Proposed Expansion of Container Port Facilities in Botany Bay, NSW

Coastal Process and Water Resources Issues

Volume 3: Waves, Currents and Coastal Process Investigations

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Proposed Expansion of Container Port Facilities in Botany Bay, NSW

Coastal Processes and Water Resources

Volume 3: Waves, Currents and Coastal Processes

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PREFACE

This report is one of a series formed of three volumes. All reports have been prepared for Sydney Ports Corporation by Lawson and Treloar as part of water resources issues and coastal processes investigations undertaken to describe and quantify the potential impacts of the proposed expansion of container port facilities in Port Botany, NSW.

Although each report is complete in itself, all reports draw upon the others for support information.

The reports prepared for this study are:-

1. Volume 1: Hydrologic and Hydraulic Studies
2. Volume 2: Water Quality Investigations
3. Volume 3: Waves, Currents and Coastal Process Investigations (This Volume)

EXECUTIVE SUMMARY

This report describes wave, current and coastal process investigations undertaken to examine the potential impacts of the proposed expansion of container port facilities in Port Botany, NSW.

This work has been undertaken on behalf of Sydney Ports Corporation (SPC), who is responsible for the planning and development of port facilities in the Sydney region.

As the operators of Port Botany, SPC has maintained long term wave and shoreline change monitoring programs that have provided reliable data for this study. Wave and current data have been recorded for shorter periods at other sites within the Bay.

The investigations have been based on longterm experience in Botany Bay and state-of-the-art numerical wave and current models. Those models were calibrated using the data provided by SPC, as well as data from the Bureau of Meteorology and Lawson and Treloar archives.

The philosophy of the approach has been to address matters from a whole of bay perspective in the first instance. It was found that there were only minor impacts beyond the precincts of Port Botany, Penrhyn Estuary and the Parallel Runway of Sydney airport. The outcomes of these analyses have shown that there would be a minor reduction in shoreline recession rate on Towra Beach. Although this result is beyond the accuracy of available modelling systems, it demonstrates that any changes would be imperceptible. There will be no change to Lady Robinson's Beach. Therefore subsequent analyses focussed on the northern region of Botany Bay.

Following detailed wave model calibration, notably for swell and local sea components, wave climate investigations were used to describe the changes that would be associated with the proposed port expansion works. As a matter of course, this also included design data for the proposed works. That data would be required for design of proper functioning of the container port facilities.

There will be no increase in swell wave energy on the eastern side of the Parallel Runway of Sydney Airport.

Local sea waves impinging on the Parallel Runway would be reduced in height as the result of reduced fetch within Port Botany.

Long wave activity within Port Botany will be increased marginally and long waves at the proposed new container berths will be of similar order to that occurring presently in Brotherson Dock. Nevertheless, long wave activity would remain low at all container berths when compared with other ports where long wave caused movements of berthed vessels causes unacceptable vessel movements. There would be no change in long wave activity on the Parallel Runway.

Other than within the region of Port Botany itself, including Penrhyn Estuary, there will be no identifiable change in bay-wide current structure, including no identifiable changes in the Mill Stream and along the Parallel Runway.

Local sea caused sediment transport will lead to continuing westward sediment movement along the Northern Foreshore Beach towards the Mill Stream entrance. There would be a smaller extent of beach exposed to local sea following proposed port expansion and hence transport over a smaller area. The proposed extension of the Mill Stream training wall will provide a groyne that traps this sand and prevents ingress to the Mill Stream waterway. This sand may need to be transferred back to the proposed new boat ramp area of the beach every 4 to 5 years as the shoreline progrades at its western end and recedes at its eastern end.

1. INTRODUCTION

This report presents the results of a range of numerical wave and current modelling studies that have addressed the potential changes that could arise in Botany Bay as a result of the container port expansion proposed by Sydney Ports Corporation (SPC). Figure 1.1 provides a locality plan for these investigations. Appendix A provides details of the proposed project.

From the point of view of wave climate, one must address swell, local sea and long waves.

The swell wave climate near the entrance to the new port area is very mild, much of the incoming wave energy having been re-directed by the entrance dredging, or obstructed by the Bumborah Point revetment. Because proposed dredging lies within the north-west Port Botany area and to a small extent on the southern side of the port entrance channel, see Appendix A, the most important issue here is the assessment of any changes in swell wave conditions along the wall of the Parallel Runway of Sydney Airport and the shorelines of the Bay to the south and west. It is also important to determine the swell wave climate within Brotherson Dock and the new port area to ensure that existing port facilities would not be affected adversely and that the proposed port area would be able to function as required.

Local sea from the south-eastern sector is the main cause of longshore sand transport along the present Foreshore Road Beach. Long term recession is occurring in the more eastern areas of this beach, though there are local hard structures (rubble along the alignment of the old coal export jetty , for example) that act as groynes. Nevertheless, longterm accumulation of sand is occurring near the Mill Stream entrance. Since SPC is considering a boat ramp in the northern part of the proposed port expansion, design of these facilities, including possible protection of Foreshore Road to the west of the proposed boat ramp, requires a description of local sea in that area.

Long waves may affect berthed ships and any potential changes in those waves in Brotherson Dock must be addressed; particularly because unloading/loading of containers is very dependent on vessel motion and moored vessel movement is most susceptible to those wave periods. Additionally, it is important to address potential changes in long wave activity along the perimeter of the Parallel Runway.

Currents in Botany Bay are caused by the astronomical tides, winds, river flows (particularly the Georges River) and offshore oceanic basin processes such as coastal trapped waves. In the surf zone breaking waves may cause additional currents along the shoreline, as well as rip currents. Currents affect the transport and deposition of sediments, the concentrations and fates of contaminants and nutrients and the transport of marine organisms. They may also affect navigation and safety.

Directly associated with wave and current processes are water levels which are important for structural design, shoreline erosion, flooding and port operations.

The principal components of this study are:-

- a description of the wave, current, water level, wind and sediment transport physical processes (Section 3)
- a short review of previous studies (Section 3)
- a description of the impacts resulting from the proposed port development on short waves (swell and sea) and long waves (Section 4)
- a description of the impacts resulting from the proposed port development on currents (Section 5), and
- concluding remarks (Section 6)

Appendix B provides a Glossary of Terms.

2. PHYSICAL PROCESSES

2.1 GENERAL

The purpose of this section is to describe the physical processes that are important to the overall physiography of Botany Bay and ongoing changes. These processes are: -

- Waves
- Currents
- Water Levels
- Winds
- Sediment Transport

2.2 WAVE PROCESSES

Ocean waves that propagate to the study area may have energy in three distinct frequency bands. These are principally related to the generation and propagation of ocean swell and local sea. Large waves generated by a storm are generally categorised as sea because wind energy is still being transferred to the ocean. However, this distinction was not made in this study for offshore storm waves and they were considered as swell. Long waves (wave periods greater than 25 seconds) in Botany Bay generally occur during storms and are caused by wave grouping, (Willoughby & Treloar, 1997).

Ocean waves are irregular in height and period and so it is necessary to describe wave conditions using a range of statistical parameters. In this study the following have been used:-

- H_{mo} significant wave height (H_s) based on $4\sqrt{M_o}$ where M_o is the zeroth moment of the wave energy spectrum (rather than the time domain $H_{1/3}$ parameter).

- H_{max} maximum wave height in a specified time period

- T_p wave energy spectral peak period, that is, the wave period related to the highest ordinate in the wave energy spectrum

- T_z average zero crossing period based on upward zero crossings of the still water line. An alternative definition is based on the zeroth and second spectral moments.

Wave heights defined by zero upcrossings of the still water line fulfil the Rayleigh Distribution in deep water and thereby provide a basis for estimating other wave height parameters from H_s. In shallow water, that is, within Botany Bay, significant wave height defined from the wave spectrum, H_{mo}, is normally larger (typically 5% to 8%) than $H_{1/3}$ defined from a time series analysis.

Ocean waves also have a dominant direction of wave propagation and directional spread about that direction that can be defined by a Gaussian or generalised cosine

($\cos^n$) distribution (amongst others), and a wave grouping tendency. Directional spread is reduced by refraction as waves propagate into the shallow, nearshore regions and the wave crests become more parallel with each other and the seabed contours. Although neither of these characteristics is addressed explicitly in this study, directional spreading was included in the numerical wave modelling work. Directional spreading causes the sea surface to have a more short-crested wave structure in deep water.

Waves propagating into shallow water may undergo changes caused by refraction, shoaling, bed friction, wave breaking and, to some extent, diffraction.

Wave refraction is caused by differential wave propagation speeds. That part of the shoreward propagating wave which is in the more shallow water has a lower speed than those parts in deeper water. When waves approach a coastline obliquely these differences cause the wave fronts to turn and become more coast parallel. Associated with this directional change there are changes in wave heights. On irregular seabeds wave refraction becomes a very complex process.

Waves propagating shoreward develop reduced speeds in shallow water. In order to maintain constancy of wave energy flux (ignoring energy dissipation processes) their heights must increase. This phenomenon is termed shoaling and leads to a significant increase in wave height near the shoreline.

A turbulent boundary layer forms above the seabed with associated wave energy losses that are manifested as a continual reduction in wave height in the direction of wave propagation - leaving aside further wind input, refraction, shoaling and wave breaking. The rate of energy dissipation increases with greater wave height.

Wave breaking occurs in shallow water when the wave crest speed becomes greater than the wave phase speed. For irregular waves this breaking occurs in different depths so that there is a breaker zone rather than a breaker line. Seabed slope, wave period and water depth are important parameters affecting the wave breaking phenomenon. As a consequence of this energy dissipation, wave set-up (a rise in still water level caused by wave breaking), develops shoreward from the breaker zone in order to maintain conservation of momentum flux. This rise in water level increases non-linearly in the shoreward direction and allows larger waves to propagate shoreward before breaking. Field measurements have shown that the slope of the water surface is normally concave upward. Wave set-up at the shoreline can be in the order of 15% of the equivalent deep-water significant wave height. Less set-up occurs in estuarine entrances, but the momentum flux remains the same. Wave set-up is smaller where waves approach a beach obliquely, but then a longshore current can be developed. Wave grouping and the consequent surf beats also cause fluctuations in the still water level.

Wave diffraction will be particularly important for this study within Port Botany itself, and an appropriate wave model was applied.

In a random wave field each wave may be considered to have a period different from its predecessors and successors and the distribution of wave energy is often described by a wave energy spectrum. In fact, the whole wave train structure changes continuously and individual waves appear and disappear until quite shallow water is reached and dispersive processes are reduced. In developed sea states, that is swell, the Bretschneider modified Pierson-Moskowitz spectral form has generally been found to provide a realistic wave energy description. For developing sea states the JONSWAP spectral form, which is generally more ‘peaky’, has been found to provide a better spectral description. Long waves have very irregular spectral forms.

For structural design in the marine environment it is necessary to define the H_{max} parameter related to storms having average recurrence intervals (ARI) of R years. However, the expected H_{max}, relative to H_s in statistically stationary wave conditions, increases as storm/sea state duration increases. Based on the Rayleigh Distribution the usual relationship is:-

$$H_{max} = H_s \sqrt{(0.5 \ln Nz)}$$

where Nz is the number of waves occurring during the time period being considered, where individual waves are defined by Tz.
ln is the natural logarithm

This relationship has been found to overestimate H_{max} by about 10% in severe ocean storms. In shallow water the relationship is not fulfilled. In very shallow water H_{max} is replaced by the breaking wave height, H_b.

Waves propagating through an area affected by a current field are caused to turn in the direction of the current. The extent of this direction change depends on wave celerity, current speed and relative directions. Wave height is also changed. Opposing currents cause wave lengths to shorten and wave heights to increase and may lead to wave breaking. When the current speed is greater than one quarter of the phase speed the waves are blocked. Conversely, a following current reduces wave heights and extends wave lengths.

2.3 CURRENTS

Currents within Botany Bay are caused by a range of phenomena, including: -

- Astronomical Tides
- Winds
- River Discharges
- Coastal Trapped Waves and Other Tasman Sea Processes
- Nearshore Wave Processes
- Density Flows

The astronomical tides are caused by the relative motions of the Earth, Moon and Sun, see Section 2.4. The regular rise and fall of the tide level in the sea causes a periodic inflow (flood tide) and outflow (ebb tide) of oceanic water to the Bay and mixed oceanic and bay/river water from the Bay to the sea. A consequence of this process is the generation of tidal currents. The volume of sea water that enters the Bay or leaves the Bay on flood and ebb tides, respectively, is termed the tidal prism; which parameter varies due to the inequality between tidal ranges. The tidal prism is affected by changes in inter-tidal areas, such as the proposed port area, but not by dredged areas below low tide, such as the proposed new dredged berthing area.

Wind forcing is applied to the water surface as interfacial shear, the drag coefficient and consequent drag force varying with wind speed. Momentum from the wind is gradually transferred down through the water column by vorticity, the maximum depth of this effect being termed the Ekman depth. At the surface, wind caused currents, are in the direction of the wind, but in the southern hemisphere they gradually turn to the left of the wind direction until they flow in the opposite direction at the Ekman depth. Botany Bay is too shallow for this condition to develop fully and wind driven currents are affected by the seabed boundary layer. Wind driven currents diminish with depth. Because wind forcing is applied at the water surface, the relative effect is greater in shallow water where there is less water column volume per unit plan area. Therefore wind driven currents are greater in more shallow areas. Maximum surface current speed is in the order of 1% to 3% of the wind speed, depending on water depth. Where water is piled up against a coastline by wind forcing, a reverse flow develops near the seabed. A vertical flow structure develops in Botany Bay, and following the proposed port expansion, there will be changes to the flow structure in the Penrhyn Estuary region.

Density currents may be caused by freshwater inflows, for example, when the Georges River is in flood. The freshwater is more buoyant and tends to spread across the Bay surface until mixing with the ambient seawater occurs. Those currents also develop during periods of higher flow to the Penrhyn Estuary area and from the Millstream.

Coastal Trapped Waves (CTW) are long period wave phenomena that propagate northward along the continental shelf, Freeland et al, 1986. Their origin is not fully understood, but they are believed to originate from the passage of successive high and low pressure meteorological systems across southern Australia. These systems have inter-arrival times varying from 3 to 7 days, typically, and these are the periods of the observed CTW. These waves are irregular and cause approximate coast parallel currents and variations in water levels. They are trapped on the continental shelf by refraction and the Coriolis force. CTW are known to occur on the continental shelf of NSW and will affect observed water levels in the Sydney – Botany Bay region.

The propagation of ocean waves (swell) into the nearshore region leads to wave breaking and energy dissipation. Where waves propagate obliquely to the shoreline this process leads to the generation of a longshore current in the surf zone, and to some extent seaward of that line. These currents are of some importance to shoreline processes in the Bay generally. Wave breaking and subsequent wave run-up are discussed further in Section 2.4.

2.4 WATER LEVELS

Water level variations in the Bay and at the coastline result from one or more of the following natural causes:-

- Eustatic and Tectonic Changes
- Tides

- Wind Set-up and the Inverse Barometer Effect
- Wave Set-up
- Wave Run-up
- Fresh Water Flow
- Tsunamis
- Greenhouse Effect
- Global Changes in Meteorological Conditions

Eustatic sea level changes are long term world wide changes in sea level relative to the land mass and are generally caused by changes to the polar ice caps. No rapid changes are believed to be occurring at present and this aspect has not been addressed. Nevertheless, a minimum rise of 1mm per annum is now generally accepted. Tectonic changes are caused by movement of the Earth's crust; they may be vertical and/or horizontal

Tides are caused by the relative motions of the Earth, Moon and Sun and their gravitational attractions. While the vertical tidal fluctuations are generated as a result of these forces, the distribution of land masses, bathymetric variation and the Coriolis force determine the local tidal characteristics.

Wind setup and the inverse barometer effect are caused by regional meteorological conditions. When the wind blows over an open body of water, drag forces develop between the air and the water surface. These drag forces are proportional to the square of the wind speed. The result is that a wind drift current is generated. This current may transport water towards the coast upon which it piles up causing wind set-up. Wind set-up is inversely proportional to depth.

In addition, the drop in atmospheric pressure, which accompanies severe meteorological events, causes water to flow from high pressure areas on the periphery of the meteorological formation to the low pressure area. This is called the 'inverse barometer effect' and results in water level increases up to 1cm for each hecta-Pascal (hPa) drop in central pressure below the average sea level atmospheric pressure in the area for the particular time of year, typically about 1010 hPa. The actual increase depends on the speed of the meteorological system and 1cm is only achieved if it is moving slowly. The phenomenon causes daily variations from predicted tide levels up to 0.05m. The combined result of wind set-up and the inverse barometer effect is called storm surge.

Wave run-up is the vertical distance between the maximum height a wave runs up the beach or a coastal structure and the still water level, comprising tide plus storm surge and wave set-up. Additionally, run-up level varies with surf-beat, which arises from wave grouping effects.

Tsunamis are caused by sudden crustal movements of the earth and are commonly, but incorrectly, called 'tidal waves'. They are very infrequent and unlikely to occur during a storm and so have not been included in this study. Nevertheless, in the context of events having recurrence intervals in the order of 100 years, one should keep this point in mind.

Global meteorological and oceanographic changes, such as the El Nino Southern Oscillation phenomenon in the eastern southern Pacific ocean, and continental shelf waves, cause medium term variations in mean sea level. The former phenomenon may persist for a year or more. The causes are not properly understood, but analyses of long term data from Australian tide gauges indicate that annual mean sea level may vary up to 0.1m from the long term trend, whilst mean sea level may vary by more than 0.2m over the time scale of weeks as a result of coastal trapped wave activity.

Many scientists believe that global warming of the Earth's atmosphere will lead to a rise in mean sea level. Predictions of global sea level rise due to the Greenhouse effect vary considerably. It is impossible to state conclusively by how much the sea may rise, and no policy yet exists regarding the appropriate provision that should be made in the design of new coastal developments.

Based on models developed by the American National Academy of Science and the American National Research Council incorporating relevant environmental factors, a guide to future ocean level rises is presented in Table 2.1.

Table 2.1: Predicted Greenhouse Related Mean Sea Level Rises

Estimate	Sea Level Rise (m) to Year Shown				
	2000	**2025**	**2050**	**2075**	**2100**
Low	0.02	0.09	0.19	0.32	0.49
Mean	0.03	0.14	0.34	0.62	0.98
High	0.03	0.20	0.49	0.92	1.48

More recent investigations undertaken by CSIRO (1998) advise a mean sea level rise of 0.2m over the 50 years period from 1998 for the NSW coastline. Investigation of the Australia State of the Environment Report 2001 web-site advises a mean sea level rise of 0.09m to 0.88m by 2100. Thus there is considerable uncertainty in this parameter estimate.

Tidal planes derived from longterm records at Fort Denison, Sydney Harbour are shown in Table 2.2, (Manly Hydraulics Laboratory, 1992). Tidal planes for Botany Bay and the study area are similar to those for Sydney Harbour, (MSB Sydney Ports Authority, 1993). Tides in Botany Bay are semi-diurnal, that is, there are two high and two low tides each day, normally. On rare occasions there may be only one high or low tide because the lunar tidal constituents have a period of about 25 hours. There may also be a significant diurnal difference, that is, a significant difference between successive high tides and successive low tides.

Table 2.2: Tidal Planes for Botany Bay

Tidal Plane	Water Level	
	m LAT	m AHD
Mean High Water Springs (MHWS)	1.61	0.69
Mean High Water Mark (MHWM)	1.48	0.56
Mean High Water Neaps (MHWN)	1.36	0.44
Mean Sea Level (MSL)	0.93	0.01
Mean Low Water Neaps (MLWN)	0.54	-0.39
Mean Low Water Springs (MLWS)	0.29	-0.64

Table 2.3 presents extreme water levels for typical Average Recurrence Intervals (ARI), also derived from the Fort Denison water level records (MSB Sydney Ports Authority, 1993). These levels exclude wave setup and relate to locations seaward of the breaker zone.

Table 2.3: Extreme Water Levels in Botany Bay

Average Recurrence Interval (years)	Water Level	
	m LAT	m AHD
20	2.26	1.34
50	2.33	1.41
100	2.35	1.43

2.5 WINDS

Wind affects both the wave and current climates in Botany Bay. Wind data has been recorded at Sydney Airport since 1939, Moneypenny et al (1997). The location and impact of airport development have changed since then. From 1939 to 16 August, 1994, a Dines anemometer was used to record 10-minute averages of wind speed and direction. Since the early 1960's, at least, this anemometer was located on a 10m mast near the intersection of the east-west and north-south runways. Recommended WMO clearances from buildings and other obstructions were maintained. During its period of service, the Dines anemometer was maintained well.

Since 16 August, 1994, wind data at the airport has been recorded using a Synchrotec anemometer installed on a 10m mast near the threshold of the main north-south runway, which is more exposed than the previous Dines anemometer site.

Analyses of these wind records, (Monypenny and Middleton, 1997), showed that there had been a gradual error (reduction) in wind speed recorded by the Dines anemometer. This reduction amounted to 2.6m/s by August, 1994. Monypenny and Middleton (1997), advise that a simplified linear adjustment be made to Sydney airport wind speeds up to 16 August, 1994 and this adjustment was made for this study. Data to 31 December, 2000 was obtained from the Bureau of Meteorology.

Appendix C presents a description of wind speed and direction joint occurrence at Mascot. Note that calms occur for about 17% of the time.

Although wind data has also been recorded by SPC at the Bulk Liquids Berth since 1994, the principal purpose of wind data for this study was to provide input for wave modelling. Hence the longer term data provides a better description of the average recurrence interval (ARI) characteristics of local sea within Botany Bay.

2.6 SEDIMENT TRANSPORT - COASTAL STABILITY

The nearshore and shoreline regions of Botany Bay are formed from marine sands and rocky headlands, with some muddy areas in the more sheltered regions such as Quibray and Woolooware Bays, and a small area within the recently formed Penrhyn Estuary area. Additionally, the perimeters of existing development works provide hard-edge areas.

The principal shoreline features of the Bay are Silver Beach at Kurnell, Towra Beach and peninsula, the Georges River mouth and spit areas, Lady Robinsons Beach and the Northern Foreshore. Most of the features of this area have formed over the last 10,000 years of the Holocene period, (Roy and Crawford, 1979) during a period of sea level rise. Relative to that period, sea level is now stable. However, natural changes to the nearshore area continue and are caused by storm waves, especially when they occur during periods of higher water level.

Development in Botany Bay since European settlement has caused other wave climate related changes, as well as the features of the developmental changes themselves. Specific characteristics of those areas are:-

- Silver Beach - this area is now protected from storm erosion by a groyne field, with only the more protected eastern end near Captain Cook's Landing Place remaining in a more natural state.

- Towra Beach is a very dynamic area and longterm changes to this area are continuing as a result of natural processes and the impacts of previous development work in the Bay. Changes are also occurring to the western trunk of the peninsula.

- The Georges River enters south-west Botany Bay near Dolls Point. The tidal flow has incised a wide, shallow entrance waterway that has steep sides in some areas. It has inter-acted with wave processes to form the Taylor Bar spit at Dolls Point.

- Lady Robinsons Beach extends from north to south along the western shoreline of the Bay. Significant changes have occurred to that shoreline since European settlement and the development of port and airport facilities in the Bay. However, SPC have managed the construction of a groyne field on southern Lady Robinsons Beach and approval to construct an additional five groynes north from Ramsgate towards President Avenue has been gained. These works include continuing planned re-nourishment of the region north of the northern-most planned groyne, as shoreline recession occurs there.

- The Northern Foreshore region of the Bay has a range of features. At its eastern end, and seaward of existing and proposed port works, the foreshore is formed from a series of enclosed bays that are generally stable, for example, Yarra Bay. Existing port facilities form a section in the middle of the foreshore. Between the existing port facilities and the Mill Stream, which enters the Bay north of the Parallel Runway, there is an extensive sandy shoreline (Northern Foreshore Beach) that was formed during the late 1970's as part of port development and access road construction - Foreshore Road. This shoreline presently suffers from longterm recession at its eastern end, mainly as a result of local sea and consequent longshore transport to the west. Nuisance sand deposition occurs near the Mill Stream entrance at the western end of the beach. Much of this area would become enclosed as part of the proposed port development, other than a short beach area north-west of the new port area.

Sediment transport is caused by the water particle motions of waves and currents that lead to a shear stress on the seabed sediment particles. In some parts of the Bay waves and currents cause combined shear stresses. Generally, sediment motion commences when the seabed shear stress exceeds a threshold value, which depends on particle size and density. Sediment may be transported as bed load or suspended load. Bed load transport is effected as a series of saltations or hops. Suspended sediment transport occurs when the turbulent mixing of the flow counteracts the fall velocity of the finer sediment particles that disperse upward from the seabed.

Where a seabed is disturbed, for example, by dredging, and where the threshold condition for sediment movement is exceeded, wave and current caused sediment transport may act to restore the pre-condition of the seabed. Experience based on historical hydrographic surveys has shown that in Botany Bay, other than at nearshore locations, the bed of the Bay is essentially stable.

At shoreline locations sediment transport may be alongshore and/or onshore/offshore. Where waves break obliquely to the shoreline, a longshore current may cause longshore transport. Offshore transport normally occurs during a storm, with a longer term onshore transport following storm abatement. However, onshore transport may not occur in very low wave energy regions such as that near Kyeemagh. These regions are characterised by a flat inter-tidal area with a steep drop-off near the low tide line.

Waterways that enter the Bay may transport fine silt particles from the catchments to the Bay. These fine particles eventually settle in the most tranquil regions of the Bay, or leave the Bay to sea.

3. PREVIOUS STUDIES

The most recent compendium of physical processes within Botany Bay and the Georges River is presented in the Healthy Rivers Commission (HRC) Report (2001). That document deals mainly with planning and management issues. However, HRC did seek technical input from various bodies, for example, the Coastal Studies Unit of Sydney University. That latter document was directed mainly at geomorphological issues and drew substantially on historical data and previous investigations. A principal outcome of the HRC investigations was the suggestion that future investigations should address the whole of Botany Bay and its catchment, and that planning of future works should be undertaken within a comprehensive planning framework.

The draft EIS, (Kinhill, 1991) prepared for the Parallel Runway of Sydney Airport, addressed wave climate, current and likely shoreline impacts. Wave climate and current issues were investigated by Lawson and Treloar.

During the construction program for the Parallel Runway, detailed wave climate studies were undertaken (SPA, 1993). Significant within that program was the extensive long term beach monitoring program involving shore normal beach surveys; initiated in the early 1970's by SPC's predecessor, the Maritime Services Board. That data has been used to estimate rates of long shore sediment transport and shoreline changes on Lady Robinsons and Towra Beaches.

More recently current and wave data were recorded at sites MID and SOUTH, see Figure 4.1, (Lawson and Treloar, 1999). That data provides useful input to this study because it follows construction of the Parallel Runway.

Many other site or issue specific investigations have been undertaken. However, those cited above provide the principal framework and information for this study.

These studies have generally shown that observed shoreline changes are attributable to both natural changes and anthropogenic changes arising from developments in the Bay since the early 1950's.

4. WAVE CLIMATE STUDIES

4.1 GENERAL

The purpose of this section of the report is to investigate any potential changes to swell, local sea and long waves throughout the Bay, and where possible, to quantify the impacts of these changes.

4.2 WAVE DATA

Wave data has been recorded at Botany Bay by SPC, and its predecessor bodies, since 1971. The principal location is offshore in a depth of about 80m using a Datawell Waverider buoy that transmits a signal onshore for processing and storage, see Figure 4.1 (offshore). In the early 1970's this was done using paper tape and records were taken about four times a day. Continuous records are taken now, thereby providing a better definition of peak storm wave parameters. These analyses provide data in terms of H_s and T_z, together with other parameters. Wave direction is a particularly important parameter for wave propagation into Botany Bay, but has not been recorded. This parameter has been mainly estimated from daily synoptic charts.

SPC have recorded wave data at other sites within Botany Bay for shorter periods, see Figure 4.1. For this study a Waverider buoy (WRB16) was installed near the 'entrance' to the proposed container port expansion area in order to describe the wave climate there. Although swell at that location was expected to be small, reliable quantification was required, as well as a reliable description of local sea there for model calibration. Long waves and swell have been recorded for periods of a few months at the sites described as 'MID ' and 'SOUTH', (Lawson and Treloar, 1999).

In order to apply the offshore wave data to this study, it has been analysed to provide a directional wave climate in parametric form, based on offshore direction and wave period bands. Direction bands were based on 22.5^o intervals centred on north, north-north-east, …, south. Wave period bands were based on T_z intervals of 1 second between 2.5, 3.5, …,10.5, 11.5 seconds. Each wave data record was classified using these divisions, thereby leading to a potential 9 directions by 9 wave period cases. However, data was not available for all of these direction-period cases, for example, north-T_z 7.5 seconds. These wave conditions are rare. This step was then followed by a probability of exceedence analysis of all records within each direction-period case, leading to conditional probabilities for the occurrence of each direction-period case and a log-normal description of wave height exceedence in terms of H_{10} and H_{90}. These waves are described by the parametric wave climate presented in Appendix D for Port Botany - data from 1971 to 1994.

Other offshore wave data has been recorded by Manly Hydraulics Laboratory at Long Reef to the north of Botany Bay. That installation includes recorded wave direction. Comparison between the analysed Long Reef and Botany Bay wave data shows that 'actual' offshore wave directions (Long Reef) are more southerly, on a probability of occurrence basis, than has been estimated for the Botany Bay data, Kulmar (1997). Therefore the SPC data is marginally more conservative from the point of view of wave penetration to Botany Bay, because south-easterly waves propagate more easily into the Bay than do southerly waves. The Long Reef data has also been included in Appendix D in the same parametric form as the offshore Botany Bay data - 1992 to 2001 data.

For the purposes of this study all wave energy recorded at the SPC offshore Waverider buoy has been classified as swell, even though there will generally be some local sea present. In severe storms, where wave growth may still be occurring to the higher waves, those waves should physically be described as sea, but the distinction is not important to this investigation.

In addition to local sea and swell waves, long wave motions may develop in Botany Bay. These waves generally have periods between 25 and 300 seconds, in so far as they may affect moored ship motions. They are generally believed to be associated with storm events in which higher than normal wave heights and longer wave periods occur, (Sand, 1982). The importance of these long period waves lies in their potential to cause excessive moored vessel motions and hence disrupt loading/unloading procedures and/or break mooring lines. No long wave caused disruptions to shipping have been reported in Botany Bay.

4.3 SHORT WAVE INVESTIGATIONS

4.3.1 Overall Description

The short period wave climate within Botany Bay is a complex combination of local sea and ocean waves (swell). The mix of these two frequency bands depends on local and distant wind conditions, as well as location within the Bay.

Wave climate conditions in the Bay have been changed significantly by human intervention since European settlement. The shoreline of the Bay has responded to these changes, as well as to natural causes (SPA, 1993); the Bay never having been fully stable and unchanging. Waves affect shipping and the condition of the shoreline within the Bay and form the dominant environmental force in much of the Bay and along the shoreline.

The proposed container port expansion is confined to the northern part of Botany Bay between the existing port and airport, together with a small change to the bathymetry on the southern side of the main shipping channel north-west of Molineux Point. Hence the impacts will be confined generally to that section of the Bay within an area between the Parallel Runway and Molineux Point. This statement relates to swell waves, which would be propagating at a direction of about 133° at the entrance to this area. Any reflections from the runway and new port area would generally continue to propagate further into this area. Only where reflections occur from the new container berth that is aligned with the northern quay of Brotherson Dock may there be wave energy reflected back into the Bay. However, this area would most likely be formed of a suspended slab berth and underlying rock revetment, which is less reflective than the present Brotherson Dock berths.

There would be no change in local sea propagation from the Bay into the area, but the increased area of filled bay within Port Botany would marginally reduce the fetches of northerly sector wind waves that propagate towards Kurnell, for example. Because water depths would be relatively deep within Port Botany, local sea is not affected by refraction there. The presence of the existing Parallel Runway will basically prevent any fetch changes to northerly sector wind waves that propagate towards western Towra Beach and Lady Robinson's Beach.

Hence wave climate investigations were undertaken to address the following issues:-

- to investigate the extent of wave climate change and consequent impact beyond the port area, especially along the southern shoreline
- to define design wave conditions at the proposed new berths and to ensure no deterioration of wave conditions at the existing Brotherson Dock berths
- to determine the extent of wave climate change, if any, along the eastern wall of the Parallel Runway
- to provide design wave criteria for the proposed re-located boat ramp
- to describe wave conditions along the Northern Foreshore west of the proposed boat ramp.

These wave climate issues were investigated using a range of data items and numerical wave models that are described below.

4.4 NUMERICAL WAVE MODELS

Two numerical wave modelling systems were applied to these investigations. Their characteristics are discussed below.

4.4.1 SWAN Model

The first of these was the SWAN model, which was used to investigate the propagation of swell into the Bay from the Tasman Sea and the generation of local sea within the Bay. This model was developed at the Delft Technical University and includes wind input, (local sea cases), combined sea and swell, offshore wave parameters (swell cases), refraction, shoaling, non-linear wave-wave interaction, a full directional spectral description of wave propagation, bed friction, white capping, currents and wave breaking. It can include nesting of finer grid areas within an overall coarser grid model. For this study a constant grid size of 50m was used covering the whole Bay from the 100m depth contour offshore to Sandringham Bay on the northern side of the Georges River entrance near Sans Souci.

The model system set up for this study is shown in Figure 4.2 and is based on a 50m grid. The bathymetry for this investigation was prepared from AUS Charts 198 and 199, with detailed bathymetry for all port areas, including the Caltex facilities at Kurnell in Southern Botany Bay, being provided by SPC in digital form. All model simulations were undertaken at MSL, this being the most common water level. This position is realistic for longterm shoreline impact studies, but would not be the case for storm bite analyses or determination of design wave parameters.

