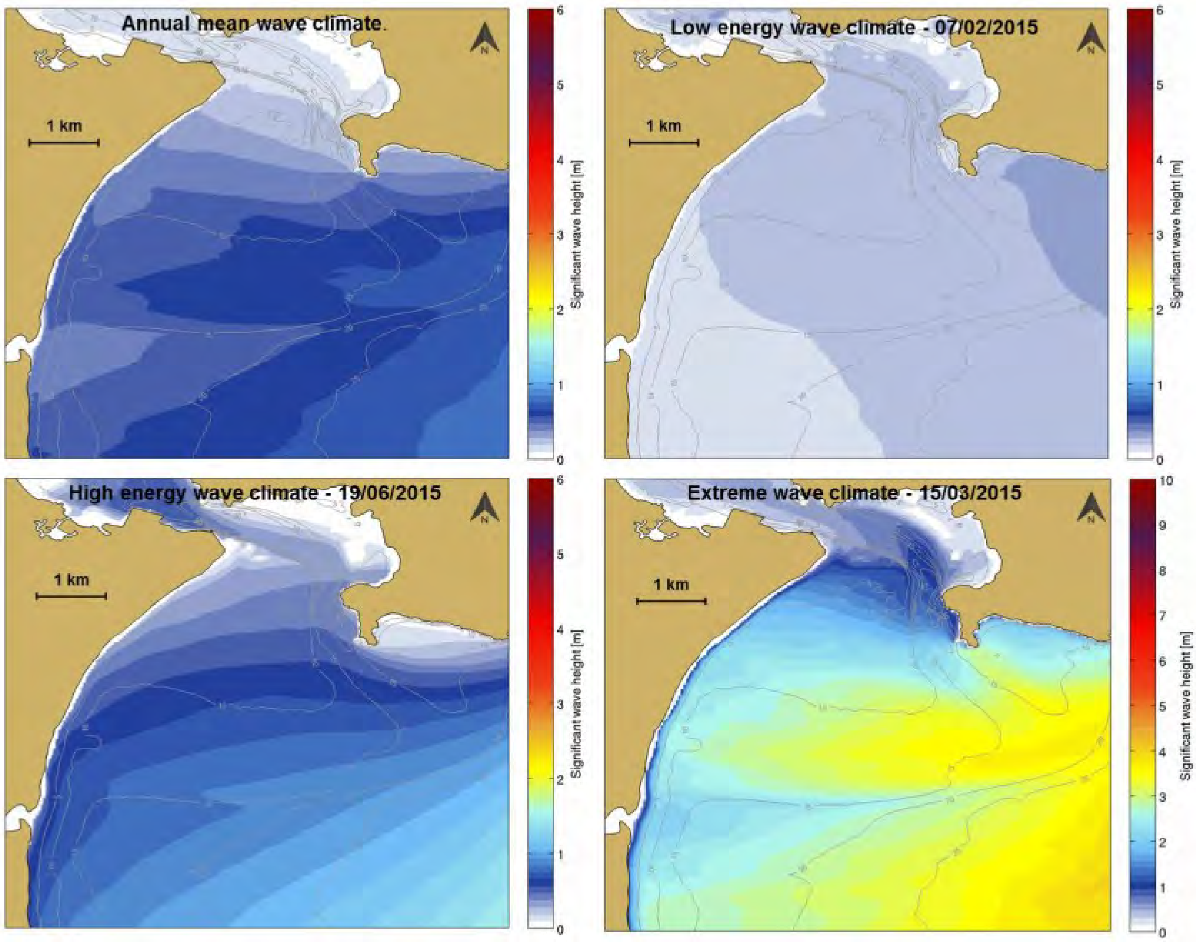
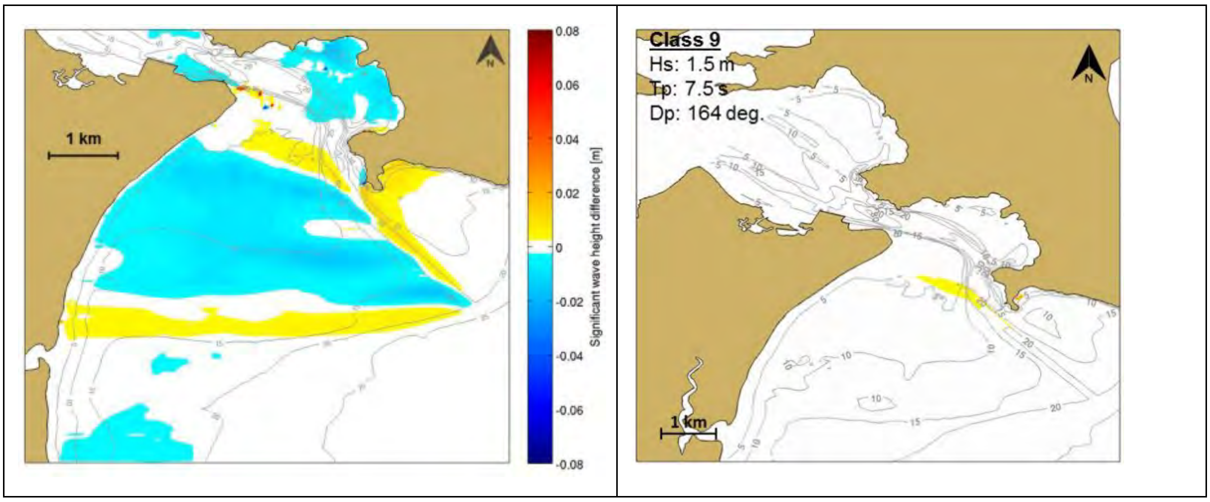


Figure 2-1 Present day annual mean, low, high and extreme wave heights in the vicinity of the harbour entrance (Source: MSL, 2016b)



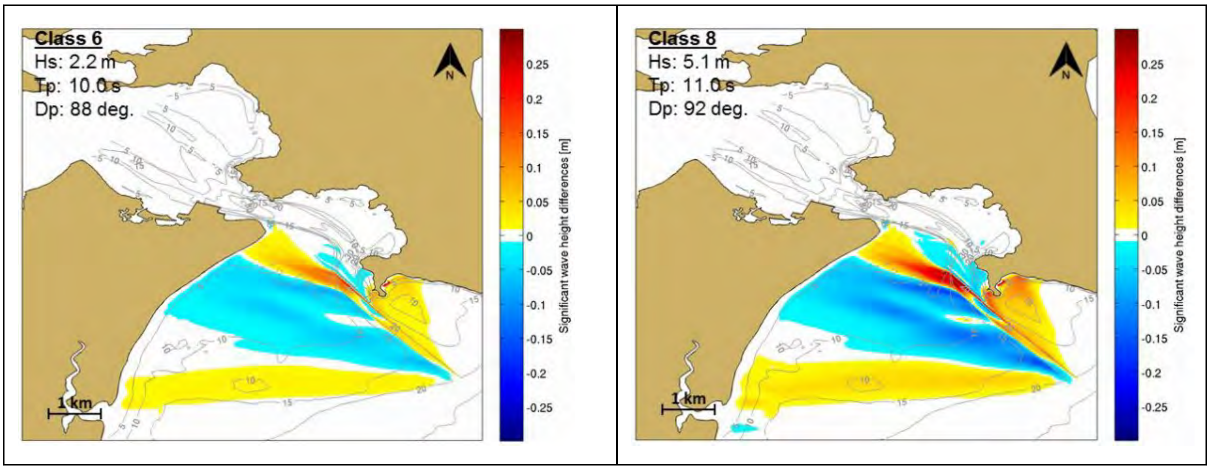


Figure 2-2 Changes in significant wave height resulting from channel dredging for average annual conditions (top left) and 19% (top right), 6% (bottom left) and 1% probability of occurrence (Source: MSL, 2016b)

2.3 Morphology

Numerical modelling of a range of sediment properties in tidal flow indicate that slopes of between 4(H):1(V) and 6(H):1(V) can occur over a period of a year, with tidal currents more effective in enabling steeper slopes (Raaijmakers, 2005). *Figure 2-3* shows the present day maximum ebb and spring tide velocities. During spring tide the ebb tide creates the highest velocities along the edge of the ebb tide delta and Mair Bank with velocities reaching 1.3 m/s. *Figure 2-4* shows the maximum velocities for the neap tide. In this situation the trend is similar, but the magnitude of the velocities are less. Peak velocities are in the order of 0.8 m/s.

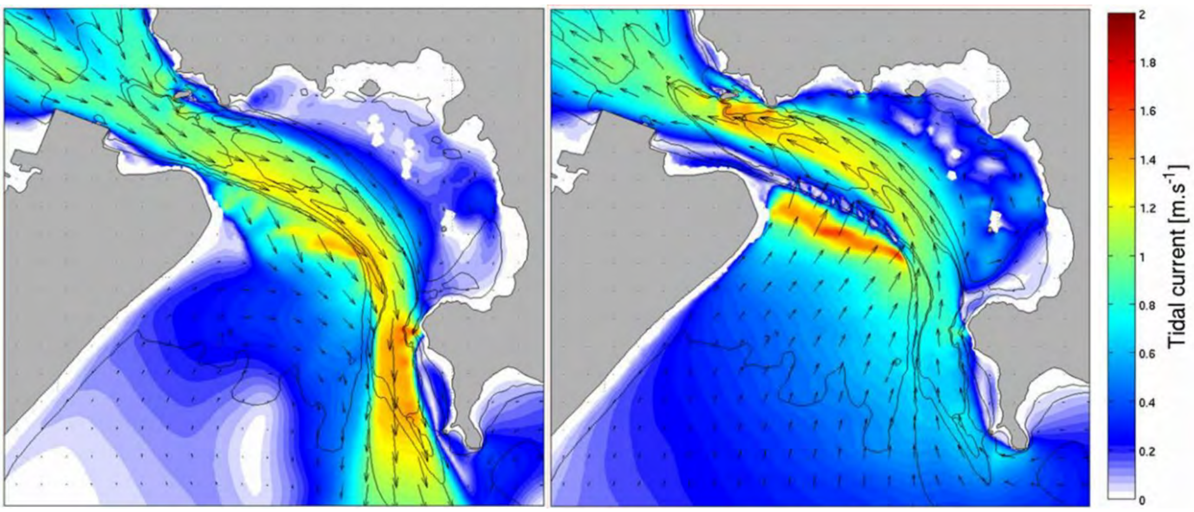


Figure 2-3 Modelled maximum ebb and flood spring tide velocities (Source: MSL, 2016b)

The change in peak tidal velocities for the spring tide situation is shown in *Figure 2-5*. The changes in velocity are generally very minor (± 0.02 m/s) and no sufficient to change the tidal flow effect on slope stability. Changes during neap tide are even less significant and are not plotted due to the very small changes.

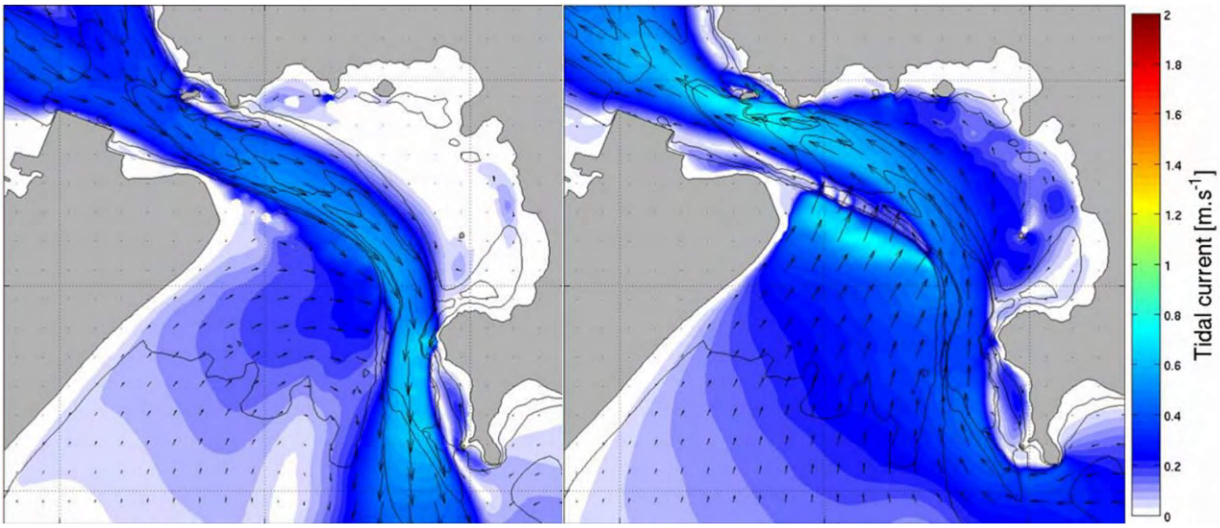


Figure 2-4 Modelled maximum ebb and flood spring tide flows (Source: MSL, 2016b)

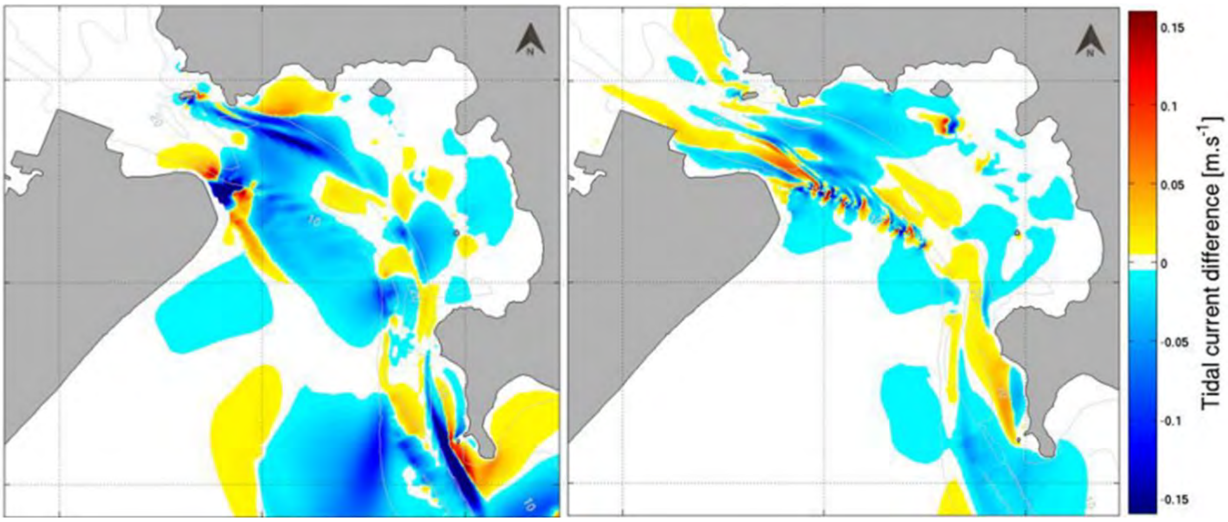


Figure 2-5 Difference in peak tidal flows post channel deepening (Source: MSL, 2016b)

3 Existing natural side slopes

Side slopes along the ebb tide delta have been measured at 100 m centres using the 2016 hydrographic survey. Figure 3-1 shows the resulting side slope of the bank at 20 locations along the side of the existing channel and *Figure 3-2* shows the examples at Profile 3, 10, 15 and 20. The steepest observed slope is 2.2(H):1(V) and the flattest slope is 10.2(H):1(V). The average slope is around 5.5 (H):1(V). In the area of highest currents the slopes are typically steepest confirming the observations of Raaijmakers (2005). The flatter slopes are situated where tidal flows reduce and it is likely these slopes include some depositional component.

Profile	Slope of exisiting
1	4.9
2	4.9
3	5.0
4	5.8
5	4.6
6	6.2
7	6.7
8	6.8
9	4.2
10	4.0
11	3.3
12	4.7
13	4.3
14	3.8
15	2.2
16	7.4
17	6.4
18	6.6
19	7.7
20	10.2
Min	2.2
Average	5.5
Max	10.2

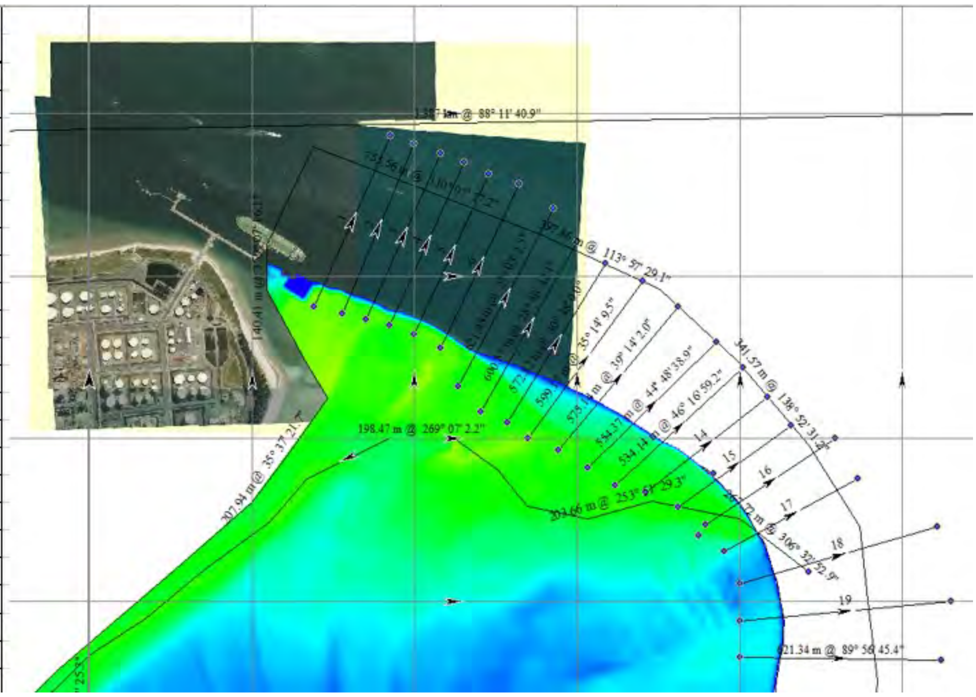


Figure 3-1 Angle of existing bank (n(H):1(V))

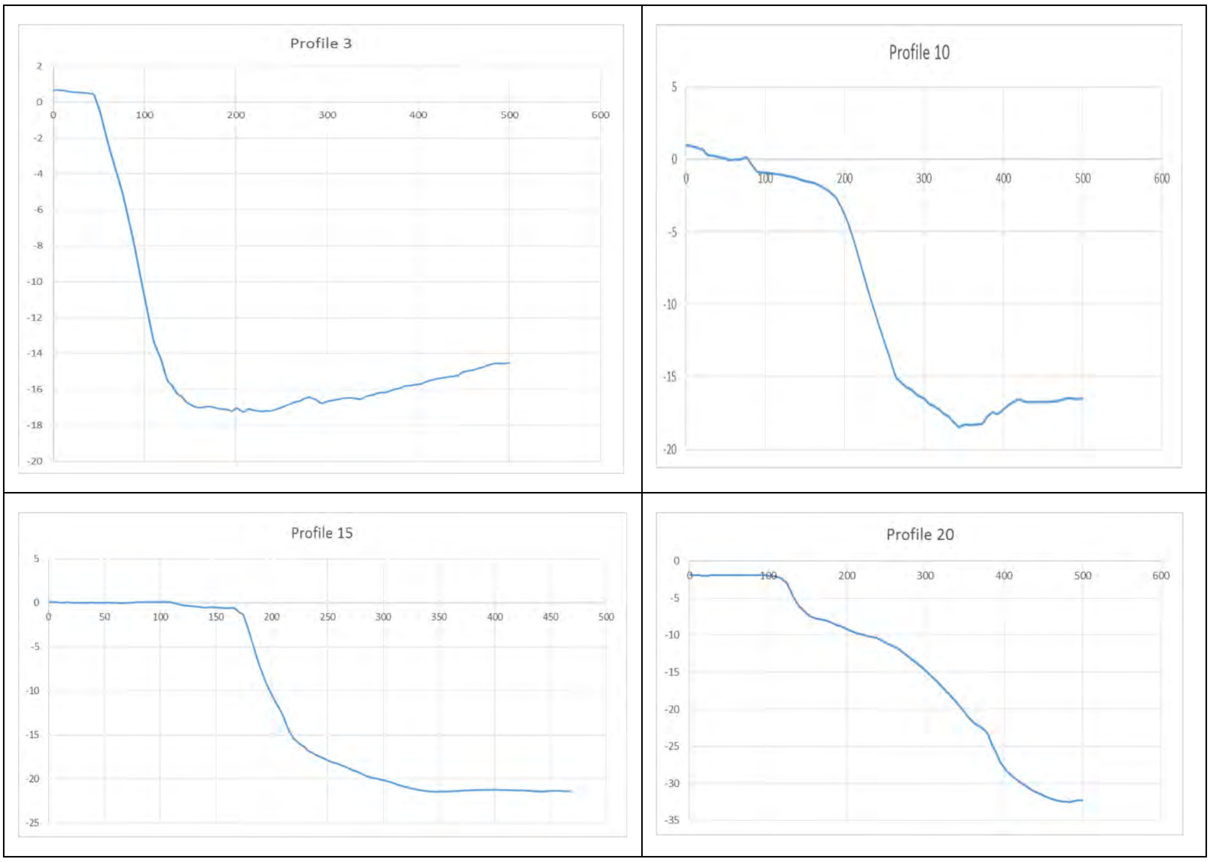


Figure 3-2 Representative profiles showing bank slopes ranging from 2(H):1(V) and 10.2(H):1(V)

4 Geotechnical investigation

4.1 Soil Profile

The boreholes in the Tonkin & Taylor (1984) Report indicate the soil profile to approximately 20m depth at the Crude Oil Terminal Wharf. Review of the borehole information indicates a soil profile of fine to medium sand with a cohesive organic clayey layer up to two metres thick at approximately 10 to 12m depth as shown on Figure A-1, Appendix A. This clayey layer is firm to stiff and will not experience flow or cyclic (typically earthquake induced) liquefaction. Figure A-1 (Appendix A) summaries the depth (stress) normalised Standard Penetration Test (SPT) values $(N_1)_{60}$, which is an indicator of soil density, at the Crude Oil Terminal Wharf. This indicates that the material from a depth of approximately 2m is dense. At depths less than 2m there could be loose material.

