Shoreline Response Modelling
Assessing the Impacts of Climate Change

C Huxley[1]
[1]BMT WBM Pty Ltd
[2]University of Queensland, St Lucia, QLD

Introduction

It is likely that future climate change will have a significant impact on coastal communities and ecosystems. Climate change driven sea level rise, variations in the local wave climate are likely to modify long-shore and cross-shore sediment transport patterns. This has the potential to increase the risk of severe coastal inundation and erosion at some locations.

Recognizing the urgent need to address this knowledge gap, the NSW Department of Environment and Climate Change (DECC) have funded a study that aims to quantify the environmental and economic impact of future climate change for two representatives coastal and estuarine systems in NSW.

As part of this study, modelling procedures have been developed to assess the likely impact of climate change on shoreline response. A brief overview of this modelling procedure is outlined in this paper.

Using the developed model for the chosen case study locations a scenario based assessment has been undertaken to identify the likely impact resulting from:

1. Sea level rise;
2. Variations in wave direction;
3. Increased swell wave heights; and
4. Increased storm wave heights.

The results of this assessment for Wooli Wooli beach, in northern NSW, are presented in this paper.

Using the sensitivity assessment approach, it is evident that projected climate change driven variations in wave climate are likely to have a significant impact on shoreline response, in addition to sea level rise alone.

These results highlight the inadequacies associated with historic climate change assessments which have relied on the Bruun Rule to define possible future shoreline recession distances. This approach only accounts for shoreline recession accounting for cross shore erosion response. Using the modelling approach developed as part of the DECC study, more detailed shoreline response projections are now able to be calculated which account for both, cross shore and longshore, sediment transport processes.

Study Description

The results discussed in this paper have been sourced from work undertaken as part of a broader climate change study being undertaken for the NSW Department of Environment and Climate Change (DECC).

The overarching DECC study is aiming to assess the likely impacts of climate change on two coastal/estuary case study locations in NSW, centered on the 2030 and 2070 planning horizons. The selected case study locations include:

1. Wooli Wooli Beach/River Estuary on the north coast of NSW; and
2. Batemans Bay/Clyde River Estuary on the south coast of NSW.

In NSW, the coastline has traditionally been considered as two distinct littoral drift units. The southern and central NSW coastlines are typically low-littoral drift coastlines (ie. Swash/ Cross-shore dominated) whereas the northern NSW coastline is typically a high-littoral drift coastline (ie. Drift/ Long-shore dominated) with estimated littoral drift rates up to 500,000 m^3/yr. Due to this distinct difference in littoral drift characteristics, the case study locations were specifically chosen, each as a representative beach/estuary within these regions.

In total the DECC study consists of three stages. The details included in this paper relate entirely to the coastal erosion assessment of Wooli Wooli beach, which are currently being assessed as a component of Stage 2 of the study.

<u>Stage 1</u>
Undertaken by CSIRO Marine and Atmospheric Research and DECC; and published in 2007, Stage 1 of the project identified the projected changes to various environmental parameters that govern coastal and estuarine processes resulting from climate change.

<u>Stage 2</u>
Currently in its final stages, is being undertaken through a collaboration between the University of Queensland, BMT WBM and DECC. Stage 2 of the study aims to quantify the physical impacts of climate change for the two case study locations. The assessed impacts include:

- Shoreline Response; and
- Estuary Response, assessing temperature, salinity and flushing time impacts.

<u>Stage 3</u>
Aims to assess the economic impacts associated with the physical impacts determined in Stage 2 whilst also investigating effective adaptation strategies to inform government policy.

Study Methodology

As stated above, the details included in this paper relate entirely to the coastal erosion assessment of Wooli Wooli beach. This work was completed as part of a research Masters study at the University of Queensland. The remaining components of the Stage 2 study, which include the shoreline response modelling of Batemans Bay and the estuary response modelling of the Clyde and Wooli Wooli estuaries have not been included in this paper.

Climate Change Shoreline Response Modelling

As a preliminary component of the Stage 2 of the study, suitable techniques capable of assessing the impacts of climate change on the open coast shoreline of Wooli Wooli Beach were reviewed. In particular, the methodologies were assessed for their capabilities to provide an indication of the combined impact on shoreline response resulting from variations to the following forcing parameters:

- Sea Level;
- Swell wave direction;
- Swell wave height; and
- Storm wave height; and
- Storm wave occurrence.

Traditionally, the effect of climate change on shoreline response has been assessed accounting for sea level rise using the Bruun Rule. The Bruun Rule estimates shoreline recession resulting from sea level rise. This approach uses a simple hand calculation method, though is commonly criticized due to its various limitations. Rangasinghe *et al* (2007), provides a thorough summary listing the limitations of the Bruun Rule.

To meet the objectives of the DECC study, modelling procedures capable of assessing the impact of combined variations in wave climate and sea level was required. Accepting the various limitations of the Bruun Rule; the Bruun Rule can only be used to estimate shoreline recession resulting from sea level rise. It cannot be used to assess the projected variations in wave climate.

To account for these projected variations, a combined longshore/cross shore sediment transport modelling approach is required. This has been achieved in this study by dynamically linking separate longshore and cross shore models. This is discussed briefly below.

Longshore Modelling

Longshore transport represents the movement of sediment along the coast, parallel to the shoreline. In terms of this study, longshore modelling is required to assess the possible variations in littoral drift, likely to result from the change in wave climate.

The longshore transport component of the modelling was undertaken using GENESIS. GENESIS is a one line model developed by the US Army Corps (Hanson and Kraus, 1989).

Cross Shore Modelling

Cross shore sediment transport represents the movement of sediment on/offshore. Shoreline response to storm wave conditions, and shoreline recession associated with sea level rise are two examples of cross shore sediment transport processes.

