Pacific Marine Management Ltd

Business & Operations Analysts -

Shipping & Ports Sector

Manukau Harbour Port Feasibility Study

Navigational Operability

5 June 2024

237e Titirangi Road Titirangi Auckland 0604 New Zealand

Email: maoxley@xtra.co.nz s 9(2)(a)

Revision History

Revision Nº	Prepared By	Description	Date
0.0	Mark Oxley	For internal review	13 June 2023
1.0	Mark Oxley	For client and peer review	15 June 2023
1.1	Mark Oxley	Navigational Operability - Interim Technical Working Paper – a progress update	11 August 2023
2.0	Mark Oxley	For client and peer review	5 June 2024

Disclaimer:

This report has been prepared for the exclusive use of Tonkin & Taylor Ltd and their client, Ministry of Transport, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than Tonkin & Taylor Ltd and their client, without our prior written agreement.

Contents

Figures

Tables

Executive Summary

Operability criteria

In the context of harbour operations, a ship's operability is being able to enter, carry out its port operations and leave the harbour. The cause of downtime is the inability of a ship to withstand adverse conditions, that is, its structural or mechanical integrity is compromised, its motions become unbearable for the crew or passengers or might damage its cargo, it becomes uncontrollable, or its capacity is reduced.

Metocean conditions

Ship motions are caused by the forces acting upon a ship from the metocean elements:

- Wind
- Swell and wind waves
- Currents.

A useful guideline to metocean limiting conditions for harbour entrances is set out by PIANC:

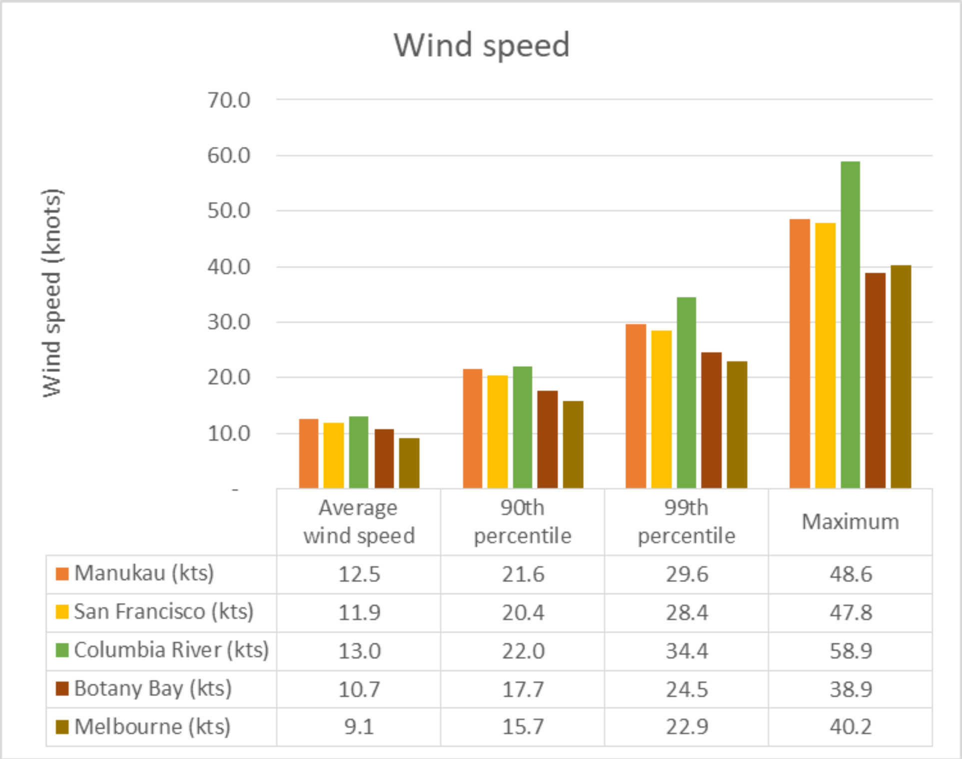
PIANC limiting conditions for harbour entrances

	Longitudinal component	Cross component
Wind gusts, at 10 m height, 60 sec gust	16 m/s (32 knots)	10 m/s (20 knots)
Significant wave, Hs	5 m	3 m
Currents, at a depth of 50% of the vessel's draught, at 1 minute interval	2 m/s (4 knots)	0.5 m/s (1 knot)

The probability of occurrence of these conditions at Manukau Harbour can be compared with the limiting conditions experienced at existing ports. Four benchmark ports have been selected: San Francisco, Columbia River, Sydney's Botany Bay and Melbourne.

Wind

Wind speed data for the benchmark ports and Manukau are compared in the following figure. Manukau has similar average and 90th percentile wind speeds as Columbia River and higher than the other ports, but less extreme winds than Columbia River, whose 99th percentile wind is 34.4 knots, higher than Manukau's 31.9 knots. Botany Bay and Melbourne generally have lower wind speeds than Manukau, San Francisco and Columbia River.



	Average wind speed	90th percentile	99th percentile	Maximum
Manukau (kts)	12.5	21.6	29.6	48.6
San Francisco (kts)	11.9	20.4	28.4	47.8
Columbia River (kts)	13.0	22.0	34.4	58.9
Botany Bay (kts)	10.7	17.7	24.5	38.9
Melbourne (kts)	9.1	15.7	22.9	40.2

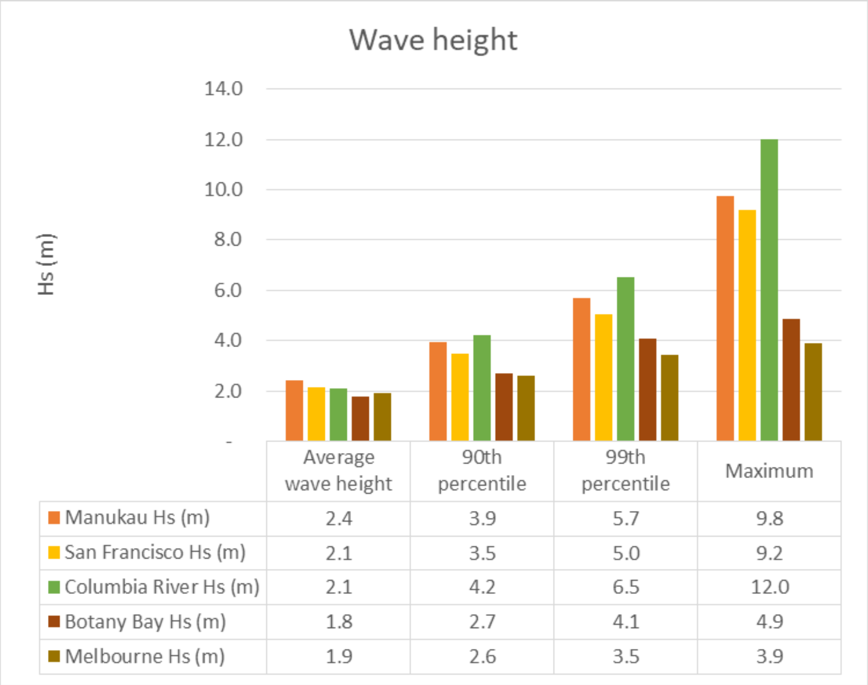
Wind speed comparison with benchmark ports

Waves

The entrance to Manukau Harbour is exposed to swell coming up from the Southern Ocean, as well as local storms in the Tasman Sea and even ex-tropical cycles descending from the southwest Pacific Ocean. As a result, its metocean conditions are more severe than most places.

Wave height

Wave height data for the benchmarks and Manukau are shown in the following figure. Manukau has higher average wave heights than the other ports. Columbia River’s 90th percentile, 99th percentile and maximum wave heights are greater than Manukau; the other ports lower. Botany Bay and Melbourne generally have lower wave heights than Manukau, San Francisco and Columbia River.

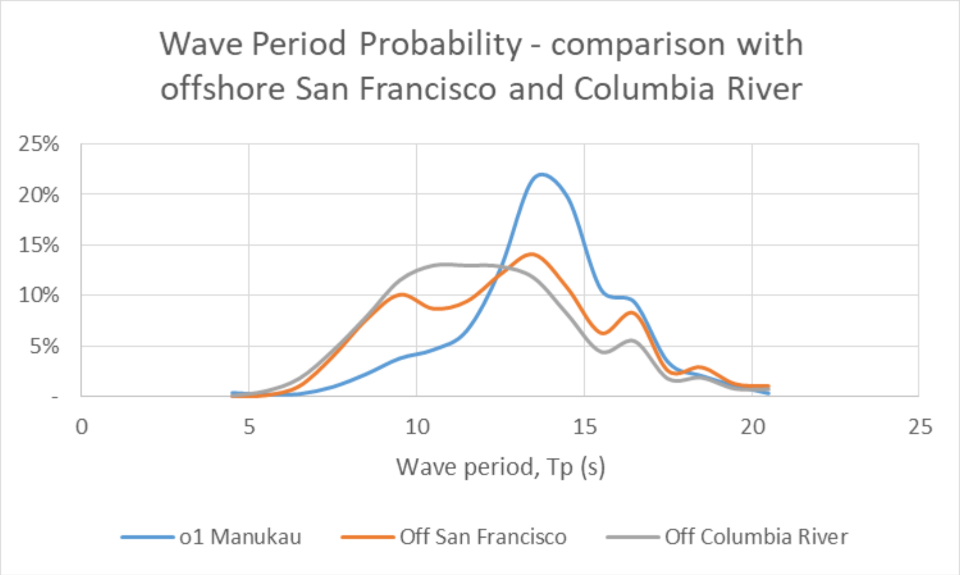


	Average wave height	90th percentile	99th percentile	Maximum
🟧 Manukau Hs (m)	2.4	3.9	5.7	9.8
🟨 San Francisco Hs (m)	2.1	3.5	5.0	9.2
🟩 Columbia River Hs (m)	2.1	4.2	6.5	12.0
🟫 Botany Bay Hs (m)	1.8	2.7	4.1	4.9
🟫 Melbourne Hs (m)	1.9	2.6	3.5	3.9

Wave height comparison with benchmark ports

Wave period

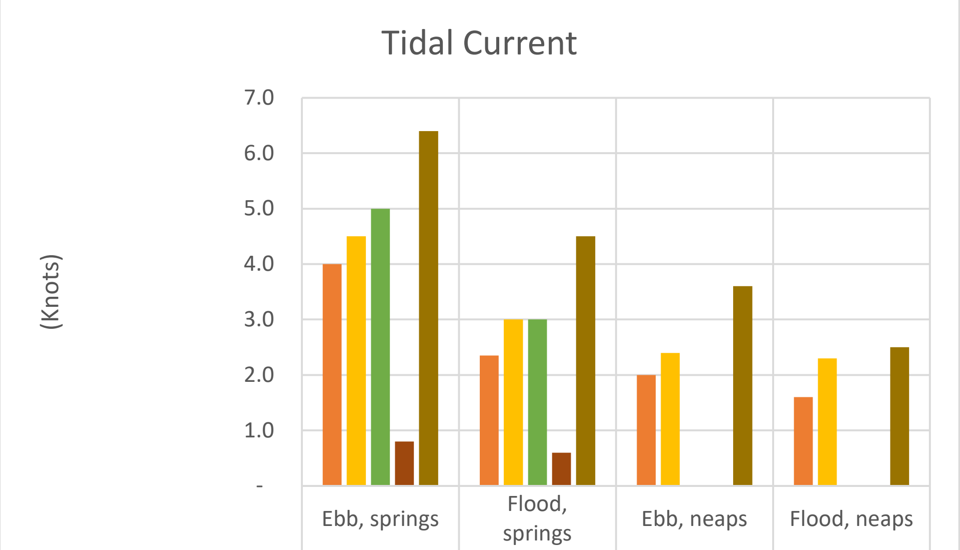
85% of waves offshore of Manukau Harbour have a peak period between 10 s and 17 s. San Francisco and Columbia River wave periods have wider bandwidths and more short/ low period waves, with 70% and 69% lying between 10 s and 17 s respectively, i.e. not dissimilar to Manukau. However, Manukau has only 18% waves with peak periods between 7s and 12s, whereas San Francisco and Columbia River have 40% and 50% respectively.



Wave period probability – Manukau (o1) compared with San Francisco and Columbia River

Currents

San Francisco, Columbia River and Melbourne have strong tidal currents at their entrances, stronger than Manukau.



	Ebb, springs	Flood, springs	Ebb, neaps	Flood, neaps
🟧 Manukau (Knots)	4.0	2.4	2.0	1.6
🟨 San Francisco (Knots)	4.5	3.0	2.4	2.3
🟩 Columbia River (Knots)	5.0	3.0		
🟫 Botany Bay (Knots)	0.8	0.6		
🟫 Melbourne (Knots)	6.4	4.5	3.6	2.5

Tidal current comparison with benchmark ports

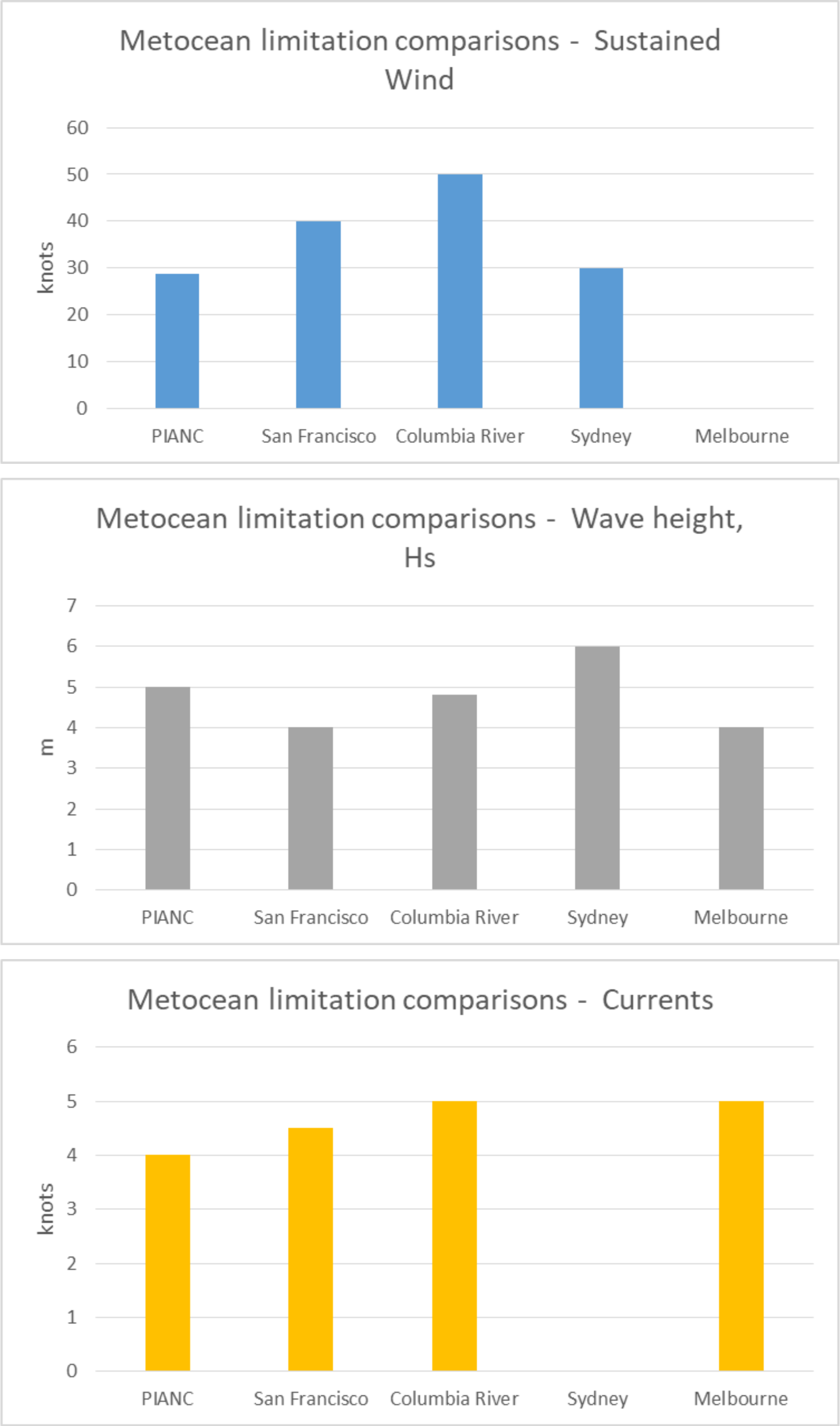
Types of limitations

Port closure (suspension of pilotage)

A port may be closed by the port authority, usually because of weather, but sometimes because of unforeseen events such as channel blockage by a casualty.

Ports are in fact, very rarely closed by the port authority; more commonly the reason for suspension of ship movements into and out of a port is suspension of pilotage services. If conditions are too rough, boarding or disembarking can become too dangerous. The safety of the pilot and pilot boat can become compromised.

The limiting metocean conditions suggested by the PIANC standard and at the benchmark ports are shown in the figures overleaf.



Metocean limitation comparisons - wind, wave and current

We have used location o5 as representative of the pilot boarding ground just outside the ship channel.

The *wave height* exceedance probabilities at o5 across the range of thresholds for our benchmark ports are:

Hs = 4m (San Francisco and Melbourne):	6.2%
Hs = 5m (PIANC and Columbia River):	2.0%
Hs = 6m (Sydney):	0.4%

If the *wind speed* threshold is reached but the wave height threshold is not, suspension of pilotage will occur because of wind (rather than waves). The sustained wind speed exceedance probabilities at o5 are:

29 knots (PIANC)	1.0%
40 knots (San Francisco)	0%
50 knots (Columbia River)	0%
30 knots (Sydney)	0.7%

That is to say, these wind thresholds are infrequently reached at Manukau heads.

Application of benchmark port pilotage suspension criteria to Manukau

At Manukau, not all ships will require a pilot. Small vessels such as small fishing boats (and of course pleasure craft) will not. And regular users such as coastal feeder ships or coastal bulk carriers can apply for pilotage exemptions for their Masters. But nearly all overseas ships and high risk domestic ships such as tankers and chemical carriers visiting Manukau would be required to use a pilot.

Applying the Manukau weather conditions to each of the benchmark port's thresholds, the number of events at Manukau causing pilotage suspension would be between 12 and 28 per year or 1.0 and 2.3 per month, more in winter and fewer in summer, representing between 0.3% and 0.7% as a percentage of total pilot transfers. The duration would range from 5 hours to 24 hours. See table and figures overleaf.

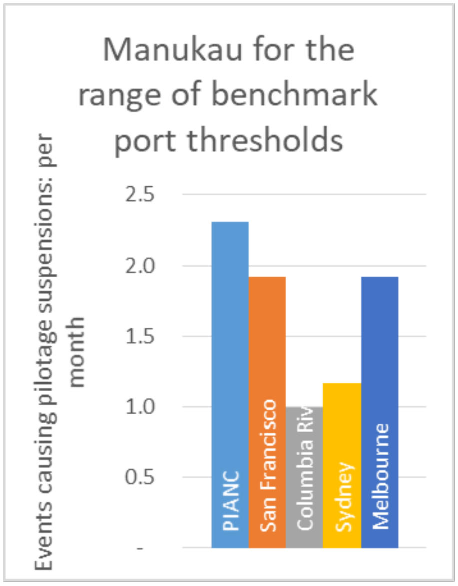
In comparison, the benchmark ports are likely to experience 6 to 8 events a year causing pilotage suspension, i.e., 0.1% and 0.3% of total pilot transfers at those ports. This represents 0.5 to 0.7 suspensions a month but perhaps twice this in winter months at places like Columbia River. The duration at each port is reported to be between 1 to 4 hours for Melbourne rising through 6 to 12 hours for San Francisco and 18 to 21 hours for Columbia River, to a high of 12 to 24 hours for Sydney

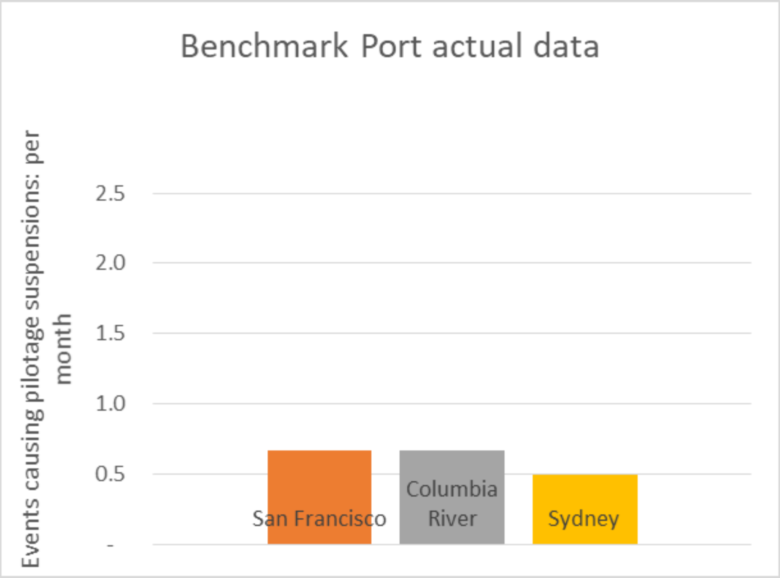
The acceptability or otherwise of these downtimes caused by pilotage suspensions is a commercial judgement. The comparison shows that Manukau's wave, wind and current regime will cause more pilotage suspension events than the benchmark ports. However, the duration of such events is quite short and would be commercially acceptable. The acceptability of the higher number of suspension events remains a commercial judgement, although overall the incidents of events and durations for Manukau do not appear to be overly onerous.

Number and duration of pilotage suspension events pa: Manukau compared with benchmark ports

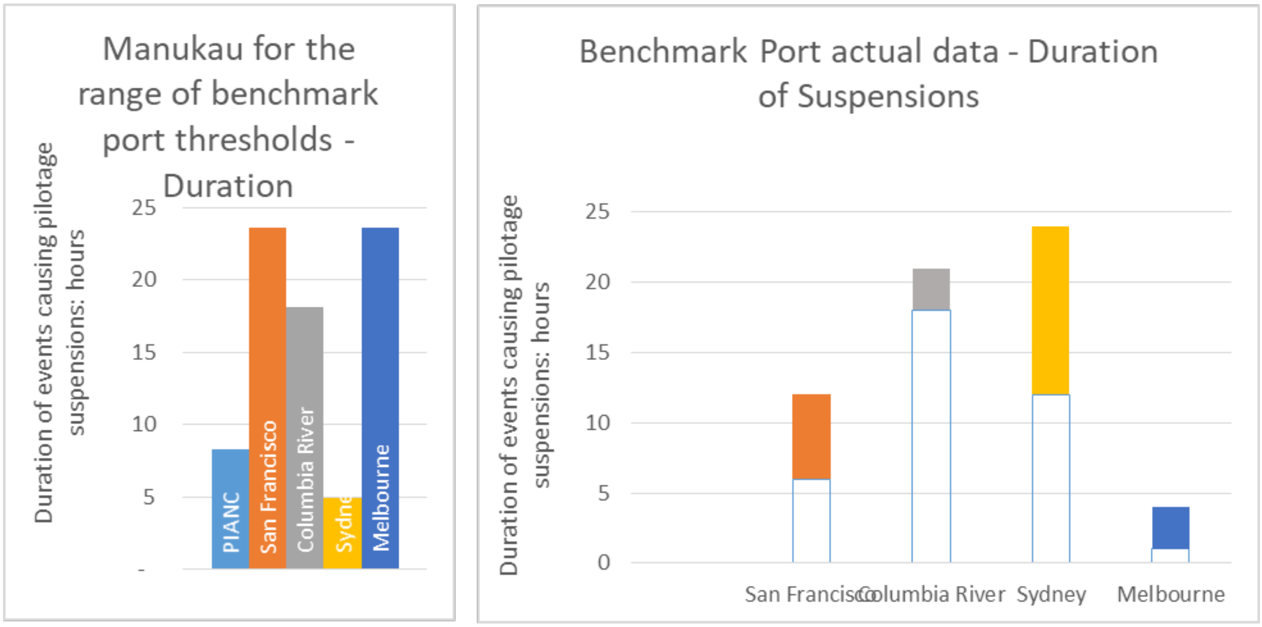
Pilotage Suspension at Manukau	**Manukau**	**PIANC**	**San Francisco**	**Columbia River**	**Sydney**	**Melbourne**
Manukau Pilotage data						
Number of piloted transits at Manukau	3,844					
Events causing pilotage suspensions: per year		28	23	12	14	23
per month		2.3	1.9	1.0	1.2	1.9
Events preventing pilot transfers as %age of total pilot transfers		0.7%	0.6%	0.3%	0.4%	0.6%
Average duration (hrs)		8	24	18	5	24

Comparison with Benchmark Port			**San Francisco**	**Columbia River**	**Sydney**	**Melbourne**
Number of piloted transits at each benchmark port			7,000	2,870	2,758	7,598
Events causing pilotage suspensions: per year			8	8	6	No data
per month			0.7	0.7	0.5	
Events preventing pilot transfers as %age of total pilot transfers			0.1%	0.3%	0.2%	
Average duration (hrs)			6 to 12	18 to 21	12 to 24	1 to 4





Number of pilotage suspension events per month: Manukau compared with benchmark ports



Average duration of pilotage suspension events (hours): Manukau compared with benchmark ports

Exiting, entering and transiting the harbour

Even if pilot transfer can be achieved, or for ships where the Master has a pilotage exemption, a ship may experience limits to its operability where the Master is able to take voluntary action to avoid problems. These voluntary limitations result from conscious decisions of a ship's Master to cease.

