COFFS HARBOUR SEDIMENT MODELLING AND INVESTIGATION

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Abstract

Water Technology has teamed with Griffith University as a part of the Industrial Affiliates Program to complete a Sediment Modelling Investigation for Coffs Harbour.

The harbour at Coffs Harbour has been infilling with sediment since breakwall construction and reclamation linked two nearshore islands with the mainland in the 1920s, interrupting the Longshore Sediment Transport (LST) pathway. The harbour has become a sand sink; sand is entering the harbour and then cannot be removed by natural processes. Following on from previous reports from Carley (2005) and Lord (1984), the investigation has used the latest numerical modelling software, volumetric analysis programs and analytical methods for LST estimation to investigate the effects of the harbour on sediment transport.

The effect of the breakwall orientation on wave height and particle velocity for different incident wave directions was investigated using a MIKE 21 Flexible-Mesh Spectral Wave model. The model predicted bottom water particle velocities throughout the harbour and mapped potential accumulation hotspots and sediment pathways.

Bathymetric surveys spreading 118 years were analysed with the volumetric analysis program 12D Model. The results showed sand accumulating within the harbour in the lee of the eastern breakwall after its construction, as predicted in the MIKE model. This shoal built up to a uniform level before extending across the entire width of the harbour. Each periodic bathymetric comparison showed the sediment extending further within the harbour as a 'wave'. The rate of infilling reached a maximum of around 50,000 $m^{3/}$yr, which requires confirmation through analysis of a current survey.

Estimates of LST were undertaken using the CERC (1984), Kamphuis (1991) and Bayram (2007) on the beach updrift of the harbour. The uncalibrated CERC method was found to overestimate sediment transport by an order of magnitude, while Kamphuis and Bayram were more accurate. The Bayram formula produced the closest estimate of LST to measured rates.

Introduction

Longshore Sediment Transport (LST), or littoral drift, is a natural phenomena of sediment movement induced by two mechanisms, beach drifting in the swash zone and transport in the breaker zone (Kamphuis, 2000). It is the main method of longitudinal sediment transport on sedimentary coastlines around the world.

Coffs Harbour is situated on the Mid North Coast of NSW. It has a coastal climate typical of Australia's east coast, experiencing the effects of tropical cyclones, mid latitude cyclones and east coast lows (Short, 2007). The result of this wave climate is a predominantly northwards LST system (Lord, 1984). Figure 1 shows important elements of harbour construction and the local beach system.

Figure 1. Harbour at Coffs Harbour

The construction of the harbour began in 1892 with the completion of the harbour jetty. Further construction works have created an almost fully sheltered harbour. Figure 2 shows the construction history from 1892 to the present day. Important dates in the construction timeline include the southern reclamation, completed in 1927, the northern breakwater, completed in 1924, and the eastern breakwater, the majority of which was completed in 1946 (Carley et al., 2005).

Since its construction sediment has accumulated at Boambee Beach (updrift of harbour), on the south side of the southern reclamation and inside the harbour. The harbour has become a sand sink; sand is entering between Muttonbird Island and the eastern breakwater and settling within the harbour. This sand cannot be significantly removed by natural processes and the functionality and safe navigation of the harbour has been maintained through dredging by local and state governments.