To undertake the cross shore component of the modelling, a finite difference time stepping cross shore profile response model was developed. Prior to the development of this model, various cross shore models were assessed. These included:

- Bruun (1962)
- Vellinga (1982,1983)
- Krieble an Dean (1985);
- Krieble an Dean (1993);
- SBEACH (Larson,1989)
- Miller and Dean (2004, 2006)

After a thorough review of the above listed cross shore response models, a suitable model structure capable of modelling both storm term erosion response and long term shoreline ressesion was developed. The framework further develops the cross shore modelling approach published by Miller and Dean (2004) by including a geometric representation of the cross shore profile beyond the depth of closure.

As a general description, the developed model uses a modified version of the Bruun equilibrium $Ax^{2/3}$ profile slope to represent the cross shore profile. Given instantaneous water level and wave height inputs, the defined cross shore profile is modified to accommodate for the water level/wave forcings. The response the these forcings is lagged exponentially, mirroring the natural cross shore erosion/accretion response.

As an example, illustrating the application the developed cross shore model Figure 1 and Figure 2 show two extreme hypothetical test cases. Although the hypothetical cases represent highly unrealistic wave height/water level situations, they do suit the purpose of illustrating the model operation well.

Figure 1 represents a hypothetical situation where the wave height is indefinitely held constant. At the first timestep the water level is increased by 2.5 m, after which it remains constant at the elevated level for the remainder of the simulation. The results show how the elevated water level results in the prediction of an upward translation of the profile. Erosion is predicted from the upper section of the profile. The eroded material is deposited offshore, facilitating the upward shift of the profile.

Figure 2 represents a hypothetical situation where the water level is fixed whilst an increase in wave height is experienced. At the first timestep the significant wave height is increased to 6.5m, after which it remains constant at 6.5m for the remainder of the simulation. The results show how the increased wave height results in the lengthening of the active profile. Erosion is predicted from the upper section of the profile. The eroded material is deposited offshore extending the profile into deeper water, accommodating for the increase in wave energy.

Overall, the inclusion of the geometric feature in the Miller and Dean approach created a model which has the following benefits:

- The model was capable of calculating shoreline response resulting from short term erosion events accounting for variation in water level and wave height (model timesteps of 1hr are currently being used).
- The model automatically accommodates for accretionary events defined by the instantaneous wave and water level conditions relative to the given profile state.
- The model included mass conservation principals similar to the Brunn Rule, making it suitable for long term sea level rise assessments.
- The geometric approach modifies the cross shore profile based on water level and wave height inputs using an exponentially lagged function. This method automatically defines the depth of closure for the profile.
- The model is suitably efficient to be used during climate change assessments without significantly compromising model simulation times.

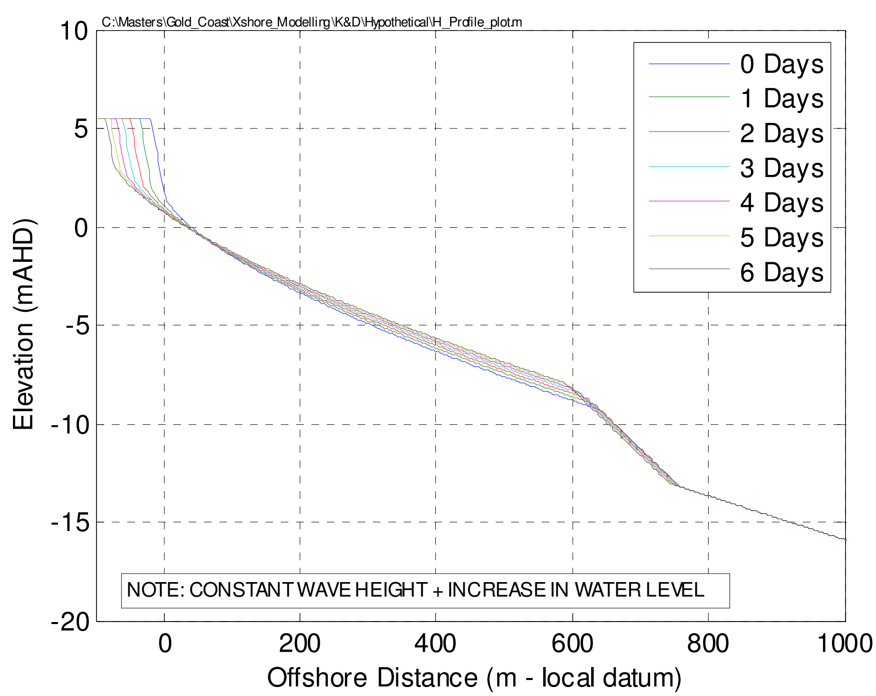

Figure 1 XSMOD Profile Change Example – Water Level Increase

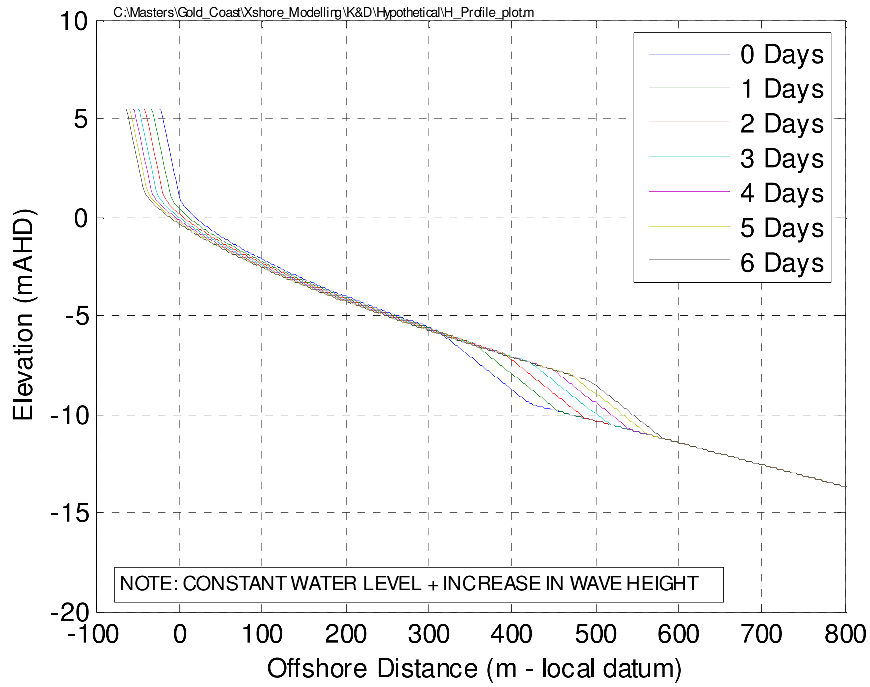

Figure 2 XSMOD Profile Change Example – Wave Height Increase

To validate the developed cross shore model, model result comparisons with profile data from the Gold Coast (Surfers Paradise) for two significant erosion events were conducted. The selected erosion events covered the periods from June to August 1967 and April to December 1988. These periods were selected for the following reasons:

- The 1967 July erosion event represents the largest recorded erosion event experienced at the Gold Coast.
- Surveyed profile information is available prior to and after the 1967 event.
- The 1988 period experienced two moderate erosion events in May and November. Between these dates there was a significant period of accretion.
- The 1988 period between April and December represents the most frequent recording period from the entire dataset available for the Gold Coast. Between these dates surveys were taken monthly.

Model results for these validation periods are shown in Figure 3 and Figure 4. Overall the developed modelling approach matches the Gold Coast data well.

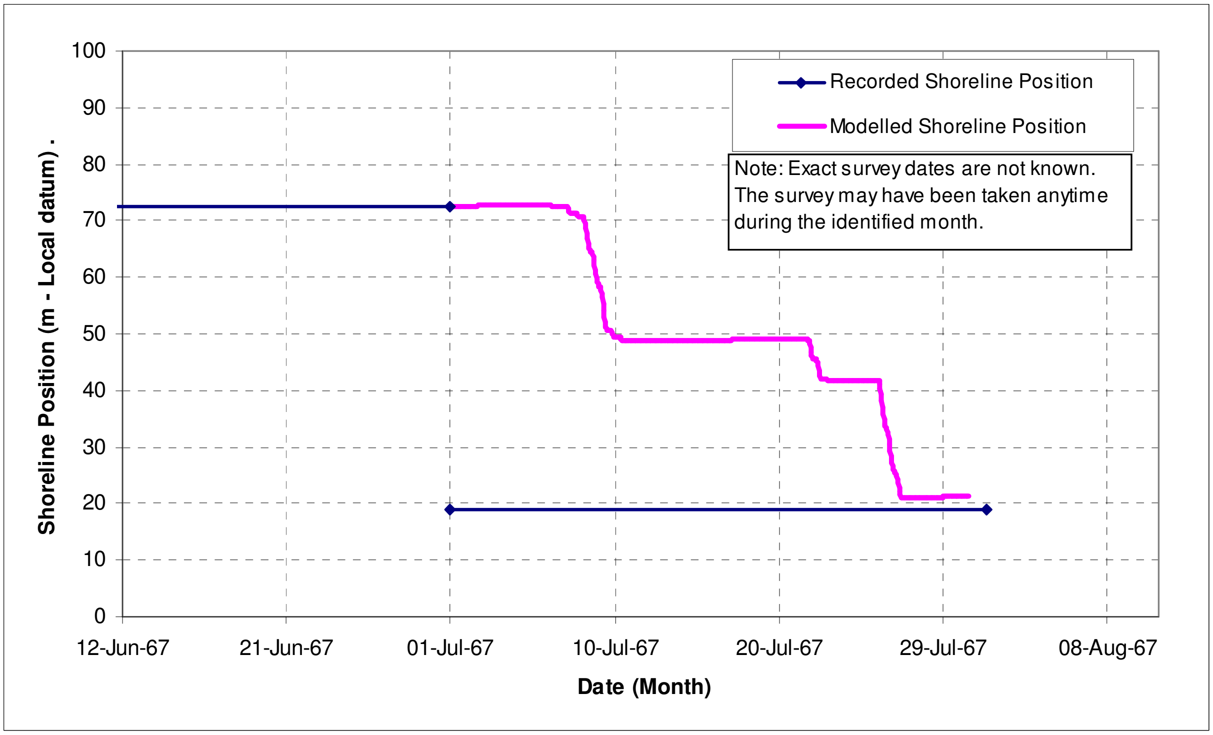

Figure 3 1967 Cross-Shore Model Validation – Shoreline Position

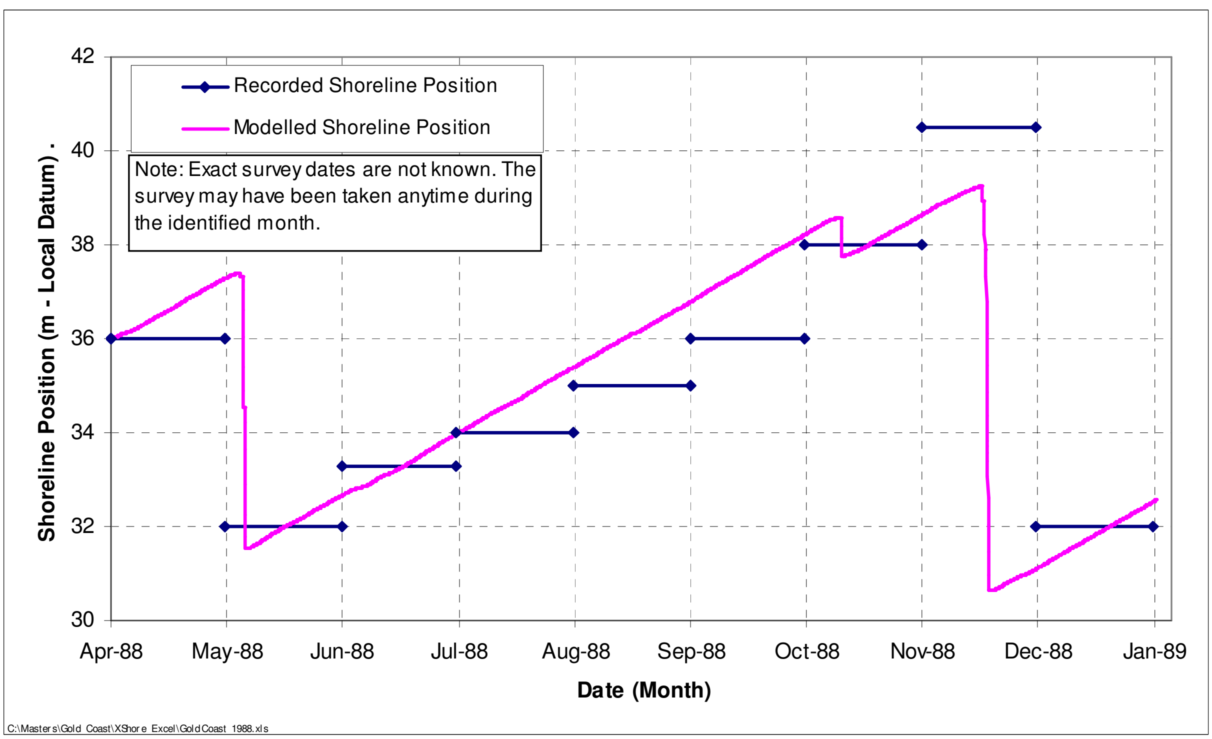

Figure 4 1988 Cross-Shore Model Validation – Shoreline Position

In addition to the model validation using the 1967 and 1988 datasets from the Gold Coast, a further assessment comparing modelled shoreline recession resulting from an increase in water level with no change in wave forcings was conducted in parallel to a Bruun Rule assessment.

