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# Video-derived mapping of estuarine evolution

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**ABSTRACT**

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Coastal changes are being monitored around Australia and New Zealand using a network of state-of-the-art coastal imaging stations. These systems are being used to build a database of frequent, long-term, spatially-extensive observations of coastal behaviour across a diverse range of coastal environments. The focus of the research detailed herein is the application of this technology to the investigation of estuarine systems. Boat-based surveying of estuaries is generally both difficult (*e.g.* shallow mudflats) and time-consuming. The ability to complete regular and repeated surveys within highly dynamic and fast-changing systems is usually limited. In contrast, image-derived methods provide a practical solution. Digital images are analysed to detect successive (hourly) waterlines at measured water levels through a single tidal cycle and then processed to generate intertidal bathymetries. Repeating these 'virtual' surveys enables the quantification of key processes such as channel infilling, growth of intertidal mudflats and response of the estuary to extreme forcing events. A particular advantage of this approach is that archived images may be used to complete 'surveys' retrospectively. Application of these research techniques are illustrated at two contrasting field sites in Australia and New Zealand. The first is a dynamic and small-scale inlet system dominated by the ingress of beach sediment (Narrabeen Lagoon, Australia) and the second is a large-scale and more slowly evolving mudflat system (Raglan Estuary, New Zealand). Results presented illustrate the practical application of video-derived methods to the monitoring and quantification of estuarine processes and evolution, and provide a unique dataset that can now be used for comparison with model simulations.

**ADDITIONAL INDEX WORDS:** *Estuary, Tidal Inlet, Monitoring, Bathymetry, Australia, New Zealand*

## INTRODUCTION

Changes to the coastline are being monitored around Australia and New Zealand using the state-of-the-art automated video systems known as ARGUS and Cam-Era respectively. The stations collect colour video images every hour from multiple cameras over extensive spatial scales (*i.e.* kilometres) and long time scales (*i.e.* years). These systems are being used to build a database of frequent, long-term, spatially-extensive observations at a number of coastal sites in both countries. These data support a range of coastal process studies and are used for verification of numerical models to predict coastal dynamics and change.

There are currently 8 sites in Australia (TURNER *et al.*, 2006) and 8 sites in New Zealand (HUME, 1998) being monitored by these video systems which include beaches, rivers, and tidal inlets.

Estuaries are presently a major focus of research around the world. Ocean entrances to coastal lakes and lagoons in particular are under continuing investigation since they provide access between inland waterways and the open ocean and thus are increasingly the focus of intense development. The presence of large areas of migrating or changing intertidal mudflats within navigable parts of estuaries is also an ongoing area of research due to their potential to cause a hazard to navigation. Both of these areas of estuarine systems raise significant engineering and management challenges.

Further to this, conventional surveying of estuarine systems is difficult, time-consuming and often not possible at all. These difficulties exist both spatially, for example due to shallow mudflats, and temporally in the case of highly dynamic fast-changing systems. In response to these challenges, two sites, one in Australia (Narrabeen Lagoon) and one in New Zealand (Raglan Estuary) have been chosen to use the technology of the video monitoring systems to map the evolution of estuarine systems.

The aim of the project at Narrabeen Lagoon is to quantify the rapid infilling processes of the entrance to the lagoon following mechanical entrance clearance, whilst at Raglan (Whaingaroa) Estuary it is to determine longer-term changes in size and location of intertidal mudflats in a navigable area of the estuary. At both sites data acquired using the video systems is being used for the verification of numerical models developed for the purpose of understanding and predicting the evolution of the two contrasting estuarine systems.

