WOLLONGONG LGA COASTAL HAZARDS STUDY SOME UNIQUE ASPECTS

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Abstract

Cardno Lawson Treloar (CLT) was engaged by Wollongong City Council to undertake a coastal hazards study for the whole of the local government area from the Royal National Park in the north to Lake Illawarra in the south. This study area includes a wide range of coastal features, from pocket beaches to slip-prone rocky headlands. The project was funded by Council and the now Department of Environment, Climate Change and Water. Due to the nature and required outcomes of the study, several unique aspects were implemented in the methodology.

This study included:-

- An assessment of relative shoreline exposure to Tasman Sea storms, in order to determine the level of storm bites to include in erosion hazard assessment, using a nested grid regional SWAN wave model. This analysis included application of the SBEACH model using output from the SWAN model and a design storm to determine storm bite in each beach area. The SBEACH results were ranked to determine the most exposed beach, for which storm bite was assigned to be 250m^3/m.
- 2D in-plan wave overtopping modelling in order to describe the extent of ocean inundation hazard using a group of overtopping waves. This modelling was undertaken using a grid size of 2m and land survey based on LiDAR.
- The consideration of sub-beach rock shelf levels to modify the likely shoreline recession that might be assessed by application of the Bruun rule, taking note of underlying rock levels.
- Computation of the mean long-term shoreline position from analysed historical aerial photographs – photogrammetric analyses.

The methods developed allow the quantification of coastal hazards in some level of detail. This paper will describe each of these processes in detail and describe some of the outcomes.

Introduction

Cardno Lawson Treloar was engaged by Wollongong City Council (WCC) to undertake a Coastal Zone Study for the Wollongong Local Government Area (LGA). The study was conducted between June 2009 and March 2010 and included the following elements: a series of site inspections of the study area, detailed studies of the coastal and geotechnical processes in the study area, and targeted stakeholder consultation. This coastal area includes a large number of individual embayed sandy beaches and cliffs.

Study area

The study area includes the coastal zone of the Wollongong LGA, extending from the shores of Lake Illawarra and the Windang Peninsula in the south, to the Royal National Park in the north. Port Kembla Harbour has been excluded from the study area as it is managed under a separate legislative and policy framework.

The study area covers approximately 60km of coastline and includes those portions of the coastal zone that are under the influence of coastal processes, including the beaches, dunes, headlands, bluffs, estuaries and nearshore waters. The coastline consists of a series of embayed sandy beaches with a headland or rock shelf at each end, separated by sandstone cliffs.