Based on available storm profile data for the Gold Coast a Bruun rule assessment was undertaken to predict possible shoreline recession resulting from a one meter increase in water level. Figure 5 shows a portion of the available data for the Gold Coast. Based on the profile data, using a depth of closure of 15m depth, a berm height of 5.5m elevation and an active surf zone width of 891.5m, the Bruun Rule predicted a shoreline recession of 43.5m for an increase in water level of 1m

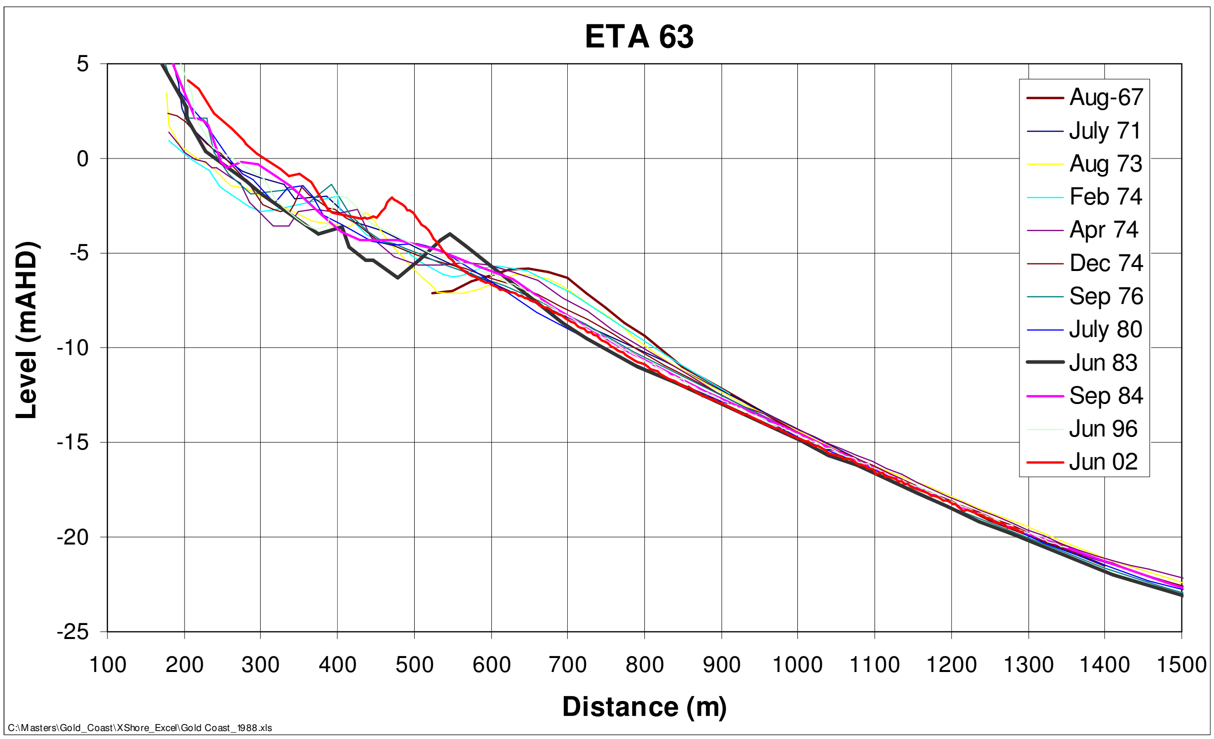

Figure 5 Gold Coast Profile Data

Using the 1967 profile as the initial profile, the test case using the developed cross-shore model calculated a shoreline recession of 40.4m resulting from a linear incremental increase in water level over 100 years by 1m (1cm per year). These results are comparable to the predicted shoreline recession calculated using the Bruun Rule. Figure 6 show the model results for the basic shoreline recession test.