For swell wave investigations, waves from nine offshore directions from north through east to south, combined with 9 wave periods (T_z) from 3 to 11 seconds were applied.

This amounts to 81 basic cases, which are consistent with the offshore parametric wave climate described in Appendix D. In each case offshore wave height was adopted to be 1.5m. Application of the 1.5m offshore wave height to wave propagation processes in equation (4.1), see below, leads to slightly conservative inshore wave heights, but to the same extent in both pre- and post-port expansion cases. Only very minor change was expected at shoreline locations outside the port area because there will be little dredging beyond the new port area, see Appendix A. This wave height is approximately the median offshore significant wave height.

One other purpose of swell wave modelling was to provide boundary wave data for input to a northern Bay regional wave model of the area between the Parallel Runway and Molineux Point. At this location bed friction and wave breaking losses are minimal and therefore model application with offshore H_s = 1.5m provides realistic wave transfer coefficients, K_w, between offshore and inshore locations.

K_w is defined by:-

$$H_i = H_o \times K_w \tag{4.1}$$

where H_i is inshore wave height
H_o is offshore wave height

K_w depends on offshore wave period and direction and includes the wave transformation processes.

Additionally, it was necessary to investigate changes in wave conditions along the Bay shorelines. A large number of other locations around the Bay shoreline were selected for model output. These were generally in a depth of 2m Chart Datum (CD), see Figure 4.3. At many of those sites, bed friction, and occasionally wave breaking will affect wave propagation to them.

Figure 4.2 shows the model layout including model results for a severe south-easterly offshore storm. The plot is in terms of wave height (H_s) contours and wave vectors that show wave height to scale and wave direction. Wave output is prepared also in tabular form and that tabulated data for each model output location was applied to further investigations.

4.4.2 MIKE-21 Boussinesq Wave (BW) Model

This model system was used to propagate swell waves into the port area between the Parallel Runway and Molineux Point from a model boundary near SWAN output Location 70, see Figure 4.3, and set normal to the shipping channel. This provides a reliable SWAN output point, from where swell propagating into Port Botany enters at an angle of about 90° to the MIKE-21 BW boundary. The MIKE-21 BW model includes refraction, diffraction, shoaling, bed friction, random directional waves and full and partial reflections from vertical impervious and sloping rock revetment walls, respectively. Sponge layers are incorporated in the model along its outer perimeter to absorb reflected wave energy propagating outward from the model area to the Bay. This is consistent with natural wave propagation processes in the Bay.

The model was set up with a grid size of 4m for swell waves and operated with a time step of 0.25 seconds. This fine grid size was necessary to resolve the profile of the shortest wave length included in the spectral wave time series input. About 8 grid points per wave length are required.

For this investigation it was necessary to model two edge variations for the proposed berths - a rock wall revetment with a reflection coefficient of 0.5 and a fully reflective vertical quay wall.

4.5 SWELL (SWAN) MODEL CALIBRATION

Wave model calibration provides confidence that the model system set up for this investigation will reproduce wave conditions in Botany Bay. The model was calibrated separately for swell and local sea cases.

Calibration cases applied in this report are those presented in the (then) Sydney Ports Authority (SPA) Report No. KSA03 (1993). Those cases are described as W, X, Y, Z, see Tables 2 and 8 in Appendix D of that report. Inshore wave heights (H_S) at Waverider buoy stations 3, 5 (Entrance Channel), 9 (Towra Beach) and 10 (Brighton) were used, see Figure 4.1. Note that for these cases combined sea and swell was recorded by SPC Waverider buoys. Therefore the SWAN wave model was run with offshore boundary wave data as well as with wind input data. Offshore wave height and period were based on the offshore SPC Botany Bay Waverider buoy, whereas wave direction was based on the Long Reef Waverider buoy operated by Manly Hydraulics Laboratory.

In all cases the offshore spectrum was described using a Pierson-Moskowitz frequency spectrum and a Gaussian directional spread with 10° standard deviation. Wave propagation processes included wind input, bed friction (Madsen factor 0.02), refraction, shoaling, wave breaking and white capping. Wind data was based on Mascot airport data and a land/sea terrain factor of 0.9, that is, wind speeds measured at Mascot were increased by a factor of 1.1. Results of those analyses are presented in Table 4.1. Measured inshore H_s are shown in bold.

Table 4.1: Results of Swell Wave Model Calibration

Calibration Case 09/08/1992 1730									
Offshore Wave Parameters				**Wind**		**Inshore H_s(m)**			
H_s(m)	**T_z(s)**	**T_p(s)**	**ϕ(°TN)**	**W(m/s)**	**Wdir (°TN)**	**WRB3**	**Channel**	**Brighton**	**Towra**
3.0	6.4	9.0	180	8.9	180	**0.33**,0.34	**0.45**,0.46	**0.34**,0.34	**0.20**,0.19
Calibration Case 25/08/1992 1200									
Offshore Wave Parameters				**Wind**		**Inshore H_s(m)**			
H_s(m)	**T_z(s)**	**T_p(s)**	**ϕ(°TN)**	**W(m/s)**	**Wdir (°TN)**	**WRB3**	**Channel**	**Brighton**	**Towra**
3.9	7.1	9.9	164.5	10.3	202.5	**0.87**,0.85	**0.80**,0.82	**0.60**,0.62	**0.28**,0.31

Calibration Case 22/10/1992 1000									
Offshore Wave Parameters				Wind		Inshore H_s(m)			
H_s(m)	T_z(s)	T_p(s)	ϕ(°TN)	W(m/s)	Wdir (°TN)	WRB3	Channel	Brighton	Towra
3.7	7.1	9.7	146	8.3	180	**1.02**,0.99	**0.72**,0.74	**0.74**,0.72	**0.50**,0.53

Calibration Case 23/10/1992 0700									
Offshore Wave Parameters				Wind		Inshore H_s(m)			
H_s(m)	T_z(s)	T_p(s)	ϕ(°TN)	W(m/s)	Wdir (°TN)	WRB3	Channel	Brighton	Towra
4.0	8.0	11.2	129	2.6	142	**1.02**,1.04	**0.78**,0.82	**0.84**,0.81	**0.60**,0.61

These results show a good calibration outcome. There is a significant spatial variation in H_s near the Entrance Channel Waverider buoy and the results and spatial variation of H_s within Botany Bay show a significant dependence on offshore wave direction. Wave direction can be an unreliable parameter when determined from direction at peak spectral energy, or where the proportions of sea and swell in a wave record are similar, yet those two frequency bands have different directions. Spectral form (sea/swell distribution) and tidal currents are also likely to affect wave propagation.

A second swell wave calibration task was undertaken. Wave propagation to Locations MID and WRB16 was investigated using two wave models – SWAN and MIKE-21 BW. The SWAN model does not include diffraction. Therefore it was used to propagate wave energy to Location 70, see Figure 4.3. From there, wave propagation into Port Botany was described using the MIKE-21 Boussinesq Wave model, which includes refraction, shoaling, diffraction and a full directional-spectral wave description. Observed wave data at Location MID showed T_p to be typically 9 seconds and that wave period was used to describe wave propagation from Location 70 to MID and WRB16 using the existing Botany Bay bathymetry.

Offshore wave data for the wave data period was available from the SPC offshore Botany Bay Waverider buoy (H_s, T_z, spectral ordinates) and the MHL Long Reef directional Waverider buoy (direction). This direction is likely to be more reliable than the offshore wave direction estimated at Botany Bay by analysis of synoptic charts. This data was provided by SPC and then collated; reducing to hourly records. Record by record transfer to Location 70 was undertaken using the wave coefficients developed from the SWAN model results and then to Locations MID and WRB16 by including the MIKE-21 BW model wave coefficients relative to Location 70. In this analysis only the swell component, frequency <0.2Hz, of the offshore waves was transferred inshore to Location 70.

The outcome of this second calibration analysis is shown in Figure 4.4 and provides additional confidence in the combined SWAN/MIKE-21 BW model system.

Overall the model can be used confidently for the port development investigations. Note also, these investigations are on a comparative basis, that is, it is the differences between wave conditions for existing and post port-expansion cases that are important, and any deficiency in model performance will be similar for both cases.

4.6 RESULTS

4.6.1 Shoreline Areas

The results of SWAN modelling of swell wave propagation into Botany Bay provided a 9 x 9 matrix of wave coefficients and weighted average wave directions at most model output locations shown in Figure 4.3. Those not included in SWAN model output were addressed separately. Each entry in a location specific wave coefficient transfer matrix represents one offshore wave direction-wave period (T_z) case. Those wave coefficients and inshore wave directions were then combined with the parameterised offshore wave climate, see Appendix D, to provide inshore wave parameters in terms of H_e (effective significant wave height) and ϕ_m (weighted mean wave direction), see Appendix E. The computation of H_e and ϕ_m is described in Appendix F.

These parameters encapsulate the integrated sediment transport potential of the long term swell wave climate at each location, when combined with the physical characteristics of the shoreline and sediment at each location. Inspection of Appendix E shows that there will be small changes in swell wave parameters at some locations along the Botany Bay shoreline. Other changes will occur within the port area.

In the first instance a 9 x 9 array of H_e parameters in the offshore area was computed as H_{eij}. A similar array of probabilities of wave occurrence for each period-direction case (P_{ij}) in the offshore region was determined from the data also. This information then describes the probability of occurrence of the (ij) (period (i)-direction (j)) cases.

The offshore H_{eij} parameters were then transferred inshore to each location. Weighted mean inshore wave directions were then calculated as:-

$$\phi_m = \sum P_{ij} \times H_{eij}^2 \times K_{wij}^2 \times T_{zi} \times \phi_{ij} / \sum P_{ij} \times H_{eij}^2 \times K_{wij}^2 \times T_{zi}$$

An overall H_e parameter was also calculated at each inshore location. The transferred offshore H_e parameters were first analysed as a log-normal distribution of H_e, and then inshore, overall H_e parameters were determined from these distributions. These results are presented in Table E1 of Appendix E for selected locations. There are no changes at most of the model output locations.

An inspection of Table E1 shows that the proposed dredging of the shipping channel will cause some changes in nearshore mean directions, typically not greater than 0.1°. There is virtually no change in effective significant wave heights. The implication of these changes, because they are so subtle, is not easy to determine from inspection of the table.

In order to determine the actual impact on the shoreline in terms of potential shoreline recession or progradation, it was necessary to calculate changes in sediment transport rates along the shoreline. Potentially the most sensitive site is Towra Beach. Silver Beach is protected by groynes and the southern half of Lady

Robinsons Beach is/will be protected similarly. Other shorelines are not affected or the wave climate is much milder.

Locations 12 to 19 refer to nearshore Towra Beach model output locations and were adopted for analysis. A shore normal profile from the July 1998 survey (No. 38) was used to describe the beach profile of Towra Beach within the LITPACK coastal processes modelling system. LITPACK has been developed at the Danish Hydraulics Institute and is based on a sediment transport module that includes bed and suspended loads, actual beach profiles, graded sediments, currents and irregular waves. The site specific H_e and ϕ_m parameters were then used to calculate annual longshore sediment transport rates at Locations 12 to 19 for pre- and post-development wave conditions.

Sediment transport rates in themselves do not describe shoreline erosion and accretion; it is the gradient in transport rate that causes those outcomes. Where there is an increase in transport rate in the direction of sediment transport there will be erosion. Where there is a decrease in sediment transport rate in the direction of sediment transport there will be accretion. A D_{50} particle size of 0.18mm was adopted. A T_z value of 6.5 seconds was considered to be appropriate with a shore normal direction of 40°TN. Computed transport rates in the order of 6,000m^3/year were determined, with smaller rates at the eastern end of the beach and a larger rate at Towra Point. All transport is westward.

Recession/progradation rates can be estimated by dividing the beach of approximate 1300m length into several compartments and considering the sediment flux through the down and updrift boundaries of each such compartment. Erosion/progradation is then based on the net sediment efflux/influx, the length of each compartment and the active beach-face height over which transport occurs along the beach. Based on the low energy wave climate of the area and tide range, this height was taken to be 2.5m. On this basis there is irregular erosion/accretion along Towra Beach and annual erosion rates up to 2m along the shoreline. This estimated longshore transport rate is consistent with rates determined from analyses of longterm shore normal surveys of Towra Beach (1973-2001) undertaken by SPC.

An examination of changes in pre- and post-development transport rates demonstrates that the changes in transport rates are in the order of 0.1%. On the basis of an estimated present, shoreline, average recession rate of 1.5m/year (determined from analyses of historical survey data), this change amounts to no more than an increase in recession rate of 0.2cm/year, which is not measurable.

It is important to note that the changes identified on Towra Beach are very small and are at the limit of the capability of any wave model to simulate. The changes in wave direction of 0.1^o essentially describe a no-change scenario. Larger changes, had they occurred, would have been quantified very reliably.

The issue of potential shoreline changes on Towra Beach is addressed further Section 4.7.3.

Although there are uncertainties in both the wave and sediment transport rate calculations, this assessment is based on model-to-model comparisons. The models include high levels of technical process description and have been validated by the authors. Therefore there will be good confidence in the study outcomes that are based on model-to-model comparisons, that is, differences between two sets of model results.

4.6.2 Parallel Runway

The propagation of swell wave energy towards the Parallel Runway from near Location 70 was investigated using the MIKE-21 BW model. Model output locations were RW1, RW2 and RW3, see Figure 4.5. The model was applied to the existing and developed cases providing wave coefficients for each selected location. Model set-up included the proposed dredged areas with batters of 1V:4H. The analysed wave climate was then used to determine the H_S exceeded for no more than 24 hours/year, on average, at the runway locations. The results are presented in Table 4.2 for the rock revetment and vertical wall options for the proposed new container berths. Figures 4.6, 4.7 and 4.8 show the wave coefficients from the MIKE-21 BW model for the existing case, rock revetment option and vertical wall option, respectively.

The berth walls in the proposed port expansion have been considered as a rock revetment with a reflection coefficient of 0.5 and a fully reflective vertical wall with a reflection coefficient of 1.0. Output locations RW1, RW2 and RW3 are about one wavelength from the runway where coherence between the incident and reflected waves is small. These locations are shown in Figure 4.5.

Table 4.2: Wave Heights Along the Parallel Runway

Probability of Exceedence	Location	Significant Wave Height (m)		
		Existing	Rock Wall	Vertical Wall
1 Day/Year	RW1	0.50	0.50	0.52
	RW2	0.47	0.42	0.45
	RW3	0.35	0.29	0.37
0.01%				
	RW1	0.79	0.78	0.81
	RW2	0.73	0.64	0.70
	RW3	0.55	0.46	0.57
10%				
	RW1	0.22	0.22	0.23
	RW2	0.21	0.19	0.20
	RW3	0.16	0.13	0.17

These results show that proposed port development with rock revetments and dredging will marginally reduce wave heights along the Parallel Runway. Wave heights at Locations RW2 and RW3 would be lower because refraction to those locations would be reduced by the proposed port dredging. Construction of the proposed berths would also partially block wave propagation to RW3.

Note that adoption of the fully reflective vertical quay wall option would cause marginally higher wave heights along the Parallel Runway.

During this analysis a range of dredging options was considered on the basis of the principles of wave propagation and the proposed layout is considered suitable, but further refinement may be required for detailed design.

Comparison between Figures 4.6 and 4.7 shows that there will be a very small increase in swell wave energy propagating towards Lady Robinsons Beach, but because the change is small and the distance to the beach relatively great, there will be no measurable change there.

4.6.3 Brotherson Dock

Similar results for Brotherson Dock model locations are presented in Table 4.3. Locations are shown in Figure 4.5.

Table 4.3: Wave Heights Within Brotherson Dock
24 Hours/Year Average Exceedence

Location	Significant Wave Height (m)		
	Existing	Rock Wall	Vertical Wall
BD1	0.10	0.10	0.13
BD2	0.10	0.10	0.14
BD3	0.09	0.09	0.13
BD4	0.09	0.11	0.16
BD5	0.11	0.11	0.16

These results show a small increase in swell wave penetration to the berths. However, all heights are very low and would not affect berthed ships or facilities.

4.6.4 Proposed Container Port Berths

Design wave heights in terms of the one day/year wave height were determined for the proposed new container port berths. They are presented in Table 4.4. Locations are shown in Figure 4.5.

Table 4.4: Wave Heights at Proposed New Container Port Berths
24 Hours/Year Average Exceedence

Location	Significant Wave Height (m)	
	Rock Wall	Vertical Wall
CT1	0.11	0.18
CT2	0.08	0.18
CT3	0.08	0.22
CT4	0.12	0.18

These results show a relatively large difference between the rock and vertical wall cases. Results for the former case are similar to those experienced presently within Brotherson Dock. Construction using vertical walls would cause significantly higher waves at this site.

4.6.5 Swell Waves - Summary

The outcome of the swell wave investigations has shown that:-

- there will be a very minor change in swell wave impact on Towra Beach - see also Section 4.7.3

- there will be no change to Lady Robinsons Beach

- all swell waves on the Parallel Runway will be equal to or less than the present maximum near its southern end

- there will generally be a small, but insignificant increase in wave heights within Brotherson Dock.

- changes would generally be greater for vertical quay walls than for rock revetment quay walls.

- operational wave conditions at the proposed new container port berths would be similar to those experienced presently in Brotherson Dock; in the case of rock wall revetments. Operational wave conditions would be higher for the vertical wall case. Location CT4 is the most exposed of the proposed new berths.

4.7 LOCAL SEA INVESTIGATIONS

4.7.1 General

The SWAN wave model was used also to investigate potential changes in the local sea wave conditions within Botany Bay. Because local sea wave lengths are relatively short there will be no changes to refraction of those waves within Port Botany. However, construction of the port facilities will reduce fetches for waves propagating to the southern shoreline and the eastern side of the Parallel Runway.

Wave simulations were undertaken for wind speeds varying from 0m/s to 25m/s in increments of 2.5m/s and for all directions at increments of 22.5°, beginning at north. All simulations were undertaken at MSL with the inclusion of bed friction, wave breaking and white-capping. Model output locations are presented in Figure 4.3.

For local sea waves, the 60 years of Mascot wind data was applied to the SWAN model results, thereby leading to a 60 years time series of nearshore wave parameters at these locations. Analyses in terms of probability of exceedence then provided the necessary parameters with considerable confidence. Results below are presented in terms of the median significant wave height, H_{50}. This wave height parameter describes the wave condition that is exceeded 50% of the time and is a realistic descriptor of common local-sea wave conditions. It is similar to an average, but is applied where the distribution of wave height occurrence may not be symmetrical.

4.7.2 Calibration

Several months of wave data recorded at SPC Location WRB16, see Figure 4.1, were available for calibration of the SWAN wave model in terms of local sea.

The recorded wave data was separated into sea and swell components. Synchronous three-hourly wind data from the Mascot airport anemometer was used to produce a time series of wave parameters on a record-by-record basis for the same periods as the recorded data.

The outcome is presented in Figure 4.9, in which modelled and measured wave heights are compared on the basis of probability of Exceedence. The agreement is considered to be very good.

4.7.3 Results

Silver Beach, Kurnell

Wave climate changes at Locations 2 and 8, see Figure 4.3, were investigated; representing the eastern and western ends of this beach. Results are presented in Table 4.5 in terms of the median significant wave height and the weighted mean wave direction.

Table 4.5: Local Sea Wave Parameters on Silver Beach

Location	Existing		Post Port Expansion	
	H_{50}(m)	ϕ_m(°TN)	H_{50}(m)	ϕ_m(°TN)
2	0.08	331.7	0.08	330.6
8	0.09	344.2	0.09	343.1

These results show that there would be no change in wave height, but that there will be some change in mean wave direction, in the order of 1°. Local sea wave direction would become marginally more westerly.

Silver Beach is protected by a groyne field, with inter-groyne spacing being in the order of 150m. A 1° westward change in wave direction would potentially lead to rotation of beach alignments within groyne compartments, with a 1.3m reduction in beach width at the western end and 1.3m increase at the eastern end of compartments. However, the magnitude of this change would be much reduced because the local sea caused sediment transport potential in this area is small compared with the swell caused sediment transport potential; see below where this parameter is evaluated for Towra Beach. A similar outcome would occur on Silver Beach. Hence there would be no identifiable negative impact.

Towra Beach

Local sea wave climate changes at Locations 12, 15 and 18, see Figure 4.3, are presented in Table 4.6 in terms of median wave heights and weighted mean wave directions. These model locations are at the eastern, middle and western points of Towra Beach, respectively.

Table 4.6: Local Sea Wave Parameters on Towra Beach

Location	Existing		Post Port Expansion	
	H_{50}(m)	ϕ_m(°TN)	H_{50}(m)	ϕ_m(°TN)
12	0.10	27.3	0.10	26.7
15	0.10	30.4	0.10	29.6
18	0.10	31.8	0.10	31.5

Again the results show no change in wave height, but there are changes of less than 1° in mean wave direction, being smallest near Towra Point. Those directional changes have the potential to affect sediment transport and the state of the shoreline, because Towra Beach is not protected by a groyne field or other works. Therefore these processes were investigated.

Only a minor change in swell caused longshore transport will occur, see Section 4.6, but the potential impact of the changes in local sea waves depends upon the relative transport potential of these two wave frequency bands. Therefore both were evaluated. A realistic estimate of longterm sediment transport potential can be made using the effective wave height parameter, see Appendix E. This parameter includes the effects of the longterm range of wave heights as they are described by the log-normal distribution.

Calculation of longshore transport rates was undertaken using the LITPACK coastal processes system developed by the Danish Hydraulics Institute. This system includes bed and suspended sediment loads, combined irregular waves and currents, graded sediments and real shore normal profiles. For this investigation a shore normal profile at SPC Survey Line 38 (near wave output Location 17, see Figure 4.3), was adopted. A characteristic sand particle size of D_{50} = 0.18mm was adopted, together with generalised sea and swell parameters determined from Tables 4.6 and Appendix E. The outcome is presented in Table 4.7, including the swell-caused longshore transport.

Table 4.7: Estimated Annual Sediment Transport Rates on Towra Beach

Process	Annual Longshore Sediment Transport Rate (m^3)
Swell - Existing	6120 westward
Swell - Post Port Expansion	6126 westward
Local Sea - Existing	260 eastward
Local Sea - Post Port Expansion	270 eastward

This result shows that the local sea component of longshore transport on Towra Beach is small and that the change that would follow port expansion would marginally reduce the total westward transport rate. Hence there would be no negative impact from changes in local sea parameters. The estimated swell caused longshore transport rate is consistent with that determined from analyses of longterm SPC shore-normal surveys and the small increase in swell-caused westward transport is offset by the small increase in local sea-caused eastward transport. Therefore any change in wave caused sediment transport will be imperceptible.

Parallel Runway

Wave model output Locations 56, 57, 58 and 59 relate to the perimeter wall of the Parallel Runway of Sydney Airport, see Figure 4.3. Model results for those locations are presented in Table 4.8.

Table 4.8: Local Sea Wave Changes Along the Parallel Runway

Model Location	Local Sea Wave Parameters			
	Existing		Post Port Expansion	
	H_{50}(m)	ϕ_m(°TN)	H_{50}(m)	ϕ_m(°TN)
56	0.09	166.8	0.09	171.2
57	0.09	160.8	0.09	164.7
58	0.07	155.6	0.06	162.6
59	0.06	143.3	0.05	148.3

These results show that the shorter fetch caused by construction of the port area will reduce local sea median significant wave heights impinging on the runway wall. There will be some changes in wave direction, caused by a reduction in easterly sector waves, but, since there is no local sea caused longshore transport along this wall, depths being too great, this change is not an issue.

Brotherson Dock

Wave model Locations 63, 64 and 65 describe local sea wave conditions within Brotherson Dock, see Figure 4.3. Results are presented in Table 4.9.

Table 4.9: Local Sea Wave Changes in Brotherson Dock

Model Location	Local Sea Wave Parameters			
	Existing		Post Port Expansion	
	H_{50}(m)	ϕ_m(°TN)	H_{50}(m)	ϕ_m(°TN)
63	0.08	203.0	0.06	196.2
64	0.06	216.0	0.06	211.5
65	0.03	234.0	0.03	234.0

These results show that wave heights remain the same or reduce. Location 65 is not affected at all because mean wave direction remains unaltered.

Lady Robinsons Beach

Because the airport runways lie between the proposed container port development and Lady Robinsons Beach, there will be no local sea changes there.

Proposed New Berth Areas

Wave model Locations 60, 61 and 62 describe wave conditions at the proposed new berth sites, see Figure 4.3. These results represent operational local sea wave conditions at the proposed berths, see Table 4.10. They describe a very mild local sea wave climate.

Table 4.10: Operational Local Sea Conditions at the Proposed New Berths

Model Location	**Local Sea Wave Parameters Post Port Expansion**	
	H_{50}(m)	**ϕ_m(°TN)**
60	0.08	174.3
61	0.06	165.3
62	0.06	161.2

In addition to operational wave conditions, the 60 years of hindcast wave data, developed from the longterm Mascot wind data and wave modelling results, was ranked from the highest to lowest H_s parameter. The highest 20 independent peak storm wave heights were then subjected to extremal analyses to provide peak storm local sea wave heights at selected average recurrence intervals (ARI). These results are presented in Table 4.11.

Table 4.11: Design Local Sea Wave Parameters for the Proposed New Berths

Average Recurrence Interval (Years)	**Significant Wave Height (m) Location**			**T_z(s)**
	60	**61**	**62**	
20	1.1	1.0	0.9	2.5
50	1.1	1.0	0.9	2.5
100	1.2	1.1	1.1	2.6

Proposed Boat Ramp Area

This area is described by wave model Location 71. Operational wave conditions are typically described by:-

H_{50}(m) = 0.05m
ϕ_m(°TN) = 155.1°

This is a very sheltered area because it is sheltered from all wind direction sectors except the south-south-east. This median wave height describes a wave climate that is suitable for a boat ramp.

Design wave conditions are presented in Table 4.12.

Table 4.12: Design Wave Parameters for the Proposed Northern Beach and Boat Ramp Area

Average Recurrence Interval (Years)	Peak Storm H_s(m)	T_Z(s)
20	0.9	2.3
50	0.9	2.4
100	1.0	2.5

Northern Foreshore

The western-most 500m of the Northern Foreshore Beach is to be rehabilitated and maintained within a "compartment" between the proposed boat ramp and the proposed extension to the northern wall of the Mill Stream exit, see Appendix A.

The local sea wave climate for this region, following proposed port expansion, is typified by the results for the proposed boat ramp area. Although this would be a very low wave energy region, there would be a continuing potential for westward sand transport. Combining the local sea wave climate, available sediment and beach profile data for the area, and applying the LITPACK coastal processes model, the resulting annual longshore sediment transport rate was estimated to be about 1050m^3.

SPC propose to build a groyne about 25m in effective length from the MSL line of the beach as part of an extended northern training wall to the Mill Stream. Based on shoreline progradation analysis, this structure would trap all of the longshore transport for a period of 4 to 5 years. Should shoreline progradation at the western end exceed this effective 25m, then the Mill Stream may also act as a partial, soft barrier to longshore transport, thereby leading to some infilling of the Mill Stream waterway. A similar annual rate of recession is likely near the boat ramp, reducing in rate as erosion occurs and the shoreline rotates.

Based on a breaking wave angle of 10° to the shoreline, long term potential for shoreline recession at the boat ramp of about 40m may occur. Assessment of historical beach cross-section survey data for the eastern end of the beach, from about 1981 to 2001 shows that the average recession rate has been about 0.6m/year. Most of the recession occurred in the first 10 years and amounted to about 10m. This scenario is likely to be more representative of the long term outcome than the breaking wave angle assessment cited above, but beach movements should be monitored.

Hence there may be a continuing need to undertake beach maintenance by removing sand as it is transported to the Mill Stream end of the beach, and replacing it near the boat-ramp. This task may be required to maintain the integrity of the boat-ramp foundations, even though a small fillet of sand would be maintained near the boat ramp as a result of local wave diffraction past the end of the boat ramp. This maintenance work may be required every 4 to 5 years.

4.7.4 Local Sea Impacts - Summary

In general, the local sea wave modelling has demonstrated that there will be only minor changes at shoreline locations. Although changes in wave height within Port Botany will be greater, they will all be reductions.

4.8 LONG WAVES

4.8.1 Present Status

Although long waves have been recorded in Botany Bay since the early 1970's, they have not been reported as having caused unacceptable moored vessel movements in Port Botany, and particularly within Brotherson Dock. That berth area has vertical impermeable walls and is of nearly rectangular shape. As such it may be conducive to seiching, which arises when the berth area dimensions are similar to multiples of long wave length. However, seiching (related to resonance), is not required to cause unacceptable vessel movements.

4.8.2 Background Issues

Long waves may have a range of origins. They include generation by wind from a very distant storm, (in a sense, very long swell), sudden changes in atmospheric pressure, (as may occur as the result of a frontal passage), edge waves (propagating along the continental shelf) and as a result of wave grouping and associated variations in radiation stresses. Nelson et al (1986) have shown that observed long wave energy in Jervis Bay, NSW, is strongly correlated with the parameter ($H_s\ T_z$) for offshore short waves. Similar outcomes have been determined at Port Kembla (Willoughby and Treloar, 1997) and at the Caltex Submarine Berth in south-eastern Botany Bay, (Lawson and Treloar, 2001), where long and short wave parameters at inshore sites were correlated. This relationship is useful for determining likely longterm long wave heights from available longterm short wave records, such as those from the offshore Waverider buoy at Botany Bay.

This approach was adopted in this investigation using the approximate five months of data recorded at the site 'MID' shown on Figure 4.1. Figure 4.10 shows the relationship between H_{sl} and $(H_s\ T_z)_s$:-

where	H_{sl}	is long period wave significant wave height
	H_s	is short period wave significant wave height
	T_z	is short period wave zero crossing period
	s	subscript describes short period waves
	l	subscript describes long period waves

all at Station 'MID'. The outcome of this analysis was:-

$$H_{sl} = 8.1 \times 10^{-3}\ (H_s\ T_z)_s^{\ 0.724}$$

which describes a very mild long wave climate.

From this relationship, an analysis of longterm swell wave heights at this station (MID) using the SWAN model results, coupled with the longterm offshore Botany Bay directional wave climate, see Appendix D, the following criteria were established – Table 4.13.

Table 4.13: Design Wave Heights at Location MID

Average Recurrence Interval (Years)	Short Wave Parameters		Long Wave Height (m)
	H_s (m)	T_z (s)	
1	1.2	8	0.042
10	1.5	8.5	0.051
100	1.7	9	0.058

Note that the highest short period wave recorded at this station over the five months data period was about H_s = 0.6m, having a direction of about 130^{o}TN and a period in the order of 8 seconds (T_p). These parameter values describe swell rather than local sea.

It is likely that offshore wave periods (short wave periods) would be longer than those presented in Table 4.13 at the times of high waves at 'MID'. Lawson and Treloar have determined previously, (Lawson and Treloar, 1994), that a reliable offshore short period wave relationship is:-

$$T_z = 4.0 + 0.64H_s$$

based on longterm observed offshore wave data. However, the longest period wave energy entering Botany Bay will be refracted significantly from the main entrance channel, with shorter period wave energy propagating along the channel. Hence this report has adopted inshore swell wave periods in Table 4.13 slightly shorter than those that would be expected for the offshore waves that would lead to these 'design' long wave heights.

At these low long wave heights there will be no non-linearity in respect of long wave height in long wave response at the berths. However, the response in terms of long wave caused horizontal motions at each berth will be non-linear in terms of long wave period. The available long wave spectra were examined to select two cases of relatively high long waves, and also those that had different characteristic periods, T_z (long waves). In both cases $H_{sl} \approx$ 0.02m, but long wave periods of 36 seconds and 81 seconds were selected. These spectra were scaled to provide the H_{sl} parameters at the selected ARI, see Table 4.13, but maintaining their respective spectral shapes and periods.

4.8.3 Model Setup

Model set up was based on the MIKE-21 BW system described in Section 4.4.2, but with a boundary near Location MID, see Figure 4.1. Due to the much longer wave lengths, compared with the swell waves of Section 4.5, the grid size was increased to 12m. Other than along the model outer boundaries, no sponge layers were included, because the reflectivity of long waves is virtually 100%, even from natural beaches.

Input long waves to the model area were generated as random directional waves from the spectral descriptions, that is, the spectral shapes determined from data analysis were maintained. Long wave direction was set at 133^{o}TN at the model boundary (along the southern edge of the model area), based on the available data. This direction is consistent with a long wave origin from short wave grouping. Model simulations extended over a period of sufficient length (30 minutes) to ensure quasi-dynamic equilibrium was established. Time series data was then extracted for analysis in terms of wave coefficients (K_w), which are defined as:-

$$K_w = H_i / H_o$$

where H_i is long wave height within the model area
H_o is long wave height at the model boundary

Willoughby and Treloar, (1997) have shown that long wave modelling is most reliably undertaken using random waves. Figures 4.11 and 4.12 present example results in terms of contours of K_w for the existing and proposed port layouts and for the case where long wave period (T_z) is 36 seconds. A comparison demonstrates some amplification and increase in long wave activity following port expansion.

4.8.4 Results

The results in Figures 4.11 and 4.12 show some minor changes in long wave conditions within Brotherson Dock. Results for the proposed port expansion also provide a basis for defining design long wave conditions at the proposed new berths. Descriptions of these analyses follow.

4.8.5 Brotherson Dock

The movement of berthed vessels, if of sufficient magnitude, can seriously disrupt loading and unloading procedures, especially for container ships. The greatest part of this movement is caused by the currents associated with the long waves, rather than the heights themselves, though along-berth water surface gradients can add to vessel movement. Potential changes were assessed by calculating root-mean-square along-berth current speeds at five locations (BD1 to BD5) within Brotherson Dock, see Figure 4.5. These results are presented in Table 4.14.

