Appendix A: Literature Review

A.1 Preamble

A substantial body of literature in the form of consultant and government technical and management reports exists for beaches within Batemans Bay, but there is a paucity of coastal science and engineering literature in the wider Eurobodalla local government area (LGA). All the available literature addressing coastal processes, coastal protection works and coastal management within the Eurobodalla LGA was consulted. This included the management of risks to public safety and built assets, as well as risks from climate change. A brief summary of key documents (where it is relevant to the study area and the scope of the Coastal Hazard Assessment) is presented in the following discourse. The quality and reliability of the data and information was also assessed. Historical context to contemporary issues was provided where possible.

A.2 The Persistence of Rip Current Patterns on Sandy Beaches (Eliot, 1973)

This conference paper outlined the results of 20 current measurement campaigns undertaken at South Durras Beach over 37 days in November and December 1972. Measurements were taken at 50 m intervals covering the full 2.25 km length of the beach. Analysis of the current measurements was used to infer nearshore water circulation patterns. The number of rips along South Durras Beach varied with incident wave energy, incident wave direction and other parameters affecting the longshore current velocity. The range of the number of rips observed along South Durras Beach as a function of incident wave height and direction is shown in Table A-1. The data indicated that there was an inverse relationship between the prevailing energy conditions on South Durras Beach and the number of rip currents which occurred along it. The average rip spacing under high energy conditions (wave height > 1.5 m) was 905 m and 200 m under low energy conditions (wave height > 1.5 m). It was noted that there were places where rips tend to occur frequently and that these places appeared to be regularly spaced. It was also noted that the more permanent rip locations were those established during high energy conditions. The drop in the number of rip currents from low to high energy conditions was accompanied by a widening of the surf zone. During low energy conditions, the width of the South Durras Beach surf zone varied from 75 to 125 m. For high energy conditions, the surf zone width was approximately 200 m.

Table A-1: Number of Rips along South Durras Beach (Source: Eliot, 1973)

Wave Direction	Number of Rips	
	Wave Height < 1.5 m	Wave Height > 1.5 m
N to ENE	7-9	2-3
ENE to ESE	6-9	2-1
ESE to S	7-11	2-3

The forms which occurred along the low water line on South Durras Beach were sinuate in shape. Their wavelengths (the distances between projections) varied from 75 to 425 m. Ninety per cent of them had wavelengths between 75 and 250 m. The projections were located landward of sandbars and shoals and the depressions landward of pools, troughs and feeder channels. There appeared to be no direct relationship between the nearshore water circulation system and the forms that developed along the shoreline. That is, the rip currents did not show any consistent locations with respect to projections or depressions along the shoreline.

A.3 Seasonal Beach Change, Central and South Coast, NSW (Thom, McLean, Langford-Smith and Eliot, 1973)

This conference paper related beach surveys at South Durras Beach and Bengello Beach with observed weather systems during 1972. The surveys at South Durras Beach were those described in detail by Eliot (1973). The surveys at Bengello Beach included four profiles from the foredune to the offshore bar measured at fortnightly intervals. The envelope of profile change relative to Mean Low Low Water (MLLW) ranged from 2 m in elevation to 56 m horizontally. The mean change in volume between successive fortnightly surveys was 25 m^3/m (with range of 7 to 85 m^3/m). During 1972, Bengello Beach generally built upwards and seawards although phases of short-term erosion were noted. The envelope of profile change at South Durras Beach was quite similar to that at Bengello Beach with an overall accretionary trend during 1972. However, recovery after an erosion phase was more rapid at South Durras Beach when compared to Bengello Beach.