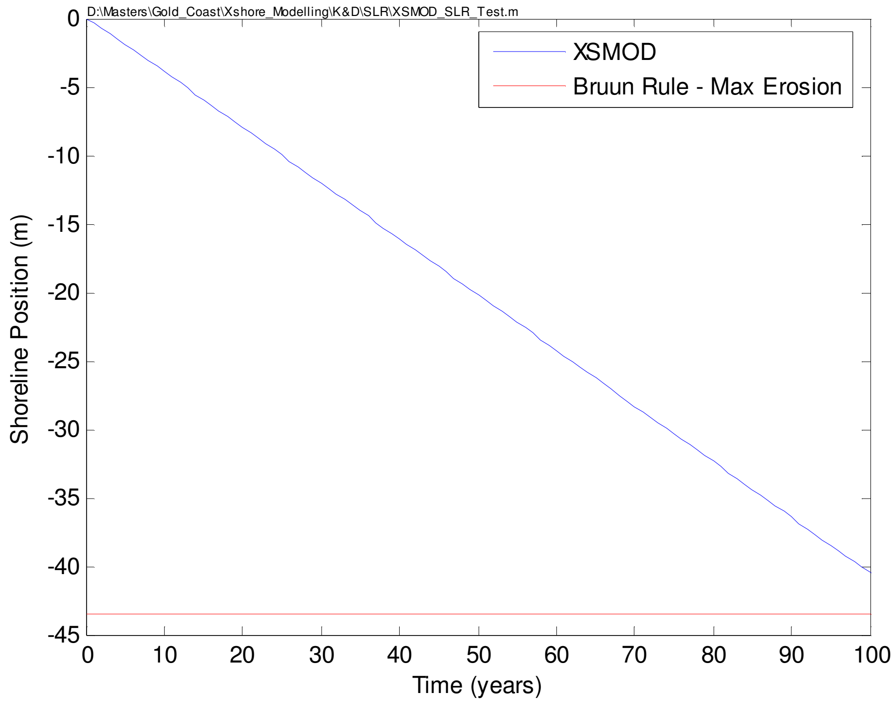

Figure 6 XSMOD Shoreline Recession Test – Shoreline Position

Combined Cross Shore/Longshore Sediment Transport Modelling

In addition to the development of the cross shore model, a procedure has also been developed enabling the dynamic coupling of the cross-shore and longshore models mentioned above. Using Matlab as the processing program, the coupling procedure uses a 30 day linking interval to dynamically link the cross-shore and longshore models.

The 30 day linking interval was chosen as it represented a linking interval which resulted in sufficiently accurate results without significantly impacting on simulation runtimes. During the model development stage various linking intervals ranging from weekly (7 days) to annually (364 days) were trial. It was found that link periods from 100 to 365 days resulted in shorter simulation runtimes, though resulted in less accurate results. In comparison the simulations using a linking interval less than 30 days resulted in excessive runtimes for a negligible increase in model result accuracy.

Throughout the model simulation, the modelled shoreline position and the most landward shoreline position for the entire simulation are tracked. The most landward shoreline position is tracked to assist in the definition of hazard lines. Figure 7 outlines the general steps required to link the modelling programs.

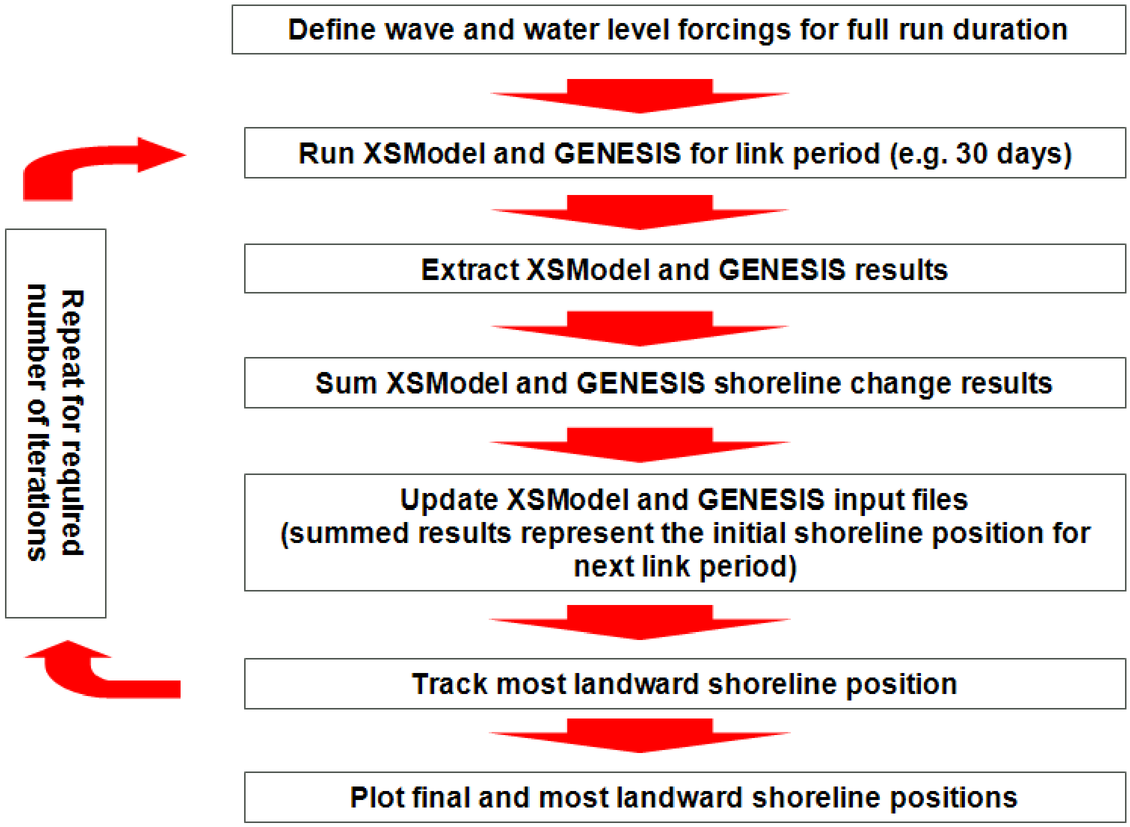

Figure 7 Cross-Shore/Longshore Model Coupling Procedure

Wooli Wooli – Historic Modelling

Using the developed dynamically linked longshore/cross shore modelling approach, modelling of Wool Wooli Beach in northern NSW was undertaken. This was completed for the period from 1/11/1999 to 1/11/2007, using recorded wave data from the Cape Byron wave rider buoy (Sourced from the Manly Hydraulics Laboratory).