4.8.6 Parallel Runway

Long waves along the Parallel Runway are likely to be of minor importance. The potential changes in long wave heights at Locations RW1, RW2 and RW3 are shown to be zero in Table 4.15.

4.8.7 Proposed New Container Port

Long wave caused root-mean-square along-berth current speeds are required for the proposed new container berths as part of design criteria. Additionally, a point in the new tug harbour area was investigated. These results are presented in Table 4.16.

Table 4.14: Along-Berth Long Wave Current RMS Speeds (m/s) for Brotherson Dock Locations
S1 is Long Wave Spectrum 1 Case – T_z = 36s
S2 is Long Wave Spectrum 2 Case – T_z = 81s

	Average Recurrence Interval (years)					
	1		10		100	
	S1	S2	S1	S2	S1	S2
BD1						
Existing	0.006	0.008	0.007	0.010	0.008	0.012
Developed	0.006	0.008	0.007	0.010	0.008	0.012
BD2						
Existing	0.006	0.008	0.007	0.010	0.009	0.012
Developed	0.006	0.008	0.007	0.010	0.009	0.012
BD3						
Existing	0.005	0.005	0.006	0.006	0.007	0.007
Developed	0.006	0.005	0.007	0.006	0.008	0.007
BD4						
Existing	0.007	0.009	0.008	0.011	0.009	0.013
Developed	0.007	0.009	0.008	0.011	0.009	0.013
BD5						
Existing	0.004	0.005	0.005	0.005	0.006	0.006
Developed	0.004	0.005	0.005	0.006	0.006	0.007

Table 4.15: Long Wave Heights (H_S-m) Along Parallel Runway
S1 is Long Wave Spectrum 1 Case – T_z = 36s
S2 is Long Wave Spectrum 2 Case – T_z = 81s

	Average Recurrence Interval (years)					
	1		10		100	
	S1	S2	S1	S2	S1	S2
RW1						
Existing	0.04	0.03	0.05	0.04	0.06	0.05
Developed	0.04	0.03	0.05	0.04	0.06	0.05
RW2						
Existing	0.04	0.04	0.05	0.05	0.06	0.06
Developed	0.04	0.04	0.05	0.05	0.06	0.06
RW3						
Existing	0.04	0.04	0.05	0.06	0.06	0.06
Developed	0.04	0.04	0.05	0.06	0.06	0.06

Table 4.16: Along-Berth Long Wave Current RMS Speeds (m/s)
for New Container Port Locations
S1 is Long Wave Spectrum 1 Case - T_z = 36s
S2 is Long Wave Spectrum 2 Case - T_z = 81s

	Average Recurrence Interval (years)					
	1		10		100	
	S1	S2	S1	S2	S1	S2
CT1 Developed	0.010	0.013	0.013	0.016	0.014	0.019
CT2 Developed	0.011	0.015	0.014	0.018	0.016	0.022
CT3 Developed	0.015	0.015	0.018	0.023	0.022	0.022
CT4 Developed	0.005	0.006	0.006	0.007	0.007	0.008
Tug Berths Developed	0.012	0.013	0.015	0.016	0.017	0.019

The following conclusions can be made from the results of the long wave modelling: -

1. There will be a minor increase in along-berth long wave caused current speeds within Brotherson Dock, of about 10%. However, those current speeds remain well below 2cm/s and it is considered that this change will have little effect on ships moored there. Mooring line forces will increase to some extent, but the change can not be quantified without moored ship movement analyses.

2. There will be no change in long wave heights along the Parallel Runway

3. Root-mean-square (rms) long wave caused along-berth current speeds at the proposed new container berths will be in the order of 1.5cm/s at the 1 year ARI. This is nearly three times greater than those in Brotherson Dock (new and potentially in the future). Based on experience in similar investigations in the Port of Geraldton, where rms along-berth speeds may be 3.5cm/s on a regular basis, (typically monthly), and where berthed ship movements have caused loading/unloading disruptions and line breakages, a problem may occur during infrequent, severe ocean storms, but less frequently than once every 10 years, on average. However, it has been found at Geraldton that disciplined attention to mooring line tensions has reduced the berthed-ship movement problem significantly. Because the present studies have shown that long wave caused currents will rarely be as high as they occur commonly at Geraldton, it is considered that berthed ship motions would only be a very rare problem.

4.8.8 Long Wave Climate - Summary

There are no known berths within Botany Bay where operations are affected by long wave activity. The investigations undertaken for this study demonstrate that this condition will remain.

5. CURRENT FIELD IMPACTS

5.1 GENERAL

The potential changes to current fields within Botany Bay were examined using numerical modelling methods. Two models were developed; they were:-

- a whole of bay model extending upstream to Lugarno, see Figure 5.1. Grid sizes were irregular, but were in the order of 50m in the Port Botany area.

- a northern Bay regional model extending north from Molineux Point, approximately, see Figure 5.2. Grid sizes as small as 5m were adopted to resolve the waterways.

Both models were based on the Delft3d modelling system. The northern Bay regional model has been described fully in Volume 2 of this report series.

The whole of bay model was developed using a curvilinear grid system, thereby allowing the grid structure to be generally consistent with the major streamline structure of tidal flows in the Bay. The model was driven using boundary tides, winds and storm water inflows to the northern region of the Bay. Grid sizes in the order of 50m were applied in Botany Bay. However, this model could not resolve the small changes proposed in the Port Botany area near the Mill Stream, for example, and the northern Bay regional model was applied to the investigation of local issues.

Tides in Botany Bay are generally similar to those at Sydney (Fort Denison) and tidal constants for that location were used with Foreman's (1977) tidal prediction package to prepare the tidal level boundary data.

Wind data, where needed, was taken from recorded Mascot airport anemometer data, see Section 2.5.

Discharge data, where needed, was prepared using hydrological investigations, see Volumes 1 and 2.

Delft3d provides solutions to the basic equations of mass and momentum conservation to third order. It includes an accurate and stable wetting and drying algorithm that is necessary when there are extensive inter-tidal areas, such as Quibray Bay. It may also include wave caused radiation stresses for longshore current development, transport-dispersion of selected conservative and non-conservative contaminants and sediment transport processes. A range of bed friction formulations is included, as well as horizontal eddy viscosity. Wind friction factor may be variable with wind speed using a piece-wise linear curve. The model system has been used extensively by Delft Hydraulics, the authors, for major international projects, and by Lawson and Treloar throughout Australia.

5.2 MODEL CALIBRATION

Calibration provides confidence that the model system can reproduce observed current structure realistically. For this task a period in early January, 1999 was chosen when current meters were deployed at Locations MID and SOUTH, see

Figure 4.1. It was also a period of spring tides, see Figure 5.3. Although other current data has been recorded in Botany Bay, those records were taken before construction of the Parallel Runway and the 1999 data will be representative of existing conditions. Recorded currents will include tidal (astronomical) and non-tidal components.

In the first instance the recorded current data at those two stations was subjected to harmonic analyses following the methods of Foreman, (1977) in order to prepare tidal current harmonic constants at both locations. Having in the order of five months of data allowed the determination of those constants with some confidence. The resulting tidal current harmonic constants were then used to predict tidal current speed and direction at both locations. The outcome of those analyses is presented in Figures 5.4 and 5.5, together with the observed current parameters. There is overall good agreement, but there are obvious differences, especially near the beginning and end of the selected calibration period. Obviously oceanic processes other than the astronomical tides were affecting flow in Botany Bay at that time.

Figure 5.6 (data provided by the Commonwealth Bureau of Meteorology), shows that there were no remarkable meteorological conditions at that time. However, Figure 5.7 shows a noticeable difference between predicted and recorded tides at Fort Denison over this period (data provided by Sydney Ports Corporation), indicating that some other oceanic/shelf processes were affecting flow structure then. Figure 5.8 (data provided by Sydney Water), describes current speeds and directions recorded at the Bondi Ocean Reference Station during this period, with the “red” data describing upper water column currents and the “black” data describing lower water column currents in a depth of about 60m. A significant change in shelf currents occurred early on 02/01/1999. Current directions are in terms of “flowing towards”. Hence this data indicates significant onshore flow for part of the calibration period; some of this flow will have penetrated into Botany Bay and affected currents there.

On the basis of this assessment it was decided to undertake a tides-only calibration exercise first. That is, the model was driven using the Fort Denison tidal constants with predicted tide levels at 6 minute intervals. The results are presented in Figures 5.9 and 5.10. Apart from some shape differences, the agreement is good at Location SOUTH. At Location MID, agreement is good on flood tide, with directions being good on flood and ebb tides. The model overestimates ebb tide speeds. Figures 5.16 and 5.17 provide current vector plot descriptions of currents in this area, (also including current vectors from post port-expansion). The eddy structure is quite complex near the entrance to Port Botany and the spatial variation in current speed and direction is significant. Therefore it will be difficult to reproduce current structure at any point particularly well in this location. However, the general structure will be reliable.

Finally, the model was driven using the measured Fort Denison water level time series and the recorded wind data for the time. Results are shown in Figures 5.11 and 5.12. These results show that currents within Botany Bay are dominated by the astronomical tides, but are also affected significantly by processes that originate seaward of the Bay, and which are generally irregular and unpredictable, see Figure 5.11, 3 January, 1999.

The outcome of these calibration and investigative processes demonstrates that the model provides a generally reliable description of currents within Botany Bay. It is quite reliable for describing tidal currents. Moreover, it is to be generally used to compare current structures from simulations of the existing and proposed port expansion layouts using a tidal level boundary, and any deficiencies in the models performance will be the same in both cases.

5.3 TIDAL PRISM

The proposed expansion to container port facilities entails some construction of land areas using sand dredged from the bed of the Bay. Hence there will be some reduction in the inter-tidal space within the Bay and thence the tidal prism. This change has been assessed using the whole of bay model, run with existing and developed model layouts.

Figure 5.13 presents a time series of accumulated flow for the three days period adopted for model calibration. Peak values are equivalent to tidal prism volume - in the order of 60 to 80 x $10^6 m^3$. There is very little change, the difference being a reduction of 0.7%.

5.4 BAY WIDE CHANGES

Figures 5.14 and 5.15 present current vectors for existing (blue) and post port expansion (green) model cases for peak flood current and peak ebb current cases, respectively. Only the land boundary for the existing bay is presented, and only selected vectors are presented for reasons of clarity. Only minor changes are indicated.

Figures 5.16 and 5.17 present more detailed views of the region of the Bay near the southern extremities of the Parallel Runway and Port Botany.

5.5 PARALLEL RUNWAY

The toe of the vertical perimeter wall of the Parallel Runway includes scour protection. Potential current speed changes were investigated at Locations RWC1 and RWC2 at the southern end of the runway, see Figure 4.5. Figures 5.16 and 5.17 show that tidal currents in that area are higher than surrounding areas under existing conditions. Changes in current speed that might be caused by the proposed port expansion were assessed using the whole of bay current model and a period of spring tides. Model input also included estimated 5 years ARI discharges from the storm water drains located in northern Botany Bay. These flows are shown in Table 5.1.

Table 5.1: Stormwater Drain Peak Discharge for 5 year ARI Storm Event

Storm Water System	Peak Flow (m^3/s)
Springvale	14.1
Floodvale	8.0
Mill Stream	22.7
Drain 1	14.3
Drain 2	17.7
Drains 3 & 4	19.2
Drain 5	20.7

The locations of these drains are described in Volume 1.

Figures 5.18 and 5.19 present time series plots of current speed and direction at Locations RWC1 and RWC2 and compare existing and post port expansion conditions. There is no significant change at either location.

5.6 MILL STREAM OUTLET CHANNEL

The Mill Stream presently discharges to north-west Botany Bay through a 40m wide lined channel between the Parallel Runway and Foreshore Road, see Figure 4.5. Part of the proposed port expansion includes a new beach area to be maintained within a compartment formed by a south-eastward extension of the north-eastern Mill Stream training wall and the proposed boat ramp at the western end of the flushing channel from Penrhyn Estuary, see Figure 4.5. The extended Mill Stream training wall provides an expansion of the Mill Stream Entrance, thereby leading to reduced currents in the lower Mill Stream. Potential changes to the current structure were assessed as part of this study.

This investigation was undertaken using the northern bay regional model because a finer grid was required to resolve the channel flows. The simulation included tides and the 5 years ARI discharges, see the tabulated data above. Time series results are presented in Figures 5.20 and 5.21 for Locations MS1 and MS2, see Figure 4.5. Figure 5.22 provides a vector plot of the immediate area and presents information for existing and post port-expansion cases.

The results show that under these conditions there is a continuous flow from the combined flows from the Mill Stream and Drain 5 ($\approx 43m^3/s$). At low tide, water depth is only about 1.4m and peak current speeds reach 0.7m/s, typically, in the present condition at MS1. This speed is sufficient to cause scouring.

There is virtually no change in current speed or direction at Location MS1. Current speeds at Location MS2 are much smaller, and would remain small following port expansion. However, this location is in a region of flow expansion and the eddy structure will be a little different following port expansion, but remaining well below speeds that can cause an initiation of sediment movement.

5.7 VESSEL WAVES/WASH

Vessels that would use the proposed new container berths will be of size similar to those presently using Brotherson Dock and will travel at similar speeds. Brotherson Dock has been in continual use since the early 1980's and no ship wave incidence on the shoreline has been reported, nor has there been any identifiable exacerbation of shoreline erosion as a result of those vessel movements.

Ship waves arise from the variation in pressure along the hull of the vessel. Vessel Froude Number, based on speed and water depth, will be no greater than about 0.35, and at this low value, the waves generated by ship passage will be of short period (3 to 5 seconds) in groups of 5 to 8 waves per vessel, approximately. Although wave heights may be up to 0.8m near the vessel, propagation of wave groups involves energy dispersion and the number of waves increases, coupled with wave height reduction as the waves propagate from the vessels track. Hence ship waves that reach the shoreline in Botany Bay are small and no vessel-caused erosion has been reported.

Vessels that would berth in the new container port area would be pushed on to the berth over the last few 10's of metres by tugs. In this mode the tugs would generate significant propeller wash towards the Parallel Runway. However, whilst pushing, they would never be closer than 300m from the Parallel Runway. Observations made in Sydney Cove at the Overseas Terminal show that some tug wash is observable at 150m. However, by 300m, any substantial wash will have been dispersed and current speeds reduced below those that can cause sediment movement.

6. CONCLUDING REMARKS

This report describes the outcomes of a range of wave, current and shoreline morphological studies undertaken to examine the potential impacts of proposed expansion of Port Botany on the environment of Botany Bay.

The changes to bay physiography associated with proposed port expansion would be predominantly limited to that part of the Bay lying within the water area between the southern end of the Parallel Runway and Molineux Point. There is only a small area of seabed proposed to be deepened on the southern side of the present shipping channel near the turn into Port Botany from the shipping channel. Hence any significant changes would most likely be limited to the region of the Bay within Port Botany. Nevertheless, it was important to consider potential impacts in an overall bay wide context.

Investigations of this nature require the application of a range of numerical models that are suited to the tasks, are technically advanced and calibrated adequately. For this study a range of model systems developed at Delft Hydraulics, The Netherlands, has been applied in 2 and 3 dimensional models, as well as one wave model within the MIKE-21 system and the LITPACK system developed by the Danish Hydraulics Institute.

Sydney Ports Corporation has collected wave, current and foreshore profile data in the Bay for about 30 years. This large source of information provided much of the data required for model setup and calibration. A site specific Waverider buoy was installed within Port Botany for this study.

Following detailed wave model calibration, notably for swell and local sea components, wave climate investigations were used to describe the changes that would be associated with the proposed port expansion works. As a matter of course, this also included design data for the proposed works. That data would be required for design of proper functioning of the container port facilities.

The outcomes of these analyses have shown that there would be minor changes in shoreline recession rates on Towra Beach. There will be no change on Lady Robinsons Beach.

There will be no increase in swell wave energy on the eastern side of the Parallel Runway of Sydney Airport.

Local sea waves impinging on the Parallel Runway would be reduced in height as the result of reduced fetch.

Long wave activity within Port Botany will be increased marginally and long waves at the proposed new container berths will be of similar order to those occurring presently in Brotherson Dock. Nevertheless, long wave activity would remain low at all container berths when compared with other ports where long wave caused movements of berthed vessels causes unacceptable vessel movements.

Other than within the region of Port Botany itself, including Penrhyn Estuary, there will be no identifiable change in bay-wide current structure, including no identifiable changes in the Mill Stream and along the Parallel Runway.

There will be a continual need to monitor the westernmost section of the Northern Foreshore Beach. Local sea will lead to continuing longshore transport towards the Mill Stream entrance and exposure of the proposed boat ramp at the eastern end of this beach area. The proposed groyne that would be built as an extension of the northern training wall to the Mill Stream would trap this sediment and prevent it from blocking the Mill Stream waterway. However, the groyne may be outflanked after five years (approximately) and the sand would need to be replaced at the eastern end of the shoreline.

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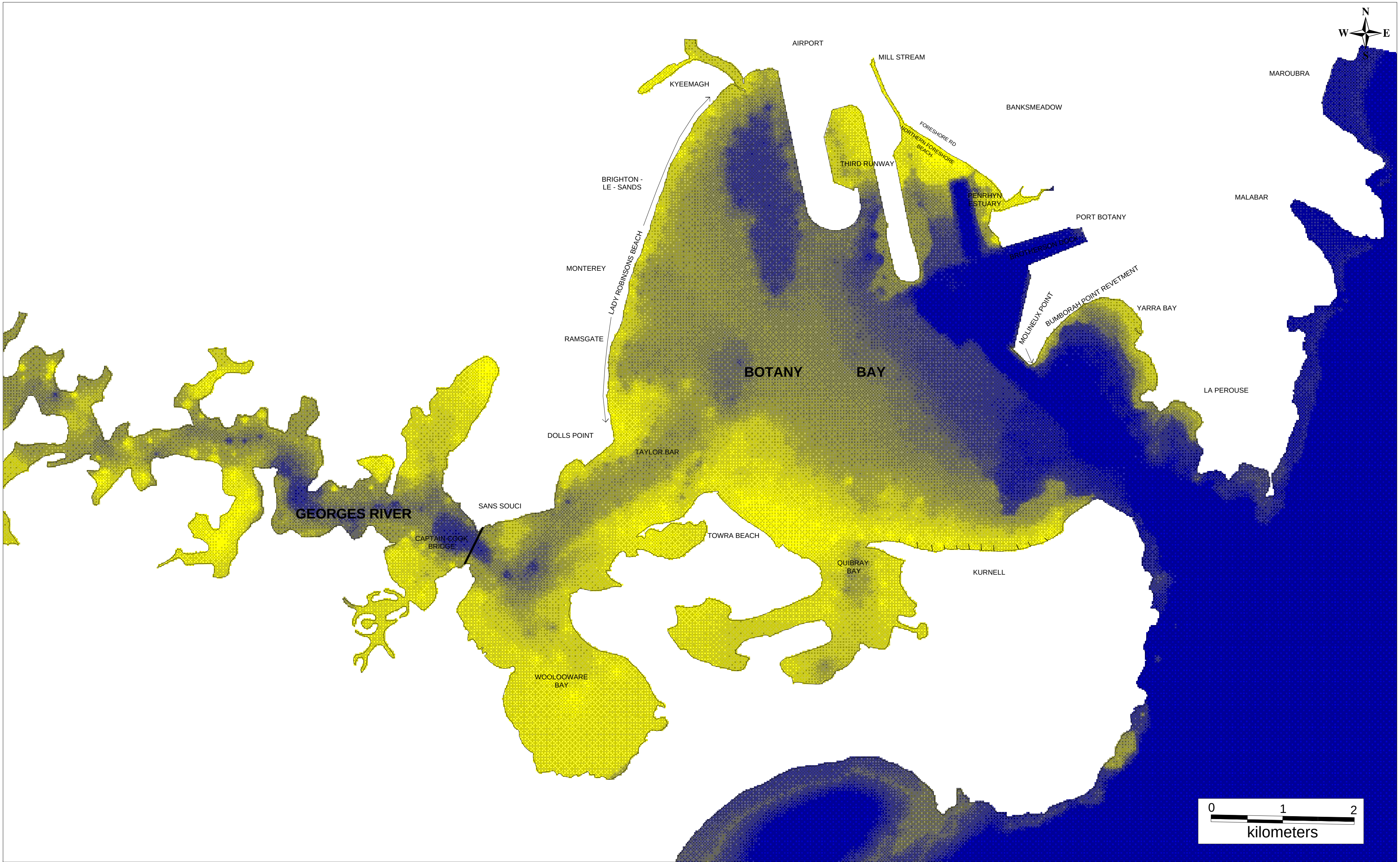
FIGURES



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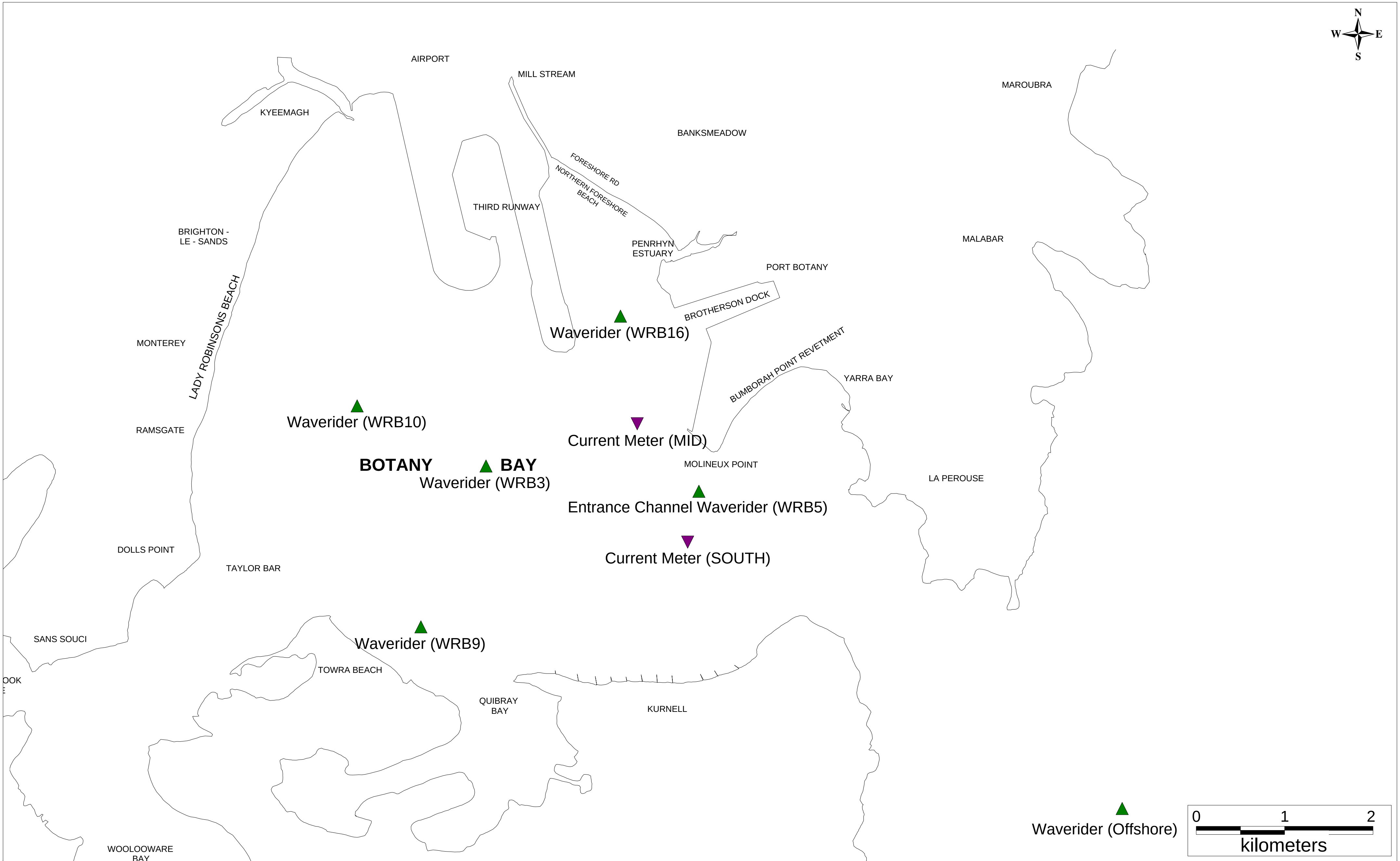
Proposed Expansion of Container Port Facilities, Botany Bay

LOCALITY PLAN

Figure 1.1



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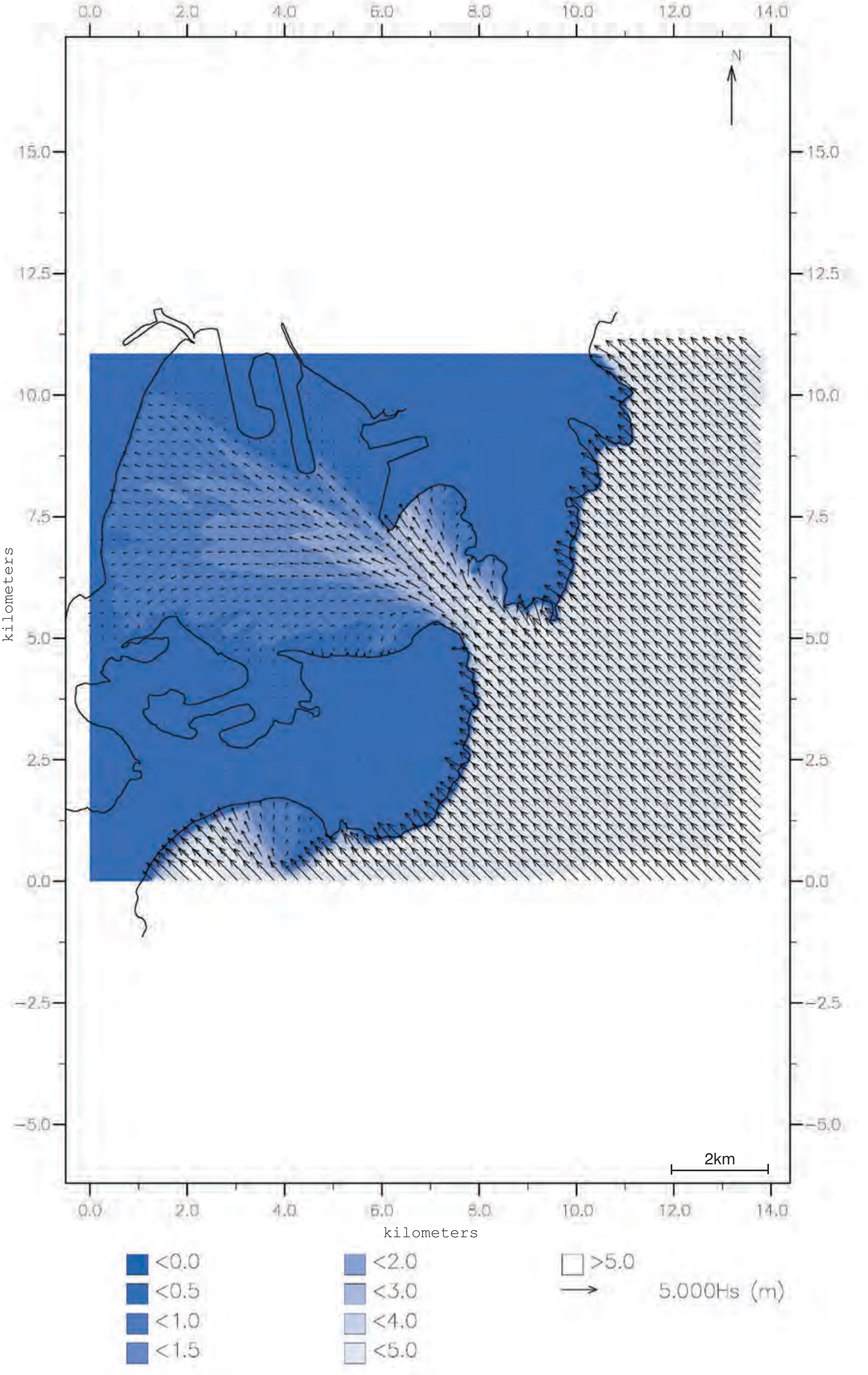
Proposed Expansion of Container Port Facilities, Botany Bay

LOCATION OF DATA COLLECTION INSTRUMENTS

Figure 4.1



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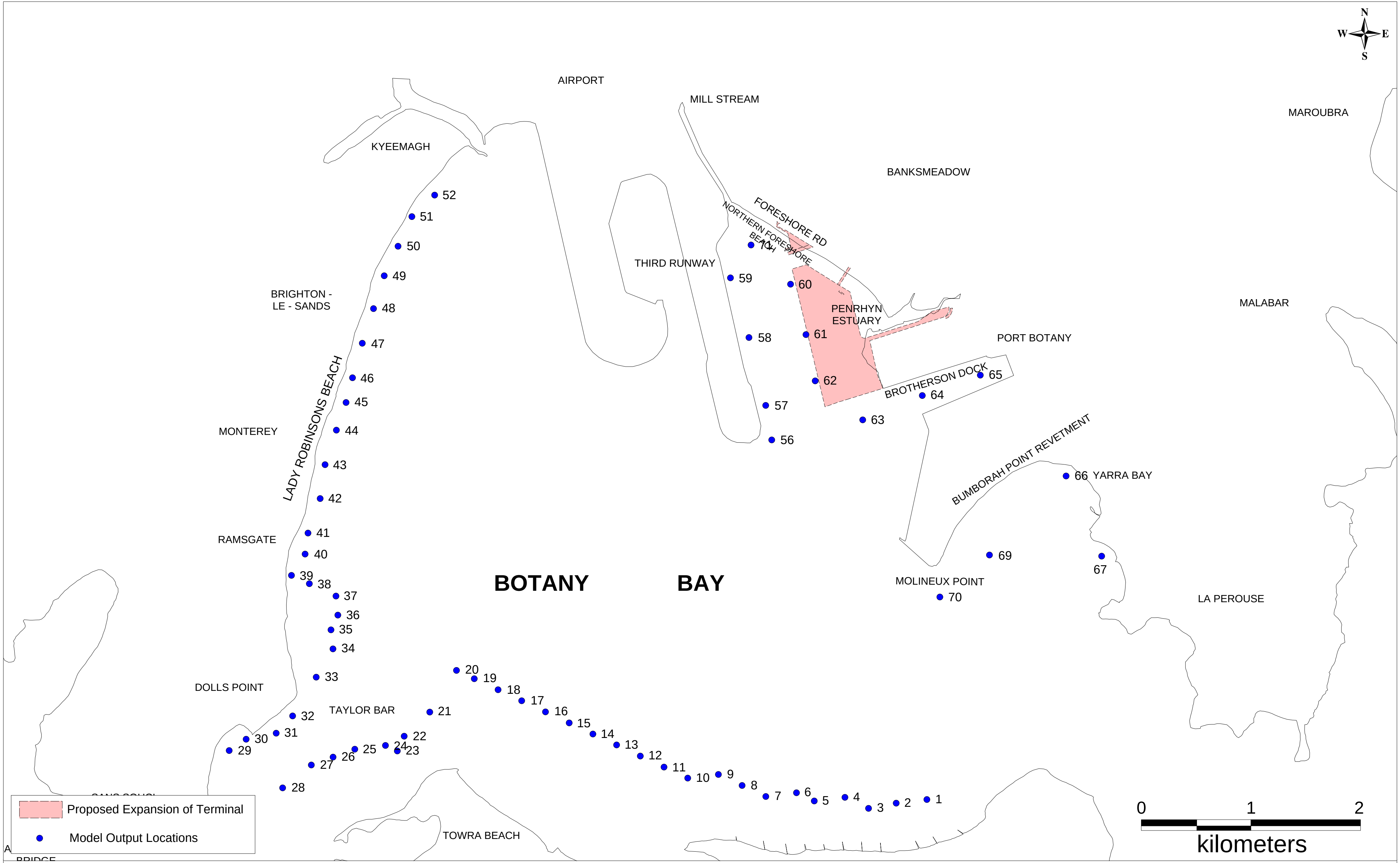
Proposed Expansion of Container Port Facilities, Botany Bay