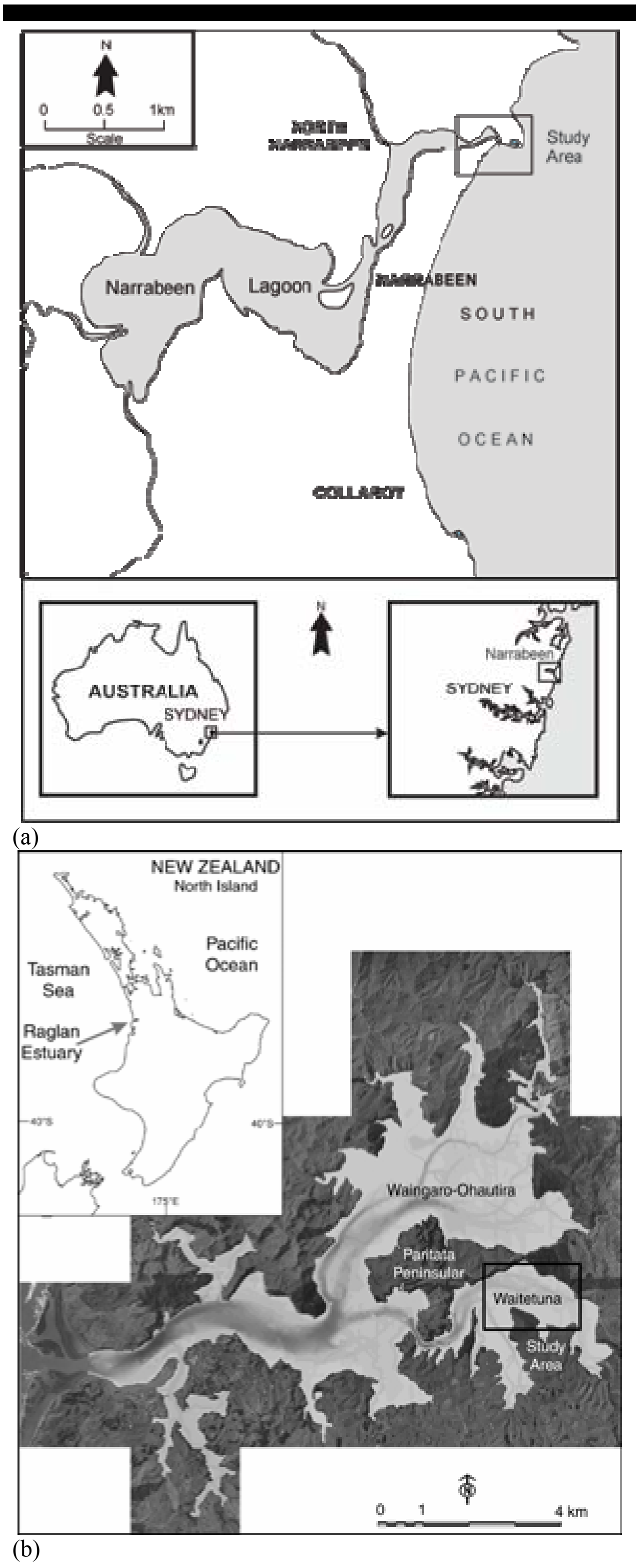



Figure 1. Maps showing location of the two study sites. (a) Narrabeen Lagoon. (b) Raglan Estuary.

## STUDY SITES

The first site is the entrance to Narrabeen Lagoon which is located in Sydney, Australia (Figure 1a), and is classified as a borderline saline coastal lake/barrier estuary system (MHL, 1989) following the classifications of ROY (1984). The entrance is subject to continuous infilling which restricts water exchange between the estuary and the ocean and in extreme cases closes the lagoon off completely. Thus it also falls into the class of estuaries (ROY *et al.*, 2001) known as an ICOLL (Intermittently Closed and Open Lakes and Lagoons). The oceanic tide in the Sydney region is microtidal (less than 2 m) whilst the wave climate is moderately energetic. Narrabeen Lagoon has a surface area of 2 km$^2$ and a catchment area of 55 km$^2$, however due to strong attenuation of the tidal currents at the entrance, the estuarine zone of the lagoon only has a spatial scale in the order of 100's of metres. This entrance area is the focus of the present study and due to the energetic wave climate is a highly dynamic and fast changing morphological system.

The other site is Raglan Estuary located in Waikato, on the North Island of New Zealand (Figure 1b), which is classified as a drowned river valley (or ria). The estuary receives runoff from a 525 km$^2$ catchment and has a surface area of 33 km$^2$, approximately 70% of which is intertidal flats (SHERWOOD and NELSON, 1979). The estuary is mesotidal (*i.e.*, 2-4 m tidal range), with spring- and neap-tide ranges of 2.8 m and 1.8 m respectively (HEATH, 1976). Raglan Estuary is almost entirely intertidal, with a spatial scale of kilometres; however it undergoes a relatively slow evolution due to the dominance of the mudflats. The camera site is located on the Paritata peninsula which separates the extensive intertidal flats of the Waingaro-Ohautira and Waitetuna arms of the estuary (Figure 1b).