Exiting the harbour

We have used a vertical acceleration on a ship's bridge of 0.15g RMS as the ship motion threshold. Generally, the pilot transfer threshold will be reached before that for vertical accelerations. The three smallest ship sizes analysed, 35m, 65m and 100m LOA are however, likely to experience such accelerations, at significant wave heights of 1m, 2m and 5m respectively. Ships of about 175m may exceed the threshold in 7m waves, although the probability of this wave height and wavelength combination is less than 0.01% of the time.

Our traffic assumption is that the two smallest sizes, 35m and 65m LOA, will not need a pilot, so they will be constrained from exiting the port by wave conditions in the channel. Ships of around 100m length are likely to need a pilot. They have a channel constraint of about 5m wave height, similar to the pilot transfer threshold, so will sometimes not be able to take a pilot, and at other times be constrained by the channel conditions.

All other ships greater than 100m that need a pilot will be constrained by the pilot transfer threshold. Those greater than this length that have a pilot exemption will be extremely unlikely to be constrained by wave-induced vertical accelerations in the channel or by outside wave conditions.

Entering the harbour

The risk when entering with following seas is that of surf-riding then broaching to. Smaller ships are more at risk of broaching than larger ships in any given sea.

There is a guideline for avoiding broaching set by IMO, which advises maximum speeds for certain wavelengths, wave heights and ship lengths. For the wave conditions at location c37, 2km seaward of the crest of the Manukau bar, the wavelength in its depth is 195m. The guideline wavelength limitation of 80% of ship length is therefore reached for ships of less than 244m length. The guideline speed limitation will arise for all ships less than 244m, when the significant wave height (H_s) is greater than 4% of the ships length. For ships as short as 35m, once waves reach 1.4m height (which is 95% of the time) the speed limitation is 10.8 knots. For slightly longer but still small ships, say 100m, this rises to 18.3 knots in seas greater than 4.0m (H_s). This maximum speed continues to rise with ship length until the wavelength to ship length limit is reached; for ships longer than 244m the limit is over 28.5 knots and in seas exceeding 9.8m Hs, speeds and wave heights unlikely to be experienced when manoeuvring through the channel.

Small craft

Small craft can use of side slope of bar channel. The side slope is 1:25, giving about 475m side-slope width each side for shallower draft vessels.

Inner harbour manoeuvring

The design channel in the inner harbour has been reviewed through use of a fast time simulation. The fast time simulation report concludes that:

- Channel dimensions are adequate for the manoeuvres under examined conservative combinations of environmental conditions. The ship leaves the designated path set out [in a section in that report] only occasionally and for short periods of time, mostly in bends; the ship is able to return to the intended course swiftly and without significant effort, meaning that the channel width is sufficient. ………….
- The ship retains sufficient control over its course throughout the entire channel, both during arrival and departure passages, as almost no instances of rudder use exceeding 20° are recorded. Most of the time, rudder angle remains within +10° to -10° range. It is therefore concluded that the channel alignment is appropriate.
- Additional runs with smaller vessels that have deeper draughts in dredged sections demonstrate that vessels are able to retain control with imposed speed limit of 8 knots, however in Section C [the inner harbour one-lane dredged section] under some conditions, manoeuvring is arguably difficult, as the ship has to resort to the maximum allowed rudder angles.

Channel sedimentation

Sedimentation may reduce the depth in the channel. Normally, this will not present a problem to ship operability; at the expected levels of sedimentation, in all but the most severe weather, even maximum design draft vessels will have more than sufficient under keel clearance.

That is to say, only large ships wishing to transit the bar channel at maximum channel draft allowance, and in severe wave conditions will be subject to delay through sedimentation and will need to wait for higher tide or the weather to abate.

It is extremely unlikely that sedimentation will cause delays of any significance to large ships. The combination of a maximum draft ship wishing to transit, waves severe enough to limit its under keel clearance and infill all occurring is rare. Even then the delays are minor; on a rising tide no more than an hour or two and no longer than 12 hours if a falling tide, and if infill is greater than the tidal range can cover, 10 hours to 48 hours for weather to abate. Smaller ships do not have drafts that might cause issues. Sedimentation is thus not a problem for operability.

Anchoring

Anchoring offshore is not considered to be a problem. There is plenty of sea-room in suitable depths. The bottom is fine sand and broken shells, generally considered to be good holding ground. Should weather conditions dictate that a ship cannot stay at anchor, there is so much sea-room (the Tasman Sea) that it can heave anchor and steam, in circles if necessary.

Airport OLS

Auckland Airport's Obstacle Limitation Surface (OLS) provides maximum heights for structures and activities around the airport. There are potential port locations within the harbour that do not intrude on the OLS. And if there is a preferred location that does intrude, there is an Aeronautical Study risk assessment process for considering exemptions.

Bio-security

Biosecurity requirements for all incoming vessels require vessels to have a clean hull when arriving to New Zealand. Short stay vessels, i.e., most commercial ships, must call only at 'places of first arrival'. Our expectation is that a major new port such as Manukau would be designated as a place of first arrival. If a ship fails inspection, it has to leave New Zealand. This can mean it goes elsewhere, or a common practice, it can be cleaned, outside the 12 mile limit at one of only three places in NZ where this takes place: off Great Barrier Island, near Tauranga (both of which are low wave energy locations) and off Lyttelton. Ships at any port that fail an inspection would need to go to one of these or leave New Zealand altogether. The implication for Manukau is that if a ship chooses cleaning outside the 12 mile limit, it would need to go further than ships at most other NZ ports. That is to say, a moderate consequence compared with a ship at any other port. The probability is rare. Most ships pass inspections. Most that fail are bulkers, not the type that would be regular callers at a Manukau port, such as containerships.

Aids to Navigation

Physical aids to navigation are today still the main method for marking channels and obstacles. Virtual aids to navigation are now also used, especially at major ports, but as a secondary method. Virtual aids to navigation use AIS (automatic identification system) which needs an AIS receiver or ECDIS electronic chart to receive. Offshore Manukau heads is a severe weather zone. Physical aids to navigation that are not fixed to the seabed or on land will be more prone to damage and displacement than in more sheltered areas. The backup of virtual aids is possible. Over time, systems will continue to develop and virtual AIS aids to navigation are expected to become more common. As ECDIS is now almost universal, we do not consider risks to physical aids to navigation to be a serious risk in the time frame for a new port at Manukau.

Conclusions

Can large ships cross the bar into the inner harbour?

Large ships are relatively unconstrained in crossing the Manukau bar into or from the inner harbour.

There will be times when weather conditions cause pilot transfers to be suspended. These are likely to be between 1 and 2 a month, more often in winter and fewer in summer, and of short duration.

Large ships, and even medium sized ships greater than about 125m length, will not experience difficulties when exiting the harbour across the bar.

Similarly, large ships, and even medium sized ships greater than about 100m length, will not experience difficulties when entering the harbour across the bar.

Can ships of any size cross the bar and navigate within the harbour safely?

Exiting the harbour

Ships less than 125m length will have occasions when exit is restricted. Note that these sizes can already cross the bar; the restriction in a dredged channel will be less than for the existing bar bathymetry.

Entering the harbour

Entering a harbour across a bar exposes ships to the risk of surf-riding and broaching to from the following seas. Short ships are more prone than long ships. It is critical that short ships proceed slowly enough so that the waves can overtake and pass beneath the ship. The ships at risk are those of less than 100m length.

What about marine activities such as anchoring?

Anchoring offshore is not considered to be a problem. Should weather conditions dictate that a ship cannot stay at anchor, it can heave anchor and move out to sea.

Are there any conflicts with other nearby activities, for example the airport?

There are potential port locations within the harbour that do not intrude on the OLS. And if there is a preferred location that does intrude, there is an Aeronautical Study risk assessment process for considering exemptions.

1 Introduction

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

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

1.1 Purpose of the document

This Technical Working Paper has been prepared by Pacific Marine Management and accompanies the study Final Report.

It covers operability criteria for ships, metocean conditions at Manukau and at four benchmark ports, the resulting comparative port closure (suspension of pilotage) and down time when exiting or entering port, and Manukau's operational navigability in the inner Harbour.

Much of the information for this assessment was obtained through engagement with institutional knowledge holders. This is reported in TWP07a which was completed within the study time and sensitivity constraints. Further detailed engagement would be expected at later stages of the design process.

The primary objective of this Manukau Harbour technical feasibility study is to assess whether it is technically possible to construct and operate a large-scale port within the Manukau Harbour. One of the key considerations is the ability for ships, large or small to enter, carry out their port operations and leave the Harbour. Assessing this requires answers to these questions:

- Can large ships cross the bar into the inner Harbour?
- Can ships of any size cross the bar and navigate within the Harbour safely?
- What about marine activities such as anchoring?
- Are there any conflicts with other nearby activities, for example the airport?

2 Operability Criteria

2.1 What is operability?

In the context of harbour operations, a ship's operability is being able to enter, carry out its port operations and leave the harbour. The measures often adopted are the weather window or its converse, the downtime that ships might experience.

Downtime refers to the period of time during which shipping operations are temporarily halted or delayed due to adverse weather conditions. This can include events such as heavy rain, high waves, high winds, strong currents, poor visibility, low water levels, thunderstorms, hurricanes, and other severe weather phenomena, which can pose significant risks to the vessel and human safety, and navigation.

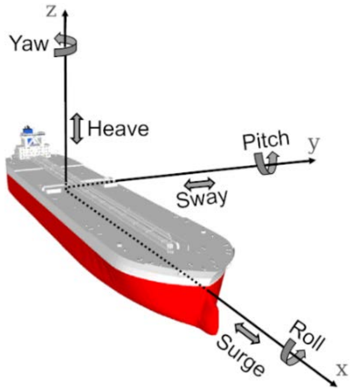
Downtime, or more likely, reduced capacity, can also be caused by reduced water depth, for example through excessive sedimentation.

The cause of downtime is the inability of a ship to withstand these adverse conditions, that is, its structural or mechanical integrity is compromised, its motions become unbearable for the crew or passengers or might damage its cargo, it becomes uncontrollable, or its capacity is reduced.

2.2 Ship motions

The motions of ships are an interaction between the ship and the metocean conditions that it is in, all linked in some way. There are 6 degrees of freedom, three that are displacements and three that are rotations:

- Displacements
    - Surge – movement forward and backward
    - Sway – movement to one side or the other
    - Heave - movement up and down
- Rotations
    - Yaw – horizontal rotation from side to side about a vertical axis
    - Roll – rotation about a longitudinal axis
    - Pitch – Vertical rotation up and down about a horizontal axis



For convenience we can separate the effects of ship motions into the following:

- Stability
- Seakeeping (vertical motions)
- Manoeuvrability

Stability is the ability of the ship to remain upright. It is mostly associated with **roll**. Vulnerability occurs when conditions are such that a ship may capsize. Failure results from dead ship condition, excessive acceleration through roll, pure loss of stability, parametric rolling, and surf riding/ broaching. A ship's master has to consider all these modes, however it is the latter three, pure loss of stability, parametric rolling and surf riding/ broaching, that are of concern in waves such as when entering or leaving port.

Seakeeping, mostly vertical motions, are associated with **heave and pitch**, and to some extent, with **roll**. Vertical motions result in accelerations that can damage the ship and its cargo, cause deck wetness or slamming (the bottom of the ship coming out of the water and 'slamming' back in), motion sickness/ discomfort or loss of function for crew and passengers. In the context of port entry/ exit, excessive vertical motions can also make it difficult for a pilot to board or disembark or result in changes in under keel clearance with the risk of grounding. Roll can reduce under keel clearance significantly for large ships with wide beams and so needs to be taken into account.

Manoeuvrability is the ability to maintain or change course as desired. It is mostly associated with control of **yaw** although it is also affected by **roll, heave and pitch**.

The ability of a ship to enter or leave a port depends on it and its crew's capability to maintain control over these ships motions.

2.3 Limiting conditions

Ship motions are caused by the forces acting upon a ship from the metocean elements:

- Wind
- Swell and wind waves
- Currents.

Excessive forces can result in loss of stability, vertical motions that are too violent or loss of steering response. Any one of these can make ship exit or entry to a port, or transit through a port too dangerous, that is to say, a limitation on navigational operability.

The port downtime that results will determine whether a port, or in Manukau Harbour's case a potential port, is commercially viable. For this feasibility study, we are benchmarking against industry standards and the conditions that cause limitations at other ports and using those limits to determine the potential downtime at Manukau Head/ Harbour.

A useful guideline to metocean limiting conditions is set out in PIANC's *Harbour Approach Channels Design Guidelines* (PIANC)[1]. For harbour entrances, in the absence of specific studies, the following limiting conditions are recommended:

Table 2-1: PIANC limiting conditions for harbour entrances

	Longitudinal component	Cross component
Wind gusts, at 10 m height, 60 sec gust	16 m/s (32 knots)	10 m/s (20 knots)
Significant wave, Hs	5 m	3 m
Currents, at a depth of 50% of the vessel's draught, at 1 minute interval	2 m/s (4 knots)	0.5 m/s (1 knot)

The probability of occurrence of these conditions at Manukau Harbour can be compared with the limiting conditions experienced at existing ports such as our benchmark ports and with the ship

---

[1] *Harbour Approach Channels Design Guidelines,* PIANC, Report No 121 - 2014

motions and manoeuvrability of ships of a range of sizes when transiting the entrance and inner channels of Manukau Harbour.

2.4 Types of limitations

2.4.1 Port closure (suspension of pilotage)

A port may be closed by the port authority[2], usually because of weather, but sometimes because of unforeseen events such as channel blockage by a casualty.

Ports are in fact, very rarely closed by the port authority; more commonly the reason for suspension of ship movements into and out of a port is suspension of pilotage services. If conditions are too rough, boarding or disembarking can become too dangerous. The safety of the pilot and pilot boat can become compromised.

In ports with exposed pilot boarding grounds such as Columbia River and Newcastle, NSW the weather window for pilot boarding/ disembarking is extended by the use of helicopters. By being able to transfer a pilot further out to sea, the ship motions are less severe. Small boat (pilot boat) capabilities need only be considered for those ships unsuited to helicopter transfer. At those ports, the limitation then becomes that of helicopter transfer operational safety for the majority of ships.

However, not all ships are suitable for helicopter pilot transfers. Many container ships for example, do not have a suitable place for landing or winching a pilot. As Manukau would have container ships as many, even most of its ship visits, the analysis here is based around pilot boat transfers.

2.4.2 Voluntary limitations

Even if pilot transfer can be achieved, or for ships where the Master has a pilotage exemption, a ship may experience limits to its operability where the Master is able to take voluntary action to avoid problems. These voluntary limitations result from conscious decisions of a ship's Master to cease.

Exiting port

- When exiting a port, the sea conditions may result in **excessive vertical accelerations** when the ship meets oncoming waves making control of the ship difficult and places crew at risk and potentially damage to ship and cargo. When combined with high winds or strong currents, the manoeuvrability may also be compromised. The master will make a judgement and decide not to exit.
- Stability issues such as **parametric rolling** may be another hazard that is faced. The danger arises when the vessel is sailing in head or stern seas or with a small heading angle, and where the length of waves is about the length of the vessel and the encounter period of the wave is equal or close to half the ship's natural roll period. The ship loses stability as the wave crest passes mid-ships. The ship rolls, and when it returns, the wave is again mid-ships (as the wave period is half the natural roll period) and results in increasing roll angles. The loss of stability depends on the load condition of the ship, and on the wave height. The wrong combinations can cause capsize. The Master can change course, provided there is sea room, or change speed or both, thus changing the encounter period.

---

[2] In New Zealand, the port authority is the Regional Council's harbour master. For benchmark ports consulted for this study, the port authorities are: Melbourne, Ports Victoria; Sydney, the Port Authority of NSW; USA ports, the US Coast Guard (USCG).

Entering port

- Entering a port invariably results in following seas. Stability issues are the main hazard. Following seas pose the risk of **broaching-to**, especially for smaller ships. The ship may surf ride on a wave, lose control of steering and broach (yaw violently), leading to grounding on the side of a channel or capsize. The Master can reduce this risk through reducing the ship speed, thus allowing the wave to pass underneath. But if wind or current make this difficult, the Master will use judgment and decide not to enter.
- **Parametric rolling** (see bullet point under 'Exiting port' above), **pure loss of stability**, or, if a ship is going too slow, **loss of steering** may also need to be considered. Pure loss of stability may occur if the ship's stability is low and wave speed is about the same as the ship (the ship may 'perch' on a wave mid-ships), risking capsize. Loss of steering can lead to grounding.

2.4.3 Transiting channels

When transiting channels, **manoeuvrability** becomes the main issue. Strong winds or currents and high waves reduce manoeuvrability and may restrict the ability to safely proceed along a channel, round bends, pass other ships or work craft such as dredgers, turn at a turning basin or berth. Wave surges, degree of exposure to swells from outside, and wind waves/ fetch also play their part. The risk is that of grounding or collision, or in the worst cases, channel blockage.

A port authority may have limiting criteria, or a pilot or Master may use judgment and decide to await better conditions. The ship can use tugs and adjust its speed accordingly, or even stop and anchor if necessary.

Channel depth also plays its part. Under keel clearance is affected by tide height, as well as by squat, roll and other ship motions. Excessive sedimentation will reduce channel depth and thus limit operability.

2.4.4 Under keel clearance limitations

Large ships may have limited **under keel clearance**. The clearance is heavily influenced by vertical ship motions; larger waves result in decreased clearance. Squat also affects under keel clearance, as does roll especially on wide-beamed ships. Because wave heights are stochastic in nature, the allowable clearance must allow for the largest expected wave, perhaps twice to three times the height of the significant wave being observed or measured. Without real time measuring of waves, the allowance needs to be conservative. Ports with under keel clearance issues are increasingly adopting dynamic under keel clearance (UKC) using real time measurements combined with knowledge of the ship's response to waves to increase the window of operability. See Technical Working Paper 04b - Navigation and Channel Design - Appendix B- Dynamic UKC Calculation for further details.

2.5 Analysis of operability limitations

This report looks at port closure through suspension of pilotage and voluntary limitations when exiting and entering the harbour. Both under keel clearance and transiting of channels are the subject of other work conducted for this feasibility study and reported in Technical Working Paper 04 - Navigation and Channel Design and its Appendix B- Dynamic UKC Calculation and Appendix C – Fast Time Simulation.

3 Metocean Conditions

3.1 Metocean conditions at Manukau

High resolution modelling of wind, wave and currents has been undertaken by MetOcean Solutions[3]. Wind, wave and currents have been modelled for the Manukau Harbour, including offshore, the bar and locations inside and outside Manukau harbour (Figure 3-1).

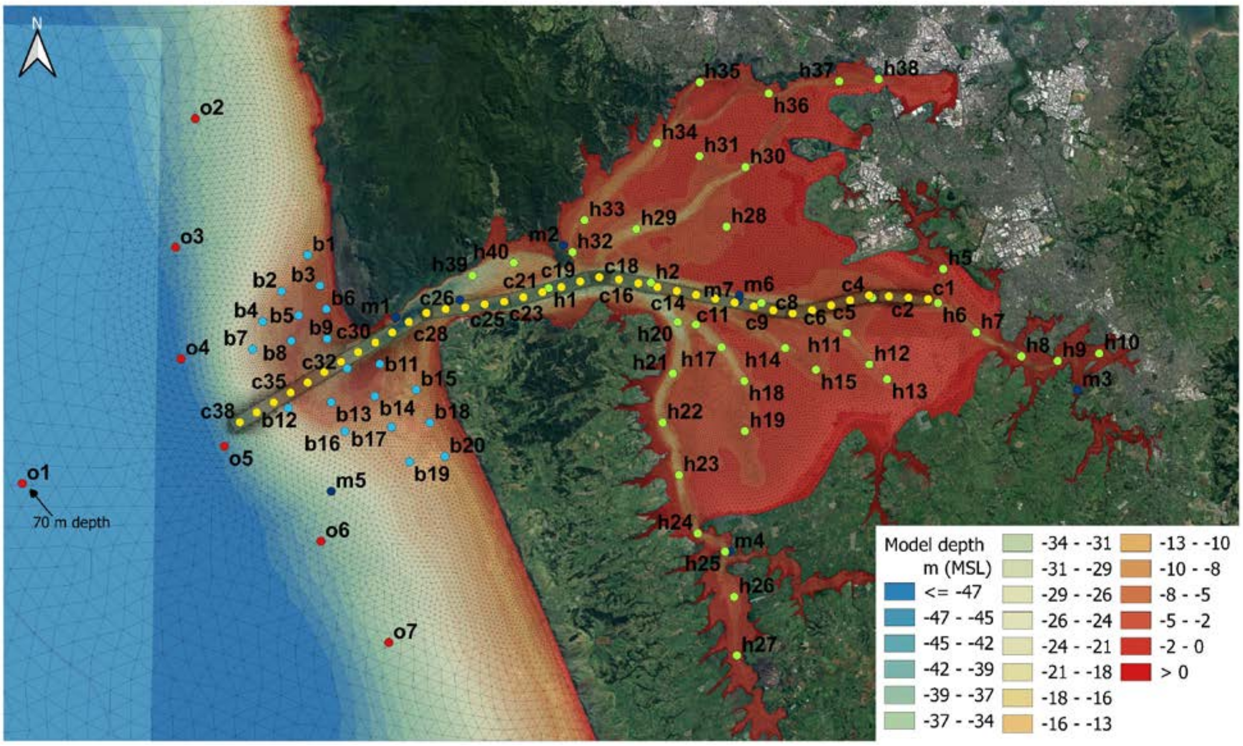


Figure 3-1: MetOcean model output location points

The wind and uncoupled wave hindcast data used in this Technical Working Paper covers 41 years from 1980 to 2020 for the existing bar bathymetry and 11 years from 2010 to 2020 for the proposed design channel bathymetry.

Two offshore locations have been used in this TWP to represent wind and wave conditions that might be experienced outside the Manukau bar:

> An offshore location, o1 for comparison with other benchmark ports at 174.2992E 37.1248S in a depth of about 70m, about 10.8 nautical miles (19.9km) 245 degrees from Ninepin Rock; and
>
> o5 which is a location where a pilot transfer might take place, at 174.41441E 37.1064S in a depth 42 m below CD about 2.5 nautical miles (4.6km) beyond the crest of the bar on the outer slope, and 5.43 nautical miles (10.05km) 231.7 degrees from Ninepin Rock.

Channel locations c34 to c38 have been used for wave and current conditions in the proposed design channel. Modelling of the wave and current hindcast has been coupled for a 12 month period only,

---

[3] See Technical Working Paper 03b – Numerical modelling (MOS).

2012. Factors to allow for more extreme wave height peaks over a more full 11 year period have been derived by comparing the exceedance probability of any given uncoupled wave height over 11 years, 2010 to 2020 with that of the same uncoupled wave height over 1 year, 2012. These factors have been applied to the coupled wave heights in the 1 year data.

3.1.1 Wind

Winds off Manukau Heads at location o1, 10.8 nm (19.9km) offshore and in about 70m depth, are predominantly from SW (13% of the time), SSW (10%) and WSW (11%), although all directions are experienced. See wind directional data in Figure 3-2.