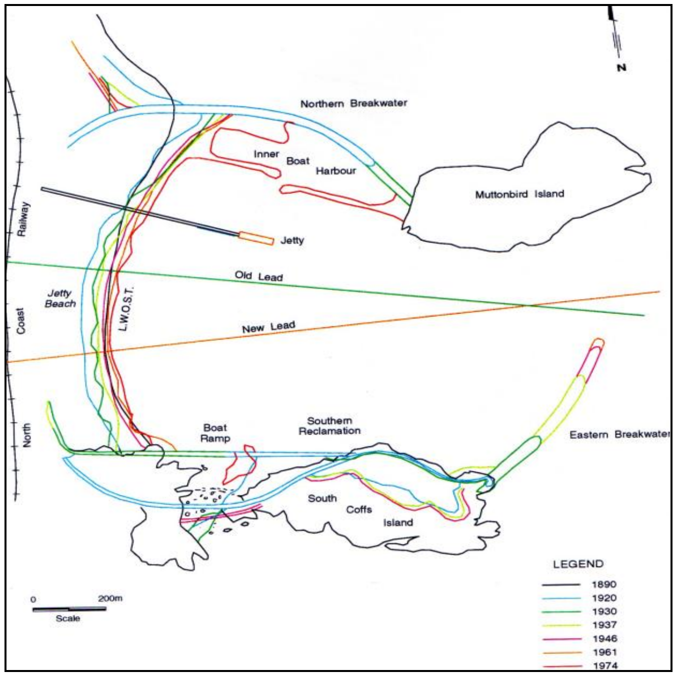


Figure 2. Construction History of Coffs Harbour harbour (Source: Carley et al., 2005).

This project aimed to verify previous studies completed at the harbour and gain an understanding of sediment processes in the harbour. The study aimed to:

1. Quantify LST rates approaching the harbour,
2. Map historic sediment build-up rates,
3. Numerically model harbour wave behavior and currents, and
4. Map and predict sediment accumulation 'hotspots'.

To achieve these goals analytical formulae and numerical modelling software was used to analyse the harbor infilling.

Part 1: Analytical Formulae

The potential LST approaching the harbour was calculated using empirical methods. This methodology was chosen to assess the use of purely empirical formulae for estimating LST. The calculated rates have then been compared to previous estimates of LST for Coffs Harbour.

1.1 Methodology

Three internationally recognised formulae for potential LST have been used to estimate the potential sediment rate approaching the harbour, proposed by the United States Army Corps of Engineers Coastal Engineering Research Centre (known as the CERC (1984) formula), Kamphuis (1991) and Bayram (2007).

CERC (1984) Formula

$$Q = K\left(\frac{\rho\sqrt{g}}{16\gamma^{0.5}(\rho_s-\rho)(1-n)}\right)H_b^{\,5/2}\sin(2\alpha_b)$$ (Source; USACE, 1984)

The *K* coefficient represents an empirical calibration parameter, H_b represents the breaking wave height, γ is the wave breaker parameter, ρ_s represents sediment density and *n* represents sediment porosity . Wave breaker angle is given by α_b whilst the water density is represented by ρ.

Kamphuis (1991) Formula

$$Q = 6.4\times10^4 H_b^{\,2}T_p^{\,1.5}m_b^{\,0.75}D^{-0.25}\sin^{0.6}2\alpha_b$$ (Source; Kamphuis, 1991)

Where *D* is the mean particle diameter, *m* represents the bathymetry slope and the peak period is given by T_p.

Bayram (2007) Formula

$$Q = \frac{\varepsilon}{(\rho_s-\rho)(1-a)gw_s}F\bar{V}$$ (Source; Bayram et al, 2007)

Where w_s represents fall speed, F represents energy flux, ε is an empirical transport coefficient, and $\bar{V}$ gives mean longshore current velocity. Sediment porosity *a* is the equivalent of *n* in the CERC formula.

Daily wave data for the offshore waverider buoys at Byron Bay (direction data) and Coffs Harbour (for significant wave height data) was obtained from the Manly Hydraulics Laboratory (MHL) for 2010. Offshore data was transformed using small amplitude linear wave theory and wave transformation equations proposed by Kamphuis (1991). Boambee Beach, positioned updrift of the harbour, was broken into segments in order to accurately represent the beach orientation (refer Figure 3). On review of the beach segments, sections North B, South A and South B were considered inappropriate for analysis due to the lack of evidence of parallel offshore contours and sheltering in the lee of headlands or the harbour structure.

Figure 3 Beach Sections at Boambee Beach.