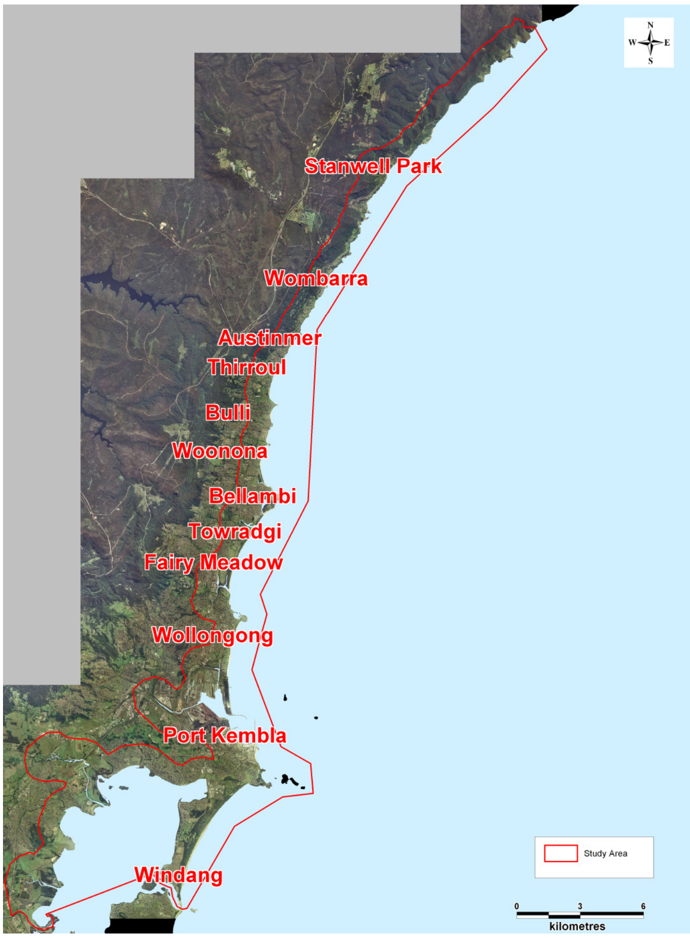

Figure 1 – Study Area: Wollongong LGA

The Illawarra Escarpment runs nearly parallel with the coast for the entire length of the Wollongong LGA and therefore much of the development that has occurred is concentrated in the coastal strip. The escarpment is generally closer to the coast in the northern part of the LGA and therefore rocky cliffs tend to predominate in the north. The longer sandy beaches predominate in the south where the escarpment is further from the coast. There are a number of coastal creeks within the study area. In the south of the study area is Lake Illawarra, a large barrier estuary with a trained entrance. The study area is shown in **Figure 1**.

Coastal Hazard Assessment Procedure

The primary goals of this coastal hazard study were to quantify, in some level of detail, coastal processes and hazards along the Wollongong LGA coastline. These analyses were undertaken in terms of the 100-years ARI design storm parameters, noting that there is some risk that these conditions can be exceeded during a selected planning period.

The stages in defining the coastal hazards were:

- Examine existing hazard and coastal processes information;
- Determine the major processes influencing the coastal region;
- Review geotechnical investigations undertaken in the LGA;
- Undertake quantitative investigations of relevant coastal processes including numerical modelling and analysis of photogrammetric data; and
- Determine coastal parameters for the 100-years ARI design condition (wave parameters, design water levels and storm erosion, wave overtopping details).
- Consider climate change issues.

Wave Climate Investigation

The wave climate investigations were carried out using the SWAN wave model. The SWAN wave model was developed at the Delft University of Technology and includes a full spectral solution for wave propagation, wind input, refraction, diffraction, shoaling, model boundary wave input, directional spread, bed friction, white-capping, wave breaking and non-linear wave-wave interaction. There is a nested modelling capability that allows for large areas to be modelled whilst providing fine resolution in areas where seabed depths have high spatial variability.

The SWAN model utilised in this study extended offshore beyond the 100m depth contour, approximately 12km offshore. A 100m resolution grid extended over the Wollongong coastline and eleven 10m resolution grids (covering the beaches and headlands of the Wollongong region) out to a depth beyond -20m AHD were nested inside the overall model.

Figure 2 describes the extent of the SWAN model applied in this study. Cardno Lawson Treloar achieved good calibration when transferring offshore Port Kembla wave data (including Sydney (Long Reef) directional wave data) to the Shellcove region using the SWAN wave model.

Design wave conditions at the site are dominated by waves breaking in near shore depths that may be as shallow as 4 to 6m. Due to the dominance of breaking wave conditions, the SWAN model has been used to determine peak storm wave conditions at selected locations within the study site for return periods of between 5 and 100-years ARI. Near shore wave conditions were obtained at sites for cliff locations and offshore of the beach compartment areas. Along the study site, wave heights and associated breaking wave water depths are strongly influenced by the offshore wave directions. The beaches within the study site are most exposed to waves from the east to south-east sector. The critical offshore wave direction for the Wollongong beaches is generally east-south-east (ESE), being the offshore wave direction that leads to the largest near-shore wave heights for a specified offshore wave height. The critical wave direction for cliff and headland regions is strongly dependent on the aspect (or exposure) of the cliff to the offshore wave direction.

Wave set-up is an important component in the design water level observed at the shoreline of the study area. Considering an open beach, when wave breaking occurs, there is an increase in water level in the direction of the shoreline. This process is referred to as wave set-up. Design still water levels, including regional and shoreline wave set-up, were derived along the coast and are integral in the definition of erosion and inundation hazards.