SWAN MODEL EXTENT
SOUTH EAST WAVES PROPAGATING INTO BOTANY BAY

Figure 4.2



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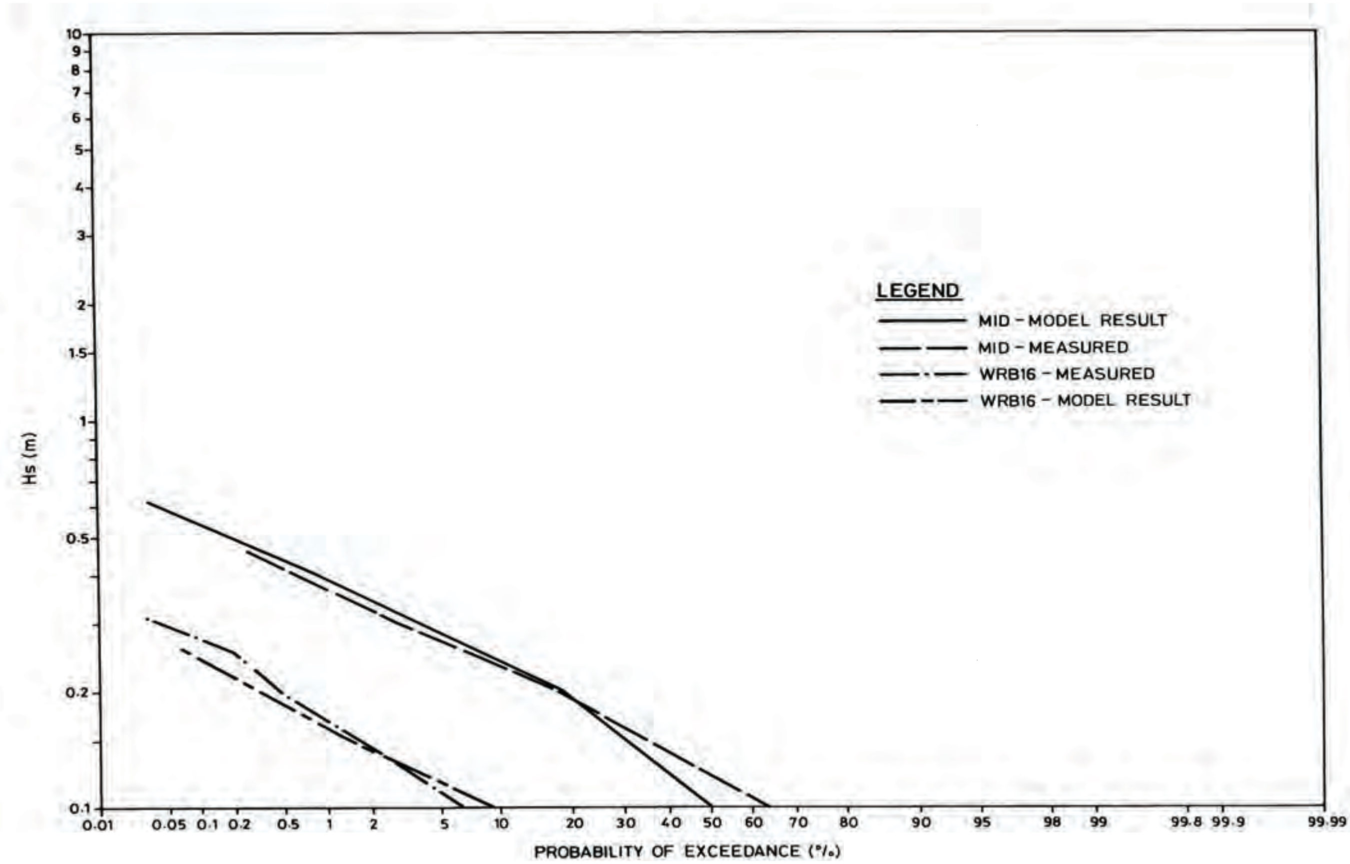
Proposed Expansion of Container Port Facilities, Botany Bay

WAVE MODEL OUTPUT LOCATIONS

Figure 4.3



Location: MID
WRB16

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Proposed Expansion of Container Port Facilities, Botany Bay

WAVE MODEL CALIBRATION - SWELL

Figure 4.4

KEY ▲ Model Output Locations (Location id)

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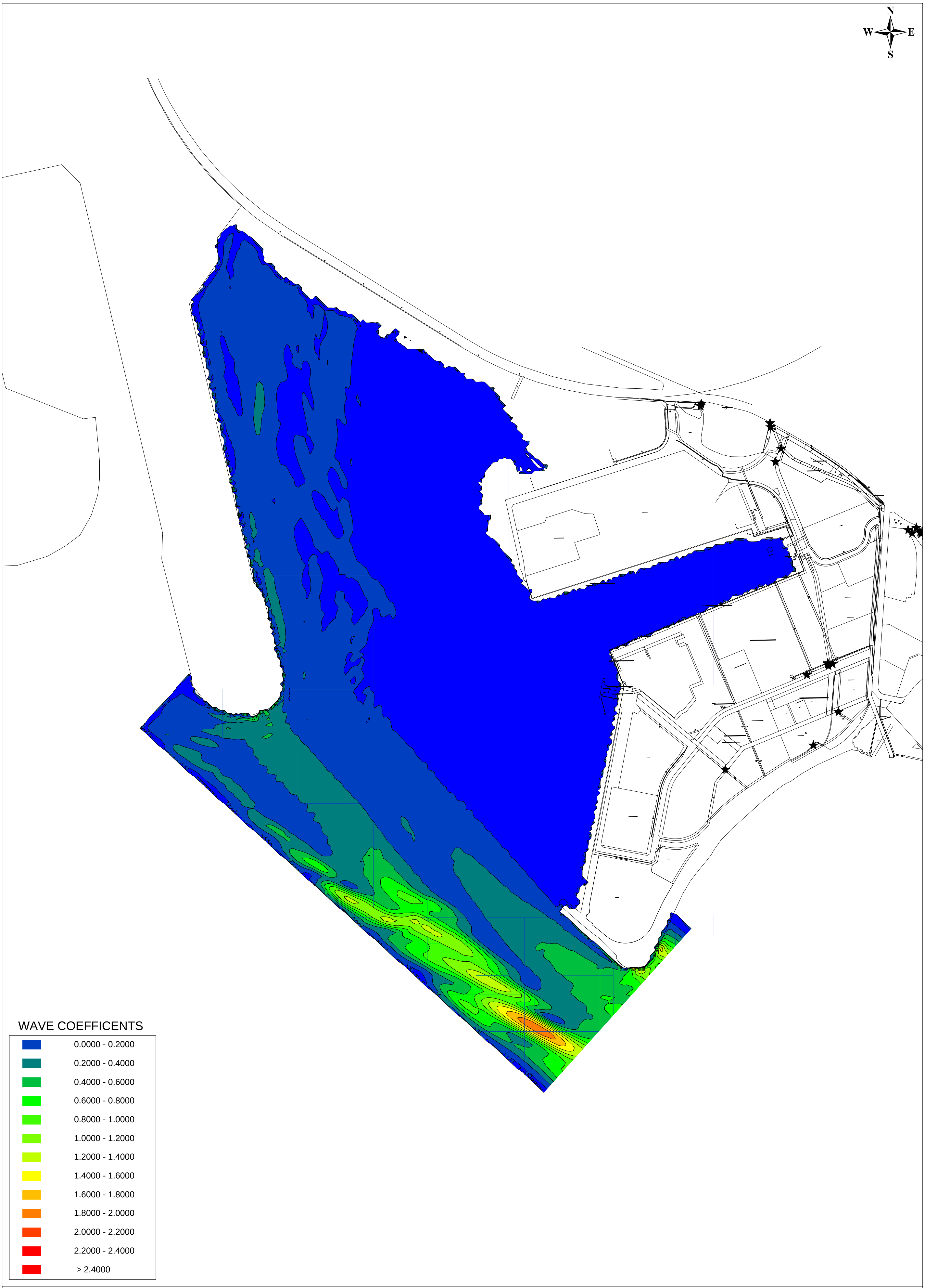
Proposed Expansion of Container Port Facilities, Botany Bay

DETAILED MODEL OUTPUT LOCATIONS

Figure 4.5



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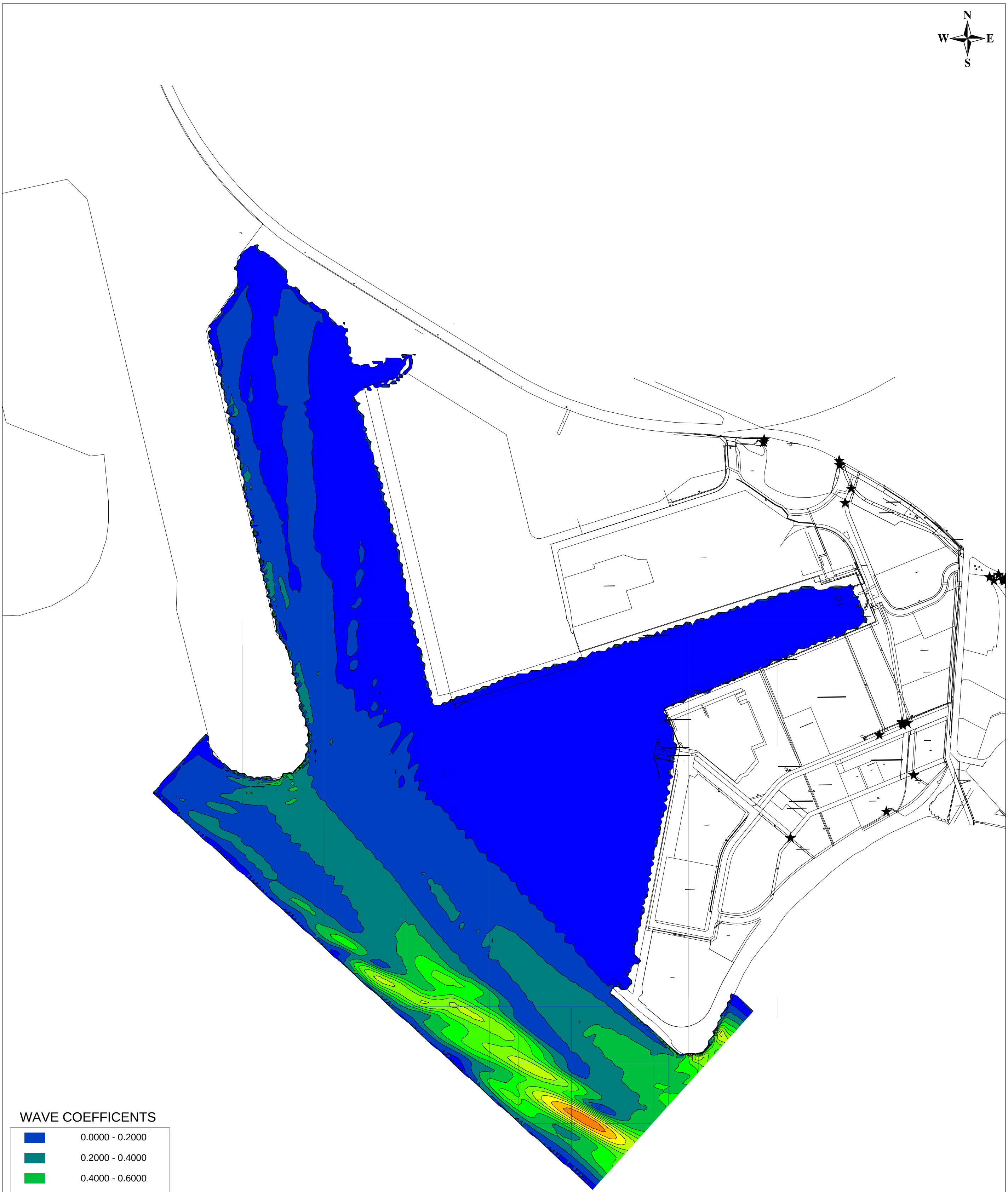
Proposed Expansion of Container Port Facilities, Botany Bay

WAVE COEFFICENTS
EXISTING
Figure 4.6



WAVE COEFFICENTS

	0.0000 - 0.2000
	0.2000 - 0.4000
	0.4000 - 0.6000
	0.6000 - 0.8000
	0.8000 - 1.0000
	1.0000 - 1.2000
	1.2000 - 1.4000
	1.4000 - 1.6000
	1.6000 - 1.8000
	1.8000 - 2.0000
	2.0000 - 2.2000
	2.2000 - 2.4000
	> 2.4000

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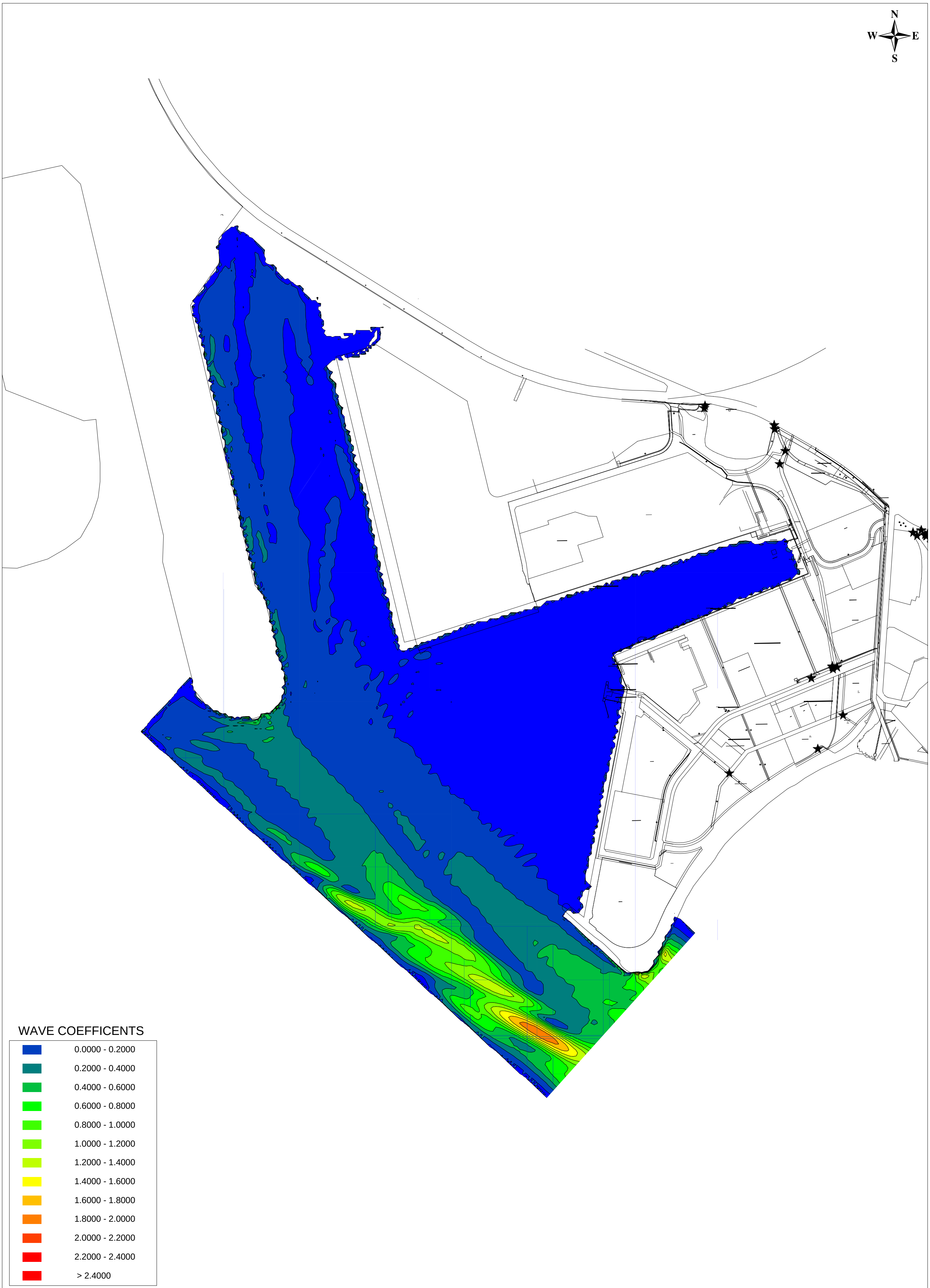
Proposed Expansion of Container Port Facilities, Botany Bay

WAVE COEFFICENTS
DEVELOPED (Rock Revetment)
Figure 4.7



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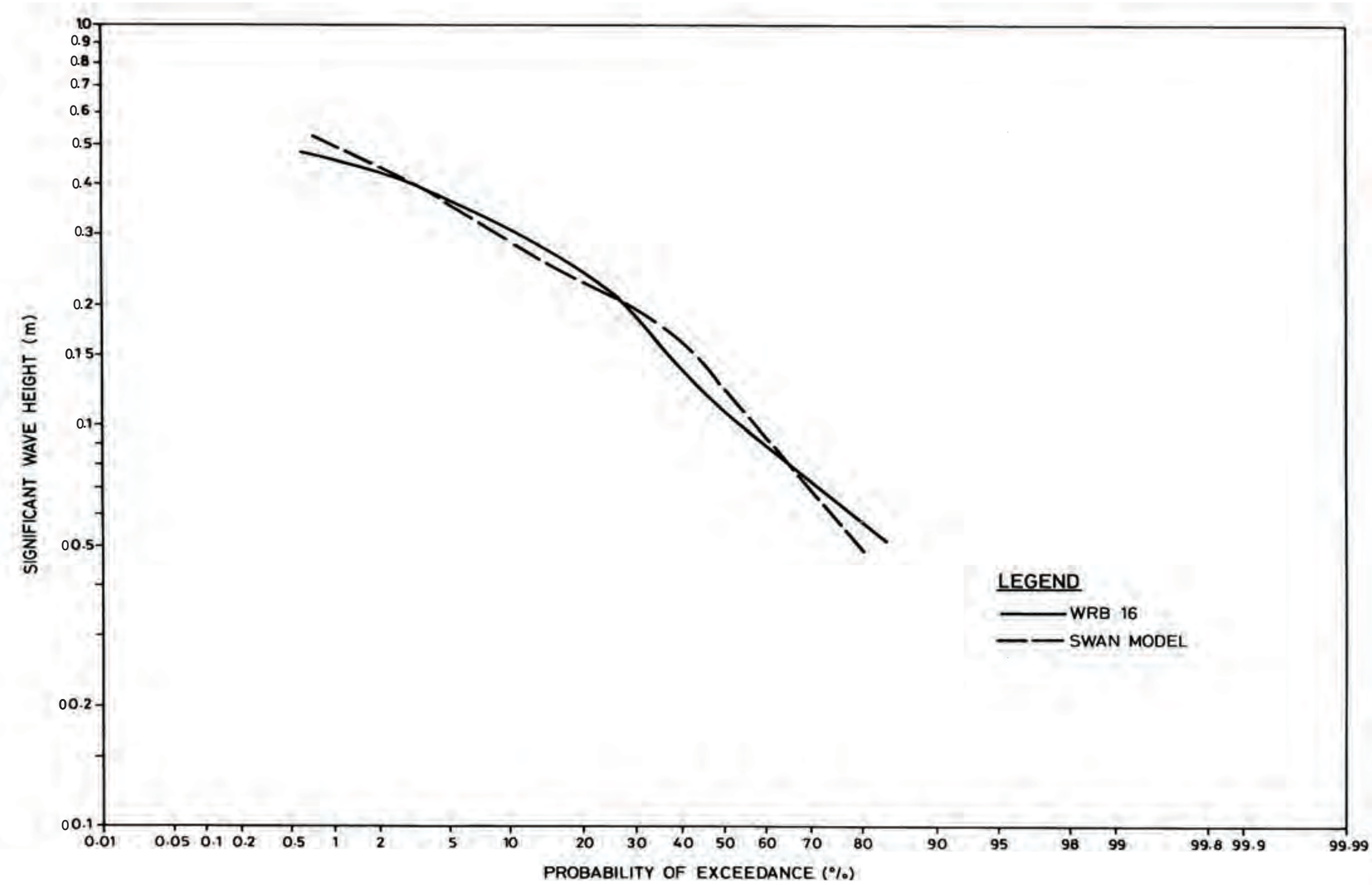
Proposed Expansion of Container Port Facilities, Botany Bay

WAVE COEFFICENTS
DEVELOPED (Vertical Walls)
Figure 4.8



Location: WRB16

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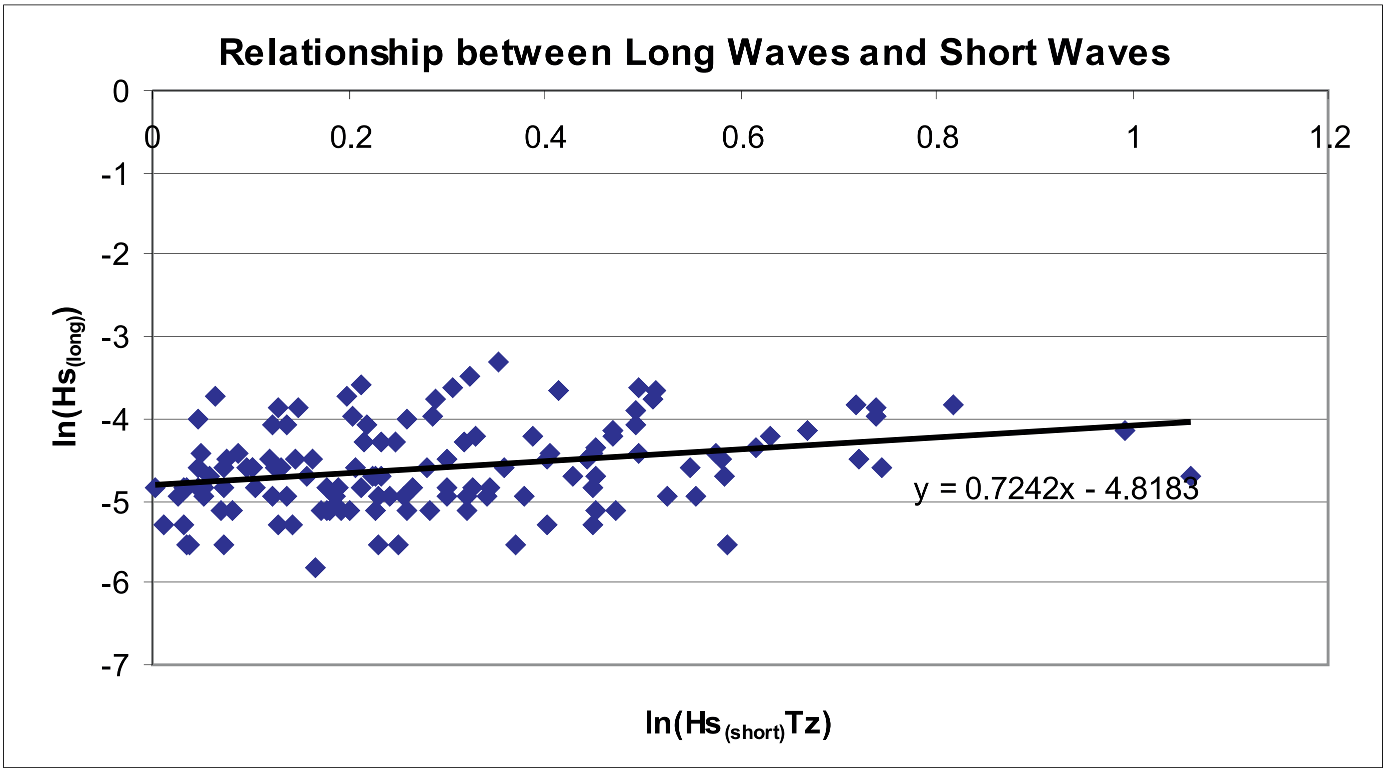
Proposed Expansion of Container Port Facilities, Botany Bay

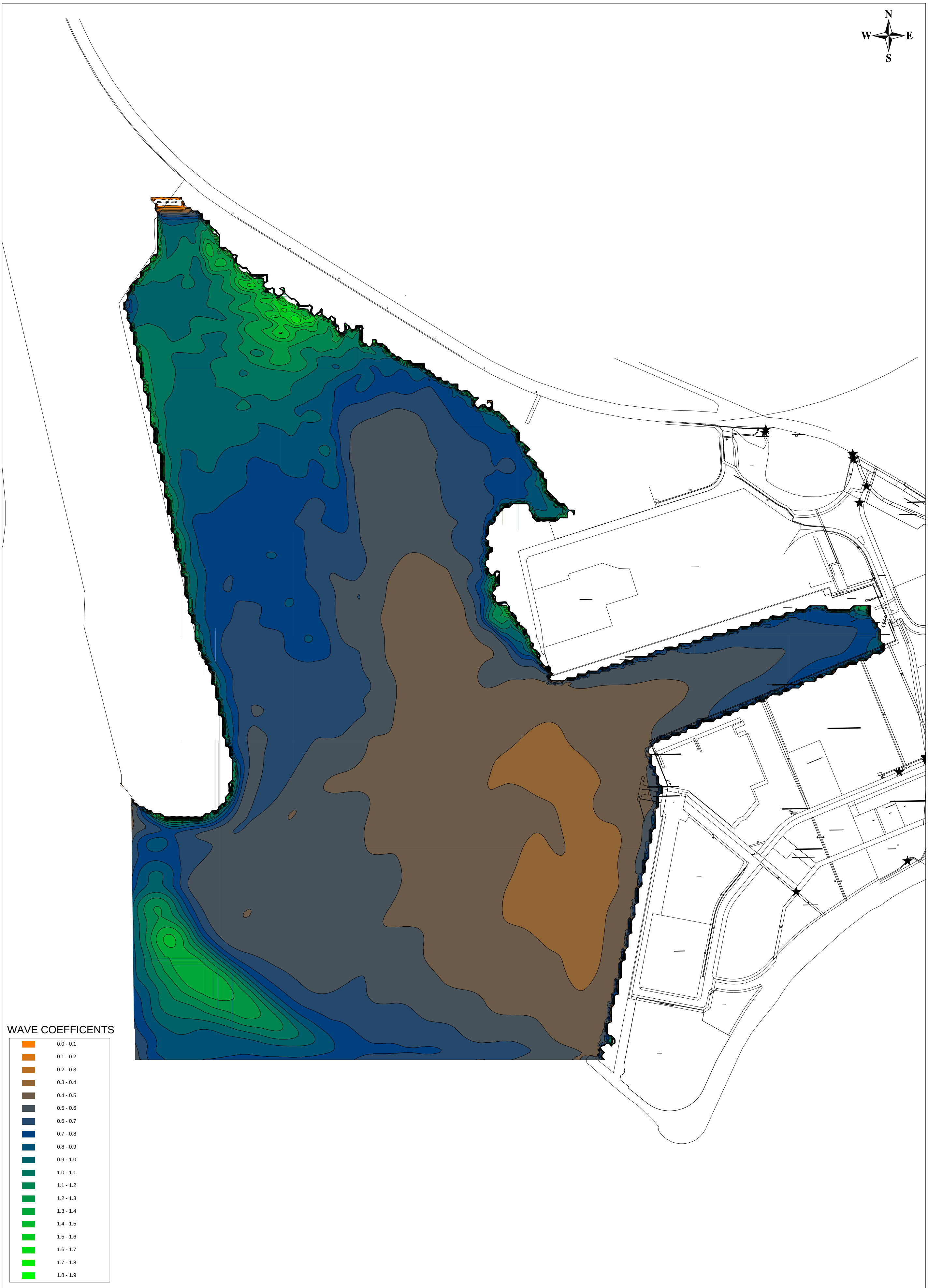
WAVE MODEL CALIBRATION - SEA

Figure 4.9



LONG WAVES/SHORT WAVES CORRELATION

Figure 4.10



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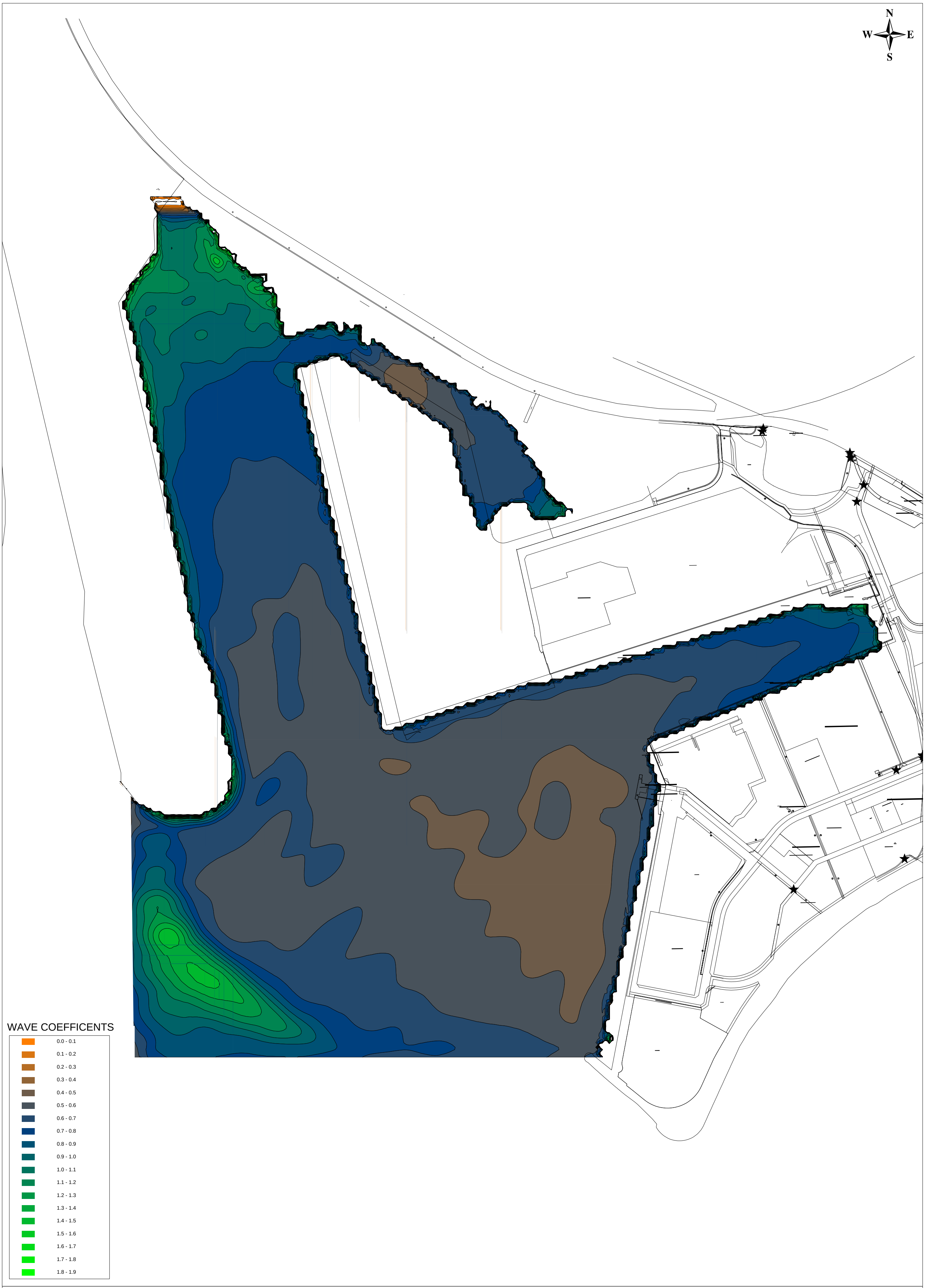
Proposed Expansion of Container Port Facilities, Botany Bay

LONG WAVES - EXISTING
CONTOURS OF WAVE COEFFICIENTS
Figure 4.11



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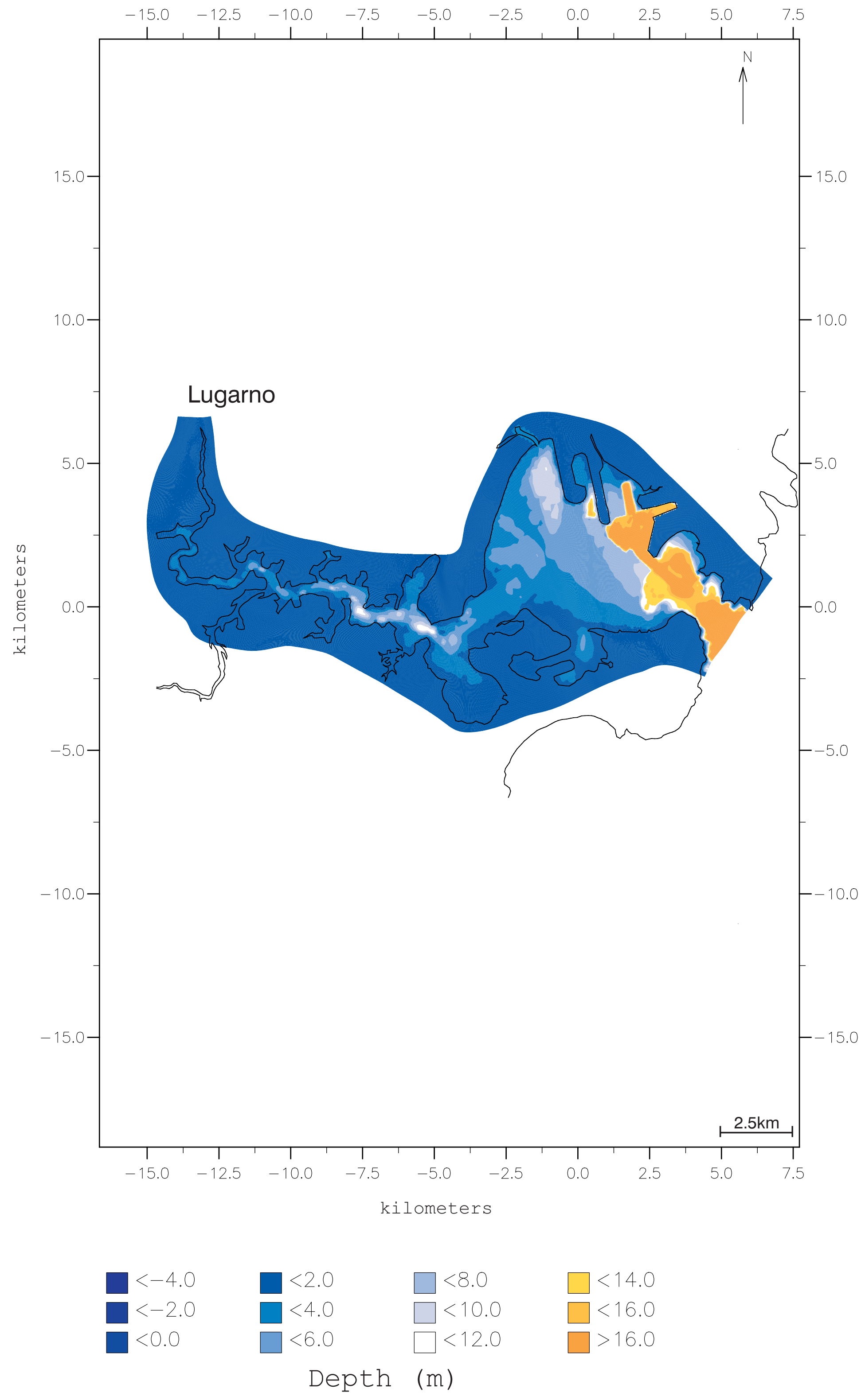
Proposed Expansion of Container Port Facilities, Botany Bay