1.2 Sediment Transport Rates

The three empirical formulae gave results of varied accuracy. The results considered to be most accurate was the Bayram (2007) formula, which gave estimates of 55,000 to 170,000m^3/yr for the year 2010. This compares well to the anticipated 70,000m^3/yr values summarised in previous studies of Carley et al. (2005). The Kamphuis (1991) formula LST rates ranged from 140,000 to 300,000 m^3/yr, while the uncalibrated CERC formula gave results at least twice that of previous estimates and other formulae. In all cases rates at for the middle section were higher due to beach orientation.

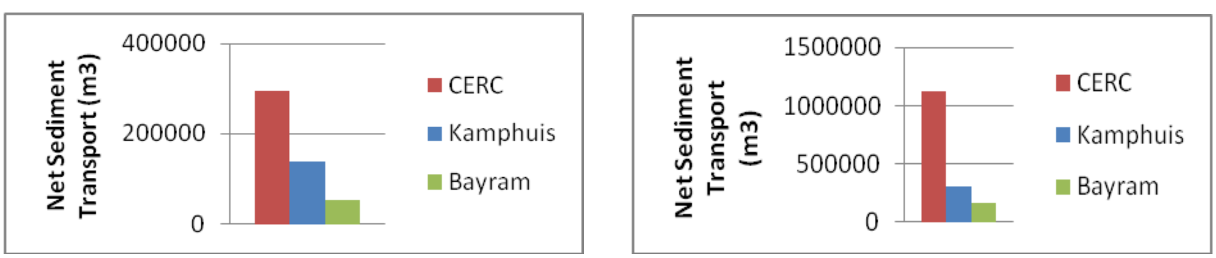


Figure 4 Estimated 2010 Sediment Transport at Beach Sections A (left) and Middle (right).

Part 2: Spatial and Volumetric Analysis

An analysis of the sediment infilling of the harbour was undertaken to determine the spatial and volumetric characteristics of the harbour sediment accumulation. The analysis was undertaken using spatial and volumetric analysis software.

2.1 Methodology

Historical bathymetrical surveys dating back to 1890 were obtained through the New South Wales Land and Property Management Authority (LPMA) and the New South Wales Public Works Department (PWD).

The majority of the surveys were scanned hardcopies of varying quality, scales, units and datums. After a comprehensive review of suitability of the surveys, maps from 1890, 1937, 1961, 1980, 1997, 2005, and 2008 were selected to be analysed. The surveys were adjusted to their respective datums, manually digitized and georeferenced using the Geographic Information System ArcGIS (Esri, 2010). The change in volume between each bathymetry was then analysed by the civil and surveying software package 12d Model (12d Solutions, 2011). As the surveys were based on bathymetric data, the analysis was not able to include the accretion on Jetty Beach. AWACS estimated this amount to be around 1800 m^3/yr in 1995.

2.2 Sediment Accumulation Rates

Through analysis of the bathymetric surveys sediment was observed to begin accreting during the initial period of harbour construction. Sediment firstly built up against the northern breakwater, which blocked the LST passageway between Muttonbird Island and the mainland.

Another large shoal was observed in the leeward side of the eastern breakwater. As this shoal built up, it decreased the depth in the harbour to approximately 6.5m. This shoal has been periodically extending into the harbour towards Jetty Beach. The final survey reveals this shoal has extended approximately two-thirds of the length of the harbor.

The bathymetric models were analysed volumetrically to calculate total sediment build-up. Any dredged material removed from the harbour during its history was included in the analysis. Sediment accumulation rates were observed to begin after harbour construction, and were relatively small during the initial years, at around 5000m^3/yr until the 1961 survey. Accumulation increased throughout the 1960-1980 period, possibly explained by the large storm events experienced during this time, particularly in 1968 and 1974 (Short, 2007). Infilling rates continued to increase until peaking around the 2005 survey at a rate of approximately 48,000m^3/yr. Recent surveys show a possible reduction in sediment infilling of the harbour, which will require confirmation through analysis of a current survey.

Figure 5 shows the results of the volumetric analysis.

Figure 6 shows the spatial progression of the shoal into the harbour over the 118 year period. Colour indicates the difference in depth experienced between bathymetric surveys.