Due to the lack of available validation data (shoreline survey data), the calibration parameters obtained during the development of the longshore/cross shore models, based on data from the Gold Coast, were adopted.

Using these calibration parameters produced a variation in shoreline position along Wooli Wooli Beach of ±15m between 1/11/1999 and 1/11/2007. Unfortunately, there are no available shoreline surveys for this modelled period. However, based on resident comments regarding shoreline change since 1999, the modelled estimate of change in shoreline position are within realistic limits.

Wooli Wooli – Climate Change Sensitivity Assessment

As a preliminary assessment, to obtain an understanding of the likely response of the shoreline at Wooli Wooli to various changes in wave conditions, a scenario based analysis has been undertaken. The assessed scenarios are listed in Table 1.

The climate change scenario assessment was undertaken using the historical conditions between 1/11/1999 and 1/11/2007 as a base case. For the climate change scenario assessments, model forcing conditions (e.g. wave height, wave direction, water level etc.) have been perturbed individually or in combination. The range in values listed in Table 1 has loosely been based on the maximum climate change impact projections to 2070 calculated by the CSIRO (McInnes et al, 2007). Similarly, the 0.6m sea level rise value is based on the NSW DECC Draft Sea Level Rise Policy (DECC, 2009), centered on 2070.

Table 1 Wooli Wooli Climate Change Forcings - Test Scenarios

Scenario	Modification to Existing Wave Climate			
	Sea Level Rise	**Change in Wave Direction**	**Change in Swell Wave Height (Hsig > 3.0m)**	**Change in Storm Wave Height (Hsig > 3.0m)**
EXG	-	-	-	-
1	0.6m	-	-	
2	0.6m	-5 degree rotation	-	-
3	0.6m	+5 degree rotation	-	-
4	0.6m	-5 degree rotation	0.1m increase in wave height	-
5	0.6m	+5 degree rotation	0.1 increase in wave height	-
6	0.6m	-5 degree rotation	-	0.1m increase in wave height
7	0.6m	+5 degree rotation	-	0.1m increase in wave height

For the alongshore locations shown in Figure 8, Figure 9 to Figure 11 show the models results for the above listed scenarios. The results shown have been calculated to represent the shoreline response relative to the model result corresponding to the existing case, featuring no climate change perturbation.

