Gold Coast Shoreline Process Modelling

Ian Teakle[1] , Chris Huxley[1], Dean Patterson[1], Jesper Nielsen[1] and Hamid Mirfenderesk[2]
[1] BMT WBM, Brisbane, Australia. ian.teakle@bmtwbm.com.au
[2] Gold Coast City Council, Gold Coast, Australia.

Abstract
This paper presents a coastal process modelling system developed for Gold Coast City Council, including wave model, 2D hydrodynamic and morphodynamic model and a shoreline evolution model using newly developed software. The EVO shoreline evolution prediction software has been developed to simulate coastal shoreline response across a range of timescales from individual storms to centuries. Both longshore and cross-shore response processes are represented and effectively coupled. This paper demonstrates the application of the model to scenario assessments for the Gold Coast and highlights the importance of coupling both longshore and cross-shore processes for analysing sea level rise response.

Keywords: Gold Coast, Coastal Process Modelling, Shoreline Evolution

1. Introduction

The dynamic nature of the Gold Coast – its location, growth, development and demand for services – makes its exposure to climate change particularly unique. Protection of natural assets, strengthening the economy, population growth and building a sustainable community currently represent some of the greatest challenges faced by Gold Coast City Council (GCCC). These challenges are all affected by the potential impact of climate change. In recognition of the future climate change risks, GCCC have developed a number of strategies which represent a contemporary, adaptive management framework providing a well-defined direction for responding to climate change risks/challenges with the aim to develop resilience to future impacts.

GCCC commissioned a coastal process modelling study to help inform their future climate change adaption response policy and planning decisions. The output of the study was to provide GCCC with a modelling suite that is capable of simulating near-shore hydrodynamics and coastal morphology/sediment transport along the Gold Coast shoreline.

A modelling toolkit has been developed for the coastline extending from the Tweed River entrance to South Stradbroke Island. The models include representation of key physical coastal evolution features and man-made protection measures within the study area, e.g. headlands, groynes, seawalls, sand bypassing at the Tweed River and Gold Coast Seaway, as well as the tidal interactions with the various estuaries.

The developed coastal process modelling toolkit comprises:

- SWAN wave propagation model/s;
- TUFLOW-FV hydrodynamic and littoral sediment transport model;
- EVO coupled cross-shore – longshore model for simulation of long-term historic and future shoreline evolution.

The model/s can be used to describe and assess:

- Longshore sediment transport along the Gold Coast shoreline;
- Cross-shore erosion resulting from coastal storm events;
- Impact of proposed coastal works in terms of shoreline response; and
- Impact of climate change (e.g sea level rise and coastal storm erosion) in terms of shoreline response.

This paper presents:

- a general description of the EVO shoreline evolution model;
- an overview of the coastal process model toolkit developed for GCCC; and
- results from some example scenario simulations.

2. EVO Model General Description

EVO is a shoreline evolution model that can represent the response to a range of processes of varying timescales as illustrated in Figure 1:

- short term processes (e.g. storm response);
- medium term processes (e.g. long-shore transport gradients);and
- long term processes (e.g. sea level rise).

2.1 Key Features

Key features of EVO are:

- Suitability for medium- to long-term simulations (years to centuries);
- Continuous (timeseries) forcing by offshore wave climate and water levels;
- Represents complex shorelines using a flexible Curvilinear grid;
- Uses “external” wave model derived wave transformation tables;

- Inshore wave transformation to breaking using linear theory;
- Coupled long-shore and cross-shore shoreline response;
- Longshore transport based on CERC formula;
- Cross-shore response based on ‘Equilibrium Profile Concept’;
- Representation of controls e.g. Groynes and Headlands; and
- Representation of seawalls and reefs.