A detailed breakdown is as follows:

- Sediment was found to begin accumulating between 1914 and 1937 during the initial period of harbour construction. Sediment built up as a large shoal on the leeward side of the eastern breakwater, which was not fully constructed during this time. Sediment also shows significant (>3.0m) accumulation along the south of the northern breakwall. Between 1.0 – 1.5m build-up is seen in the harbour mouth.

- From 1937 to 1961 around 6.0m of sediment accumulation was observed in the lee of the eastern breakwater. The sand shoal began to propagate into the harbour from the mouth into the centre of the harbour. Build-up is also evident on the south and south – east side of Muttonbird Island. The harbour mouth had accumulated a minimum of 1.5m during this time. Accumulation across the northern breakwater was minimal due to the completion of the southern and eastern breakwaters.

- Between 1961 to 1980 the shoal extended north-south across the entire harbour and continued extending eastward. Large accumulation in the south east section of the harbour was seen which was linked to major storm events of 1967, 1971, and 1974. Build up in the mouth of the harbour was in the order of 1.5m, however accumulation on the leeward side of the eastern breakwater had reduced. Limited accumulation was seen on the northern breakwater. The inner harbour breakwater was completed and experienced significant build-up on the western wall.

- The 1980 to 1997 surveys confirmed the continued eastward propagation of the sand into the harbour, and the relative stabilisation of depth at the harbour mouth. Major buildup (>3.0m) was seen around the mouth of the inner harbour breakwater, particularly on the eastern wall.

- 1997 to 2005 surveys shows the shoal continuing to enter the harbour and spread across its entirety. Build-up at the mouth of the inner breakwater has ceased.

- Analysis between the surveys of 2005 and 2008 further confirmed the advance of the sand shoal and the stability of the depth to approximately 6.5m. Some build-up is seen at the harbour mouth, boat ramp and the southern end of Jetty Beach.