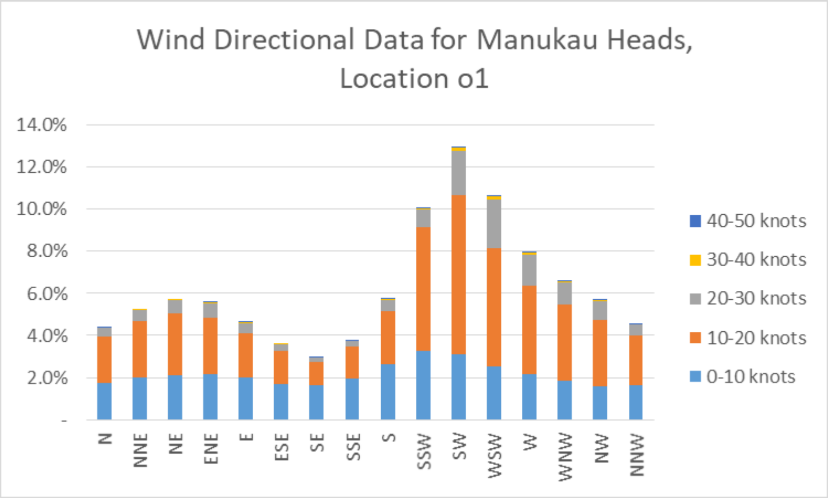


Figure 3-2: Wind directional data for Manukau Heads

Over the 41 years covered by the hindcast for location o1, the average wind speed at this offshore location is 6.5 m/s (12.5 knots). See Figure 3-3. At the extreme, the 90th percentile wind speed is 11.1 m/s (21.6 knots) and there is less than 1% chance that the wind speed will exceed 15.2 m/s (29.62 knots). The maximum wind speed in this 41 year hindcast is 25.0 m/s (48.6 knots) in March 1980.

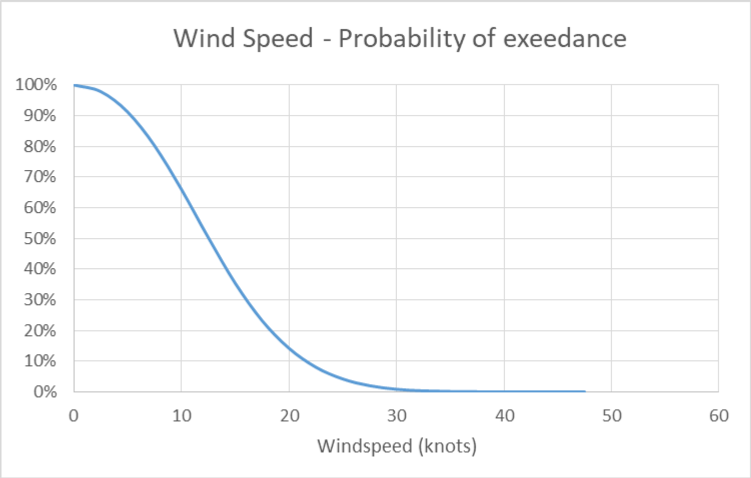


Figure 3-3: Wind speed probability of exceedance - Off Manukau Heads

At location o5, closer to the shoreline, and only 2.5 nautical miles (4.6km) beyond the crest of the bar on the outer slope, the wind speeds reduce by about 5% compared with further offshore. The average wind speed reduces to 6.1 m/s (11.8 knots). The 90th percentile wind speed is 10.54 m/s

(20.5 knots) and there is less than 1% chance that the wind speed will exceed 14.5 m/s (28.2 knots). The maximum wind speed in this 41 year hindcast is 24.1 m/s (46.8 knots) in March 1980.

3.1.2 Swell and sea waves

The waters around New Zealand have some of the highest waves in the world, being exposed to swell coming up from the Southern Ocean, as well as storms in the Tasman Sea and Pacific Ocean. Mean wave heights decrease further north, as exposure to Southern Ocean swell decreases.

Waves offshore Manukau Harbour are almost always from the SW or WSW (92% of the time). See wave direction rose in Figure 3-4.[4]

At the offshore location of MetOcean Solution's hindcast, o1, significant wave heights average 2.2 m. See Figure 3-5. At the extreme, the 90th percentile wave height is 3.6 m and there is less than 1% chance that the height will exceed 5.4 m. The maximum significant wave height in this 41 year hindcast is 9.7 m in August 1982.

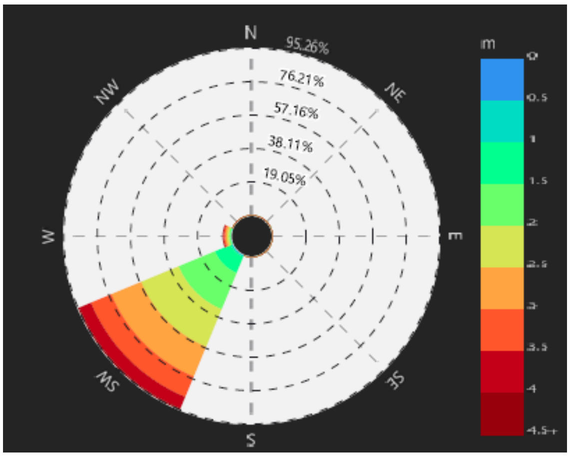


Figure 3-4: Wave direction rose - offshore Manukau

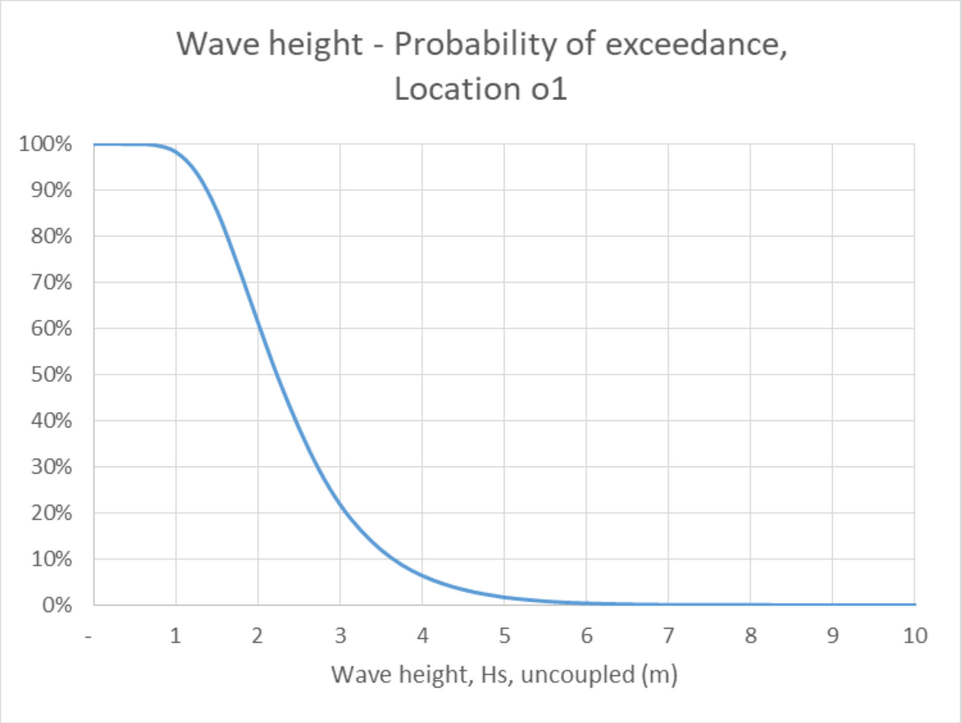


Figure 3-5: Significant wave height probability of exceedance - offshore Manukau Harbour, location o1

---

[4] Wind and wave roses in Chapter 3 are sourced from MetOcean Solutions MetOceanView website, unless otherwise noted.

Wave periods for the hindcast are shown in Figure 3-6. Ocean swells dominate, with an average period of 13.4 s. 87% of waves have a period between 10 s and 17 s.

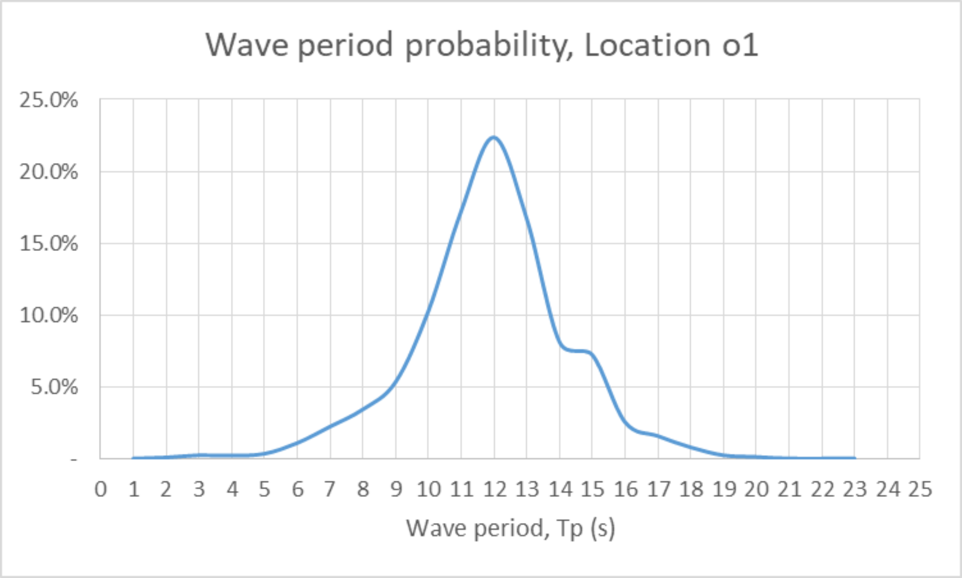


Figure 3-6: Wave period - offshore Manukau Harbour, location o1

3.1.3 Currents

MetOcean Solutions hindcast for waves coupled with tidal currents in the design channel shows that the strongest channel currents are in the channel outside the heads but inside the Bar (about at Location c31). The maximum spring ebb tidal stream at c31 is 4.0 knots (2.1 m/s), flood 3.1 knots (1.6 m/s). At neaps, the maximum ebb tidal stream is 2.0 knots (1.0 m/s), flood 1.6 knots (0.8 m/s). See Figure 3-7.

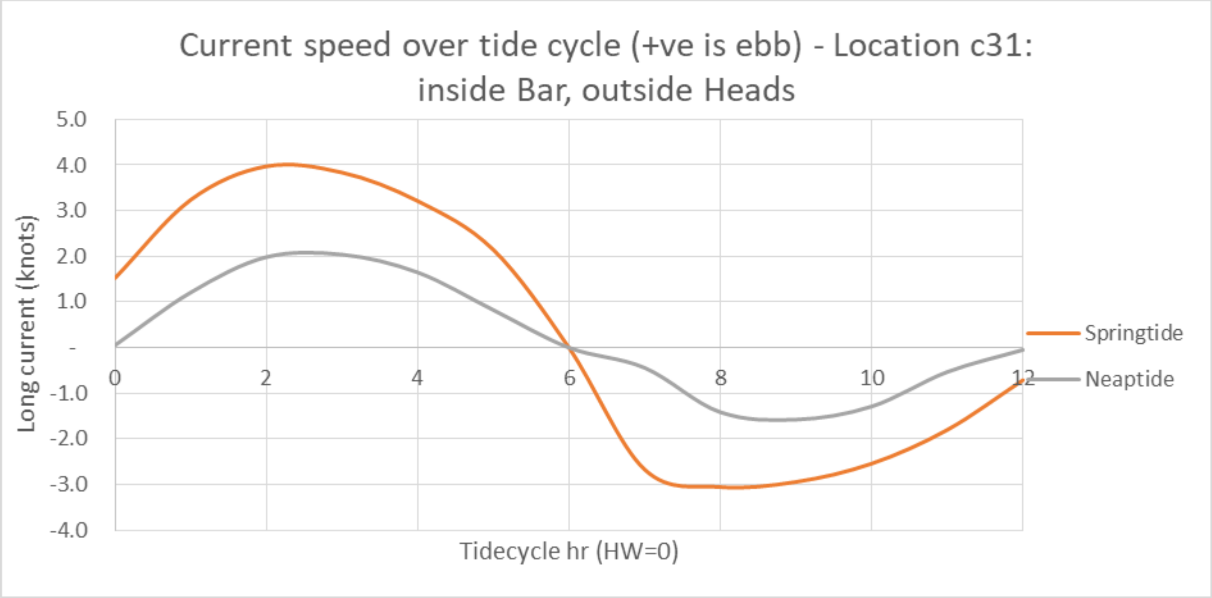


Figure 3-7: Tidal streams at Manukau Heads

Note: these rates differ from those indicated on marine chart NZ 4314 at very nearly the same position, where the maximum spring tidal stream is 2.7 knots (ebb and flood) and at neaps 1.5 knots (ebb and flood).

3.2 Metocean conditions at benchmark ports

We have used **San Francisco, Columbia River, Botany Bay** and **Melbourne** as benchmarks for this operability analysis. We selected them for their geographical and metocean condition similarities to Manukau Harbour:

- They are all ports with entrances on exposed open ocean coasts
- They all have narrow entrances to their harbours, with high currents in the entrance channels and a bar at the entrance or seaward with severe wave conditions
- Their metocean conditions are among the most severe in the world. See Figure 3-8. In their respective winters, they all have very high wave heights.

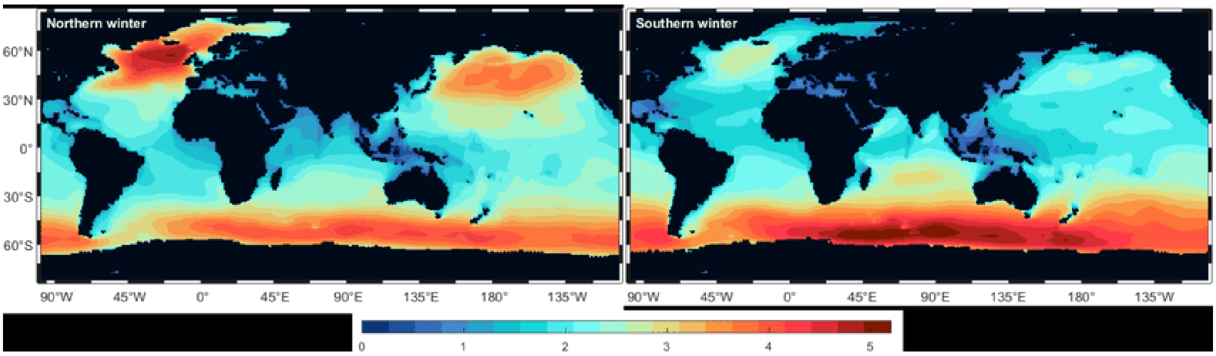


Figure 3-8: Global maps of mean significant wave height (m) in the northern and austral winter half years of 2015 (data from ECMWF)

Three of these ports, San Francisco, Columbia River and Melbourne, also have strong tidal currents at their entrances.

3.2.1 Coastal settings of benchmark ports

Refer to Technical Working Paper 7a – Institutional Knowledge for further details.

San Francisco Harbour is a large tidal estuary with a narrow entrance through Golden Gate. It has an ebb tidal delta located about 4 nm off the heads, with a natural depth of 7 m Chart Datum (CD) to 10 m CD. This compares with Manukau's ebb tidal delta bar, which is about 2 to 3 nm off the heads and has a depth of 3 m to 8 m. The geology of coastal setting is different from Manukau, being predominantly a rock coast, with limited sediment supply, while the open coast in the vicinity of Manukau has extensive sediment supply, an important distinction from the point of view of coastal processes, although no so much from the influence of weather on navigability..

San Francisco's inner harbour is shallow over most of its area, with natural channels that are used for navigation, and maintained by dredging where required. This too is similar to Manukau Harbour. See Figure 3-9.

The ports in San Francisco harbour cater for a wide range of vessel types including annual arrivals of about 1,500 container ships, 750 tankers, 380 bulk carriers, and 275 vehicle carriers.

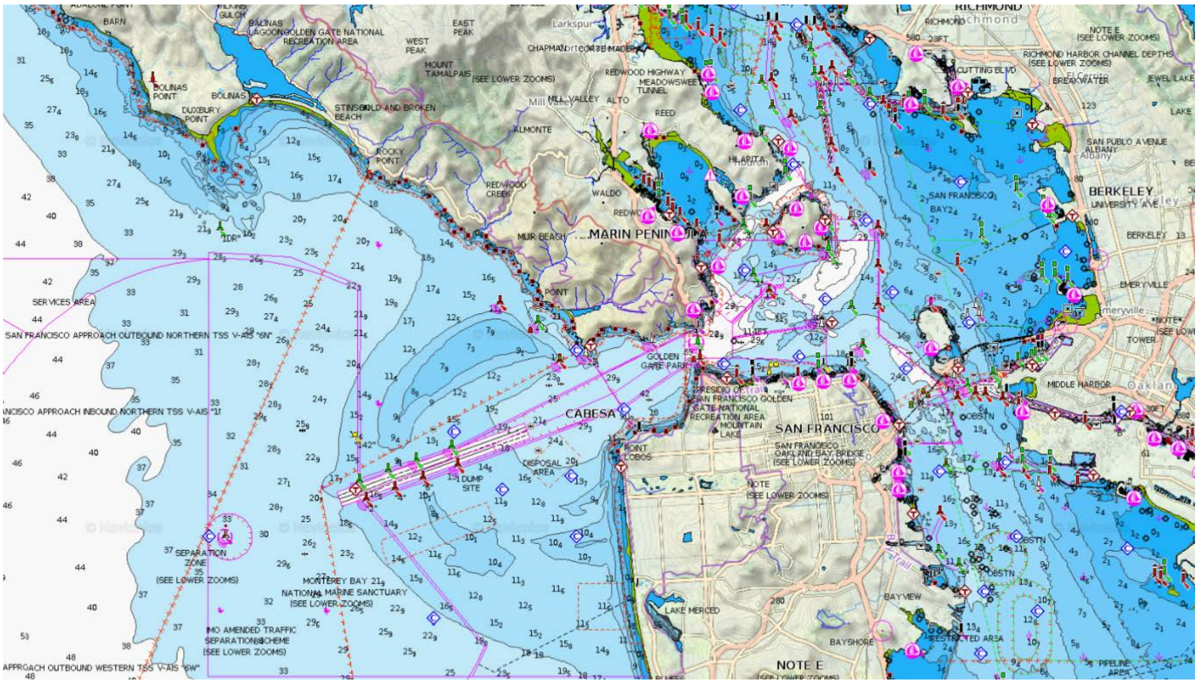


Figure 3-9: Hydrographic chart of San Francisco Harbour

Columbia River is a major river, the border between Oregon and Washington states. The firm headlands at the entrance direct the flow into the ocean, increasing the currents. Beyond the headlands where the river flow spreads out, the currents decrease. As a result, the entrance is naturally deep, with a shallower bar just offshore. The natural depth on the bar is between 12 m CD and 16 m CD. The bar is notorious for its rough weather, especially in winter. See Figure 3-10

Annually there are about 1,500 vessel calls, mostly bulk carriers (about 875) and car carriers (125).

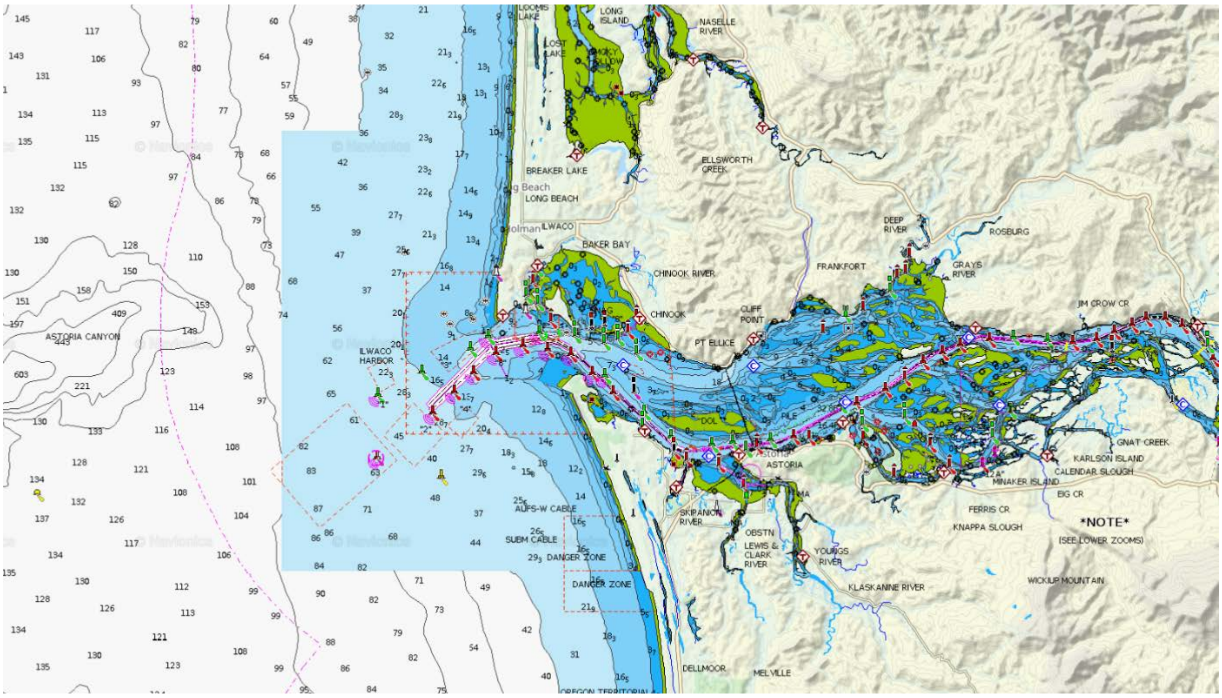


Figure 3-10: Hydrographic chart of Columbia River

Sydney's Botany Bay is an oceanic embayment with an open entrance. Its wide, shallow estuary is exposed to winds from all directions and waves from the adjacent high energy coastal zone. Waves and currents determine the erosion, deposition, transportation and therefore, the ultimate fate of sediment in the Bay. It has deep water immediately offshore, but a bar exists just inside the headlands with a minimum depth between 16 m CD and 15 m CD. See Figure 3-11.

Around 1600 ships carrying over 2.5 million containers (TEU) pass through Port Botany each year. Liquid bulk ships also use the port.

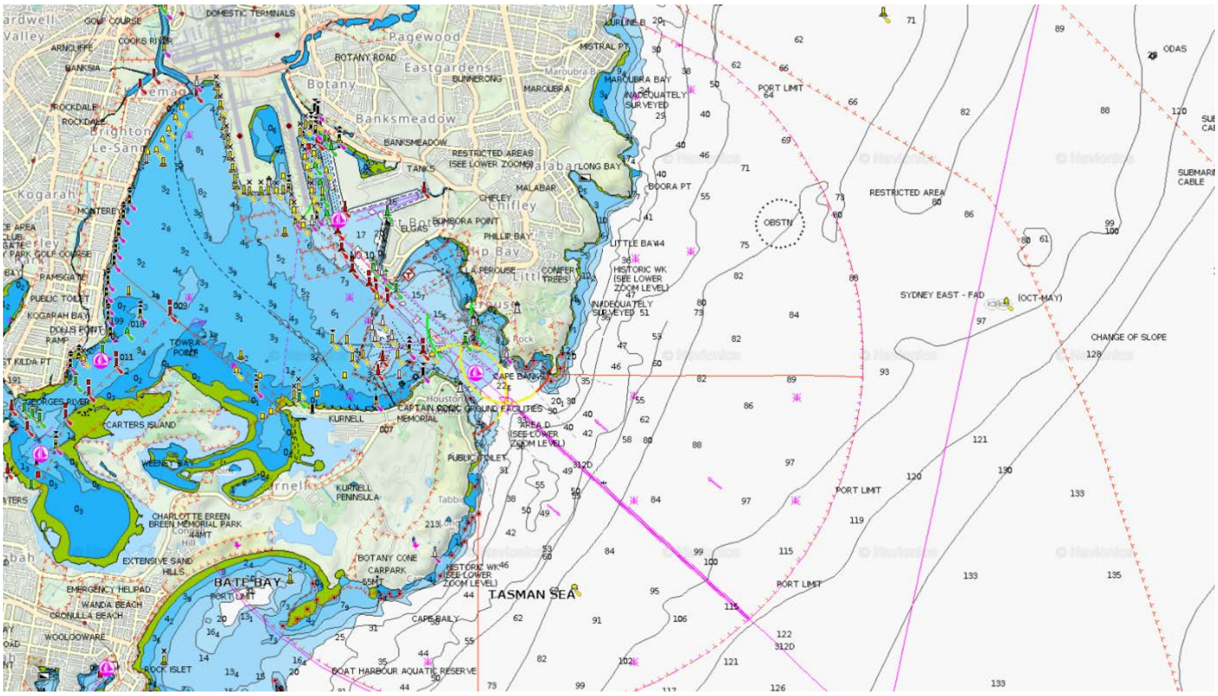


Figure 3-11: Hydrographic chart of Botany Bay

Melbourne's Port Phillip Bay is a large coastal lagoon with large sand spits on the open coast side. It has a narrow entrance (the Heads) with steep bathymetry. Energetic waves that propagate from the Southern Ocean interact with strong ebb tidal currents making wave conditions difficult, (the 'rip'). The natural bar is some 7 m CD to 10 m CD depth, dropping off to deeper water. A dredged ship channel through the Heads is maintained to 17 m CD at its deepest. See Figure 3-12

Around 3,500 ships visit Melbourne each year, a mixture of all types; containerships, general cargo, dry bulk, liquid bulk and others.

