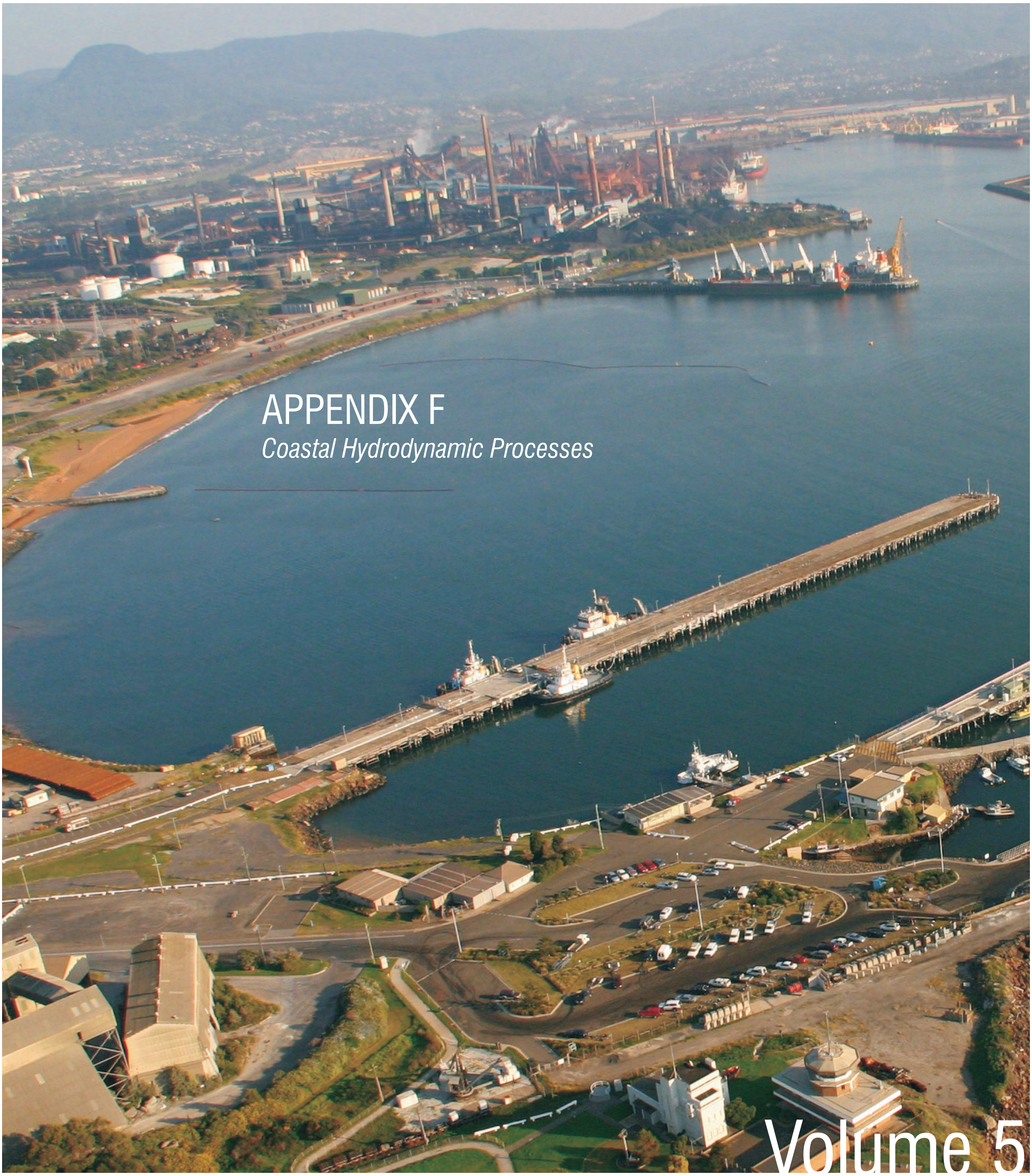
APPENDIX F
Coastal Hydrodynamic Processes
Volume 5

Port Kembla Port Corporation

5 January 2010

Port Kembla Outer Harbour Development Environmental Assessment

Coastal Hydrodynamics

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Coastal Hydrodynamics

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Executive Summary

AECOM (formerly Maunsell │ AECOM) has been engaged by Port Kembla Port Corporation (PKPC) to assist with the development of a Master Plan for the Port Kembla Outer Harbour. The Master Plan (Maunsell │ AECOM 2008b) outlined a staged development of the port over the next 25 to 30 years. This work has included extensive investigation and hydraulic modelling of the relevant hydrodynamic processes including water level fluctuations, wave transformation and tidal discharge and the impacts of these on the development and *vice versa*.

The existing Outer Harbour experiences long wave resonance (seiching), which puts a significant constraint on shipping operations. The resonance characteristics of the harbour can be de-tuned through reclamation and the Master Plan reclamation has been designed with this as one important objective. The seiching within the Outer Harbour would be sensitive to the staged development. Maunsell │ AECOM (2009a) outlined the extent of seiching activity within the Outer Harbour for each of the staged development milestones. This report, undertaken in conjunction with Cardno Lawson Treloar and OMC International, summarises the key findings of these studies.

The long wave modelling has demonstrated that the Outer Harbour can be designed and developed progressively as a functional port. Moored ship modelling under seiching conditions for tugs, cargo and container ships at their respective berths has confirmed that the proposed development would be suited for these types of proposed shipping operations. The predicted ship movements were found, generally, to be well within guideline standards for the 1% design event (100 year storm).