The entrance to Narrabeen Lagoon has undergone numerous engineering changes including the building of an artificial dune field, a road bridge and a seawall. The entrance also undergoes mechanical clearance every 3 – 5 years. This is in response to flooding and water quality problems due to the infilling nature of the estuary. These challenges are ongoing and the local authority, Warringah Council, have both a short and long term entrance management scheme in place (WARRINGAH COUNCIL, 2002).

In contrast to the rapidly evolving and engineered Narrabeen Lagoon site, the Raglan Estuary is an essentially natural system with minimal anthropogenic impact, particularly in the study area, and a relatively slow evolution.

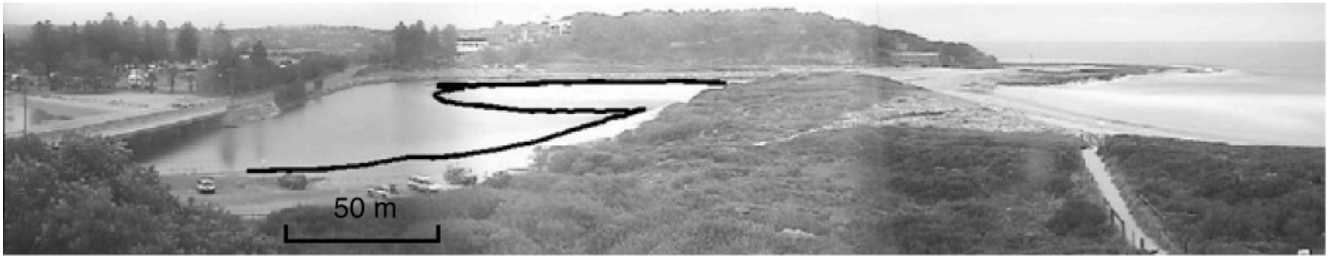
## METHODOLOGY

Whilst both sites utilise state-of-the-art video systems, the methodology of image collection in place at each site differs due to the difference in spatial and temporal scales of the morphological changes.

At the Narrabeen Lagoon site the video images are acquired via a fixed ARGUS station (HOLMAN *et al.*, 1993) located on the roof-top of an adjacent surf life-saving club. The colour images are collected hourly from four cameras during daylight hours and the station has been collecting images since July, 2005.

The video images collected at the Raglan Estuary site are collected from a site on the Paritata peninsula during one-off yearly surveys using two portable cameras rather than a fixed installation. This is because of the much slower evolution of the estuarine channels and mudflats. Each annual survey collects colour video images each hour from low to high tide through a single tide cycle only. Two surveys have been undertaken so far, the first in April, 2005 and the second in February, 2006.

Water elevations are recorded at both sites, via a permanent water level recorder at Narrabeen Lagoon and using a boat mounted RTK-DGPS during each survey at Raglan Estuary. These recorded water elevations and the collected video images allow the mapping of bathymetric contours. This is done by first



(a)

(b)

Figure 2. Merged oblique images showing detected shorelines at the two sites. (a) Narrabeen Lagoon entrance on January 31, 2006 with water level 0.5 m with respect to the Australian Height Datum. (b) Raglan Estuary on February 1, 2006 at low tide, -0.4 m with respect to the Mount Eden Local Circuit

detecting the edge between wet and dry in each image which gives a contour, or shoreline for the corresponding water elevation.

At Narrabeen Lagoon the shorelines are detected using a modified version of the technique outlined in AARNINKHOF *et al.* (2003). This technique uses the colour information in 'Hue-Saturation-Value' (HSV) space from each image to differentiate between wet and dry pixels and thereby detect the waters edge. The performance of the shoreline detection technique is greatly improved in terms of reliability and robustness for a given site by modifying which elements of the HSV space are used. This choice of elements is relatively simply determined and is based primarily on contrast between sediment and water colour. At Raglan Estuary the shorelines are manually picked in each image due to the smaller number of images collected and the complexity of the morphology. Examples of shorelines detected from the Narrabeen and Raglan sites are shown in Figure 2a and 2b respectively.

The shorelines picked in the oblique images (*i.e.* as UV image coordinates) are rectified to real-world (xyz) coordinates using the methods of HOLLAND *et al.* (1997) and HEIKKILÄ (2000) at the Narrabeen and Raglan sites respectively. This process requires a limited number of known real-world positions in the images, or Ground Control Points (GCPs) as well as water elevation data. At Narrabeen Lagoon the GCPs were surveyed using RTK-DGPS at the time of the installation of the cameras whilst at the Raglan site the GCPs are collected using a boat mounted RTK-DGPS during each annual survey. This process thus provides geo-referenced shorelines, or contours, for each image and its corresponding water elevation.