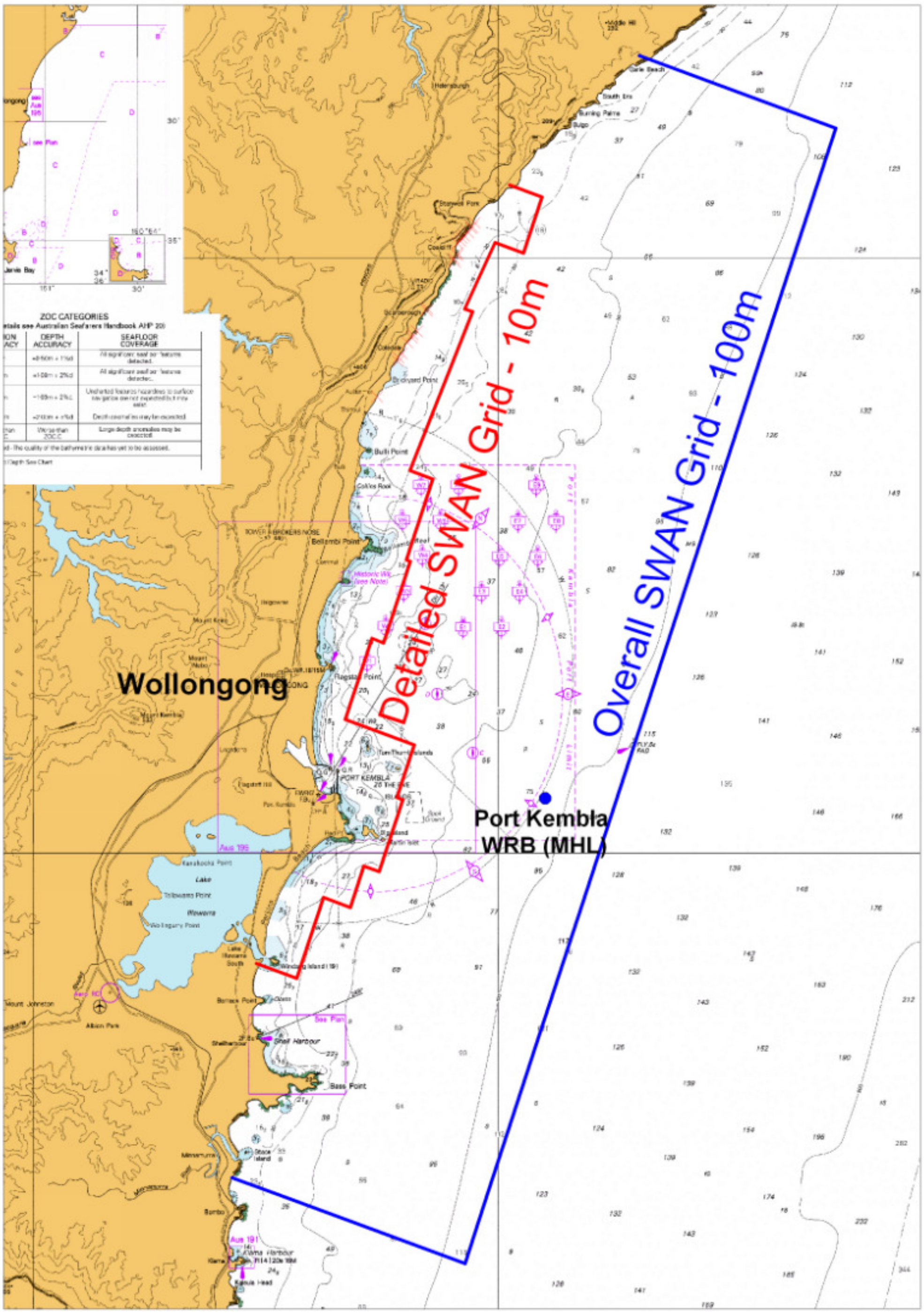

Figure 2: SWAN Wave Model Domain

Historical Beach Profile Analysis

Photogrammetric data for 11 sandy beach areas within the study site were obtained from DECCW. The data sets provided to CLT covered a range of years from 1936 to 2007 and contained between four and twelve surveys during this period of time for most beaches. Photogrammetric data was analysed in several different ways to gain an understanding of historical beach changes within the study area. It was found that there is presently no evidence of long term shoreline recession or loss of beach volume.

For almost all locations, the minimum beach volume was observed from the 1974 profiles. The data for these profiles was collected approximately 5 months after the May and June 1974 storms that caused extensive erosion along the NSW coast. The storm erosion which was observed along the mid-NSW coast during 1974 was the most severe in recent history and has commonly been adopted as the 'design' erosion event for this section of coast. However, since then almost all the profiles have shown a steady accretion of beach width and beach volume. To this end no long-term shoreline recession could be indentified and was therefore adopted to be zero (for present MSL) for the determination of erosion hazard lines.

To aid in the verification of the SBEACH storm demand modelling, the photogrammetric data was analysed to determine the largest volume loss occurrences along each beach compartment, thereby providing the relative exposure of each beach compartment. Note that this data was not available for all beaches and the dates of photogrammetry varied from one beach to another. This enables an indirect estimate of the impacts of large storm events (such as the 1974 storms) where consecutive photogrammetric dates are suitably close. Volume losses between consecutive photogrammetric dates were averaged over all available open coast profiles at a given site in order to provide a single averaged value at each beach compartment.

