Journal of Coastal Research	SI 50	1086 - 1091	ICS2007 (Proceedings)	Australia	ISSN 0749.0208

Modelling of the Gold Coast Seaway tidal inlet, Australia

G. Sennes†, B. Castelle†, X. Bertin‡, H. Mirfenderesk† and R.B. Tomlinson†

†Griffith Centre for Coastal Management
Griffith University
QLD 9726, Australia
gillessennes@msn.com
b.castelle@griffith.edu.au
h.mirfenderesk@griffith.edu.au
r.tomlinson@griffith.edu.au

‡ National Civil Engineering Laboratory
Estuaries and Coastal Zones Division
1700-066, Lisbon, Portugal
xbertin@lnec.pt

ABSTRACT

SENNES, G., CASTELLE, B., BERTIN, X., MIRFENDERESK, H. AND TOMLINSON, R.B., 2007. Modelling of the Gold Coast Seaway tidal inlet, Australia. Journal of Coastal Research, SI 50 (Proceedings of the 9th International Coastal Symposium), 1086 – 1091. Gold Coast, Australia, ISSN 0749.0208

The Seaway entrance is a tidal inlet located on the Gold Coast (Queensland, Australia). Before the 80s, the entrance was highly variable in terms of inlet location and sand bar characteristics. The Seaway stabilisation with two training walls combined with an artificial sand bypassing system were completed in 1986 with the aims of fixing the entrance, maintaining a safe navigable channel, preventing shoreline erosion to the north and a buildup of sand to the south. Despite these training works, the dynamics of the Seaway is still poorly understood: channel infilling problems and navigation issues remain. For these reasons, the present study aims to develop a comprehensive model of the entrance to be used for further dredging and training work issues. The present investigation is carried out in two stages. The first stage is based on historic aerial photograph analysis of the Seaway before training works. It shows that the mouth was periodically driven northward by the longshore drift, with an average cycle time of 10 years. The second stage is based on numerical modelling after training works. Refined Delft3D modelling is undertaken with a 2DH approach on the Seaway area, taking into account the training walls and the sand bypassing system. This local model is coupled with MIKE21 implemented on a regional scale to provide accurate tide and flow forcing at the boundaries. After calibration, the analysis of flow patterns shows that the Gold Coast Seaway is ebb-dominated and that the more intense flow velocities are observed in the northern channel. Morphological evolution of the inlet is also investigated with a qualitative approach. Results indicate the pathways and rate of the sand movement within the tidal inlet in its current configuration and provide information about a planned 400 m extension of the southern training wall. A significant calibration work, involving sediment transport and bathymetry measurement, is required for the model to be used as a comprehensive tool for further dredging and dumping strategies within the entrance.

ADDITIONAL INDEX WORDS: *bypassing, training wall, Delft3D, human impact, aerial photographs*

INTRODUCTION

Tidal inlets represent an interface between oceanic and continental systems, permanently remodelled by both tide and waves. Tidal inlets can be considered as restricted, narrow channels developed across a barrier, where tidal currents are accelerated. According to HAYES (1979), tidal inlets are usually located in meso-tidal environments with moderate wave energy. Sedimentary processes and geomorphology depend on the combined action of tidal currents and wave-induced currents. Authors have put in place energetic classifications (HAYES, 1975; DAVID and HAYES, 1984) but also geometric classifications based on the inlet morphology (BRUUN and GERRITSEN, 1960; G; HUME and HERDENDORF, 1987). Authors have also combined inlet morphology with hydrodynamics (OERTEL, 1975, 1988; NICHOLS et ALLEN, 1981). Sediment bypassing plays a key role in tidal inlet morphodynamics. Sediment bypassing includes all the processes carrying sediment from the upstream to downstream of the tidal inlet, transiting by the channels or the ebb-tidal delta. Sand generally comes from the erosion of the updrift coast, carried out by the wave-induced longshore current (FITZGERALD *et al*., 2001).

The economical and environmental importance of tidal inlets has been recognised for the last few decades. Nowadays, management of tidal inlets is not only concerned with maintaining navigable channels but also by new issues: adjacent littoral stability (ELIAS *et al*., 2006; CASTELLE *et al*., 2006), sand reserves for beach nourishments (D'AGATA and MCGRATH, 2001; CASTELLE *et al*., 2006, 2007), water replacement in the lagoons for aquaculture (BERTIN *et al*., 2007) and water quality (NEWTON and MUDGE, 2005).