The proposed Outer Harbour reclamation would not affect significantly the long wave processes or the tidal discharge of the Inner Harbour, nor would it have any significant impact on tidal velocities within the harbour. However, the reclamation would change the tidal hydraulics of Salty Creek by reducing salinity and water level fluctuations within the estuary. It may also impact on the passage of fish from the estuary to the ocean and *vice versa*.

The proposed reclamation levels have been set to be sustainable for predicted extreme sea level rises for 100 years, with a freeboard suitable to cater for further sea level rise beyond that time.

1.0 Introduction

AECOM (formerly Maunsell │ AECOM) has been engaged by Port Kembla Port Corporation (PKPC) to assist with the development of a Master Plan for the Port Kembla Outer Harbour (Figure 1). This work has included extensive investigation and hydraulic modelling of relevant hydrodynamic processes including water level fluctuations, wave transformation and tidal discharge.

Navigation and mooring conditions within the Outer Harbour must be safe. Major movements of moored vessels at berth that would have adverse effects on operations must be prohibited. Particularly dangerous conditions can develop with vessel ranging, a phenomenon known to be prevalent within the Outer Harbour under the action of infragravity (long) waves and harbour seiching. The problem is severe particularly for LNG and LPG facilities where uncontrolled movements can result in explosions. Efficient loading/unloading operations for containers cannot tolerate large vessel movements. Dealing with this issue was a primary objective of the hydrodynamic studies because, without adequate management of the long wave processes, the Outer Harbour cannot be developed to be operated efficiently and safely.

This report documents the coastal hydrodynamics relevant to the Port Kembla Outer Harbour Master Plan development. These include the impact on the development of long waves and harbour seiching, ocean swell waves, tides and sea level rise, and the impact of the development on harbour seiching and tidal flushing of the harbour.

The reclamation footprint of the Concept Plan is almost the same as that of the Major Project Application. The difference is that the latter:

- omits dredging and reclamation along a relatively narrow strip adjacent to the Gateway Jetty, as the Jetty will be in use for some time yet; and
- some additional relatively minor dredging in the main navigation channel of the Outer Harbour to enlarge the ship turning circle.

Therefore, there will be very little, if any, difference between the impacts of each Application on tidal currents, wave processes and water levels and *vice versa*. For this reason, the hydrological analysis for the Concept Plan and for the Major Project Application is the same.

However, as the development of the Outer Harbour would be undertaken in stages, each stage of the reclamation has been modelled to ensure that there would be no adverse impacts from infragravity wave processes, which is the major hydrological issue that needed to be considered for this proposal. Accordingly, the structure of this Appendix may differ from that of companion appendices to this Environmental Assessment in that the impacts of the Concept Plan and Major Project Application, being identical, are not reiterated.

This study has been undertaken in conjunction with Cardno Lawson Treloar and OMC International.

2.0 Port Kembla Outer Harbour Development

The Port Kembla Outer Harbour Master Plan (Maunsell │ AECOM 2008b) outlines a staged port development based on projected trade growth to 2037. The plan accommodates container ships in the range 3,000 to 5,000 TEU's with vessel lengths in the range 230 m to 300 m and bulk carriers of Panamax size around 70,000 DWT and length of approximately 230 m. A new tug harbour is to be constructed also to accommodate four tugs and two pilot vessels but these works are not part of the current application.

As the Outer Harbour is planned as a staged development, long wave modelling was undertaken for a number of stages of the proposed development as summarised in Table 1 and Figure 2 and 3.

Table 1 Outer Harbour Staged Modelling Scenarios

Stage	Description
Tug Harbour	Tug Harbour with Existing Layout
1	Tug Harbour with Stage 1 Layout
2	Tug Harbour with Stage 2 Layout
3	Tug Harbour with Stage 3 Layout

The reclamation generally comprises fill with vertical quay walls, with the exception of the northern extent of the container terminal, as shown in the yellow outlined portion on Figure 2. This section would be constructed as a deck on piles, which was developed during modelling to mitigate excessive long wave seiching in this part of the harbour. The fill underneath this deck would be a sloping armoured revetment. As the yellow outlined portion of the container berth has no footprint in the water, being a deck on piles, it is not schematised for hydrodynamic modelling.

The proposed berths are designed for a depth along-side of -15 m PKHD. *In-situ* bed levels along the edge of the proposed Stage 1 berth vary from between -4 m PKHD and -10 m PKHD. From available survey data the bed rock varies from -15 m to -11 m PKHD. Available geophysical survey data has indicated that bed rock is present at levels of less than -15 m PKHD in some locations. Dredging of soft bed material would be required together with some excavation of rock. The staged dredging is shown in Figure 2 and coincides with the staged development of berths. The dredged materials would be included in the reclamation.

Excessive vessel ranging at the existing tug berths in the Outer Harbour during seiching events restricts berth availability and functionality. While not a part of this approval process, a new Tug Harbour is to be developed to berth the tug and pilot vessels that will service the proposed port development. The new Tug Harbour will be constructed as a composite rubble-mound and caisson breakwater and fitted with a system of floating pontoons as berthing modules. The location of the existing tug berths are shown in Figure 1. The location of the proposed Tug Harbour is shown in Figure 2 and the general layout and reference design is shown in Figure 4.

3.0 Infragravity (Long) Waves

3.1 Introduction

Port Kembla Outer Harbour has been known to experience seiching (long wave resonance within the harbour) during periods of heavy seas. This process has limited operations within the harbour and has lead to dangerous ship movements at berth.