On the inside of the Crude Oil Terminal Wharf Borehole BH6 (Tonkin & Taylor, 1984) presents a loose to medium dense profile of sand to 13.5m depth as shown in Figure A-2 (Appendix A). From 13.5m depth the profile is medium dense to dense. This profile is loose to 4m depth where it reaches a layer of medium dense sand.

The boreholes in the Hawthorn Geddes (2009) Report and the Tonkin & Taylor (2016) vibrocore holes indicate the soil profile to approximately 4m depth in the channel. The vibrocores indicate a fine to medium sand profile. Figure A-3 (Appendix A) summaries the depth normalised Standard Penetration Test (SPT) values ($(N_1)_{60}$) from the boreholes. This show that a medium dense sand profile is reached within 1.5m of the sea floor with loose material over the top.

While BH6 at the Crude Oil Wharf Terminal indicates a loose soil profile to 4m depth, general the investigations at the Crude Oil Terminal Wharf and along the channel indicate only a thin layer of loose to medium dense sand, 2m in the area of the Crude Oil Wharf Terminal and 1.5m in the outer channel.

4.2 Basis of assessment

The problem of slope grade for channels is complex due to the fully saturated nature of the soil profile and the hydrodynamic forces. While complex the fundamental question to ask is of, the soil type and density/state i.e. is it sandy or silty and is it loose or dense.

This is fundamental because very loose to loose granular soils exhibit significantly poorer slope performance in terms of geotechnical stability because of their contractive behaviour on small shear stresses which can lead to flow liquefaction. Flow liquefaction is where the static shear stress of the slope exceeds the liquefied shear strength and large displacements occur as a flow of soil and water.

The potential sources of shear stress causing flow liquefaction could be slope induced shear from dredging, wave or hydrodynamic forces or earthquake shaking. As discussed in Section 2.2 wave loading is unlikely to be a significant factor both with the existing and proposed channel modifications.

4.2.1 Static stability

The stability factor using the friction angle of the slope can be used to provide a relative stability factor (refer Appendix D). Using this approach a factor greater than 2 is achieved for slopes flatter than 1V:3.5H. A slip circle analysis (Appendix F) confirmed stability factors in excess for a range of possible slip circles.

4.2.2 Flow liquefaction

The liquefied strength of loose soil is such that flow liquefaction could occur on grades steeper than 1V:10H (refer Appendix E). While flow liquefaction may occur, shallower slope grades can limit the effect/consequence.

Flow liquefaction is not likely an issue for medium dense sand, with a depth normalised SPT $(N_1)_{60}$ of 15 or greater unless triggered by strong earthquake shaking as they are dilative having a greater liquefaction resistance and liquefied strength. Therefore, liquefaction risk is an issue for the looser surficial sediments.

4.2.3 Earthquake and liquefaction

The likelihood of earthquake shaking causing liquefaction was considered.

There is a risk that loose soils on the surface will liquefy because of low levels of earthquake shaking levels with a return period of less than 500 years. This is indicated in Figure C-5 by the 4No. SPT with a value less than 7.

For medium dense to dense soils liquefaction from earthquake shaking is unlikely as at least a Peak Ground Acceleration of 0.25g would be required to trigger liquefaction (for the approximate dominant earthquake rupture magnitude 5 to 6 in the northland earthquake hazard) (refer Appendix C). This level of shaking is estimated to have an Annual Exceedance Probability of 0.04% which is low. Therefore, for medium dense sand steeper slope grades shallow than 1V:3.5H are stable as the slope angles are notably less than typical soil friction angles (30 to 35 degrees).

4.2.4 Residual risk from loose soils

If slopes are cut greater than a grade of 1V:10H there is a risk of flow liquefaction in the overlying loose soils. To provide some estimate of the impact of this on sedimentation within the channel we have conservatively considered the consequence of liquefaction in this loose sand up to 1.5m thick and 2.0m thick. Calculations indicate that a grade of 1V:10H is required to limit the slope shear stress below the liquefied strength of a loose soil to limit flow liquefaction. We have assumed that when flow liquefaction occurs the loose soil portion of the slope regresses to the 1V:10H grade and the evacuated material ends up at the base of the slope on the channel edge as shown in Figure 4-1. Table 4-1 presents the resulting change in depth within the base of the channel assuming that the evacuated material is deposited with a grade of 1V:10H at the channel slope base for a range of cut slope angles. It is expected that this would provide an upper bound of potential elevation change on the base of the channel.

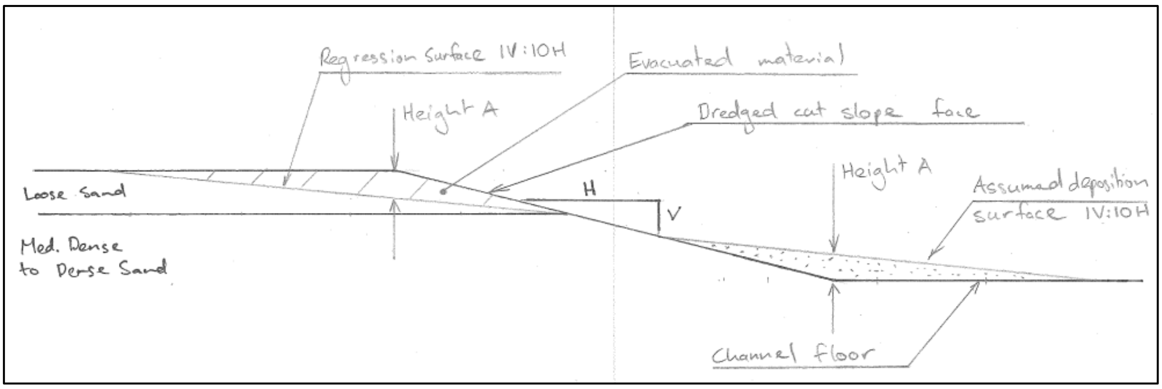


Figure 4-1 Schematic of the regression and deposition depth considerations for the residual risk of liquefaction in localised loose overlying sands

The results show that there could be local increases in depth at the edges of the channel in excess of the 0.5 m sedimentation allowance for slopes steeper than 1V:7H.

Table 4-1 Maximum depositional depth with slope liquefaction of the loose overlying sand

Dredge cut slope grade	Deposited material height effecting the channel depth for a 1.5m thickness of loose sand representing the situation in the outer channel. Height A (m)	Deposited material height effecting the channel depth for a 2.0m thickness of loose sand representing the situation at the Crude Oil Terminal Wharf. Height A (m)
1V:3.5H	1.0m	1.3m
1V:4H	0.9m	1.2m
1V:5H	0.8m	1.0m
1V:6H	0.6m	0.8m
1V:7H	0.5m	0.6m
1V:8H	0.3m	0.4m
1V:9H	0.2m	0.2m
1V:10H	0m	0m

5 Assessment

The present channel design is for sides slopes of 1V:4H with a benched slope at the berth that provides a composite slope of 1V:5.1H or an effective upper slope above the 4.2 m CD bench of 1V:7.8H.

The examination of existing natural slopes showed range from 1V:2.2H to 1V to 10:2H with an average slope of 1V:5.2H. This shows the existing slopes are stable at relatively steep angles. Micro-stability analysis shows a stability factor of 2 for slopes flatter than 1V:3.5H.

The boreholes and vibro-cores along the channel alignment indicate a layer of loose sand (up to 2.0m thick in the areas of the Crude Oil Terminal Wharf and 1.5m in the outer channel) over a profile of typically medium dense to dense sand.

We have assessed the likelihood of liquefaction using the Boulanger and Idriss (2014) liquefaction method and the Bridge Manual (NZTA, 2016) Peak Ground Acceleration values. This assessment indicates it is unlikely (less than 0.04% chance per year) that liquefaction will be triggered causing instability in the medium dense to dense soil material below 1.5m to 2.0m depth. Therefore, there is a low risk of macro stability of the slope because of liquefaction and for the medium dense to dense sand profile (SPT $(N_1)_{60}$>15) slope grades of 1V:3.5H or shallower are expected to be stable.

However, there is a possibility that the thin mantle of overlying loose soil could experience liquefaction. This could result from a low intensity of earthquake shaking or wave loading from a large tropical cyclone. It is difficult to determine the likelihood of this given the contractive and therefore sensitive nature of such soils and the additional factor of slope, however, this could be from earthquake shaking with a return period less than 500 years or a tropical cyclone with a return period of around 100 years.

The consequence of this liquefaction is likely a flow type failure of the upper layer of loose soil and to mitigate against the likelihood of flow liquefaction a slope grade of 1V:10H would be required.

The consequence of flow liquefaction of the overlying loose soils was considered and the effect on the channel depth was shown to reduce with slope grade. Figure 4-1 and Table 4-1 in Section 4.2.4

presents an assessment on the effect on channel depth and the assumptions made. Depending on the slope grade and thickness of the overlying loose sand the effect on the channel depth could vary from 1.3m to 0.5m for slope grades from 1V:3.5H to 1V:7H.

If earthquake did occur causing strong shaking (Peak Ground Acceleration of 0.1g of greater) at Marsden Point, or after a significant tropical cyclone, it would be prudent to inspect the channel before further passage by ships.

6 Information reviewed

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Drawing No. PA1028-MA-1123 Revision B, Refining New Zealand Crude Freight Project, Channel Design Option 4-2 Indicative Vibrocore Locations

Drawing No. 1028/MA/1122 Revision G, Refining New Zealand Crude Freight Project, Channel Design Option 4-2 Dredge Footprint 16.6m Draft Vessel 95% Access 1V:4H Channel Batter

Drawing No. 1028/MA/1121 Revision G, Refining New Zealand Crude Freight Project, Channel Design Option 4-2 Channel Alignment

Drawing No. PA1028-MA-2122, Revision B, Refining New Zealand Crude Freight Project, Channel Design Option 4-2 Geophysical Long Sections Channel Toe Lines, Revision B'

Raaijmakers, T. (2005). Submarine slope development of dredging trenches and channels (Final Thesis Report). TUDelft. June 2005.

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8 Appendix A: Soil Profile

Crude Oil Terminal Berth

The soil profile at the crude oil terminal berth is characterised by the information contained in the Tonkin + Taylor (1984) report, specifically:

- Section A-A on Drawing 6208-2
- Section C-C on Drawing 6208-4
- BH1, BH1A, BH2, BH2A, BH3, BH3A, BH6

Borehole 1 to 3A indicate a medium dense to dense profile of fine to medium sand with a cohesive organic clayey layer at RL 67 up to two metres thick. This clayey layer is firm to stiff.

Borehole 6 presents a loose to medium dense profile of sand to 13.5m depth. From 13.5m depth the profile is medium dense to dense.

The grade of the existing channel slope at chainage 500 is approximately 1:4 at the crude oil berth.

Channel between Marsden Point and Home Point

Vibrocores.

Outer channel between chainage 3800 to 8300

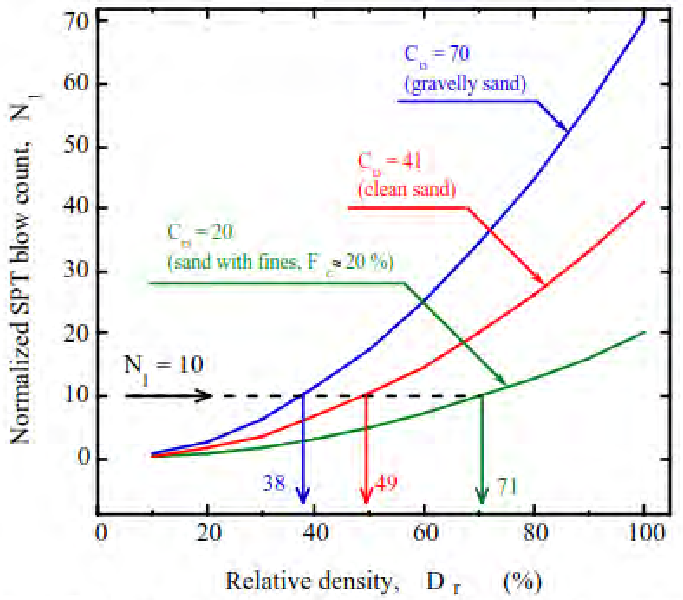
The soil profile in the outer channel is represented by information contained in the Hawthorn Geddes 2009 report, specifically:

MBH8, MBH10, MBH6, MBH2, MBH3a, MBH3b, MBH4, MBH1

These boreholes reached a limited depth of 1.35 to 3.85m.

The recovery from the boreholes was limited. The material recovered indicates fine sand to medium sand. The top 0.5 to 1.5 m was loose reaching a medium dense state below.

Vibrocores.



N_1 - D_r relationships for three sandy soils with different grain-size characteristics

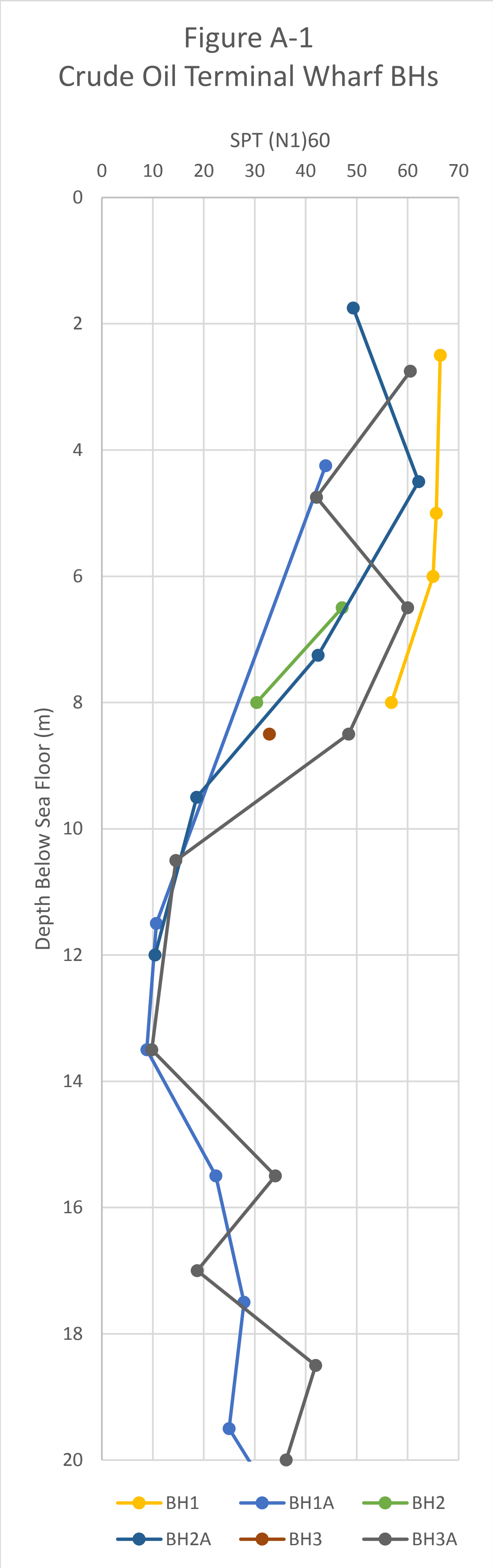


Figure A-1
Crude Oil Terminal Wharf BHs
SPT (N1)60
0 10 20 30 40 50 60 70
Depth Below Sea Floor (m)
0 2 4 6 8 10 12 14 16 18 20
BH1
BH1A
BH2
BH2A
BH3
BH3A

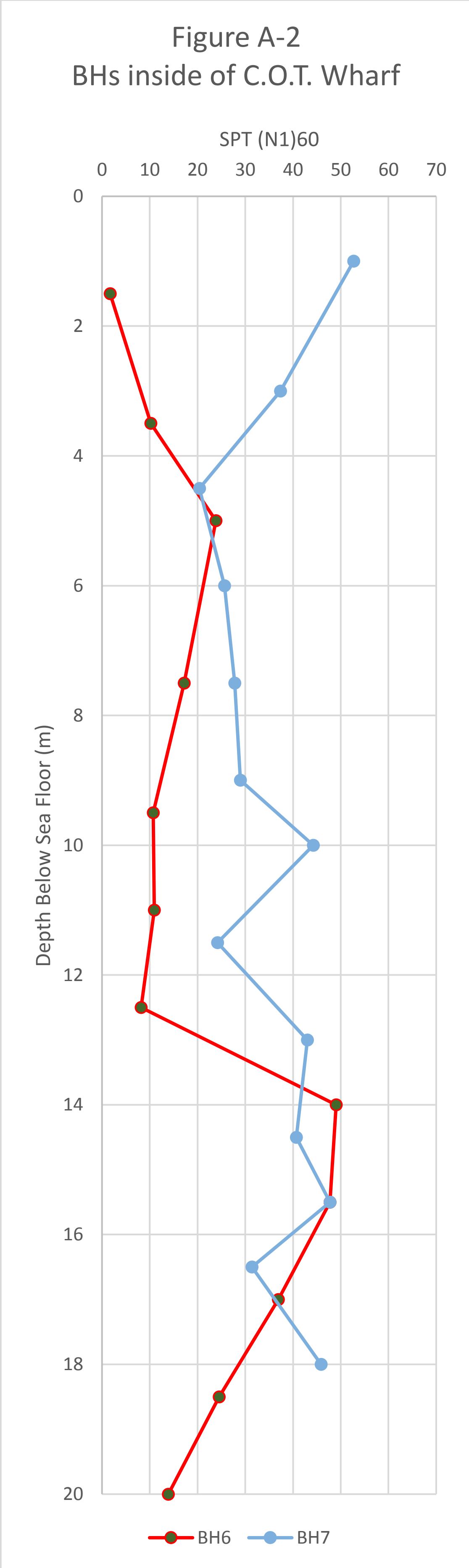


Figure A-2
BHs inside of C.O.T. Wharf
SPT (N1)60
0 10 20 30 40 50 60 70
Depth Below Sea Floor (m)
0 2 4 6 8 10 12 14 16 18 20
BH6
BH7

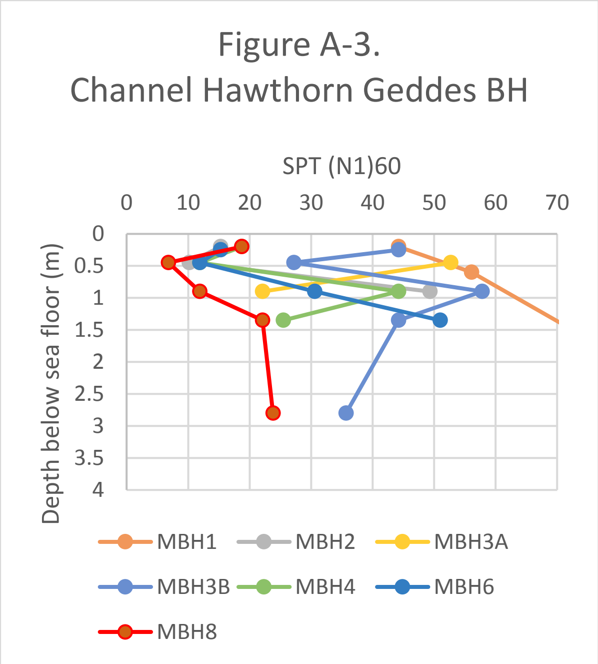


Figure A-3.
Channel Hawthorn Geddes BH
SPT (N1)60
0
10
20
30
40
50
60
70
Depth below sea floor (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
MBH1
MBH2
MBH3A
MBH3B
MBH4
MBH6
MBH8

8.1 Appendix B: Earthquake hazard

The Marsden Point Channel at the Whangarei Heads is approximately 20km from the centre of Whangarei CBD.

We have assessed the likelihood of earthquake shaking at Marsden Point using the New Zealand Transport Agency Bridge Manual (NZ Transport Agency, 2016) for a ground profile equivalent to the New Zealand Structural Design Actions (NZ Standards, 2004) Subsoil Class C. Table 1 presents the return period and annual and 100 year exceedance probability for increasing levels of shaking.