The Gold Coast Seaway is located at the northern extremity of Australia's Gold Coast, Queensland (Figure 1). In the early 1980's, the entrance was stabilised with two training walls and the implementation of an artificial sand bypassing plant. Nowadays, the Gold Coast Seaway entrance is one of the busiest in Queensland with a huge fishing and recreational boat activity. However, both navigation issues during high wave events and channel infilling problems remain and the entrance behaviour is still poorly understood. Indeed, detailed studies on this area are limited (ANDREWS and NIELSEN, 2001; MIRFENDERESK *et al*., 2006). The purpose of this paper is to investigate the tidal entrance behaviour in relation with engineering works and to develop a

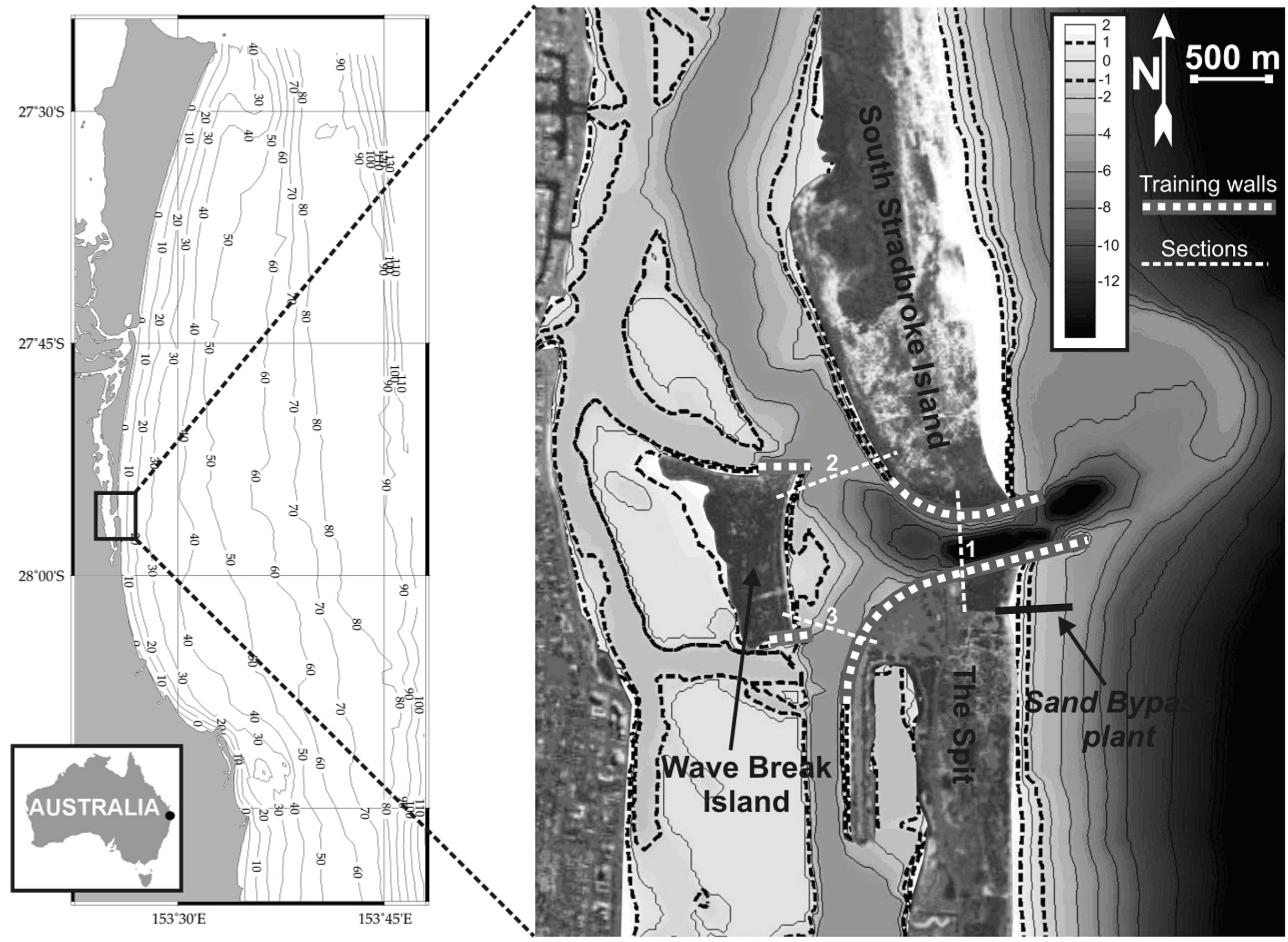

Figure 1. Location and current morphology of the Gold Coast Seaway (Queensland, Australia), with location of the training walls and the sections where flow data was collected

model of the entrance. This model is planned to be used as a comprehensive tool for further dredging and training work issues.