Seiching within the Outer Harbour can be managed by judicious engineering planning, assisted by numerical modelling studies. Maunsell │ AECOM (2008a) presented a review of historical studies of vessel ranging and sway due to harbour seiching and, in conjunction with Cardno Lawson Treloar (CLT), undertook additional studies comprising original field data capture, analysis and numerical modelling of infragravity waves (long waves) to better understand and quantify the magnitude and frequency of seiching within the Outer Harbour, with the objective to design a reclamation that would alter the resonance frequencies of the harbour basin in such a way as to ameliorate the seiching processes.

For the harbour configuration investigations, long wave spectra were derived from available field data. Analysis of all available data at the wave/current instrument location outside of and north of the Outer Harbour showed that the majority of those long wave spectra, especially under higher incident swell waves, were bi-modal in form. Peak periods ranged from between 140 s to 240 s and 50 s to 140 s and *significant* long wave heights (H_s) up to 0.35 m were observed over the entire energy band of the spectra.

Based on the measured field data, two bimodal, long-wave frequency spectra, combining two single peaked JONSWAP spectral shapes with peakedness parameters of 4, were adopted for the modelling, one with peaks at 0.005 Hz (200 s) and 0.017 Hz (60 s) with a significant long wave height of 0.34 m, (Spectrum 1, Figure 5), the other with peaks at 0.007 Hz (150 s) and 0.0125 Hz (80 s) (Spectrum 2). The lower frequency peaks at around 0.007 – 0.005 Hz (150 s – 200 s) contained the larger part of the energy. The field data indicate that the long wave heights have a 5% chance of being exceeded for around 1 day per year (Figure 6)

Surge and sway currents have the most significant bearing on the suitability of berths in the Outer Harbour. As such, statistical velocity data were derived from the modelling and spectral analysis of these data was undertaken for both of these axes of motion. The sea surface displacement component of the seiching has only a minor impact on the operational and mooring aspects of the vessels berthed in the Outer Harbour as the amplitudes of the oscillations were relatively small. Frequencies less than 0.002 Hz (>500 s) also were excluded from the analysis as these much lower frequencies do not present dangers or difficulties for loading/unloading and they do not coincide with the natural frequencies of oscillation of the moored ships.

Seiching within the Outer Harbour has been assessed for all stages of the development (Maunsell │ AECOM 2009a). However, only the results relating to the existing conditions and the final layout are presented in this report.

It is noted that the following discussion on vessel surge and sway is based on the modelled water particle excursions. This interpretation has been undertaken to identify what berths, if any, may be problematic. It is likely that any vessel excursion under these currents would be smaller than free body movements due to the influence of the vessel mass and mooring lines unless dangerous ranging develops, which can occur if the long wave frequency coincides with the natural frequency of oscillation of the ship on her mooring lines (analogous to a mass suspended on a spring). A detailed assessment of moored vessel movement, including the potential for dangerous ranging, is presented in **Appendix B** of this report for selected locations and vessels and those results are included in the interpretation.

3.2 Existing Conditions at Port Kembla Outer Harbour

Plan distributions for existing long wave height coefficients and current magnitudes of seiching activity within the Outer Harbour are shown in Figure 7and Figure 8. Inner Harbour results are shown in Figure 9 and Figure 10. The Outer Harbour results indicated an amplification of long wave heights around the western and southern shorelines as well as the southern section of the eastern breakwater. The plot for currents is influenced by the water depths in the Outer Harbour with higher current speeds observed in the shallower depths.

The Inner Harbour showed very little response to the long wave energy with only minor wave height amplification at the northern extent of the berthing areas where wave reflection occurs. Current speeds associated with long wave motion were not significant except in these same areas.

3.3 Tug Harbour

Baseline data were extracted from the Outer Harbour long wave numerical model at the location of the existing tug berths (Figure 1) and compared with the model results for the proposed Tug Harbour after the final stage of development in Figure 11 to Figure 14. Contour plots of long wave height coefficients and current magnitudes for Spectrum 1 and Spectrum 2 indicated increases in wave height and currents speeds within the proposed Tug Harbour (Table 2).

Table 2 Compared modelled long wave parameters at existing and proposed Tug Berths

Case	Spectrum	H_{rms} (m)	v_{rms} (m/s)
Existing Tug Berth	1	0.128	0.064
After Development (Location 'Tug 4')	1	0.214	0.063
After Development (Location 'Tug 4')	2	0.266	0.088

Current speed spectral analysis results for surge (Figure 15) showed that at the existing tug berths long wave activity is concentrated at frequencies of 0.006 and 0.016Hz (166 s and 63 s), as per the input spectrum. It is known that here the tugs experience dangerous ranging, suggesting that the natural period of oscillation of the tugs at their moorings may coincide with these long wave harmonics, probably at the lower period of around 60 s. For the proposed Tug Harbour, long wave activity is generally negligible at these frequencies with only a small amount of energy present at 0.03Hz (33 s) for Spectrum 1.

Spectral sway results are presented in Figure 16 and showed long waves occurring at a frequency of 0.014 Hz (71 s) for the existing tug berths. For the proposed Tug Harbour there was no significant energy along the sway axis at this frequency for both Spectrum 1 and Spectrum 2. There was some energy at a period of around 400 s for Spectrum 2, but the amount of energy is far less than that experienced at the existing berths and it is considered that this longer period sway would not have an adverse effect on the tug vessels as it would not coincide with their natural period of oscillation.

The mooring analysis for the tugs in the harbour showed that surge and sway for the tugs would be negligible (<0.05 m – see Appendix B) whereas heave could approach 1 m. However, this sea surface displacement component of seiching would not have any adverse impact on the operations or mooring of the tug vessels at berth as the vessels would be moored on pontoons.