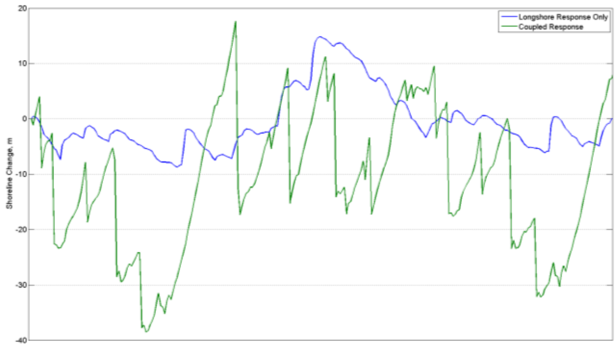

Figure 1 Example shoreline position timeseries. Blue – longshore transport only; Green – coupled longshore/cross-shore transport response.

The curvilinear grid is illustrated in the figure below and overcomes the problem of shoreline definition that conventional shoreline models with linear baseline grids experience for complex and highly embayed coastlines.

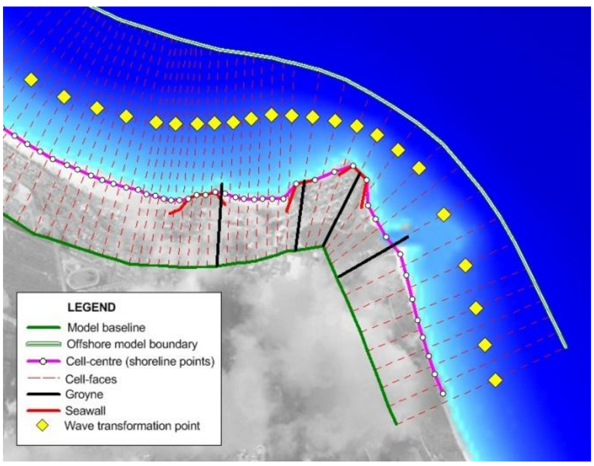

Figure 2 Example Curvilinear EVO Domain.

The EVO update scheme involves a fully coupled response to both longshore and cross-shore processes.

2.2 Long-shore response model

Longshore transport potential is calculated at the curvilinear grid cell-faces using the CERC formula. The influence of groyne structures, headlands and seawalls on the longshore transport rate is accounted for using a simple fraction active parameterisation. Longshore transport rate gradients are used to derive a volume change for the shoreline position update routine.

2.3 Cross-shore model

In addition to the longshore gradient response, the EVO shoreline position update can also take into account the cross-shore response using a parametric equilibrium profile model. Two parametric models have been developed to date.

The first “simple” model type does not respond to instantaneous wave conditions and therefore when using this configuration the EVO model is similar to the traditional one-line models, except that it is capable of analysing long-term sea level rise response.

The second cross-shore model type is based on the dynamic equilibrium profile parameterisation detailed in Huxley (2011). This model has a geometric representation (Figure 3) of the cross-shore profile which evolves towards a parameterised equilibrium with the instantaneous wave and water level conditions using a lagged response model. An example erosive response during a storm event is illustrated in Figure 4. Cross-shore erosion and accretion response time-scales are determined through model calibration, and will generally differ by an order-of-magnitude or more.

3. Gold Coast Wave Model

A central component of the coastal process modelling system developed for GCCC was a series of nested SWAN spectral wave models as shown in Figure 5. The models have been developed in order to transform wave conditions, as measured at the Point Lookout or Byron Waverider Buoys into the Gold Coast embayment.

Validation of the wave model transformation results has been performed against a range of nearshore measured datasets supplied by the Queensland Department of Environment and Heritage Protection (DEHP) and GCCC, including:

- DEHP Gold Coast waverider buoy;
- 2010 Gold Coast Seaway and Palm Beach measurements; and
- 2011 nearshore measurements (Kirra, Tugun, Palm Beach, Burleigh and Narrowneck);

The 100m nested domains were used to extract near-shore wave conditions at around the 10m depth contour. Higher resolution (20m) domains were also developed for coupling with the TUFLOW-FV hydrodynamic and morphodynamic model.