Storm Demand Analysis

To quantify the storm demand for the 100-years ARI design parameters, numerical modelling of a series of beach profiles was undertaken using SBEACH. SBEACH was developed by the U.S. Army Corps of Engineers (USACE) to investigate storm induced profile response on fine to medium grain sand beaches. It is an empirically based model that includes wave shoaling, refraction, breaking, set-up and run-up. The model can simulate a temporally varying wave breaking-point, which produces offshore bar migration. The model has been widely applied at sites all over the world and has demonstrated reasonable levels of calibration. This model was used to determine the relative site exposure of each beach with respect to a most exposed open coast beach resulting from extreme offshore design conditions.

Several site inspections during the course of the study, as well as anecdotal/observational evidence suggested the presence of underlying rock layers that are exposed during major ocean storm erosion events. The presence of such underlying rock layers (or hard clay) acts as a limiting factor in storm induced erosion. Hence, in order to ensure the accuracy of any storm bite analysis, it was necessary to determine the location and extent of any underlying rock layers within the beach compartments. Geotechnical surveys were conducted by WCC at most beaches, with the resulting rock layer upper level and sediment size data being incorporated into the SBEACH modelling for site specific storm bite analyses.

SBEACH was used to model the storm erosion resulting from 100-years ARI storm parameters, adopting a 7-days storm event (Carley and Cox, 2003) at a number of profiles within each beach compartment in order to describe the variation in storm demand along the Wollongong coast. These storm 'hydrographs' include varying wave parameters (with the 100yr ARI Wave Height taken from the associated SWAN wave modelling) and tide level as shown in **Figure 3**. Average profiles developed from the photogrammetric data record for each beach were utilised for the modelling task. Smaller, closed beaches were usually represented by two profiles, while larger, more open coast beaches required consideration of more profiles, usually three or four. The resulting storm demand values varied significantly amongst beaches, as erosion is dependent upon wave conditions (relative exposure), profile shape and the presence of rock layers. The relative exposures indicated by the simulated storm demands are in keeping with the findings from the analysis of the photogrammetry, as described previously in this paper.