The reduced surge and sway energy modelled indicated that there would be less long wave activity at the proposed Tug Harbour than that currently experienced at the existing tug berths and the resulting surge and sway would be minor. The frequency at which the long wave energy would peak in the proposed tug harbour would be quite different from that occurring at the existing tug berths and it is considered that it would not engender dangerous ranging.

3.4 Outer Harbour Development

Figure 17 and Figure 18 present the plan distribution of long wave height coefficients and current magnitudes for Spectrum 1 and Figures Figure 21 and Figure 22 present the results for Spectrum 2.

The long wave height coefficients indicated, generally, no amplification and, hence, no seiching of the Outer Harbour. There was a hint of an amplification factor of around 1.0 at the end of the outer container berth, within the proposed Tug harbour and at the root of Port Kembla Gateway Jetty for both Spectrum 1 and Spectrum 2 and currents of up to 0.10 m/s were indicated at distinct locations along the bulk and container berths, Port Kembla Gateway Jetty and at shallow locations along the northern breakwater.

3.4.1 Port Kembla Gateway Jetty

The locations of berths 202 and 204 at Port Kembla Gateway Jetty remain unchanged throughout the re-development of the Outer Harbour. Baseline data was extracted from the Outer Harbour long wave model and compared with the numerical model results after completion of the proposed development to determine the impact that the development would have at this location.

Modelled long wave parameters both prior to and after development of the Outer Harbour at Port Kembla Gateway Jetty are presented in Table 3. These showed slight reductions in long wave heights and current speeds at the Jetty.

Table 3 Modelled long wave parameters at Port Kembla Gateway Jetty prior to, and after development

Case	Spectrum	H_{rms} (m)	V_{rms} (m/s)
Existing Gateway Jetty ('Loc 1')	1	0.164	0.062
After Development Gateway Jetty ('Loc 1')	1	0.092	0.055
After Development Gateway Jetty ('Loc 2')	2	0.116	0.050

Current speed spectral analysis results for surge (Figure 21) indicated energy peaks at 0.015 Hz (66 s) and 0.017 Hz (58 s) for the existing conditions. The development of the Outer Harbour caused an increase of energy at a frequency of 0.017 Hz (58 s) with elimination of virtually all of the energy at 0.015 Hz (67 s) for Spectrum 1. For Spectrum 2, the same amount of energy remained a frequency of 0.017 Hz (58 s), energy at 0.015Hz (66 s) was reduced significantly but there was a small increase in energy at 0.011 Hz (90 s).

Spectral analysis results for sway showed very little long wave activity for any of the scenarios modelled (Figure 22). What little energy there is at present along the sway axis is ameliorated by the construction of the new Tug Harbour.

Long wave parameters after completion of the Outer Harbour development are all within the range of the conditions experienced currently at Port Kembla Gateway Jetty. As the post development results for Spectrum 1 and 2 showed, the berths at Port Kembla Gateway Jetty are prone to seiching when incident long waves occur. Only sway is considerably reduced due to the construction of the proposed Tug Harbour.

3.4.2 Bulk Handling Berths

Two new bulk handling berths are proposed to be constructed as part of the Outer Harbour development. The first berth to be constructed and also the berth with the most significant long wave activity, as seen in the plan distribution Outer Harbour current magnitude contour plots (Figure 18 and Figure 20), is at 'Location 3'.

Modelled long wave parameters at 'Location 3' for both Spectrum 1 and Spectrum 2 are presented in **Table 4**

Table 4 Bulk berth long wave parameters (Location 3)

Case	Spectrum	H_{rms} (m)	V_{rms} (m/s)
After Development Bulk ('Loc 3')	1	0.102	0.070
After Development Bulk ('Loc 3')	2	0.087	0.079

Current speed spectral analysis results for both surge and sway are presented in Figure 23 and Figure 24 respectively. Along both axes the amount of long wave energy is minimal at this location.

All parameters analysed are negligible and, when compared to each other, show little variability.

The mooring analysis at the bulk handling berths (**Appendix B**) showed surge to be less than 0.1 m, sway less than 0.5 m and heave less than 0.5 m. These were all well within the motion criteria for safe working conditions for general cargo vessels recommended in the Permanent International Association Navigation Congress Report (PIANC) (1995), which are 2.0 m, 1.5 m and 1.0 m (respectively).

3.4.3 Container Berths

Four new container berths are proposed to be constructed at Port Kembla as part of the Outer Harbour development. For the purpose of analysing the affects of long waves on the container berths 'Location 6' was used as this location encountered the most long wave activity as shown in the plan distribution long wave height coefficients and current magnitude contour plots (Figure 18 and Figure 20). Modelled long wave parameters at 'Location 6' for both Spectrum 1 and 2 are presented in Table 5

Table 5 Container berth long wave parameters (Location 6)

Case	Spectrum	H_{rms} (m)	V_{rms} (m/s)
After Development Container ('Loc 6')	1	0.148	0.053
After Development Container ('Loc 6')	2	0.131	0.060

Statistical velocity data derived from the modelled spectral analysis for surge showed distinct peaks in energy at 0.006Hz (167s) and 0.017Hz (59s) for both Spectrum 1 and Spectrum 2 consistent with the input spectrum (Figure 21). Spectral analysis results for sway show very little long energy for both spectra (Figure 22).