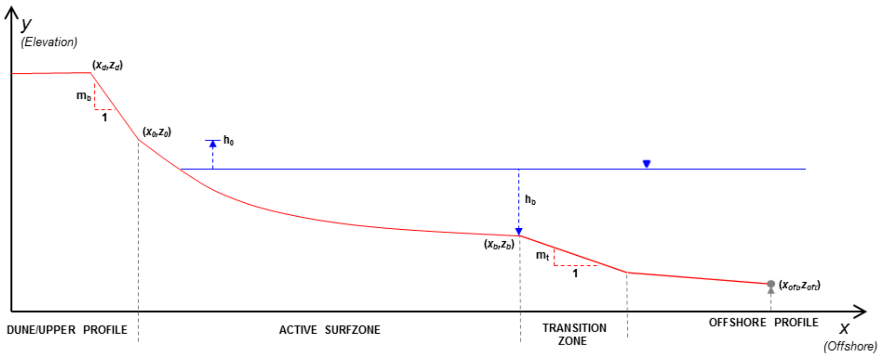

Figure 3 Huxley (2011) cross-shore parametric model construction.

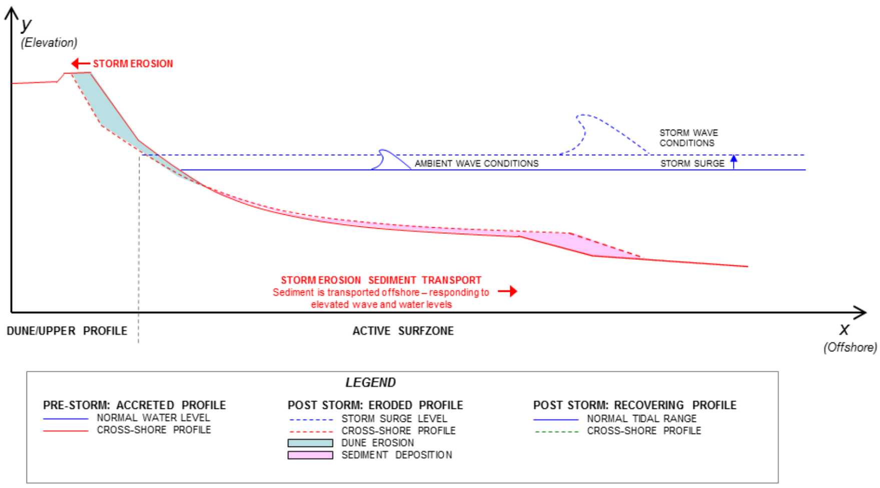

Figure 4 EVO cross-shore storm response.

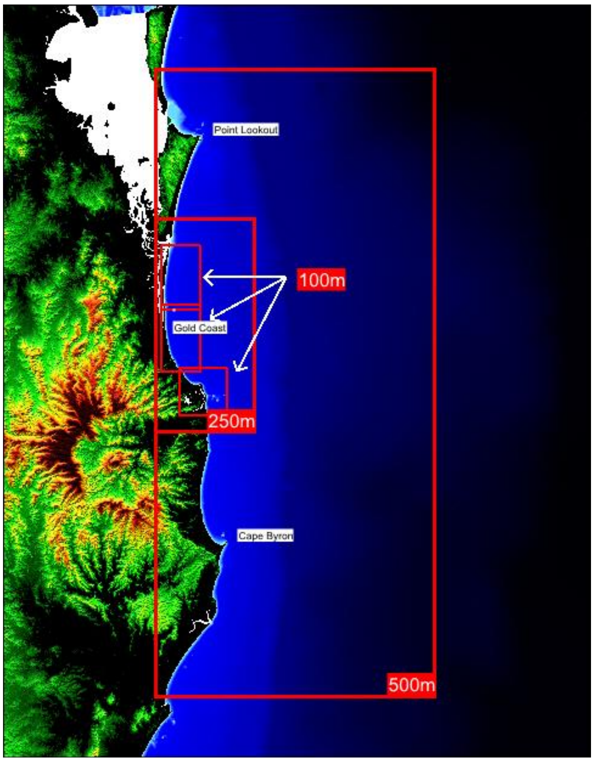

Figure 5 Gold Coast SWAN model grids.