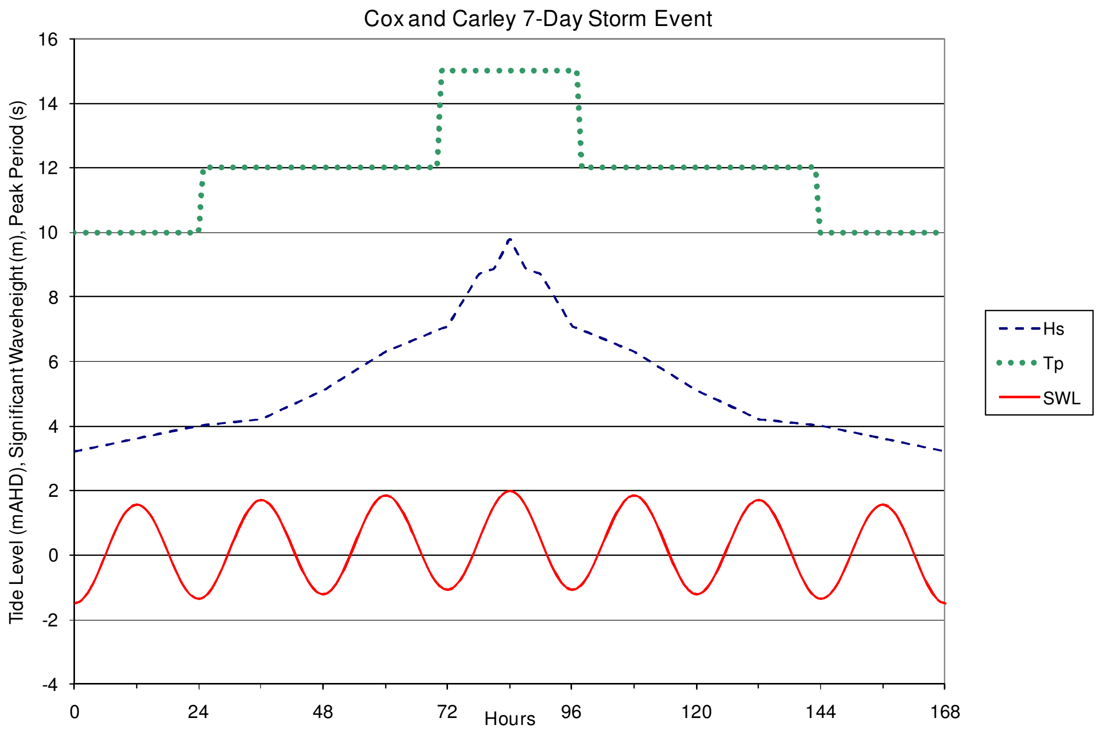

Figure 3: Cox and Carley 7-Day Storm Event

Gordon (1987) undertook an assessment of beach fluctuations and shoreline change along the NSW coast. That study provides storm demand values at a range of recurrence intervals for both high and low demand open coast beaches. Based on this information and the assessment of eroded beach profiles (e.g. Nielsen et al, 1992) it is typically considered that the 100-years ARI high storm demand for open coast beaches along the NSW coast is 250m^3/m above 0m AHD (Gordon, 1987). Similarly, low storm demand is defined at 160m^3/m above 0m AHD for open coast beaches

In light of the fact that there was no appropriate data to validate the storm demand modelling, the outcomes were normalised to these commonly adopted storm demand values. That is, in the southern region of the study area there are beaches that fulfil the description of an open coast, fully-exposed sandy beach. Two examples within the Wollongong study area are Bulli Beach and the southern end of Perkins (Windang) Beach; Bulli being high demand and Windang a low storm demand site. The predominant difference between these two beaches is their profile shape; the design storm conditions being very similar.

The largest SBEACH storm demand results were observed at Bulli Beach, being 212m^3/m above 0mAHD. Therefore, this storm bite result was scaled up to the 250m^3/m value. Storm demand requirements on other beaches were scaled accordingly. In this way the SBEACH modelling provided the relative exposure of each beach in terms of storm bite. **Table 1** presents the outcomes at Bulli and Windang Beaches and shows that the methodology adopted to define storm demand provides realistic outcomes.

Table 1: Storm Demand Results (above 0mAHD)

Location	SBEACH Result (m^3/m)	Adopted Storm Demand (m^3/m)	100-years ARI Storm Demand (m^3/m) (Gordon, 1987)
Bulli (High Demand)	212	250	250
Windang (Low Demand)	141	166	160

Erosion Hazard Extents

The present day, 2050 and 2100-years erosion hazard extents were determined along all beaches within the study area at selected profile locations using site specific wave climate and beach profile information. For each planning period, two hazard extents were specified:

- **Immediate Impact Zone** – the landward extent of the eroded scarp following the 100-years design event at the end of the specified planning period
- **Zone of Reduced Foundation Capacity** – the zone in which any structure will require piles to a suitable depth to prevent failure following the design storm.

The hazard zones were calculated using the method described by Nielsen et al (1992). A diagram describing this method is provided in **Figure 4**. An average beach profile based on either available photogrammetric data or ALS data was used to calculate the baseline volume, and average ground level for each profile. The calibrated storm erosion volume was taken from the SBEACH results for each beach profile and applied to this methodology, and an Immediate Impact Zone and Zone of Reduced Foundation Capacity was created for each beach.