The mooring analysis (Appendix B) indicated a surge of 0.2 m, sway of 1.0 m, heave of 0.3 m, roll of 0.1°, pitch of 0.15° and yaw of 0.35°. For 100% efficiency, PIANC (1995) recommends a surge of 1.0 m, sway of 0.6 m, heave of 0.8 m, roll of 1.0°, pitch of 1.0° and yaw of 3.0° and, for 50% efficiency, PIANC (1995) recommends a surge of 1.0 m, sway of 1.2 m, heave of 1.2 m, roll of 1.5°, pitch of 2.0° and yaw of 6.0°. The results indicated, therefore, that for this "worst berth" location, the computed vessel movements generally were well within PIANC guidelines, except for sway which was close to 100% efficiency. All other container berths had better results.

3.5 Inner Harbour

The effects of the Outer Harbour development on the Inner Harbour are shown in Figure 3.23 and 3.24. Spectrum 1 results showed a slight amplification of long wave coefficients between Berths 106 and 111 (Figure 27) when compared with the existing conditions (Figure 9). Associated with this amplification is RMS current speeds increasing from 0.04 m/s to 0.06 m/s between Berths 106 and 111 (Figure 28). Wave reflection at the northern extent of the Inner Harbour and associated currents also are amplified slightly when compared with existing conditions. The Spectrum 2 results, generally, showed reduced long wave height coefficients (Figure 29) and RMS current speeds (Figure 30) when compared with existing conditions.

3.5.1 Berth 102

Modelled water levels at Berth 102 show little variability between the existing conditions and the estimated conditions after completion of the Outer Harbour development (Table 6).

Table 6 Modelled long wave parameter at Berth 102 in the Inner Harbour

Case	Spectrum	H_{rms} (m)	V_{rms} (m/s)
Existing Berth 102	1	0.134	0.028
Final Development Berth 102	1	0.137	0.026
Final Development Berth 102	2	0.112	0.022

Spectral analysis results for surge at Berth 102 showed a peak in energy at 0.006Hz (167s) (Figure 31). The amount of energy at this frequency was reduced after completion of the Outer Harbour development in both the Spectrum 1 and Spectrum 2 results.

Spectral analysis results for sway show a peak in energy at 0.017Hz (59s) (Figure 32). Energy at this frequency is similar for the existing conditions and the post Outer Harbour development Spectrum 1 results. The Spectrum 2 results show a reduced amount of energy at this frequency compared to the existing conditions.

All long wave parameters after completion of the Outer Harbour are within the range of the results for the existing conditions and berthing conditions are likely to be unchanged at Berth 102.

3.5.2 Berth 109

Modelled water levels and current speeds at Berth 109 were similar for all cases investigated (Table 7).

Table 7 Modelled long wave parameter at Berth 109 in the Inner Harbour

Case	Spectrum	H_{rms} (m)	v_{rms} (m/s)
Existing Berth 109	1	0.142	0.031
Final Development Berth 109	1	0.168	0.035
Final Development Berth 109	2	0.120	0.036

Statistical velocity data derived from the modelled spectral analysis for surge showed a distinct peak in energy at 0.017Hz (59s) for the existing conditions (Figure 33). The Spectrum 1 results showed very little long wave energy after development of the Outer Harbour. The Spectrum 2 results however, showed a peak in energy at 0.011Hz (90s) of the same magnitude as the results for the existing condition. Spectral analysis results for sway showed no significant energy for all cases (Figure 34).

All long wave parameters after completion of the Outer Harbour are within the range of the results for the existing conditions and berthing conditions are likely to be unchanged at Berth 109.

3.5.3 Berth 112

Modelled water levels at Berth 112 were of a similar magnitude but slightly lower for the cases investigated but current speed results were slightly higher for Spectrum1 after development of the Outer Harbour (Table 8).

Table 8 Modelled long wave parameters at Berth 112 in the Inner Harbour

Case	Spectrum	H_{rms} (m)	v_{rms} (m/s)
Existing Berth 112	1	0.151	0.033
Final Development Berth 112	1	0.132	0.046
Final Development Berth 112	2	0.124	0.035

Spectral analysis results for surge show a peak in long wave energy at 0.016Hz (63s) for all cases (Figure 35). The amount of energy at this frequency was larger for Spectrum 1 results after development of the Outer Harbour when compared to the existing conditions, but smaller for Spectrum 2. Spectral analysis results for sway showed no significant energy for all cases (Figure 36).

With the exception of surge velocity for Spectrum 1, all long wave parameter results at Berth 112 after completion of the Outer Harbour are within the range of the results for the existing conditions and it is considered that the proposed Outer harbour development would not change the berthing conditions at this berth.

3.6 Summary

Numerical modelling of infragravity waves using measured wave spectra has indicated that the proposed Outer Harbour reclamation would ameliorate long wave activity within the Port Kembla Harbour and conditions at all berths would be satisfactory for port operations.

4.0 Gravity (Ocean Swell) Waves

4.1 Offshore Wave Climate

Offshore wave height duration statistics at Port Kembla are shown in Figure 37 based on data from the Manly Hydraulics Laboratory. The data are presented in this way to represent statistics for storm duration, as storm wave conditions must persist for at least 6 hours for harbour resonance to develop.

4.2 Swell Wave Penetration

A numerical swell wave penetration model was developed to determine the wave climate incident on the Outer Harbour development during severe storms. An extensive review of previous swell wave penetration studies undertaken at Port Kembla was carried out with the physical and numerical models of Fitzpatrick, W.A. & B.E. Sinclair (1954), Foster, D.N. (1957) and MSB (1993) used for calibration and verification of the numerical model (Maunsell │ AECOM, 2008). This model was updated to reflect the proposed staged development of the Outer Harbour and the proposed tug harbour. Details of the modelling are documented in (Maunsell │ AECOM, 2008).