LONG WAVES - DEVELOPED

CONTOURS OF WAVE COEFFICIENTS

Figure 4.12



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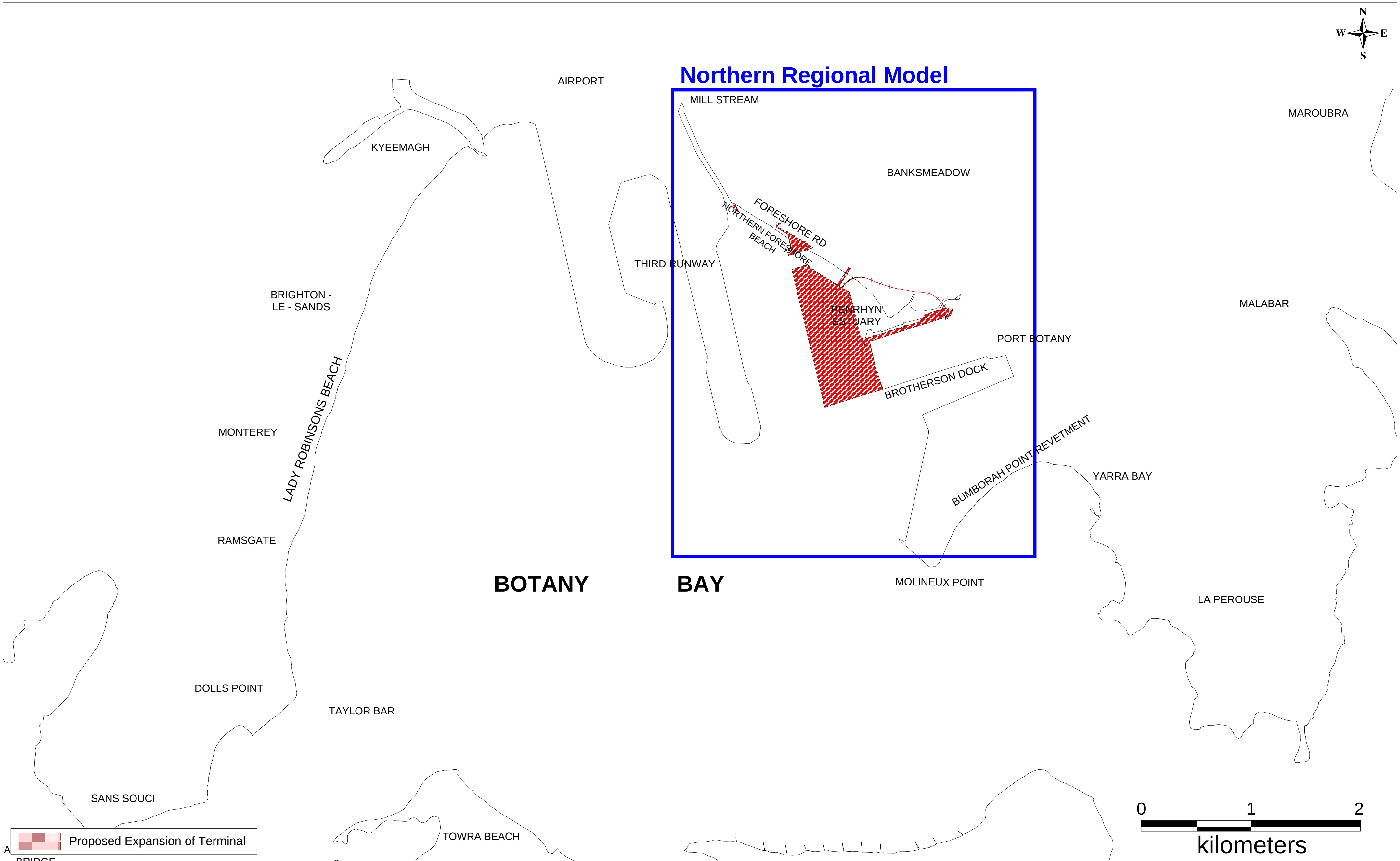
Proposed Expansion of Container Port Facilities, Botany Bay

EXTENT OF WHOLE OF BAY FLOW MODEL

Figure 5.1



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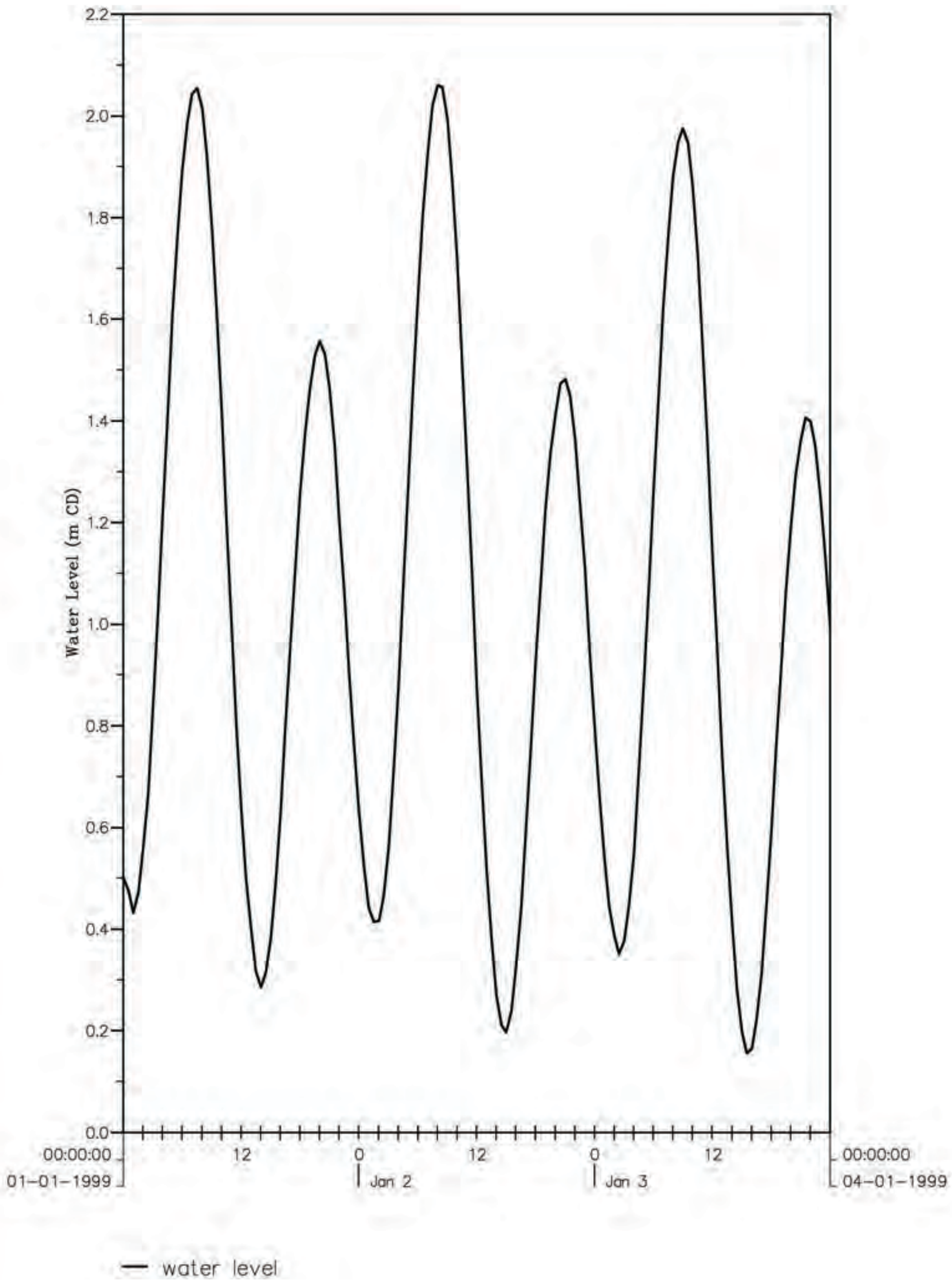
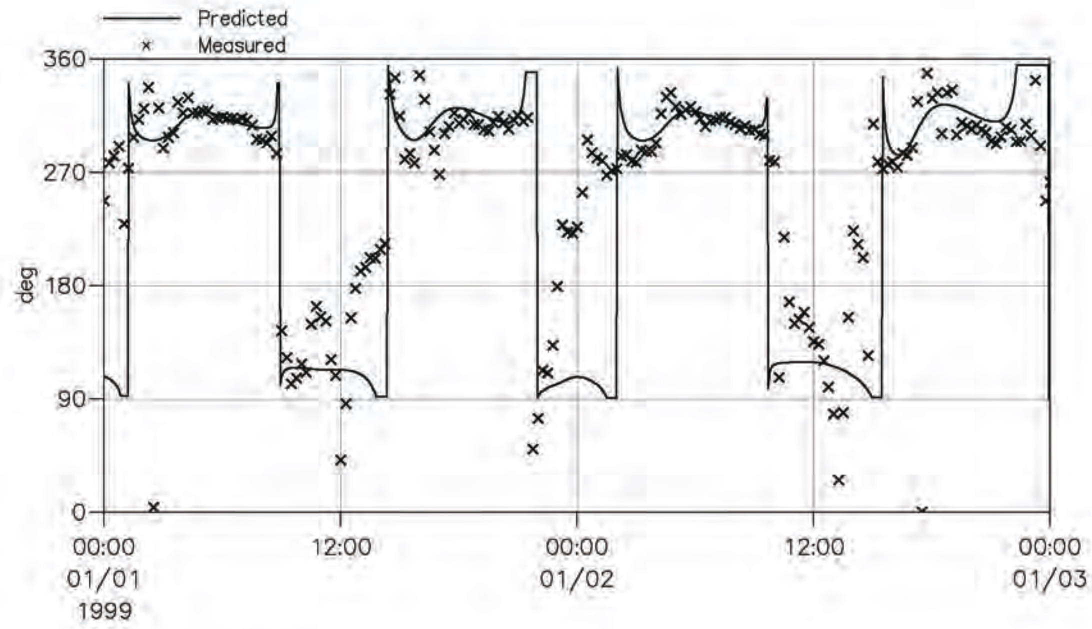
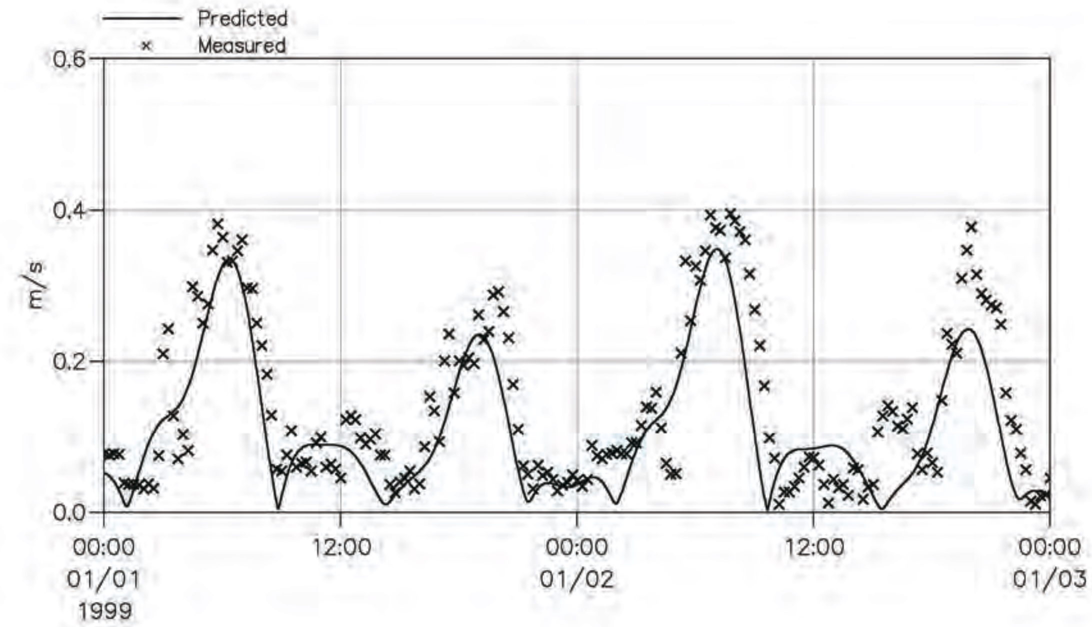
EXTENT OF NORTHERN REGIONAL FLOW MODEL

Figure 5.2



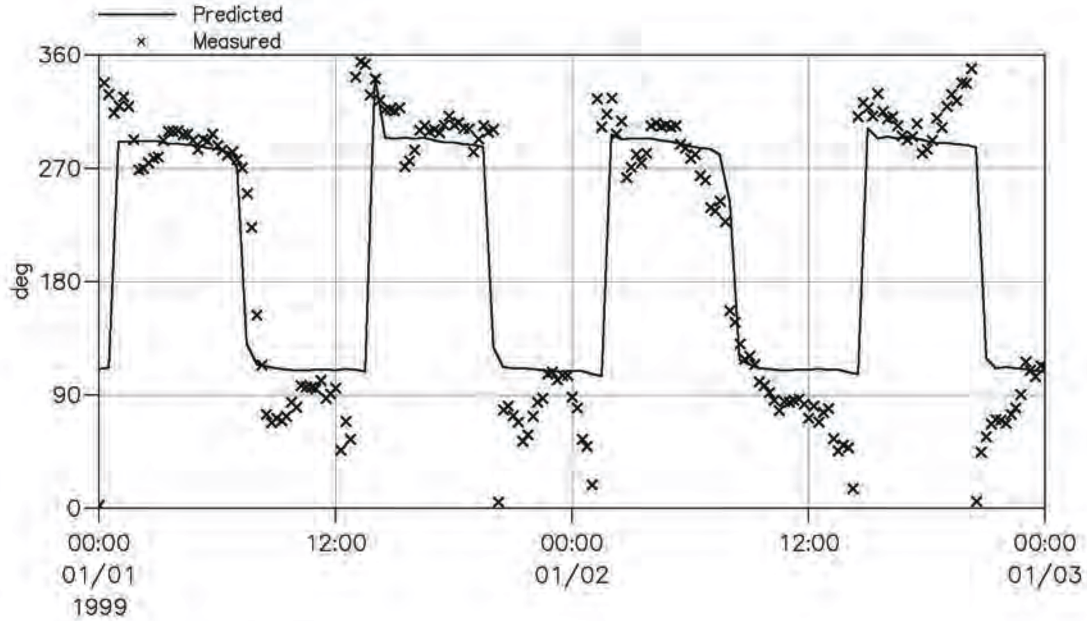
TIDAL WATER LEVEL IN BOTANY BAY
WHOLE OF BAY MODEL
Figure 5.3

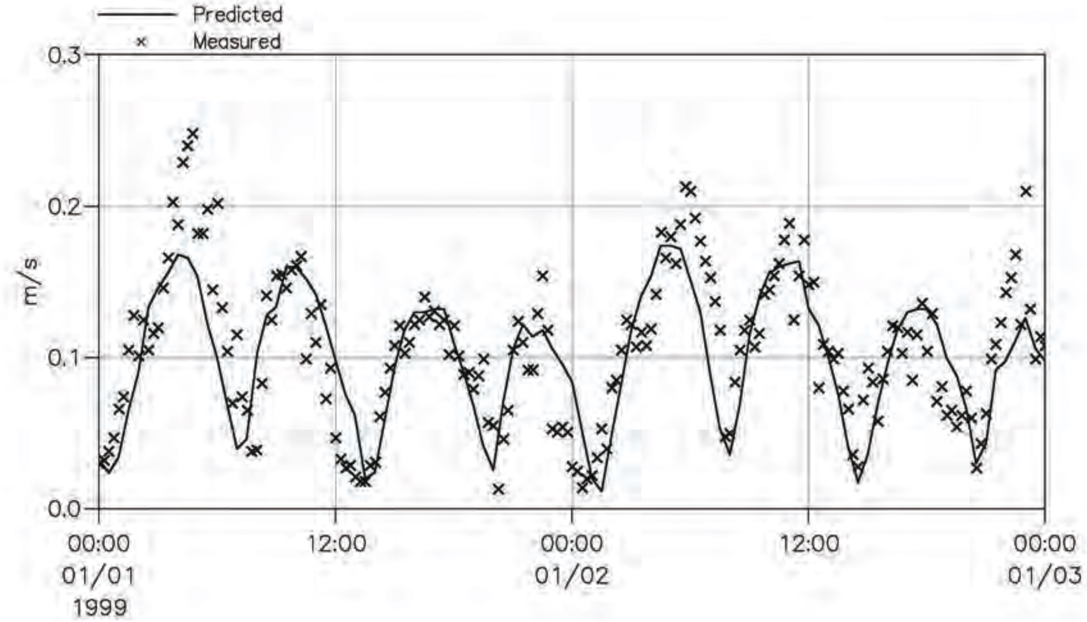




CURRENT LOCATION MID
PREDICTED TIDAL & RECORDED CURRENTS

Figure 5.4





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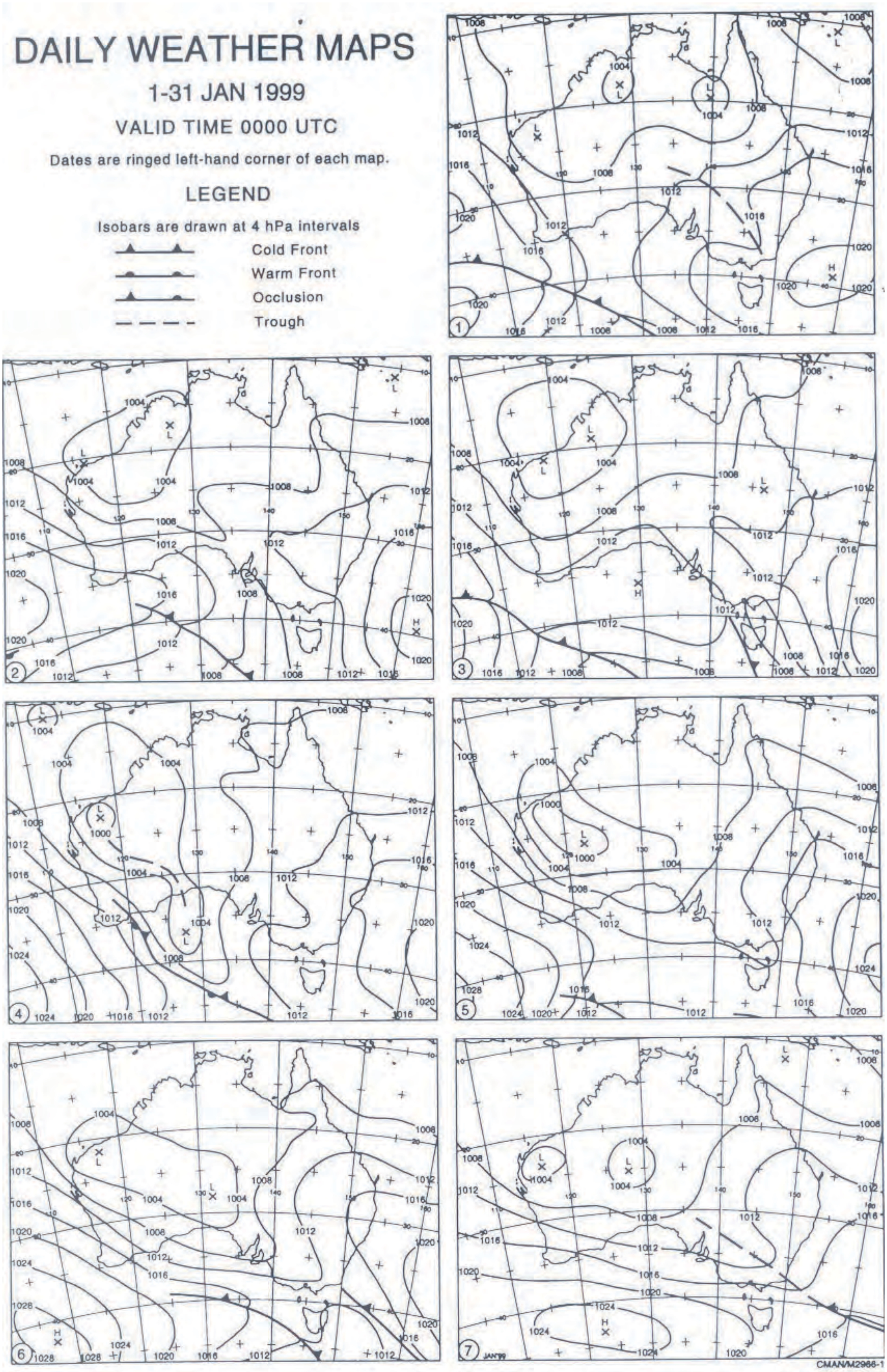
Proposed Expansion of Container Port Facilities, Botany Bay

CURRENT LOCATION SOUTH
PREDICTED TIDAL & RECORDED CURRENTS

Figure 5.5



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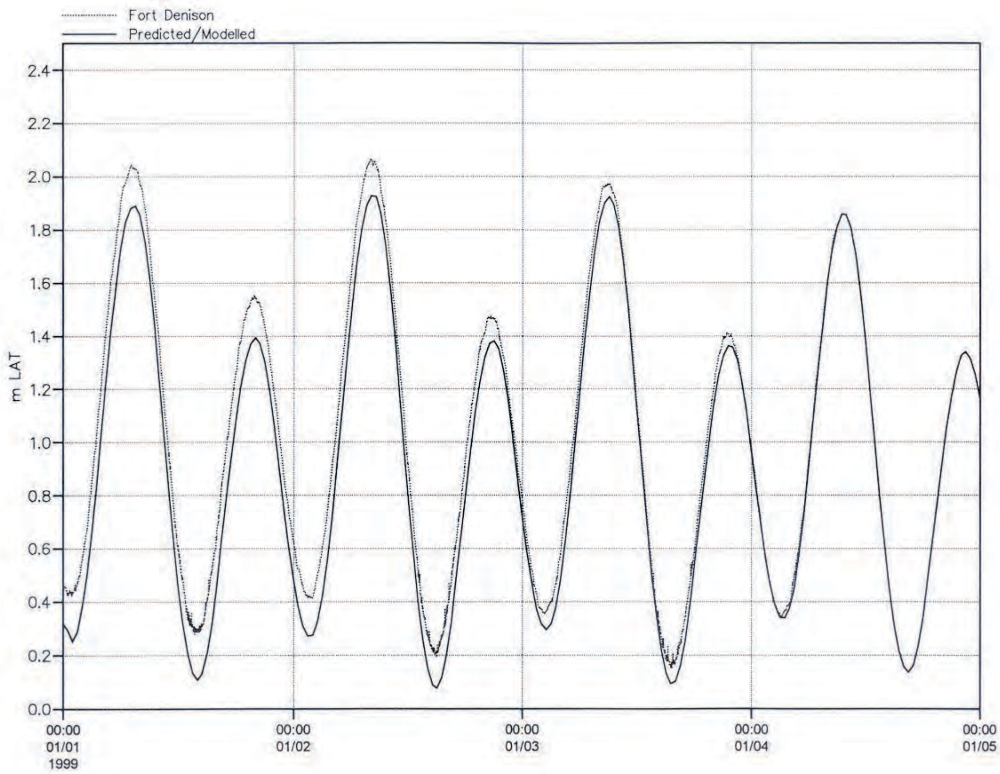
Proposed Expansion of Container Port Facilities, Botany Bay

BoM SYNOPTIC CHARTS 1 - 7 JANUARY 1999

Figure 5.6



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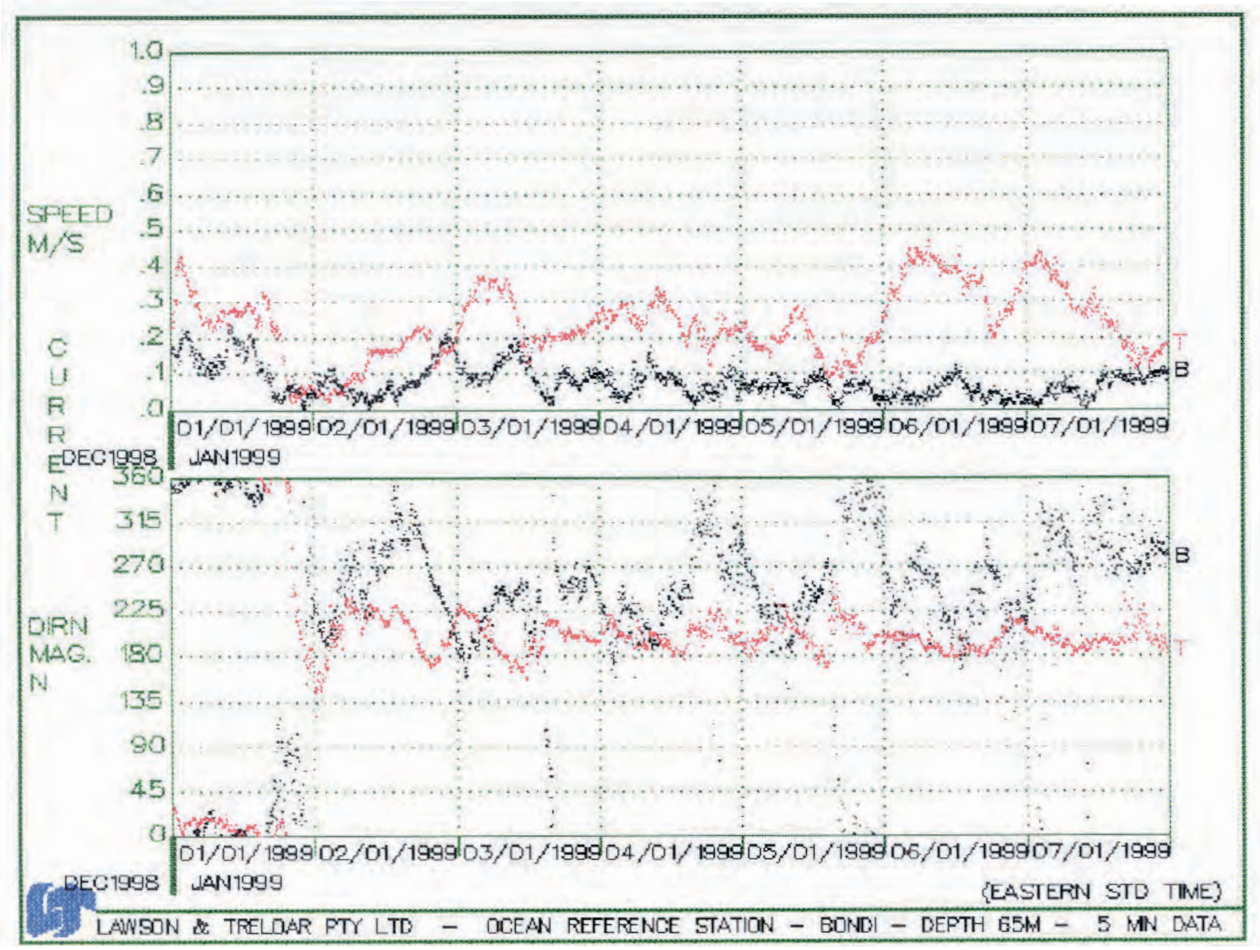
Proposed Expansion of Container Port Facilities, Botany Bay