Wave transformation tables for Point Lookout to 63 nearshore locations were developed as an input to the Gold Coast EVO model, which interpolates the prevailing nearshore wave conditions at each time step from the input deep water time series. The transformation tables were developed for the following offshore wave conditions:

- H_s = 1, 4, 10 m;
- T_p = 5, 7, 10, 13, 20 s; and
- Dir_p = 10, 20, 40, 60, 80, 100, 120, 140, 160, 170 degrees true.

4. Gold Coast EVO Model

4.1 Domain

The Gold Coast EVO model extends approximately 50km from Letitia Spit in the south to Jumpinpin in the north as shown in Figure 2 4. The model has a grid resolution of 50-200m in the region from the Tweed River to the Gold Coast Seaway.

4.2 Boundary Conditions

Offshore wave boundary conditions were derived from the Point Lookout waverider buoy measurements, which provide the necessary directional data post 1996. For simulations outside the period 1997-2012, the available wave data has been looped. Representative offshore water level boundary conditions were derived from the Gold Coast Seaway tide gauge measurements. A constant 550,000m^3/annum sediment supply rate is input to the southern model boundary based on Patterson et al. (2011), while the northern model boundary is pinned.

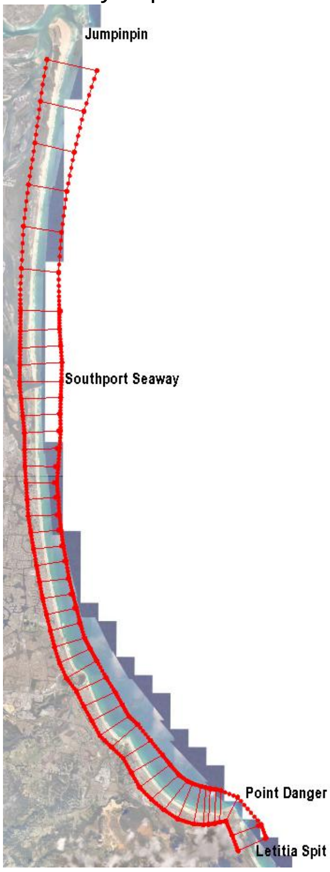

Figure 6 Gold Coast EVO model domain

During the simulation the most significant littoral zone structural works were dynamically added to the model as summarised in the following table.

Table 1 Gold Coast Model Structure Components.

Date	Name
1963	Tweed River Walls
1972	Kirra Point Groyne
1973	Currumbin Groyne
1975	Little Kirra Groyne
1978	Tallebudgerra Groyne
1984	Palm Beach Groynes
1986	Gold Coast Seaway

Mechanical bypassing by both dredging and trestle systems is included as sink/source terms while nourishment from offshore borrow areas are included as source terms only. An offshore supply of sand to the Spit (north of Narrowneck) as identified in Patterson (2013) has also been included as a littoral zone sediment source.

4.3 Other Details

The Gold Coast model is run using an hourly timestep in order to have sufficient temporal resolution to respond to storm events.

A 1000 year warmup of the model was performed in order to lose initial condition dependent transients from the simulation prior to performing hindcast or forecast simulations. A key measure of the model setup validation was that it closely matched the pre-development (circa 1950) shoreline at the end of the warmup period.

4.4 1950-2012 Hindcast

A hindcast of the period from 1950-2012 was performed as a means of validating the model performance against the observed evolution of the Gold Coast beaches during this period. As mentioned, the boundary conditions prior to 1997 used looped data from 1997-2012 (for which measured directional wave data is available). Therefore the simulation does not directly replicate the substantial storm-induced erosion during the late 1960's and 1970's. It is also likely that the model forcing is somewhat biased towards an El Nino dominated wave climate, due to the predominance of this ENSO pattern during the period of available wave data. Never-the-less, the substantial impact of the structural works between 1963 and 1986 is still well represented by the hindcast approach using available data, and actual events in the period 1997-2012 are fully represented.