Peak Ground Acceleration Estimation[1.]	**Return Period (yrs)**	**Annual Exceedance Probability**	**Exceedance Probability in a period of 100 years**
0.07g	100	1%	63%
0.13g	500	0.2%	18%
0.17g	1000	0.1%	10%
0.24g	2500	0.04%	4%
0.40g[2.]	10000[2.]	0.01%	1%

1. NZTA Bridge Manual unweighted peak ground acceleration i.e. no magnitude weighting applied in probabilistic seismic hazard calculation. Calculation based on the Stirling et al. 2002 National Seismic Hazard Model.
2. Peak ground accelerations are only reported up to 2500 years by the NZTA Bridge Manual. We have assessed an R-value of 3.0 for 10000 year return period by fitting the Dowrick et al. 1995 equation to the R-values for 500, 1000, 2000 and 2500 years and extrapolating out the seismic hazard.

The NZ Bridge Manual provides an effective magnitude of 5.8 (for shaking return periods 50 to 2500 years) which is an approximation of the dominant mean magnitude of the earthquake ruptures in the seismic hazard model contributing to this peak ground acceleration estimation.

8.2 Appendix C: Liquefaction

We used the Boulanger and Idriss (2014) liquefaction assessment method to assess the SPT N60 with depth required for liquefaction to be triggered at 0.13 g, 0.17g and 0.24g (500, 1000 and 2500 year shaking level return period) for a magnitude 5.8 rupture.

Crude Oil

BH1, BH1A, BH2, BH2A, BH3, BH3A, BH6

BH1, BH1A, BH2, BH2A, BH3, BH3A Liquefaction is unlikely to be triggered under 0.24g magnitude 5.8.

BH6 indicates liquefaction could be triggered with 0.13g and magnitude 5.8 (500 year return period shaking).

Outer Channel

MBH1, MBH2, MBH3A, MBH3B, MBH4, MBH6, MBH8

MBH2, MBH4, MBH6 and MBH8 have SPT values in the top 1.5m that liquefy under 0.13g and magnitude 5.8 (500 year return period shaking).

Figure C-4. Crude Oil SPT Values plotted against SPT N60 value required to resist liquefaction

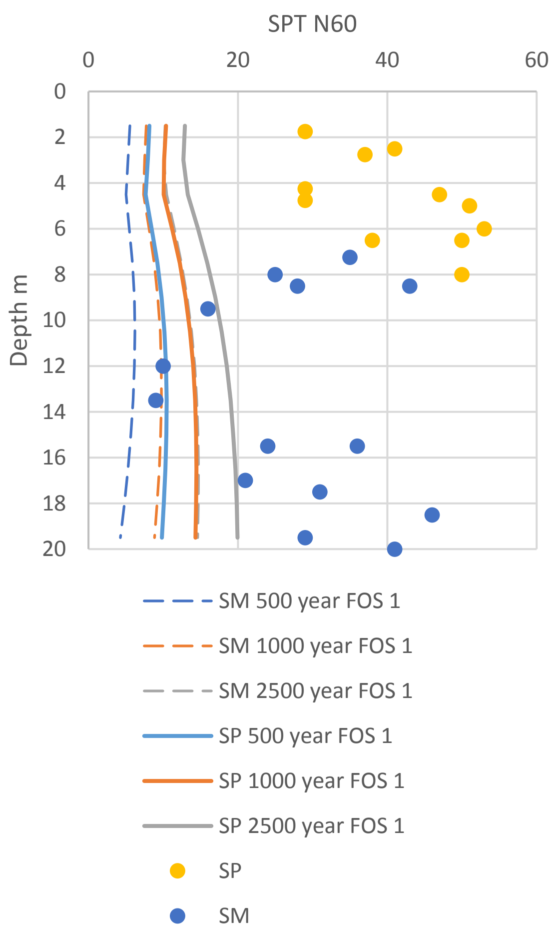
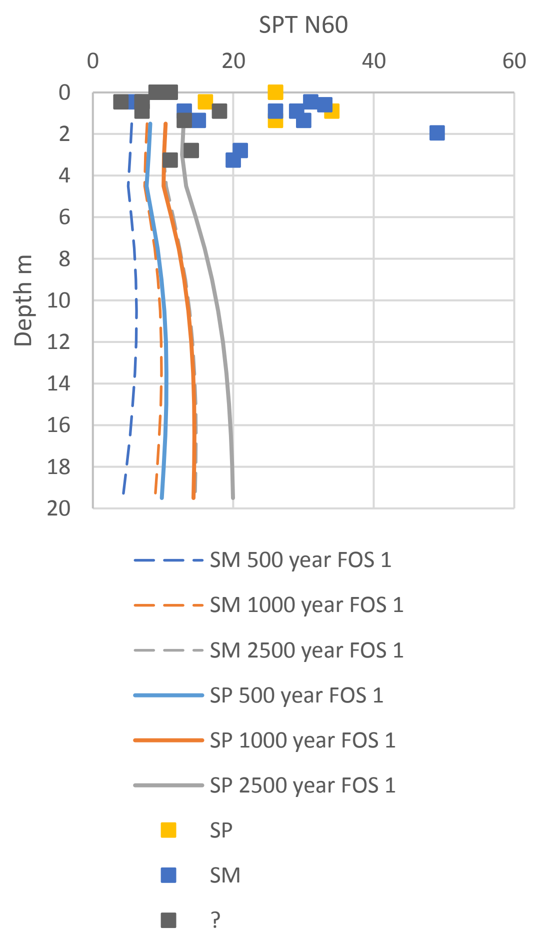
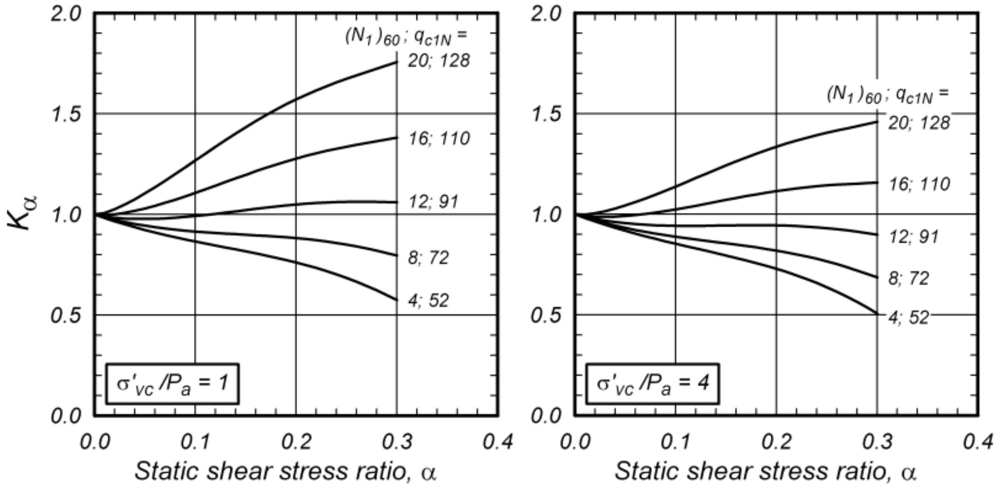


Figure C-5. Channel SPT Values plotted against SPT N60 value required to resist liquefaction



Slope shear stress factor (K alpha) for liquefaction. Indicates that for a SPT (N1)60 >15 the shear stress of the slope adds resistance. Below this slope shear stress reduces a soils resistance to liquefaction. This is a broad indication where the soil density is such that dilation in the soil occurs.



$$K_\alpha = \frac{\mathrm{CRR}_\alpha}{\mathrm{CRR}_{\alpha=0}}$$

8.3 Appendix D: Static channel slope stability

The material is sand, therefore the use of friction angle is appropriate. Micro stability governs over macro stability (Raaijmakers, 2005) for sandy soils.

Relative stability factor = $\tan \phi / \tan \beta$

Table 2. Relative micro stability factor for different slope grades

Slope Grade	Phi = 30degrees	Phi = 35degrees
1V:1.5H	0.87	1.05
1V:2.0H	1.15	1.40
1V:2.5H	1.44	1.75
1V:3.0H	1.73	2.10
1V:3.5H	2.02	2.45
1V:4.0H	2.31	2.80
1V:5.0H	2.89	3.50
1V:6.0H	3.46	4.20
1V:7.0H	4.04	4.90

8.4 Appendix E: Flow liquefaction grade calculation

Based on Olson and Stark (2002) the liquefied strength of a sandy soil in flow failures is in the range of $Su_{liq}/\sigma_v' = 0.1$ for loose soils.

The driving shear stress for a fully saturated slope under hydrostatic conditions beneath the sea is approximately $\tau = \sigma_v' * \text{Sin}(\beta)$, for low angle slopes.

Therefore, the slope angle which flow liquefaction would not occur due to lack of driving shear stress is $\beta=\text{Sin}^{-1}(0.1) = 5.7$deg.

1/Tan(5.7deg)=10 ie. 1V:10H

8.5 Appendix F: Slip circle calculations

Slip circle calculations were undertaken for two profiles to support the geotechnical stability assessment of the proposed channel dredged cut slopes, these were:

- Profile 1: Upper cut slope 5m at 1V:4H, then 30m bench, with lower cut slope 13m at 4V:1H (to consider the cut slope at CH500)
- Profile 2: 5m high slope at 1V:4H (to consider the cut slopes at CH4400 and approximate the outer channel slopes)

The soil profile for each was:

i 2m thick loose sand layer (phi = 30degrees, c=0kPa, mohr-coulomb soil model, unit weight 17.5kN/m^3). In the outer channel the loose soils were typically less than 1.5m.

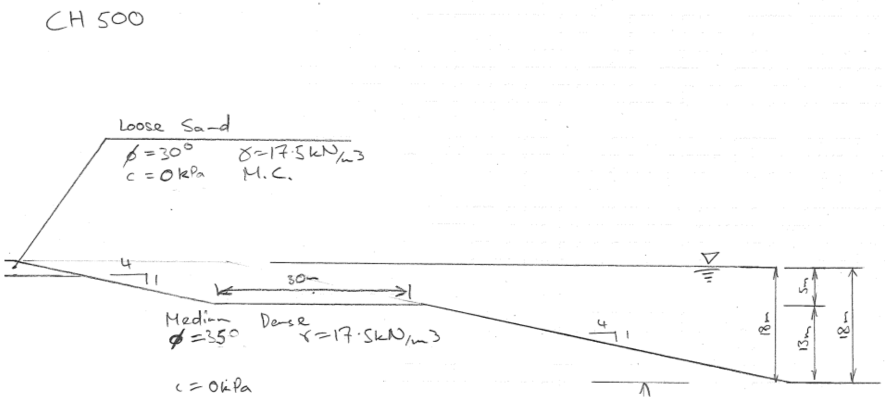
ii Base layer of medium dense sand (phi = 35degrees, c=0kPa, mohr-coulomb soil model, unit weight 17.5kN/m3)

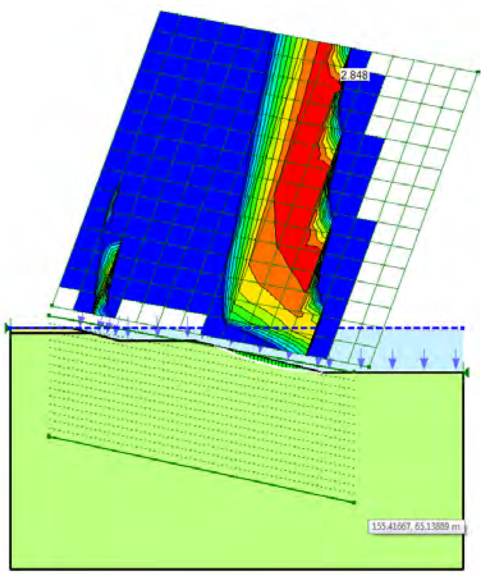
The slip circle calculations were undertaken in the software Slope/W using a limit equilibrium calculation approach. As friction materials tend to have shallow failure surfaces the calculations were undertaken for minimum slip surface depths of 1m, 5m and 10m below the slope surface to show how the Factor of Safety FOS value changes. The calculated FOS values were:

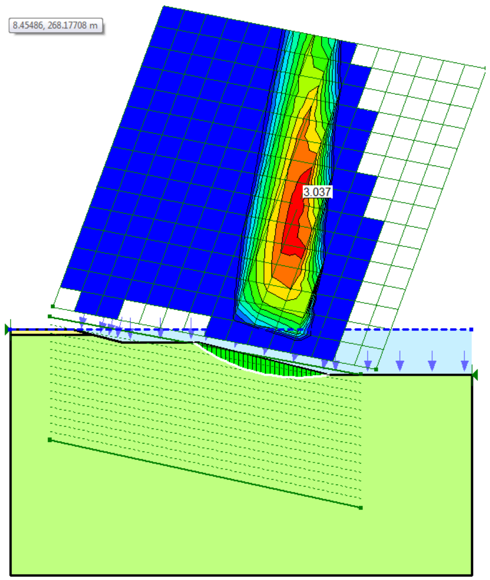
Table 8-1 Factor of safety FOS = Resisting/Driving Forces

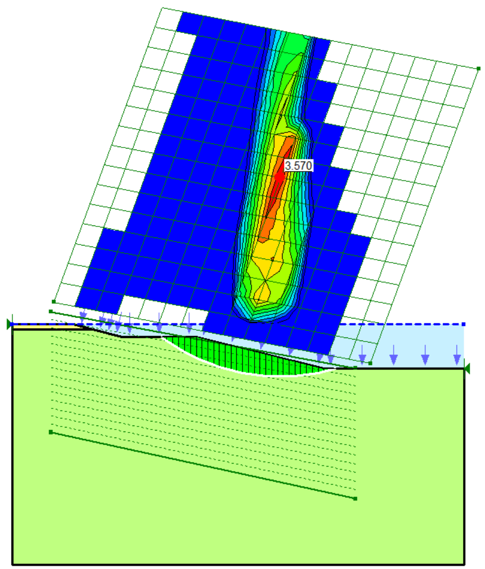
Location	**Minimum slip surface depth**		
	1m	**5m**	**10m**
Profile 1 (Ch500)	2.8	3.0	3.6
Profile 2 (Ch4400 and outer channel)	2.9	3.9	5.9

Profile 1 – Input parameters and Slope/W outputs

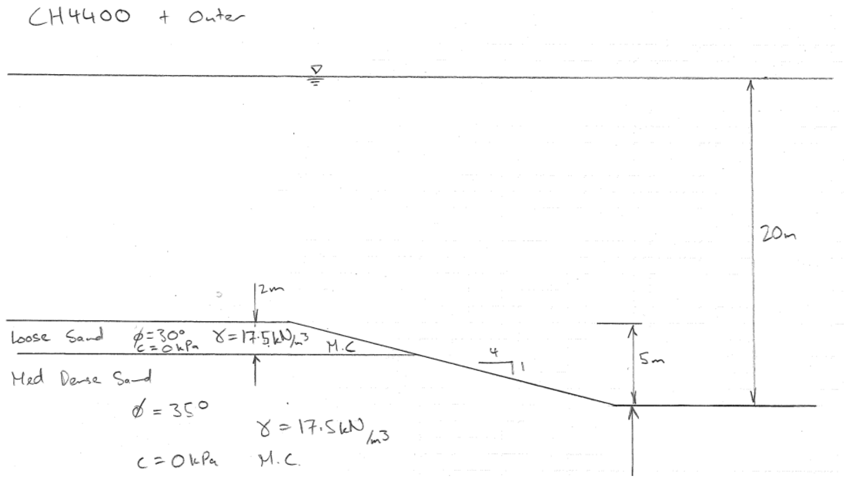


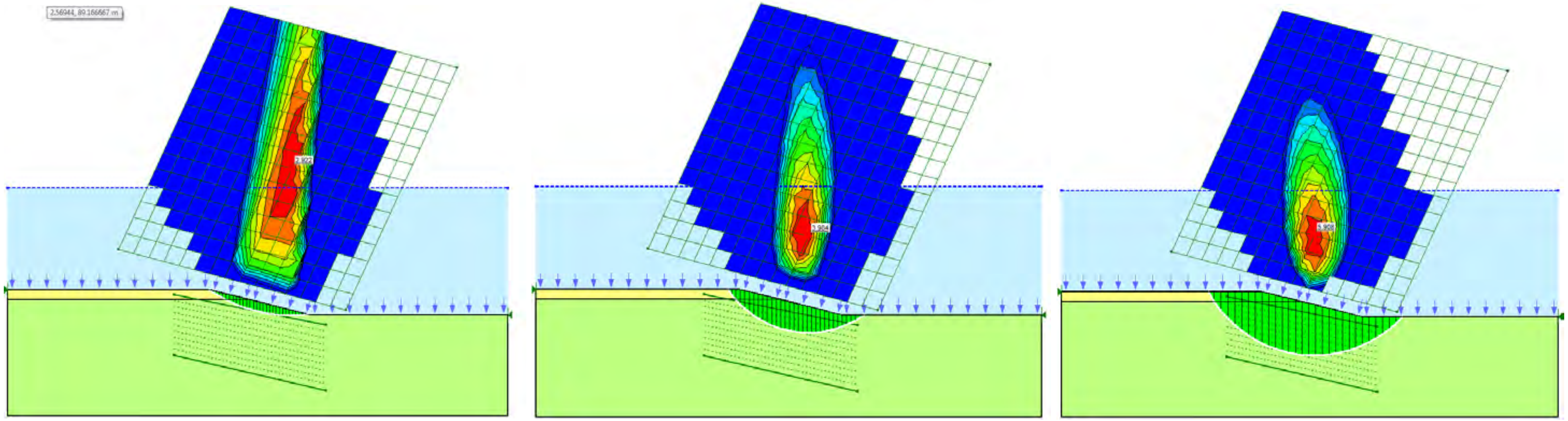






Profile 2 – Input parameters and Slope/W outputs





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Annexure Two: Technical Reports

d) **Crude Shipping Project – Coastal Processes Assessment. T & T. Richard Reinen-Hamill. Dated July 2017**

REPORT

Tonkin+Taylor

Crude Shipping Project

Coastal Processes Assessment

Prepared for

Chancery Green on behalf of Refining NZ Ltd

Prepared by

Tonkin & Taylor Ltd

Date

July 2017

Job Number

30488.CPA.v9

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Table of contents

Executive summary

Refining NZ is proposing to dredge the entrance to Whangarei Harbour to enable Suezmax ships - which currently visit the Marsden Point Refinery partially loaded - to carry greater loads while safely transiting to and from the Refinery. As part of the technical studies being carried, ChanceryGreen on behalf of Refining NZ, commissioned Tonkin + Taylor Ltd (T+T) to assess the potential effects of the proposed activities on coastal processes, including whether the proposed activities could result in increased erosion or shoreline change, and effects on the stability of the ebb delta and Mair Bank.

This assessment supports the Assessment of Environmental Effects. It is part of a suite of technical reports that assess the actual and potential effects of the applications.

Setting

Refining NZ is situated on Marsden Point at the entrance to Whangarei Harbour. Whangarei Harbour is located at the northern end of Bream Bay on the north east coast of the North Island and is a meso-tidal drowned river valley.

The harbour is relatively shallow due to extensive intertidal flats. The harbour is accessed through a relatively narrow tidal inlet which is around 680 m wide and 32 m at its deepest point. The inlet is bounded by Tertiary volcanic rocks on the northern side and a Holocene prograded sandy barrier spit on the southern side, which forms Marsden Point. Several bays indent the northern shoreline of the lower harbour, the largest of which is Parua Bay. The inlet channel separates a large ebb tide delta that extends seaward to around the 20 m depth contour. Mair Bank is situated on the northern side of the channel, largely within the intertidal and subaerial portion of the southern ebb tide delta. Snake Bank and McDonald Bank are the two main flood-tidal deltas located within the harbour inlet embayment.

The sediments within the tidal inlet largely comprise medium to fine sands with a reasonable proportion of shell and low levels of silt. The majority of sediment within the subtidal areas of Bream Bay including the deeper parts of the ebb tide shoal can be generally characterised as fine to medium sand with some shell fragments. There is an increase of silt content in deeper water. Beaches on the open coast comprise predominately fine to medium sand.

Typically the suspended sediment concentration values within the tidal channel and on Mair Bank are low (around 6 mg/L). Concentrations of up to 30 mg/L on the intertidal areas of the harbour occur during moderate to low energy conditions. Significantly higher suspended sediment concentrations within Bream Bay can occur during more energetic wave conditions.

The mean tide range is 2.3 m during spring tide and 1.5 m during neaps. Tidal current velocities gradually decrease up-harbour, from around 1 m/s (≈2 knots) at Marsden Point to 0.8 m/s (≈1.5 knots) at Limestone Island. Tidal streams are strongest in the area adjacent to Home Point southeast of Marsden Point, where rates up to 1.5 m/s (≈ 3 knots) may be experienced. The constricted tidal inlet results in currents reaching peak depth-averaged velocities of 1.1-1.3 m/s (≈2.1 to 2.3 knots) during spring tides.