This study is carried out in two steps. Firstly, a conceptual model of the entrance prior to training works is undertaken using aerial photographs. Secondly, a depth-averaged modelling strategy is developed in order to assess both flow and sediment rate and pathways within the entrance.

STUDY AREA

General settings

The Seaway tidal inlet is located on the Australian East coast at a longitude of 27°56'10S and a latitude of 153°25'60E (Fig. 1). The Gold Coast Seaway represents a connection between the open ocean and the Broadwater. An extensive description of this system is given in MIRFENDERESK *et al*. (2006). The Seaway tidal cycle is a semi-diurnal cycle, varying from 0.2 to 2 m, with a mean of 1 m. The area is exposed to high energy wave conditions. Three swell regimes can be considered dominant on coastal dynamics (ALLEN and CALLAGHAN, 1999). The first one is S to SE swells in winter and spring, which contribute to the main component of the northerly longshore drift. The second swell regime is NE to E high energy swells generated by Tropical Cyclones from November to April. The third swell regime is NE to SE, generated by East Coast Lows from March to July. Sediment along the Gold Coast consists of fine sand (d_{50}=200 µm). The longshore drift along the Gold Coast is estimated to be about 500 000 m^3/year toward the north (compromise of 650 000 m^3/year toward the north and 150 000 m^3/year toward the south) (TURNER *et al*., 2006).

History of the entrance

Before the early 1980's the entrance did not provide safe access to the ocean. The permanently dynamic ebb-tidal delta was a dangerous obstacle which resulted in numerous boating accidents. The river mouth itself was migrating northward at the rate of up to 60 m/yr. For example, in 1840 the entrance was located at Main Beach near Surfers Paradise which is nowadays the main town of the Gold Coast City. These inexorable sand movements caused severe erosion of South Stradbroke Island (Fig. 1) and dangerous navigation conditions. By the early 1980's the rapid growth of the Gold Coast into the nation's premier resort area has brought with it a vast increasing boating activity. It was then decided to train the entrance to realise the full recreational and commercial potential of the Gold Coast area. Delft Hydraulics was commissioned to investigate means of stabilising the entrance and to undertake the layout design of the engineering work.

The Gold Coast Seaway stabilisation was completed in 1986 with two training walls. A new island, known as Wave Break Island, was created in order to reduce wave penetration and protect the western shore of the Broadwater. A previous report from Delft Hydraulics (DHL, 1970) made clear that, because of the high magnitude of the northerly longshore drift on the Gold Coast any scheme to stabilise the entrance would require commitment to artificial sand bypassing across the entrance. The bypassing plant was completed in 1986. Since then, the entrance is stable but its behaviour is still poorly understood. Navigation issues remain during high energy wave conditions and dredging campaigns have to be undertaken in order to address channel infilling issues.

METHODOLOGY

Aerial photographs

Aerial photographs taken by the Queensland Government Department of Natural Resources and Mines were analysed to have a better understanding of the entrance behaviour before training works. Fifteen photographs were used to assess the cyclic channel migration and to create a conceptual model of the entrance before training works.

Tidal current data

Measurements of spatial and temporal variations in tidal currents were collected within the study area by MIRFENDERESK *et al. (*2006). A broadband 1200 kHz Acoustic Doppler Current Profiler (ADCP) was used for collecting velocity data over a full tidal cycle. Among the fourteen transect lines designed for the study of MIRFENDERESK *et al*. (2006) and MIRFENDERESK (2007), three sections were located within the area of interest of the present study (Fig. 1). These sections were specifically designed to provide a quantitative measure of the volume flux, which is exchanged between the open ocean and the estuarine system.