A.4 Beach Changes at Moruya, 1972-1974 (McLean and Thom, 1975)

This conference paper related beach surveys undertaken at Bengello Beach with observed weather systems from January 1972 to October 1974. Bengello Beach was described as being a relatively undisturbed, crescent-shaped beach facing slightly south of east and exposed to moderate to high energy waves emanating from directions between NE and S. Headlands at the extremities of the beach cause refraction of ocean swell from the north and south and act as barriers to littoral drift from adjacent beaches. The active beach is backed by a series of parallel relict beach ridges (or foredunes) 5 to 8 m high which have accumulated since the Postglacial Marine Transgression. Sediments at Bengello Beach were described as predominantly well sorted, fine to medium grained (d_{50} range of 0.15 to 0.35 mm) clean quartz sands; the proportion of shell being less than 10% on the sub-aerial portion of the beach, although it increases seawards of this zone. Waldrons Swamp is located landward of the active beach. It drains Waldrons Creek towards the northern end of Bengello Beach.

The analysis for 1972 was presented in WRL's review of Thom et al (1973) and is not reproduced for brevity. From January to June in 1973, Bengello Beach continued to accrete. However, in mid-June 1973, the beach was severely depleted by a storm. The authors identified that the storm in June 1973 marked an abrupt change from an accretionary period to an erosional regime. For the remainder of 1973 and into 1974, the general tendency was one of gradual depletion. In February, March and April 1974, storms further eroded Bengello Beach which was left relatively undernourished. Bengello Beach was then further changed dramatically during late May and June 1974. Over three weeks of successive storms, with two major storms from 24-27 May and 9-15 June, the mean change in volume was 130 m^3/m above -0.94 m AHD. From July to October 1974, Bengello Beach was observed to begin recovery. The envelope of profile change relative to Mean Sea Level (MSL) ranged from over 3 m in elevation to 60 m horizontally from January 1972 to October 1974. Finally, the authors asserted that frequent monitoring of one beach which is considered "representative" of the region will shed more light on temporal variations than infrequent monitoring of many beaches. As such, extrapolation of behaviour at Bengello Beach to other beaches in the region was considered to be reliable.

A.5 Observations of Resonant Surf and Current Spectra on a Reflective Beach and Relationships to Cusps (Wright, Thom, Cowell, Bradshaw and Chappell, 1977)

This journal paper outlined observations of inshore wave and current behaviour at McKenzies Beach on 9 December 1976. It was described as being a pocket beach with a steep linear beachface with slopes of 1V:7H to 1V:10H. It was noted that a gravel step is consistently present at the subaqueous base of the beach face, and beach cusps are invariably present. This experiment provided evidence that beach cups are related to low-mode edge waves which oscillate parallel to as well as perpendicular to the beach (strong inshore resonance).

A.6 Batemans Bay Waterway Planning Study (Laurie, Montgomerie and Pettit, 1978)

This report by Laurie, Montgomerie and Pettit examined hydraulic and engineering aspects of Batemans Bay to inform its use and management. It attempted to delineate between sensitive and inherently stable areas. The report provided a preliminary plan for conservation and future development with respect to ecology and urban planning. It was asserted that care for the Clyde River and Cullendulla Creek requires skilful management for effects on the inner bay due to erodible catchment slopes. The Clyde River was described as a well-mixed estuary system with a wide and deep mouth and extensive headwaters draining a basin with an area in excess of 1,600 km^2. The principal characteristics of the area were deemed to be:

- exposure to easterly storms;
- navigation restrictions imposed by the Clyde River bar and extensive sand shoals in the inner bay;
- relative frequency of high river discharges; and
- topographical limitations on public access to the water.