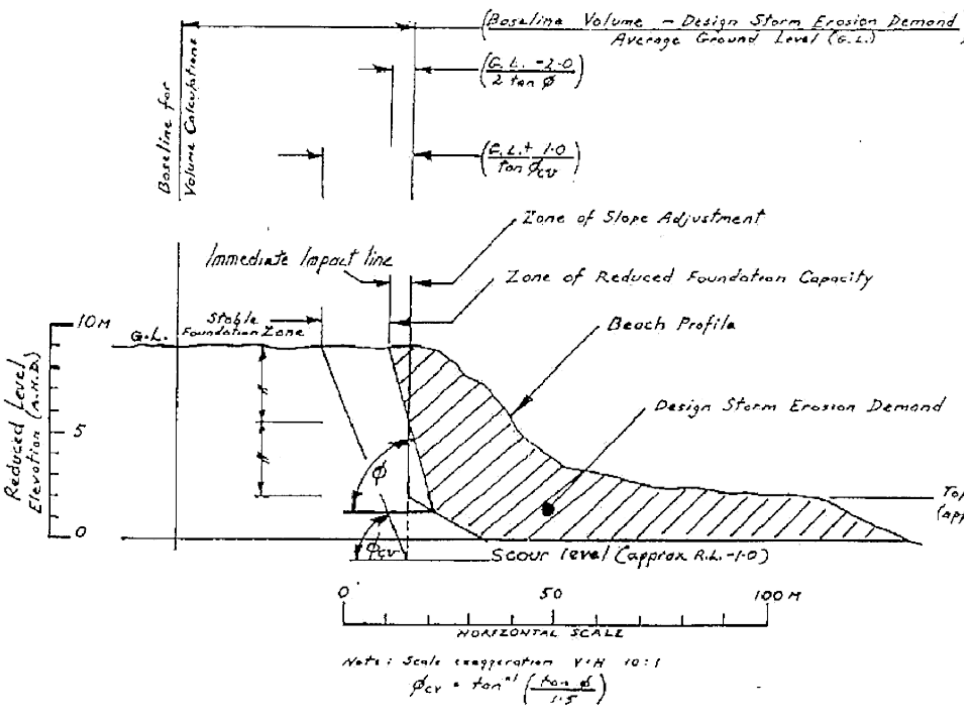

Figure 4: Storm Erosion Hazard and Stability Zones (Nielson *et al* 1992)

Erosion hazard definition at the ends of the beach compartments required some extrapolation of the storm demand/recession results and considered the presence of rock headland and cliff features. These areas of the mapping underwent review and incorporated the geotechnical advice (slope and cliff stability) that was undertaken by GHD as part of this overall study. Furthermore, the reduction in erosion extent in these areas also considered the generally steeper slopes and reduced wave exposure (from the wave modelling) that the ends of the beach compartments are commonly subjected to as a result of protection from headland features.

Sets of hazard lines were then produced for the 2050 and 2100 planning horizons that include beach response to sea level rise based on the NSW sea level rise benchmarks. These lines were produced by implementing the Bruun rule. It is widely discussed that the traditional Bruun Rule approach, which is based on the equilibrium beach profile concept, is not valid where particular shoreline features are present (e.g. Cooper and Pilkey, 2004) and there are limitations in the application of the Rule throughout the coastal zone (Ranasinghe et. al., 2007). These include nearshore rock shelves and underlying rock/clay strata, amongst others. Nevertheless, there is presently no other practical coastal planning alternative for the estimation of beach profile response to SLR. To this end, site specific features were considered in defining the beach profile for practical application of the Bruun Rule.

The Bruun Rule is applied to what is termed the active beach slope, being the slope between the berm level and the closure depth. Closure depth is defined as the depth limit of effective seasonal profile fluctuations (Dean, 2002). In other words, the seaward extent of observed long-term profile variations, past which no profile change would be normally expected. It is important to note that there is a range of definitions of closure depth, some referring to inner closure depths, beyond which there is no ‘effective’ sediment transport and other definitions refer to ‘outer’ closure depths which are the absolute seaward limit (depth) of wave driven net sediment transport. For the application of the Bruun Rule, Dean (2002) and others generally agree that the equilibrium beach profile should be based on the 'inner' (shallower) closure depth. The closure depth is related to the offshore wave climate and the wave transformation processes in the nearshore area at a particular site. Along the open NSW coast, the inner closure depth is generally considered to be in the order of 9 to 12m below MSL. The presence of rock shelves, however, would limit this closure depth, thereby steepening the active beach profile. Therefore, where shallow rock shelves were present, a closure depth based on the shelf level was adopted (see **Figure 5**).