The Whangarei Harbour inlet entrance emerges in a zone of low energy that provides natural stability to the inlet. Wave activity inside the harbour is mostly locally generated (fetch ~5km near Marsden Point) although some ocean swell refracts and diffracts to reach the port vicinity. The results of the numerical modelling shows the sheltering effect of Whangarei Heads and the influence of the ebb tide delta in locally reducing wave heights. Even during extreme onshore storms wave heights are generally less than 5 m offshore from the delta and reduce to less than 0.5 m at Marsden Point. Offshore average significant wave heights are typically between 0.7 and 1.0 m.

Coastal processes

An annual net littoral drift of 20,000 m^3 per annum has been estimated between Ruakaka River Inlet and Marsden Point. This is the net difference between northerly and southerly directed transport and is a relatively small value for open coast locations but is consistent with a low energy and predominantly shore normal wave direction. Based on observations of movement of the Ruakaka River entrance to the south, there is little evidence of pronounced trends of movement, either to the south or north, also suggesting a small net littoral transport rate. These low transport rates suggest that the formation of the ebb tide delta is more controlled by local wave climate effects influenced by the sheltering effect of Whangarei Heads, together with the strong tidal flows from the harbour. The ebb delta and flood tide shoals are supplied by small amounts of northerly directed alongshore transport.

Based on an average suspended sediment concentration of 6 mg/L[1] and the tidal prism, the suspended tidal flux entering and departing the harbour is approximately 360 m^3/tide. The tidal flux is an order of magnitude greater than the alongshore transport, confirming the dominance of tidal effects at the entrance to the harbour.

The analysis of historic bathymetric data over the 76 year (1939 to 2015) shows that there has been no significant change to the ebb tide delta below the 2 m depth contour. More detailed analysis of Mair Bank and the shallower part of the ebb tide delta, shows that Mair Bank has been dynamically stable, with natural fluctuations in the surface topography in the order of ± 1 m (vertical) and ± 2 m (horizontally) as banks and channels shift in response to storm events and tidal currents.

Over the last 16 years there has been more detailed survey data that has allowed greater examination of changes. Over this time there appears to have been a northerly migration of sand towards and extending into the main channel typically above the 5 m depth contour, with this change largely occurring between 2000 and 2010. Surveys from 2010 to 2016 show much smaller changes than occurred from 2000 to 2010. The northerly migration has largely resulted in accretion of the upper part of the channel slopes with some evidences of slight steepening with some erosion of the lower channel slopes.

Stability of the harbour entrance has also been attributed to the presence of shell material, which provides an armour layer protecting the underlying soft sands. This was confirmed by Healy and Black (1982) who investigated sediment transport in Marsden Point and concluded the shell lag present on much of the inlet rarely moves, even in spring tide conditions, and that much of the bed has an aged appearance with the shells being covered by algae - testimony to the stability of the sediment and the low rates of sand supply by alongshore drift. Morgan, Kench and Ford (2011) and Kerr and Associates (2016) also identify the role of shells in the long term stability of the ebb tide delta and Mair Bank.

However, sea level rise may result in increased erosion pressure on the ebb tide shoal with changes in tidal asymmetry increasing sediment transport potential into the harbour.

Proposed channel

The preferred channel alignment has evolved through the design process taking into account navigational safety, potential changes to the hydrodynamic system and environmental considerations and will provide for unrestricted design vessel access except in extreme wave climate or swell events (i.e. accessible for 98% of the time).

The proposed channel depths vary from 19.0 m below Chart Datum (CD) at the entrance to the channel, to 16.5 m below CD at the berth area with -17.9 m CD at the berth pocket. These depths

[1] based on records in the harbour entrance see Section 3.5.4

include a sedimentation allowance of 0.5 m for the mid and outer parts of the channel, 0.3 m for the inner part of the channel and 0.37 m for the berthing pocket.

Estimated disposal volume and areas of disturbance are 3,700,000 m^3 and 1.44 km^2 respectively (refer Table 2-1). This volume is around 2.2% of the total ebb tide delta volume. The main areas for dredging are the outer channel and the berth pocket. In the remaining areas only targeted dredging is required. Total footprint of proposed channel area is 3.9 km^2.

Maintenance dredging is to be expected, particularly within the first few years following the capital dredging as side slopes settle. The main areas that will require maintenance dredging is in the vicinity of the berth pocket (due to sand transported from the ebb delta over Mair Bank) and at the outer section of the channel where the majority of capital dredging has occurred.

The average annual rate of sedimentation requiring maintenance dredging is assessed to be between 56,000 and 122,000 m^3 per annum (i.e. between 1.5% and 3.4% of the capital dredge volume). These annual volumes are between 0.03% and 0.07% of the estimated volume of the ebb tide delta.

Maintenance dredging may need to occur every 2 to 5 years in the berth pocket area to maintain navigable draft around the jetty dolphins as well as at localised areas along the channel such as adjacent to Busby Head and at sections of the right hand side of the channel in the mid-section. Assuming uniform distribution of sedimentation within the outer section, the 0.5 m sedimentation allowance could be reached in the order of 5 to 20 years of the completion of the capital dredging.

Proposed marine disposal areas

Refining NZ seeks some operational flexibility in the volume of material to be disposed at specific locations. Two marine disposal areas are proposed. Area 3-2 is situated approximately 45 m below Chart Datum to the south east of the channel within Bream Bay and Area 1-2 is situated on the outer part of the ebb tide shoal. Area 1-2 is included to provide a means of maintaining a sediment transport pathway to the coast. Accordingly, it is anticipated that up to 97.5% of capital dredging is to be placed in Area 3-2, between 2.5% and 5% is placed in Area 1-2 with the option to dispose of some proportion of the dredged material to land (subject to separately obtaining any authorisations for that disposal, if required). Flexibility is also sought in respect of maintenance dredging, with the ability sought to place dredged material either within Area 3-2 or Area 1-2, or to land (again subject to separately obtaining any necessary authorisations).

In order to preserve this flexibility, Area 3-2 has been sized to accommodate all capital and maintenance dredged sediment over the period of the consent. Area 3-2 has an area of placement of 2.5 km^2 and a maximum settlement/buffer zone area of 5.75 km^2 which defines the outer boundary of where a portion of the sediment placed within the 2.5 km^2 area is expected to disperse over time.

Assuming the sediment is uniformly distributed, the average height of the placement mound as a result of the capital dredging will be approximately 1.5 m. However, it is possible that targeted disposal may occur within the larger disposal area to reduce capital disposal footprint and should that happen then a maximum placement height of not more than 4 m would result. This maximum placement height is less than 9% of the water depth.

The maximum placement height within Area 3-2 after 35 years of capital and then maintenance dredging would be no more than 4 m based on the conservative assumptions of 1) the upper rate of predicted annual sedimentation, 2) all maintenance dredging being placed in this area and 3) no settlement or loss of material from this area.

Some sediment is proposed to be placed in the nearshore location referred to as Area 1-2. Area 1-2 is a 2.5 km^2 area of seabed situated on the southern end of the ebb tidal delta in water depth of between 7 and 15 m Chart Datum. Area 1- 2 is designed to enable placed sediment which will then be slowly transported landward during higher energy wave events to maintain sediment volumes on the ebb delta and help offset effects of sea level rise. It is also sufficiently large to enable different locations to be targeted for the placement of maintenance dredging which could be done to optimise the movement of placed material based on monitoring results and desired outcomes. If the dredged sediment is placed uniformly in this area the average depth would be approximately 0.06 m and the maximum depth is likely to be in the order of 1.5 to 2.0 m. However, it is more likely that there would be a smaller area targeted within this larger area during maintenance dredge disposal, with average placement depths of around 0.6 m (i.e. covering an area of around 250,000 m^2 or 10% of the total placement area) with a similar maximum depth.

Both Areas 3-2 and 1-2 areas comprise sand of a similar composition to the channel area to be dredged. From a geomorphological perspective, it is appropriate to dispose of material in areas of similar composition (i.e. on a 'like for like' basis). Land based locations may also be used to dispose of some of the capital dredging although this will only be undertaken where there is a demand by third parties, and where they have the necessary environmental authorisations (including resource consents) in place to enable the use.

Predicted changes to hydrodynamics

Waves

The predicted change in wave height resulting from the dredged channel in average and moderate wave climate conditions are negligible (less than ± 0.02 m). This variation is an order of magnitude less than the annual variability in mean wave heights over the 35 year hindcast of 0.31 m (i.e. from 0.68 m to 0.99 m). Change to average wave heights resulting from placement of sand in the disposal areas are negligible.

For extreme storm events there is some channel refraction effect which may result in slightly higher waves breaking on the edge of Mair Bank and towards Busby Head (between 0.1 m and 0.3 m increase with waves around 5m high). Again, comparing the inter-annual variability on wave heights shown in Table 3-6, the relative change is an order of magnitude less than the annual variability of 1.36 m for the 99% wave height currently experienced. Change to storm wave heights resulting from placement of sand in the disposal areas are negligible.

Tidal currents

The effects of the dredging on currents is limited to the channel in the vicinity of the harbour entrance and the ebb tide shoal. Changes to tidal currents are negligible as there is no change to the regional scale hydrodynamics or hydrodynamics within Bream Bay, and no change to water levels within the harbour although there may be very slight changes to the timing of the tidal phase.

There is generally a very small reduction in tidal velocities as a result of the channel modifications (generally less than 0.02 m/s) except along the channel between Marsden Bank and Mair Bank, within the channel between Mair Bank and Home Point and between Home Point and Busby Head. In these areas the changes are in the order of 0.1 m/s.

The effect of the velocity changes resulting from the dredging on the sediment transport potential (as measured by changes in bed shear stress) are small. For sediments of 200 µm or coarser (medium sand) there will be very little change in sediment transport patterns following the dredging. There are small variations in bed shear stress which indicate localised areas within the channel and adjacent seabed where slight changes may occur which match the areas where tidal flows changes are in the order of 0.1 m/s. In these areas there is less than ±10% change in the percentage of time that bed shear stress exceeds the critical bed shear stress over 28 days. These modelled changes are likely to be within the natural variability of the seabed resulting from existing hydrodynamic processes and will not have any discernible change to the bathymetry of the seabed adjacent to the dredged channel.

Combined effects

Overall the changes to tidal flows and wave conditions resulting from the channel dredging and marine disposal are small and typically within the existing variability of tidal currents and wave energy. Changes to existing coastal processes are anticipated to be negligible on the open coast from Marsden Point to Ruakaka River or along the rocky coast from Home Point to Smugglers Bay, on the ebb tide shoal and Mair Bank or within the inner harbour area.

Recommended measures to remedy or mitigate effects

Mair Bank and the coastline extending southward from Marsden Point are currently experiencing change and, in recent times, some net loss of sand. This may result in increased erosion pressure on Mair Bank as well as ongoing shoreline erosion due to increased wave heights reaching the shoreline as a result of the lower seabed levels on the ebb tide shoal. The proposed dredging may add to the net loss of sand from the ebb tide shoal. Therefore, it is necessary to consider the cumulative effects of a continuous removal of sand from the ebb tide delta which may reduce the net volume of sand stored in the delta.

Placing suitable dredged sediment within the ebb tide shoal that can migrate landward is a practical means of maintaining the volume of the ebb tide shoal and enhancing a supply of sand to both the shoal and the adjacent shoreline. The proposed volume for placement in Area 1-2 are in the same order as the volume of sand removed from the active part of the ebb tide delta. This minimises the risk of potential adverse effect (in terms of ecological effect), to replace the observed loss from the active part of the delta and to protect to some degree against increase losses in the future resulting from sea level rise.

Provided some portion of sand is retained within the active ebb tide shoal system of a similar order of magnitude as the sediment to be dredged, the residual effects on coastal processes of the proposed channel dredging is expected to be less than minor.

The effects of placing sand in the marine disposal area 3-2 in terms of coastal processes are negligible. No measures are proposed for this location.

Monitoring

The principal monitoring requirement is for the long term potential change with Mair Bank, the channel and the shoreline in the vicinity of the ebb tide shoal. There is a developing data-set of historic bathymetric survey in this area and continuation of monitoring of changes in seabed and shoreline in the vicinity of Mair Bank based on the methods currently employed by Northport is the most useful form of long term monitoring. It would enable the monitoring of channel sedimentation and the requirement for maintenance dredging and the preferred location of disposal.

It is recommended that the annual monitoring of bathymetry of the ebb tide shoal and channel be proposed as shown on Figure 1-1. Pre and post dredging surveys should also be undertaken to augment this data set and information of the volumes and locations of deposition of both the capital and maintenance dredging recorded.

1 Introduction

1.1 Background

Refining NZ is proposing to dredge the entrance to Whangarei Harbour to enable Suezmax ships - which currently visit the Marsden Point Refinery partially loaded - to carry greater loads while safely transiting to and from the Refinery. As part of the technical studies being carried, ChanceryGreen on behalf of Refining NZ, commissioned Tonkin & Taylor Ltd (T+T) to assess the potential effects of the proposed activities on the physical coastal processes, including whether the proposed activities could result in increased erosion or shoreline change, and effects on the stability of the ebb delta and Mair Bank.

The assessment will support the Assessment of Effects on the Environment. It is part of a suite of technical reports that investigate the potential effects.

This report makes use of the geotechnical field investigation reports (RHDHV, 2015 and T+T, 2016) and the hydrodynamic modelling reports (MSL, 2016a, b) to inform the assessment of effects on coastal processes.

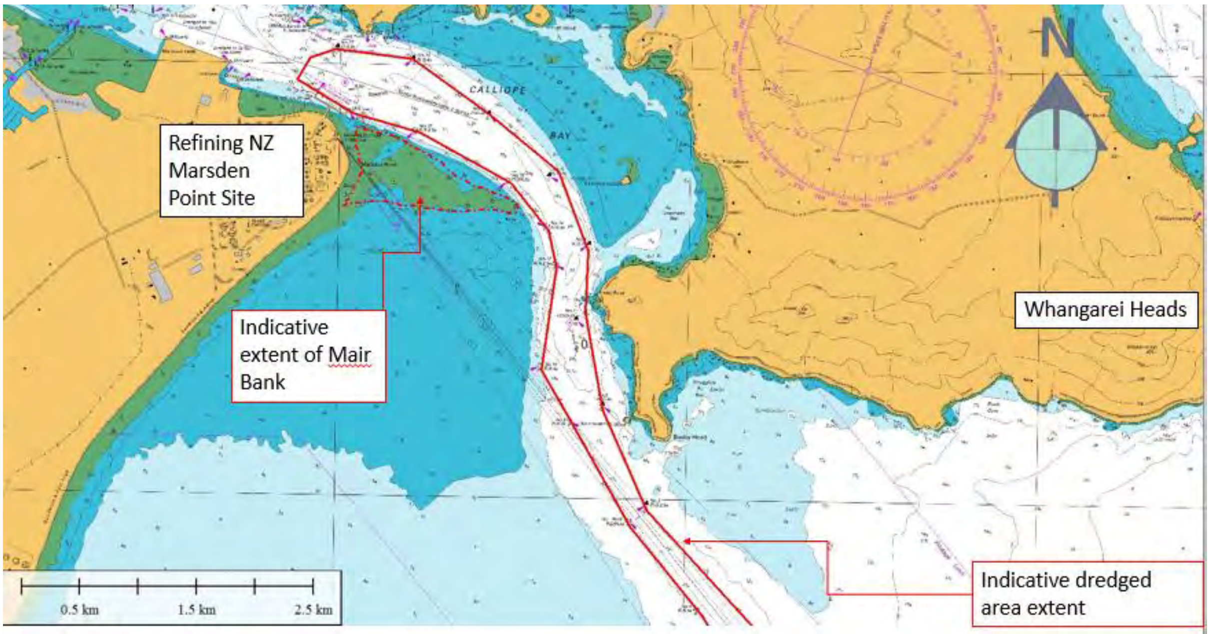


Figure 1-1: LINZ Hydrographic Charts (NZ 5214) showing the channel boundaries and indicative dredging area as well as the indicative extent of Mair Bank extending above Chart Datum contour (green area) and Ebb Tide Shoal (dark blue area)

1.2 Report layout

Section 2 sets out the proposed project and the physical setting of the harbour entrance and the northern part of Bream Bay is described in Section 3 followed by a description of the existing coastal processes in this area in Section 4. Section 5 sets out the predicted changes in physical processes based on field investigations and numerical model studies. Section 6 includes the assessment of effects of the changes and Section 7 sets out the proposed methods to avoid, reduce and mitigate effects. Proposed monitoring conditions are included in Section 8.

1.3 Datums and coordinates

All levels within this report are presented in terms of One Tree Point Vertical Datum 1964 (OTP64 or Reduced Level). Coordinates are presented in terms of New Zealand Transverse Mercator (NZTM).

2 Description of the proposal

Crude shipments to site are currently brought to site via smaller fully loaded Aframax ships and larger partially loaded "Suezmax" ships. Suezmax ships are partially loaded in order to clear the shallower parts of the tidal inlet. Refining NZ are looking to increase the amount loaded to reduce shipping costs.

A comprehensive range of high level studies and investigations have been carried out to better understand and characterise the existing environment and to identify possible dredge and disposal options. This was followed by more detailed studies, investigations and analysis to refine understanding of how these options would affect the environment and to develop more preferred options.

After consideration of tide and wave conditions, navigation safety and manoeuvrability for a range of possible channel configuration alternatives, three channel options that provided safe all tide and 98% of wave condition access were shortlisted for more detailed assessment. Following that detailed assessment, the preferred option both in terms of navigation safety and overall environmental effects is Option 4-2. This option limits the majority of dredging to the outer reaches seaward of Home Point, with targeted dredging at selected areas in the mid and upper parts of the channel and at the berth. The estimated upper bound capital dredge volume and areas of disturbance are 3,700,000 m^3 and 1.44 km^2 respectively with around 1.5 to 3.4% of this volume (around 56,000 to 122,000 m^3) required to be dredged annually to maintain the channel.

A comprehensive exercise was also used to evaluate potential marine areas to place the dredged sediments. A range of adjacent and distant deep-water (greater than 60 m water depth), intermediate water depth (30 to 60 m) and shallower water depth disposal areas were considered together with land based disposal options. Two marine disposal options are preferred, being a site at around 45 m water depth (Area 3-2), and the placement of sediment on the ebb delta (Area 1-2) in water depth of between 7 and 15 m below Chart Datum. Land based disposal is also supported by the analysis undertaken and while Refining NZ is not proposing any land-based disposal as part of its resource consent application, it is investigating options for land-based disposal including beach nourishment.

2.1 Channel alignment

The preferred channel alignment has evolved through the design process taking into account navigational safety, potential changes to the hydrodynamic system and environmental considerations and provision of unrestricted design vessel access except in extreme wave climate or swell events (i.e. accessible for 98% of the time).

The key characteristics of the channel are:

- Alignment – the existing route is simplified from 5 to 3 main headings reducing the number of bends to navigate and increasing the distance between changes as well as moving slightly away from Home Point (refer Drawing 01).
- Widths (excluding batter slopes) – base channel widths have been developed using PIANC guidelines (RHDHV, 2016) and vary from 210 m to 280 m, with the channels widening at the bends in the channel.
- Depths – the depths vary from 19.0 m below Chart Datum (CD) at the entrance to the channel to 16.5 m below CD at the berth area (refer Figure 2-1). These depths include a sedimentation allowance of 0.5 m for the mid and outer parts of the channel, 0.3 m for the inner part of the channel and 0.37 m for the berthing pocket.
- Side slopes – Trimming the sides of the channel to 1V:4H for all channel slopes.