By repeating this process of automated/manual picking and rectification, waterlines for each hourly image over a tidal cycle are combined to obtain intertidal bathymetries. At the Raglan site only the rising tide is used, whereas at the Narrabeen site the entire tidal cycle is used. This technique has been used previously, for example, to study beach slope changes (MADSEN and PLANT, 2001), to quantify evolution of beach nourishment (ELKO *et al.*, 2005) and to map short term evolution of ebb shoals of a tidal inlet (BALOUIN *et al.*, 2004).

Whilst the technique of obtaining intertidal bathymetries from a series of video images by picking shorelines has been rigorously verified for beaches (*e.g.* AARNIKHOF *et al.* 2003; PLANT and HOLMAN 1997) some verification of its accuracy is desirable for its use in estuarine systems. At Narrabeen Lagoon the ability to undertake regular surveys using RTK-DGPS allows the direct comparison of detected shorelines with field data. However, at Raglan Estuary, because of the inaccessibility by boat (or otherwise) of much of the study area due to the extensive mudflats, direct comparison is not possible. Rather the survey boat is identified in images when positional data was taken with the RTK-DGPS and these UV coordinates are transformed to real-world (xyz) coordinates and compared to the survey data.

## RESULTS AND DISCUSSION

Verification of the accuracy of the image derived rectified shorelines from both sites was undertaken using two different methods.

At Narrabeen Lagoon the shorelines were compared directly with RTK-DGPS survey data. A series of shorelines were picked in images collected during a rise in lagoon water elevation in June-July, 2006 after a significant rainfall event. The lagoon entrance was closed at the time, as it has been for the majority of the time since the deployment of the video system.

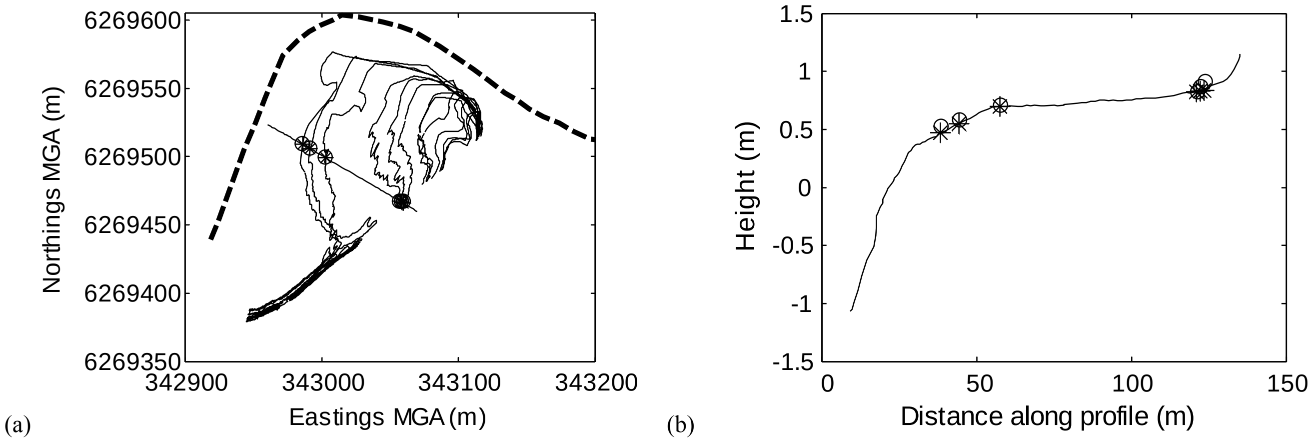



Figure 3. Comparison of picked shorelines and survey data at Narrabeen Lagoon. (a) Plan view showing shorelines, location of profile and intersections (dashed line is the seawall). (b) Heights and location along profile, as a distance from the seawall, of picked shorelines (o) and corresponding survey height (*).

The intersection of the series of shorelines and a set of survey profile lines were determined and the differences in heights at these intersection points were calculated. The results for one of the survey profiles are shown in Figure 3. The location of the profile, along with the intersection points, is shown in Figure 3a, with the seawall on the northern side of the entrance shown for reference and the heights and location along the profile are shown in Figure 3b.