The model results for the existing conditions within the Outer Harbour indicated that around 10% of the offshore significant wave height reaches the southern shore (Figure 38). In the harbour itself, between 30% and 40% of the offshore significant wave energy is present.

The final layout of the Outer Harbour including the proposed tug harbour was modelled in the calibrated BOUSS-2D model. The results (Figure 39) show very little penetration into the Outer Harbour once fully developed and it can be expected that around 10% of wave energy will reach the outer perimeter of the proposed Tug Harbour, the multi-purpose terminal and the northern embankment of the container terminal.

4.3 Discussion

The wave transformation model setup previously represented accurately the transformation of swell waves from deep water to within the Outer Harbour at Port Kembla. The results showed that once completed, less than 10% of the incident wave energy would impact upon the proposed berths.

During detailed design of the proposed rubble mound structure beneath the northern extent of the container terminal, the affects of excess pressure beneath the deck exerted from wave uprush would need to be considered if overtopping conditions cannot be avoided.

It is noted that the foreshores north and south of the Gateway Jetty, except for the area of the existing Red Beach, are protected by a rubble revetment as are those of the southern foreshore of the Outer Harbour. In all stages of harbour development, the wave energy reaching the remaining undeveloped foreshores would be reduced from that existing at present and there would be no increase in the potential for bank erosion.

5.0 Tidal Hydraulics

5.1 Introduction

The Outer Harbour development has the potential to change the tidal hydraulics of Port Kembla. The possible impacts of this include:

- Changes to the tidal prism
- Changes to tidal velocities
- Changes to tidal flushing

Cardno Lawson Treloar (CLT) was engaged to assess the effects of the proposed development on tidal flushing between the Inner Harbour and Outer Harbour and details of the modelling are in Appendix A.

5.2 Inner/Outer Harbour Tidal Prism

The tidal prism is the total volume of water that flows into and out of the harbour during the tides. This is measured most accurately by measuring the tidal stage variation over the tidal cycle.

Modelling of the tidal discharge of the harbour was undertaken by CLT (Appendix A). The modelling showed that for the Outer Harbour (Figure 40) there was no discernible difference in the tidal levels, the average difference in the tidal elevation from before and after harbour development was calculated to be –0.01 mm and at any one time the maximum calculated water level difference was ±4 mm. For the Inner Harbour (Figure 41) there was also no discernible difference in the tidal levels, the average difference in the tidal elevation from before and after harbour development was calculated to be 0.01 mm and at any one time the maximum calculated water level difference was ±7 mm.

These differences are insignificant and are most likely to be simply a factor of the resolution of the numerical modelling program.

5.3 Inner/Outer Harbour Tidal Flushing

To assess the relative tidal flushing performance of the proposed Outer Harbour development on the Inner Harbour, an inert tracer was added to the hydrodynamic model set up by CLT. No catchment inflows were included in the model. However, inflows, such as Allans Creek would improve flushing times. By excluding these inflows from the model the 'worst case' scenario flushing conditions were modelled.

The inert tracer added, having no density, simulated a dissolved contaminant. Initially, both the Inner Harbour and Outer Harbour were filled with this conservative tracer at a uniform concentration while the initial tracer concentration outside of Port Kembla Harbour in the ocean was set at zero. Simulations were run for both the existing and proposed layouts for a two week period incorporating both neap and spring tides.

The modelling results are presented as the time taken for the tracer to reach 37% of its initial concentration, known as the e-folding time. Figure 42 shows the modelled existing tidal flushing characteristics and Figure 43 the tidal flushing after the development of the Outer Harbour.

E-folding times differ greatly between the Inner and Outer Harbours in both cases. In the Outer Harbour e-folding times of between 5 and 20 days have been estimated for both the existing and developed layouts. These times increase significantly through the "cut" to an e-folding time of around 100 days just north of this region. Maximum e-folding times in the Inner Harbour occur in the upper reaches, with e-folding times up to 400 days estimated.

It should be noted that the significant depths in the Inner Harbour mean that there is a large initial mass of contaminant in the system as the tracer was dosed through the whole water column, and, as stated, no inflows were included. Therefore, e-folding times would not necessarily be comparable to observed times in the field and are likely to be conservative. However, the modelling results do allow for a valid comparison between layouts.

To estimate the influence of re-developing the Outer Harbour a comparative plot, in terms of percentage change in e-folding time, is presented in Figure 44. This shows very small changes in the Inner Harbour basin, with an improvement in flushing times in the most critical upper reaches and an increase in e-folding time through the "cut". Overall, however, these changes are small and it could be concluded that the development of the Outer Harbour will have little effect on flushing in the Inner Harbour.

Note that these results cannot be translated directly to water quality outcomes as the modelling is a relative assessment. That is, a decrease in flushing will only be of concern should water quality contamination be sufficiently large to maintain elevated concentrations above any water quality objectives. Furthermore, this analysis is conservative when considering point source spills in that any actual spill would be more localised and disperse much more quickly than indicated by the model results; which describe a case where the whole harbour area is assumed to be contaminated.

5.4 Salty Creek

The proposed reclamation has the potential to impact on Salty Creek. The existing Salty Creek estuary can be termed an intermittently closed or open lake or lagoon (ICOLL). The estuary entrance crosses a beach that, from time to time and in the absence of heavy rainfall, builds up in height under persistent low swell wave action such that the flood tide can become constricted or prevented in entering the estuary. This also has the effect of hindering the outflow discharge of freshes caused by rainfall, which can exacerbate flooding upstream. The characteristics of such ICOLLs are that they experience far greater ranges in fluctuations of water levels and salinity than do those estuaries that are open permanently to the sea.