PREDICTED TIDE & RECORDED WATER LEVELS
FORT DENISON 1-5 JANUARY, 1999

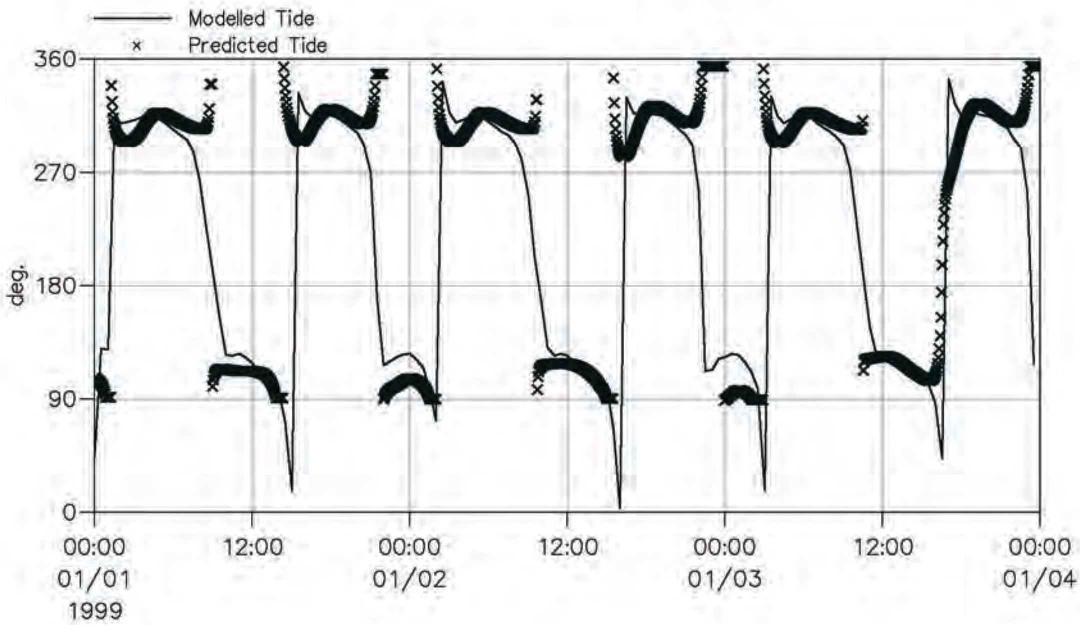
Figure 5.7

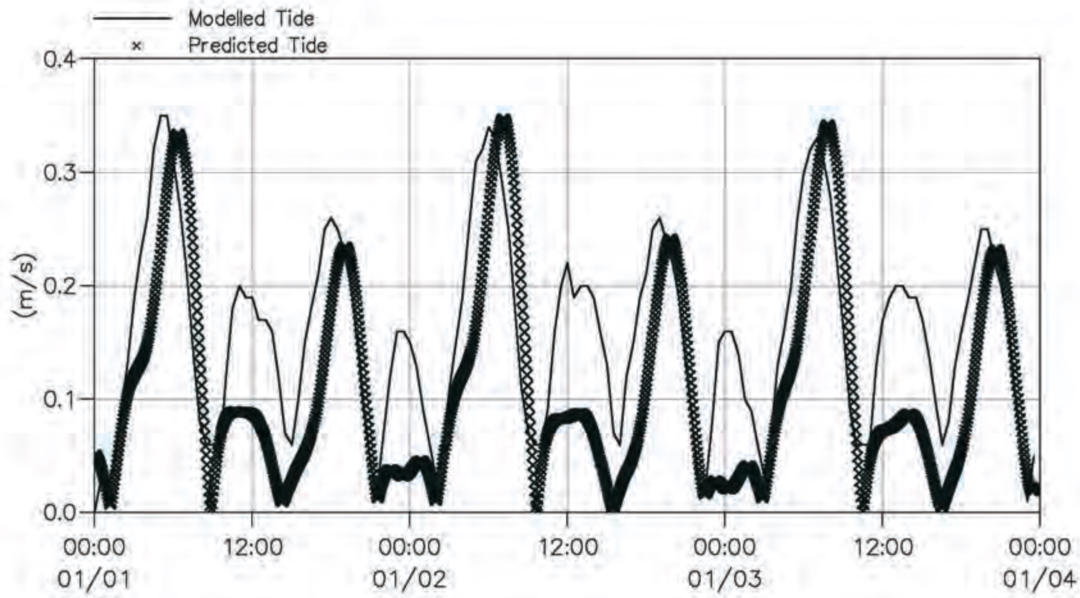


Data courtesy of Sydney Water
Location: Offshore Reference Station

SYDNEY OFFSHORE CURRENT DATA 1 - 7 JANUARY 1999

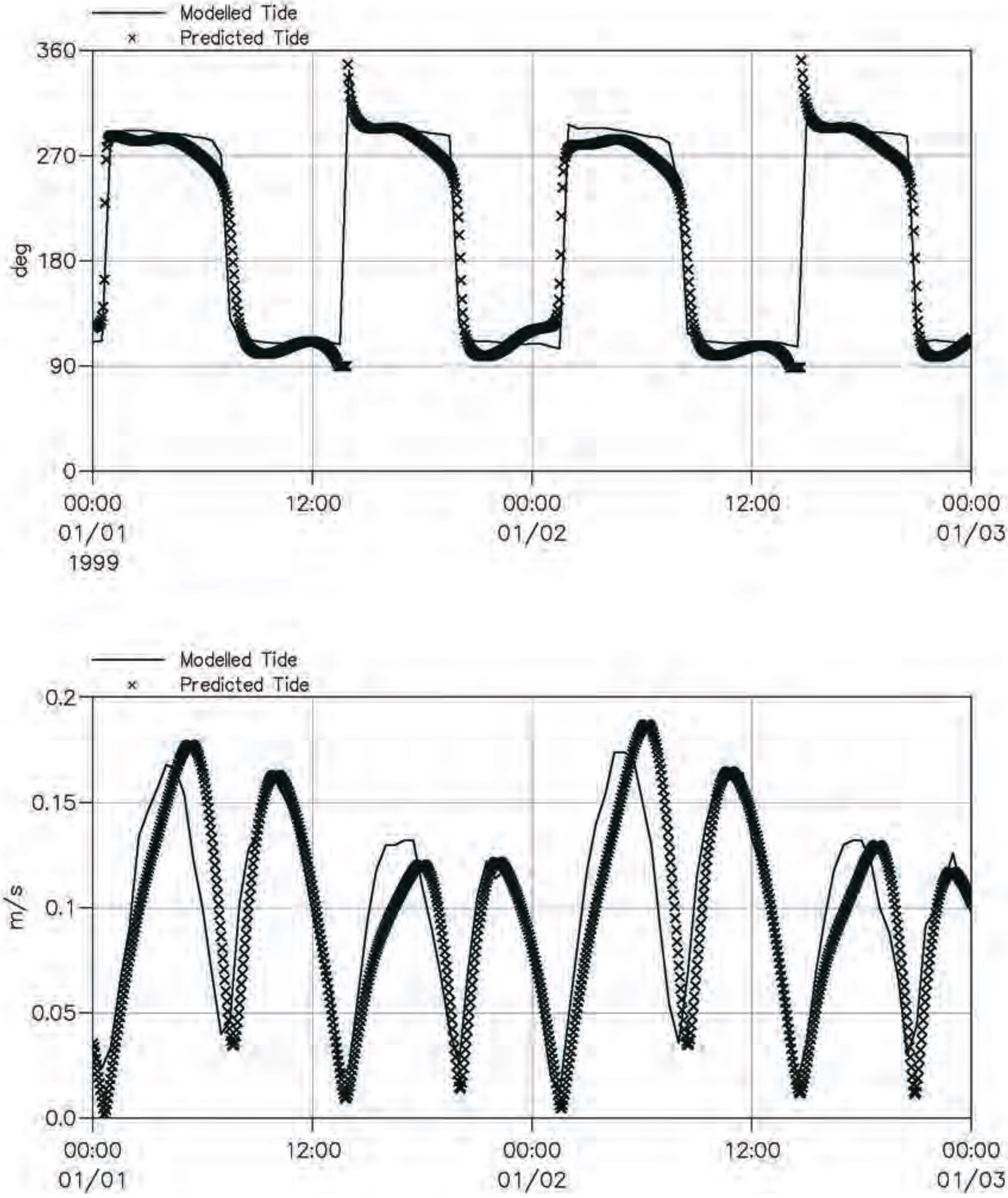
Figure 5.8





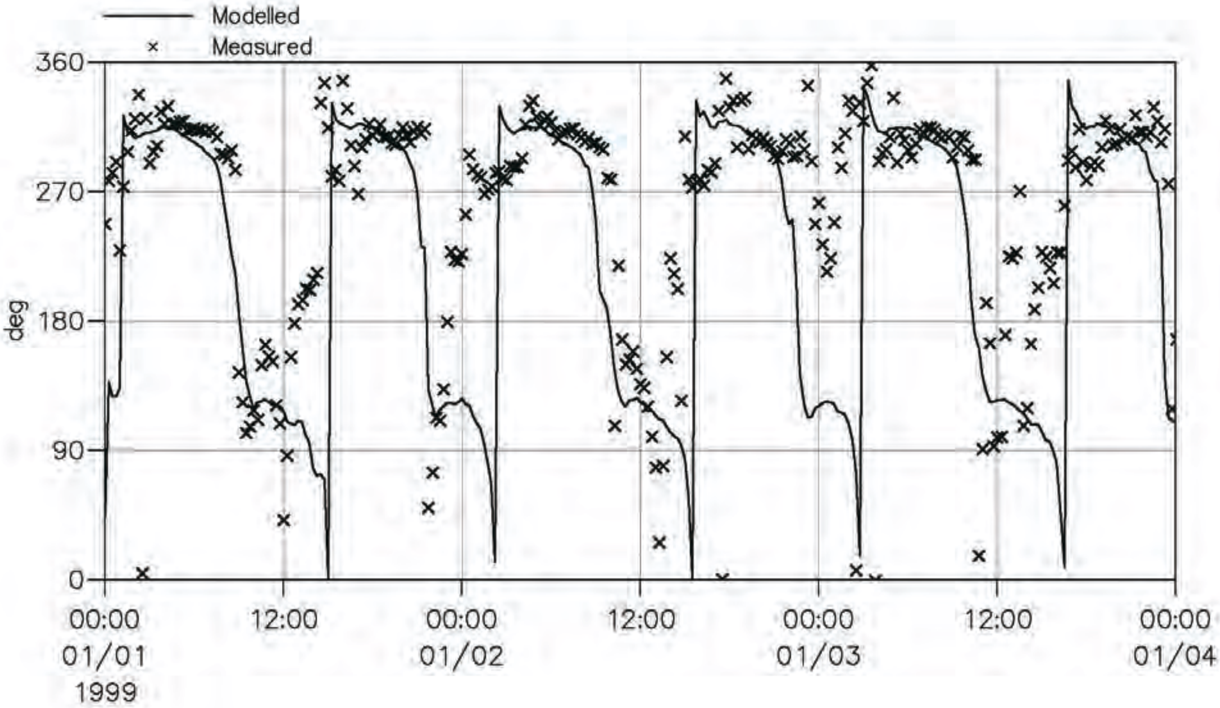
TIDAL CURRENTS AT LOCATION MID

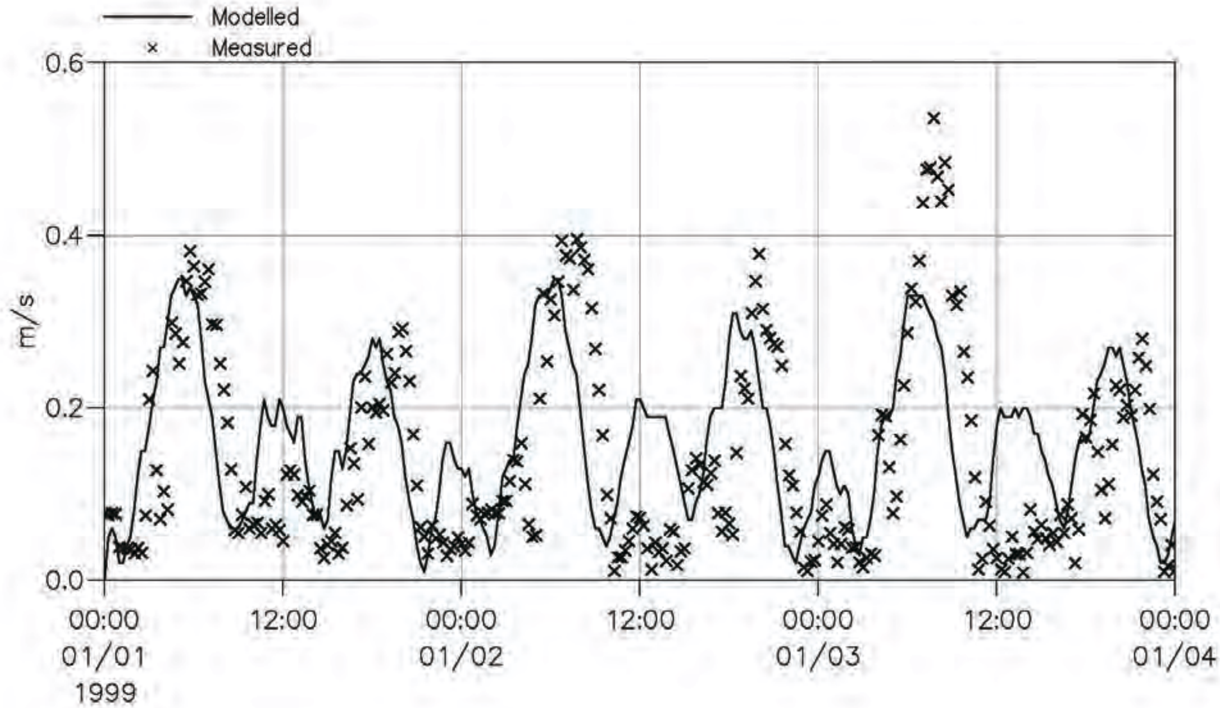
Figure 5.9



TIDAL CURRENTS AT LOCATION SOUTH

Figure 5.10





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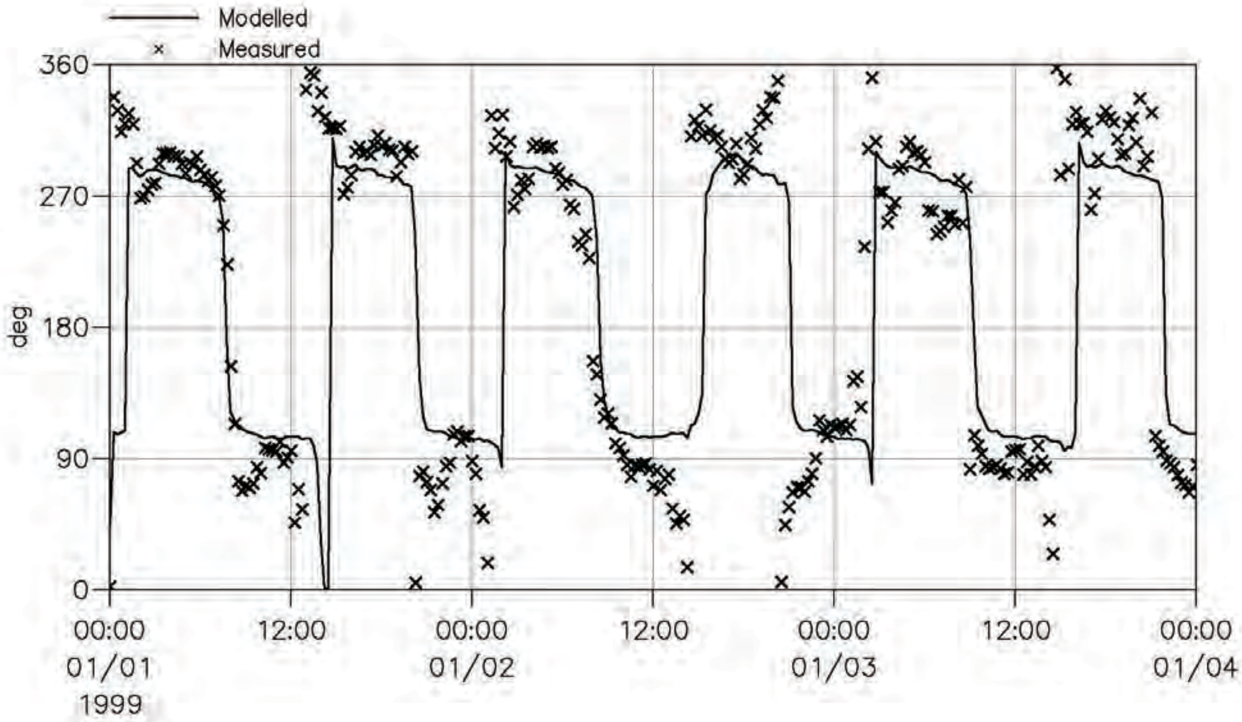
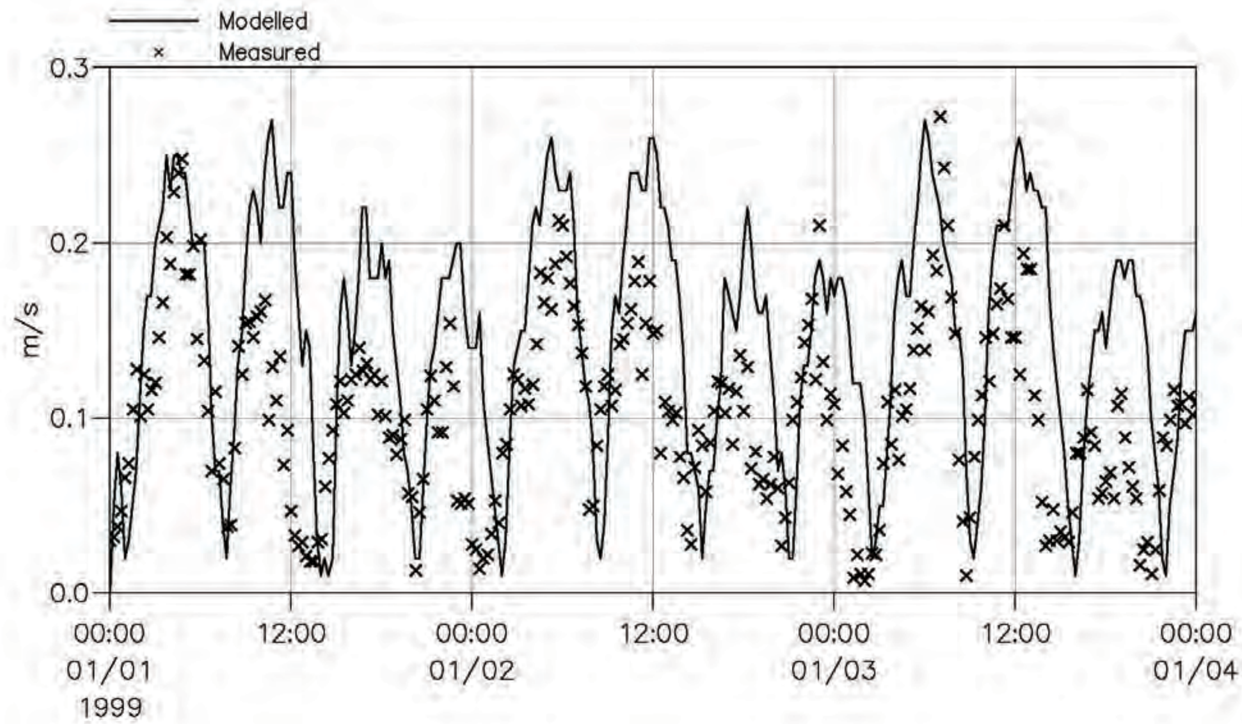
Proposed Expansion of Container Port Facilities, Botany Bay

CURRENT LOCATION MID
MODELLED & MEASURED CURRENTS

Figure 5.11





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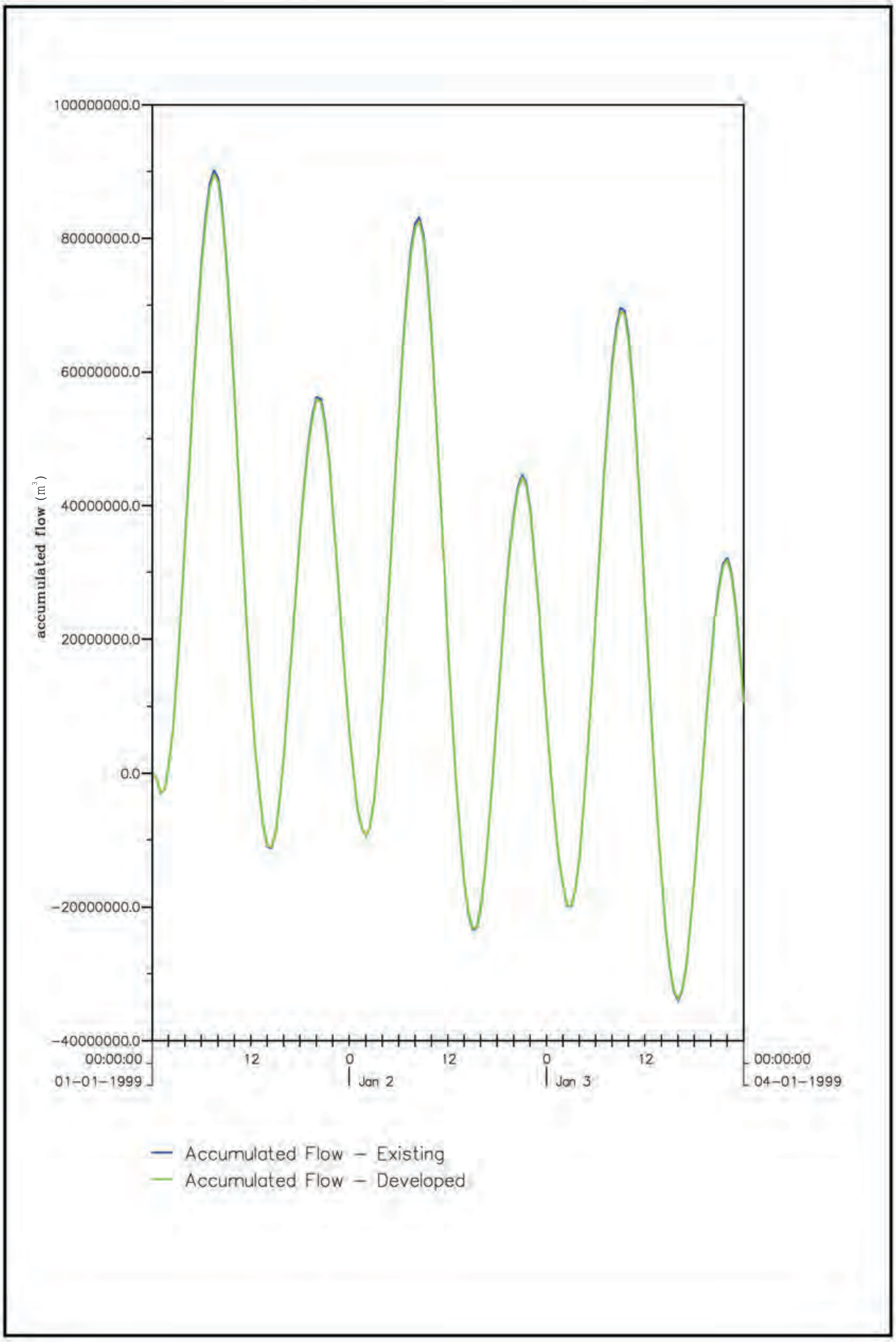
Proposed Expansion of Container Port Facilities, Botany Bay

CURRENT LOCATION SOUTH
MODELLED & MEASURED CURRENTS

Figure 5.12



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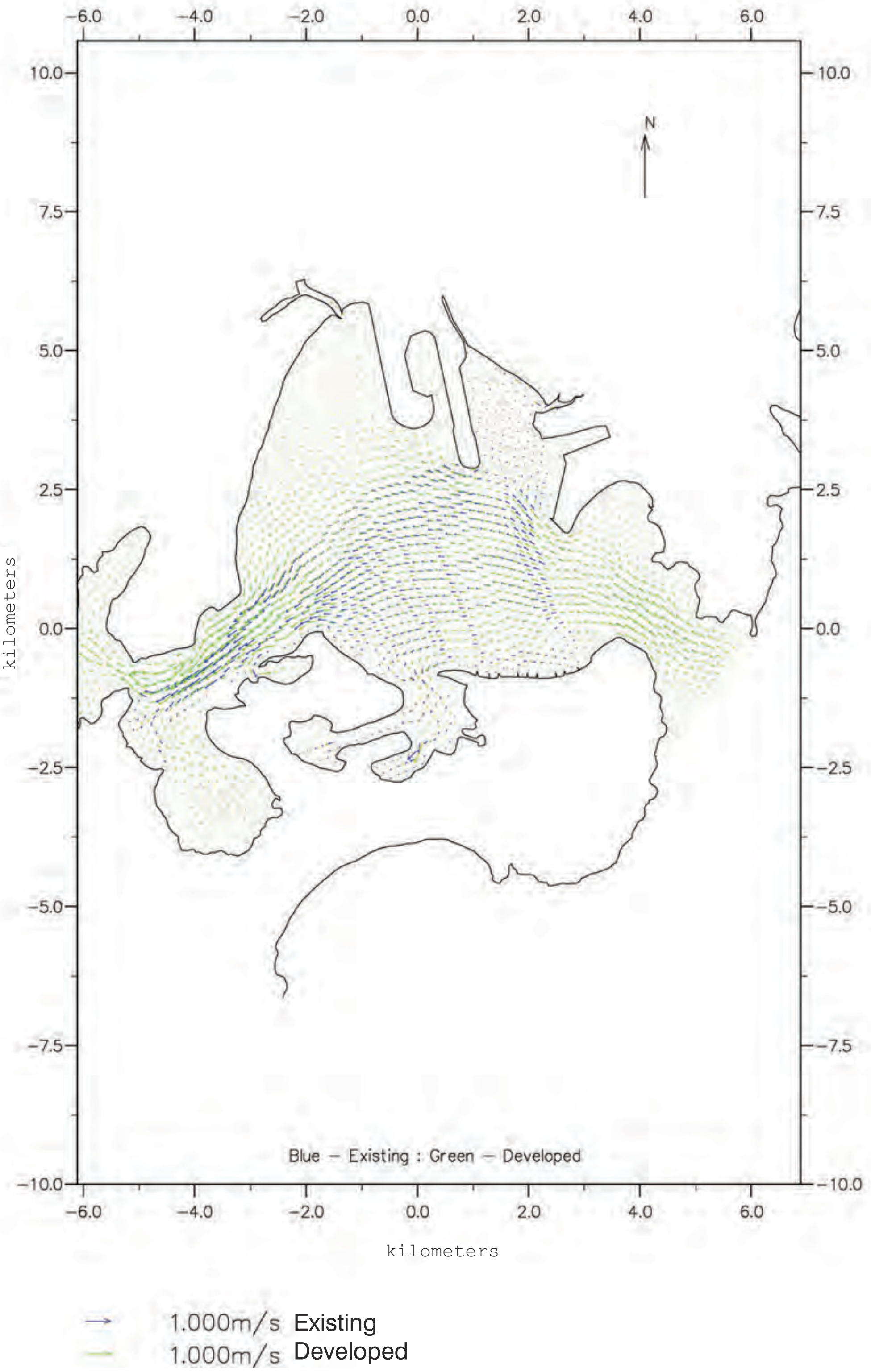
Proposed Expansion of Container Port Facilities, Botany Bay

BOTANY BAY ENTRANCE ACCUMULATED FLOW

Figure 5.13



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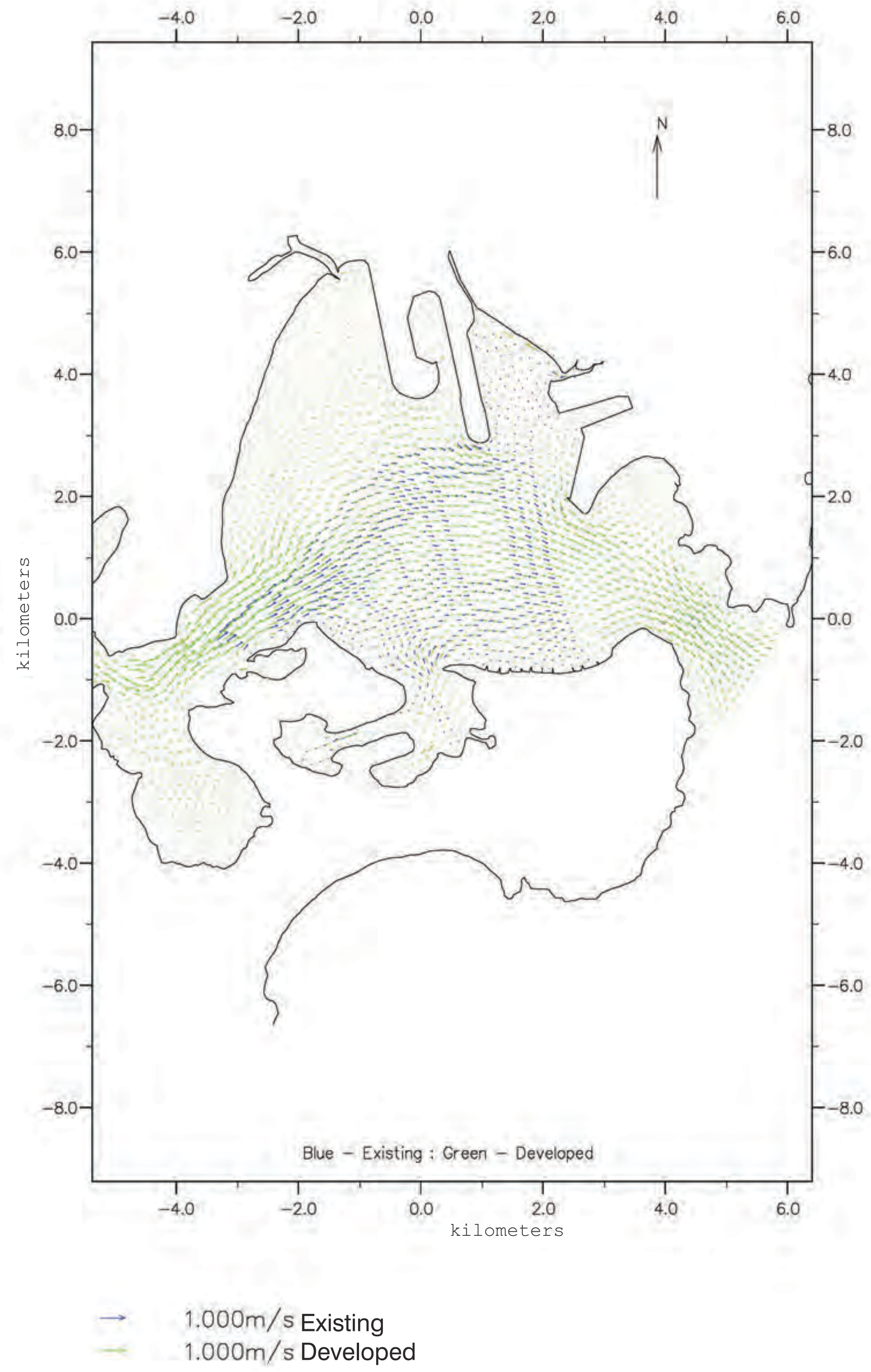
Proposed Expansion of Container Port Facilities, Botany Bay

FLOOD TIDE CURRENT VECTORS
BOTANY BAY

Figure 5.14



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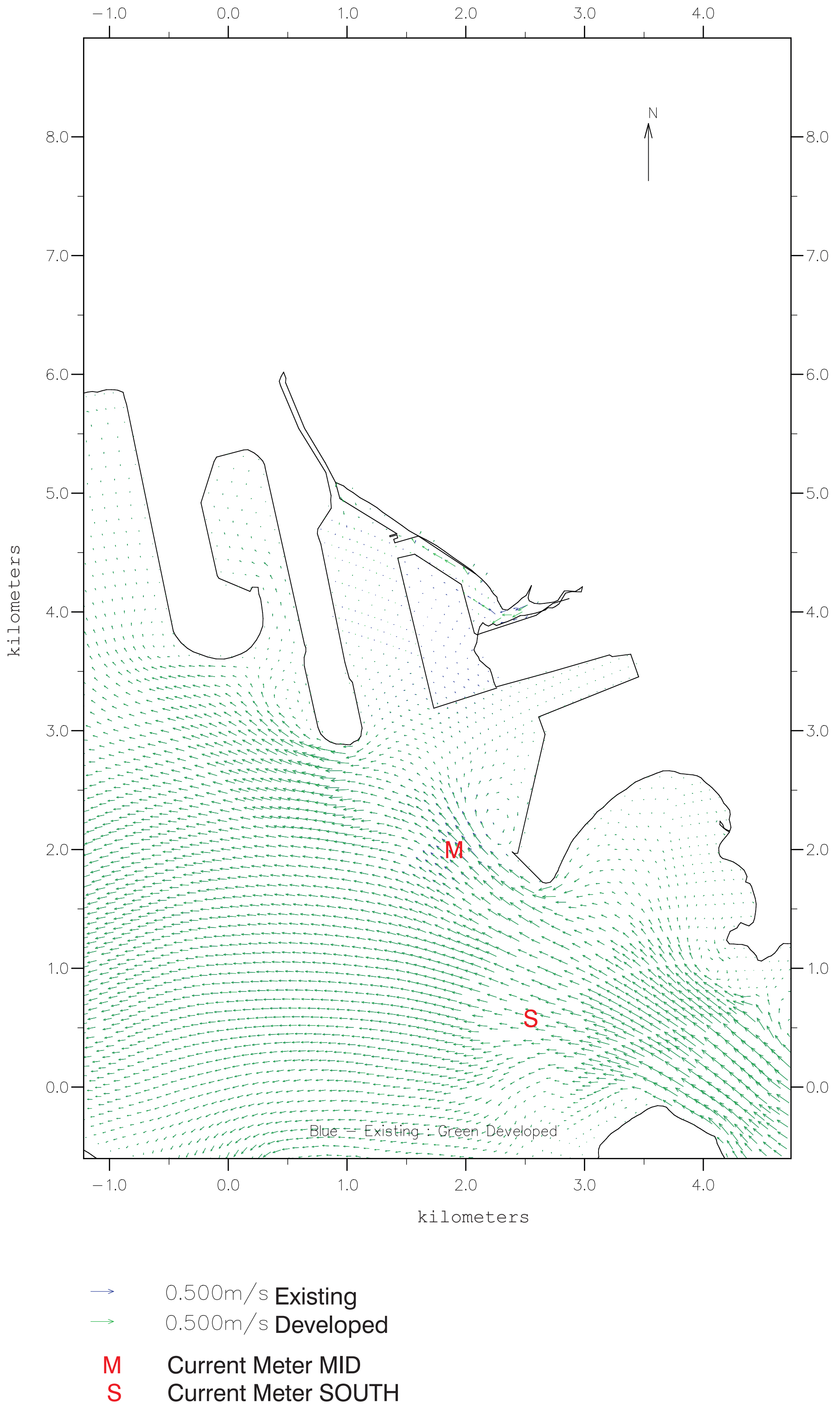
Proposed Expansion of Container Port Facilities, Botany Bay

EBB TIDE CURRENT VECTORS

BOTANY BAY

Figure 5.15



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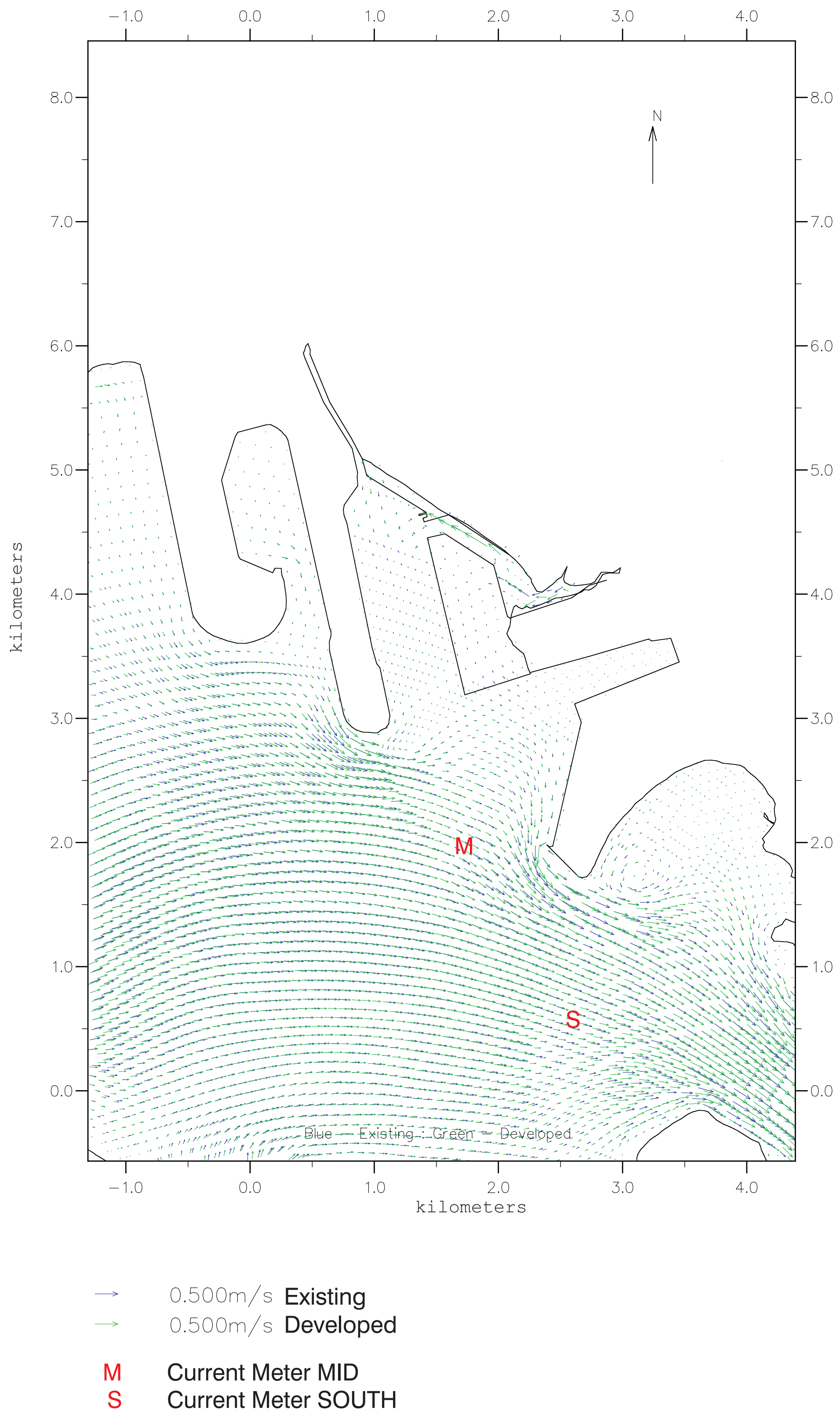
Proposed Expansion of Container Port Facilities, Botany Bay