The report defined the inner bay as the region between the highway bridge and a line between Square Head and Observation Head. This is equivalent to the current study area with the exclusion of Maloneys, Long and Caseys Beaches. The inner bay was found to be a complex area with the greatest degree of fluvial and marine interaction. Sediment in this area was found to be largely fluvial in origin but bi-directionally forced by the tides, river flows and wave action. This influx of riverine sands is from the Clyde River, smaller creeks and rapid weathering of local headlands. Sand in the inner bay is finer than in the outer bay, with the coarsest sand accumulating on the Clyde River bar and at the northern end of Corrigans Beach. Following construction of the training wall in the early 1900s, the river mouth bar moved further east and accretion occurred behind the wall and at the northern end of Corrigans Beach. Erosion of the inner bar northern shoreline was observed during this time. The Clyde River bar is mobile but generally located within a few hundred metres east and north of the end of the training wall. As early as 1864, bathymetric charts show it in this same position even prior to dredging and construction of the training wall. Commercial shipping services ceased in 1955. In 1964, dredging was stopped since, although desirable, it was not economically practical. Infilling of the boat harbour on the south side of the inner bay was deemed to be primarily due to wind and wave transport through the entrance and to a lesser extent wave overtopping and sediments from Hanging Rock creek. Virtually the whole north side of the inner bay was considered to be in a state of instability or fragile stability and not suited to development of waterfront structures other than for several hundred metres downstream of the highway bridge. The most severe conditions for erosion were deemed to be when flooding and associated channel scour occurred just prior to a large wave event. The south side of the inner bay was generally considered stable. The report noted that accretion at the northern end of Corrigans Beach had seemed to have temporarily ceased but that it may occur again in the future and recommended ongoing monitoring in this area. The report also cautioned against development in the Cullendulla Creek catchment, which is a shallow estuary in its own right with a small input of freshwater. This area is a depositional plain with unique geomorphic qualities. It has "chenier-like" plains of sand-shell ridges separated by saltmarsh and mangrove flats. The report recommended that it should be protected for its geomorphic uniqueness, rich oysters, flora and Aboriginal middens. It was noted that between 1864 and 1899, the location of the Cullendulla Creek mouth moved westward from its current position by 200 m during a period of accretion, but had returned to its present position by 1922.

In the outer bay (seaward of a line between Square Head and Observation Head), there was little evidence of long term variations in bathymetry between 1893 and 1960. The beaches on the southern side (including Caseys Beach) were generally described as pocket beaches between rocky headlands with minor depositional plains from creeks. The southern beaches were noted to be generally protected from southerly, south-easterly and westerly storms with highest wave impacts during summer. Shell (and hence sand) production in shallow waters offshore of the southern beaches was considered to be effective in maintaining beach sediment budgets. It was recommended that dredging not be undertaken in this area. Caseys Beach was described as an independent sediment unit with little longshore movement of sand beyond the platforms and headlands at both ends of the beach. On the northern side of the outer bay, Maloneys and Long Beaches were considered not be influenced by river mouth processes; with erosion and accretion only occurring due to wave variability. It was recommended that building and construction at Maloneys, Long and Surfside Beaches should be avoided and, where practicable, the width of the foreshore reservation be extended to at least 100 m.

A significant storm in June 1975 was described with overtopping and damage to structures and vessels. It was considered that seiching may have occurred in the inner bay. High flows in the Clyde River were noted to mainly pass under the northern half of the highway bridge before heading towards the south side of the inner bay and along the training wall. This sudden channel width expansion also caused high velocity eddy currents downstream of the highway bridge.

The report considered a series of proposals to improve boat moorings including:

- a breakwater at the southern end of Caseys Beach;
- a marina at Corrigans Beach;
- a breakwater wall just downstream of the highway bridge on the northern bank; and
- dredging and improvement works behind the training wall (to raise the crest).

A.7 Surf-Beach Dynamics in Time and Space – An Australian Case Study, and Elements of a Predictive Model (Chappell and Eliot, 1979)

This journal paper outlined the results of 20 beach survey campaigns undertaken at South Durras Beach over 37 days in November and December 1972. These were undertaken in parallel with the current measurements outlined in Eliot (1973). Profiles were taken at 50 m intervals covering the full 2.25 km length of the beach. South Durras Beach is described as being a medium to high energy surf beach. The beach fronts a Holocene barrier structure which test drilling has shown to have a 25 m thickness above bedrock. The beach sediment is dominated by medium sand compromised largely of shell carbonate and quartz. The bathymetry offshore of South Durras Beach is inherited from Pleistocene subaerial erosion subdued by

Holocene sediment cover, is moderately complex and refraction thus significantly affects the longshore distribution of wave energy. It was noted that the inshore morphology and circulation patterns are very changeable and the beach is not homogenous along its length. Statistical analysis of the inshore morphology behaviour through varying energy conditions and modelling of the general inshore/nearshore profile under different wave energies was also presented.