When the seabed fronting the Salty Creek entrance is reclaimed, a culvert would be constructed within the reclamation to ensure that the tidal and flood hydraulic conveyances would be maintained for Salty Creek; that is, Salty Creek would no longer be an ICOLL as the entrance would become open permanently to the sea and, hence, to tidal flushing. This will result in a reduction in the variations of salinity and water levels within Salty Creek, which would revert to those experienced generally by estuaries with permanent entrances.

With reclamation undertaken, the entrance and exit from the Salty Creek estuary to the ocean would comprise a dark passageway for fish travelling from the sea to the estuary and *vice versa*.

6.0 Water Level

6.1 Preamble

During storms the ocean water level and that at the shoreline is elevated above the normal tide level. While these higher levels are infrequent and last only for short periods they may exacerbate any storm damage on the foreshore. Elevated water levels allow larger waves to cross the offshore sand bars and reefs and break at higher levels on the beach. Further, they may cause flooding of low lying areas and increase tail water control levels for river flood discharges.

The components of elevated storm water levels comprise astronomical, meteorological and global factors. All of the components do not act or occur necessarily independently of each other but their coincidence and degree of interdependence generally is not well understood.

6.2 Components of Oceanic Water Level Variations

6.2.1 Astronomical and Meteorological Components

The tidal regime of NSW is microtidal semidiurnal with a diurnal inequality. This means that the tidal range is less than 2 meters, there are two high tides and two low tides each day and there is a once-daily inequality in the tidal range. The mean tidal range at Port Kembla is around one meter and the tidal period is around 12.5 hours. The higher spring tides occur near and around the time of new or full moon and rise highest and fall lowest from the mean sea level. The average spring tidal range is 1.3 meters and the maximum range reaches two meters. Neap tides occur near the time of the first and third quarters of the moon and have an average range of around 0.8 meters.

The storm surge and nearshore water level depends primarily on:

- the intensity, wind speed, scale, direction and speed of movement of the storm;
- the bathymetry of the coastal area including the presence or otherwise of offshore reefs and islands which condition wave transformation;
- the shape of the coastline including the topography of the nearshore areas;
- the prevailing barometric pressure (the inverse barometer effect); and
- the prevailing astronomical tide.

Further elevation of the water level at the shoreline results from the breaking action of waves causing what is termed wave setup and wave runup. Wave setup may be perceived as the conversion of part of the wave's kinetic energy into potential energy. The amount of wave setup will depend on many factors including, among other things, the type, size and periods of the waves, the nearshore bathymetry and the slope of the beach. As a "rule of thumb", maximum wave set-up can be estimated as being around 15% of the unrefracted deepwater *significant* wave height. The energy of a wave is dissipated finally as the water runs up the beach or shoreline. Wave run-up is the vertical distance the wave will reach above the level of the tide, storm surge and wave setup and can be several metres. Wave run-up at any particular site is very much a function of the foreshore profile, the surface roughness and other shoreline features on which the breaking waves impinge.

6.2.2 The Greenhouse Effect

In the longer term, there may be possible meteorological changes resulting from the *Greenhouse Effect*. The term *Greenhouse Effec*t is used to describe a postulated warming of the earth due to the accumulation in the atmosphere of certain gases, in particular carbon dioxide, resulting from the burning of fossil fuels.

The current consensus of scientific opinion is that such changes could result in global warming of 1.5° to 4.5°C over the next 100 years. Such a warming could lead to a number of changes in climate, weather and sea levels. Global warming may produce also a worldwide sea level rise caused by the thermal expansion of the ocean waters and the melting of ice caps. According to the U.S. National Research Council, global mean sea level is projected to rise by 0.1 to 0.9metres by 2100. It is predicted that the severity and frequency of storms will increase, rainfall intensity could increase and there could be a more severe wave climate. However, the likely degree of change in these processes has not been quantified.

6.2.3 El Nino Southern Oscillation

Global meteorological and oceanographic changes such as the El Nino Southern Oscillation in the eastern southern Pacific Ocean cause medium-term variations in mean sea level of up to 0.1m.

6.2.4 Extreme Value Analysis of Elevated Water Levels

Combining the statistical properties of storm parameters with the results of surge modelling it is possible to determine the recurrence statistics of surge levels. There is, however, some difficulty in combining surge frequency statistics with tide height statistics. Methods based on the application of conditional probabilities have been applied but there are still difficulties in allowing for the variability of tidal amplitude, with wave setup introducing a further time-dependent variable making the solution intractable.

An alternative method of generating synthetically extreme water level statistics involves the mathematical simulation of the occurrences of a large number of randomly occurring storms with coincident tides. From results of this type water level frequency relationships can be derived.

6.3 Tidal Planes

The tidal planes for Port Kembla as provided in Table 9.

Table 9 Tidal Planes for Port Kembla

Tidal Plane	Tidal Level (m PKHD)
Highest Astronmical Tide	2.0
Mean High Water Spring	1.5
Mean Heigh Water Neap	1.3
Mean Sea Level	0.9
Mean Low Water Neap	0.6
Mean Low Water Spring	0.3
Lowest Astronmical Tide	0.0

6.4 Extreme Water Levels (Includes Tide + Storm Surge)

Storm surge is statistically independent of tidal stage. The joint probability of elevated water levels for the Sydney region has been examined by NSW Government Manly Hydraulics Laboratory based on water levels measured continuously at Fort Denison in Sydney Harbour for over 100 years. Figure 45 presents the recurrence of extreme elevated ocean water levels, converted to the Port Kembla Harbour Datum.