FLOOD TIDE CURRENT VECTORS
PORT ENTRANCE AREA

Figure 5.16



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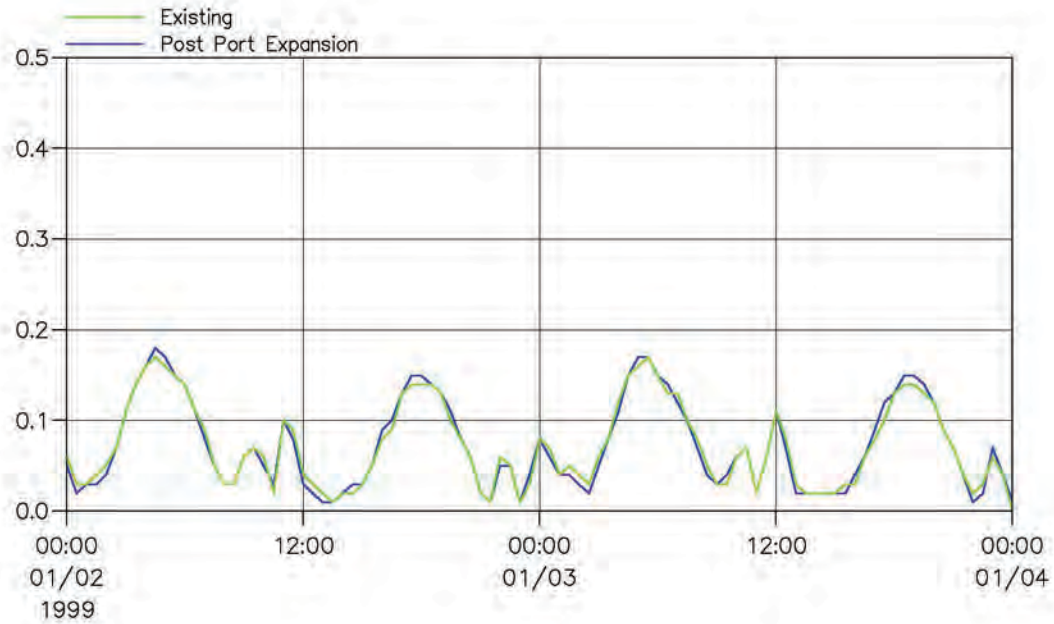
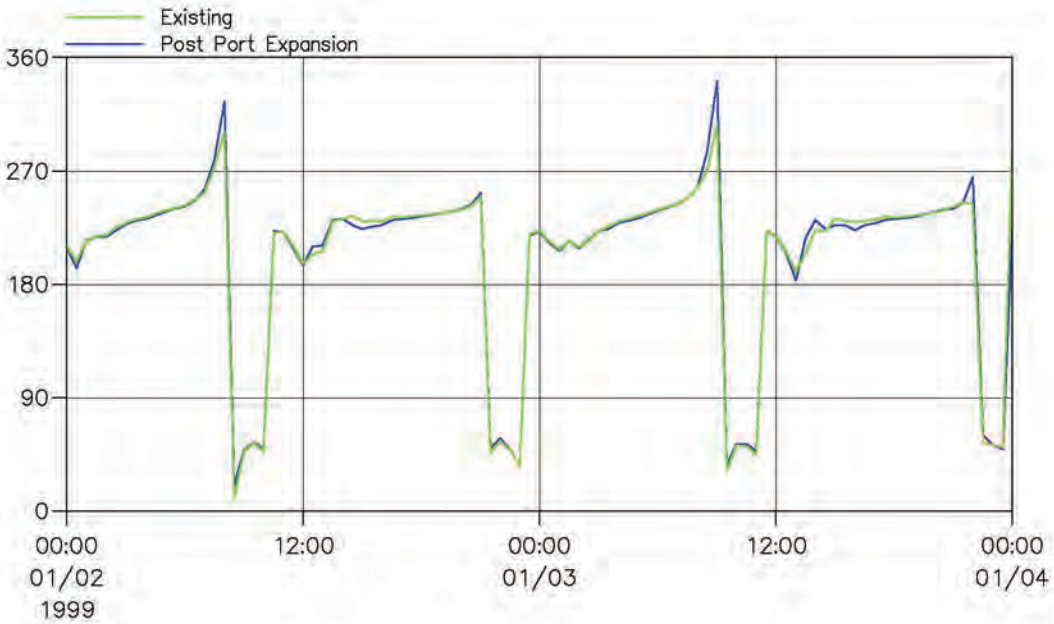
Proposed Expansion of Container Port Facilities, Botany Bay

EBB TIDE CURRENT VECTORS
PORT ENTRANCE AREA

Figure 5.17





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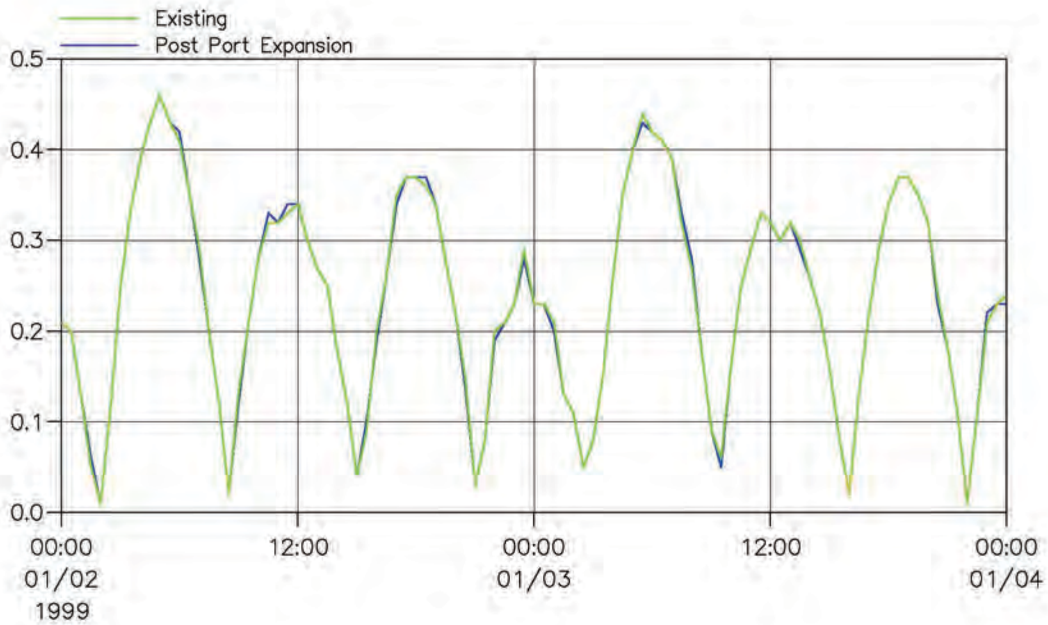
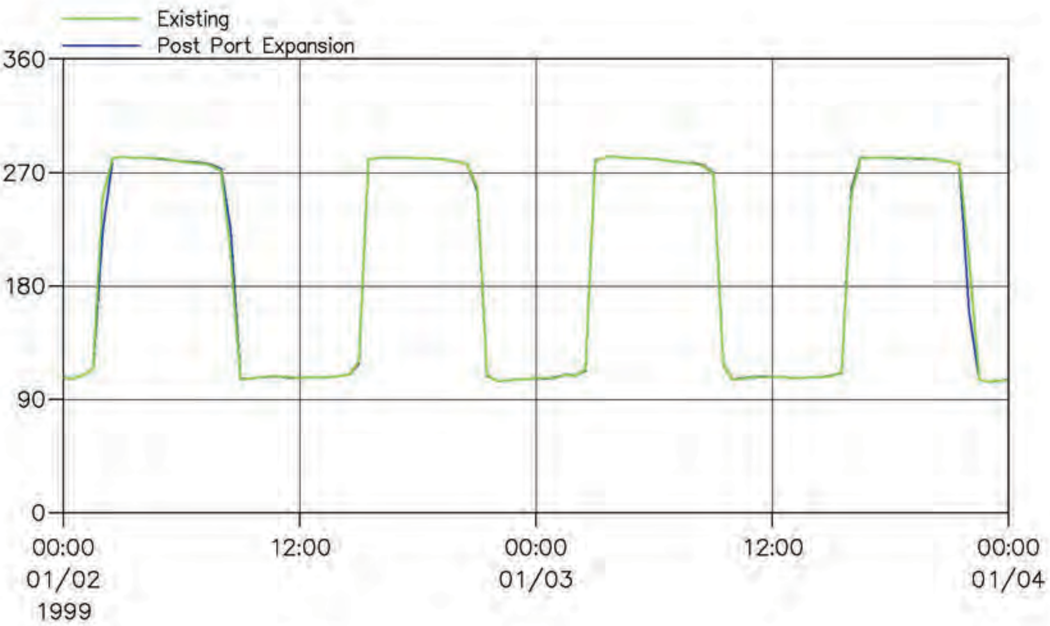
Proposed Expansion of Container Port Facilities, Botany Bay

RUNWAY CURRENT LOCATION RWC1

Figure 5.18





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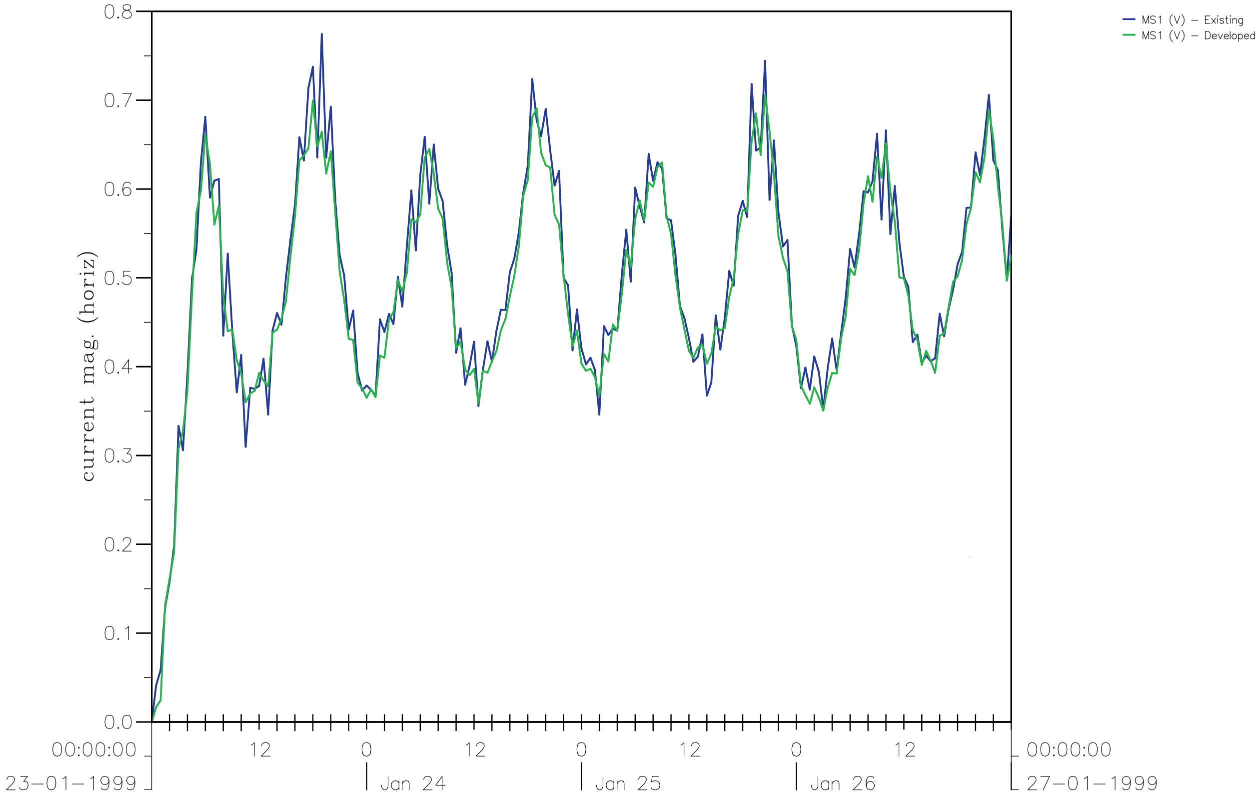
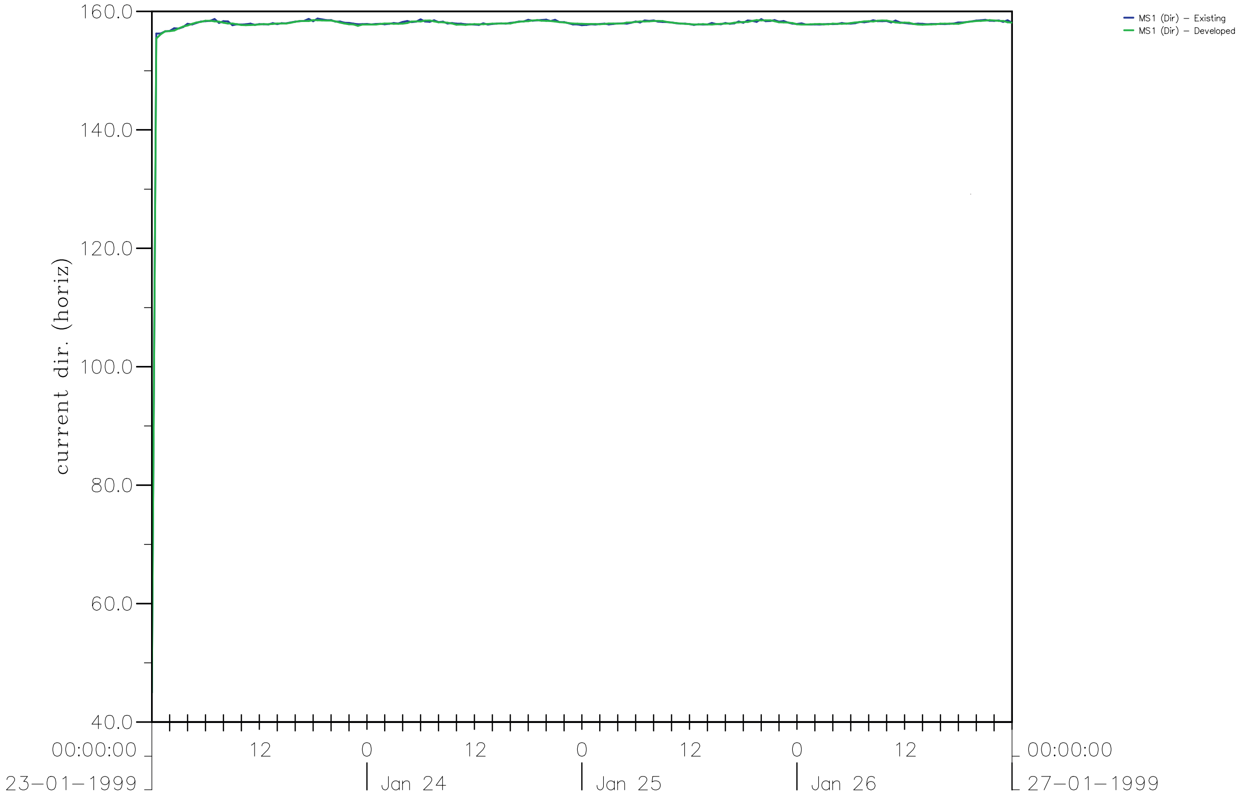
Proposed Expansion of Container Port Facilities, Botany Bay

RUNWAY CURRENT LOCATION RWC2

Figure 5.19





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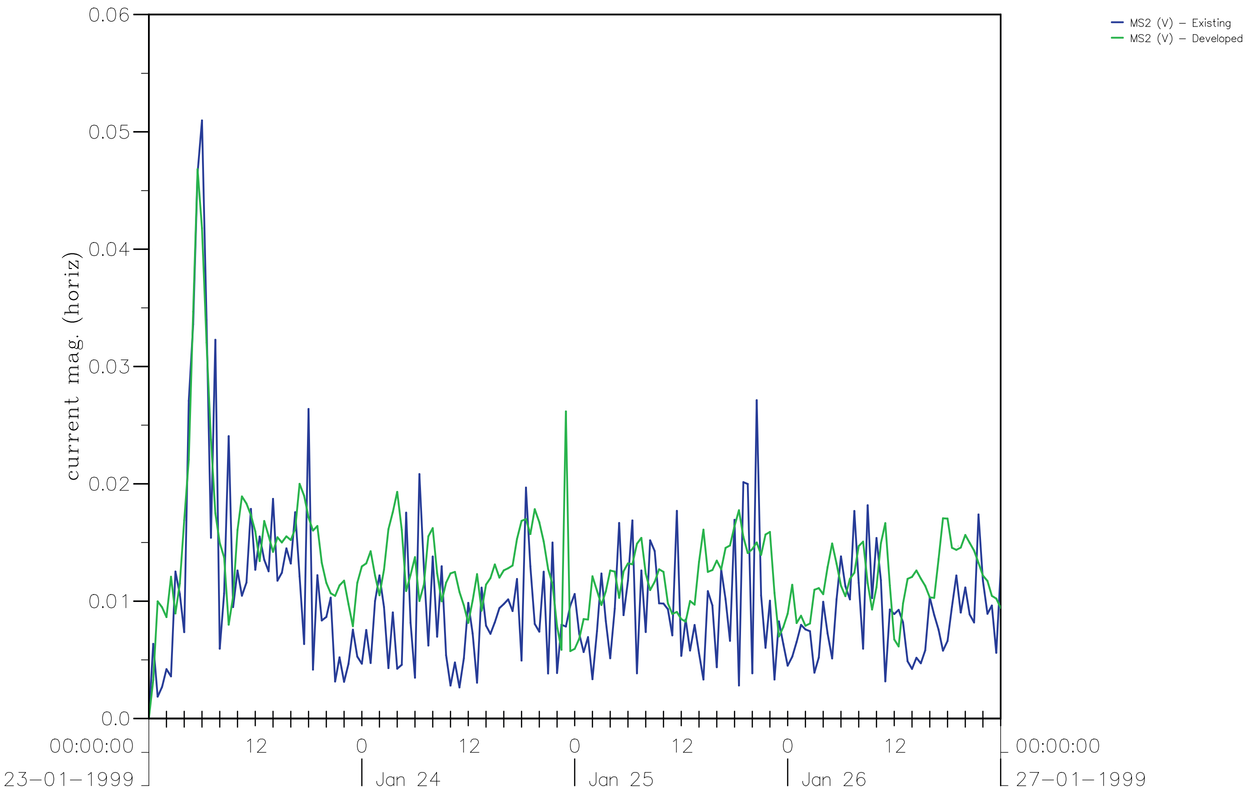
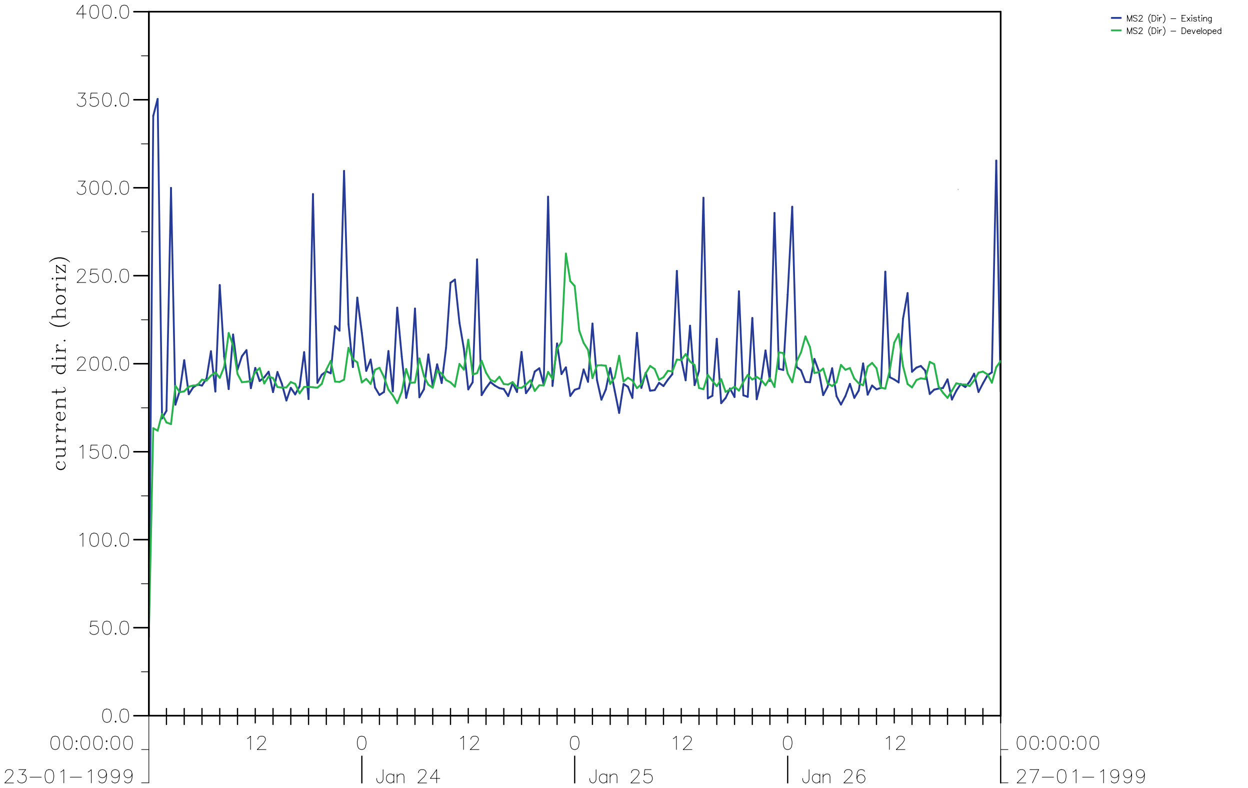
Proposed Expansion of Container Port Facilities, Botany Bay

MILL STREAM CURRENT LOCATION MS1

Figure 5.20





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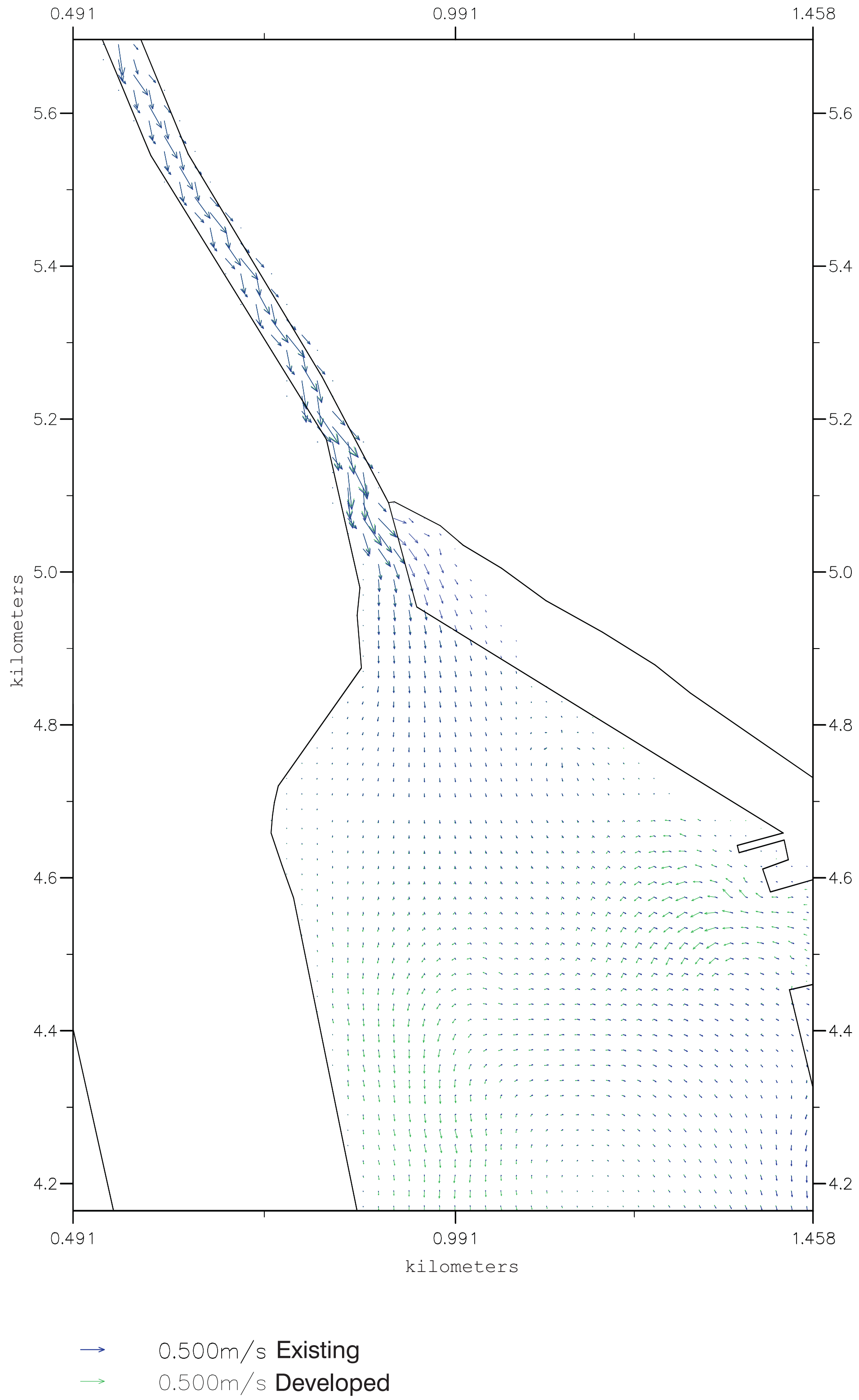
Proposed Expansion of Container Port Facilities, Botany Bay

MILL STREAM CURRENT LOCATION MS2

Figure 5.21



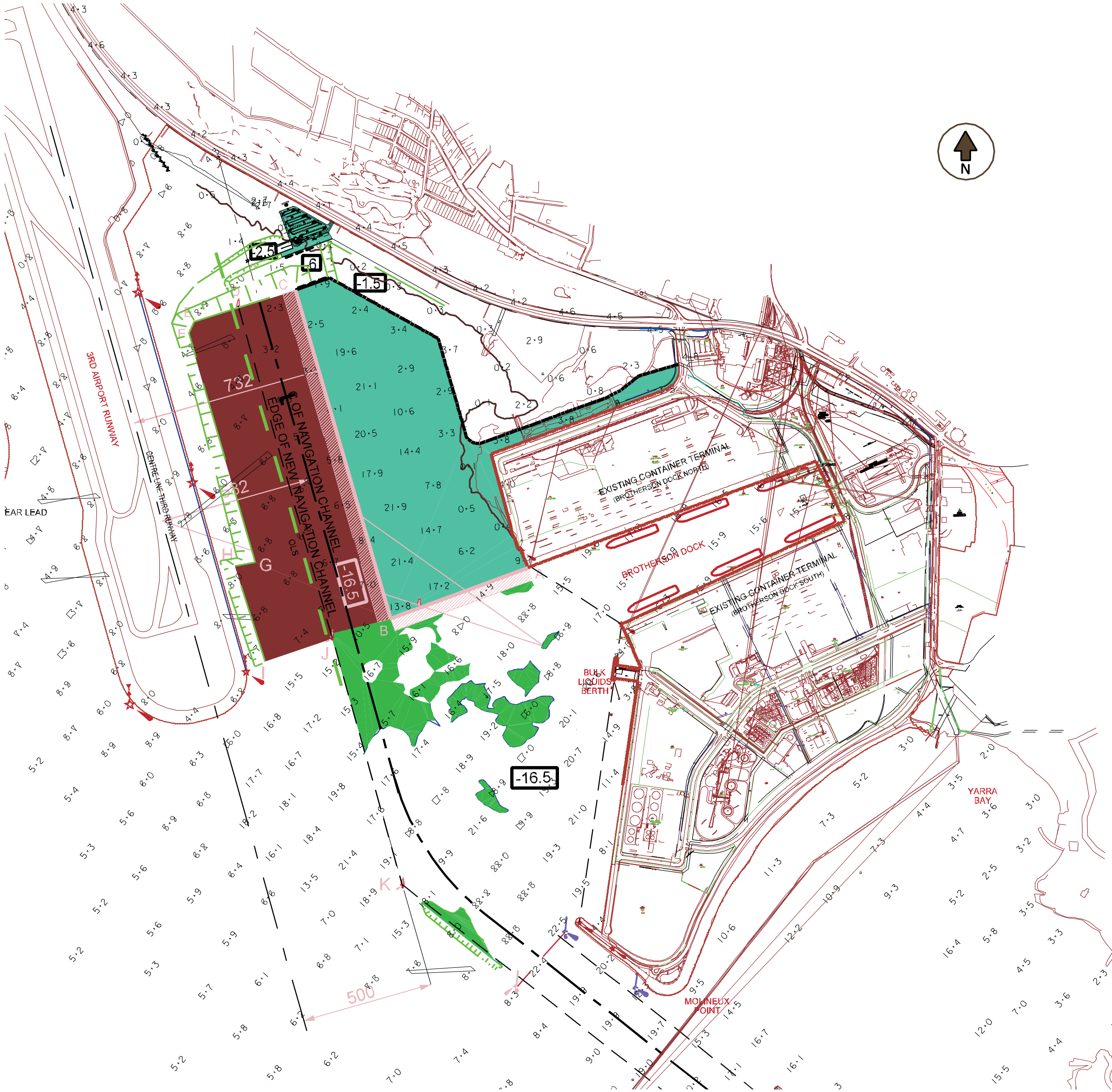
Proposed Expansion of Container Port Facilities, Botany Bay

CURRENT VECTORS AT MILL STREAM EXIT

Figure 5.22

APPENDIX A

PROPOSED SPC DEVELOPMENT LAYOUT



-16	DENOTES MINIMUM DREDGED DEPTH
	BERTHING BOX (50m WIDE) TO BE DREDGED TO -16
	AREA TO BE DREDGED TO MAXIMUM DEPTH OF -17.5
	HIGH SPOTS TO BE DREDGED TO -16.5

Lawson and Treloar

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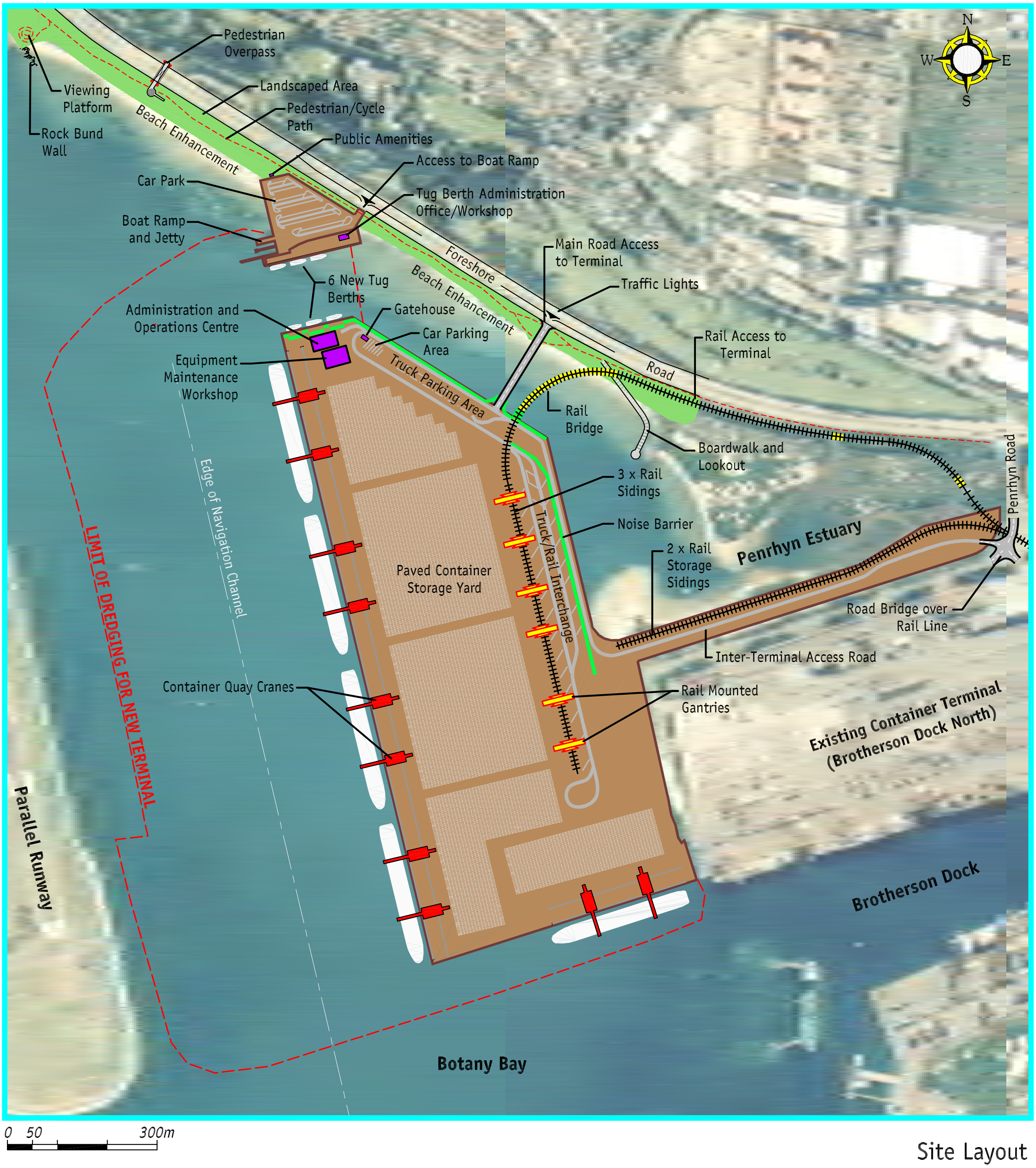
File: Figures/Vol Feb03/Appendix/updatedbath.cdr