The most significant impact on the Gold Coast system during this period resulted from the construction of the Tweed River training walls in 1963. Macdonald & Patterson (1984) documented that by 1983 erosion of 5.7M m^3 had occurred in the section from Point Danger to Bilinga. Roelvink and Murray (1992) estimated a total of 7.2Mm^3 had eroded from the southern Gold Coast beaches by the time that dredge bypassing and nourishment commenced in the late 1980's. This volume gain and deficit responses can be seen in the model predictions in Figure 7. Note that substantial dredge bypassing and nourishment events occurred prior to sand bypassing in 2000, offsetting some of the sand loss.

The volume change response downdrift of Bilinga was further complicated by the construction of the Currumbin Rock groyne and Tallebudgerra Groyne in the 1970s. A deficit of around 1.5Mm^3 was predicted to peak at Burleigh in the early 1990's before recovering slightly. The sand deficit is seen to migrate progressively to the north and is currently predicted to be reaching a minima in the Miami-Nobby to Broadbeach compartment; a prediction which correlates well with this areas current predicament as an erosion "hotspot".

Validation against ETA-line survey data was also undertaken for the 1997-2012 period for which the actual forcing data has been used. An example of the model validation for Narrowneck is shown in Figure 9. The different timescales for erosive and accretive responses can be clearly seen in this figure.

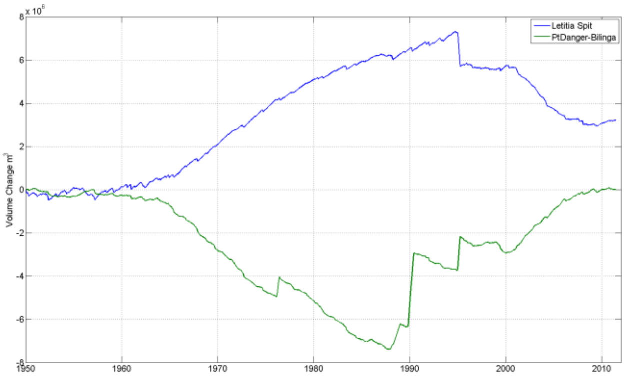

Figure 7 Volume gain/deficit 1950-2012for Letitia Spit and Southern Gold Coast beaches.

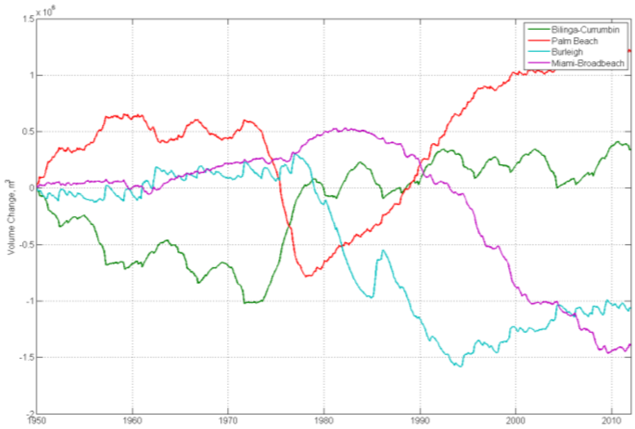

Figure 8 Volume Change 1950-2012 downdrift of Bilinga, including the response to Kirra and Currumbin groynes.

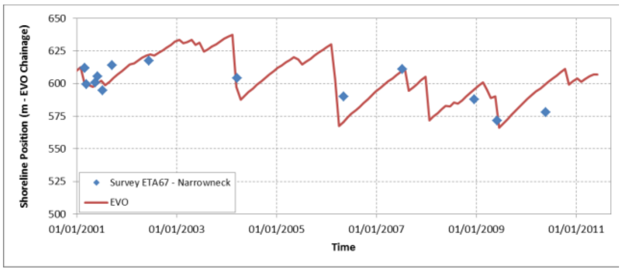

Figure 9 Model Validation against Narrowneck ETA survey data.