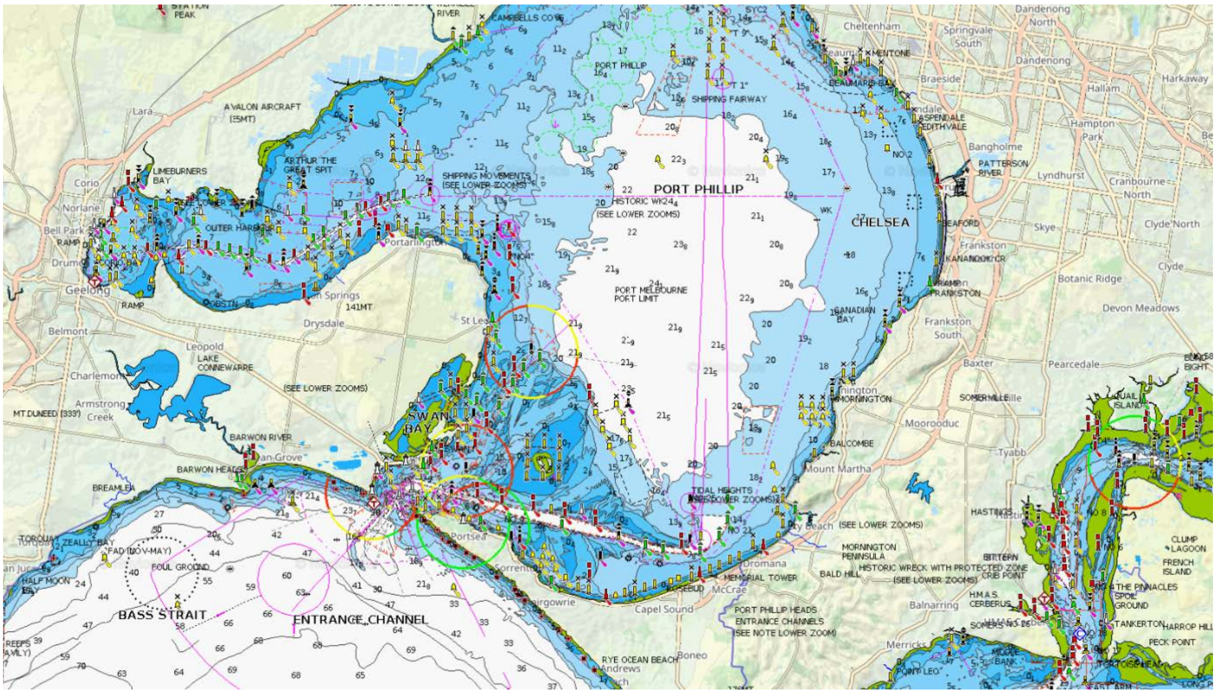


Figure 3-12: Hydrographic chart of Melbourne

3.2.2 Maintenance dredging

San Francisco's Main Ship Channel through the bar is maintained by dredging, usually on an annual basis. In 2020, 350,000 m^3 was dredged from the Main Ship Channel over two months. Silting is primarily tidal related with strong currents carrying material out of the Bay. Dredging disposal is approximately 90% sand and done in a position which allows dispersal to and feeding of a beach along the San Francisco Peninsula. Disposal amounts range from 75,000m^3 to 750,000 m^3 per year averaging at 300,000 m^3.

Annual dredging of the **Columbia River** entrance channel and bar is between 2.3 and 3.8M m^3.

At **Melbourne,** the current annual maintenance dredging task amounts to 770,000 m^3 of which 100,000 m^3 is removed from the South Channel at the Harbour entrance and the balance from the Northern part of Port Phillip Bay and the lower reaches of the Yarra River.

Very little maintenance dredging is required at **Botany Bay.**

Refer to Technical Working Paper 7a – Institutional Knowledge for further details.

3.2.3 Wind

Winds at the three of the four benchmark ports come from several directions. Columbia River mouth, however, has a strongly predominant wind from the NW. See Figure 3-13, Figure 3-14, Figure 3-15 and Figure 3-16.

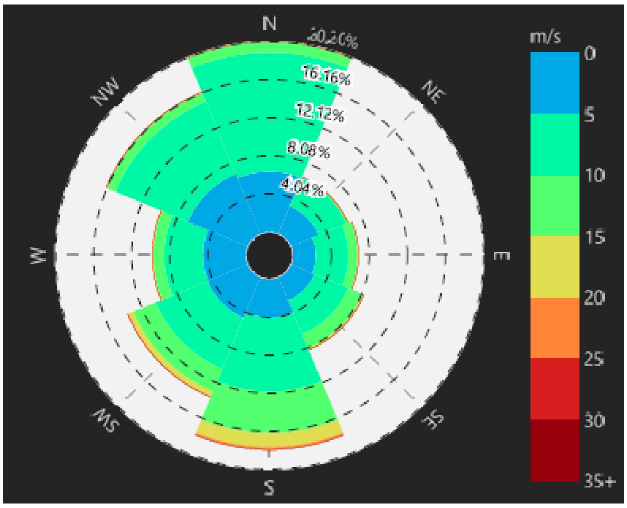


Figure 3-13: Wind rose, offshore San Francisco

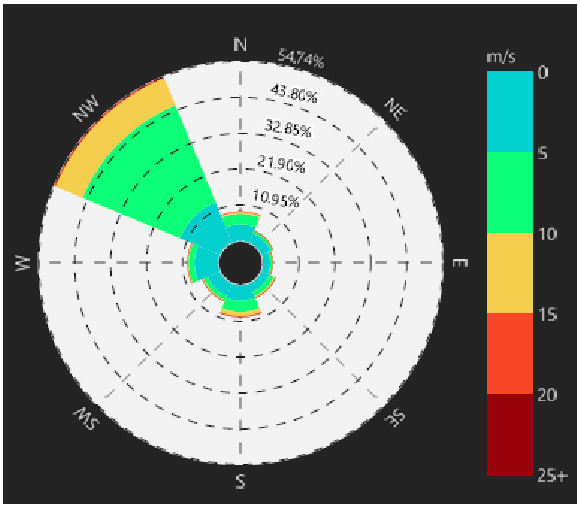


Figure 3-14: Wind rose, offshore Columbia River mouth

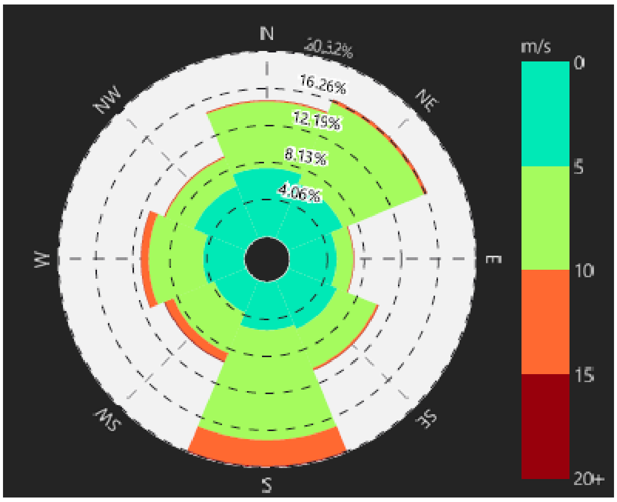


Figure 3-15: Wind rose, Botany Bay (NSW)

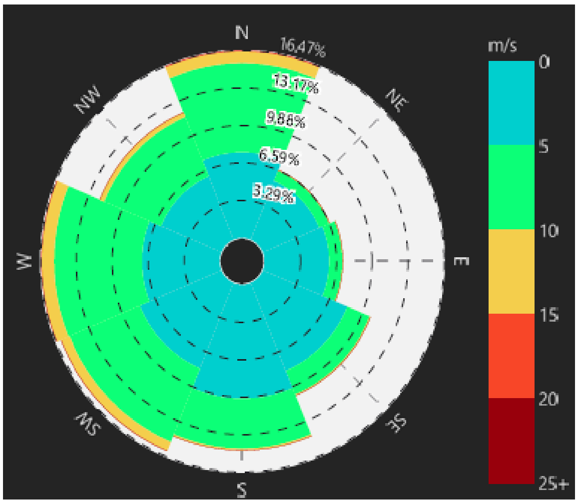
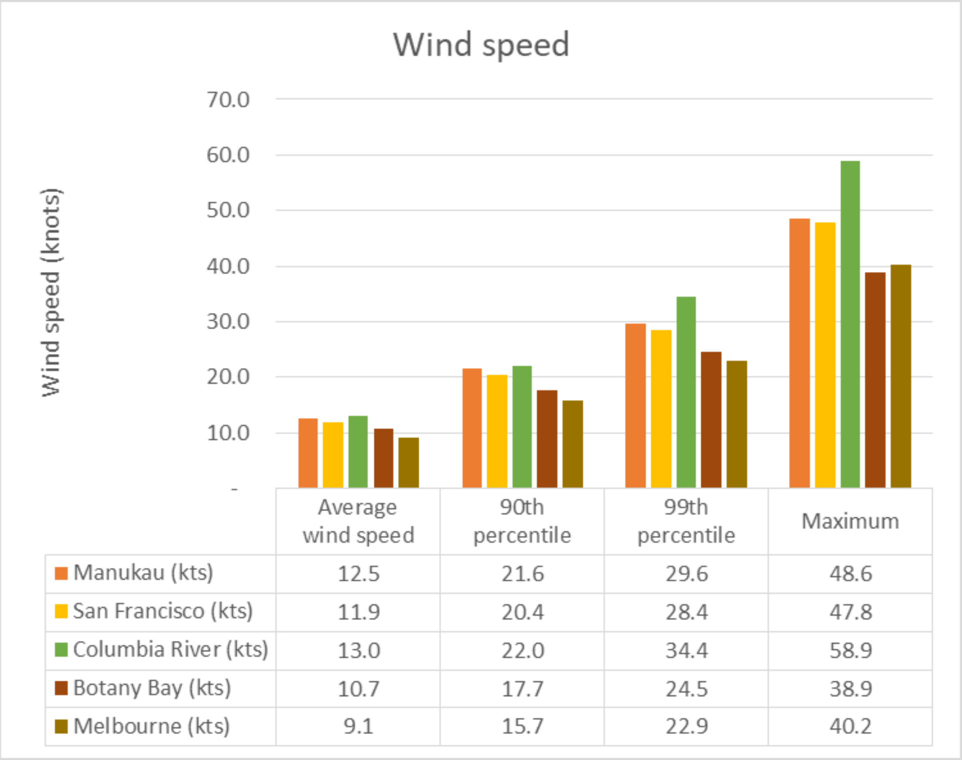


Figure 3-16: Wind rose, Port Phillip Bay heads (Victoria)

Wind speed data for the benchmarks[5] and Manukau are compared in Figure 3-17.

Manukau has similar average and 90th percentile wind speeds as Columbia River and higher than the other ports, but less extreme winds than Columbia River, whose 99th percentile wind is 34.4 knots, higher than Manukau's 31.9 knots. Botany Bay and Melbourne generally have lower wind speeds than Manukau, San Francisco and Columbia River.



	Average wind speed	90th percentile	99th percentile	Maximum
🟧 Manukau (kts)	12.5	21.6	29.6	48.6
🟨 San Francisco (kts)	11.9	20.4	28.4	47.8
🟩 Columbia River (kts)	13.0	22.0	34.4	58.9
🟫 Botany Bay (kts)	10.7	17.7	24.5	38.9
■ Melbourne (kts)	9.1	15.7	22.9	40.2

Figure 3-17: Wind speed comparison with benchmark ports

3.2.4 Swell and sea waves

The entrance to Manukau Harbour is exposed to swell coming up from the Southern Ocean, as well as local storms in the Tasman Sea and even ex-tropical cycles descending from the southwest Pacific Ocean. As a result, its metocean conditions are more severe than most places.

The west coast of North America is similarly exposed to long fetches of ocean, across the Pacific, with swells generated by high winds in the north Pacific especially in the winter.

---

[5] **Benchmark data sources**:

San Francisco: MSL WW3 Global ST4, at point: (237.0000, 37.50000), 1979 to 2017, 54.37 km 50 degs off Point Bonita, on the edge of Continental Shelf, depth 329 m below CD.

Columbia River: MSL WW3 Global ST4, at point: (235.5000, 46.00000), 1979 to 2017, 44.6 km 235 degs off southern head, on Continental Shelf, depth 148 m below CD.

Botany Bay: WW3 Southern Ocean ERA5/GLORYS ST4, at point: (151.2500, -34.1000), 7.6km offshore in depth 116m below CD, between 1993 and 2018

Melbourne: Australia Wave, at point: (144.6333, -38.3000) in the Port Philip Bay dredged entrance channel in 11.9m depth below CD, between 1979 and 2016

Wave height

Wave height hindcast data from the sources quoted above[6], i.e., at locations some distance offshore for San Francisco and Columbia River, are graphed in Figure 3-18. San Francisco and Columbia River experience similar conditions to those encountered at Manukau; for any given probability, San Francisco has slightly lower wave heights, and for year round, Columbia River slightly higher once wave heights exceed about 3 m (22% of the time)[7]. See Figure 3-18.

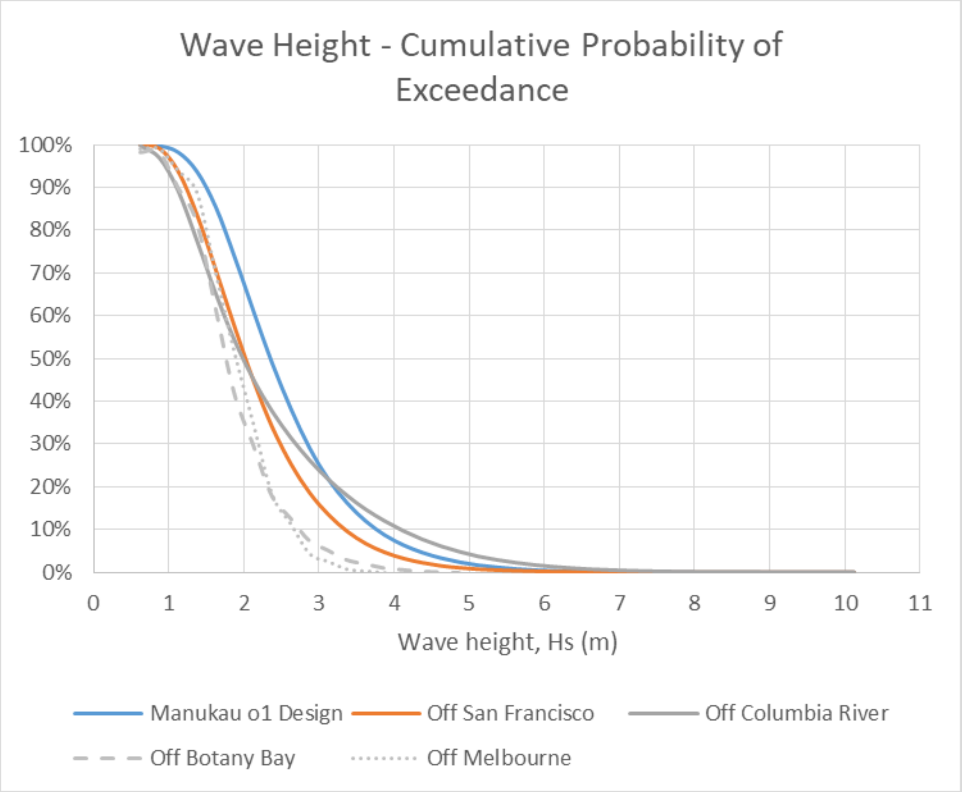


Figure 3-18: Significant wave height probability - Manukau compared with San Francisco and Columbia River (year round)

In winter conditions, the difference between Manukau and Columbia River becomes even more marked, with Columbia River conditions being worse than Manukau once wave heights reach about 2.2 m (70% of the time). See Figure 3-19Figure 3-19 below.

---

[6] See Footnote 4 for Manukau, Footnote 6 for the benchmark ports and Appendix 2 for a more full description. Although further offshore, the San Francisco and Columbia River hindcast locations are on the edge of the continental shelf, and we consider the wave conditions to be similar to those experienced further in, at 70m depth, where the Manukau hindcast is located

[7] Botany Bay and Melbourne do not experience the same wave regime as Manukau and the two North American ports and have been shown in grey dashed and dotted lines respectively.

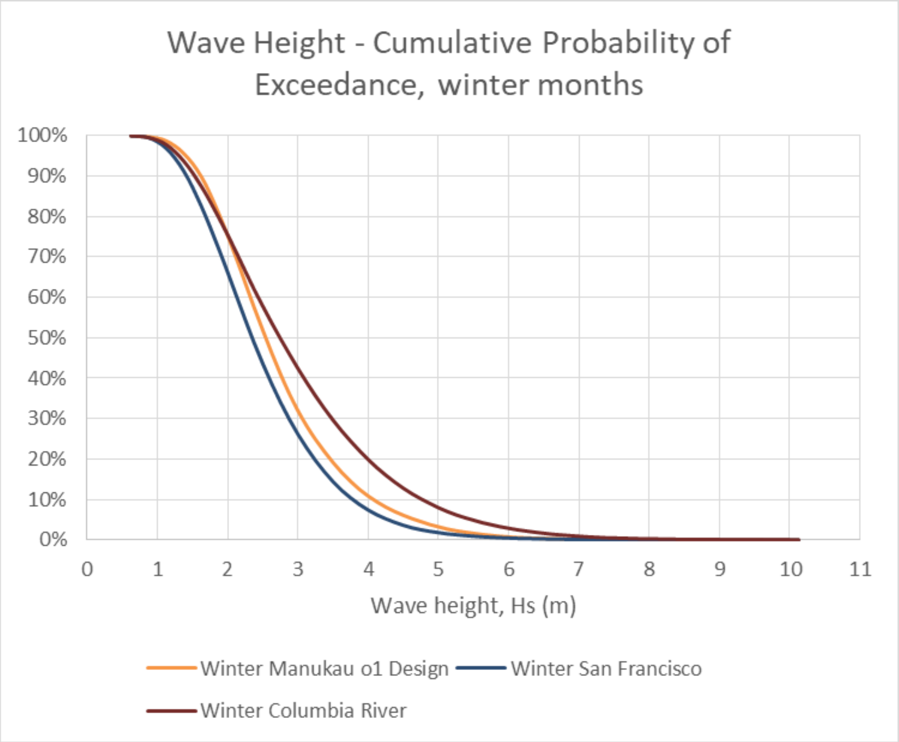
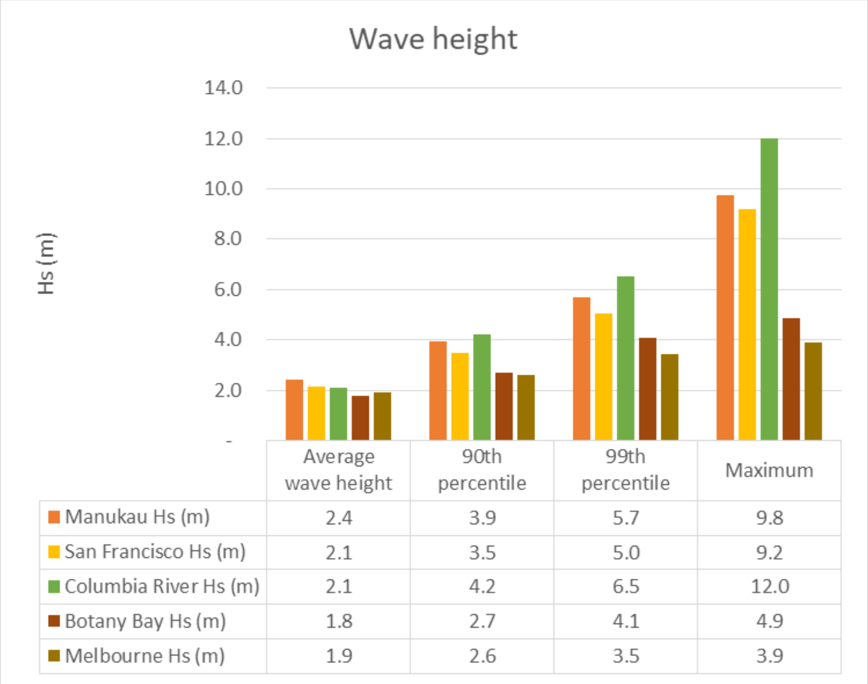


Figure 3-19: Significant wave height probability - Manukau compared with San Francisco and Columbia River (winter months)

Wave height data for the benchmarks and Manukau are shown in Figure 3-20Figure 3-20. Manukau has higher average wave heights than the other ports. Columbia River's 90th percentile, 99th percentile and maximum wave heights are greater than Manukau; the other ports lower. Botany Bay and Melbourne generally have lower wave heights than Manukau, San Francisco and Columbia River.



	Average wave height	90th percentile	99th percentile	Maximum
Manukau Hs (m)	2.4	3.9	5.7	9.8
San Francisco Hs (m)	2.1	3.5	5.0	9.2
Columbia River Hs (m)	2.1	4.2	6.5	12.0
Botany Bay Hs (m)	1.8	2.7	4.1	4.9
Melbourne Hs (m)	1.9	2.6	3.5	3.9

Figure 3-20: Wave height comparison with benchmark ports

Wave period

85% of waves offshore of Manukau Harbour have a peak period between 10 s and 17 s. San Francisco and Columbia River wave periods have wider bandwidths and more short/ low period waves, with 70% and 69% lying between 10 s and 17 s respectively, i.e. not dissimilar to Manukau. However, Manukau has only 18% waves with peak periods between 7s and 12s, whereas San Francisco and Columbia River have 40% and 50% respectively. See Figure 3-21.

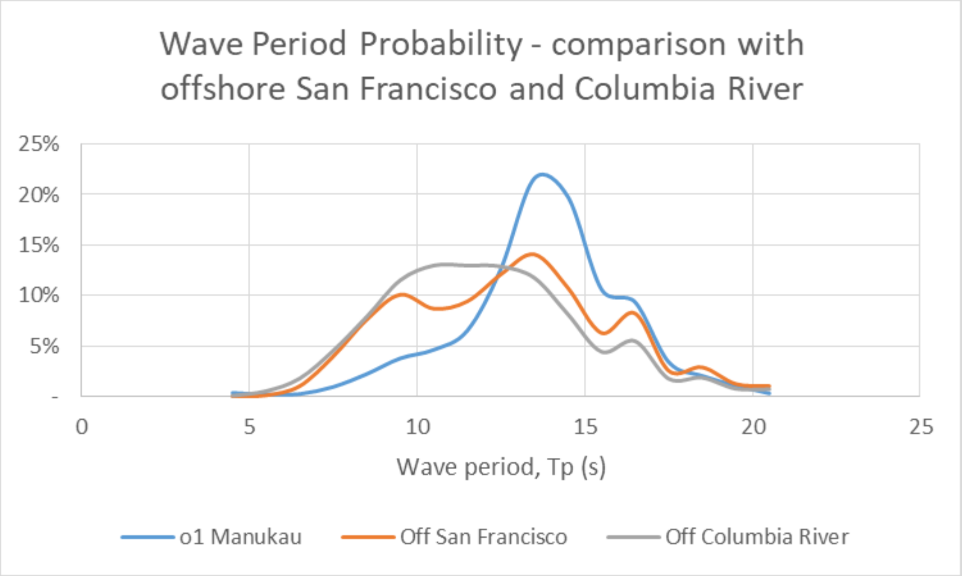


Figure 3-21: Wave period probability – Manukau (o1) compared with San Francisco and Columbia River

3.2.5 Currents

San Francisco, Columbia River and Melbourne have strong tidal currents at their entrances, from large estuaries in the case of San Francisco and Melbourne, and from a large river at Columbia River. Botany Bay's tidal currents are very low in comparison. See Figure 3-22.