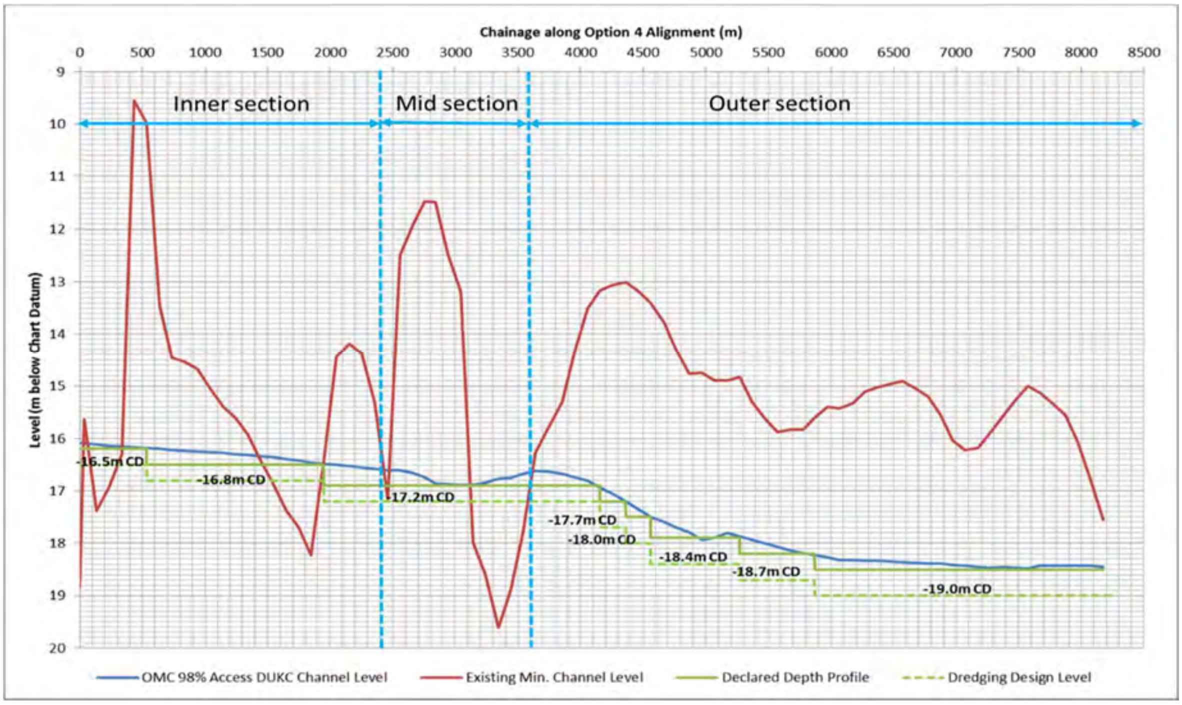


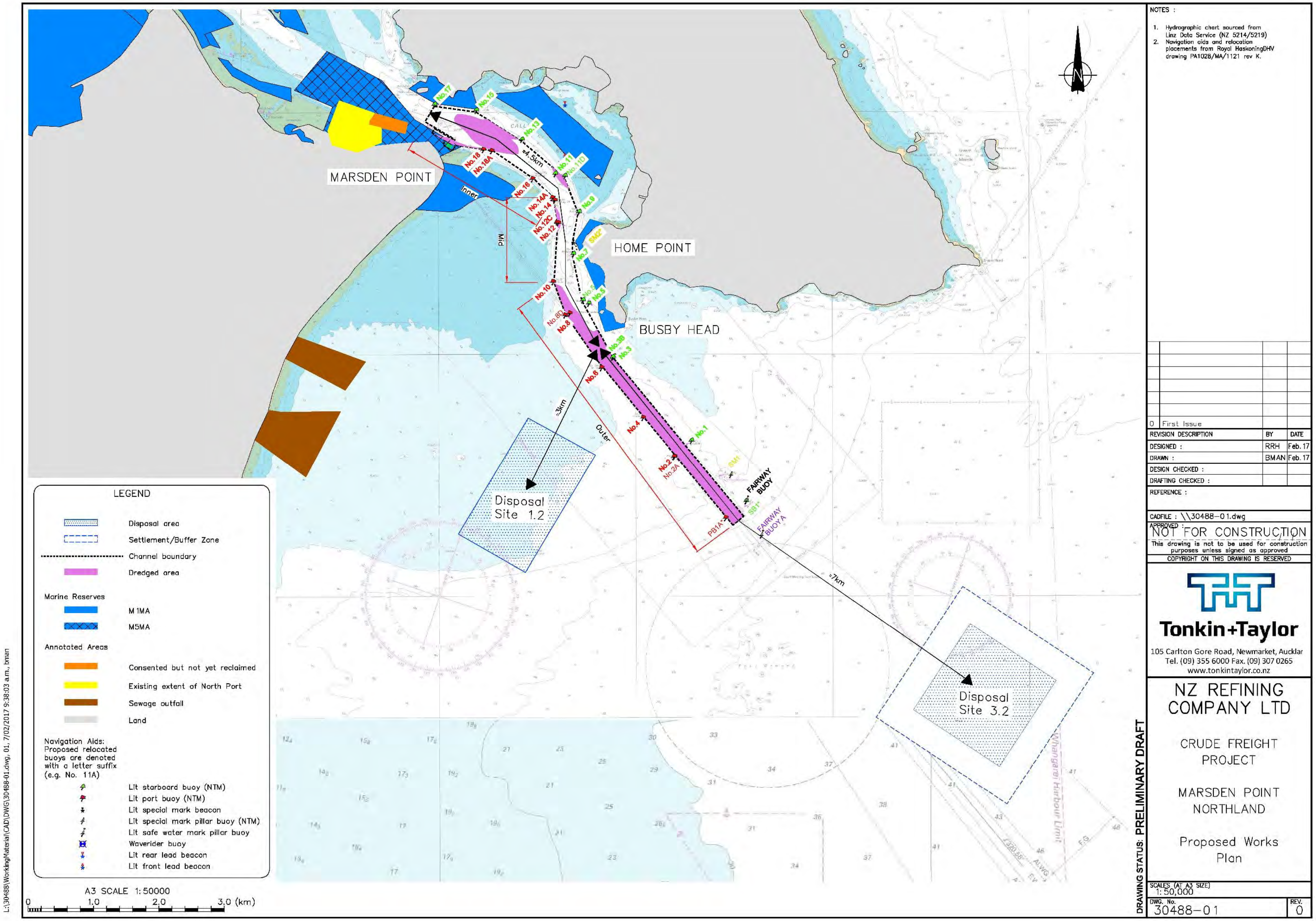
Figure 2-1: Channel design depths for Option 4-2 (Source: RHDHV, 2016)

2.2 Capital dredging requirements

Based on the channel alignment and section shown in Drawing 01 and Figure 2-1 the estimated disposal volume and areas of disturbance (3,620,200 cubic metres (m^3) rounded up to 3,700,000 m^3 and 1.44 square kilometres (km^2) respectively, refer Table 2-1). This volume represents 2.2% of the ebb tide delta volume with around 150,000 m^3 dredged above the 10 m depth contour (0.1% of the total ebb tide delta volume) and 3,470,200 m^3 dredged below the 10 m depth contour (2.1% of the total ebb tide delta volume), with the majority of this below the 15 m Depth Contour. The main areas for dredging are the outer channel (from around chainage 3,500m to 8,500 m, refer Figure 2-1) and the berth pocket adjacent to the Jetty. In the remaining areas of the channel (inner and mid-section as shown in Figure 2-1) only targeted dredging is required.

Table 2-1: Estimated volumes and area of disturbance within dredged area including over-dredge allowance

Channel area	Volume (m^3)	Area of disturbance (km^2)
Inner section (including berth pocket)	593,900	0.5
Mid section	57,200	0.02
Outer section	2,969,100	1.02
Total	3,620,200	1.44



Proposed Works Plan

2.3 Maintenance dredging

Maintenance dredging is to be expected to be necessary, particularly within the first few years following the capital dredging as side slopes settle. The main areas where maintenance dredging will be undertaken is in the berth pocket area due to sand transported from the ebb delta over Mair Bank, and at the outer section of the channel where the majority of capital dredging has occurred.

In the outer channel, average annual sedimentation rates are predicted to be within the range of 42,000 to 92,000 m^3 (rounded to 50,000 to 100,000 m^3) per annum and could be distributed reasonably evenly along the channel (MSL, 2016b). In the berth pocket the volume of sedimentation to manage is based on sand transported over Mair Bank from the southern part of the ebb tide delta and from sediment transport deposition along the tidal channel due to slight reductions in tidal flows at certain locations. It is expected that the volumes will be approximately 8,000 to 15,000 m^3 per annum along the entire bank between Profile 1 and 19 (refer Figure 4-15), and between 3,000 to 6,000 m^3 per annum within the berth pocket and dolphin area. Therefore, the average annual rate of sedimentation for the entire project area is assessed to be between 56,000 and 122,000 m^3 per annum (i.e. between 1.5% and 3.4% of the capital dredge volume). These annual volumes are between 0.03% and 0.07% of the estimated volume of the ebb tide delta.

Over the maximum duration of the expected consent (35 years), the volume of material required to be dredged is between 1,960,000 and 4,270,000 m^3, representing some 1.2 to 2.5% of the current ebb tide delta volume.

Maintenance dredging may need to occur every 2 to 5 years in the berth pocket area to maintain navigable draft around the jetty dolphins as well as at localised areas along the channel such as adjacent to Busby Head and at sections of the right hand side of the channel in the mid-section in the vicinity of Profile 19 (refer Figure 4-15). Assuming uniform distribution of sedimentation within the outer section, the 0.5 m sedimentation allowance could be reached in the order of 5 to 20 years of the completion of the capital dredging.

2.4 Marine disposal areas

Marine disposal areas are shown on Drawing 30488-01. Flexibility in the volume of material to be disposed at specific locations is sought in this application. It is anticipated that up to 97.5% of capital dredging is to be placed in Area 3-2, between 2.5% and 5% is placed in Area 1-2 with some dredging disposed of to land. Maintenance dredging may be placed in either Area 3-2, Area 1-2 or to land, depending on the requirements and results on monitoring.

Area 3-2 has been conservatively sized to provide for 100% of all capital and maintenance dredging in order to provide the maximum potential occupancy of the coastal marine area for the assessment of effects. The area of placement in Area 3-2, is 2.5 km^2, although a maximum area of 5.75 km^2 which defines the outer boundary of where placed sediment may settle over time. Area 3-2 is situated 45 m below Chart Datum to the south east of the channel.

If the sediment is uniformly distributed, the average height of the placement mound after the capital dredging has occurred will be approximately 1.5 m. However, it is possible that targeted disposal could occur within the larger disposal area resulting in maximum placement heights for both capital and maintenance dredging of not more than 4 m. That equates to less than 9% of the water depth.

The maximum height is conservative and based on the following assumptions:

- the upper rate of predicted annual sedimentation;
- all maintenance dredging being placed in this area; and
- no settlement or loss of material from this area occurs over time.

Some sediment (2.5 to 5%) is proposed to be placed in the nearshore known as Area 1-2. Area 1-2 is a 2.5 km^2 area of seabed situated on the southern end of the ebb tidal delta in water depth of between 7 and 15 m Chart Datum. Area 1- 2 is designed to enable placed sediment to be slowly transported landward during higher energy wave events to maintain sediment volumes on the ebb delta. It is also sufficiently large to enable different locations to be targeted for the placement of maintenance dredging. If the dredged sediment is placed uniformly in this area the average depth would be around 0.06 m. However, it is more likely that there would be a smaller area targeted within this larger area during each dredge campaign, with average placement depths of around 0.6 m (i.e. covering an area of around 250,000 m^2 or 10% of the total placement area).

Both marine disposal areas comprise sand of a similar composition to the channel area to be dredged. Land based locations may also be used to dispose of some of the capital dredging although this will only be undertaken where there is a demand by others, and they have the necessary environmental authorisations (including resource consents) in place to enable the use.

3 Physical setting

3.1 Location

Refining NZ is situated on Marsden Point at the entrance to Whangarei Harbour. Whangarei Harbour, located at the northern end of Bream Bay on the north east coast of the North Island, is a meso-tidal 98 km^2 drowned river valley with a spring tide prism[2] of around 155 x 10^6 m^3 (Hume and Herdendorf, 1988). The harbour is relatively shallow (mean high-tide depth of 4.4m) due to extensive intertidal flats, particularly in the lower harbour which accounts for 58% of the high tide area (Swales et al, 2013). The harbour is typically unstratified and has minimal inputs of fresh water (Inglis et al., 2006). The Hātea River is the main source of fresh water to the harbour, with a mean annual flow of 1 m^3 s^{-1}. The Waiarohia and Raumahanga streams have mean annual flows of 0.35 m^3 s^{-1} and 0.34 m^3 s^{-1}, respectively (Reeve et al., 2010). During summer, most of the harbour is well mixed, while in winter the lower harbour remains well mixed.

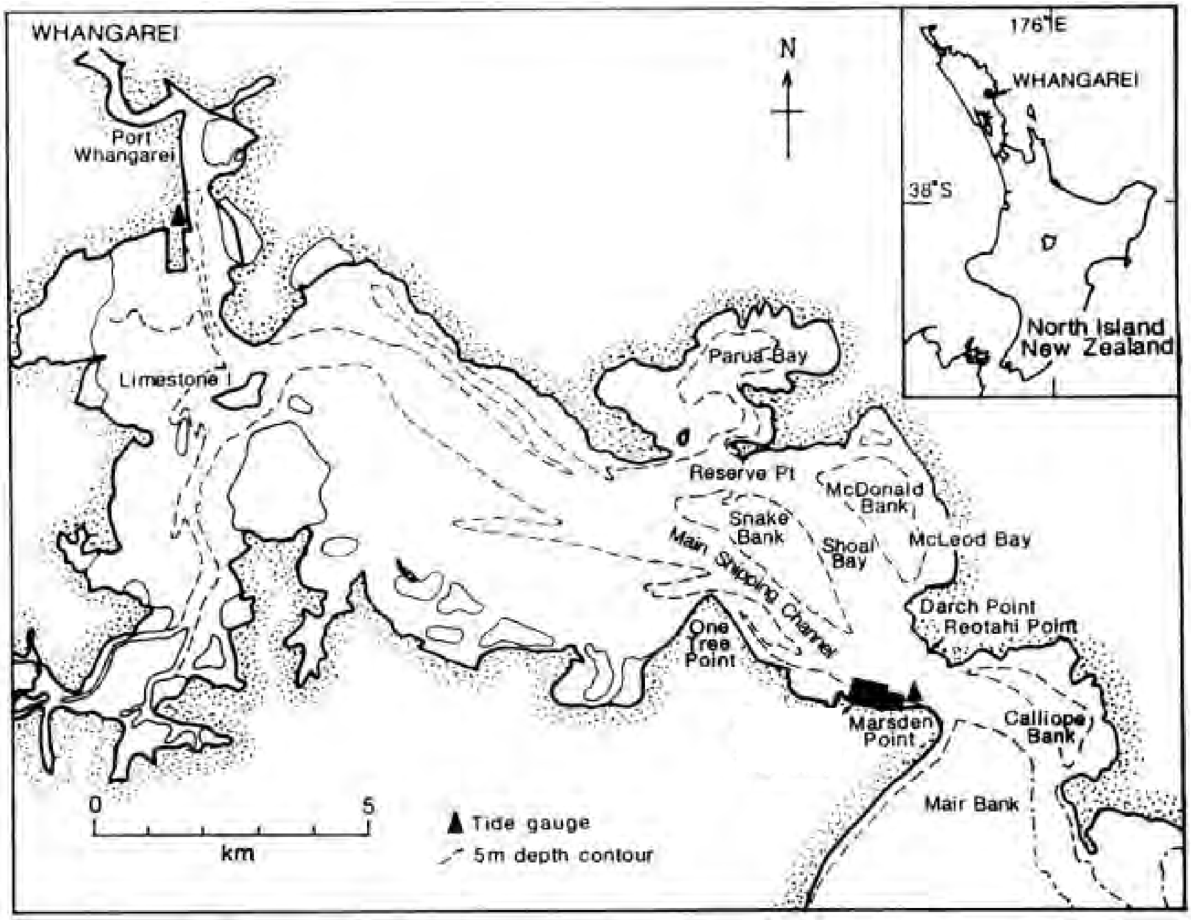


Figure 3-1: Location of shoals and banks adjacent to Marsden Point (Source: Black et al, 1989)

The harbour is accessed through a relatively narrow tidal inlet which is around 790 m wide and 32 m at its deepest point. The inlet is bounded by Tertiary volcanic rocks on the northern side and a Holocene prograded sandy barrier spit on the southern side, which forms Marsden Point (Longdill and Healy, 2007). Several bays indent the northern shoreline of the lower harbour, the largest of which is Parua Bay Figure 3-1. The inlet channel separates a large ebb tide delta that extends seaward to around the 20 m depth contour (refer Figure 1-1). Mair Bank, situated largely within the intertidal and subaerial portion of the southern ebb tide delta, extends to the east of Marsden Point

[2] Tidal prism is the volume of water between low and high spring tides.

and Calliope Bank is situated on the northern side of the channel. Snake Bank and McDonald Bank are the two main flood-tidal deltas located within the harbour inlet embayment (Morgan et al., 2011).

The harbour shoreline to One Tree Point is a sandy beach system backed by weakly consolidated cliffs. The sandy beach comprises fine sand fronted by intertidal flats which range in width between 30 m and 200 m out to the entrance channel.

The open coast section has a sandy beach comprising fine sand. The beach has a narrow dry beach with a width of approximately 5 m above the high tide line. The dune system has a crest elevation of between RL 5 to 13 m, increasing towards the north. The dune face is generally over steep with recent erosion scarps, particularly at the northern end of the shoreline. Dune vegetation exists along the dune crest (spinifex).

Figure 3-2: Beach and dune system at Marsden Point

3.2 Geology

GNS Science geological maps reveal a very variable geological nature (displayed on Figure 3-3). According to Allen, Whangarei Harbour has experienced relatively recent submergence followed by considerable infilling. Other work indicate that the Harbour may technically be termed an estuarine lagoon, however a number of tectonic movements may have contributed to the harbour's formation. These include a combination of tectonic activity, ancient block faulting, the formation of a drowned river valley and the existence of a barrier enclosing the mouth of the former valley.

The oldest rocks in the Marsden Point area are Palaeozoic greywackes and argillite of the Waipapa Group. These rocks outcrop north, south and southwest of the harbour and constitute the basement to Quaternary costal and estuarine sediments at the site. Although Tertiary sandstones, mudstones and limestone overlie basal Waipapa Group rocks and outcrop west of Ruakaka and at Mangawhai Point, these rocks are discontinuous and are not encountered in the Marsden Point Area.

Andesitic agglomerate, lava and dikes and small areas of andesitic tuffs, cones and lava outcrop with Tertiary mudstones and together comprise the Whangarei Heads, directly across the Whangarei Harbour (NE) from the site.

The low lying Marsden Point area comprises Quaternary aged older foredunes higher terrace deposits and undifferentiated sands with rare peaty areas, collectively described as alluvium.

The site is located between two parallel inferred faults orientated northwest-southeast. To the west, a fault in part concealed beneath recent alluvial materials extends along the Ruakaka River Valley and the Otaika Stream. The second fault, immediately north of the site is inferred to have resulted in the present harbour alignment. Neither fault is considered to be active.

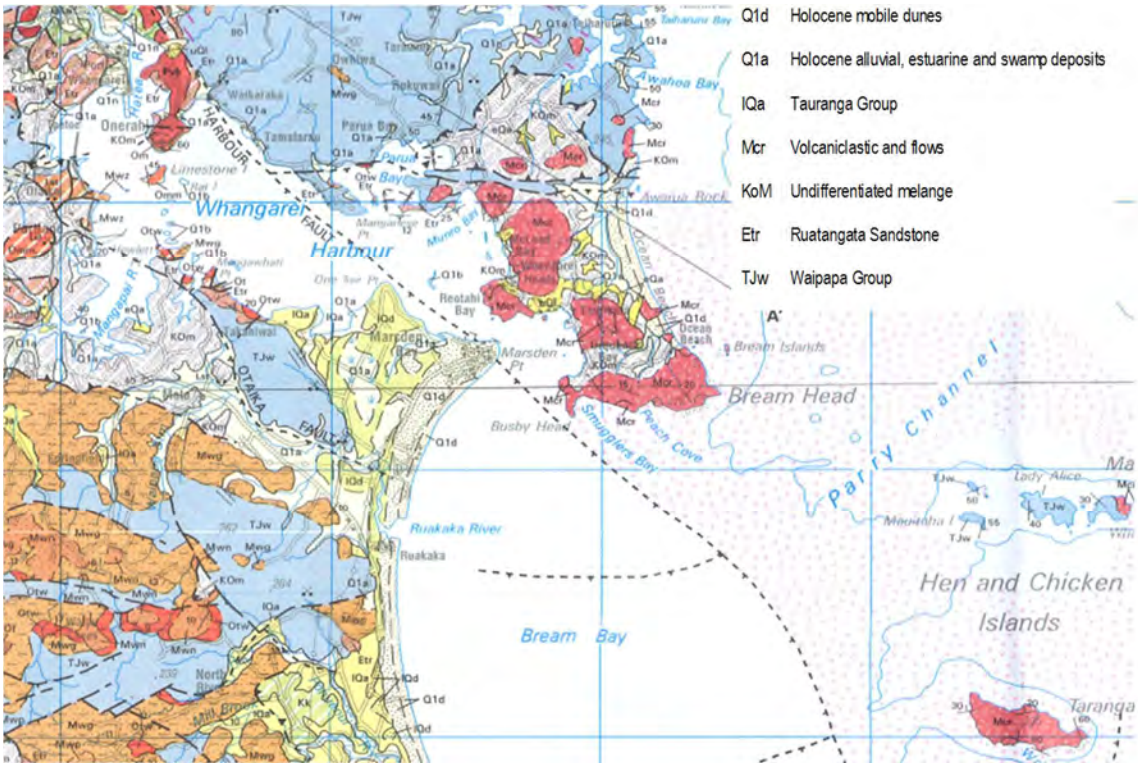


Figure 3-3: Geological Map, known faults are represented by solid and dashed lines (source: GNS 1:1,000,000 Geological Units)

3.3 Bathymetry

Historic and current hydrographic charts of the harbour and approaches to Marsden Point that show the wider coastal context are displayed in Appendix A and summarised in Table 3-1. A more detailed assessment of bathymetry is included in MSL (2016b). There are frequent surveys of the fairway, approaches terminal and shoal areas that have been carried out to confirm the lowest depths. There have also been regular surveys of Mair Bank, situated on the intertidal and subaerial part of the ebb tide delta, that were commissioned by Northland Regional Council.