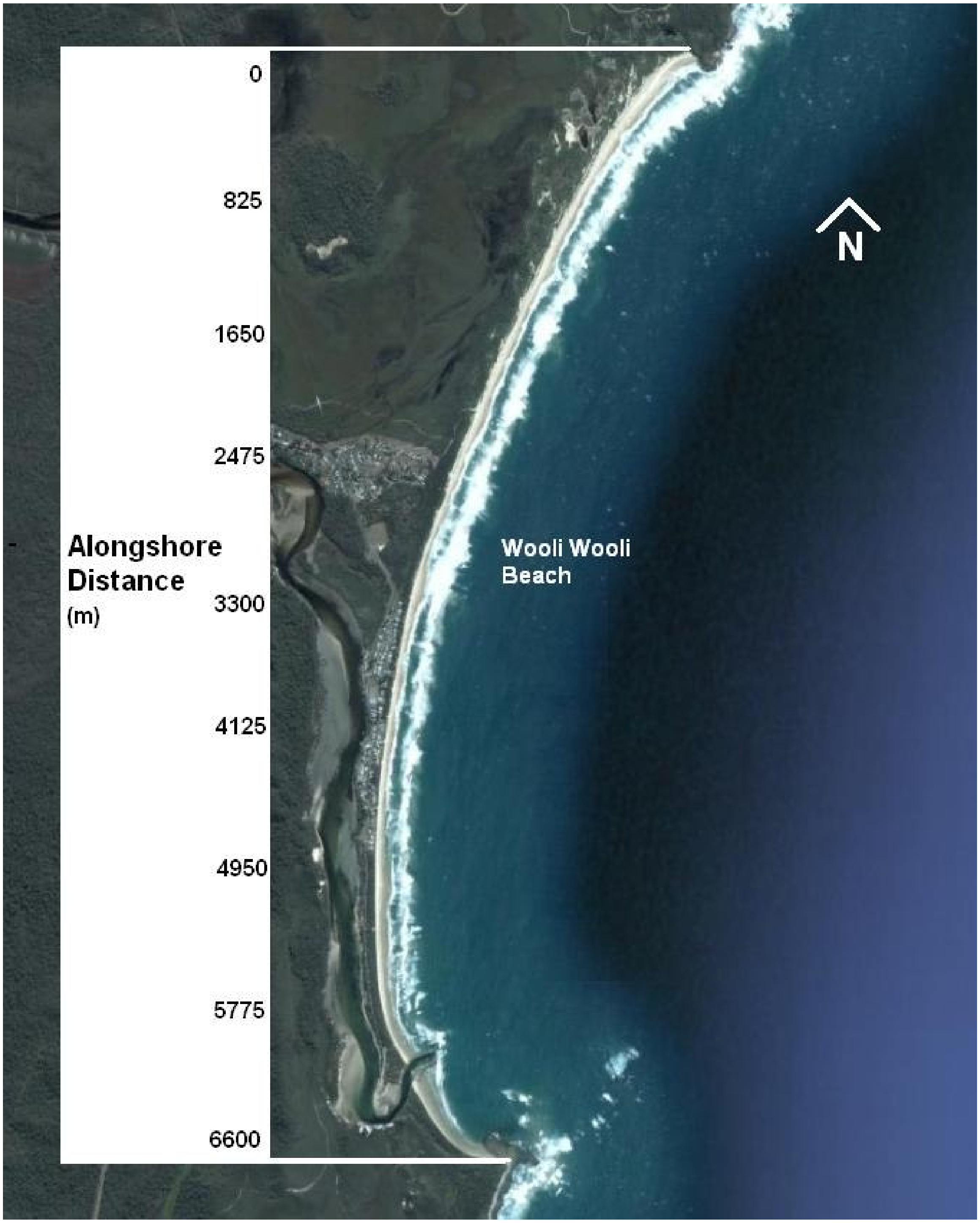

Figure 8 Wool Wooli Model Orientation

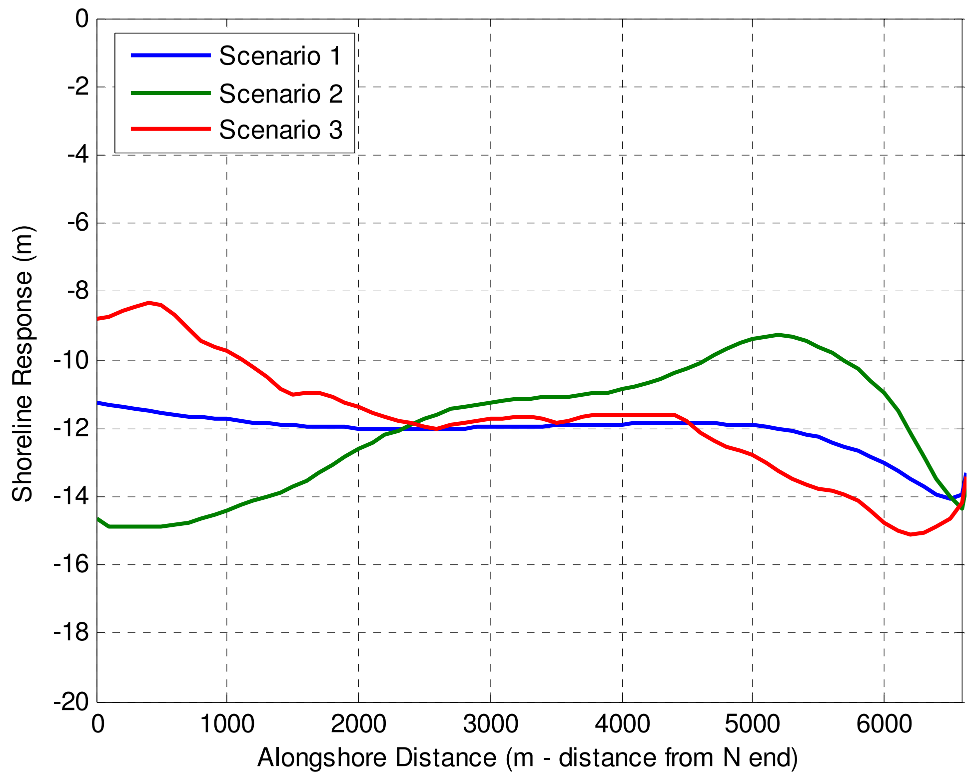

Figure 9 Wool Wooli Climate Change Sensitivity Test Results

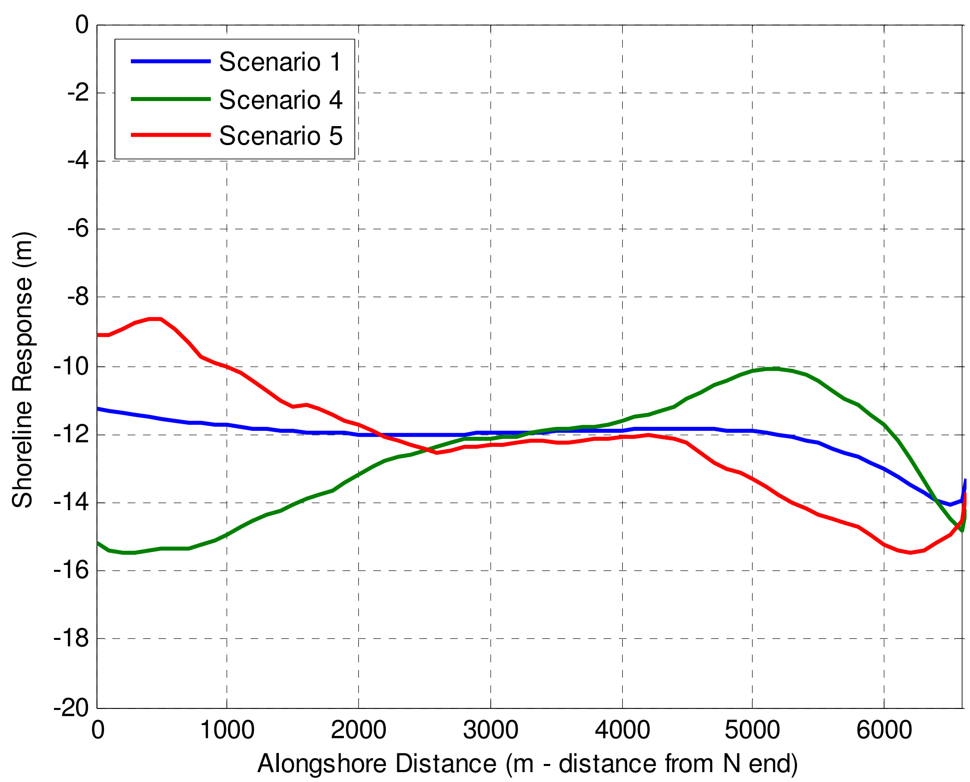

Figure 10 Wool Wooli Climate Change Sensitivity Test Results

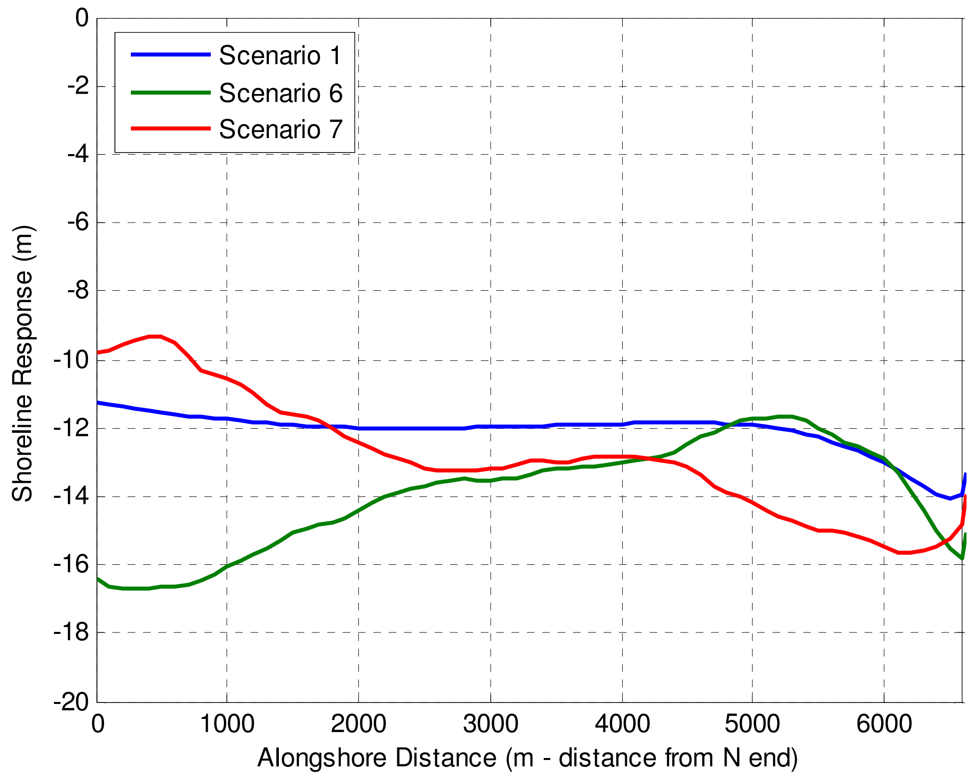

Figure 11 Wool Wooli Climate Change Sensitivity Test Results

Based on the results shown above, the variation in shoreline response resulting from changes in wave climate are explicitly shown.

- In isolation, the 0.6m sea level rise is likely to result in an approximate shoreline recession of 12 meters. (Scenario 1)
- Shifting the wave directions by -5degrees in a counter clockwise direction results in the counter clockwise rotation of the beach. This increases the calculated shoreline recession in the north of Wooli Wooli Beach by up to approximately 25% and inversely reduces the shoreline recession in the south by an equivalent amount. (Scenario 2)
- Shifting the wave directions by +5degrees in a clockwise direction results in the clockwise rotation of the beach. The magnitude of change is equivalent to the -5degree shift in wave direction. (Scenario 3)
- Increasing significant swell wave heights by 0.1m increases calculated shoreline recession values approximately by an additional 8%. (Scenario 4 and Scenario 5)
- Increasing significant storm wave heights by 0.1m result in an additional increase in calculated shoreline recession value by approximately 15%. (Scenario 6 and Scenario 7)
- Overall, Scenario 6 results in the greatest shoreline recession. Compared with Scenario, 1 which assessed the impacts of sea level rise in isolation, the additional

variations in wave climate included in Scenario 6 result in up to a 50% increase in calculated shoreline recession.

Although these results do not explicitly relate to a particular climate change emission scenario, the results do highlight the impact that changes in wave climate may have on climate change related shoreline recession.

These results highlight the possible inadequacies in shoreline recession estimates based souly on Bruun Rule calculations, which make no account for possible variations in wave climate.

To assist local and state government planning decisions there is a significant need for more detailed assessments, accounting for combined longshore/cross shore sediment transport processes. The modelling procedures used as part of this study represent a means of fulfilling this need.

Wooli Wooli – Climate Change Assessment