In the Golden Gate channel at San Francisco, ebb tide currents can reach 4.5 knots at spring tides, flood tide currents 3.0 knots. Neap tide currents are about 2.3 to 2.4 knots[8]. These rates are slightly higher but similar to those modelled for Manukau Harbour's entrance channel (see Section 3.1.3 above).

Columbia River mouth flows depend on the river flow. At river mile zero (between the breakwaters at the mouth), ebb tide flows normally peak in the range 2 m/s (4 knots) to 2.5 m/s (5 knots) and can reach 3 m/s (6 knots) plus. Flood tide inward flows are in the range 1.5 m/s (3 knots) to 2 m/s (4 knots) but can be outwards, between slack and 1 knot[9].

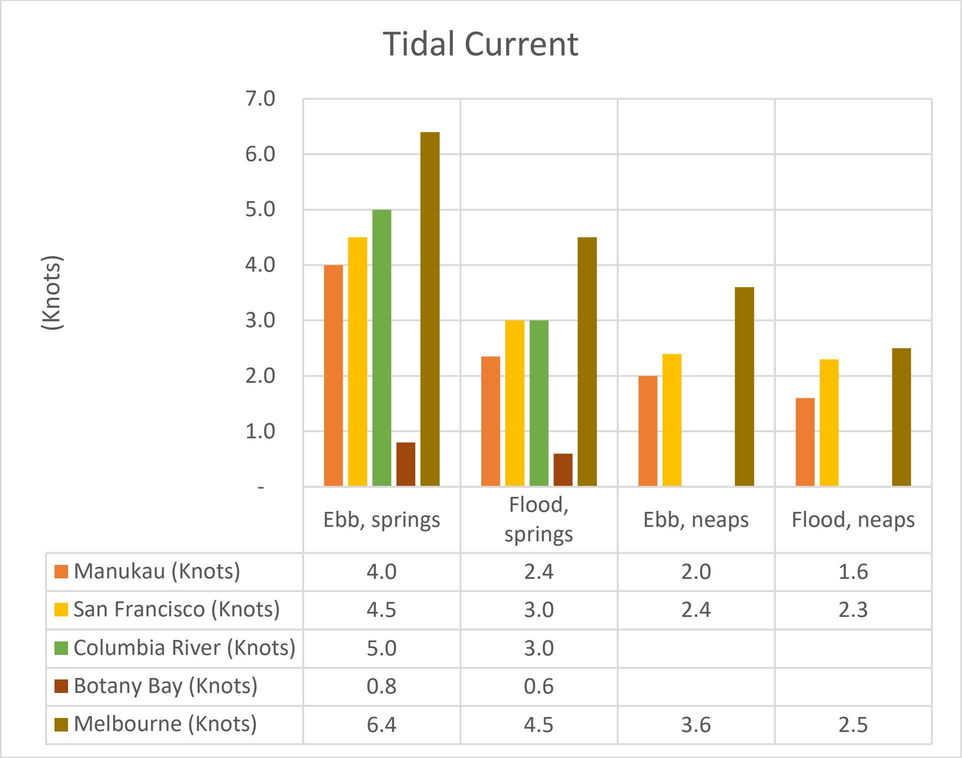
---

[8] NOAA Current Predictions, San Francisco Bay Entrance (Outside) (SFB1201) Depth: 58 feet, https://tidesandcurrents.noaa.gov/noaacurrents/Annual?id=SFB1201_20

[9] NOAA Current Predictions, Sand Island Tower, 1nm SE of (midchannel), https://tidesandcurrents.noaa.gov/noaacurrents/Annual?id=PCT1106_1

Port Phillip Heads at Melbourne experiences 6.4 knot ebb tidal streams and 4.5 knot floods at springs. Neaps are about 3.6 knots and 2.5 knots respectively. These are 50% greater than Manukau at springs, and about the same at neaps[10].

Botany Bay heads experience maximum tidal flows of about 0.8 knots ebb and 0.6 knots flood.



	Ebb, springs	Flood, springs	Ebb, neaps	Flood, neaps
🟧 Manukau (Knots)	4.0	2.4	2.0	1.6
🟨 San Francisco (Knots)	4.5	3.0	2.4	2.3
🟩 Columbia River (Knots)	5.0	3.0		
🟫 Botany Bay (Knots)	0.8	0.6		
🟫 Melbourne (Knots)	6.4	4.5	3.6	2.5

Figure 3-22: Tidal current comparison with benchmark ports

3.3 Waves at bar entrances

As water shallows, waves interact with the seabed, causing them to slow down, initially slightly reducing in height then increasing (shoaling). When waves are in this transition (slowing down as the depth reduces), the wave period does not change; instead, the wavelength shortens, thus steepening the wave slope. Eventually when very shallow water is reached (when depths are between 1 to 2 times the wave height) the waves will break, thereafter rapidly losing energy.

Waves crossing a bar change wavelength and steepness rapidly. This is important for ships; their response to waves is magnified at wavelengths similar to the ship's own length. When heading into waves, sudden changes in wavelength create sudden changes in response, especially vertical motions and accelerations.

Tidal currents are also important in estuaries. When the current is moving in the opposite direction to the waves, the waves get steeper. This is why harbours such as the Manukau, which has a large tidal range, can be deceptively dangerous, especially for small boats.

---

[10] Australian Bureau of Meteorology, Tidal Stream Predictions, The Rip – Victoria

3.3.1 San Francisco and Columbia River bars

Wave rider buoys are located at the entrances to both San Francisco and Columbia River. The wave height and energy reduction compared with deeper water is evident in the wave rider buoy records.

At *San Francisco bar*, the wave height probability of exceeding a 3 m wave reduces from 14% at an offshore location (54 km offshore) to only 4% at the bar, and a 4 m wave reduces from 3% offshore to less than 1%. The wavelength change is very marked; a change in wavelength range from up to 600 m and greater offshore, to less than 300 m at the bar. The peak at the bar is very narrow with most waves being between 100 m and 200 m length, of concern to medium sized ships.

At *Columbia River mouth*, the wave height probability of exceeding a 3 m wave reduces from 22% at an offshore location (44 km offshore) to 14% at the bar, and a 4 m wave reduces from 10% offshore to 5%. The wavelength change is also very marked; a change in wavelength range from up to 600 m and greater offshore, to less than 300 m at the bar. The wave lengths at the bar however have three peaks at about 90 m, 140 m and 210 m, still of concern to small and medium sized ships.

We were not able to obtain actual wave buoy records for either Botany Bay or Melbourne.

3.3.2 Waves at Manukau Bar

There is no long-term data set from a wave buoy on the Manukau bar. To provide a comparison with San Francisco and Columbia River, the MetOcean hindcast for the existing bathymetry at location c36 in similar depths to the wave buoys at those two benchmark ports has been used. C36 is on the outside slope of the bar in a depth of CD-16.5m.

At *Manukau Bar*, the wave height probabilities between o1 offshore and c36, on the outer bar slope provide a similar result to the benchmark ports' offshore/ bar comparisons. At Manukau, the probability of exceeding a 3 m wave reduces from 28% at the offshore location to 19% at the bar, and a 4 m wave reduces from 9% offshore to 5%. See Figure 3-23.

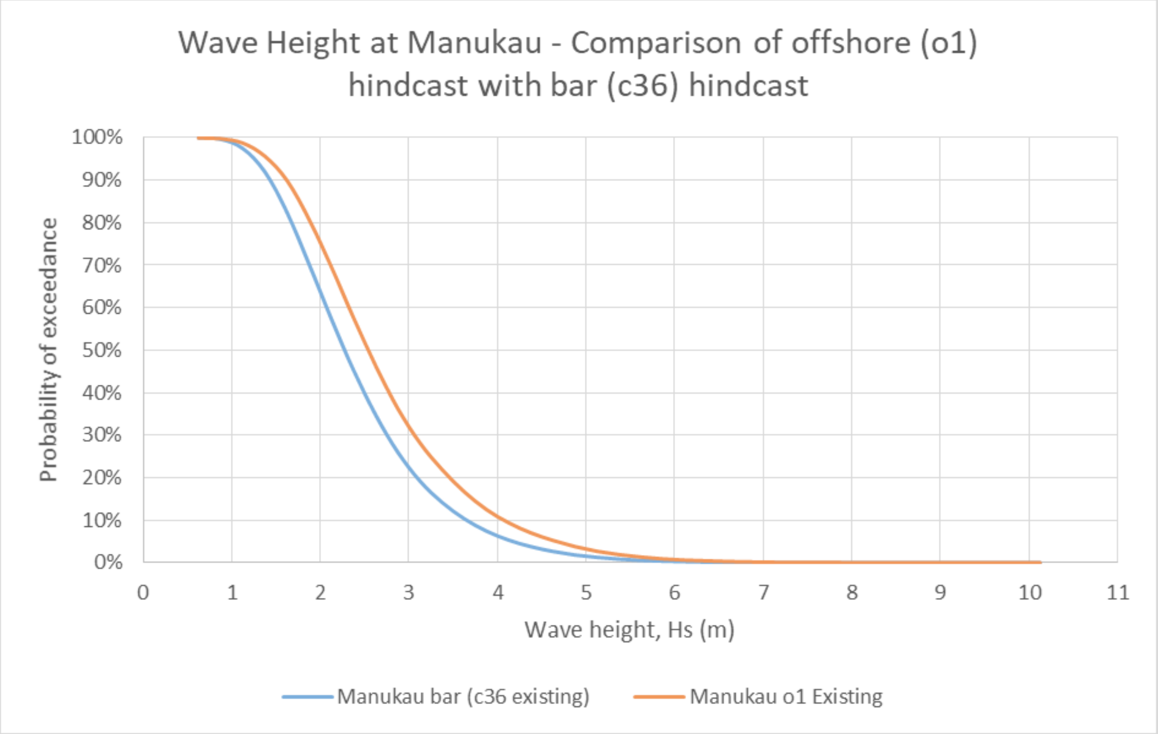


Figure 3-23: Significant wave height - comparison of offshore (o1) hindcast with bar (c36) hindcast – Manukau Bar

As with the two other benchmark ports above, at Manukau bar the wavelength change is also very marked; a change in wavelength range of up to 500 m and greater offshore, to less than 200 m at the bar. The peak at the bar is very narrow with most waves being between 150 m and 250 m length, the size of medium sized ships. See Figure 3-24.

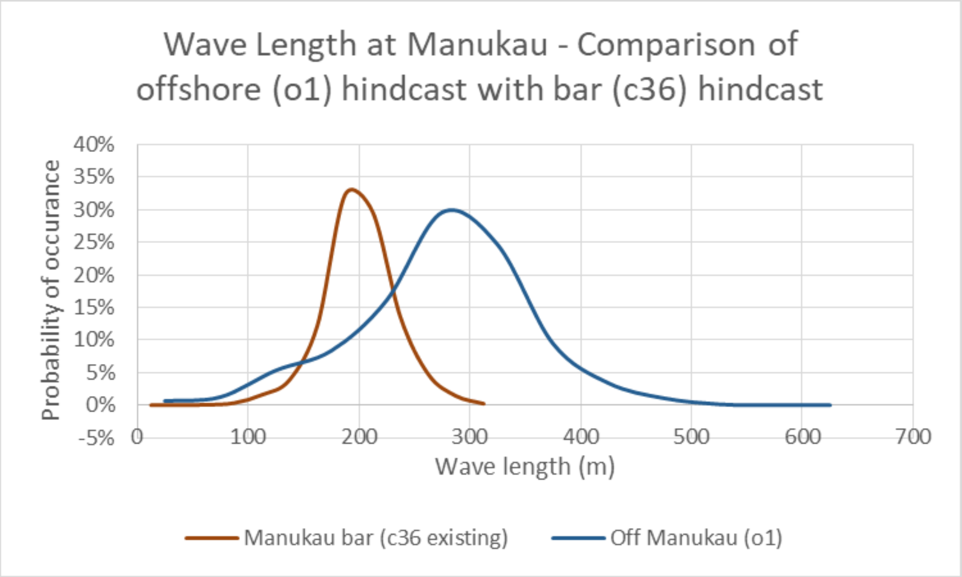


Figure 3-24: Wave Length - comparison of offshore (o1) hindcast with bar (c36) hindcast – Manukau Bar

3.3.3 Comparison of bar wave conditions at Manukau, San Francisco and Columbia River

Comparing Manukau with the benchmark ports, Manukau bar has a greater probability of high waves. Figure 3-25. This is disadvantageous to ship crossing.

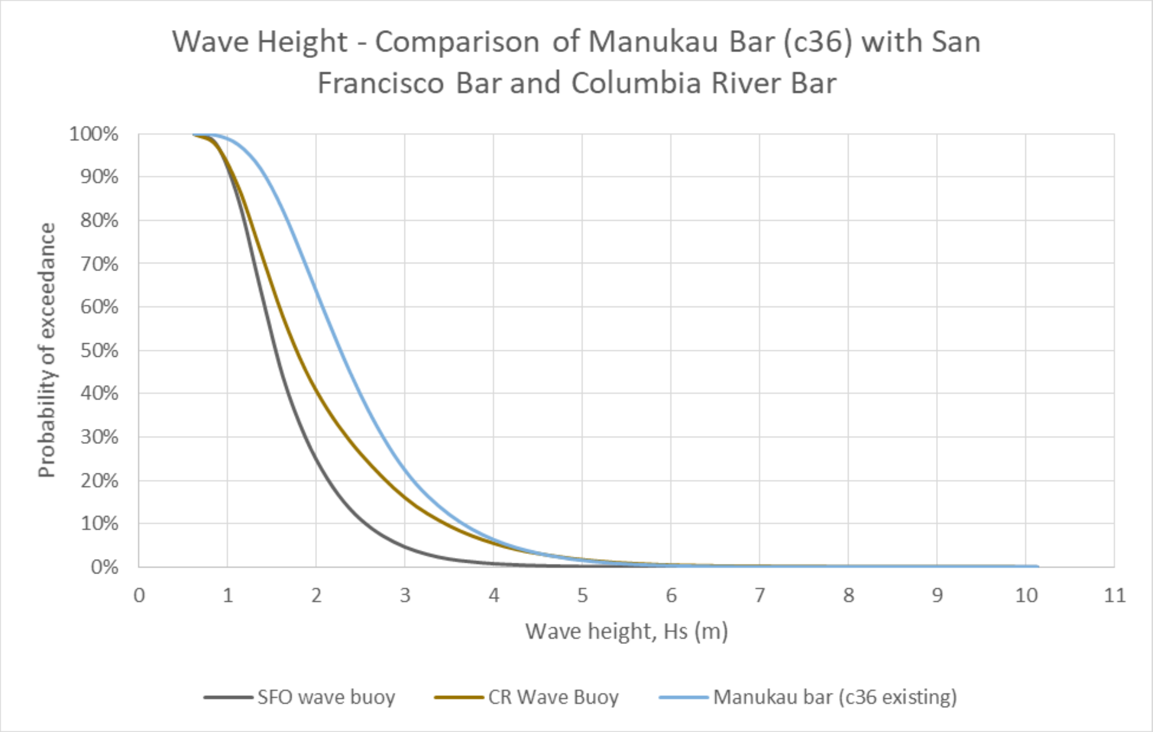


Figure 3-25: Wave height - Comparison of Manukau bar with San Francisco and Columbia River bars

But Manukau Bar has longer wave lengths than San Francisco and Columbia River. That is, Manukau will be more kindly to short, small ships, those less than 150m length. See Figure 3-26.

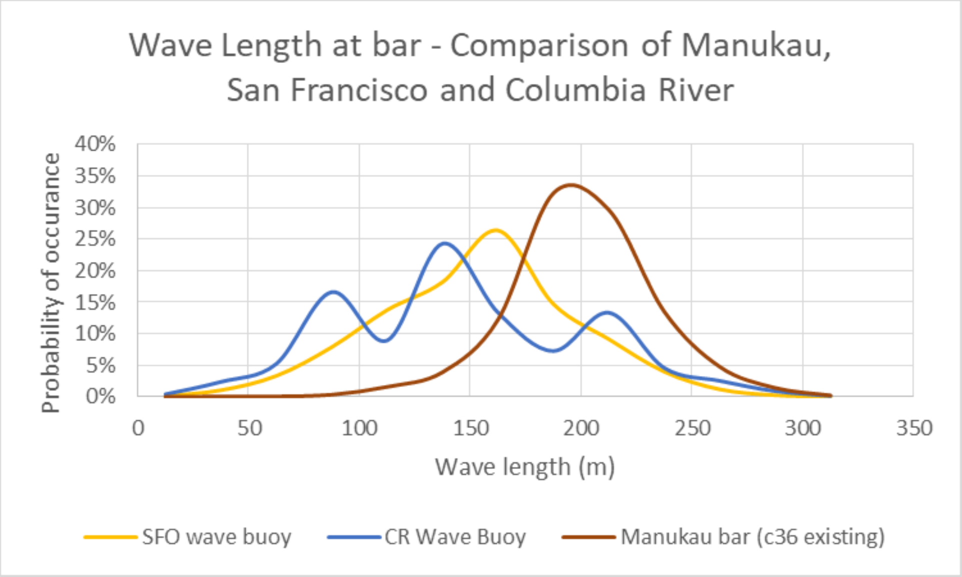


Figure 3-26: Wavelength - Comparison of Manukau bar with San Francisco and Columbia River bars

3.4 Conditions in the Design Ship Channel

The dredged design ship channel at Manukau bar, the South-West Channel, runs from Location c36 on the outside to Location c33 on the inside, a distance of some 3km (1.6nm). The water flow before and after the dredged channel is influenced by the channel, so the wave and current conditions interact further than this distance. The wave height, wavelength and current conditions for Locations c38 to c31 are shown in Figure 3-27, Figure 3-28 and Figure 3-29 below.

3.4.1 Ship channel wave height

In the figures below, the yellow line is c35, the crest of the bar. The three locations outside the bar, c36, c37 and c38 have greater probabilities of higher wave heights. Inside the bar, c31 to c34, the wave height is attenuated; the waves refract out of the channel onto the adjacent shallower bar.

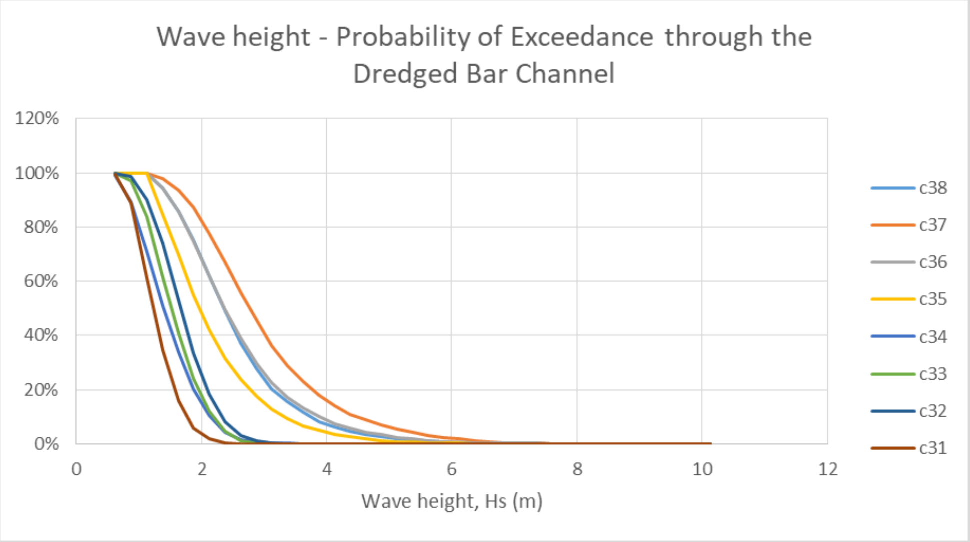


Figure 3-27: Wave height - Probability of Exceedance through the Dredged Bar Channel

3.4.2 Ship channel wave length

We are more interested in wavelength than wave period; it is the relationship between a ship's length and its encountered wavelength that causes ship motions. Period does not change even in shallowing water. Wavelength does. In the slightly deeper water at c38 and c37, the wavelength probability shows longer wavelengths than in the uniformly deep channel.

The peak wavelength in the channel is between 175m and 200m. Once over the crest of the bar (c35), the probability of the peak wavelength reduces, with the difference tending to spread to much shorter wavelengths.

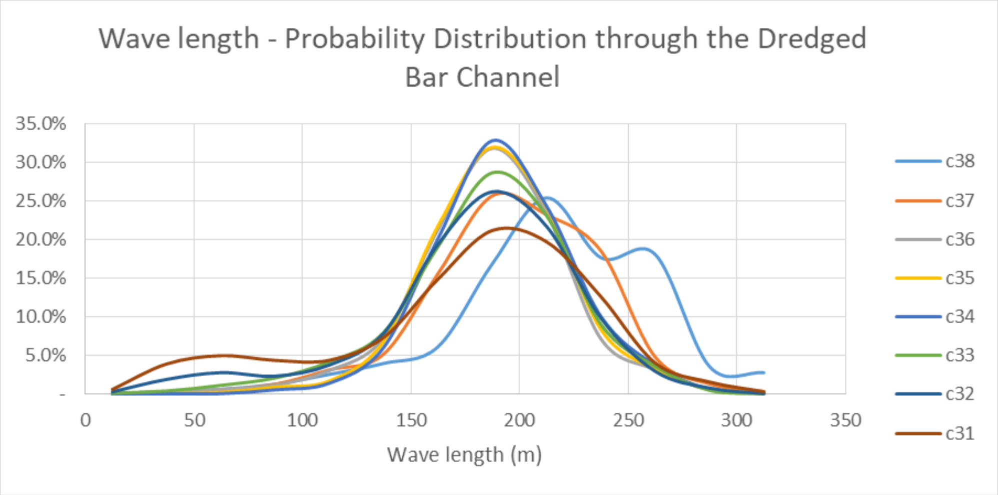
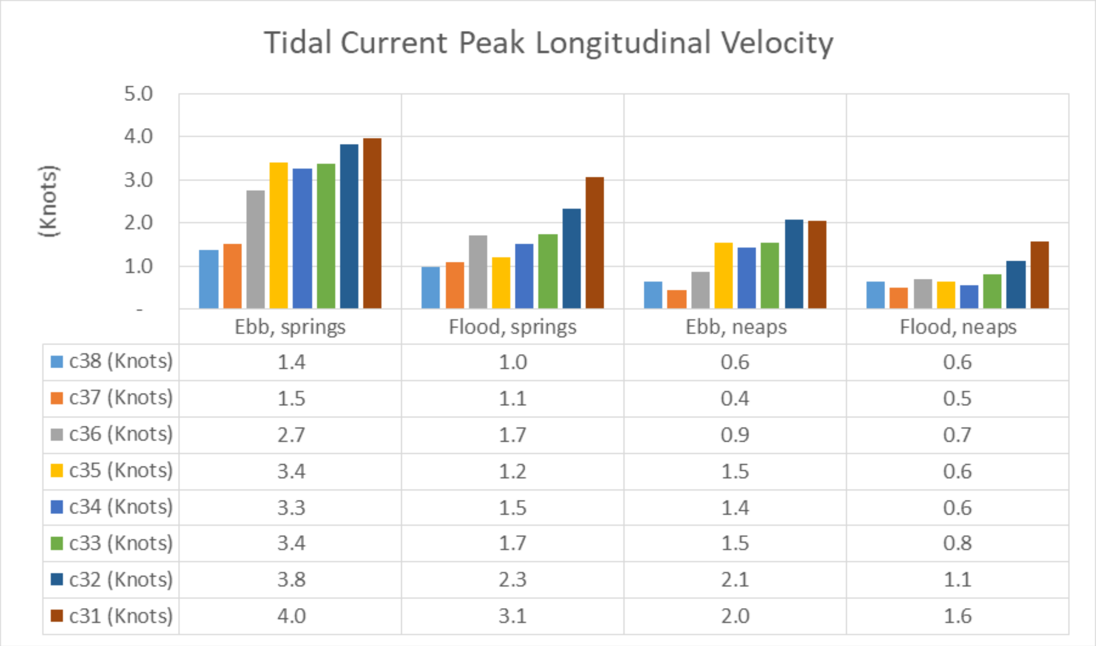


Figure 3-28: Wave length - Probability Distribution through the Dredged Bar Channel

3.4.3 Ship channel currents

Tidal currents are strongest on the inshore end of the channel, with ebb peaks stronger than floods. The ebb velocity drops off sharply once the current is over the crest.