Numerical modelling

Coastal model Delft 3D, developed by Delft Hydraulics (ROELVINK and BANNING, 1994), is used in this study to simulate tide- and wave-induced currents. The computational grid is rectangular with a first mesh size of 400*100 m and refined around the Seaway area with square meshes of 20*20 m. The wave model used herein is SWAN (BOOIJ *et al.*, 1999). Typical wave conditions on the Gold Coast were implemented at the offshore boundary conditions, i.e. a SE swell with a significant wave height *Hs* of 1.5m, and a peak wave period *Tp* of 8 s. The depth-averaged (2DH) mode of the flow module is used for the simulations. The wave-induced forces are given by the spatial gradient of the radiation stress tensor (LONGUET-HIGGINS, 1964). The bed shear stress is given by the quadratic friction law and has been calibrated by tuning the Chezy coefficient C_D. The Bijker formula (BIJKER, 1971) was used to compute sediment transport and bed evolution. Both the artificial sand bypassing plant and training walls were taken into account in the model.

This morphodynamic model is coupled with a hydrodynamic MIKE 21 model (DHI WATER & ENVIRONMENT) which was developed by the Griffith Centre for Coastal Management (GCCM) at a regional scale (MIRFENDERESK, 2007). Within the Broadwater, the lateral boundary conditions were forced with water level and flow provided by the MIKE 21 regional modelling. The hydrodynamic model was calibrated against measured flow data along transects 1, 2 and 3 (Fig. 2)

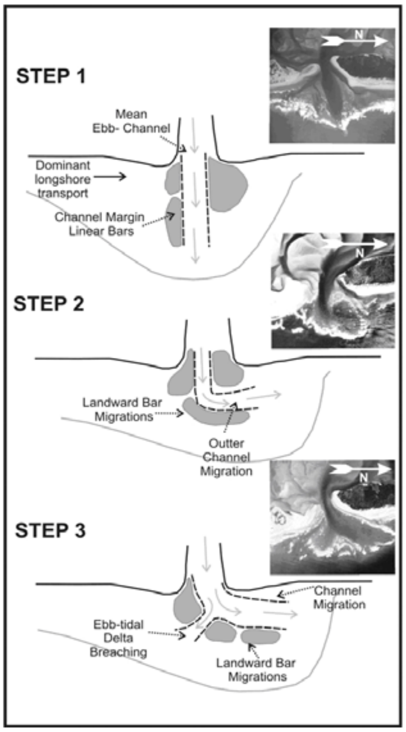

Figure 2. Conceptual model adapted to the Gold Coast Seaway tidal inlet prior to training works

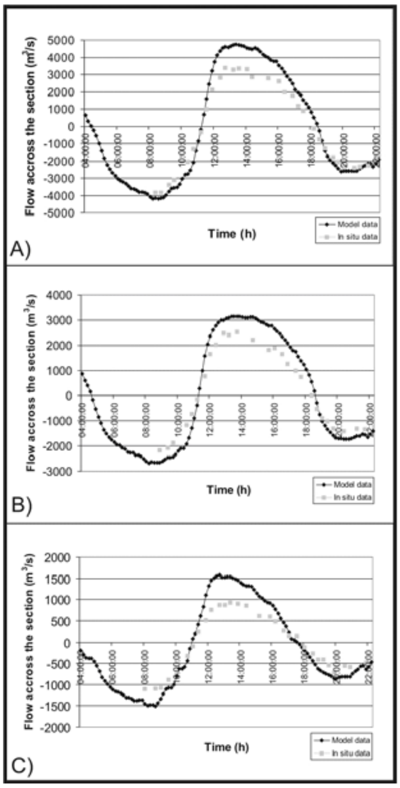

Figure 3. Comparison of computed flow across the sections (see Fig. 1 for location of the three sections) with field measurements: A) Section 1; B) Section 2; C) Section 3.