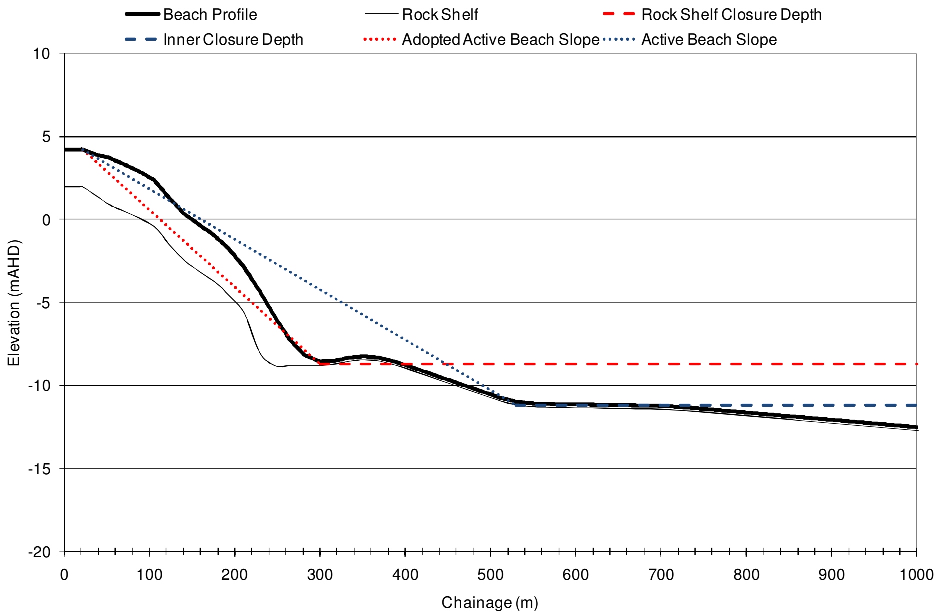

Figure 5: Inclusion of Rock Shelves in the Bruun Rule

Ocean Inundation

Ocean inundation extent is defined as the point to which wave overtopping and run-up occurs. Wave inundation modelling has been undertaken for the existing, 2050 and 2100 climate change scenarios. This inundation modelling was carried out using 2D Delft3D Flow models. A series of models was developed for this study for the various beach compartments. Typically, model grids extended landward from the erosion hazard line, over the back beach area and beyond the 10m AHD contour. Grid resolutions in the order of 1m were adopted. An example of one of these grids is shown in **Figure 6**. The model setup is similar to 2D overland flow models for catchment flooding investigations, the primary difference being the application of the boundary condition.

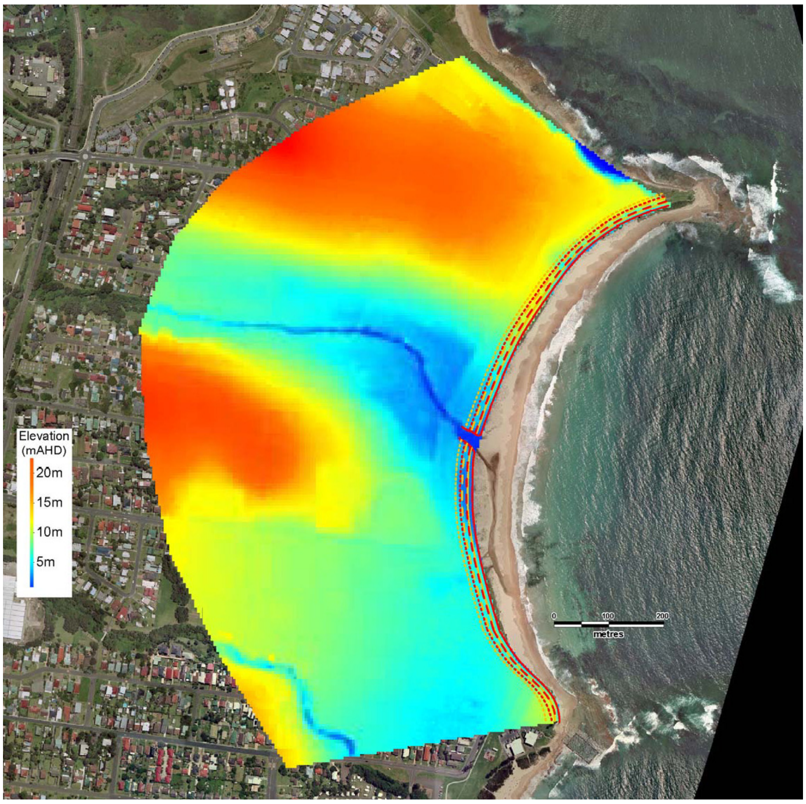

Figure 6: D3D Overtopping Grid at Sandon Point Beach with ALS Data

The inundation scenarios assumed an eroded beach profile; therefore wave inundation extends from the relevant erosion hazard line. Topographical information of the back-beach area integrated into the modelling setup allows the spatial definition and mapping of these inundation lines.

The boundary conditions of the 2D models were derived by incorporating the freeboard (the difference between the eroded scarp height and the storm surge water level) and the local wave conditions to derive wave run-up and overtopping parameters. This resulted in an overtopping depth that was transformed into boundary time series that replicated the pulsing nature of a set large overtopping waves.