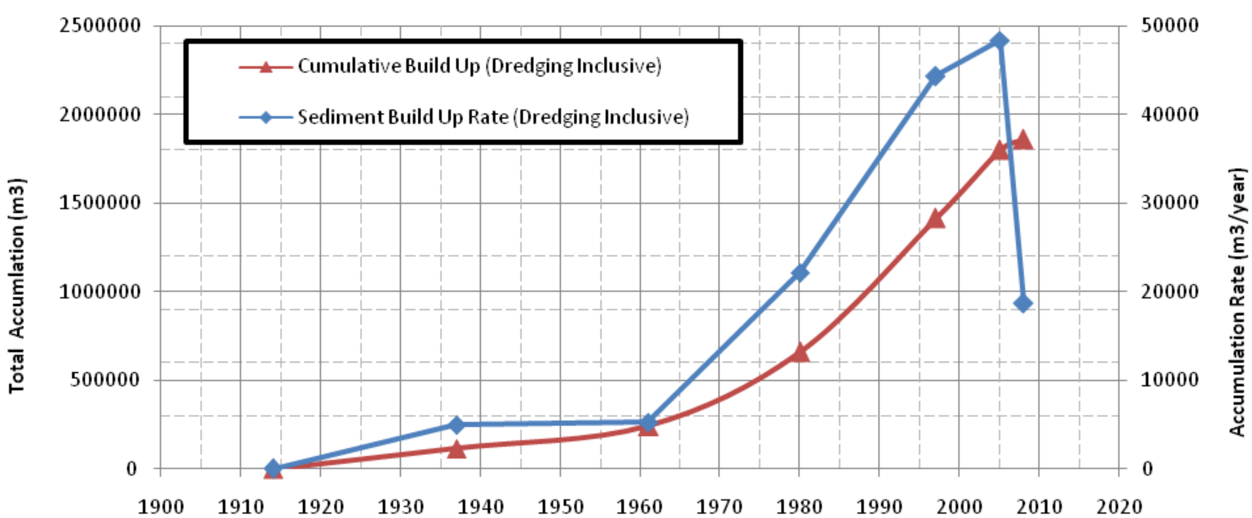


Figure 5 Volumetric sediment accumulation rates within Coffs Harbour

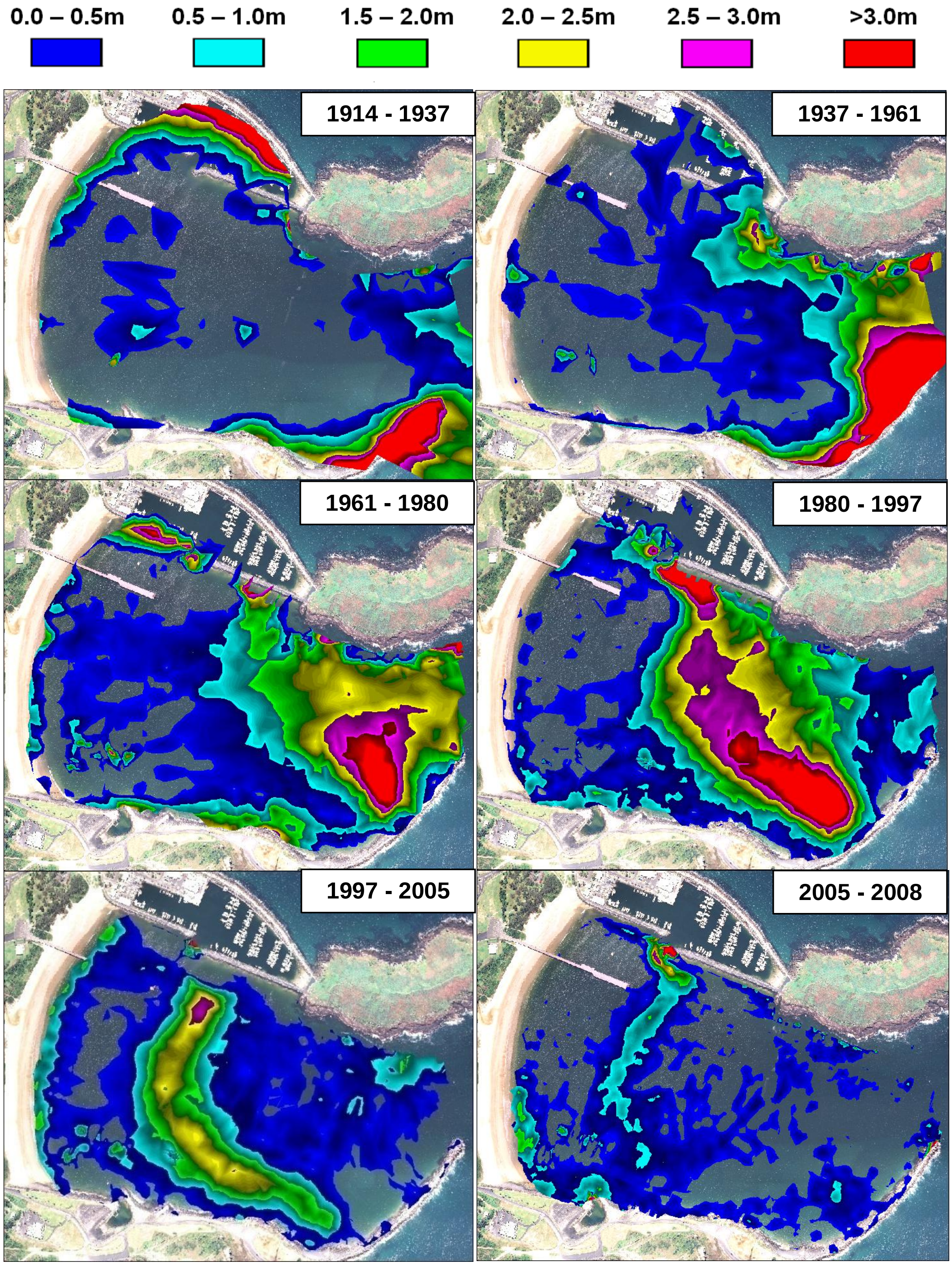


Figure 6 Spatial sediment accumulation within Coffs Harbour

Part 3: Numerical Modelling

The wave conditions and currents experienced within the harbour was analysed by creating a numerical model based on the latest bathymetric survey.