	Ebb, springs	Flood, springs	Ebb, neaps	Flood, neaps
■ c38 (Knots)	1.4	1.0	0.6	0.6
■ c37 (Knots)	1.5	1.1	0.4	0.5
■ c36 (Knots)	2.7	1.7	0.9	0.7
■ c35 (Knots)	3.4	1.2	1.5	0.6
■ c34 (Knots)	3.3	1.5	1.4	0.6
■ c33 (Knots)	3.4	1.7	1.5	0.8
■ c32 (Knots)	3.8	2.3	2.1	1.1
■ c31 (Knots)	4.0	3.1	2.0	1.6

Figure 3-29: Tidal Current Peak Longitudinal Velocity through Dredged Bar Channel

4 Port Closure (Suspension of Pilotage)

4.1 Benchmark ports

It is apparent from data and information obtained from the benchmark ports that the most common reason for port closure is suspension of pilotage. Our contact at Columbia River highlighted three considerations:

- Is it safe for the ship?
- Can the pilot get on or off?
- Can the pilot boat or helicopter get home after the transfer?

He stated that this changes with the flood or ebb currents, high or low tide, swell period and directions of swell, seas and wind.

Columbia River's bar closure data shows that over the last 29 years, there were 209 closures. An average of 54 ships a year were delayed on 7 occasions pa for an average of 18 hours each. In the last 10 years there were 77 closures. In this period, closures averaged delays to 63 ships a year on 8 occasions delayed for 21 hours each. Analysis of their data shows a reasonably close correlation with wave height. Closures over the 10 years from 2013 coincided with wave conditions that averaged 4.8m significant wave height. The distribution of wave heights for these closures had a standard deviation of 0.9 m, 5th percentile of 3.4 m and a 95th percentile of 5.8 m. These closures occurred on about 3% of possible ship transits. A wave height of 4.8 m occurred 1.8% of the time at the nearby Clatsop Spit wave buoy. A wave height of 4.5 m occurred 2.7% of the time.

Ebb currents are very high at the Columbia River mouth normally peaking in the range 2 m/s (4 knots) to 2.5 m/s (5 knots) and can reach 3 m/s (6 knots) plus. This is about 1 knot more than the Manukau entrance where the modelling indicates ebb currents between 2 and 4 knots. It could be that the difference between 3% closures at wave heights occurring 1.8% of the time is explained on many occasions, by the high rate of river flow and ebb tide flow at lower wave heights causing conditions that close the bar[11].

Swell period when Columbia River bar was closed averaged 12.7 seconds, with a 90% probability range of 9.2 s to 16.4 s. This is typical of ocean swells. The swell direction is fairly consistently normal to the shoreline. Note that Columbia River pilots predominantly board by helicopter.

San Francisco has very few bar closures. The USCG operate the Vessel Traffic Service (VTS) for San Francisco and advised that they recorded no closures due to weather conditions (other than fog) in the past 10 years. San Francisco Bar Pilots Association advise that they do not record suspension of pilotage because they are very infrequent and are generally for only 6 to 12 hours. Ship's agents are notified in advance so they can plan accordingly. The consensus among our contact's colleagues is that out of 7,000 bar crossings per year, fewer than 8 (0.1%) are delayed due to weather and UKC concerns. Their guidelines are to suspend pilotage in sustained winds greater than 40 knots or seas exceeding 4 m, depending on ship size and power. They also avoid strong ebbs. Pilots at San Francisco board by pilot boat.

---

[11] Note that the Columbia River Bar Pilots Association data does not differentiate between causes. Suspensions may be for any of safety of the ship, pilot getting on or off, or ability for pilot boat or helicopter get home after the transfer.

Melbourne's harbour master stated that in general, entry into the Harbour is limited only by the swell or sea state and pilots will stop boarding when wave height exceeds 4 m. There are also tidal rate restrictions on ships transiting at Port Phillip Heads. For example, non-tanker ships with draft greater than 12.1 m are not permitted to transit through the heads when the tidal streams reach 5 knots inbound (flood or ebb), 5 knots flood outbound or 4 knots ebb outbound. Tankers, oversized ships and low-powered ships are more restricted.

These rates are normally only met for a few days either side of spring tides, and only on the ebb. So in a 2 week period, for say, 6 days and 4 hours a tide (8 per day), ships may be restricted. That is, about 14% of the time, ships are restricted for 1 to 4 hours duration. Pilots at Melbourne board by pilot boat.

At **Sydney**, the port also does not "close" but rather "suspends pilotage" – this happens 5 or 6 times a year, most closures are for 12 to 24 hours. A recent closure (2023) was for 26.5 hours while in January 2023 there was a closure for 60 hours. The longest closure was for 96 hours, five years ago in 2018 when there was a massive East Coast Low. Closures occur at 30kt cross winds and if this is not reached, if 6 m of swell is exceeded. Pilots at Sydney board by pilot boat.

4.2 Closure/ suspension criteria

The limiting metocean conditions suggested by the PIANC standard and at the benchmark ports can be summarised:

Wind:

- PIANC 32 knots gusts (29 knots sustained) longitudinally
  29 knots gusts (26 knots sustained) cross wind
- San Francisco: Sustained 40 knots
- Columbia River 50 knots
- Sydney: 30 knots cross wind

Wave height:

- PIANC 5 m longitudinally, 3m cross component
- San Francisco: 4.0 m (very infrequently reached)
- Columbia River: 4.8 m average with a range from 3.4 m to 5.8 m
- Melbourne: 4.0 m (very infrequently reached)
- Sydney: 6.0 m (very infrequently reached)

Currents:

- PIANC 4 knots longitudinally, 2 knots cross current
- San Francisco: Avoid high ebb currents
- Columbia River: High ebb currents, occurring on most tides
- Sydney: n/a (very little within harbour)
- Melbourne:
  - Inbound: 5 knots (flood or ebb).
  - Outbound: 5 knots flood, 4 knots ebb

See also Figure 4-1.

Note that at places that are exposed to weather such as Columbia River and Newcastle, NSW, helicopters are used for 65% and 85% of transits respectively, as well as pilot boats in order to reduce the number of pilotage suspensions.

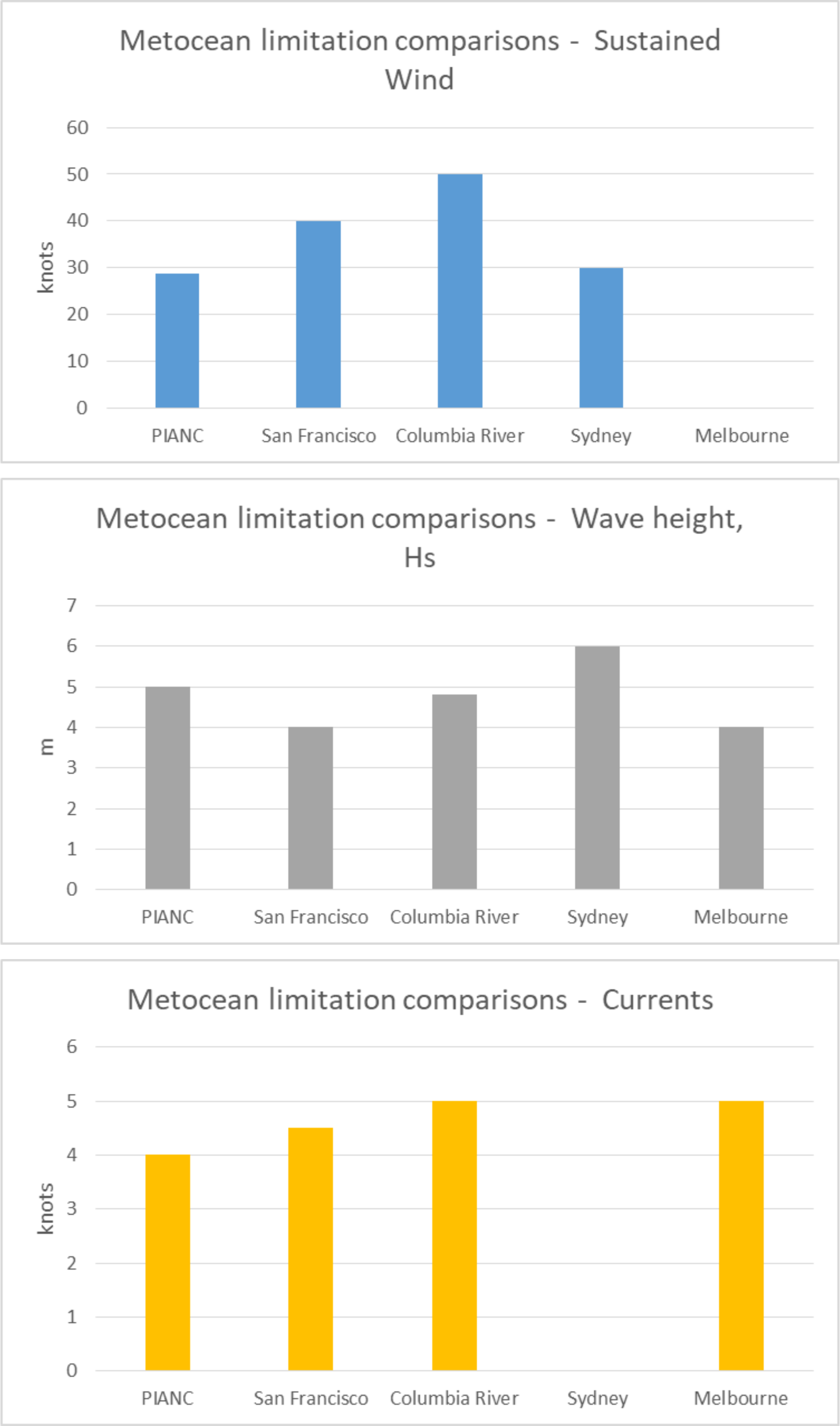


Figure 4-1: Metocean limitation comparisons - wind, wave and current

4.3 Port closure/ pilotage suspension at Manukau

As discussed in the above section, port closure as a result of pilotage suspension is the most common cause of downtime for port entry or exit. Pilotage suspension occurs when weather thresholds are exceeded, most commonly excessive wave action, but sometimes severe wind or high tidal currents.

For our analysis we have chosen a pilot boarding ground just outside the ship channel at Location o5.[12] See Figure 4-2

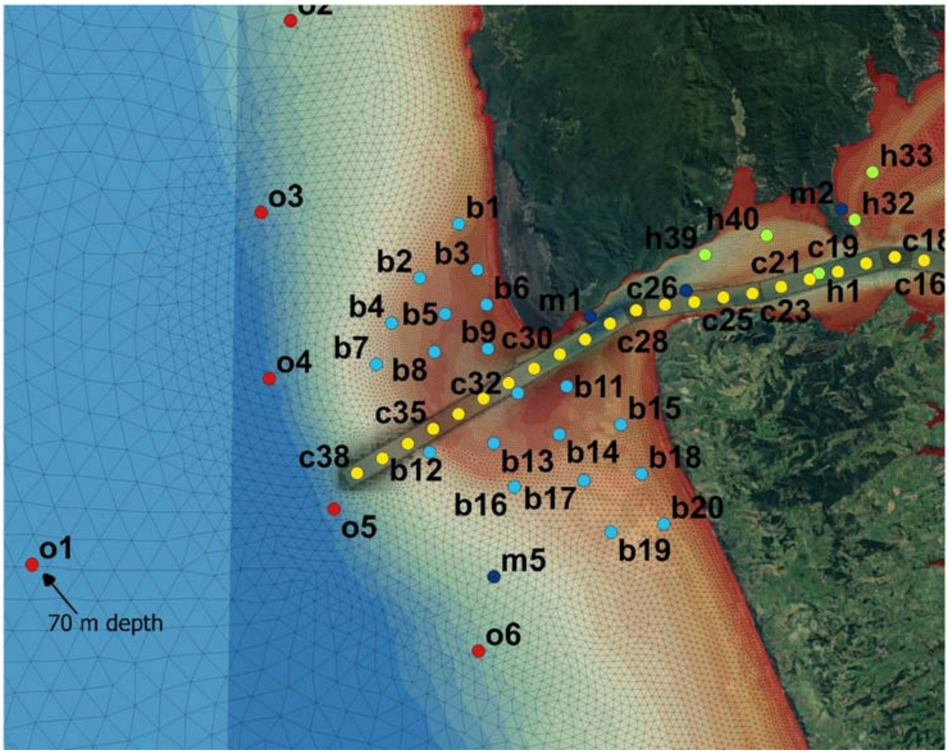


Figure 4-2: Pilot boarding ground, location o5

The *wave height* exceedance probabilities at o5 across the range of thresholds for our benchmark ports are:

- Hs = 4m (San Francisco and Melbourne): 6.2%
- Hs = 5m (PIANC and Columbia River): 2.0%
- Hs = 6m (Sydney): 0.4%

See Figure 4-3. This graph also compares the wave height probability of location o5 with o1.

---

[12] o5 is at 174.41441ºE 37.1064ºS in a depth 42 m below CD about 2.5 nautical miles (4.6km) beyond the crest of the bar on the outer slope, and 5.43 nautical miles (10.05km) 231.7º from Ninepin Rock.

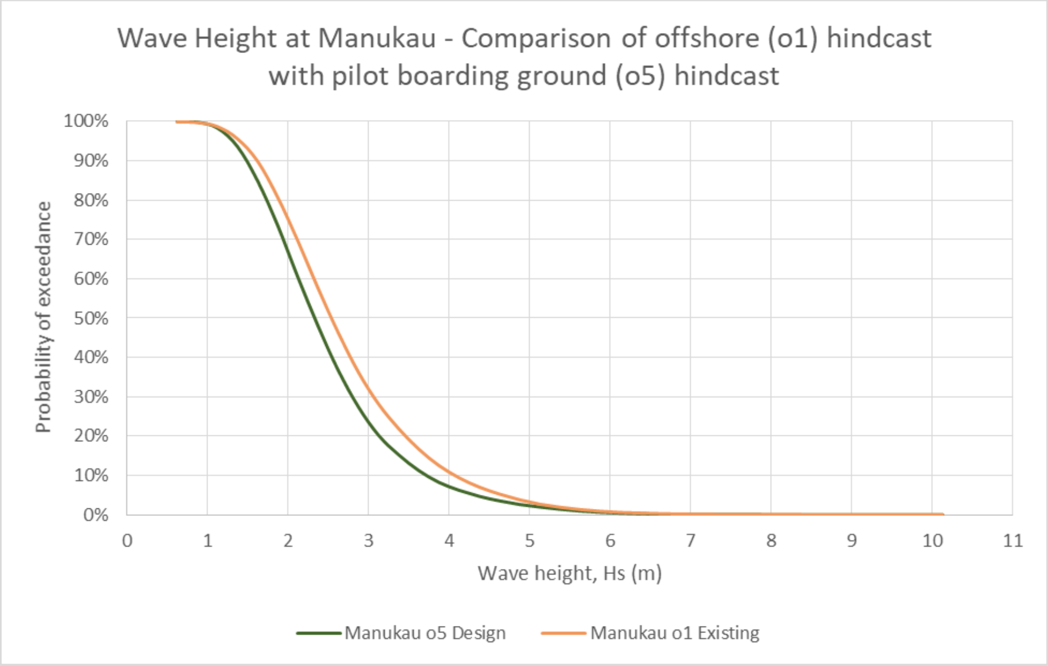


Figure 4-3: Wave height probability of exceedance at Location o5 - Pilot boarding ground

If the *wind speed* threshold is reached but the wave height threshold is not, suspension of pilotage will occur because of wind (rather than waves). The sustained wind speed exceedance probabilities at o5 are:

29 knots (PIANC)	1.0%
40 knots (San Francisco)	0%
50 knots (Columbia River)	0%
30 knots (Sydney)	0.7%

That is to say, these thresholds are infrequently reached at Manukau heads. See Figure 4-4.

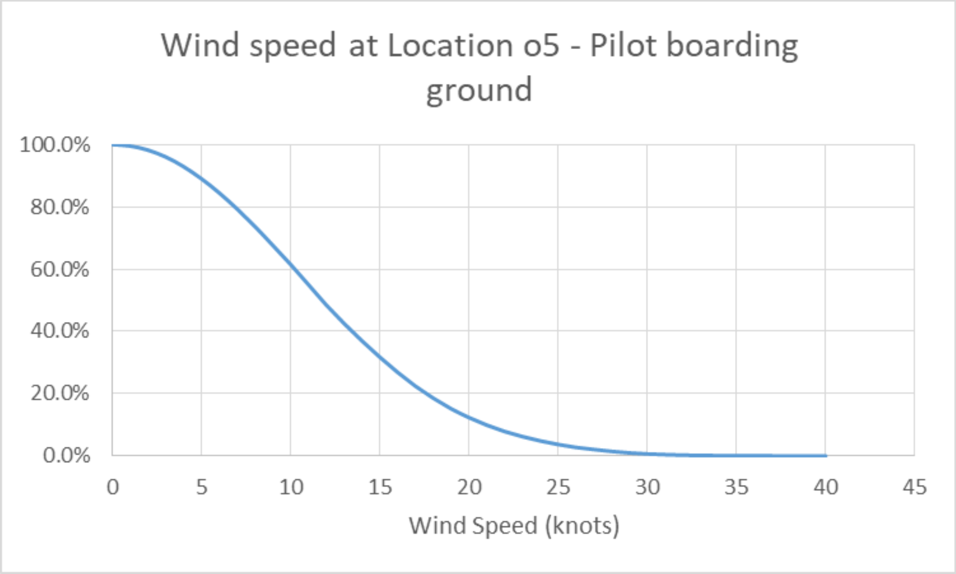


Figure 4-4: Wind speed probability of exceedance at Location o5 - Pilot boarding ground

Peak *currents* at full ebb on spring tides reach less than 1.5 knots outside the bar, well below the threshold currents at the benchmark ports.

4.4 Downtime

At Manukau, not all ships will require a pilot. Small vessels such as small fishing boats (and of course pleasure craft) will not. And regular users such as coastal feeder ships or coastal bulk carriers can apply for pilotage exemptions for their Masters. But nearly all overseas ships and high risk domestic ships such as tankers and chemical carriers visiting Manukau would be required to use a pilot. Of the 4,432 ships pa that we forecast might call by 2079, about 1,922 might require a pilot, 350 might have pilotage exemptions, and 2,160 might be fishing vessels or small service craft. That is to say, 3,844 piloted transits (twice 1,922) would take place. See Table 4-1.

Table 4-1: Ship visits requiring a pilot/ pilot exempt at Manukau

	Requiring a pilot	Pilot exempt
Overseas ships	1,922	
Coastal feeder ships/ coastal bulkers		350
Fishing vessels		1,460
Service craft		700
Total	**1,922**	**2,510**

The criteria we have used for measuring pilotage suspension are:

- The aggregate percentage of time that weather would cause pilotage suspension
- The number of events that this occurs in a year
- The duration of each such event

combined with:

- The number of crossings each year requiring a pilot

From these, we can ascertain:

- Number of events causing pilotage suspension
  - over a period of time, say a year or per month; and
  - as a percentage of total pilot transfers
- Average duration of these events in hours

Applying the Manukau weather conditions to each of the benchmark ports' thresholds[13], we get the following results (Table 4-2):

---

[13] The PIANC criteria includes a 3m Hs cross component, but for pilot transfers the ship places itself to provide a lee (shelter) for the pilot boat. This is normally with the wind/ waves about 30 degs/45 degs on the bow , so no cross component

Table 4-2: Number and duration of pilotage suspension events pa: Manukau compared with benchmark ports

Pilotage Suspension at Manukau	**Manukau**	**PIANC**	**San Francisco**	**Columbia River**	**Sydney**	**Melbourne**
Waves						
Hs Threshold (m)		5	4	4.8	6	4
Percentage of time exceeded at Manukau		2.0%	6.2%	2.5%	0.4%	6.2%
Average number of events pa		11	23	12	4	23
Average duration (hrs)		16	24	18	10	24
Wind when in excess of wave limit						
Sustained wind threshold (knots)		29	40	50	30	
Percentage of time exceeded at Manukau		0.7%	0.0%	0.0%	0.4%	
Average number of events pa		17	-	-	10	
Average duration (hrs)		3	-	-	3	
Combined waves and wind will cause pilotage to be suspended:						
Percentage of time at Manukau		2.6%	6.2%	2.5%	0.8%	6.2%
Average number of events pa		28	23	12	14	23
Average duration (hrs)		8	24	18	5	24
Manukau Pilotage data						
Number of piloted transits at Manukau	3,844					
Events causing pilotage suspensions: per year		28	23	12	14	23
per month		2.3	1.9	1.0	1.2	1.9
Events preventing pilot transfers as %age of total pilot transfers		0.7%	0.6%	0.3%	0.4%	0.6%
Average duration (hrs)		8	24	18	5	24

Comparison	**Benchmark Port**			**San Francisco**	**Columbia River**	**Sydney**	**Melbourne**
	Number of piloted transits at each benchmark port			7,000	2,870	2,758	7,598
	Events causing pilotage suspensions: per year			8	8	6	No data
	per month			0.7	0.7	0.5	
	Events preventing pilot transfers as %age of total pilot transfers			0.1%	0.3%	0.2%	
	Average duration (hrs)			6 to 12	18 to 21	12 to 24	1 to 4

Using the benchmark ports' criteria, the number of events at Manukau causing pilotage suspension would be between 12 and 28 per year or 1.0 and 2.3 per month, more in winter and fewer in summer, representing between 0.3% and 0.7% as a percentage of total pilot transfers. The duration would range from 5 hours to 24 hours. See Table 4-2, Figure 4-5 and Figure 4-6.

In comparison, the benchmark ports are likely to experience 6 to 8 events a year causing pilotage suspension, i.e., 0.1% and 0.3% of total pilot transfers at those ports. This represents 0.5 to 0.7 suspensions a month but perhaps twice this in winter months at places like Columbia River. The duration at each port is reported to be between 1 to 4 hours for Melbourne rising through 6 to 12 hours for San Francisco and 18 to 21 hours for Columbia River, to a high of 12 to 24 hours for Sydney.