A.8 Experimental Control of Beach Face Dynamics by Water-Table Pumping (Chappell, Eliot, Bradshaw and Lonsdale, 1979)

This journal paper outlined the results of the first known field experiments of beach groundwater manipulation undertaken in Australia at South Durras Beach. Beach groundwater manipulation, or beach dewatering, is an alternative to more traditional coastal stabilisation methods. Beach dewatering consists of the artificial lowering of the groundwater table with its proponents suggesting that this results in enhancing infiltration losses during wave uprush/backwash cycles while promoting sediment deposition at the beach face. Two beach dewatering experiments were undertaken on a 150 m long segment of South Durras Beach 7 October 1973 and 22 January 1975. An array of wells plus a large pump were used to regulate the intertidal beach water table while inshore and nearshore morphologies, water circulation and sedimentary processes were monitored adjacent to and away from the well array. The first experiment involved four pumped wells at 2 m centres while the second involved 24 wells at 1.5 m centres. The experiments indicated that beach dewatering has potential as an effective means of beach stabilisation.

A.9 Surf Zone Resonance and Coupled Morphology (Chappell and Wright, 1978)

This conference paper discussed the results of field experiments involving direct measurements of inshore current spectra, inshore circulation patterns and depositional morphology at McKenzies Beach and Bengello Beach. For brevity, WRL has not reviewed this paper as its content is discussed in greater detail in Wright et al (1979) and Wright (1982).

A.10 Morphodynamics of Reflective and Dissipative Beach and Inshore Systems: Southeastern Australia (Wright, Chappell, Thom, Bradshaw and Cowell, 1979)

This journal paper compared the results of field experiments involving direct measurements of surf and inshore current spectra, inshore circulation patterns and depositional morphology at McKenzies Beach, Broulee Beach and Bengello Beach. With the exception of McKenzies Beach which is composed of a bimodal population of sand and gravel, the beaches are primarily composed of medium sand.

McKenzies Beach was described as being a relatively high energy, reflective beach. Runup (relative to breaker amplitude) was noted as being high. Two experiments examining the spectral characteristics of and cross-spectral relationships between water surface and horizontal flow oscillations at different locations in the inshore system were conducted on 9 December 1976 (see Wright et al, 1977) and 26 May 1977. Wave data measured at McKenzies Beach showed pronounced narrow spectral peaks centred at swell frequencies. The peaks were noted to be conspicuously narrower and sharper than is the case for Broulee Beach and Bengello Beach, owing to sheltering.

Broulee Beach was described as being a partially protected dissipative beach. It is sheltered from the dominant south-easterly swell and from the south-easterly storm waves and exhibits a narrow range of temporal variability (compared to Bengello Beach), typically having a low tide terrace beach typography year round. An experiment conducted at the northern end of Broulee Beach on 31 July 1976 was discussed.

Bengello Beach was described as being a relatively high energy, dissipative beach. It is long and weakly embayed with the full spectrum of beach typographies evident along it. Wave exposure is greatest in the middle of the beach, slightly reduced at the northern end and most protected at the southern end. Two experiments conducted at the northern end of Bengello Beach (30 July 1976 and 27 May 1977) and three experiments conducted at the middle of the Bengello Beach (8 December 1976, 24 May 1977 and 25 May 1977) were discussed.

Runup (relative to breaker amplitude) at Broulee Beach and Bengello Beach was noted as being lower than at McKenzies Beach. Wave spectra from the surf zones at Broulee Beach and Bengello Beach showed significant energy at a much wider range of frequencies than at McKenzies Beach.