3.1 Spectral Wave Model Analysis

A Flexible Mesh MIKE21 Spectral Wave Model of the harbour was created using the 2008 bathymetric survey. Three incident waves were used as boundary conditions, with a significant wave height (Hs) of 2.14m, a period (Tp) of 7.46 seconds and wave directions from the north-east, east and south-east (64^{O} 93^{O} and 154^{O} respectively), refer to Table 1.

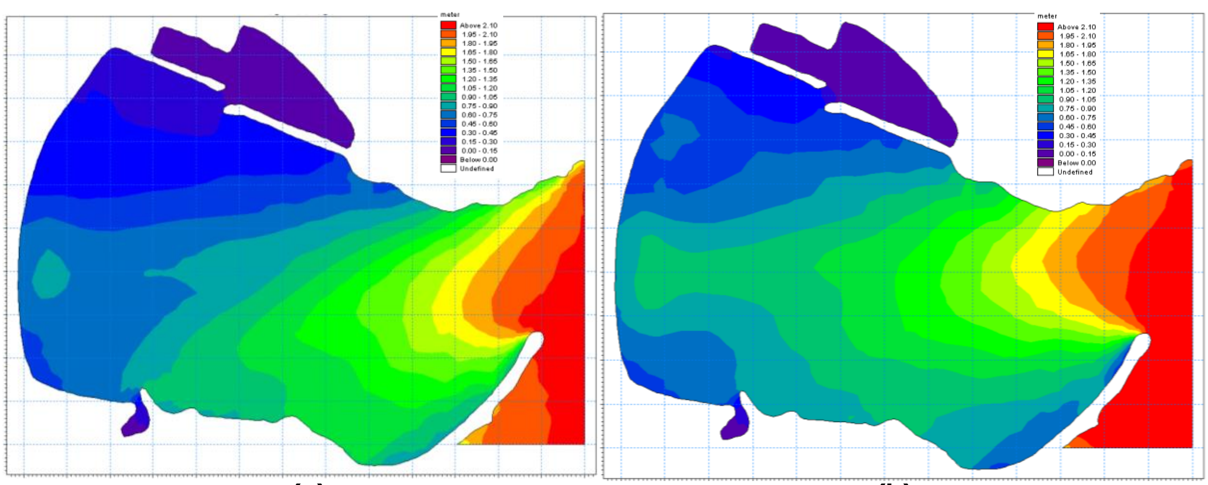
The absence of wave gauges the outer harbour did not allow full calibration of the model. A wave gauge does exist in the inner harbour, however it is positioned in an area of minimum wave influence and is used as a tide gauge. It was not deemed appropriate for use in this study.

Table 1 Wave Events Modelled in Coffs Harbour MIKE21 Spectral Wave Model

Scenario	Hs (m)	Tp (s)	Dir. (Deg TN)
Verification	1.76	15.1	154
NE Swell	2.14	7.46	64
Easterly Swell	2.14	7.46	93
SE Swell	2.14	7.46	154

3.2 Modelled Harbour Conditions

Wave energy was seen to reduce upon entering the harbour, while north-easterly and easterly storm event waves penetrated the harbour further than the south-easterly event. The energy dissipation due to the orientation of the eastern breakwater is shown to be highly effective during south-easterly swell. Figure 7 shows wave penetration during the easterly and north-easterly wave events.



(a) **(b)**

Figure 7 North Easterly (a) and Easterly (b) Wave Penetration in the Harbour.