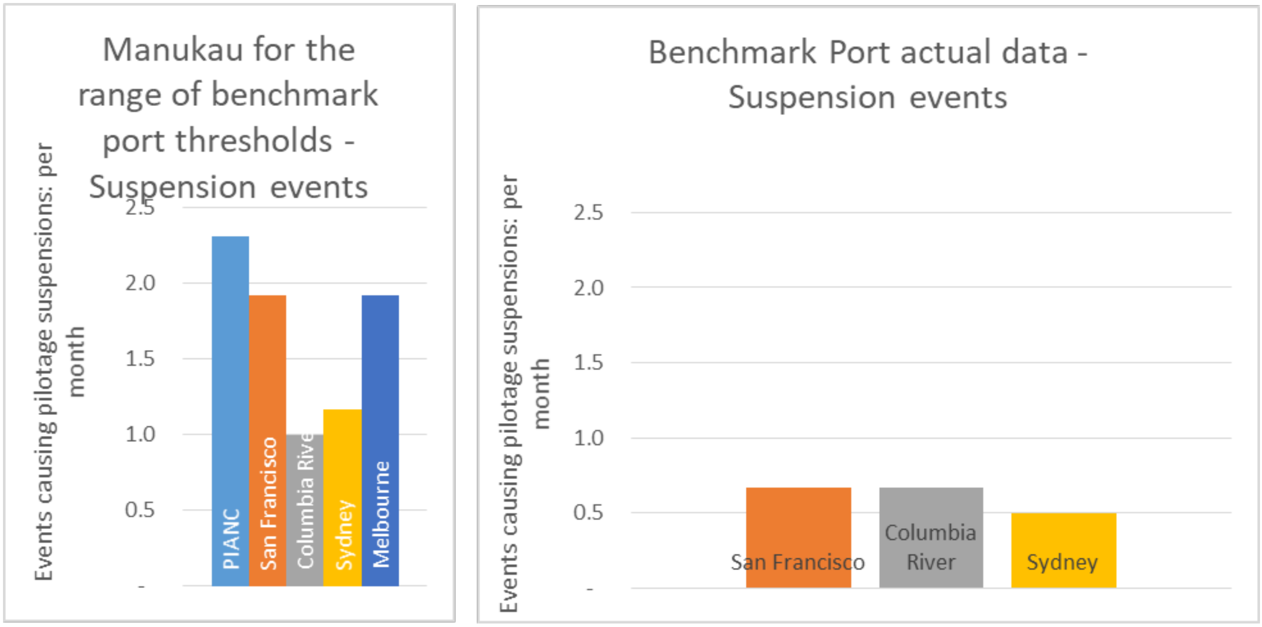


Figure 4-5: Number of pilotage suspension events per month: Manukau compared with benchmark ports

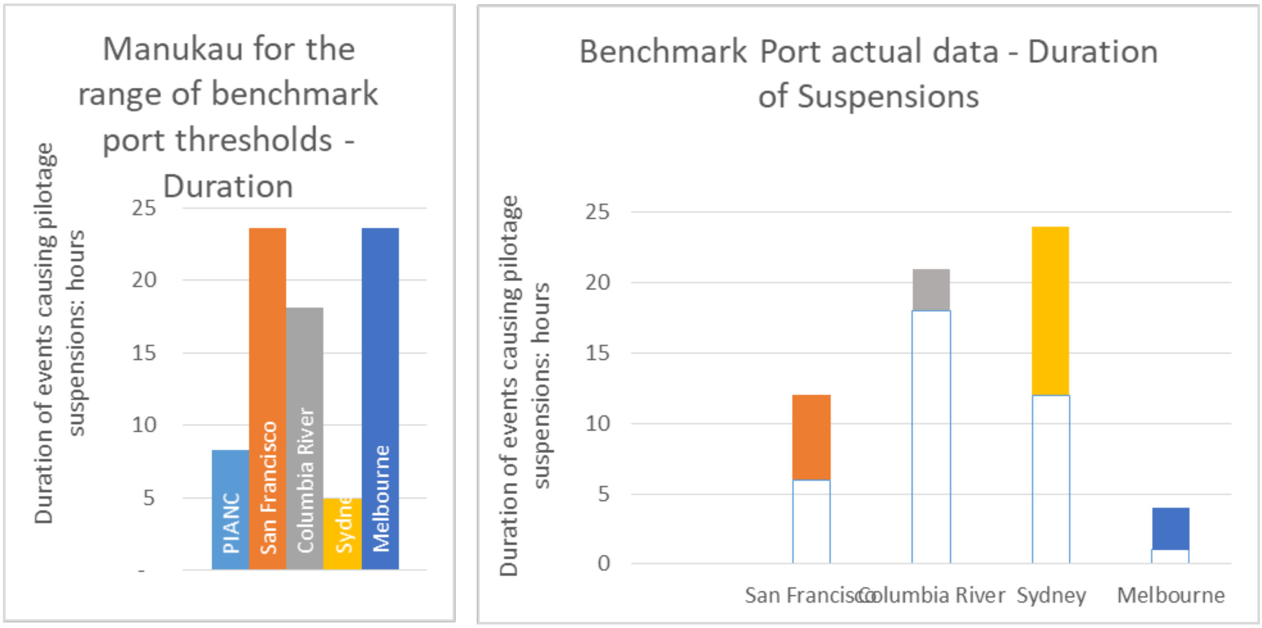


Figure 4-6: Average duration of pilotage suspension events (hours): Manukau compared with benchmark ports

The acceptability or otherwise of these downtimes caused by pilotage suspensions is a commercial judgement. The comparison shows that Manukau's wave, wind and current regime will cause more pilotage suspension events than the benchmark ports, 0.3% to 0.7% of total pilot transfers compared with 0.1% to 0.3% for the benchmark ports. However, the duration of such events is similar, 5 to 24 hours for Manukau compared with between a low of 1 and 4 for one benchmark port (Melbourne) through to a high of 12 and 24 hours for the most prone benchmark port (Sydney).

These are short durations. At San Francisco, pilotage suspensions due to weather (other than fog) are anecdotally generally between 6 and 12 hours and are not even recorded. Although not strictly comparable, New Zealand's two major container ports are constrained to slack water or very low tidal currents at high water for movements of large container ships, i.e., for about 3 to 4 hours every 12 (25% to 35% of the time).[14] These indicate that the duration of pilotage suspensions at Manukau would be commercially acceptable. The acceptability of the higher number of suspension events remains a commercial judgement, although overall the incidents of events and durations for Manukau do not appear to be overly onerous.

---

[14] The tidal water level & current windows for Auckland and Tauranga are not strictly comparable with weather/wave-related pilotage suspensions because the accuracy and long horizon of tidal window predictions differs from that for weather/wave events.

5 Exiting, Entering and Transiting the Harbour

Even if a pilot is able to embark or disembark, it may not be possible for a ship to enter, exit or transit a harbour. Other ships that have a pilotage exemption will also be constrained by severe weather when entering, exiting or transiting. When exiting, the wave height, encounter frequency and wave length/ steepness may combine to push the ship beyond acceptable limits. When entering, following waves and wind can affect manoeuvrability, and in extreme cases, a vessel may surf and broach. Manoeuvrability when transiting inner harbour channels is affected by currents and wind, and in exposed parts by waves. The master and pilot need to judge the likely response of the ship and decide whether any of these hazards occur. That is to say, the ship may reach limitations where a voluntary decision to cease exit or entry is made. In some ports, the port authority imposes limitations. For example, Ports Victoria at Melbourne and Port of Tauranga have tidal stream restrictions on transiting their channels. At Botany Bay, a cross wind speed and wave height limit is imposed.

5.1 Exiting the Harbour

5.1.1 Ship responses when exiting

When exiting, a ship meets oncoming waves. It is also influenced by wind, especially the crosswind component, and currents, both longitudinal and cross.

Waves cause a ship to heave and pitch, and to some extent, roll. These result in a change in under keel clearance, and accelerations imposed on the ship's structure, cargo and personnel. Ships near the largest size the port can accommodate will have to be conscious of under keel clearance. Smaller ships respond more to waves than larger ships; they will have to be mindful of vertical accelerations.

Cross winds can shift a ship bodily sideways ('leeway') and cause the ship to yaw. In open sea where there is plenty of sea room, this is not usually a problem, but in confined waters such as a channel, the swept track of the ship is wider than normal and may cause a limit to be breached.

Similarly, *cross currents* at an entrance to a channel 'set' a ship sideways. On entering the channel, the ship then needs to straighten, which in a narrow entrance is risky.

Longitudinal currents can markedly change the ships speed over the ground. A following current can speed the ship up to the extent that little time is available to make corrective actions. Too strong a head current can mean the ship makes little or no headway. In a narrow channel, neither is desirable. Where there are bends, swift currents make keeping on course much more difficult. A strong ebb current meeting oncoming waves can steepen the waves, making ship motions more violent.

5.1.2 Ships exiting Manukau Harbour

Wave conditions coupled with the tidal stream over the tidal cycle have been modelled by MetOcean Solutions for this project[15]. A 12 month hindcast covering 2012 has been produced and outputs for locations c30 to c38 provided, i.e., an 8km distance from deep water, about 30m CD, inside the design channel, through the 3km channel at 20.5m CD to a depth of 37m CD outside. The tidal flow

---

[15] See TWP03b – Numerical modelling

can change the ‘uncoupled’ wave height, by up to 1.5m increase at peak ebb, and a 0.25m decrease at peak flood.

The greatest concern for ships exiting the harbour is the response to the waves encountered. The *under keel clearance* implications of vertical motions in these wave conditions has been separately assessed[16]. That leaves accelerations to be considered. A commonly used threshold for *vertical accelerations* is 0.15g (RMS)[17]. Greater accelerations than this make ship-board decision-making and physical response difficult.

In order to estimate the vertical accelerations for the range of ship sizes that will commonly use the harbour, a semi-analytical method that calculates the wave-induced motions/ accelerations of a box-shaped vessel has been used[18]. This simplified procedure is restricted to the main dimensions: length, breadth, draught and block coefficient together with speed and heading. The formulas make it simple to obtain quick estimates of the wave-induced motions and accelerations at the conceptual level and to perform a sensitivity study of the variation with main dimensions and operational profile. We thus have a simple tool that allows comparative estimates of motions/ accelerations for the range of ship sizes, 13 ships from 35m length to 387m.

For each ship, its vertical acceleration is calculated for the range of wave heights and wavelengths that are experienced at the various locations in the Manukau bar channel. This is combined with the probability of each wave height/ wavelength occurring to produce the probability of vertical accelerations exceeding the threshold at each location along the channel, for the number of outbound crossings forecast for each ship size for this project[19].

Ships respond most in heave and pitch to wavelengths which are about 0.9 to 1.2 times the ship length. The greatest response to wave height will therefore be at wavelengths similar to the ship’s length.

The result of this analysis is presented in Table 5-1 and Figure 5-1 in the form of the average number of ships that would exceed the vertical acceleration threshold in a year. It can be seen that the greatest response is at locations c36 and c37. Further out, at c38, the shallowing effect of shortening the wavelength to become similar to the ships’ lengths is not as great as at c 36 and c37, and the wave heights are lower, as neither the effects of shallowing nor of the tidal stream are as great. Further in, at c35 (the crest of the natural bar) although the wavelength profile is similar to c 36 and c37, the wave height is very much reduced. By the time waves reach c34 (which is over the crest of the bar) the response is even more reduced, reflecting the very much lower wave heights.

It can also be seen that only smaller ships are likely to exceed the threshold. In fact, the modelling results in only ships of the size that can already cross the bar being exposed; those of 35m and 65m LOA, fishing boats for example and at the margin ships of 100m to 124m LOA such as the cement ships, small container ships and RoRo ships that have used Onehunga as their Auckland port in the

---

[16] See TWP04b – Navigation and Channel Design – Under Keel Clearance

[17] The limiting RMS (root mean square) of vertical acceleration at bridge for a merchant ship is 0.15g in NORDFORSK 1987 Assessment of Ship Performance in a Seaway. Copenhagen, Nordforsk, and 0.20g for naval ships in NATO 2000 Standardization Agreement (STANAG): Subject: Common Procedures for Seakeeping in the Ship Design Process, NATO, Military Agency for Standardization. We have used the more conservative 0.15g.

[18] Estimation of ship motions using closed-form expressions, JJ Jensen, AE Mansour, AS Olsen, Ocean Engineering, January 2004, https://www.sciencedirect.com/science/article/abs/pii/S0029801803001082

[19] See TWP01 - Ship Traffic & Design Vessel

past. Ships of about 175m do just show up in the data. The wavelengths in the channel peak between 175m and 200m and although the wave heights are not enough to cause concern, it can be seen that ships of this length range will respond more than others.

There are very few waves in the channel that are longer than 250m. Ships greater than this length will have very small vertical accelerations.

Table 5-1: Number of ships p.a. experiencing vertical accelerations greater than 0.15g (RMS)

LOA	**35**	**65**	**100**	**124**	**145**	**175**	**210**	**230**	**275**	**300**	**337**	**351**	**387**
Location													
c34	3	0	-	-	-	-	-	-	-	-	-	-	-
c35	9	1	0.0	0.0	-	0.0	-	-	-	-	-	-	-
c36	16	3	0.0	0.0	0.0	0.1	-	-	-	-	-	-	-
c37	**16**	**3**	**0**	-	-	**0**	-	-	-	-	-	-	-
c38	15	3	0.0	-	-	-	-	-	-	-	-	-	-

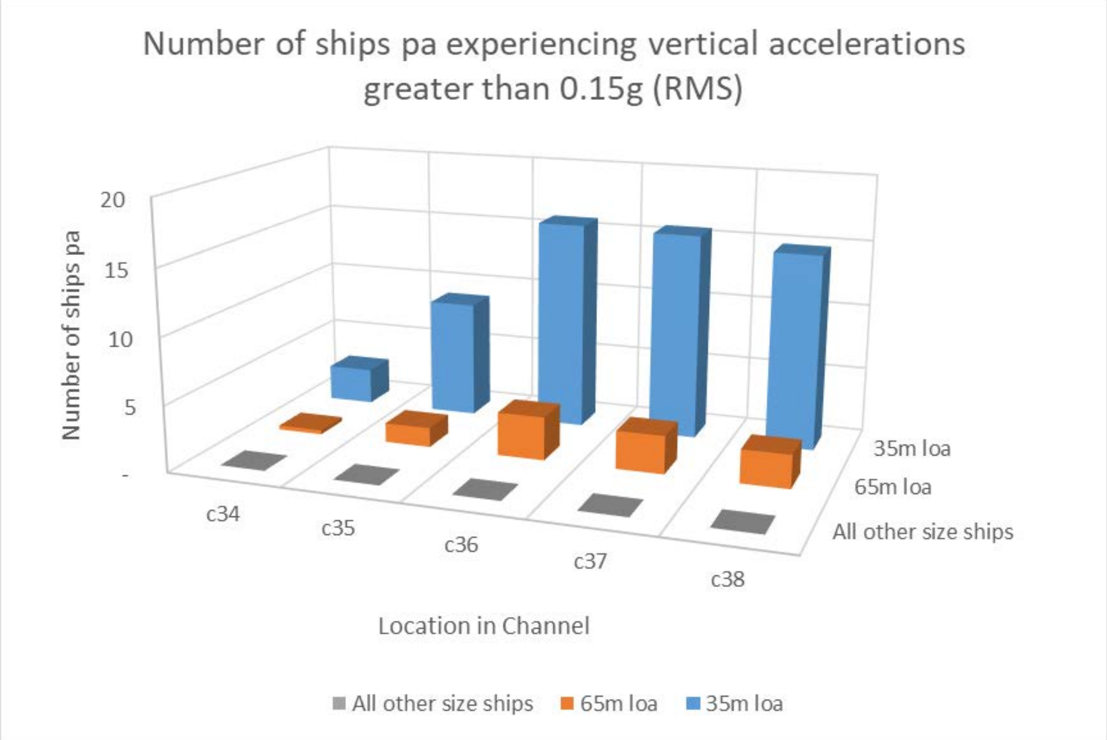


Figure 5-1: Number of ships p.a. experiencing vertical accelerations greater than 0.15g (RMS)

Generally, the pilot transfer threshold will be reached before that for vertical accelerations. See Table 5-2. Most ship sizes will not reach the acceleration threshold at wave heights less than 10m. The three smallest sizes analysed, 35m, 65m and 100m LOA are likely to, at significant wave heights of 1m, 2m and 5m respectively. Ships of about 175m may exceed the threshold in 7m waves, although the probability of this wave height and wavelength combination is less than 0.01% of the time.

Our traffic assumption is that the two smallest sizes, 35m and 65m LOA, will not need a pilot, so they will be constrained from exiting the port by waves conditions in the channel (rather than at the pilot transfer location). Ships of around 100m length are likely to need a pilot. They have a channel constraint of about 5m wave height, similar to the pilot transfer threshold, so will sometimes not be able to take a pilot, and at other times be constrained by the channel conditions. All other ships greater than 100m that need a pilot will be constrained by the pilot transfer threshold. Those that have a pilot exemption will be extremely unlikely to be constrained by wave-induced vertical accelerations in the channel or by outside wave conditions.

All ships exiting the harbour will meet a constraint imposed by wind or cross currents. The limits for the PIANC standard and the benchmark ports are set out in Section 4.2 above- Closure/ suspension criteria above.

Table 5-2: Minimum significant wave height (H_s) that vertical accelerations exceed threshold

LOA	**35**	**65**	**100**	**124**	**145**	**175**	**210**	**230**	**275**	**300**	**337**	**351**	**387**
Minimum wave height Hs (m) that vert accel exceeds threshold	1.0	2.0	5.0	>10	>10	7.0	>10	>10	>10	>10	>10	>10	>10

5.2 Entering the Harbour

5.2.1 Ship responses when entering

When entering a port, a ship encounters *following waves*. As when exiting a harbour, it is also influenced by *wind*, especially the crosswind component, and *currents*, both longitudinal and cross.

Wave speeds are such that in most cases, the waves pass the ship from behind. If though, the ship speed matches or nearly matches the wave speed, the ship can surf ride which puts it at risk of broaching-to, that is, a sudden and uncontrollable turning despite the opposite action of the rudder to counteract it. In a confined channel, this can result in grounding. And regardless of sea room, broaching can result in capsize.

Smaller ships are prone to broaching. Surf riding takes place when wavelength is about one to three times the ship length, and when the wave speed is marginally higher than the ship's, combined with a wave steepness great enough to generate a sufficient wave surge force. The wave 'picks up' the ship, it accelerates, and the wave does not pass beneath the ship; it is surf riding. In deep water, larger ships, those greater than about 200 m length, are too long, as waves greater than this length are fast, and pass by ships. Short ships, less than 120 m or so, need to use caution. Ships between 120 m and 200 m need to be considered on a case-by-case basis. In shallowing water, the wave speed decreases, and this needs to be considered.

Waves cause a ship to heave and pitch. Larger ships in following seas may not heave and pitch violently, but they still move vertically. This can cause under keel clearance risks[20].

The dangers of winds and currents are the same as when exiting a port. Cross winds can shift a ship bodily sideways ('leeway') and cause the ship to yaw. Cross currents will 'set' a ship sideways. Longitudinal currents can markedly change the ships speed over the ground. A following current can speed the ship up. With following seas, this may push a ship's speed relative to the waves beyond the critical safe speed that avoids surfing. Too strong an ebbing head current can mean the ship makes little headway and stays in the risky zone of steeper seas where the current meets the waves.

---

[20] See TWP04b – Navigation and Channel Design – Under Keel Clearance

5.2.2 Ships entering Manukau Harbour

The International Maritime Organisation (IMO) has developed a set of guidelines on intact stability criteria for ships at risk of *broaching/ surf-riding* in following seas (and for other stability issues such as parametric rolling). As part of these, a conservative ‘simplified operational guidance’ has been given that provides acceptable forward speeds and headings[21]. For broaching/ surf-riding, the simplified operation guideline reads:

> *nominal ship speed of* $0.94 \cdot L^{1/2}$ *(m/s), or greater, should be avoided when the wavelength, based on mean wave period, is greater than 80% of the ship length, the significant wave height is greater than 4% of the ship length L (m) and the heading angle μ (deg) from the wave direction is less than 45 degrees* [i.e., following seas from astern to 45 degrees either side of astern].

All ships entering the harbour will come within the ship heading limitation as waves will be more or less directly following. Smaller ships are more at risk of broaching than larger ships in any given sea. For the wave conditions at location c37, 2km seaward of the crest of the Manukau bar, wavelength in the depth at c37 is 195m. The above-quoted wavelength limitation of 80% of ship length is therefore reached for ships of less than 244m length. The speed limitation will therefore arise for all ships less than 244m, when the significant wave height (H_s) is greater than 4% of the ships length. For ships as short as 35m, once waves reach 1.4m height (which is 95% of the time) the speed limitation is 10.8 knots. For slightly longer but still small ships, say 100m, this rises to 18.3 knots in seas greater than 4.0m (H_s). This maximum speed continues to rise with ship length until the wavelength to ship length limit is reached; for ships longer than 244m the limit is over 28.5 knots and in seas exceeding 9.8m Hs, speeds and wave heights unlikely to be experienced when manoeuvring through the channel. See Figure 5-2.

For other reasons, e.g., pilot transfer, ships are unlikely to enter the channel when wave heights rise between 4m and 6m, and so broaching is really only a risk to ships shorter than 100m.

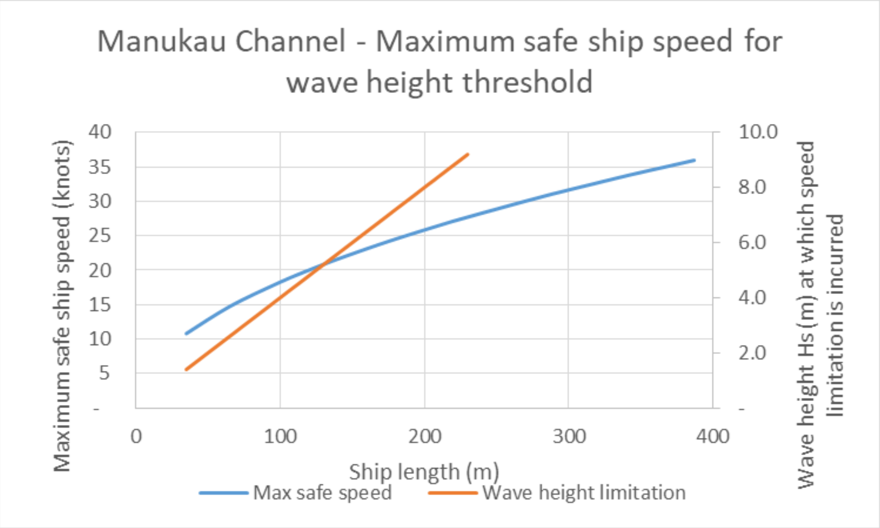


Figure 5-2: Ship speed limitations to avoid broaching when entering Manukau Harbour

---

[21] IMO MSC.1-Circ.1627 - Interim Guidelines on The Second Generation Intact Stability Criteria, Section 4.5.6

As is the case when exiting harbour, all ships entering the harbour may meet a constraint imposed by wind or cross currents. The limits for the PIANC standard and the benchmark ports are set out in section 4.2 above - Closure/ suspension criteria above.

5.3 Small craft

Small craft can use of side slope of bar channel. The side slope is 1:25, giving about 475m side-slope width each side for shallower draft vessels.

5.4 Transiting the Harbour

5.4.1 Ships transiting Manukau Harbour

The design channel in the inner harbour has been reviewed through use of a fast time simulation[22]. The simulation tests that the channel's width and alignment are satisfactory by means of ship passage under a variety of challenging environmental conditions, using ship models corresponding to anticipated vessels. Refer to TWP04 for further discussion including consideration of infragravity waves at the entrance, currents at inner channel confluences and windage.

The fast time simulation report concludes that:

- Channel dimensions are adequate for the manoeuvres under examined conservative combinations of environmental conditions. The ship leaves the designated path set out [in a section in that report] only occasionally and for short periods of time, mostly in bends; the ship is able to return to the intended course swiftly and without significant effort, meaning that the channel width is sufficient. …………
- The ship retains sufficient control over its course throughout the entire channel, both during arrival and departure passages, as almost no instances of rudder use exceeding 20° are recorded. Most of the time, rudder angle remains within +10° to -10° range. It is therefore concluded that the channel alignment is appropriate.
- Additional runs with smaller vessels that have deeper draughts in dredged sections demonstrate that vessels are able to retain control with imposed speed limit of 8 knots, however in Section C [the inner harbour one-lane dredged section] under some conditions, manoeuvring is arguably difficult, as the ship has to resort to the maximum allowed rudder angles.

---

[22] See TWP04 – Navigation and Channel Design and its Appendix C – Fast Time Simulation

6 Channel Sedimentation

6.1 Channel infill

A Manukau bar ship channel will be prone to sedimentation. See TWP03c – Numerical modelling – Sediment transport report for details. The estimate is that on average, the South-West Channel would have a net sedimentation of about 7.5 million m^3 p.a. A dredging regime has been modelled using the 40 year hindcast of wave and currents from which the depth of infill at any one time has been estimated.

The base case for channel infill assumes that maintenance dredging can take place when wave height, H_s is below 3.0m. It assumes that a $10,000m^3$ TSHD dredge can remove $50,000m^3$ over 24 hours[23]. On average, over a year this results in 17 times when the channel has some infill for nearly 8 days average duration. Infill of more than 1.5m will occur an average of 1.5 times a year for an average duration of 20 days. Greater infills are less frequent and for shorter durations.

Monitoring of infill and channel depth generally will need to be done on a day-to-day basis by daily soundings by a pilot vessel. Consideration could also be given to survey carried out by two jet skis (one for safety) with state of the art hydrographic survey equipment, such as RTK, multi-beam sounder and heave compensation, with real time data link to onshore. In addition, the maintenance dredger (TSHD, 10,000 m3 hopper capacity) should provide first indications of changes in channel depth when restarting after severe weather, with real time data link to onshore

6.2 Implications for ships

Sedimentation is mainly an issue for large ships seeking to transit the channel at or near the maximum draft that the channel is designed for, in wave conditions that may cause large vertical motions through heave, pitch and roll, and when tide height is insufficient to give adequate under keel clearance. The sequence of events for transit is:

- If the channel has sediment infill, the first issue faced by a ship approaching will be, what is my required UKC for the conditions? The Master will have been advised this from the port's DUKC system.
    - The design channel depth of 19m below CD is based on a probability of 0.07% that the design ship, a 7000 teu containership, will touch bottom. We estimate that up to 250 ships of this size will use the harbour in a year. That is, weather conditions are such that being unable to enter would occur on average once in 5.7 years.
- Normally there won't be a problem.
- But if wave conditions combined with sediment are such that the ship cannot transit at the depth available, including the tide depth at that time, the ship waits until tide depth is sufficient or weather abates, whichever is first.
- Duration is short:
    - on a rising tide transit might be possible in the next hour or so, on a falling tide not longer than 12 hours.
    - If lack of depth rules out being able to use the tide, the weather will eventually abate. At o5 (just offshore from the channel), wave heights greater than 4m have a duration of about 24 hrs, 5m 16hrs, 6m 10hrs.