A.11 Field Observations of Long Period, Surf-Zone Standing Waves in Relation to Contrasting Beach Morphologies (Wright, 1982)

This journal paper extended the work presented by Wright et al (1979) at McKenzies Beach and Bengello Beach. In addition to the field experiments on 9 December 1976 and 26 May 1977 at McKenzies Beach, results from supplementary experiments on 10 and 11 December 1977 were outlined. In addition to the experiments at the northern end of Bengello Beach (30 July 1976 and 27 May 1977), results from a more extensive experiment on 12-14 December 1977 were presented. Analysis of the measurements of surf and inshore current spectra, inshore circulation patterns and depositional morphology and their inter-relationships were set out.

A.12 Transgressive and Regressive Stratigraphies of Coastal Sand Barriers in Southeast Australia (Thom, 1983)

This journal paper discussed the stratigraphic characteristics of the coastal sand barrier at Bengello Beach. The author asserted that the series of parallel relict beach ridges, which back the active beach, were deposited during the Postglacial Marine Transgression. Radiocarbon dating results from sediment cores forming a cross-section through the middle of Bengello Beach were presented.

A.13 Batemans Bay Drainage Study (Willing and Partners, 1984)

This report by Willing and Partners concerns the construction of a shopping complex upstream of the Soldiers Club in the CBD. The catchment was considered to be a single valley with an area of 50 ha which discharges into the Clyde River with varying degrees of tidal inundation. During extremely high water levels, water was noted to back up in existing drainage works. Rainfall and runoff analysis and retardation effects were undertaken with the RAFTS (Runoff Analysis and Flow Training Simulation) numerical model. 10 and 100 year ARI rainfall events were considered. The design of the shopping complex was based on a river water level of 1.5 m AHD and required the infilling of an existing swamp which acted as a natural retarding basin. The report discussed the requirements of a new retarding basin to offset this impact and other necessary drainage requirements.

A.14 Coastal Storms in NSW in August and November 1986 (Higgs and Nittim, 1988)

This report by WRL documented wave runup at beaches in Batemans Bay during storms on 4-9 August and 17-23 November 1986. A variety of oceanographic and meteorological data was collected with wave buoys (offshore of Batemans Bay), tide gauges (Snapper Island and Princess Jetty) and an anemometer (Moruya Heads).

The August storm had a peak H_S of 5.6 m and typical T_P of 10-13.5 s. Local winds were from the SSW-SSE. The maximum water level recorded at the Snapper Island tide gauge was 0.86 m.

The November storm had a peak H_S of 6.0 m and typical T_P of 10-13.5 s. Local winds were from the S-SW. The maximum water level recorded at the Snapper Island tide gauge was 1.02 m.

The location and elevation of maximum runup were pegged and surveyed after both storm events and are shown in Table A-2.

Table A-2: Runup Levels During 1986 Storms

Site	**Maximum Runup Elevation** (m AHD) 4-9 August	**Maximum Runup Elevation** (m AHD) 17-23 November
Maloneys Beach	1.9-2.2	2.2-3.7
Long Beach	2.7	2.1-3.7
Cullendulla Beach	-	1.4-1.8
Surfside Beach	-	2.3-2.8
Wharf Road	2.0	1.5-1.7
Central Business District	-	1.4
Boat Harbour West	-	1.5
Boat Harbour East	-	1.4
Corrigans Beach	2.2-2.8	2.2-2.3
Caseys Beach	-	2.5-3.2
Malua Bay	5.5	-

A.15 Batemans Bay Inundation Study (Willing and Partners, 1988)

This report by Willing and Partners followed the 1984 Drainage Study (Willing and Partners, 1984). It reviewed the 100 year ARI oceanic still water level at the CBD (2.60 m AHD) and recalculated flood levels with 1, 5, 20, 50 and 100 year ARI rainfall for additional flooding impacts. It was noted that if the 100 year ARI rainfall was coincident with the 100 year ARI oceanic still water level, the CBD tail water level would rise by 0.16 m. As such, the effect of additional rainfall under such an oceanic flooding event was considered minimal.