Wave generated currents were observed to travel against the north and south boundaries of the harbour. North-easterly swells produced currents travelling against the southern boundary, and south-easterly swells against the northern boundary. Easterly swells produced currents travelling around both the northern and southern boundaries, which extend to run parallel past Jetty Beach. These currents supported previous studies including the Coffs Harbour Boat Ramp Siltation Investigation (AWACS 1995)), the Coffs Harbour Port - Shoal Management Planning Program (CHCC 2002) and the Specialist Coastal Engineering Advice for Harbourside Project – Coffs Harbour (Carley et al 2005).

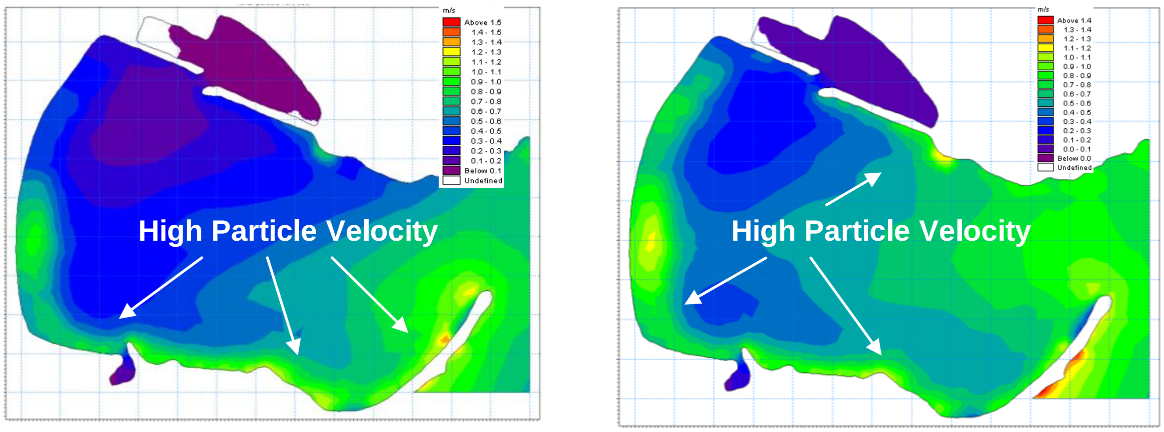


Figure 8 North easterly (a) and easterly (b) swell event particle velocity at harbour bed

Discussion and Conclusion

The aims of the Coffs Harbour Sediment Modelling Investigation were to quantify and draw conclusions relating to the sediment entering and bypassing Coffs Harbour via LST.

The use of solely empirical formula for determining LST has had mixed results. The results from Bayram (2007) have shown to give reasonable estimates of LST, while Kamphuis (1991) was found to overestimate. Bayram (2007) potential LST rates ranged from around 55,000-170,000m^3/yr, similar to previously published rates of approximately 70,000m^3/yr given by Carley et al (2005). The results produced by the CERC formula were extremely high. This supports criticism of the formula in papers such as Stutz and Pilkey (1999). The applicability of theoretical wave transformation and breaking calculations was a limitation of the study. To obtain more accurate results it is recommended that a numerical wave transformation model such as SWAN by Delft Hydraulics be used. Never-the-less, the results from Bayram formula produced a reasonable estimate of LST.

The use of the GIS and volumetric analysis software as a method of comparing a time series of bathymetric surveys was successful, however the potential for error when digitizing and geo-referencing hardcopy maps could impact reliability of the data. Infilling rates in the harbour initially remained relatively small after the breakwater construction, which increased due to severe weather events during the 1970s. Sediment accumulation peaked around 48,000m^3/yr during 2005. The infilling rate has appeared to have since decreased however this trend requires further analysis to be confirmed.

The MIKE Spectral Wave Model, while uncalibrated, offered indications of wave behaviour and currents within the harbour. The orientation of the eastern breakwall significantly reduced wave energy during south-easterly events, while wave penetration was greatest during north-easterly and easterly wave events. Currents were observed to travel around the landward boundaries of the harbour, which may be a method of sediment transport towards Jetty Beach. These currents supported the proposed sediment transport currents in previous studies.

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