---

[23] Variations to this dredgibility are considered in the risk assessment.

    - Even the range of duration is not high. The 90th percentile durations are: 4m, 42h; 5m 28h; 6m,16h
- If sediment is extreme such as to be more than the sum of the weather limit plus the tide margin, then the ship has to wait for the weather to abate, maybe to much lower wave heights for extreme sedimentation beyond that modelled, or for the dredge to increase the channel depth. For infill of 1.5m this may take 20 days, but the tidal range is greater than 1.5m and bad weather doesn't last that long, so at some time early in those 20 days, the infill will be reduced sufficiently.

6.3 Channel design mitigation

It may be that an amount of selective over-dredging in the channel at places when infill accumulates would be advantageous. A mitigation in terms of future design work would be to carry out a time series analysis, hour by hour for say 40 years, of the loss of UKC when a ship wishes to enter or leave combined with the amount of sedimentation. Varying the over-dredging will change the number of hours that transit is possible/ not possible and its duration.

6.4 Conclusion

Only large ships wishing to transit the bar channel at maximum channel draft allowance, and in high wave conditions are subject to delay through the expected levels of sedimentation. Infill depth reduction will normally be covered by waiting for higher tide.

It is extremely unlikely that sedimentation will cause delays of any significance to large ships. The combination of a maximum draft ship wishing to transit, waves severe enough to limit its under keel clearance and infill all occurring is rare. Even then the delays are minor; on a rising tide no more than an hour or two and no longer than 12 hours if a falling tide, and if infill is greater than the tidal range can cover, 10 hours to 48 hours for weather to abate. Smaller ships do not have drafts that might cause issues. Sedimentation is thus not a problem for operability.

7 Other Operability Considerations

7.1 Anchoring

Anchoring offshore is not considered to be a problem. Large ships typically anchor in depths between 25m and 80m. Less and the anchor cable scope is too short; more is beyond the required lifting capability of anchor windlasses. Off Manukau harbour, this 'strip' of coastal waters is 9 to 10 nautical miles wide, extending both north and south along the coast, providing more than adequate sea-room. The chart, NZ 4314 shows that the bottom is fine sand and broken shells, generally considered to be good holding ground.

Should weather conditions dictate that a ship cannot stay at anchor, there is so much sea-room (the Tasman Sea) that it can heave anchor and steam, in circles if necessary. Note that ships tend to slow-steam to arrive at a port entry to meet the pilot and proceed straight in. Anchoring is reverted to when scheduled entry is disrupted.

Anchoring inside the harbour may be necessary, for example while awaiting improvement in weather or for an oncoming ship to pass. There are numerous places in the inner harbour that are suitable. A port plan would designate places clear of the navigation channel with adequate swinging room. If required, these could be dredged to suit.

7.2 Airport Obstacle Limitation Surface (OLS)

An airport's Obstacle Limitation Surface (OLS) provides maximum heights for structures and activities around the airport.

Figure 7-1 shows Auckland Airport's OLS overlaid on a plan of Manukau harbour. Figure 7-2 shows two limiting contours from the OLS; one at 70 m above MSL to cater for maximum expected ships' air draft, and another at 130 m above MSL for the height of ship to shore gantry cranes when 'boom up'[24]. These limiting contours are both on the OLS conical slope which slopes from 52m above MSL to 157m.

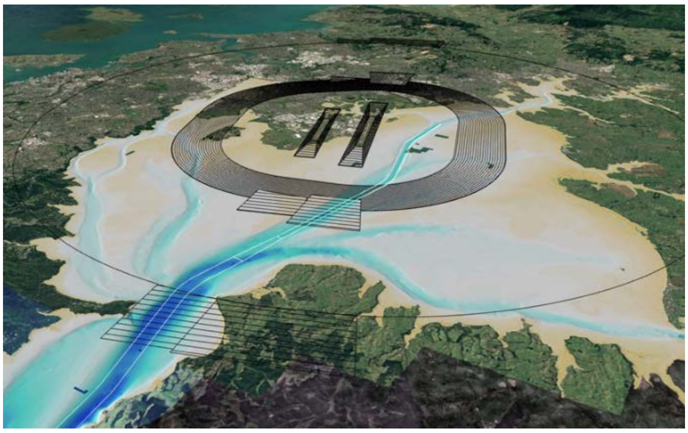


Figure 7-2: Auckland Airport's OLS

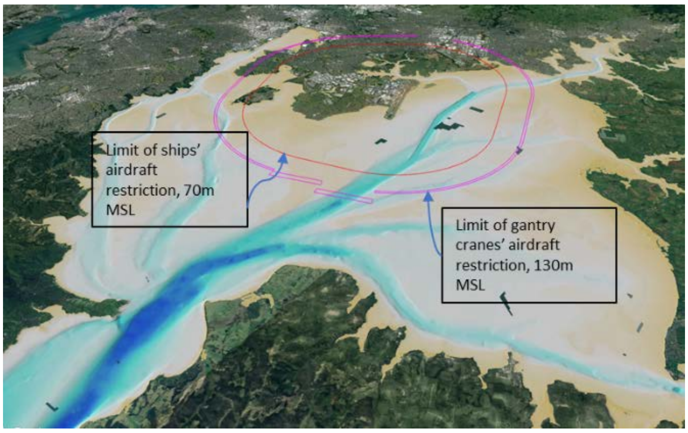


Figure 7-1: Manukau Harbour showing OLS limits for ships' airdraft (70m above MSL) and gantry cranes' airdraft (130m above MSL)

---

[24] See Appendix 1 for details

In order to be clear of the OLS, a port and its approaches would need to be located outside these limiting contours so that ships transiting channels and respectively, crane booms are not an obstacle.

The figures show that some channels and potential port sites are well within the OLS limitations, while other channels and sites are well clear. A discussion with Auckland International Airport, which administers the OLS, indicated that should a port location within these limiting contours wish to be considered, an Aeronautical Study risk assessment would be required in order to consider an exemption. This would need to be approved by the Civil Aviation Authority. This is a process that has been followed by other major airports/ sea ports, for example Sydney Airport.

The conclusion is that there are potential port locations within the harbour that do not intrude on the OLS. And if there is a preferred location that does intrude, there is a process for considering exemptions.

7.3 Biosecurity

Biosecurity requirements for all incoming vessels require vessels to have a clean hull when arriving to New Zealand. Most commercial shipping should be able to obtain clearance into New Zealand, in regard to biofouling, by following current best practice in biofouling management. Short stay vessels, i.e., most commercial ships, must call only at 'places of first arrival'. Our expectation is that a major new port such as Manukau would be designated as a place of first arrival.

The Ministry for Primary Industries carries out inspections of a ship's documents and if necessary the ship's hull. If a ship fails, it has to leave New Zealand. This can mean it goes elsewhere, or a common practice, it can be cleaned at sea, outside the 12 mile limit. There are currently only three places in NZ where this takes place: off Great Barrier Island, near Tauranga (both of which are low wave energy locations) and off Lyttelton, north or south of Banks Peninsular, depending on the wave conditions.[25]

Ships at any port that fail an inspection would need to go to one of these, or leave New Zealand altogether. The implication for Manukau is that if a ship chooses cleaning outside the 12 mile limit, it would need to go further and thus take more time and use more fuel than a ship at most other NZ ports. That is to say, a moderate consequence compared with a ship at any other port.

The probability is rare. Most ships pass inspections. Most that fail are bulkers, not the type that would be regular callers at a Manukau port, such as containerships.

7.4 Aids to Navigation

Physical aids to navigation are today still the main method for marking channels and obstacles. Virtual aids to navigation are now also used, especially at major ports, but as a secondary method. The Chief of the USCG Office of Navigation Systems[26] gives some insight to the future, "The transition to eNavigation has been going on for almost 40 years, and affects all areas of ship operation. The next level of transition may well be from analogue to digital, or visual to virtual. The IMO states that eNavigation is intended to establish an integrated information environment for the maritime

---

[25] Personal communication, April 2024: Mark Oxley with Craig Harris, recently Managing Director, ISS-McKay Ltd, a major agent for bulk carriers visiting New Zealand.

[26] *Transitioning from traditional aids to navigation*, Mike Sollosi, Chief of the Office of Navigation Systems, US Coast Guard Headquarters, Chairman of the IMO Safety of Navigation Sub-committee, Seaways, March 2012

community. This environment will of necessity reach beyond the ship itself, and will affect the provision of aids to navigation and waterway management services".

Maritime New Zealand's policy on using virtual aids to navigation[27] is that "virtual aids to navigation can be effective where it is difficult to place or maintain a physical aid to navigation due to water depth, sea state or other environmental conditions. International guidance is that virtual AIS aids to navigation should only be used as a temporary mark or where a physical mark cannot be installed, and are not currently considered a viable replacement for physical ones. If the risk to safe navigation exists for all vessels, irrespective of size, then a physical aid to navigation (buoy, daymark, light, etc.) should be the primary choice. However, if the risk to safe navigation only exists to deep draught merchant ships (expected to be carrying compliant AIS equipment) then a virtual aid to navigation may be appropriate". MNZ goes on to say, technology and availability of compliant systems will continue to develop and virtual AIS aids to navigation are expected to become more common. Maritime NZ will reconsider its policy as appropriate.

Virtual aids to navigation use AIS (automatic identification system) which needs an AIS receiver or ECDIS electronic chart to receive. All ships (except very small craft) are required to be fitted with AIS and most that are over 3000 GT with ECDIS, so only those small ships without AIS or ECDIS cannot use virtual aids to navigation.

Offshore Manukau heads is a severe weather zone. Physical aids to navigation that are not fixed to the seabed or on land will be more prone to damage and displacement than in more sheltered areas. The backup of virtual aids is possible. As MNZ states, over time, systems will continue to develop and virtual AIS aids to navigation are expected to become more common. As ECDIS is now almost universal, we do not consider risks to physical aids to navigation to be a serious risk in the time frame for a new port at Manukau.

---

[27] *Aids to Navigation Guideline,* Maritime New Zealand, August 2019

8 Manukau's Operational Navigability

8.1 Can large ships cross the bar into the inner harbour?

Large ships are relatively unconstrained in crossing the Manukau bar into or from the inner harbour.

8.1.1 Pilotage suspensions

Pilotage suspension is more a function of pilot and pilot boat safety than the size of ship, although larger ships are more able to offer a lee (shelter) for a pilot boat than smaller ships.

Most but not all ships require a pilot, although the larger ones almost certainly will not have pilotage exemption.

We have used our benchmark ports' pilotage suspension criteria to estimate downtime. The number of events causing missed transfers would be between 12 and 28 per year or 1.0 and 2.3 per month, more in winter and fewer in summer, representing between 0.3% and 0.7% as a percentage of total pilot transfers. The duration would range from 5 hours to 24 hours.

8.1.2 Exiting harbour

Large ships, and even medium sized ships greater than about 125m length, will not experience difficulties when exiting the harbour across the bar.

8.1.3 Entering harbour

Similarly, large ships, and even medium sized ships greater than about 100m length in this case, will not experience difficulties when entering the harbour across the bar.

8.1.4 Sedimentation

Large ships have to be mindful of their under keel clearance (UKC). The dredged ship channel through the bar has a design depth based on the UKC requirements of a 7000 teu containership. Sedimentation modelling has estimated the net infill to the channel, including the maintenance dredging regime. The infill is normally well within the tidal range and thus infill depth reduction will be covered by waiting for higher tide. It is extremely unlikely that sedimentation will cause delays of any significance to large ships. Smaller ships do not have drafts that might cause issues. Sedimentation is thus not a problem for operability.

8.2 Can ships of any size cross the bar and navigate within the harbour safely?

Many of the comments in the section above apply to all ships. The exceptions are:

8.2.1 Exiting the harbour

The limitation on ships exiting the harbour relates to the ability of the ship, crew and cargo to withstand the ship motions. We have used a threshold of 0.15g RMS vertical accelerations in assessing this. Short ships are those that respond most to the waves at Manukau bar. Ships less than 100m length will have occasions when exit is restricted. In any given year, perhaps 16 ships of 35m length, for example a fishing boat or service craft, and 3 ships of 65m length would be restricted. Note that these sizes can already cross the bar. The restriction in a dredged channel will be less than for the existing bar bathymetry.

8.2.2 Entering the harbour

Entering a harbour across a bar exposes ships to the risk of surf-riding and broaching to from the following seas. Short ships are more prone than long ships. It is critical that the ship proceeds slowly enough so that the waves can overtake and pass beneath the ship.

IMO's intact stability guidelines have been used to show that for ships as short as 35m, once waves reach 1.4m height (which is 95% of the time) the safe speed limitation is 10.8 knots. This rises to 18.3 knots in seas greater than 4.0m Hs for ships of 100m length. This maximum speed continues to rise with ship length; for ships longer than 244m the limit is over 28.5 knots and in seas exceeding 9.8m Hs, speeds and wave heights unlikely to be experienced when manoeuvring through the channel. The ships at risk are those of less than 100m length.

8.3 What about marine activities such as anchoring?

Anchoring offshore is not considered to be a problem. There is plenty of sea-room in suitable depths. The bottom is fine sand and broken shells, generally considered to be good holding ground. Should weather conditions dictate that a ship cannot stay at anchor, there is so much sea-room (the Tasman Sea) that it can heave anchor and steam, in circles if necessary.

8.4 Are there any conflicts with other nearby activities, for example the airport?

Auckland Airport's Obstacle Limitation Surface (OLS) provides maximum heights for structures and activities around the airport. There are potential port locations within the harbour that do not intrude on the OLS. And if there is a preferred location that does intrude, there is an Aeronautical Study risk assessment process for considering exemptions.

Appendix 1: Airport Obstacle Limitation Surface (OLS)

An airport's Obstacle Limitation Surface (OLS) provides maximum heights for structures and activities around the airport.

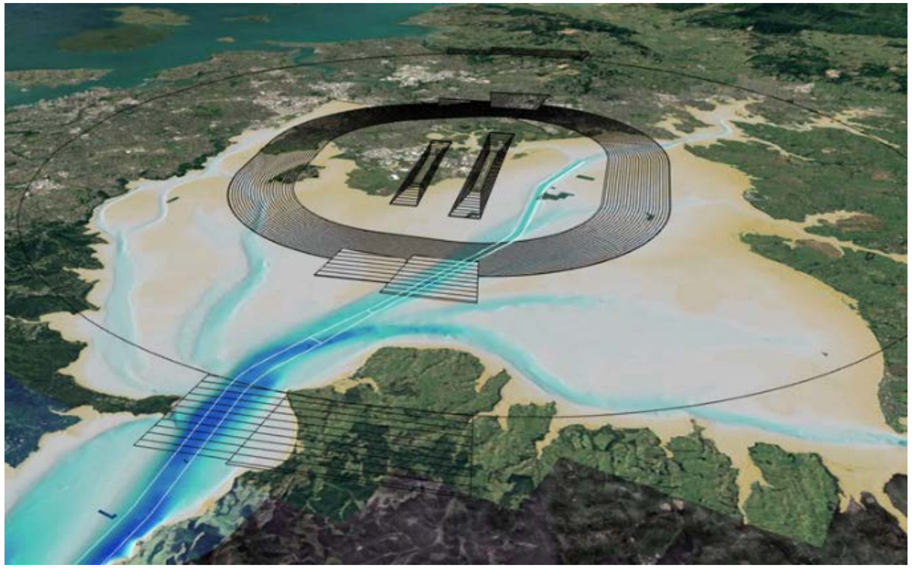
The larger design ships being used in the feasibility study typically have an air draft, the overall height from waterline to truck (top of mast) of about 50m to 60m, depending on load condition. The highest machines in a port are container ship-to-shore gantry cranes. A super post-Panamax crane has a boom-up height (when not working) of about 120m above the wharf deck, and 77m when boom-down, i.e. higher than the mast of the ship it is working.

The table below shows the calculation to arrive at the limiting contours for ships at berth and in transit through the harbour, and for the ship to shore gantry cranes on the berths. The limiting contour for ships is about 70 m above MSL, for gantry cranes 130 m. A 20,000 teu container ship, larger ship than the design ship greatest air draft, is also shown.

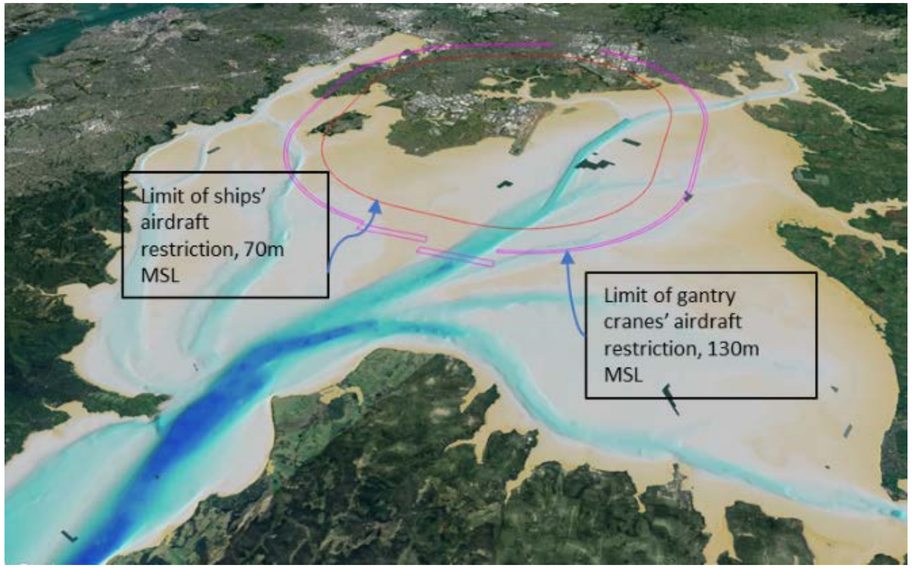
								Vessel air draft intrusion to min OLS at varying water levels				Elevation at which there is no interference with the OLS (m above MSL)				
Design vessel		LOA	Beam	Load factor	Operating draft	Vessel air draft (m above waterline)	min OLS (m above MSL)	MSL	MHWS	HAT	HAT +1m SLR	MSL	MHWS	HAT	HAT +1m SLR	
Container	20,000 TEU	400	59.0	64%	12.3	59.70	51.83	7.9	9.6	10.0	11.0	67.6	69.3	69.7	70.7	
Container	15,000 TEU	387	53.6	64%	12.1	58.90	51.83	7.1	8.8	9.2	10.2	66.0	67.7	68.1	69.1	needs to be >70m
Container	10,000 TEU	370	45.8	90%	14.2	53.20	51.83	1.4	3.1	3.5	4.5	54.6	56.3	56.7	57.7	
Vehicle	8,500 CEU	230	40.0	85%	11.5	49.80	51.83	-2.0	-0.3	0.1	1.1	47.8	49.5	49.9	49.9	
Container	7,000 TEU	272	42.8	90%	14.3	49.30	51.83	-2.5	-0.8	-0.4	0.6	46.8	48.5	48.9	50.9	
Tanker	LR2	260	45.0	100%	15.5	39.50	51.83	-12.3	-10.6	-10.2	-9.2	27.2	28.9	29.3	49.9	
Bulk	50,000 T	195	29.0	100%	11.5	38.50	51.83	-13.3	-11.6	-11.2	-10.2	25.2	26.9	27.3	30.3	
Tanker	MR	210	32.2	100%	12.6	31.40	51.83	-20.4	-18.7	-18.3	-17.3	11.0	12.7	13.1	28.3	

Port equipment		Port equipment air draft (m) above wharf deck	min OLS (m above MSL)	Wharf deck (mCD)	Equipment above wharf deck (mCD)	Port equipment intrusion to min OLS (m)	
Ship-shore crane	Boom up	120	51.83	6.54	126.5	74.7	needs to be >130m
Ship-shore crane	Boom down	77	51.83	6.54	83.5	31.7	

The figures below show Auckland Airport's OLS overlaid on a plan of Manukau harbour. The plans show two limiting contours; one at 70 m above MSL to cater for maximum expected ships' air draft, and another at 130 m above MSL for the height of ship to shore gantry cranes when 'boom up'. These limiting contours are both on the OLS conical slope which slopes from 52m above MSL to 157m.



Auckland Airport's OLS



Manukau Harbour showing OLS limits for ships' airdraft (70m above MSL) and gantry cranes' airdraft (130m above MSL)

The figures show that some channels and potential port sites are well within the OLS limitations, while other channels and sites are well clear. A discussion with Auckland International Airport, which administers the OLS, indicated that should a port location within these limiting contours wish to be considered, an Aeronautical Study risk assessment would be required in order to consider an exemption. This would need to be approved by the Civil Aviation Authority. This is a process that has been followed by other major airports/ sea ports, for example Sydney Airport.

The conclusion is that there are potential port locations within the harbour that do not intrude on the OLS. And if there is a preferred location that does intrude, there is a process for considering exemptions.

Appendix 2: Wind, Wave and current data sources and their location points

Manukau

Two offshore locations have been used in this TWP to represent wind and wave conditions that might be experienced outside the Manukau bar:

> An offshore location, o1 for comparison with other benchmark ports at 174.2992E 37.1248S in a depth of about 70m, about 10.8 nautical miles (19.9km) 245 degrees from Ninepin Rock; and
>
> o5 which is a location where a pilot transfer might take place, at 174.41441E 37.1064S in a depth 42 m below CD about 2.5 nautical miles (4.6km) beyond the crest of the bar on the outer slope, and 5.43 nautical miles (10.05km) 231.7 degrees from Ninepin Rock.

The wind and uncoupled wave hindcast data used in this Technical Working Paper cover 41 years from 1980 to 2020 for the existing bar bathymetry and 11 years from 2010 to 2020 for the proposed design channel bathymetry.

Channel locations c34 to c38 have been used for wave and current conditions in the proposed design channel. Modelling of the wave and current hindcast has been coupled for a 12 month period only, 2012. Factors to allow for more extreme wave height peaks over a more full 11 year period have been derived by comparing the exceedance probability of any given uncoupled wave height over 11 years, 2010 to 2020 with that of the same uncoupled wave height over 1 year, 2012. These factors have been applied to the coupled wave heights in the 1 year data.

Benchmark ports – hindcast data locations

For San Francisco and Columbia River, the readily available hindcasts were for locations 54km (30nm) and 45km (25nm) offshore respectively. Although further offshore than the Manukau data location, o1, these are on the edge of the continental shelf, and we considered the wave conditions to be similar to those experienced further in, at 70m depth, where the Manukau hindcast is located.

Botany and Melbourne do not experience the same wave conditions as Manukau or the two North American ports. Botany's hindcast location is 7.6km (4nm) offshore. Melbourne experiences high tidal currents between the heads at Port Phillip Bay and thus the place for comparison is located there.

Benchmark data sources:

> *San Francisco*: MSL WW3 Global ST4, at point: (237.0000, 37.50000), 1979 to 2017, 54.37 km (30nm) 50 degs off Point Bonita, on the edge of Continental Shelf, depth 329 m below CD.
>
> *Columbia River:* MSL WW3 Global ST4, at point: (235.5000, 46.00000), 1979 to 2017, 44.6 km (25nm) 235 degs off southern head, on Continental Shelf, depth 148 m below CD.
>
> *Botany Bay:* WW3 Southern Ocean ERA5/GLORYS ST4, at point: (151.2500, -34.1000), 7.6km (4nm) offshore in depth 116m below CD, between 1993 and 2018
>
> *Melbourne:* Australia Wave, at point: (144.6333, -38.3000) in the Port Philip Bay dredged entrance channel in 11.9m depth below CD, between 1979 and 2016

Benchmark ports – wave buoys

We also have wave buoy records for San Francisco and Columbia River bars. We have compared these with the dredged channel wave conditions from the MOS hindcasts for Channel locations c34 to c38 in the Manukau dredged channel.

The San Francisco wave buoy is NOAA Station 46237 – San Francisco Bar, CA (142). It is located about 2km (1nm) to the north of the main ship channel on the outer slope of the bar in 16.76m CD of depth, position 37°47'16" N 122°38'1" W. 16 years of half-hourly data have been obtained.

The Columbia River wave buoy is NOAA Station 46243 - Clatsop Spit, OR (162). It is located only 340m from the southern edge of the entrance ship channel, on the outer slope of the bar in 24.4m CD of depth, position 46°12'58" N 124°7'42" W. 13 years of half-hourly data have been obtained.