6.5 Sea Level Rise Projections

The IPCC Fourth Assessment Report (2007 Table 10.7) projections of global average sea level rise ranged from 0.18 - 0.59 m by 2090-2100 relative to 1980-1999 levels, with the upper ranges of projected sea level rise possibly increasing by 0.1 - 0.2 m due to an additional contribution from a future rapid dynamical response of the ice sheets. The upper estimates were lower than those in the IPCC Third Assessment Report (2001). Therefore, the range of projected sea level at 2090 - 2099 is 0.18 - 0.79 m above 1980-1999 levels. For this report, it has been assumed that these projections are applicable to 2100 and they lie above 1990 levels. As the IPCC Fourth Assessment Report does not speculate on what the sea level rise would be by 2050, the values of the IPCC Third Assessment have been adopted, these being a sea level rise of 0.05 - 0.30 m above 1990 levels.

CSIRO modelling undertaken on behalf of the NSW DECC indicated a further local (NSW) increase of up to 0.08 m by 2030 and 0.12 m by 2070 for the NSW coastline. This result is associated with a strong warming of the sea surface temperatures in the region and a strengthening of the East Australian Current (CSIRO 2007). By linear interpolation and extrapolation of these upper limit projections, a value of 0.10 m was adopted for 2050 and 0.14 m for 2100 (NSW DECC 2009).

The best estimate for sea level rise in the Sydney region is therefore 0.20 - 0.90 m in 2100 and 0.05 - 0.40 m in 2050 above 1990 levels. These values are consistent with the recently issued NSW DECC Draft Sea Level Rise Policy. Table 10 summaries these values. Sea level rise projections adopted for this project are in accordance with NSW Government Sea Level Rise Policy Statement, which is a sea level rise of 0.4 m by 2050 and 0.9 m by 2100 relative to 1990 levels.

Table 10 Sea level rise projections for Port Kembla (IPCC 2001, 2007 & NSW DECC 2009)

Sea Level Rise Scenario	Year 2050	Year 2100
Lower Bound Estimate	0.05 m	0.20 m
Medium Estimate	0.23 m	0.55 m
Upper Bound Estimate	0.40 m	0.90 m

6.6 Design Water Levels and Reclamation Level

The Harbour is to be operational at all times including during extreme storm events. An acceptable level of risk for operational conditions could be that there is less than a 1% chance of the design water level being exceeded in any year. That design event is a 100 year ARI. For this condition the design water level for the Outer harbour would be 2.3 m PKHD.

For the year 2050, for structural design, an acceptable level of risk could be that there is only a 5% chance that the design conditions are ever exceeded. That design event is a 1,000 year ARI, for which the water level is 2.4 m PKHD. Adopting 0.4 m for an extreme estimate of future sea level rise, the design event is an extreme ocean water level at 2.8 m. Within the harbour, 0.2 m would be added to this level for long wave activity and, for a 100 year ARI *significant* wave height of 6 to 12 hours duration within the Outer Harbour of H_s = 0.8 m, the design water level for extreme events would be 3.4 m PKHD to prevent inundation. The proposed reclamation level has been set to RL 4.0 m PKHD providing a freeboard of 0.6 m to the top of the reclamation.

For the year 2100, adopting 0.9 m for sea level rise on top of an extreme ocean level of 2.4 m PKHD, with 0.2 m added for long wave activity and, for a 100 year ARI *significant* wave height of 6 to 12 hours duration within the Outer Harbour of H_s = 0.8 m, the design water level for extreme events would be 3.9 m PKHD to prevent inundation. For a finished pavement level of 5.2 m PKHD, there would be an adequate freeboard for the year 2100.

7.0 Summary and Conclusions

The coastal hydrodynamics pertinent to the proposed master plan development of Port Kembla Outer Harbour have been analysed in respect of their impact on shipping operations. Particular emphasis has been given to long wave processes (harbour seiching), which are known to present a significant constraint on shipping operations in the existing Outer Harbour. The impacts of the proposed reclamation, including its staging, on long wave action and tidal hydraulics in the Inner harbour have been analysed also. The studies have defined the infragravity (long) and gravity (swell) wave climates, water levels, tidal velocities and tidal discharges for which the development would be designed.

Long wave modelling has demonstrated that the proposed Outer Harbour reclamation has been designed effectively to ameliorate seiching within the Outer Harbour. While long wave processes cannot be eliminated entirely, the proposed reclamation would result in changing the amplitudes and frequencies of the long waves that could develop within the Outer Harbour to such a degree so as to not effect adversely shipping operations. Subsequent moored ship modelling of tugs, cargo and container ships at their respective berths has confirmed that the proposed development would be suited for these types of proposed shipping operations. The predicted ship movements were found, generally, to be well within guideline standards.

The proposed Outer Harbour reclamation would not affect the long wave processes or the tidal discharge of the Inner Harbour significantly, nor would it have any significant impact on tidal velocities. However, the reclamation would change Salty Creek from an ICOLL to a small estuary with an ocean entrance that would be open permanently, thereby reducing salinity and water level fluctuations within the estuary. It may also impact on the passage of fish from the estuary to the ocean and *vice versa*.

The proposed reclamation and finished pavement levels have been set to be sustainable for predicted extreme sea level rises for the year 2100, with a freeboard suitable to cater for further sea level rise beyond that time.

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