Table 3-1: Summary of bathymetric survey information

Information type	Survey date
Bathymetric chart	1848
Bathymetric Chart	1849
Fairsheet	1939

Information type	Survey date
Fairsheet	1959
Chart NZ 5213 (1970)	First published 1964 with updates in 1966 and 1970
Fairsheet	1981
NZ5214 (2004)	Main channel and port area to One Tree Point 2011. Ebb tide area 1981, Nearshore area around Ruakaka 1961, Nearshore area around point 2003.
Channel surveys to confirm least depth in the fairway, approaches, terminal and shoal area	2004 to 2009 at approx. 6 monthly intervals (Feb 04, Aug 05, Apr 06, Dec 06, Aug 07, Nar 08, Sep 08, Mar 09, Oct 09) 2010 to 2014 annual (Mar 10, Mar 11, Mar 12, Apr 13, Mar 14).
Surveys of Mair Bank, the ebb tide delta and edges of inlet channel	Annual surveys from 2000 to 2016

The first hydrographic survey of the Whangarei Harbour is dated 1848 (R B Graham) and illustrated the Mair and the Calliope banks although the names of the banks subsequently changed. In 1849, Captain Stokes completed another hydrographic survey and named the Mair and Calliope Banks, and the broader ebb tide delta system. He also identified the Snake and the MacDonald Banks and the main channel.

In 1964 the channel between One Tree point and the Snake Bank was shown as being 8 fathoms deep (approximately 14 m). It remained 14 m deep in 1974, while in 2004 the hydrographic chart shows it being 17 m deep. Further dredging modifications and reclamations have taken place at North Port in the early 2000's.

An assessment of the stability of the ebb tide delta has been made by comparing the 5 m, 10 m and 15 m depth contours from 1939 to 2015 (refer Figure 3-4 and Figure 3-5). These results show that the ebb tide delta has changes little over the 79 year period.

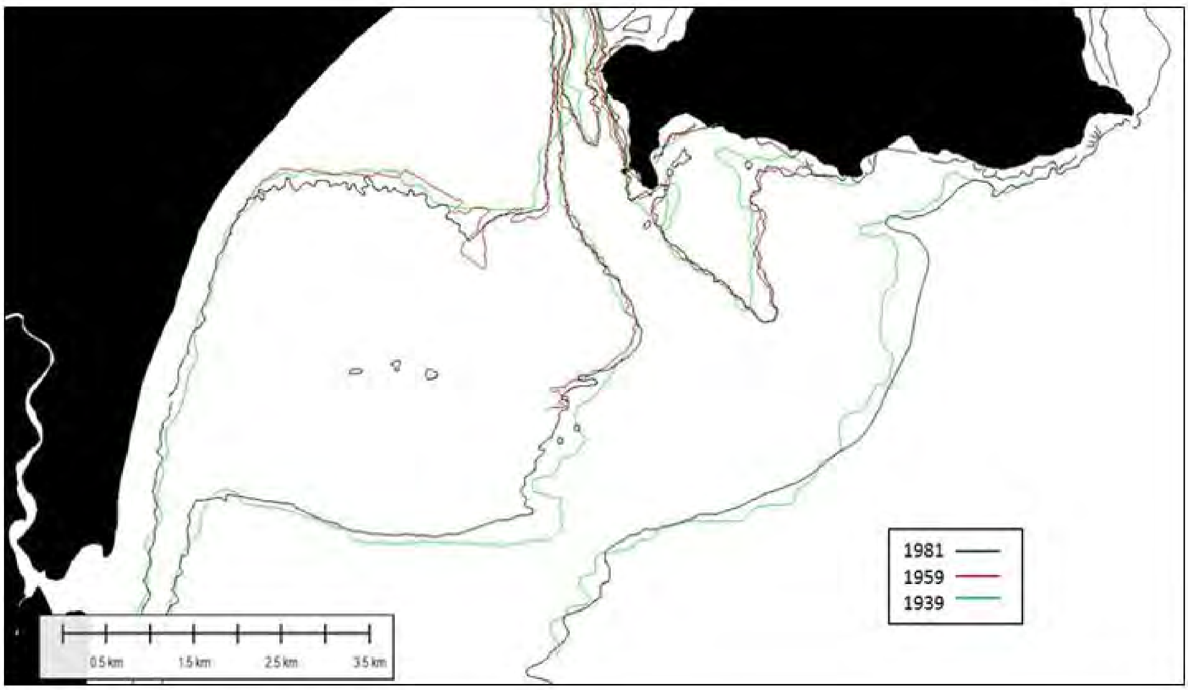


Figure 3-4: Historic changes at the 5 m, 10 m and 15 m depth contours from 1939 to 1981

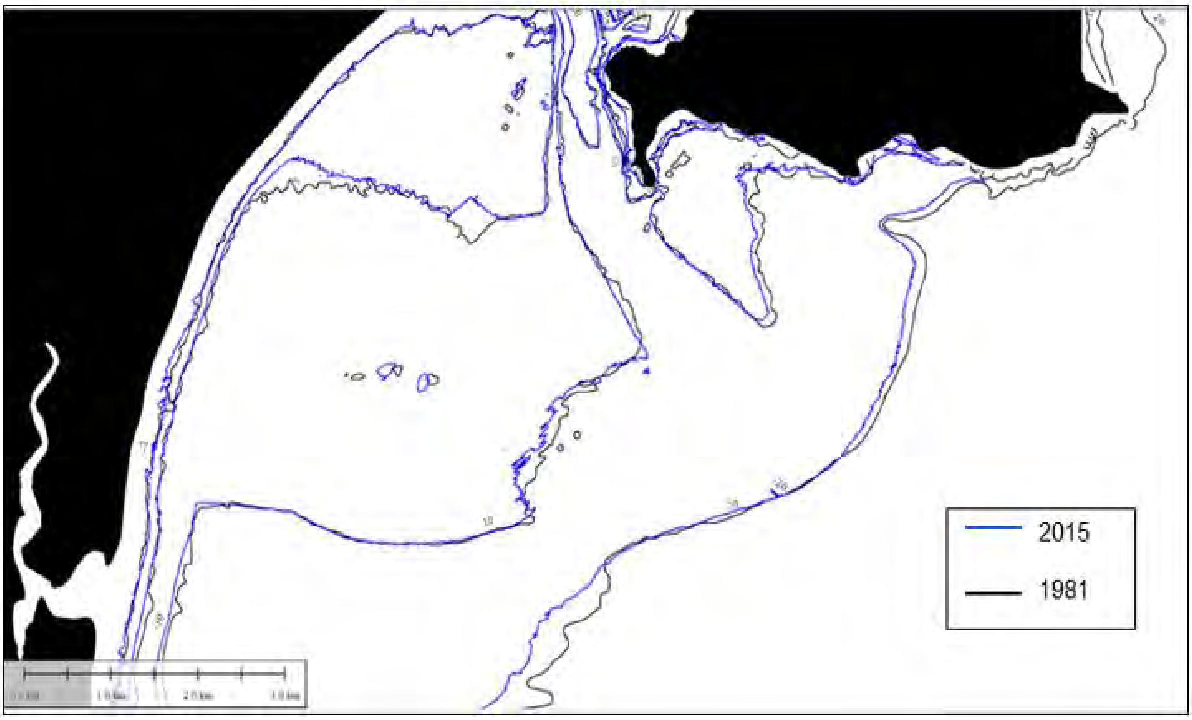


Figure 3-5: Historic changes at the 5 m, 10 m and 15 m depth contours from 1981 to 2015

3.4 Historical shoreline change

Historic shoreline change has been investigated in the vicinity of the entrance to Whangarei Harbour using information from data sources from previous investigations and observations and judgement from the project team.

A selection of historic aerial and satellite images are included in Appendix B that show shoreline and development changes from 1942 to 2014. Oblique satellite images have been prepared showing 2014 shoreline to enable comparison with Whites Aviation photographs from 1962.

Figure B 1 (Appendix B) shows an aerial photograph of Marsden Point prior to any significant development. It is likely that during this time some of the backshore area was used for grazing. A sediment transport pathway can be seen moving northward along the coast and turning into the harbour. The higher elevations of Mair Bank are also visible. The variability of the shoreline movement at Marsden Bank and Mair Bank is evident in the early photographs prior to development at the point (e.g. Figure B 2 and Figure B 5). The development at Marsden Point and the shoreline towards the Ruakaka River mouth can be seen from Figure B 7. The migration of sand along the point into the harbour in recent years (e.g. Figure B 14) appears similar to transport processes that occurred earlier (e.g. Figure B 2). Based on the aerial photographs and satellite images, the developments at Marsden Point and Northport do not seem to have changed the large scale coastal processes operating at Marsden Point.

3.4.1 Marsden Point

Shoreline changes around Marsden Point have been obtained by analysis of aerial photographs and GPS shoreline analysis. Figure 3-6 shows shoreline changes from 1985 to 2009 with a 1975 aerial photograph as a base that represents the observed changes that have occurred over the last four decades. These changes include erosion of the shoreline along the open coast to the south of Mair Bank, some local accretion in the vicinity of Mair bank and slight erosion between Mair Bank and the Jetty.

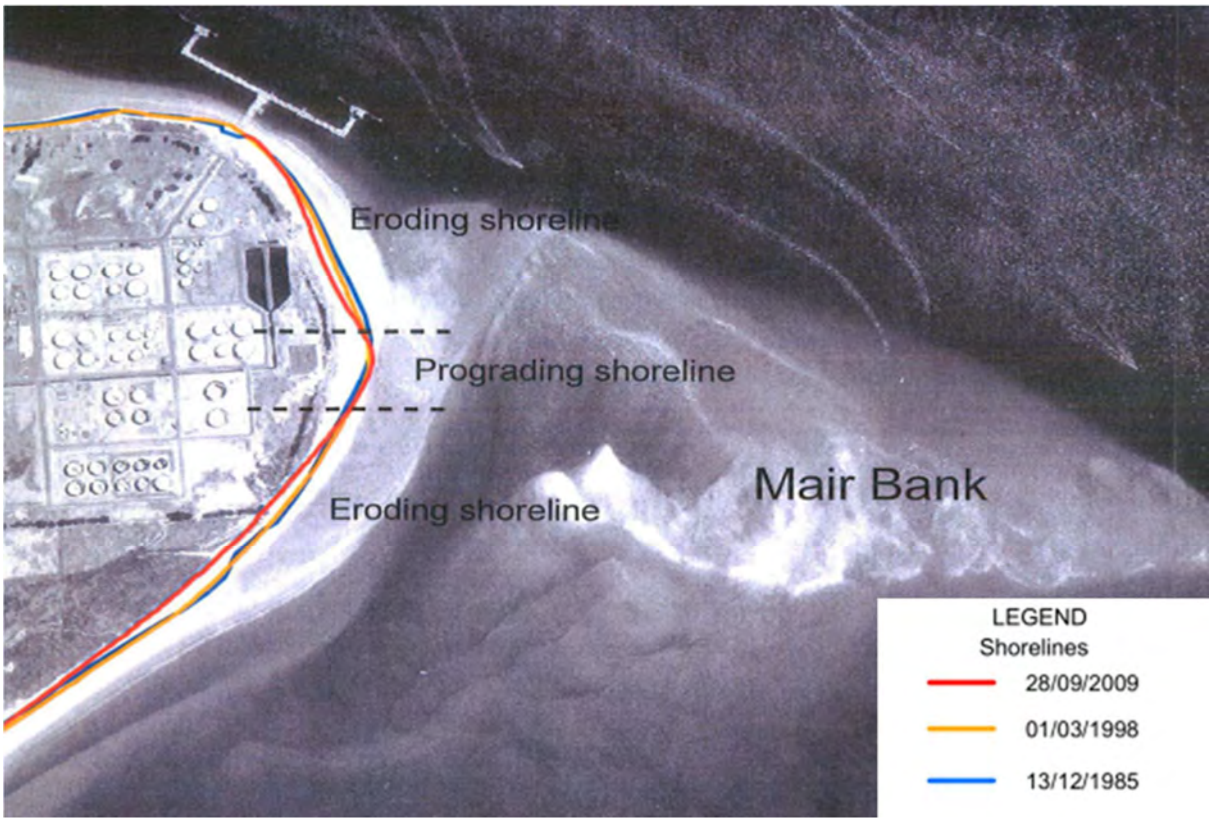


Figure 3-6: Results of historic aerial photograph analysis showing coastline areas of erosion and accretion at Marsden Point with a 1979 base photograph (T+T, 2010)

3.4.2 Coastal erosion hazard extents from the Inner harbour adjacent to Marsden Point to the Ruakaka River mouth

A coastal hazard assessment utilising all available historic data has been carried out for the wider coastal area adjacent to Marsden Point (T+T, 2014). The resulting coastal hazard assessment for the sandy shorelines along the southern shores within entrance to Whangarei Harbour to the Ruakaka River is included in Appendix C.

The hazard assessment was based on an assessment of existing erosion trends, storm effects and the potential effects of sea level rise. The hazard assessment for Marsden Point (Appendix C) shows a greater trend of long term erosion in the vicinity of the point compared to the open coast shoreline further to the south. This is due to a larger change in the shoreline from the aerial photographs as shown in Figure 3-6. There is also the potential for slightly greater impact of sea level rise effects at this location as a result of a flatter beach profile.

3.4.3 Home Point to Smugglers Bay

Home Point to Busby Head area is a M1MA area in the Northland Regional Coastal Plan (seaward of MWHS), and an Outstanding Landscape Area in the Whangarei District Plan (landward of MHWS).

There has been no detailed hazard assessment of the shoreline from Home Point to Smugglers Bay. This shoreline comprises volcanoclastic cliffs with narrow alluvial beach at Home Point and a wider sandy beach within Smugglers Bay (refer Figure 3-7 and Figure 3-8). The cliff shorelines from Home Point to Busby Head are typically characterised as stable features due to the nature of the underlying geology with low rates of change compared to sandy coasts.

However, based on satellite imagery assessment, there is a narrow intertidal rock platform area evident along the shoreline. This suggests very small amount of cliff retreat has occurred over the last 6,500 years as sea level rise stabilised from the Holocene transgression. Evidence from the photographs taken along the shoreline also show evidence of erosion currently occurring along the shoreline from Home Point to Busby Head, both on the alluvial beach area adjacent to Home Point and along the cliff coast from Home Point to Busby Head (refer Figure 3-7).

The shoreline from Home Point to Busby Head is sheltered from the direct impact of waves generated by onshore storms from all directions so is unlikely to be experiencing wave dominated erosion processes. It is likely that the cliff erosion processes are probably dominated by weathering of the subaerial cliffs and the continued removal of debris that falls from the cliff face to the sea by ongoing tidal flows and low wave energy conditions along the entrance channel.

Within Smugglers Bay the beach is within an embayment that prevents sand migrating from the beach by alongshore transport processes, although it is likely that the beach is more subject to storm processes than the shoreline from Home Point to Busby Head, it is still relatively sheltered from direct effects of tropical cyclones that are the main cause of large offshore wave heights. During storms, particularly from south-east, sand from the upper part of the beach would move offshore and returning to the upper beach area during more quiescent periods.

Erosion of the cliff shore at Busby Head can be seen in Figure 3-8 which is part of the slow cycle of weathering and erosion of the steep slopes that is characteristic at this location even in cliff areas not subject to coastal processes acting at their base.

Figure 3-7: Home Point showing a mix of rock and coarse sand and shell along a narrow eroding beach in the foreground as evidenced by exposed tree roots on the upper foreshore and localised cliff erosion as evidenced by steep unvegetated slopes in the background towards Busby Head (Source: GoogleEarth)

Figure 3-8: Smugglers Bay showing a broader sandy beach within the embayed area and evidence of landslides and erosion along Busby Head (Source: GoogleEarth)

3.5 Sediment data

Sediment sampling was targeted and combined with drop camera images of the seabed, to identify sediment properties within the dredged area and to characterise the seabed at possible disposal options and within the adjacent seabed areas that provide the potential for controls during the dredge disposal operation and monitoring.

Marine sediment data for the area in the vicinity of the channel dredging is available from previous port development studies (Hawthorn Geddes, 2009), Beca (1992); investigations commissioned by NRC in December 2012. The broader characterization of seabed sediment texture within the environment of Bream Bay and the ebb tide shoal has been done from extensive sediment analysis carried out as part of studies prepared for these applications and reported in Coffey (2016), Kerr and Associates (2016a, b) and T+T (2016).

Figure 3-9 shows the location of sediment sampling within the entrance channel to the harbour and Figure 3-10 shows sediment sampling locations within Bream Bay. Sediment grading information for these areas are included in Appendix D.

3.5.1 Channel area

Figure 3-11 shows a summary plot of the sediment gradings within the channel footprint for both the vibrocore data (T+T, 2016) and the historic reports (Hawthorne and Geddes, 2009 and T+T, 1984).

The surficial sediments within the main channel of Whangarei Harbour are a mix of sands and coarser material (likely to be shell) in varying proportions. Coring has shown that a minor fraction of silty material is also found at depth (around 3% silts and 0.3% clay). The subtidal regions of the ebb tidal shoal along the edges of the proposed channel are mainly made up of sandy material (around 95%) with around 5% silts. This was observed both by diver survey as well as coring, with some shell material (5 to 10%) also found at depth in the cores. The vibrocoring data shows similar grading information to the previous studies.

Figure 3-9: Location of sediment sampling on the seabed along the channel and the ebb tide shoal. The red box indicated the proposed nearshore disposal site (1-2)

Figure 3-10: Sediment sampling within Bream Bay with the red and blue box showing proposed disposal areas

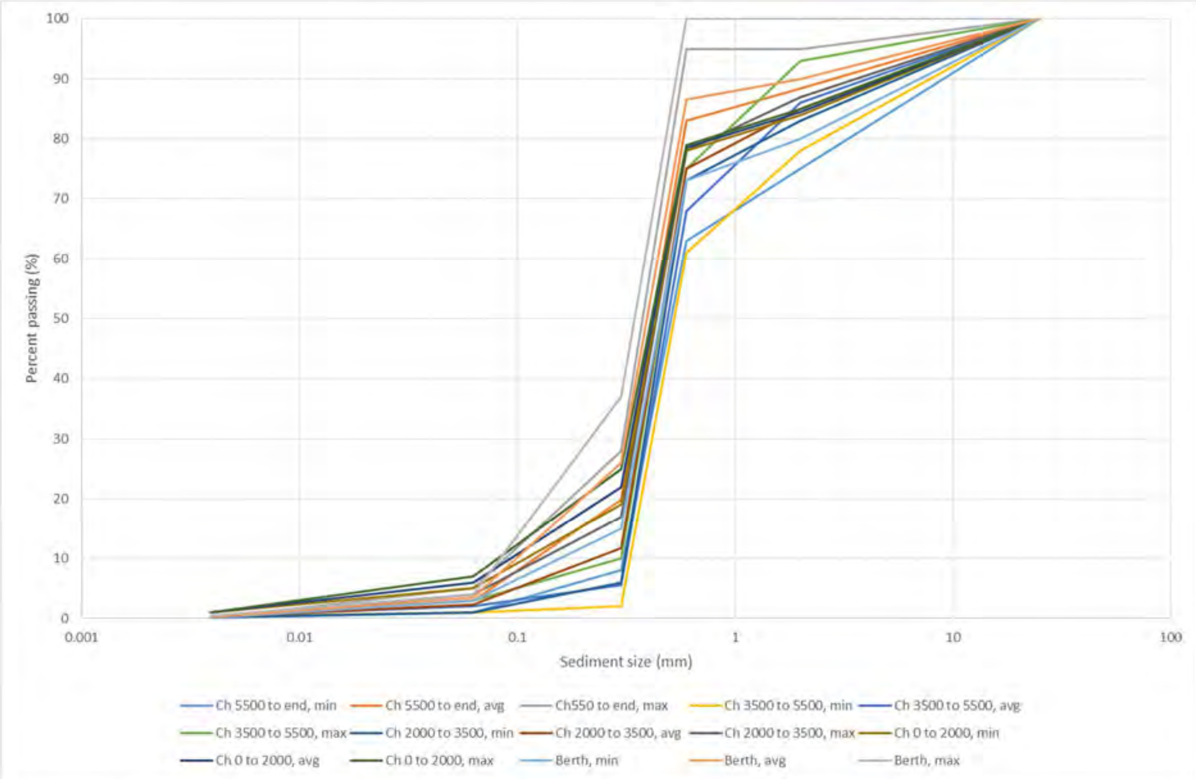


Figure 3-11: Sediment grading curve within the dredged channel footprint

3.5.2 Seabed area along ebb tide shoal and within proposed disposal areas in Bream Bay

Sediment gradings were taken within the nearshore environment and at a range of potential disposal locations (refer Figure 3-10). Figure 3-12 shows the resulting sediment grading data in terms of percent passing for Mair Bank and the ebb tide shoal. Mair Bank is covered with a shell substrate, mostly consisting of Pipi shells, with deposits of fine sands in the lee of shell ridges. With increasing water depth the amount of sand interspersed with the shells increases down the edge of the bank and the remaining ebb tide shoal is predominantly fine to medium sands.