The difference in heights from picked rectified shorelines and survey data show that the overall vertical accuracy of the technique is order 0.05 m.

Following the rise in water elevation the entrance to the lagoon was mechanically opened by local council in early July, 2006 as a flood mitigation measure in accordance with its management policy (WARRINGAH COUNCIL, 2002). The entrance closed to the ocean again in mid August, 2006. A subsequent video 'survey' showed that there was no significant change to the morphology of the flood shoal during this opening/closure event. This is due to the fact that the entrance to the lagoon has reached a state of infill such that ebb flows, either from release of the elevated water levels or tidal exchange, are not sufficient to scour out the necessary amount of sediment for the entrance to remain open.

At Raglan Estuary verification of the accuracy of the technique at this site was obtained by comparing known real-world positions with rectified image coordinates of the survey boat. An example of the results, from camera 1 during the 2006 survey, is shown in Figure 4a. It was found that, for both cameras, positions less than approximately 1000 m from the camera location, a range which encompasses most of the major intertidal features, had an overall horizontal accuracy of order 5 m.

Results from shorelines picked at corresponding low tide water levels from the two video surveys show no significant change in the size or location of any of the major intertidal mudflat features between 2005 and 2006, see Figure 4b.

The limited change in the intertidal flats and the main channel of the Raglan Estuary might be due to either a low spring runoff in

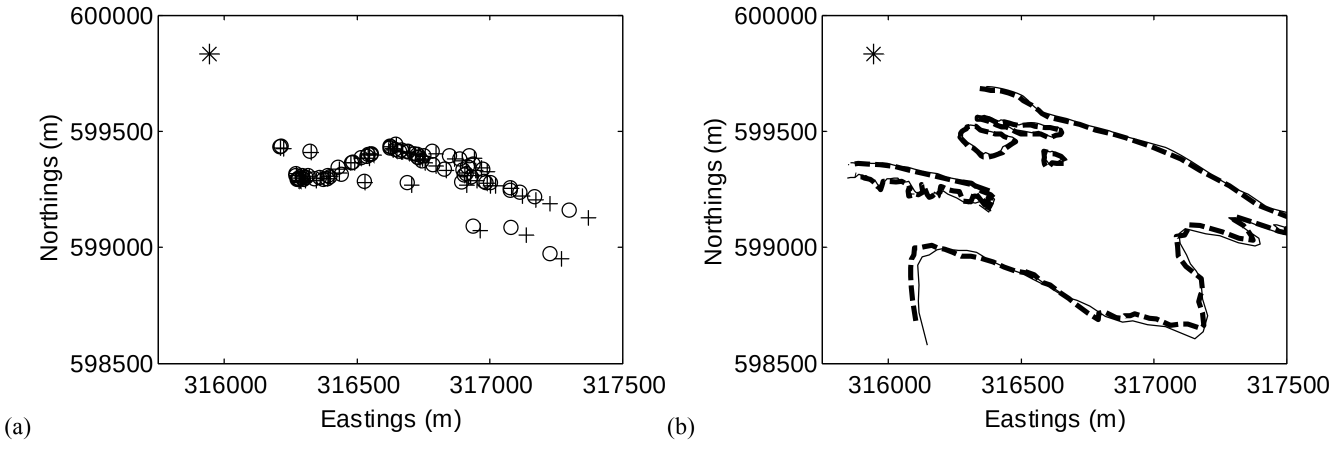



Figure 4. Results from Raglan Estuary, the camera position is shown as a star (*) in both figures. (a) Plan view showing comparison between calculated positions (+) and survey positions (o) for Camera 1 in 2006. (b) Comparison between picked rectified shorelines of major features at low tide from 2005 (solid) and 2006 (bold-dashed) surveys.

2005 (analysis of time series of river discharge and precipitation patterns is underway) or, given that the estuary is already substantially infilled and tidal flows dominate harbour circulation, it might simply be an indication of low sedimentation rates at the site analysed.

The method of obtaining bathymetry from video image data works equally well at both sites. At the Narrabeen site the normally rapidly changing morphology precludes sufficient temporal coverage using traditional survey methods. However, the video-derived mapping of the lagoon entrance overcomes this by collecting data daily. The method is further assisted by the small scale of the site and the sediment composition, ***i.e.*** predominantly beach sand, which provides a high contrast between wet and dry.