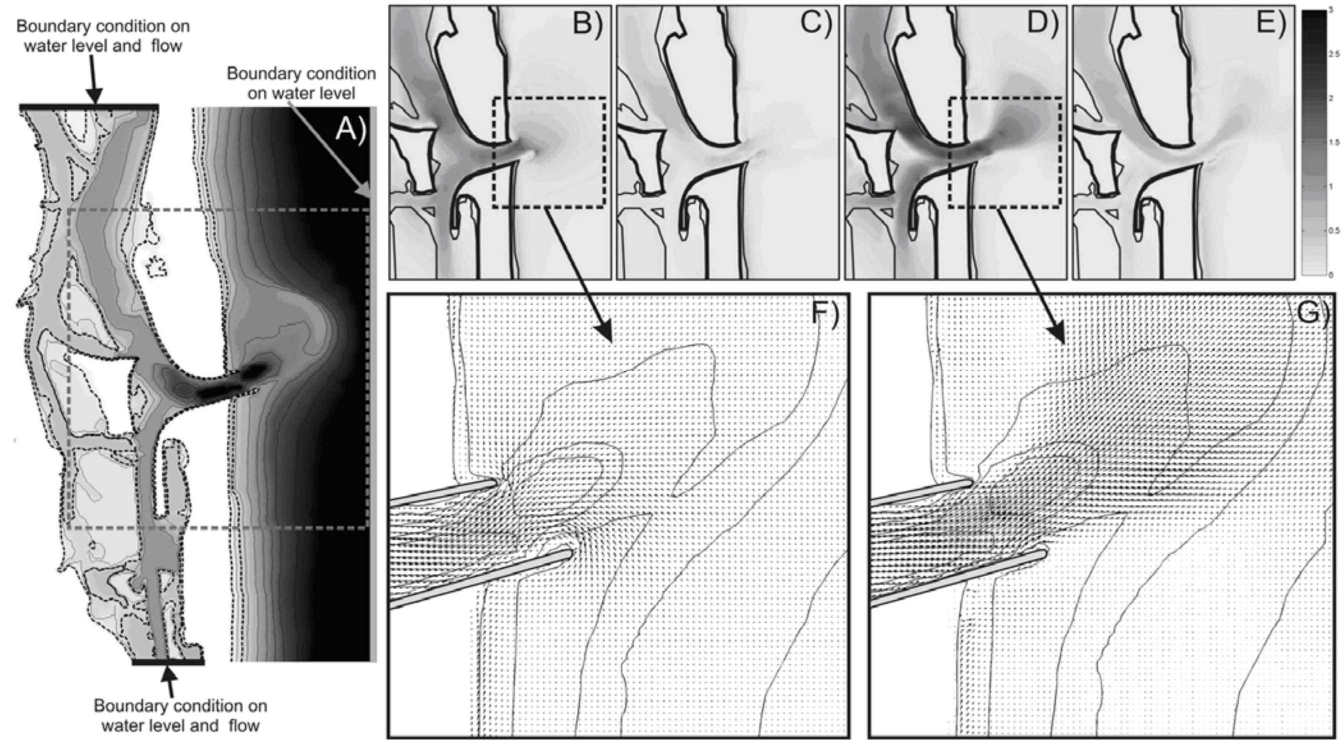

Figure 4. Simulation of tide- and wave-induced currents in the Seaway area. A) Modeling area and boundary conditions; Depth average flow velocity (m/s) with offshore SE swell (H_S= 1.5 m, Tp=8 s) B) Jan 12 at 8h30 (Flood); C) Jan 12 at 11h (High tide); D) Jan 12 at 13h30 (Ebb); E) Jan 12 at 18h00 (Low tide); F) zoom on veolicty vectors Jan 12 at 8h30; G) Zoom on velocity vectors Jan 12 at 13h30

RESULTS

Conceptual model

The analysis of 15 aerial photographs from 1955 to 1985 has permitted to demonstrate the Seaway inlet morphological changes. The main channel evolution seems to follow a cyclic downdrift shifting, which is similar to the outer channel shifting model of FITZGERALD et al. (2001). A 3-stage conceptual model can be established as a synthesis for these evolutions. In agreement to FITZGERALD et al. (2001), the entire cycle takes about 10 years to be completed (Fig. 2):

(1) The main channel is perpendicular to the shore and the ebb-tidal delta consists of elongated sand bodies, which develop on each side of it.

(2) The Outer part of the channel migrates downdrift and tends to parallel the shore. This new setting caused the erosion of the downdrift part of the ebb-tidal delta, while sand tends to accumulate updrift.

(3) A breach occurs within the updrift ebb-tidal delta and leads to the development of a second channel and a net movement of the entrance downdrift. This new channel is more hydraulically efficient and will catch a larger part of the tidal prism, causing the ancient channel to be progressively abandoned.

This conceptual model illustrates the strong morphological variability this tidal inlet has experienced before the early 1980's. The subsequent navigation and shoreline movement issues have then motivated its stabilisation with training walls and artificial sand bypassing.