3.5.3 Sediment properties of adjacent beaches

Sediment sampling results and the grain size distribution of six beach sites where existing data is available from previous publications is presented below. This enables a comparison of the dredged sand with the beach sand along the open coast and the harbour. The sediment characteristics of the foreshore were taken from the mid-beach slope along each site. The sediments were sampled from the top 300 mm of the beach face using a trowel and separately bagged for analysis. The sediment samples were analysed for grain size at the University of Waikato using the Rapid Sediment Analysis (RSA) method. Sediment size information is provided in Appendix D. The results shows that the beach sand at all six sites has a similar composition to the sands within the channel area and that sand from the channel dredging will be compatible with the beach sand.

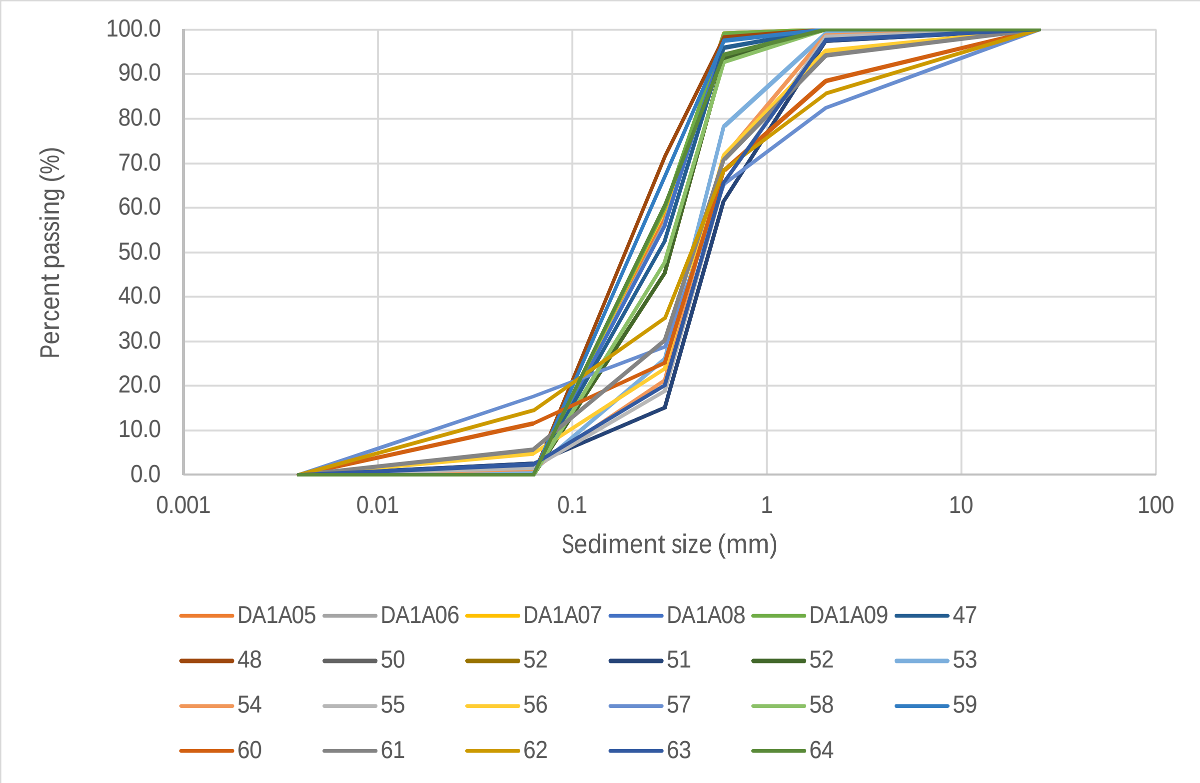


Figure 3-12: Sediment grading curve for sediments within ebb tide shoal

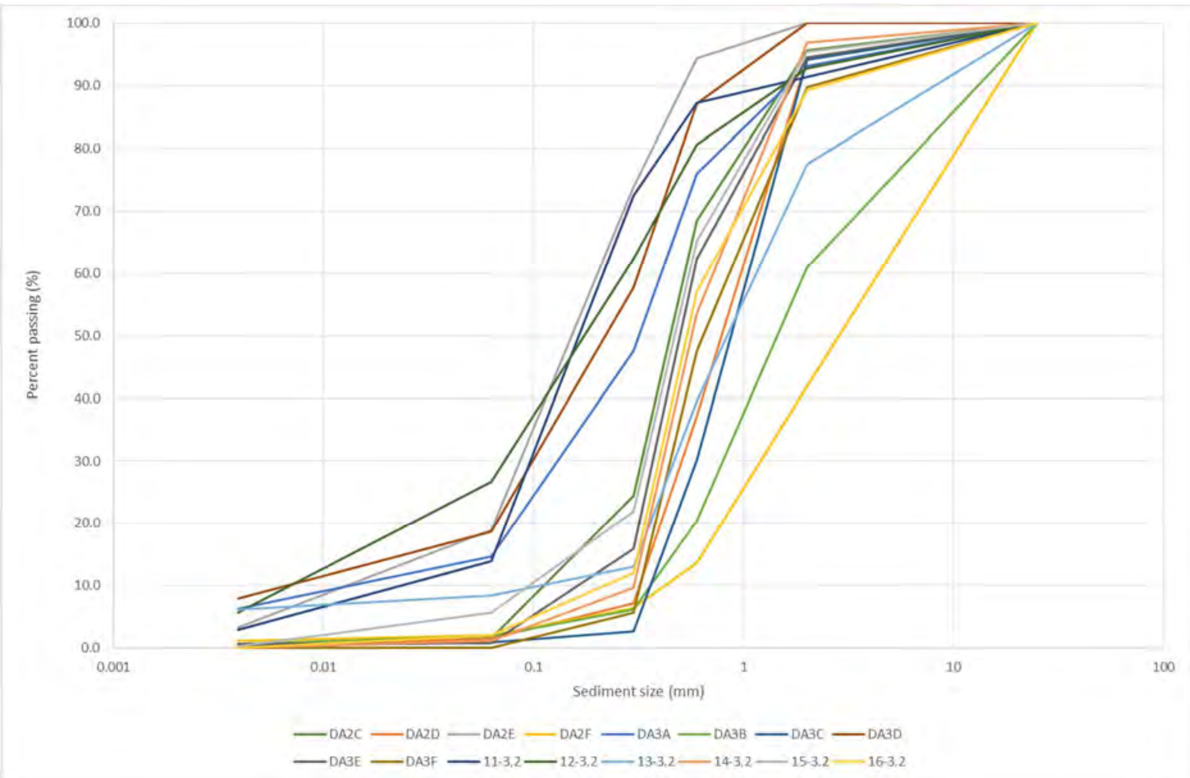


Figure 3-13: Sediment grading curve for sediments within deeper water in Bream Bay

3.5.4 Suspended sediments

Suspended sediment sampling was carried out by MWH between June 2008 and May 2009 at four locations in the vicinity of the harbour entrance; at the harbour entrance, in the channel off Busby Head, south of Mair Bank and on the southern Ebb tide shoal (refer Figure 3-14).

Figure 3-14: Water quality location plan (Source: MWH, 2009)

Table 3-2: Results of surficial water quality survey at four locations in the vicinity of the harbour entrance (Source: MWH, 2009)

Site	Name	Date	Time	Tide	Weather	TSS (mg/L)
1	Harbour Entrance	16-Jun-08	9:50	ebb	wet	9
1	Harbour Entrance	1-Jul-08	9:15	ebb	dry	5
1	Harbour Entrance	1-Jul-08	12:45	flood	dry	8
1	Harbour Entrance	26-Aug-08		flood	dry	6
1	Harbour Entrance	3-Dec-08	14:11	ebb	dry	3
1	Harbour Entrance	3-Dec-08	8:48	flood	dry	5
1	Harbour Entrance	7-May-09	8:53	ebb	dry	5
2	Mair Bank	16-Jun-08	9:57	ebb	wet	6
2	Mair Bank	1-Jul-08	9:30	ebb	dry	8
2	Mair Bank	1-Jul-08	12:36	flood	dry	5
2	Mair Bank	26-Aug-08		flood	dry	2
2	Mair Bank	3-Dec-08	14:00	ebb	dry	3
2	Mair Bank	3-Dec-08	9:09	flood	dry	4
2	Mair Bank	7-May-09	9:05	ebb	dry	4
3	Ebb Tide Shoal	16-Jun-08	10:02	ebb	wet	7
3	Ebb Tide Shoal	1-Jul-08	9:35	ebb	dry	6
3	Ebb Tide Shoal	1-Jul-08	12:32	flood	dry	21
3	Ebb Tide Shoal	26-Aug-08	N.D.	flood	dry	4

Site	Name	Date	Time	Tide	Weather	TSS (mg/L)
3	Ebb Tide Shoal	3-Dec-08	13:49	ebb	dry	2
3	Ebb Tide Shoal	3-Dec-08	9:24	flood	dry	6
3	Ebb Tide Shoal	7-May-09	9:12	ebb	dry	2
4	Channel off Busby Head	16-Jun-08	10:02	ebb	wet	7
4	Channel off Busby Head	1-Jul-08	9:35	ebb	dry	18
4	Channel off Busby Head	1-Jul-08	12:32	flood	dry	9
4	Channel off Busby Head	26-Aug-08	N.D.	flood	dry	6
4	Channel off Busby Head	3-Dec-08	13:49	ebb	dry	1
4	Channel off Busby Head	3-Dec-08	9:24	flood	dry	7
4	Channel off Busby Head	7-May-09	9:12	ebb	dry	3

Average values of around 6 mg/L occur on the intertidal areas of the harbour seabed, while within the channel and ebb tide shoal areas, average values are also around 6 mg/L.

For the main channel and wider Bream Bay area, suspended sediment concentrations are relatively low apart from during more energetic wave events. Monitoring shows suspended solid values vary between 2 and 21 mg/L on the ebb tide shoal.

During higher wave energy events it is likely that suspended sediment concentrations within Bream Bay would be significantly higher than the values identified in the tables above. Table 3-3 shows the depth average sediment concentration at a water depth of 12 m for a range of higher energy wave events using the method of Van Rijn (1991). These results show that during more energetic wave driven events in shallower water depths there is significantly greater suspended sediment than the average conditions set out in the tables above.

Table 3-3: Depth average sediment concentration at Disposal Area 1-2 during higher energy events

Case	Significant wave height (m)	Peak period (s)	Percent occurrence per year (approx.)	Depth average suspended sediment concentration (mg/L)
1	1.5	8.6	10%	100
2	3.1	9	3%	600
3	5.0	11	1%	2,000

3.5.5 Summary of sediment properties

The sediments within the tidal inlet largely comprise medium to fine sands with a reasonable proportion of shell and low levels of silt. The majority of sediment within the subtidal areas of Bream Bay including the deeper parts of the ebb tide shoal, is characterised as fine to medium sand with some shell fragments, and increasing silt content in deeper water. The beach sediment on the open coast comprises predominately fine to medium sand and has a similar composition to the sediments sampled in the channel area. Typically the suspended sediment concentration values are low, with around 6 mg/L within the tidal channel and on Mair Bank and up to 30 mg/L on the intertidal areas of the harbour. During higher energy events the suspended sediment concentration on the open coast is several orders of magnitude greater.

3.6 Water level data

Key components that determine water level are:

- Astronomical tides
- Barometric and wind effects, generally referred to as storm surge
- Medium term fluctuations, including El Nino-Southern Oscillation (ENSO) and Inter-decadal Pacific Oscillation (IPO) effects
- Long-term changes in sea level due to wave transformation processes through wave setup and run-up.

We examine each in turn in the sections below.

3.6.1 Astronomical tide

Tidal levels for primary and secondary ports of New Zealand are provided by LINZ (2016) based on the average predicted values over the 18.6 year tidal cycle. Values for Marsden Point in terms of Chart Datum are presented in Table 3-4. The mean tide range is around 2.3 m during spring tide and 1.5 m during neaps.

Table 3-4: Tidal levels given for Marsden Point (LINZ, 2016)

Tide state	Chart Datum (m)	OTP64 (RL)
Highest Astronomical Tide (HAT)	2.99	1.31
Mean High Water Springs (MHWS)	2.76	1.08
Mean High Water Neaps (MHWN)	2.35	0.67
Mean Sea Level (MSL)	1.59	-0.09
Mean Low Water Neaps (MLWN)	0.84	-0.84
Mean Low Water Springs (MLWS)	0.42	-1.26
Lowest Astronomical Tide (LAT)	.14	-1.54

Source: LINZ Nautical Almanac 2016 – 17

3.6.2 Storm surge

Storm surge results from the combination of barometric setup from low atmospheric pressure and wind stress from winds blowing along or onshore which elevates the water level above the predicted tide (Figure 3-15). Storm surge applies to the general elevation of the sea above the predicted tide across a region but excludes nearshore effects of storm waves such as wave setup and wave run-up at the shoreline.

Previous studies of storm surge around New Zealand's coastline have concluded that storm surge appears to have an upper limit of approximately 1.0 m (MfE, 2004). Given the perceived upper limit of storm surge for New Zealand, a standard storm surge of 0.9 m is considered representative of a return period of 80 to 100 years (MfE, 2004).

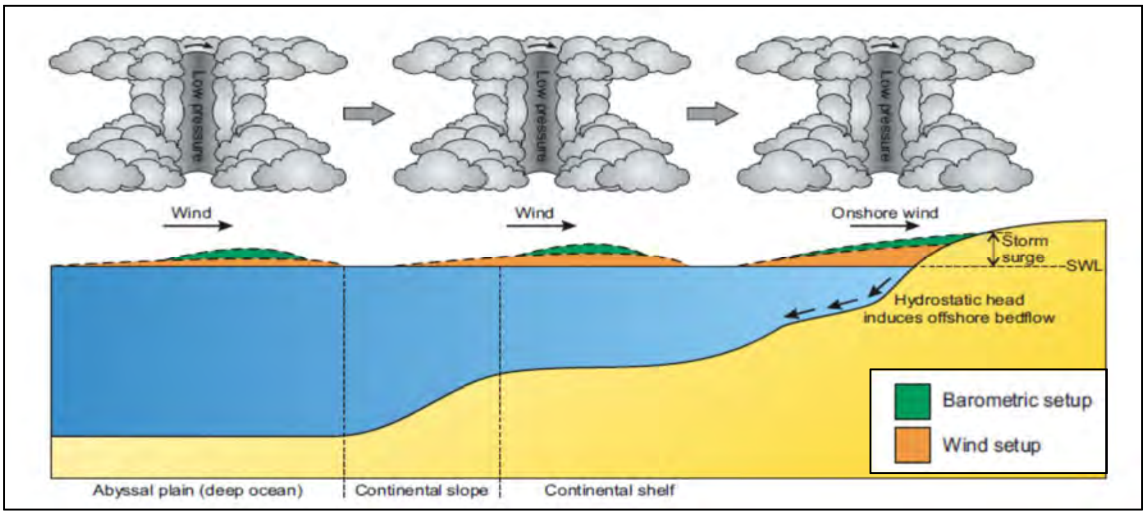


Figure 3-15: Processes causing storm surge (source: Shand, 2010)

3.6.3 Medium term fluctuations and cycles

Atmospheric factors such as season, ENSO and IPO can all affect the mean level of the sea at a specific time (refer to Figure 3-16). The combined effect of these fluctuations may be up to 0.25 m (Bell, 2012).

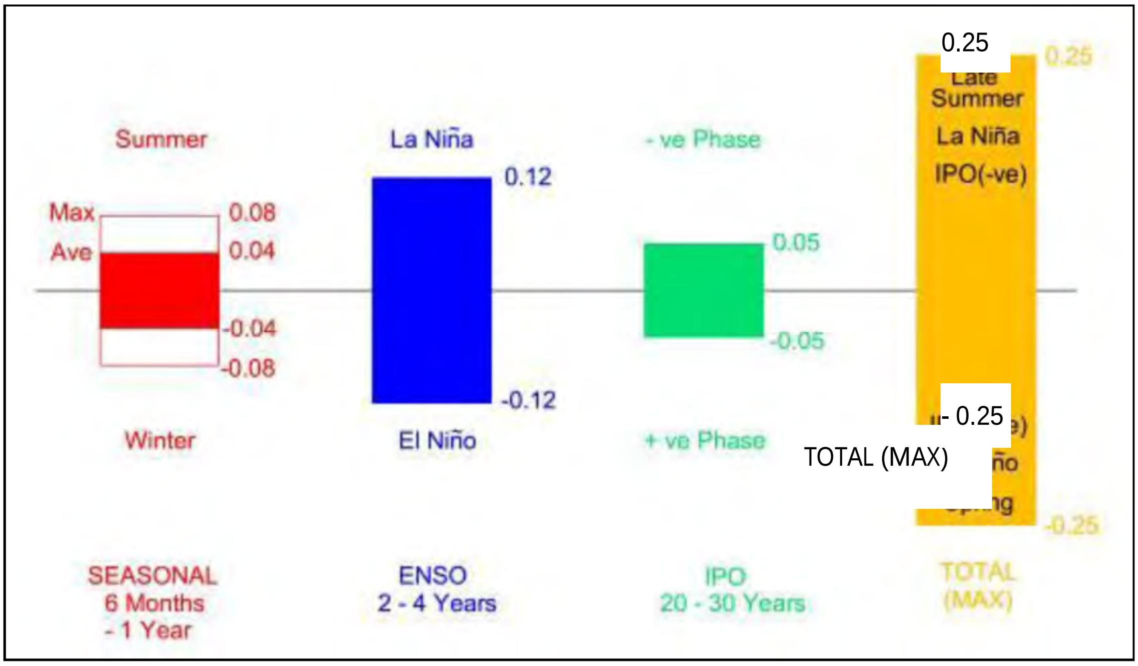


Figure 3-16: Components contributing to sea level variation over long term periods (source: Bell 2012)

3.6.4 Storm tide levels

The combined elevation of the predicted tide, storm surge and medium term fluctuations is known as the storm tide. Results of an extreme value analysis of hourly sea level data for Marsden Point using a Weibull distribution and Gringorten plotting position formula are shown in Figure 3-17. On this basis, 10 and 100 year Average Recurrence Interval (ARI) storm tide levels utilised in storm response modelling are selected with a slight reduction in elevation for open coast Northland east coast beaches, and an increase for west coast sites to account for variation in astronomical tidal range based on LINZ (2013) secondary port tidal information and Bell and Gorman (2003) analysis.

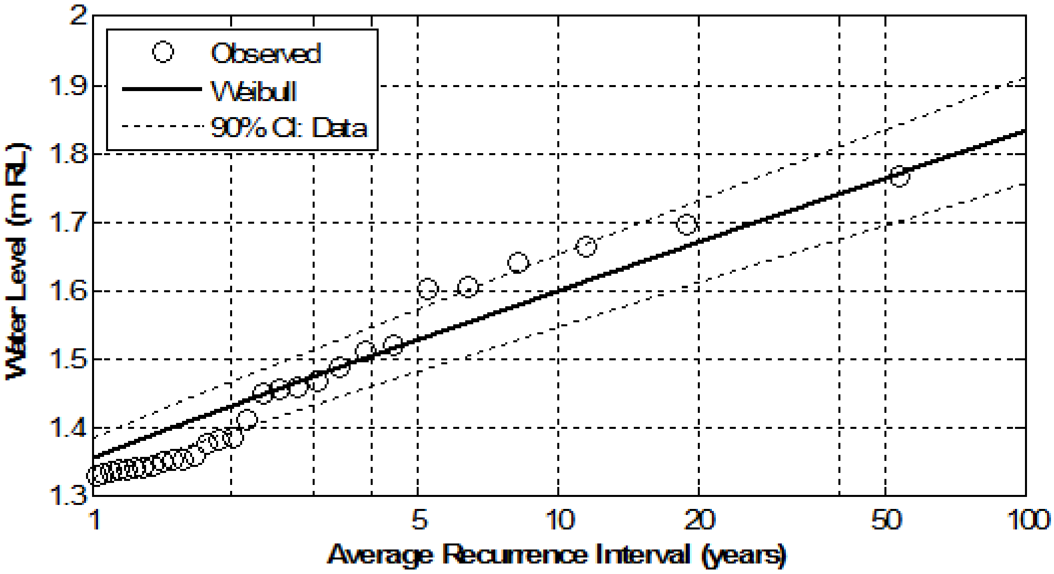


Figure 3-17: Extreme one hour averaged water level for Marsden Point (1984 - 2013)

Table 3-5: Storm tide level

Site	Peak storm tide level (m RL)	
	10 year ARI	100 year ARI
Bream Bay	1.6	1.83

3.7 Waves climate

The wave climate in the vicinity to the harbour entrance has been modelled by MSL (2016b). Modelling used a 35 year hindcast between 1979 and 2014. Figure 3-18 shows the plot of significant wave height statistics at the Wave Rider Buoy, located at the seaward edge of the ebb tide shoal.