On the contrary, at the Raglan site temporal coverage is not so critical due to the slowly changing morphology. However, spatial coverage by traditional surveying is limited by the estuaries large scale, complex morphology and large expanses of shallow mudflats which are only accessible for limited parts of the tidal cycle. The wide area covered by the video images allows the instantaneous mapping of the entire study area at any given water elevation.

Thus, by detecting the wet/dry edge contours in video image data intertidal bathymetry in estuarine systems can be obtained at sites with different sediment types as well as over a wide range of spatial and temporal scales.

## CONCLUSION

Estuarine systems are an extremely complex and important part of the coastal environment. The work presented here highlights a method by which the morphology of estuarine systems can be monitored. Two contrasting estuaries are the focus of this international collaboration in order to broaden the applicability of the method; one dynamic and small-scale dominated by infilling beach sediment (Narrabeen Lagoon), the other slowly changing and large scale dominated by intertidal mudflats (Raglan Estuary). Ongoing work is focussing on the assimilation of the data collected using the video systems into numerical model simulations of the two estuaries.

## ACKNOWLEDGEMENTS

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## LITERATURE CITED

AARNINKHOF, S.G.J., TURNER, I.L., DRONKERS, T.D.T., CALJOUWC, M., and NIPIUS, L., 2003. A video-based technique for mapping intertidal beach bathymetry. *Coastal Engineering*, 49(4), 275-289.

BALOUIN, Y., MORRIS, B.D., DAVIDSON, M.A., and HOWA, H., 2004. Morphology evolution of an ebb-tidal delta following a storm perturbation: Assessments from remote sensed video data and direct surveys. *Journal of Coastal Research*, 20(2), 415-423.

ELKO, N.A.; HOLMAN, R.A., and GELFENBAUM, G., 2005. Quantifying the rapid evolution of a nourishment project with video imagery. *Journal of Coastal Research*, 21(4), 633-645.

HEATH, R.A., 1976. Broad classification of New Zealand inlets with emphasis on residence times. *New Zealand Journal of Marine and Freshwater Research*, 10(3), 677-687.

HEIKKILÄ, J., 2000. Geometric camera calibration using circular control points. *IEEE Transactions on Pattern and Machine Intelligence*, 22(10), 1066-1077.

HOLLAND, K.T.; HOLMAN, R.A.; LIPPMAN, T.C.; STANLEY, J., and PLANT, N., 1997. Practical use of video imagery in nearshore oceanographic field studies. *IEEE Journal of Oceanic Engineering*, 22(1), 81–92.

HOLMAN, R.A., SALLENGER, A.H., LIPPMAN, T.C., and HAINES, J.W., 1993. The application of video image processing to the study of nearshore processes. *Oceanography*, 6, 78-85.

HUME, T.M., 1998. Cam-Era – computer controlled monitoring of the coastal environment. *Coastal News*, NZ Coastal Society, IPENZ, Wellington, 10, 5 & 12.

MADSEN, A.J., and PLANT, N.G., 2001. Intertidal beach slope predictions compared to field data. *Marine Geology*, 173, 121-139.

MHL, 1989. Narrabeen Lagoon Entrance Study. Manly Hydraulics Laboratory, Public Works Department, N.S.W., Technical report. *MHL552*, 105p.

PLANT , N.G., and HOLMAN, R.A., 1997. Intertidal beach profile estimation using video images. *Marine Geology*, 140, 1-24.

ROY, P.S., 1984. New South Wales Estuaries: Their origin and evolution. *In:* THOM, B.G. (ed.) *Coastal Geomorphology in Australia*, Academic Press, Sydney, 99-120.

ROY, P.S., WILLIAMS, R.J., JONES, A.R., YASSINI, I., GIBBS, P.J., COATES, B., WEST, R.J., SCANES, P.R., HUDSON, J.P., and NICHOL, S., 2001. Structure and function of south-east Australian estuaries. *Estuarine, Coastal and Shelf Science*, 53, 351-384.

SHERWOOD, A.M., and NELSON, C.S. 1979. Surficial sediments of Raglan harbour. *New Zealand Journal of Marine & Freshwater Research*, 13(4), 475-496.

TURNER, I.L.; AARNINKHOF, S.G.J., and HOLMAN, R.A., 2006. Coastal imaging applications and research in Australia. *Journal of Coastal Research*, 22(1), 37-48.

WARRINGAH COUNCIL, 2002. Narrabeen Lagoon Entrance Management Policy. Warringah Council Policy Manual, *ENV-PL 420*, 6p.