Figure 7 presents an example of inundation extents at Stanwell Park Beach. It is noted that structures (including buildings and stormwater infrastructure) are not described in the modelling and hence the inundation extents provided can be considered conservative. The duration of inundation would be much shorter than that of catchment flooding and would correspond to the peak of the high (storm) tide, being in the order of 1-2 hours, after which it is considered that the stormwater systems and natural drainage paths within the affected areas would be sufficient to allow the drainage of the ocean waters.

The inundation hazard extents identify areas that would be potentially subject to inundation under the 100-years ARI ocean storm event and consider the eroded form of the beach as well as the likely wave characteristics that cause overtopping.

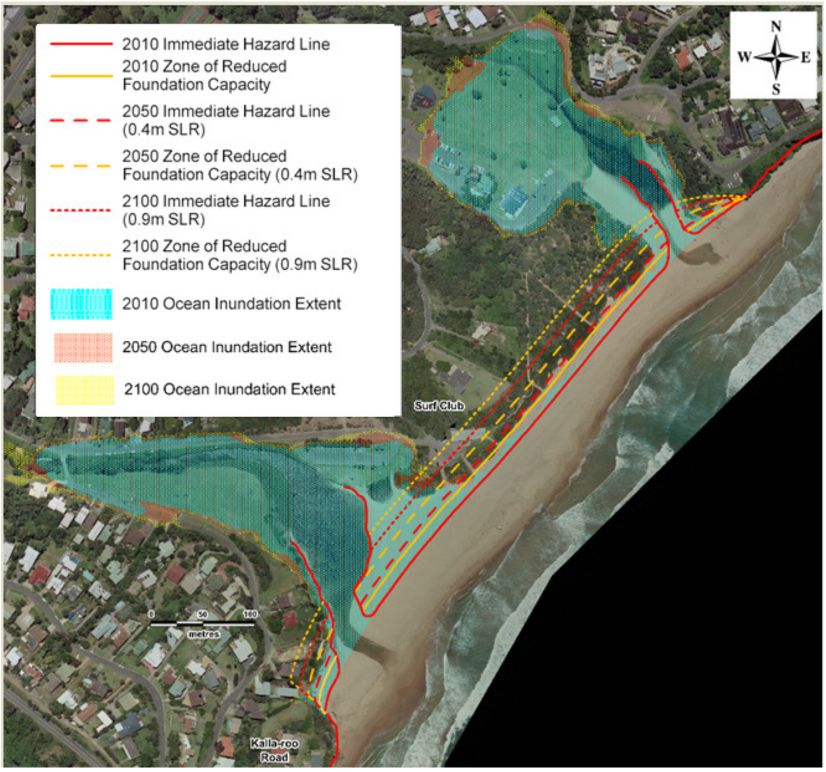

Figure 7: Erosion and Inundation Hazard Mapping at Stanwell Park Beach

Conclusion

Cardno were commissioned by Wollongong City Council to undertake a coastal hazards study for the whole of the local government area. Due to the nature and required outcomes of the study, several unique aspects were implemented in the methodology.

SWAN wave models were used to determine local inshore waves, an important component in the design water level observed at the shoreline of the study area. SBEACH was then used to determine the local storm demand at each beach. The presence of underlying rock layers (or hard clay) that act as a limiting factor in storm induced erosion were incorporated into this modelling. This information was based on site inspections by council's geotechnical department. In light of the fact that there was no appropriate data to validate the storm demand modelling, the outcomes were normalised to commonly adopted storm demand values. In this way, the SBEACH modelling provided the relative exposure of each beach compartment while adopted values were based on actual measured data.

To further aid in the verification of the SBEACH storm demand modelling, the photogrammetric data was analysed to determine the largest volume loss occurrences along each beach compartment. These outcomes were generally consistent with the SBEACH modelling.

The erosion hazard zones were calculated using the method described by Nielsen et al (1992), with climate change scenarios integrating site specific features for a practical application of the Bruun Rule. Specifically, the presence of shallow rock shelves in the nearshore area were assessed and thought to limit the shape of the active beach profile.

Inundation modelling was carried out using 2D Delft3D Flow models, driven by local storm conditions. The model setup mimics those developed for overland flow studies, by applying a 3D terriain model of the backbeach area to the hydrodynamic model. Wave overtopping parameters are then calculated based on a set of large consecutive waves.

Cardno believes that this applied methodology provides an accurate and efficient appraisal of coastal hazards to foreshore areas, especially in a spatial sense. The methods developed allow the detailed quantification coastal hazards over large areas.

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Acknowledgements

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