Proposed Expansion of Container Port Facilities, Botany Bay

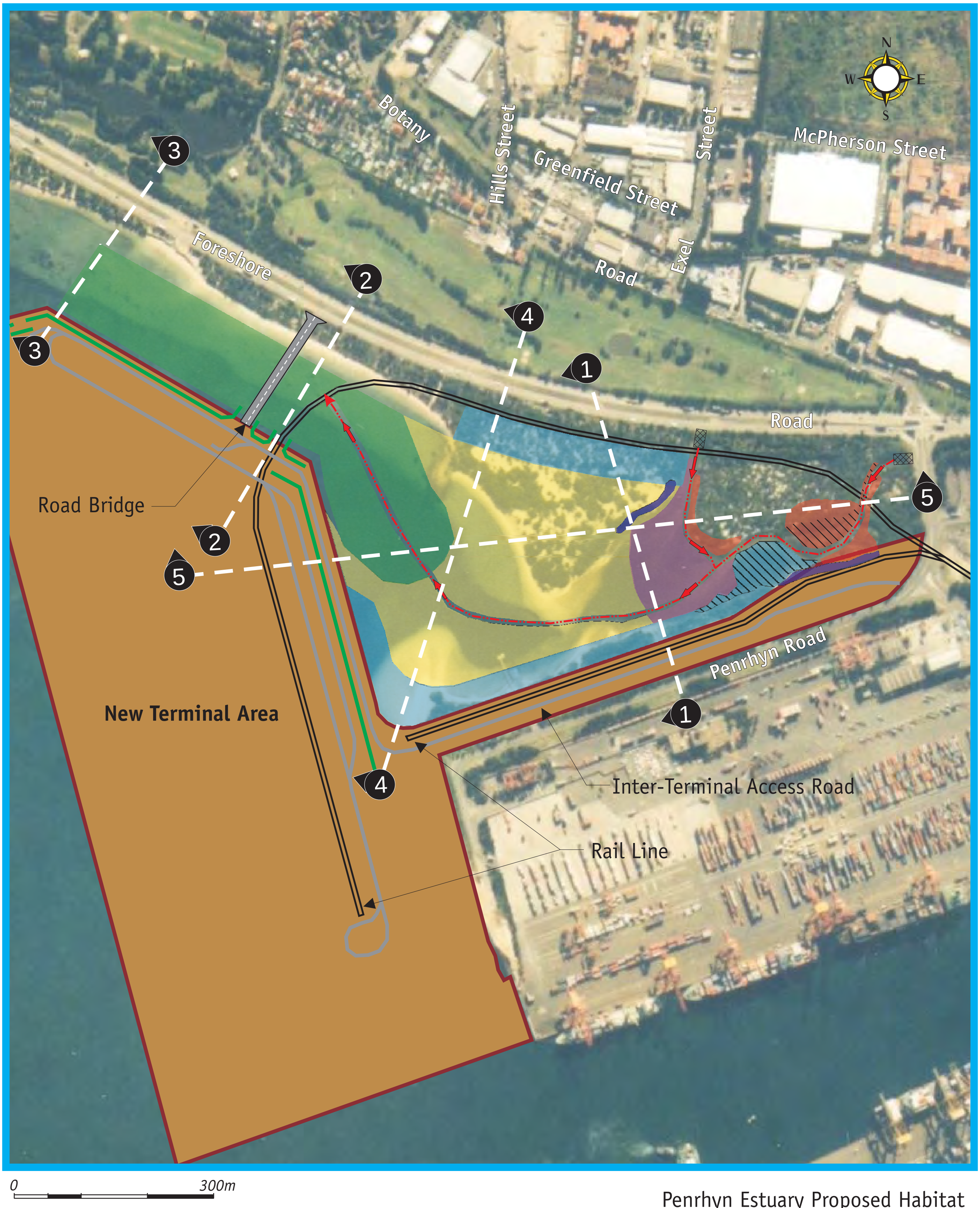
PROPOSED BATHYMETRY OF PORT AREA

Appendix A



N
W
E
S
Pedestrian Overpass
Viewing Platform
Rock Bund Wall
Landscaped Area
Pedestrian/Cycle Path
Beach Enhancement
Public Amenities
Access to Boat Ramp
Car Park
Tug Berth Administration Office/Workshop
Boat Ramp and Jetty
Foreshore
Main Road Access to Terminal
6 New Tug Berths
Beach Enhancement
Traffic Lights
Administration and Operations Centre
Gatehouse
Car Parking Area
Rail Access to Terminal
Road
Equipment Maintenance Workshop
Truck Parking Area
Rail Bridge
Boardwalk and Lookout
Penrhyn Road
3 x Rail Sidings
Noise Barrier
Edge of Navigation Channel
Penrhyn Estuary
2 x Rail Storage Sidings
Paved Container Storage Yard
Truck/Rail Interchange
Road Bridge over Rail Line
Inter-Terminal Access Road
LIMIT OF DREDGING FOR NEW TERMINAL
Container Quay Cranes
Rail Mounted Gantries
Existing Container Terminal (Brotherson Dock North)
Parallel Runway
Brotherson Dock
Botany Bay
0 50 300m

Site Layout



Proposed Intertidal Sand/Mud Flats (area 11.0ha)

Existing Mudflats To Be Retained (area 1.5ha)

Proposed Saltmarsh Habitat (area 5.2ha including 0.6ha of existing mangroves to be removed)

Existing Saltmarsh To Be Transplanted into Proposed Saltmarsh Habitat (area 0.35ha)

Existing Saltmarsh To Be Retained (area 1.0ha)

Existing Mangroves To Be Removed & Replaced With Saltmarsh Habitat

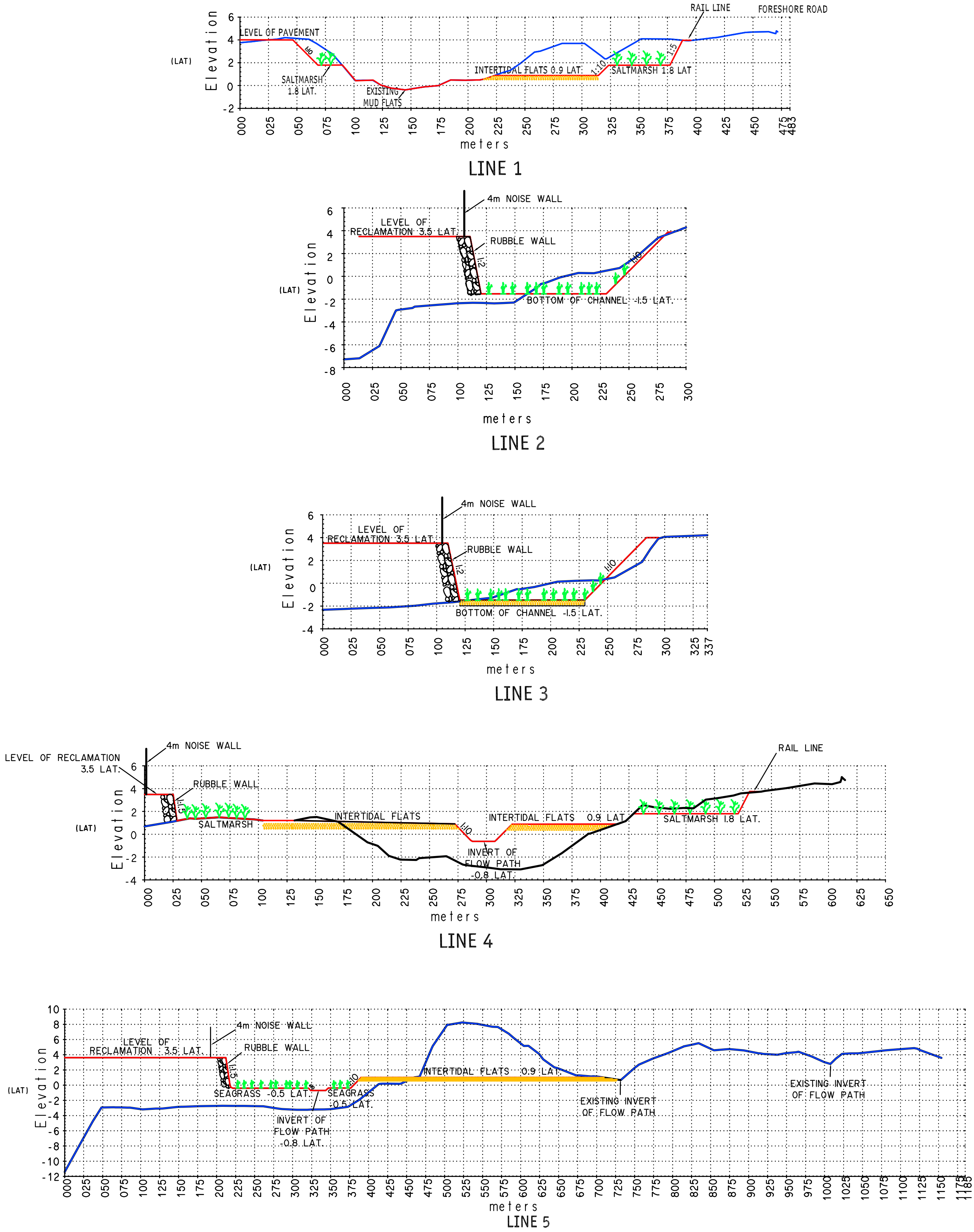
Proposed Seagrass Habitat (area 8.1ha)

Potential Opportunity For Sediment/litter Traps (subject to detailed assessment on drain hydraulics)

Proposed Preferential Flow Channel

Proposed Preferred Noise Wall Location (approx. 4m High)

Penrhyn Estuary Proposed Habitat Enhancement Plan



Vertical Exaggeration = 10x

All areas and measurements are approximations

Natural Surface

Proposed Development

Penrhyn Estuary Proposed Habitat Enhancement Cross Sections

APPENDIX B

GLOSSARY OF TERMS

GLOSSARY*

Advective Transport	The transport of dissolved material by water movement.
Australian Height Datum (AHD)	A common national plane of level corresponding approximately to mean sea level.
Amenity	Those features of an estuary/beach that foster its use for various purposes, eg. Clear water and sandy beaches make beach-side recreation attractive.
ARI	Average Recurrence Interval
Bed Load	That portion of the total sediment load that flowing water moves along the bed by the rolling or saltating of sediment particles.
Calibration	The process by which the results of a computer model are brought to agreement with observed data.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
CD	Chart Datum, common datum for navigation charts - 0.92m below AHD in the Sydney coastal region. Typically Lowest Astronomical Tide.
Discharge	The rate of flow of water measured in terms of volume per unit time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is flowing.
Dispersive Transport	The transport of dissolved matter through the estuary by vertical, lateral and longitudinal mixing associated with velocity shear.
Diurnal	A daily variation, as in day and night.
Ebb Tide	The outgoing tidal movement of water within an estuary.
Eddies	Large, approximately circular, swirling movements of water, often metres or tens of metres across. Eddies are caused by shear between the flow and a boundary or by flow separation from a boundary.
EIS	Environmental Impact Statement
Estuarine Processes	Those processes that affect the physical, chemical and biological behaviour of an estuary, eg. predation, water movement, sediment movement, water quality, etc.

Estuary	An enclosed or semi-enclosed body of water having an open or intermittently open connection to coastal waters and in which water levels vary in a periodic fashion in response to ocean tides.
Flocculate	The coalescence, through physical and chemical processes, of individual suspended particles into larger particles ('flocs').
Flood Tide	The incoming tidal movement of water within an estuary.
Fluvial	Relating to non-tidal flows.
Fluvial Processes	The erosive and transport processes that deliver terrestrial sediment to creeks, rivers, estuaries and coastal waters.
Fluvial Sediments	Land-based sediments carried to estuarine waters by rivers.
Foreshore	The area of shore between low and high tide marks and land adjacent thereto.
Fortnightly Tides	The variation in tide levels caused by the monthly variation of Spring and Neap Tides.
Geomorphology	The study of the origin, characteristics and development of land forms.
H_s (Significant Wave Height)	H_s may be defined as the average of the highest 1/3 of wave heights in a wave record ($H_{1/3}$), or from the zeroth spectral moment (H_{mo}), though there is a difference of about 5 to 8%.
Hydraulic Regime	The variation of estuarine discharges in response to seasonal freshwater inflows and tides.
Intertidal	Pertaining to those areas of land covered by water at high tide, but exposed at low tide, eg. intertidal habitat.
Isohaline	A line connecting those parts of a water mass having the same salinity, ie, a contour of equal salinity levels.
Littoral Zone	An area of the coastline in which sediment movement by wave, current and wind action is prevalent.
Littoral Drift Processes	Wave, current and wind processes that facilitate the transport of water and sediments along a shoreline.
Mangroves	An intertidal plant community dominated by trees.
Marine Sediments	Sediments in sea and estuarine areas that have a marine origin.

Mathematical/ Computer Models	The mathematical representation of the physical processes involved in runoff, stream flow and estuarine/sea flows. These models are often run on computers due to the complexity of the mathematical relationships. In this report, the models referred to are mainly involved with wave and current processes.
MHL	Manly Hydraulics Laboratory
MSL	Mean Sea Level
Neap Tides	Tides with the smallest range in a monthly cycle. Neap tides occur when the sun and moon lie at right angles relative to the earth (the gravitational effects of the moon and sun act in opposition on the ocean).
NSW	New South Wales
NTU	Nephelometric Turbidity Units
Numerical Model	A mathematical representation of a physical, chemical or biological process of interest. Computers are often required to solve the underlying equations.
Phase Lag	Difference in time of the occurrence between high (or low water) and maximum flood (or ebb) velocity at some point in an estuary or sea area.
Salinity	The total mass of dissolved salts per unit mass of water. Seawater has a salinity of about 35g/kg or 35 parts per thousand.
Saltation	The movement of sediment particles along the bed of a water body in a series of 'hops' or 'jumps'. Turbulent fluctuations near the bed lift sediment particles off the bed and into the flow where they are carried a short distance before falling back to the bed.
Sediment Load	The quantity of sediment moved past a particular cross-section in a specified time by estuarine flow.
Semi-diurnal	A twice-daily variation, eg. two high waters per day.
Shear Strength	The capacity of the bed sediments to resist shear stresses caused by flowing water without the movement of bed sediments. The shear strength of the bed depends upon bed material, degree of compaction, armouring,
Shear Stress	The stress exerted on the bed of an estuary by flowing water. The faster the velocity of flow the greater the shear stress.
Shoals	Shallow areas in an estuary created by the deposition and build-up of sediments.

Slack Water	The period of still water before the flood tide begins to ebb (high water slack) or the ebb tide begins to flood (low water slack).
Spring Tides	Tides with the greatest range in a monthly cycle, which occur when the sun, moon and earth are in alignment (the gravitational effects of the moon and sun act in concert on the ocean)
SS	Suspended Solids
Storm Surge	The increase in coastal water levels caused by the barometric and wind set-up effects of storms. Barometric set-up refers to the increase in coastal water levels associated with the lower atmospheric pressures characteristic of storms. Wind set-up refers to the increase in coastal water levels caused by an onshore wind driving water shorewards and piling it up against the coast.
Suspended Sediment Load	That portion of the total sediment load held in suspension by turbulent velocity fluctuations and transported by flowing water.
Tidal Amplification	The increase in the tidal range at upstream locations caused by the tidal resonance of the estuarine water body, or by a narrowing of the estuary channel.
Tidal Exchange	The proportion of the tidal prism that is flushed away and replaced with 'fresh' coastal water each tide cycle.
Tidal Excursion	The distance travelled by a water particle from low water slack to high water slack and vice versa.
Tidal Lag	The delay between the state of the tide at the estuary mouth (eg. high water slack) and the same state of tide at an upstream location.
Tidal Limit	The most upstream location where a tidal rise and fall of water levels is discernible. The location of the tidal limit changes with freshwater inflows and tidal range.
Tidal Planes	A series of water levels that define standard tides, eg. 'Mean High Water Spring' (MHWS) refers to the average high water level of Spring Tides.
Tidal Prism	The total volume of water moving past a fixed point in an estuary during each flood tide or ebb tide.
Tidal Propagation	The movement of the tidal wave into and out of an estuary.
Tidal Range	The difference between successive high water and low water levels. Tidal range is maximum during Spring Tides and minimum during Neap Tides.

Tidally Varying Models	Numerical models that predict estuarine behaviour within a tidal cycle, ie, the temporal resolution is of the order of minutes or hours.
Tides	The regular rise and fall in sea level in response to the gravitational attraction of the Sun, Moon and Earth.
Tributary	Catchment, stream or river which flows into a larger river, lake or water body
Training Walls	Walls constructed at the entrances of estuaries to improve navigability by providing a persistently open entrance.
Turbidity	A measure of the ability of water to absorb light.
T_z (Zero Crossing Period)	The average period of waves in a train of waves observed at a location.
Velocity Shear	The differential movement of neighbouring parcels of water brought about by frictional resistance within the flow, or at a boundary. Velocity shear causes dispersive mixing, the greater the shear (velocity gradient), the greater the mixing.
Wind Shear	The stress exerted on the water's surface by wind blowing over the water. Wind shear causes the water to pile up against downwind shores and generates secondary currents.

* A number of definitions have been derived from the Estuary Management Manual (1992).

APPENDIX C

JOINT OCCURRENCE OF WIND SPEED AND DIRECTION AT MASCOT AIRPORT

Table C1: Joint Occurrence of Wind Speed and Direction at Mascot
Percentage Calms - 17.4

	Wind Speed (m/s)										
Dirn	0.0-2.5	2.5-5.0	5.0-7.5	7.5-10.0	10.0-12.5	12.5-15.0	15.0-17.5	17.5-20.0	20.0-22.5	22.5-25.0	**TOTAL**
N	0.48	1.73	0.98	0.33	0.07	0.01	0.00	0.00	0.00	0.00	3.60
NNE	0.25	1.36	1.39	0.88	0.37	0.08	0.01	0.00	0.00	0.00	4.34
NE	0.34	1.94	2.51	1.72	0.74	0.15	0.01	0.00	0.00	0.00	7.41
ENE	0.22	1.10	1.18	0.48	0.08	0.01	0.00	0.00	0.00	0.00	3.07
E	0.33	1.66	1.32	0.28	0.03	0.01	0.00	0.00	0.00	0.00	3.63
ESE	0.21	1.09	0.82	0.21	0.04	0.01	0.00	0.00	0.00	0.00	2.38
SE	0.31	1.82	1.95	0.79	0.19	0.05	0.02	0.00	0.00	0.00	5.13
SSE	0.19	1.61	2.28	1.31	0.56	0.18	0.05	0.01	0.00	0.00	6.19
S	0.31	1.84	3.13	2.86	1.62	0.67	0.18	0.03	0.01	0.00	10.66
SSW	0.16	0.84	1.05	1.01	0.54	0.23	0.06	0.02	0.00	0.00	3.92
SW	0.37	1.25	0.98	0.55	0.18	0.06	0.02	0.01	0.00	0.00	3.41
WSW	0.29	1.32	1.13	0.64	0.24	0.07	0.02	0.00	0.00	0.00	3.71
W	0.86	3.03	2.00	1.03	0.52	0.20	0.06	0.01	0.00	0.00	7.70
WNW	1.08	2.87	0.98	0.45	0.26	0.12	0.04	0.00	0.00	0.00	5.79
NW	1.78	4.34	1.19	0.44	0.22	0.07	0.02	0.00	0.00	0.00	8.07
NNW	0.59	1.90	0.69	0.26	0.10	0.02	0.01	0.00	0.00	0.00	3.56
TOTAL (%)	7.78	29.71	23.56	13.23	5.77	1.92	0.49	0.08	0.02	0.01	82.58
P of E (%)	82.58	74.79	45.08	21.52	8.29	2.52	0.60	0.11	0.03	0.01	

APPENDIX D

PARAMETRIC OFFSHORE WAVE CLIMATE

PARAMETRIC OFFSHORE WAVE CLIMATE

θ	Tz	P1	H_{10}(m)	H_{50}(m)	H_{90}(m)	σ_y
N (348.75-11.25)						
	3.0	0.000	-	-	-	-
	4.0	0.001	1.45	0.92	0.59	0.35
	5.0	0.003	1.77	1.06	0.63	0.40
	6.0	0.001	1.98	1.34	0.91	0.30
	7.0	0.000	-	-	-	-
	8.0	0.000	-	-	-	-
	9.0	0.000	-	-	-	-
	10.0	0.000	-	-	-	-
	11.0	0.000	-	-	-	-
NNE (11.25-33.75)						
	3.0	0.000	-	-	-	-
	4.0	0.003	1.32	0.99	0.75	0.22
	5.0	0.009	1.73	1.28	0.95	0.23
	6.0	0.007	2.30	1.45	0.91	0.36
	7.0	0.003	2.89	1.72	1.02	0.41
	8.0	0.001	3.26	1.87	1.07	0.43
	9.0	0.000	-	-	-	-
	10.0	0.000	-	-	-	-
	11.0	0.000	-	-	-	-
NE (33.75-56.25)						
	3.0	0.000	-	-	-	-
	4.0	0.020	1.29	0.94	0.69	0.24
	5.0	0.048	1.63	1.17	0.84	0.26
	6.0	0.034	2.05	1.36	0.90	0.32
	7.0	0.010	2.18	1.37	0.86	0.36
	8.0	0.003	2.73	1.56	0.89	0.44
	9.0	0.000	-	-	-	-
	10.0	0.000	-	-	-	-
	11.0	0.000	-	-	-	-
ENE (56.25-78.75)						
	3.0	0.000	-	-	-	-
	4.0	0.008	1.35	0.97	0.70	0.26
	5.0	0.027	1.73	1.19	0.84	0.28
	6.0	0.033	2.14	1.44	0.97	0.31
	7.0	0.012	3.07	1.87	1.14	0.39
	8.0	0.007	3.33	2.20	1.46	0.32
	9.0	0.001	4.20	2.53	1.53	0.39
	10.0	0.001	3.96	2.80	1.98	0.27
	11.0	0.000	-	-	-	-
E (78.75-101.25)						
	3.0	0.000	-	-	-	-
	4.0	0.009	1.23	0.92	0.69	0.23
	5.0	0.034	1.70	1.19	0.84	0.28
	6.0	0.040	2.21	1.43	0.92	0.34
	7.0	0.021	2.85	1.73	1.05	0.39
	8.0	0.005	3.77	2.16	1.24	0.43
	9.0	0.001	4.62	2.73	1.61	0.41
	10.0	0.000	-	-	-	-
	11.0	0.000	-	-	-	-

θ	Tz	P1	H_{10}(m)	H_{50}(m)	H_{90}(m)	σ_y
ESE (101.25-123.75)						
	3.0	0.000	-	-	-	-
	4.0	0.004	1.36	1.00	0.73	0.24
	5.0	0.021	1.84	1.22	0.81	0.32
	6.0	0.022	2.55	1.56	0.95	0.39
	7.0	0.014	3.39	1.99	1.17	0.42
	8.0	0.007	4.27	2.36	1.30	0.46
	9.0	0.001	5.65	2.94	1.53	0.51
	10.0	0.000	-	-	-	-
	11.0	0.000	-	-	-	-
SE (123.75-146.25)						
	3.0	0.000	-	-	-	-
	4.0	0.009	1.36	0.91	0.61	0.31
	5.0	0.039	1.84	1.20	0.78	0.33
	6.0	0.053	2.58	1.61	1.00	0.37
	7.0	0.038	3.08	1.97	1.26	0.35
	8.0	0.014	4.06	2.39	1.41	0.41
	9.0	0.004	4.30	2.48	1.43	0.43
	10.0	0.001	5.01	2.80	1.56	0.46
	11.0	0.000	-	-	-	-
SSE (146.25-168.75)						
	3.0	0.000	-	-	-	-
	4.0	0.008	1.18	0.84	0.60	0.26
	5.0	0.033	1.85	1.25	0.85	0.30
	6.0	0.059	2.58	1.68	1.09	0.34
	7.0	0.046	3.20	1.96	1.20	0.38
	8.0	0.018	4.08	2.61	1.67	0.35
	9.0	0.005	4.81	2.83	1.67	0.41
	10.0	0.001	5.37	3.13	1.83	0.42
	11.0	0.000	-	-	-	-
S (168.75-191.25)						
	3.0	0.000				
	4.0	0.014	1.17	0.86	0.63	0.24
	5.0	0.059	1.77	1.18	0.79	0.31
	6.0	0.083	2.47	1.57	1.00	0.35
	7.0	0.063	3.21	2.07	1.33	0.34
	8.0	0.026	3.80	2.43	1.56	0.28
	9.0	0.007	4.14	2.68	1.73	0.34
	10.0	0.001	5.77	2.70	1.26	0.59
	11.0	0.000	-	-	-	-

θ -is offshore dominant wave direction.
Tz-is average zero upcrossing period.
P1-is the probability that a particular offshore direction-wave period (θ -Tz) Combination occurs
H_{10}, H_{50}, H_{90}- significant wave heights exceed 10% 50% and 90% of the time based on a log normal distribution.
σ_y is standard deviation of y : y=lnH.

Parametric Offshore Wave Climate - Botany Bay

PARAMETRIC OFFSHORE WAVE CLIMATE

θ	Tz	P1	H_{10}(m)	H_{50}(m)	H_{90}(m)	σ_y
N (348.75-11.25)						
	3.0	0.000	-	-	-	-
	4.0	0.000	-	-	-	-
	5.0	0.000	-	-	-	-
	6.0	0.000	-	-	-	-
	7.0	0.000	-	-	-	-
	8.0	0.000	-	-	-	-
	9.0	0.000	-	-	-	-
	10.0	0.000	-	-	-	-
	11.0	0.000	-	-	-	-
NNE (11.25-33.75)						
	3.0	0.000	-	-	-	-
	4.0	0.000	-	-	-	-
	5.0	0.000055	1.90	1.44	1.09	0.22
	6.0	0.000	-	-	-	-
	7.0	0.000	-	-	-	-
	8.0	0.000	-	-	-	-
	9.0	0.000	-	-	-	-
	10.0	0.000	-	-	-	-
	11.0	0.000	-	-	-	-
NE (33.75-56.25)						
	3.0	0.0000	-	-	-	-
	4.0	0.0044	1.30	1.02	0.78	0.20
	5.0	0.0291	1.79	1.42	1.12	0.18
	6.0	0.0130	2.21	1.64	1.19	0.24
	7.0	0.0023	2.60	1.83	1.27	0.28
	8.0	0.0010	3.18	2.21	1.54	0.28
	9.0	0.0002	2.94	2.66	2.50	0.06
	10.0	0.0000	-	-	-	-
	11.0	0.0000	-	-	-	-
ENE (56.25-78.75)						
	3.0	0.0002	1.15	0.86	0.63	0.23
	4.0	0.0036	1.35	1.01	0.74	0.23
	5.0	0.0264	1.67	1.25	0.93	0.23
	6.0	0.0202	2.01	1.46	1.05	0.25
	7.0	0.0105	2.45	1.70	1.17	0.29
	8.0	0.0040	2.81	1.97	1.37	0.28
	9.0	0.0008	2.64	2.04	1.56	0.21
	10.0	0.000	-	-	-	-
	11.0	0.000	-	-	-	-
E (78.75-101.25)						
	3.0	0.0002	0.80	0.59	0.43	0.24
	4.0	0.0039	1.29	0.94	0.68	0.25
	5.0	0.0285	1.52	1.12	0.81	0.26
	6.0	0.0410	1.98	1.45	1.07	0.24
	7.0	0.0290	2.70	1.93	1.37	0.26
	8.0	0.0103	3.59	2.47	1.70	0.29
	9.0	0.0018	4.23	2.89	1.99	0.29
	10.0	0.000	-	-	-	-
	11.0	0.000	-	-	-	-

θ	Tz	P1	H_{10}(m)	H_{50}(m)	H_{90}(m)	σ_y
ESE (101.25-123.75)						
	3.0	0.0000	-	-	-	-
	4.0	0.0044	1.10	0.82	0.61	0.23
	5.0	0.0224	1.43	1.08	0.80	0.23
	6.0	0.0363	2.00	1.40	0.99	0.27
	7.0	0.0287	2.71	1.76	1.14	0.34
	8.0	0.0112	3.21	2.10	1.39	0.33
	9.0	0.0020	4.58	3.14	2.15	0.30
	10.0	0.0000	-	-	-	-
	11.0	0.0000	-	-	-	-
SE (123.75-146.25)						
	3.0	0.0000	-	-	-	-
	4.0	0.0064	1.10	0.80	0.57	0.26
	5.0	0.0331	1.45	1.02	0.70	0.28
	6.0	0.0574	2.02	1.46	1.10	0.24
	7.0	0.0473	2.61	1.77	1.21	0.30
	8.0	0.0174	3.61	2.33	1.50	0.34
	9.0	0.0040	4.52	2.89	1.73	0.37
	10.0	0.0000	-	-	-	-
	11.0	0.0000	-	-	-	-
SSE (146.25-168.75)						
	3.0	0.0000	-	-	-	-
	4.0	0.0097	1.10	0.79	0.57	0.26
	5.0	0.0578	1.48	1.05	0.73	0.28
	6.0	0.1051	2.08	1.41	0.96	0.30
	7.0	0.0893	2.69	1.84	1.26	0.30
	8.0	0.0377	3.75	2.67	1.89	0.27
	9.0	0.0112	4.62	3.19	2.20	0.29
	10.0	0.0018	5.95	3.90	2.58	0.33
	11.0	0.0000	-	-	-	-
S (168.75-191.25)						
	3.0	0.0000	-	-	-	-
	4.0	0.0049	1.15	0.90	0.69	0.20
	5.0	0.0334	1.76	1.40	1.10	0.18
	6.0	0.0655	2.36	1.77	1.34	0.22
	7.0	0.0545	3.11	2.34	1.75	0.22
	8.0	0.0190	3.91	2.78	1.95	0.27
	9.0	0.0045	4.90	3.22	2.08	0.33
	10.0	0.0000	-	-	-	-
	11.0	0.0000	-	-	-	-

θ -is offshore dominant wave direction.
Tz-is average zero upcrossing period.
P1-is the probability that a particular offshore direction-wave period (θ -Tz) Combination occurs
H_{10}, H_{50}, H_{90}- significant wave heights exceed 10% 50% and 90% of the time based on a log normal distribution.
σ_y is standard deviation of y : y=lnH.

Parametric Offshore Wave Climate - Long Reef

APPENDIX E

EXISTING AND POST PORT-EXPANSION SWELL WAVE PARAMETERS AT SHORELINE LOCATIONS

Table E1: Comparison of Nearshore Wave Parameters
For Pre- and Post-Proposed Container Port Expansion

Location	Wave Conditions			
	Swell - Existing		Swell - Developed	
	H_e(m)	ϕ_m(°TN)	H_e(m)	ϕ_m(°TN)
1	0.31	22.9	0.31	22.9
2	0.24	32.8	0.24	32.8
3	0.19	46.1	0.19	46.1
4	0.17	57.3	0.17	57.3
5	0.17	57.8	0.17	57.8
6	0.22	61.5	0.22	61.5
7	0.19	64.6	0.19	64.6
8	0.22	64.6	0.22	64.6
9	0.25	62.9	0.25	62.9
10	0.24	59.7	0.24	59.7
11	0.21	64.4	0.21	64.4
12	0.20	69.5	0.20	69.5
13	0.19	68.3	0.19	68.4
14	0.24	74.7	0.24	74.7
15	0.24	72.7	0.24	72.8
16	0.23	75.5	0.23	75.6
17	0.23	77.7	0.23	77.8
18	0.27	75.8	0.27	75.9
19	0.31	71.5	0.31	71.6
20	0.30	63.3	0.30	63.4
21	0.26	60.3	0.26	60.3
22	0.19	50.7	0.19	50.7
23	0.16	44.4	0.16	44.4
24	0.25	40.6	0.25	40.6
25	0.19	45.5	0.19	45.5
26	0.15	47.4	0.15	47.4
27	0.13	51.5	0.13	51.5
28	0.11	48.6	0.11	48.6
29	0.07	96.9	0.07	96.9
30	0.09	92.3	0.09	92.3
31	0.10	95.9	0.10	95.9
32	0.13	102.0	0.13	102.0
33	0.20	84.7	0.20	84.7
34	0.22	76.9	0.22	76.9
35	0.25	81.6	0.25	81.6
36	0.19	67.6	0.19	67.6
37	0.13	77.6	0.13	77.6
38	0.12	84.4	0.12	84.4
39	0.11	91.8	0.11	91.8

Location	Wave Conditions			
	Swell – Existing		Swell – Developed	
	H_e(m)	ϕ_m(°TN)	H_e(m)	ϕ_m(°TN)
40	0.19	100.4	0.19	100.4
41	0.19	110.9	0.19	110.9
42	0.24	99.5	0.24	99.4
43	0.25	97.8	0.25	97.8
44	0.24	110.4	0.24	110.4
45	0.29	120.2	0.29	120.2
46	0.20	115.9	0.20	115.9
47	0.20	110.5	0.20	110.5
48	0.24	108.8	0.24	108.8
49	0.26	118.5	0.26	118.5
50	0.16	124.1	0.16	124.1
51	0.06	131.8	0.06	131.8
52	0.05	144.3	0.05	144.3

APPENDIX F

MEAN WAVE PARAMETER ESTIMATION

The quantity of littoral drift along a shoreline is proportional to T x H_e^2 x sin 2β

where T is wave period
H_e is effective wave-height
β is the angle between the shoreline and breaking wave crests

H_e is a significant or root-mean-square wave-height which must incorporate the description of long term wave occurrence near the shoreline. First, nearshore wave heights were computed using the longterm offshore Botany Bay wave climate and computed wave coefficients, (combined K_r, K_s and K_f). At each nearshore location the log-normal probability of exceedence distribution describing wave climate was prepared for swell waves. H_e was then calculated from:-

$$H_e^2 = \int H^2 \, p(H) \, dH$$

where p(H) is the log normal distribution

with the result that

$$H_e = H_{50} \, e^{\sigma y2}$$

where H_{50} is the median wave-height defined by the log normal distribution = $(H_{10} \times H_{90})^{1/2}$
y = ln(H)
σ_y = standard deviation of y = 1/2.563 ln (H_{10}/H_{90})

Weighting factors E_{ij} for coastal process analyses are defined by the wave energy input

$$E_{ij} = P_{ij} \times H_{eij} \times T_j$$

where P_{ij} is probability of the occurrence of waves in direction band i period band j

A similar procedure was applied to local sea analyses. In that case P_{ij} relates to wind speed and direction occurrence.

Weighted mean wave direction, ϕ_m, is estimated from:-

$$\phi_m = \sum P_{ij} \times H_{ij}^2 \, T_j \, \phi_i \, / \sum P_{ij} \times H_{ij}^2 \, T_j$$

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