5. Example Scenario Simulations

5.1 Existing Climate Forecast

The hindcast simulation was extended with a forecast to the year 2097, simply looping the 1997-2012 wave and water level datasets for boundary conditions. An "existing" climate simulation was performed assuming a base case zero rate of sea level rise. This simulation is interesting from the perspective of understanding what sand supply problems have arisen due to interference in the littoral zone during the 1960s to 1980s and how the system will continue to respond to this in the future.

Figure 10 shows predicted southern Gold Coast beach shoreline position timeseries for the 1950-2097 period. The results show the effect of the Tweed River training wall sand supply deficit, peaking in the late 1980s prior to first dredged and then pumped bypassing of sand. The truncated shoreline retreat at Coolangatta and Kirra demonstrates the activation of seawalls at these locations. The model analysis shows full recovery of these beaches (and some prior overshoot) by circa 2010.

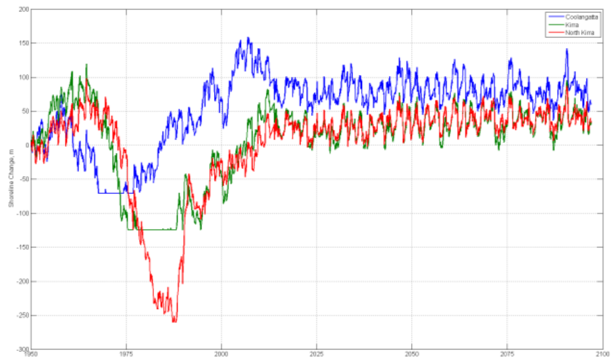

Figure 10 Hindcast and forecast (1950-2012) shoreline position predictions for Coolangatta, Kirra and North Kirra beaches.

On the other hand Figure 11 shows the modelled response of three beaches north of Burleigh Headland; Miami-Nobby, Broadbeach and Narrowneck. The results show the lagged response of Miami-Nobby Beach to the induced littoral supply deficit and the very slow rate of recovery due to the significant distance to the downdrift control point at the Gold Coast Seaway.

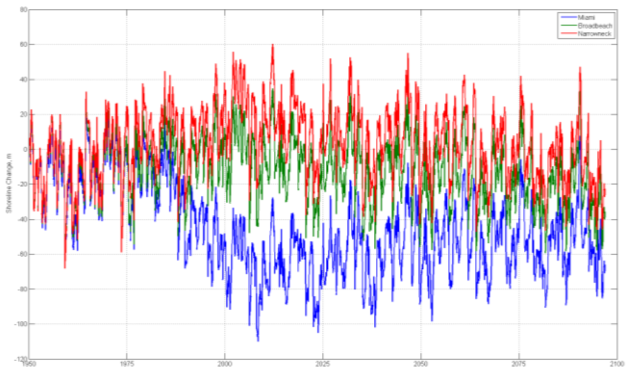

Figure 11 Hindcast and forecast (1950-2012) shoreline position predictions for Miami-Nobby, Broadbeach and Narrowneck.

5.2 Sea Level Rise Forecast

A second scenario analysis was performed including 0.9m of Sea Level Rise occurring at a constant rate between 1997 and 2097. From this analysis the model results indicate a substantial difference between the response of beach systems updrift and downdrift of headland controls.

For instance, the Tugun and Palm Beach shoreline response in Figure 12 shows effectively no progressive shoreline retreat due to the sea level rise. This can be understood in terms of these locations relatively close proximity to downdrift control features (Currumbin and Burleigh headlands respectively). At these locations the profile position is effectively controlled by the downdrift control while the littoral supply is capable of feeding the sand surplus requirements associated with the upward Bruun rule profile translation.