A significant wave height is defined as the mean wave height of the highest third of the waves. Table 3-6 shows the wave statistics of the entire hindcast period and of the most energetic (1989) and least energetic year (1990). Figure 3-19 shows wave propagation modelling over the ebb tide delta and into the harbour for low, average and extreme wave height conditions.

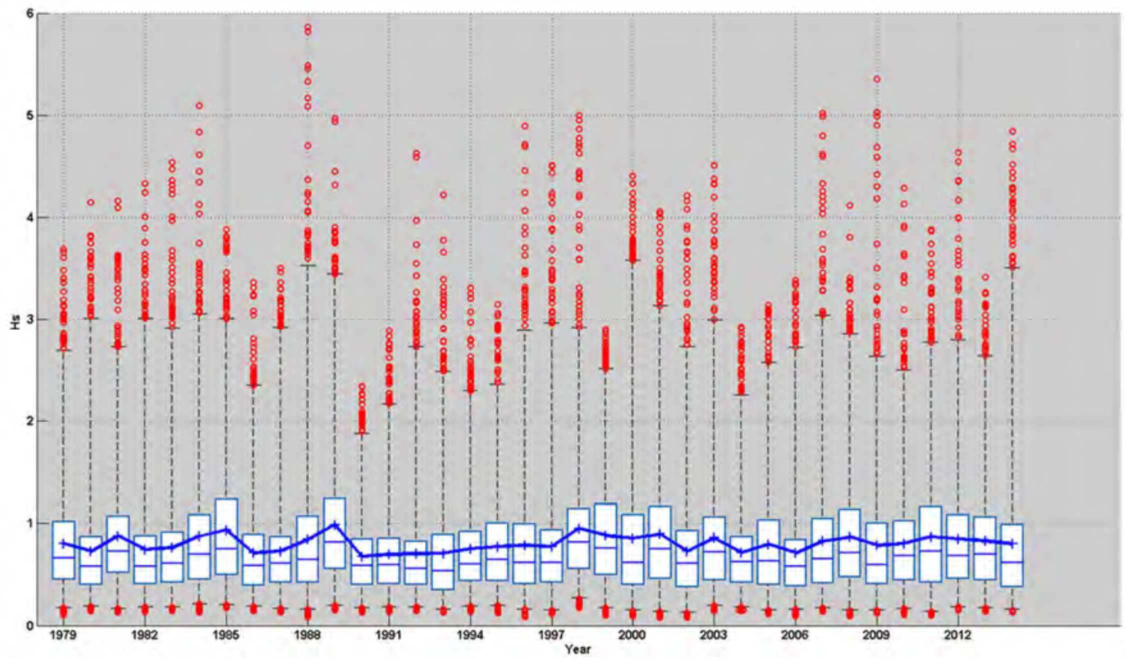


Figure 3-18: 35 year hindcast at the Wave Rider Buoy showing annual mean significant wave height (solid blue line), 25%, median and 75% (light blue box) and more extreme events (red dots). Source: MetOcean Solutions Ltd.

Table 3-6: Comparison of annual wave statistics over the entire hindcast period and the most energetic and mild years (Source: MSL, 2016b)

	Mean (m)	Median (m)	P90% (m)	P95%	Max (m)
Energetic (1989)	0.99	0.82	1.89	2.28	4.97
Entire period	0.80	0.65	1.50	1.89	5.86
Mild (1990)	0.68	0.59	1.23	1.46	2.34

The 35 year hindcast shows that the majority of significant wave heights are typically below 1 m, although during Cyclone Bola in 1988 the significant wave height approached 6 m which resulted in the largest wave event over the last 35 years. The mean wave height over the 35 year time period varies by around ± 20%.

Wave refraction patterns in Bream Bay show that the Whangarei Harbour inlet entrance emerges in a zone of low energy that provides natural stability to the inlet (Morgan et al., 2011). Wave activity inside the harbour is mostly locally generated (fetch ~5km near Marsden Point), although some ocean swell refracts and diffracts to reach the port vicinity (Black and Healy, 1982). The results of the numerical modelling presented in Figure 3-19 shows the sheltering effect of Whangarei Heads and the influence of the ebb tide delta in locally reducing wave heights. Even for the extreme situation with a 5.1 m offshore wave height, wave heights are generally less than 5 m offshore from the delta, and reduce to less than 0.5 m at Marsden Point.

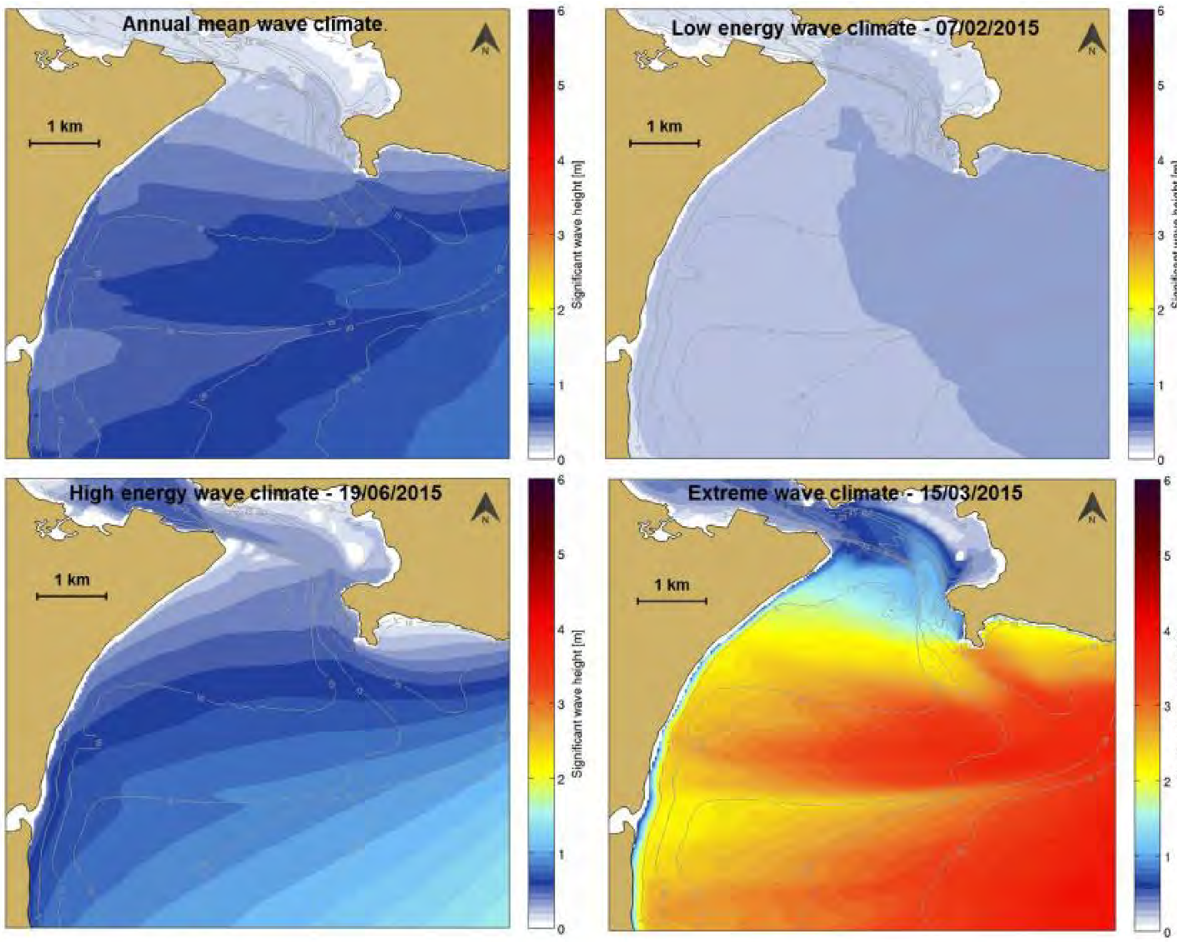


Figure 3-19: Present day annual mean, low, high and extreme wave heights in the vicinity of the harbour entrance (Source: MSL, 2016b)

3.8 Tidal circulation in Bream Bay

The large scale oceanography of northern New Zealand is dominated by a general west to east movement of oceanic water from the Tasman Sea (Tomczak and Godfrey, 1994). Part of this flow temporarily attaches to the north-eastern New Zealand continental shelf as it flows toward the Eastern Pacific, forming a south-eastward-flowing current of warm (16 - 22^{o}C), saline (>35.4 psu) subtropical water, the East Auckland Current (EAUC) (Stanton et al., 1997; Zeldis et al., 2004).

In the analysis of current meter data from 5 locations inside the Gulf Greig (1990) observed that the strongest signal in the time series were associated with tidal forcing. The major constituents for the area were M_2, S_2 and N_2, where M_2 is the dominant signal and flows were aligned with the local bathymetry. The phases were consistent with the essentially standing-wave nature typical of gulf tides and found in the M_2 numerical model of Greig and Proctor (1988). Maximum recorded flows are of the order of 0.25-0.4 m/s throughout the Gulf except near Cape Colville where 0.8 m s^{-1} was recorded. Greig and Proctor (1988) modelled the response of the Gulf to M_2 tidal forcing and they found that tidal residual circulation is weak. Based on field investigations of the change in currents with depth, Sharples and Greig (1998) inferred that seasonal and weather-band variability in the strength of vertical stratification has a marked effect on the observed tidal currents through the addition of a baroclinic tide, which is highly non-linear. They also found that surface mean flows observed throughout all deployments were generally along the shelf edge, and towards the southeast at speeds of 0.2-0.3 m/s and reaching 0.6 m/s at times near Cape Brett. This indicates that circulation in the Hauraki Gulf is strongly 3-dimensional, with a primary dynamical balance between surface wind stress and the associated pressure gradients against the land (Black et al., 2000). This leads to persistent up/down-welling and surface manifestations in sea surface temperature patterns which are shown to vary systematically and markedly with wind direction and stratification intensity.

The long term net flow in the Hauraki Gulf is oriented from north to south (i.e. alongshore) and this is the same for Bream Bay. However, there is a residual circulation within Bream Bay due to the sheltering effect of Whangarei Heads. The interaction of offshore flows and tidal variation contribute to tidal circulation within Bream Bay.

3.9 Tidal currents in the vicinity of the harbour inlet

Based on previous studies, it was identified that tidal current velocities gradually decrease up-harbour, from around 1 m/s at Marsden Point to 0.8 m/s at Limestone Island (Inglis et al., 2006). Tidal streams are strongest in the area adjacent to Home Point southeast of Marsden Point, where rates up to 1.5 m/s may be experienced (Inglis et al., 2006). The constricted tidal inlet results in currents reaching peak depth-averaged velocities of 1.1-1.3 m/s during spring tides (Black et al., 1989; Longdill and Healy, 2007).

Tidal currents have been modelled by MSL (2016b). Figure 3-20 shows the present day maximum ebb and spring tide velocities. During spring tide, the ebb tide creates the highest velocities along the edge of the ebb tide delta and Mair Bank with velocities reaching 1.3 m/s. Figure 3-21 shows the maximum velocities for the neap tide. In this situation the trend is similar to Black et al. (1989).

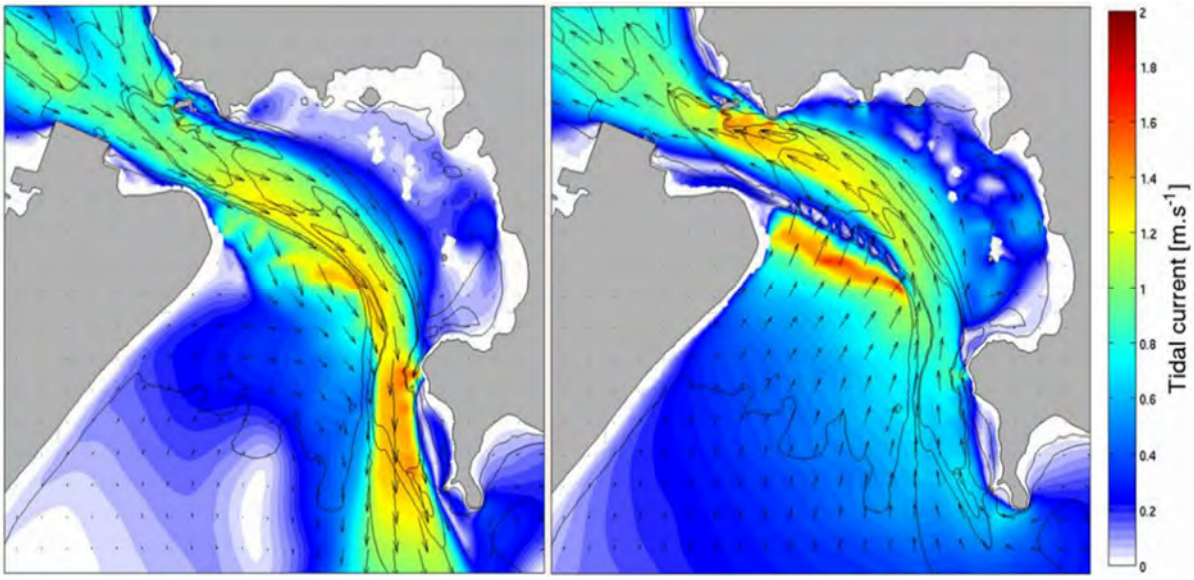


Figure 3-20: Modelled maximum ebb and flood spring tide velocities (Source: MSL, 2016b)

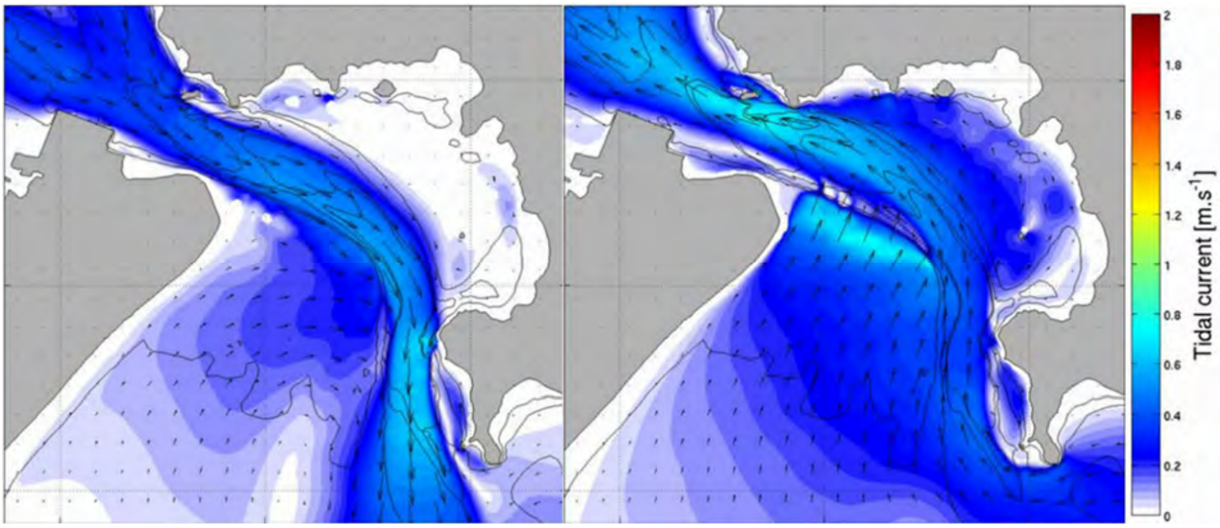


Figure 3-21: Modelled maximum ebb and flood neap tide flows (Source: MSL, 2016b)

3.10 Tsunami

Northland Regional Council contracted NIWA to undertake an initial study on the risk of tsunami inundation facing communities in the Northland Region (Arnold et al., 2011). Two credible sources were modelled; one for a South American origin with a return period 50-100 years, and a less frequent tsunami event with moment magnitude scale (M*) 8.5 and M* 9.0 from the Tonga/Kermadec Trench. The return period of the Tonga/Kermadec Trench events is much longer (500-2000+ years) and represents a worst-case scenario for a tsunami striking the Northland coast.

The current study investigated tsunami propagation into the Whangarei Harbour using computer simulation. Inundation modelling was performed assuming that the tsunami arrives at Mean High Water Spring (MHWS) and for MHWS + 50 cm to assess potential effects of sea level rise. Results of the MHWS inundation depth and velocity plots are included in Figure 3-22 to Figure 3-24 for the South American tsunami with and without 0.5 m sea level rise (Figure 3-22 and Figure 3-24) and M_w 9.0 Tonga/Kermadec Trench scenarios (Figure 3-23).

These results show relatively low levels of inundation in the vicinity of the harbour entrance and that inundation is greater for the South American tsunami. Similarly velocities within the tidal inlet are higher, with velocities of up to 3 m/s, approximately double the tidal velocities. The additional 0.5 m of sea level rise from climate change results in small increases in velocities.

The large velocities that occur as a result of the tsunami are capable of causing large scale changes to the physical system. This is likely to manifest in scour along the inlet and along Mair Bank and deposition both within the inner harbour and offshore. Over time a proportion of the transported sand may return to the ebb tide shoal system, but there may also be some volume that is not able to be returned as it may either be too far up on the inner harbour system, or in too deep water within Bream Bay. Even in the present day situation this is likely to require inspection of the channel and inlet to confirm the safe operability of vessels accessing the port and jetty and it is likely that some maintenance dredging may be required to maintain operability.

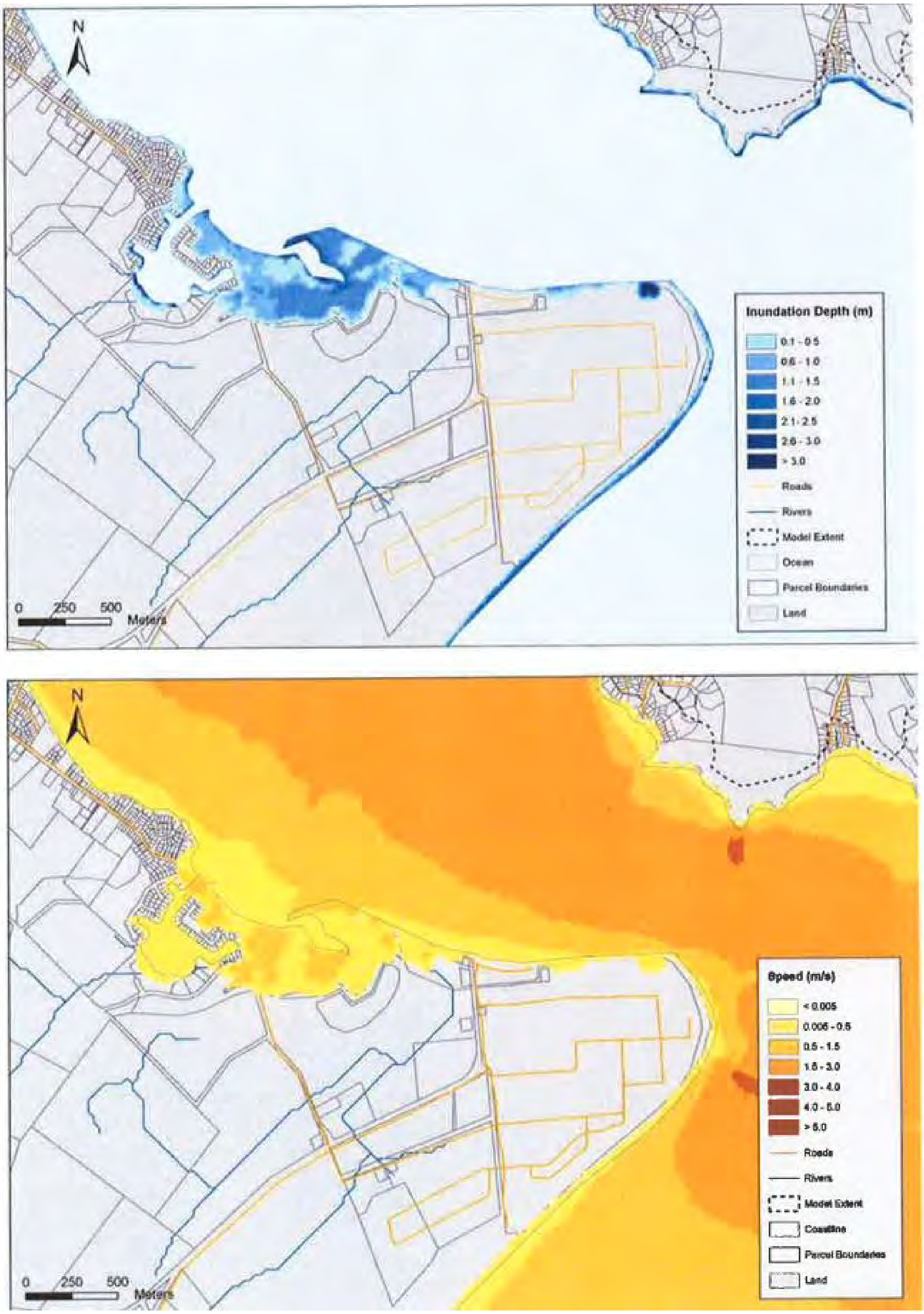


Figure 3-22: Maximum inundation depth (upper) and speed (lower) for the South American tsunami scenario at MHWS (Source: Arnold et al. 2011)