Hydrodynamics

Simulations were performed for values of the spatially constant Chezy coefficient C_D ranging from 20 to 260. This coefficient governs both the magnitude of flow and the phase difference of maximum flow occurrence at the different sections of the inlet. Best results were obtained for C_D=40, which was the best compromise between flow magnitude accuracy and temporal occurrence of maximum ebb and flow velocity magnitude. Figure 3 shows the comparison between computed and measured flow across the three sections over a tide cycle. The model slightly overestimates the flow magnitude, particularly in the southern channel (section 3, see Fig. 1). However, the model shows an overall agreement with field data.

The calibrated model was used to address flow pattern around the Gold Coast Seaway. Figure 4 shows the typical computed flow magnitude around the Gold Coast Seaway at low tide, high tide, ebb and flood. Simulations show that the Gold Coast Seaway is ebb-dominated and that the more intense flow velocities are observed in the northern channel (section 2 of Fig. 3 and Fig. 4). Overall flow patterns within the entrance are in agreement within the Broadwater are in agreement with MIRFENDERESK (2007). Results also show that tide-induced currents do not significantly interact with wave-induced currents and that tide-induced currents are significant up to 1500 m offshore Fig. 4F and 4G.

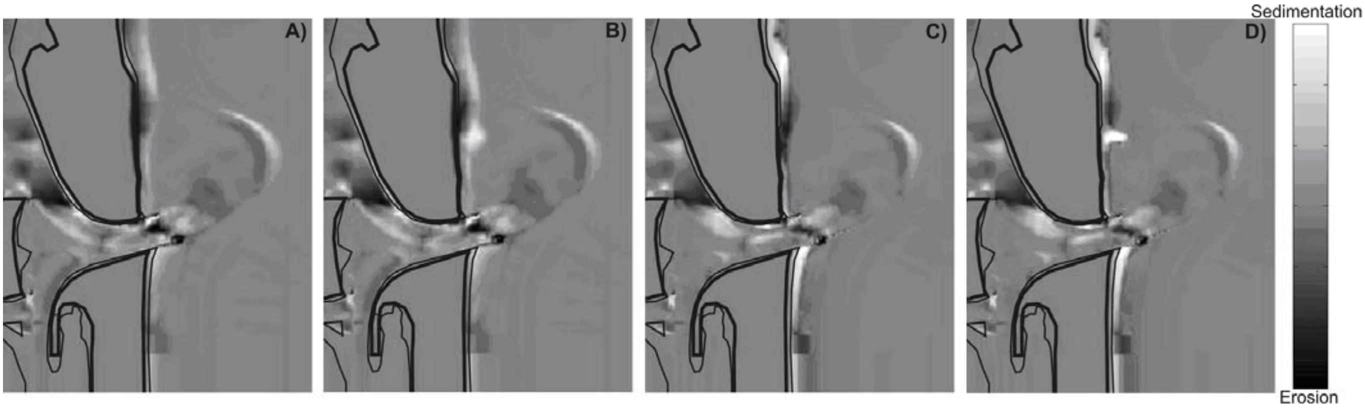

Figure 5. Erosion/sedimention patterns around the Gold Coast Seaway after a 12 day simulation. A: Current configuration without the sand by-pass system; B: Current configuration with the sand by-pass system; C: Configuration with the southern training wall extension but no sand by-pass system; D: Configuration with the southern training wall extension and the sand bypass system.

Sediment transport and morphological evolution

There is a considerable amount of detailed survey (at least every 6 months) by Queensland Transport for the Seaway. However, there is a lack of detailed regional morphology necessary for complete calibration of sediment transport. Thus, qualitative assessment of sediment transport pathway and morphological evolution of the area was undertaken. Figure 5 shows erosion/sedimentation patterns in the area in its current configuration without the sand bypassing plant (Fig. 5.A) and with the sand bypassing plant (Fig. 5.B). Due to proposed construction a cruise ship terminal, involving a required 400 m extension of the southern training wall, the impact of such a project on sediment pathways was also investigated without the sand bypassing plant (Fig. 5.C) and with the sand bypassing plant (Fig. 5.D). Simulations show that:

- The inlet has infilling problems
- Artificial sand bypassing reduces erosion of the downdrift beaches, as expected.
- Sedimentation is more intense in the southern channel than in the northern channel (Figure 5.A and 5.B). This is confirmed by field observations.