However, this updrift response obviously results in a littoral supply deficit downdrift of the control, which can be seen in the progressively eroding response predictions for the Miami-Nobby and Narrowneck shorelines in Figure 13. In particular, the Miami-Nobby beach location just downdrift of Burleigh headland means that in response to sea level rise it experiences both the Bruun rule profile translation and a littoral supply deficit. This effectively amplifies the recession rates and has the very significant effect that the duration for which there is a beach in front of the seawalls reduces progressively, particularly at Miami-Nobby, where the beach width reduces to near zero by around 2070.

6. Discussion

The coastal process modelling system described in this paper introduces an ability to analyse shoreline evolution of the entire Gold Coast system over a broad span of timescales. As demonstrated, this greatly enhances our ability to understand the historical and ongoing impacts from past changes imposed on the coastal system.

The importance of considering coupled cross-shore and longshore response in the analysis of sea level rise impacts has been demonstrated using the model.

Further validation of the model and insight into recent erosion problems could be gained by extending the analysis to include the recent storms. Improvements to the shoreline hindcast and forecast modelling assessments could potentially be gained through access to an extended boundary condition dataset, if a reliable wave hindcast dataset was available.

7. Acknowledgements

The authors would like to acknowledge Gold Coast City Council, which funded the shoreline modelling project.

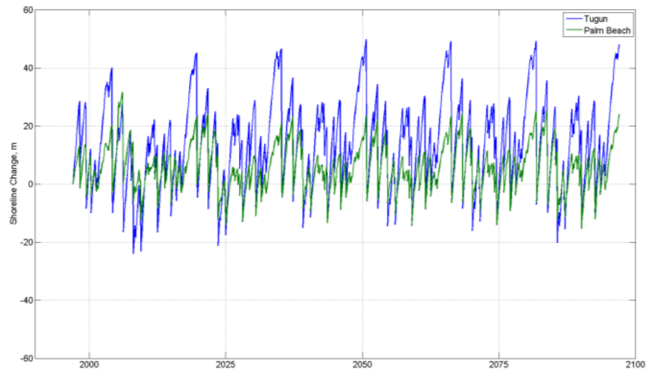

Figure 12 Forecast shoreline response with Sea Level Rise at Tugun and Palm Beach.

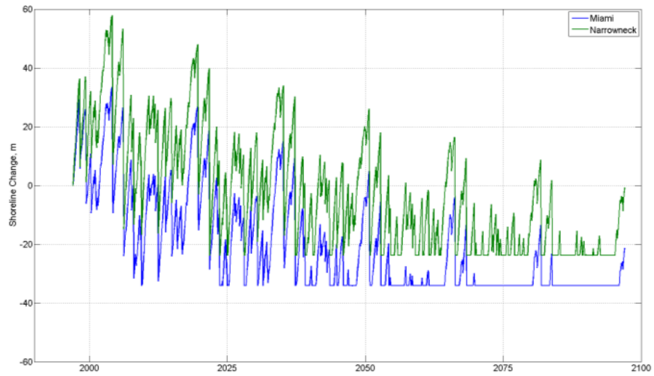

Figure 13 Forecast Shoreline response with Sea Level Rise at Miami-Nobby Beach and Narrowneck.

8. References

Huxley, C.D., 2011. Quantification of the physical impacts of climate change on beach shoreline response, Master's Thesis, The University of Queensland, Brisbane, 141 pp.

Macdonald, H.V. & D.C. Patterson, 1984. Beach Response to Coastal Works, Gold Coast Australia. Proc. 19th ASCE Coastal Engineering Conference, 1984, Houston Texas.

Patterson, D.C., G. Elias & P. Boswood, 2011. Tweed River Sand Bypassing Long Term Average Sand Transport Rate. Proc. 28th NSW Coastal Conference, Tweed Heads.

Patterson, D.C., 2013. Modelling as an aid to understand the evolution of Australia's central east coast in response to late Pleistocene-Holocene and future sea level change. PhD Thesis, The University of Queensland, Brisbane.

Roelvink, J.A. & R.J. Murray, 1992. Gold coast Queensland Australia – Southern Gold Coast Littoral Sand Supply. Report H85 prepared by Delft Hydraulics Laboratory for the Qld. Govt.