Using the modelling procedure developed for Wooli Wooli, assessment of the CSIRO CCM2 and CCM3 climate change scenarios is current being undertaken. These assessments will require the modelling of 100 year simulations centered on the 2030 and 2070 planning horizons. The wave climate and sea level rise values being adopted for these assessments are shown in Table 2.

Table 2 Wooli Wooli Climate Change Forcings

Scenario	Sea Level Rise	Change in Swell Direction	Change in Swell Height	Change in Storm Wave Height			
				NE	E	SE	S
CCM2 20303	0.27	-3.1	0	-0.1	-0.1	0.3	0.1
CCM3 2030	0.27	0.6	0	0.2	0.1	-0.1	-0.1
CCM2 2070	0.6	-3-3	-0.1	0.2	0.1	-0.1	-0.1
CCM3 2070	0.6	-1.3	0.1	0.4	0.0	0.0	-0.1

Summary and Conclusions

Future climate change is likely to impact coastal communities and ecosystems. These changes primarily relate to changes in local cross-shore and longshore sediment transport characteristics. The potential first order climate change driven impacts on New South Wales coastline are likely to be driven by:

- Sea level rise;
- Changes in storm wave characteristics;
- Changes in swell wave characteristics;

Funded by the NSW DECC a study assessing the impact of these forcings on two case study locations is currently being assessed. To undertake this assessment, modelling procedure capable of assessing the impact on shoreline response resulting from variations in the parameters has been developed. A brief summary of this model has been outlined in this paper, the full details of the model, documenting the model development and validation is included in Chris Huxley's research Masters Thesis, to be submitted at the University of Queensland by the close of 2009.

Using the developed modelling approach for the Wooli Wooli Beach case study location, sensitivity testing has been undertaken to identify the impact of various changes in wave climate combined with a 0.6m increase in sea level. These results highlighted the need to account for both cross shore and longshore processes during climate change assessments so that variations in wave climate can be accounted for. Using the developed modelling approach this is now possible. As an indication of the relative response, increases in shoreline recession up to 50% greater than those resulting from sea level rise alone were calculated for one of the assessment scenarios which accounted for wave climate variations.

Using this modelling approach, the likely impacts of climate change on the shoreline at Wooli Wooli is currently being assessed, centred on the 2030 and 2070 planning horizons.

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