Results show that the 400 m southern training wall extension would significantly increase channel sedimentation. Changes in tide-induced flow patterns would also result in a significant modification of the ebb-delta shape (Fig. 5.C and 5.D). Further numerical exercises, involving sediment transport calibration, have to be done in order to make a more in-depth investigation of the morphological evolution of the entrance.

DISCUSSION AND CONCLUSIONS

Before training works, the tidal entrance investigated in this paper was highly variable in terms of both position and morphology. Aerial photographs were analysed to undertake a conceptual model of the entrance in its natural configuration. Results show the unstable behaviour of the discharge point prior to training works associated with a cyclic channel migration (on a ten year period). A 2DH model of the Gold Coast Seaway was developed, with tide forcing provided by the MIKE21 model used on a regional scale by GCCM. The model is in good agreement with measured flow in the area. Results confirm that the inlet is ebb-dominated with maximum flow intensity occurring in the northern channel. This study shows once again the appropriateness of the depth-averaged flow approach for tidal inlet investigations. In particular, this kind of approach provides relatively low time-consuming both computations and calibration works.

Sediment transport and bed evolution modelling also provided qualitative information on sediment transport rate and pathways in the area. This part of the modelling work requires further in depth calibration works in order to be used for improving the current dredging and dumping strategy within both the entrance and the Broadwater area. This model enhancement can be done only by undertaking an extensive field measurement within the area involving both sediment transport and bathymetric survey analysis.

The engineering works undertaken on the inlet have been successful in stabilisation of the entrance and reduction of navigation hazards. Thus, it has greatly improved both recreational and economical activity of the Gold Coast area. However, the model developed for this study clearly identifies infilling areas remaining within the entrance. One reason could be the building of the Wavebreak Island and other land reclamation works within the Broadwater which have led to a significant decrease in intertidal zones, as shown in Figure 1 with respect to Figure 2. Actually, the presence of wide intertidal areas and tidal flats causes tidal asymmetry and tends to enhance ebb-dominance (FRIEDRICHS and AUBREY, 1988; FORTUNATO and OLIVEIRA, 2005). The new bathymetric setting subsequent to engineering works could have thus decreased the ebb-dominated behaviour of the tidal inlet and could explain why infilling problems persist.

Recently, the proposed construction of a cruise ship terminal, involving a required 400 m extension of the southern training wall, raised high community concerns and environmental issues. The impact of this engineering work is qualitatively investigated in this study. In particular, this study shows that such a project would significantly change the ebb-tidal delta morphology and would aggravate channel infilling problems and would result in significant increase of the dredging costs. A fully calibrated model would be useful to confirm this hypothesis.

ACKNOWLEDGEMENTS

The research presented in this paper was performed within the framework of the development of a Gold Coast Shoreline Management Plan (GCSMP) on behalf of the Gold Coast City Council.

LITERATURE CITED

ALLEN, M. and CALLAGHAN, J., 1999. Extreme wave conditions for the South Queensland coastal region: Environmental Protection Agency Report, 7p.

ANDREWS, M. and NIELSEN, C., 2001. Numerical modelling of the Gold Coast Seaway. *Proceedings of Coasts & Ports* 2001 (Gold Coast, Australia), pp. 469-474.

BERTIN, X., CHAUMILLON, E., SOTTOLICHIO, A. and PEDREROS, R., 2005. Tidal inlet response to sediment infilling of the associated bay and possible implications of human activities: the Marennes-Oléron Bay and the Maumusson Inlet, France. *Continental Shelf Research*, 25, 1115-1131.

BIJKER, E., 1971. Longshore transport computations. *Journal of Waterways*, Harbors and Coastal Eng. Div. ASCE, 97(WW4), 687-701.

BOOIJ, N., RIS, R., HOLTHUIJSEN, L., 1999. A third generation wave model for coastal regions, part i: Model description and validation. *Journal of Geophysical Research*, 104 (C4), 7649-7666.

BRUUN P., GERITSEN, F., 1960. Stability of coastal inlets. *North Holland publ. Co., Amsterdam*, 123 p.

CASTELLE, B., BOURGET, J., MOLNAR, N., STRAUSS, D., DESCHAMPS, S., TOMLINSON, R.B., 2007. Dynamics of a wave-dominated tidal inlet and influence on adjacent beaches, Currumbin Creek, Gold Coast, Australia, *Coastal Engineering*, 54, 77-90

CASTELLE, B., LAZAROW, N., MARTY, G. and TOMLINSON, R.B., 2006. Impact of beach nourishment on Coolangatta Bay morphology over the period 1995-2005. *Proceedings of the 15th NSW Coastal Conference* (Coffs Harbour, New South Wales, Australia), 12p.

DAVID, R.A. and HAYES, M.O., 1984. What is a wave-dominated coast? *Marine Geology*, 60, 313-329.

DHL, 1970. Gold Coast, Queensland, Australia – Coastal erosion and relative problems. Delft Hydraulics Laboratory, The Netherlands, Report R257.

ELIAS, E.P.L., CLEVERINGA, J., BUIJSMAN, M.C., ROELVINK, J.A. and STIVE, M.J.F., 2006. Field and model data analysis of sand transport patterns in Texel tidal inlet (The Netherlands). *Coastal Engineering*, 53, 505-529.

FITZGERALD, D.M., KRAUS, N.C. and HANDS, E.B., 2001. Natural Mechanisms of Sediment Bypassing at Tidal Inlets. Coastal Engineering Technical Note US Army Corps of Engineers ERDC/CHL CETN-IV- 30. U.S. Army Engineer Research and Development Centre, Vicksburg, MS.

FORTUNATO, A.B., OLIVEIRA, A., 2005. Influence of Intertidal Flats on Tidal Asymmetry, *Journal of Coastal Research*, 21(5), 1062-1067.

FRIEDRICHS, C.T. and AUBREY, D.G., 1988 Non-linear tidal distortion in shallow well-mixed estuaries: a synthesis. Estuarine Coastal and shelf Science 27 (5), 521-545

HAYES, M.O., 1975. .Morphology and sand accumulation in estuaries. Estuarine Research, L.E.Cronin (ed.). *Academic press*, New York, vol.2, 183-200.

HAYES, M.O., 1979. Barrier island morphology as a function of tidal and wave regime. *In*: LEATHERMAN, S.P. (ed.), *Barrier Islands, from the Gulf of St Laurence to the Gulf of Mexico.* Academic Press, N.Y., pp. 1-28.

HUME, T.M. and HERDENDORF, C.E., 1987. Tidal inlet stability: Proceedings of a workshop, Christchurch, 4th December, 1985. Water & Soil Miscellaneous Publication n° 108, 987, 82p.

JACKSON L. A. (1989). Gold Coast beaches, review of protection, management and funding strategies.

LONGUET-HIGGINS, M., STEWART, R., 1964. Radiation stress in water waves: a physical discussion with application. *Deep Sea Research*, 11, 529-562.

NEWTON, A. and MUDGE, S.M., 2005. Lagoon-sea exchanges, nutrient dynamics and water quality management of the Ria Farmosa. *Estuarine, Coastal end Shelf Science*, 62, 405-414.

MIRFENDERESK, H., TOMLINSON, R.B., SZYLKARSKI, S. and RASMUSSEN, E.B., 2006 Development of 3D Model to Understanding a Modified tidal Entrance Dynamic. *Proceedings of ICCE* (San Diego, Californian, USA).

MIRFENDERESK, H., 2007. Numerical simulation of water movement in a coastal lagoon of the Coral Sea. *Proceedings of ICS 2007* (Gold Coast, Queensland, Australia).

NICHOLS, M.M. and ALLEN, G., 1981. Sedimentary processes in coastal lagoons. Coastal lagoons research, present and future, UNESCO, Tech. Pap. Mar. Sc. 33, 27-80.

OERTEL, G.F., 1975. Ebb-tidal delta of Georgia estuaries. *Estuarine Research*, 2, 267-276.

OERTEL, G.F., 1988. Processes of sediment exchange between tidal inlets and barrier islands. In: D.G. Aubrey and L.Weishar (ed.), Hydrodynamics and Sediment Dynamics of Tidal Inlets, New York: Springer-Verlag, 186-225.

ROELVINK, J.A. and BANNING, G.K.F.M., 1994. Design and development of Delft3D and application to coastal morphodynamics. Hydroinformatics '94, VERMEY, MINNS, BABOVIC & MAKSIMOVIC (ED.), BALKEMA, ROTTERDAM,451-455

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