A.16 Batemans Bay Oceanic Inundation Study (NSW PWD, 1989)

This report by the NSW Public Works Department was commissioned to determine the likely water levels during extreme storm events in Batemans Bay. The bay was described as funnel shaped; reducing from 5 km width near the Tollgate Islands to approximately 500 m at the Princes Highway bridge. Most of the beaches, dunes and hind dunes are typically 2 m AHD. Oceanic flooding had historically occurred at Surfside Beach, Wharf Road, the CBD, the boat harbour (east and west), Corrigans Beach and Caseys Beach. At the time of writing, the mid-range sea level rise estimate was described as 1.0 m by 2100 but this was not taken into account in the calculated design water levels. The area was considered to be tectonically stable and the impact of tsunamis was not considered.

A brief outline of historic oceanic inundation and river flooding was presented. To the south-east of Wharf Road, a survey in 1898 showed that a high sand spit existed 1.5 m above the high water mark. However, in 1959 this sand spit (and the associated subdivisions) were washed away during a flood event coinciding with spring tides. On 22 May 1960, a severe earthquake in Chile triggered a tsunami that caused oscillations of approximately 0.84 m at 45 minute intervals below the highway bridge. In August 1963, flooding occurred mainly due to rainfall combined with a high tide. In the storms during May and June in 1974, the peak still water level at Wharf Road was observed as 1.5 m AHD, with runup exceeding 3.4 m AHD at Surfside Beach. In June 1975, 90 m of Beach Road at Caseys Beach was damaged due to wave overtopping. In June and July 1984, wave overtopping and sand deposition occurred along Beach Road and the CBD foreshore (peak H_S of 5.6 m). In August 1986, waves overtopped the culvert at McLeod Street on the northern shoreline of the inner bay. In November 1986, wave runup was within approximately 0.2 m of the seawall crest of the CBD. The highest still water level observed in Batemans Bay is approximately 1.85 m AHD at the Princes Highway bridge (date unknown).

This study focused on storm events with significant offshore wave heights greater than 5 m. A bathymetry survey of Batemans Bay was commissioned as part of the project. Water levels were derived at 17 locations around the bay through a series of modelling exercises. Storm surge (determined by Monte Carlo analysis) was found to be common to all parts of Batemans Bay, but other components of elevated water levels (such as wave setup and river flooding) may vary. While joint probability analysis was undertaken for the ocean water levels, the probability of their occurrence with river flooding was not included in the simulations. However, it was noted that some dependency exists between the occurrence of river floods and elevated ocean water levels. A hydraulic flood model was constructed to determine the contribution of flooding to elevated water levels between Surfside Beach and the boat harbour. Wave setup was found to be greatest at Maloneys and Long Beaches. Northerly winds were found to be unlikely to generate high elevated water levels as they generate an offshore current due to the Coriolis force. A 0.3 m uncertainty factor was applied to each of the design water levels. Wave runup was then calculated for each of the 17 locations based on the 20 and 100 year ARI wave events (determined from 5 years of wave data at Jervis Bay, 1982-1986). Except at the western end of Long Beach, wave runup exceeded the nominal crest level at each location for the 100 year ARI event. Importantly, at Cullendulla Beach, Wharf Road, the CBD, the boat harbour and the southern end of Corrigans Beach, the 100 year ARI design still water level is above the nominal crest elevation. At these locations, the crest would be inundated even without wave runup. The crest levels would need to be raised by 1 to 4 m to prevent inundation and wave overtopping.

Finally, due to the protection offered by Square Head, the modelling indicated that a wave setup (and consequent pressure head) differential exists between Surfside and Cullendulla Beaches. It speculated that this difference in head drives a current which continues to supply sand to the shoal on the western side of Square Head.

A.17 Joes Creek Flood Study (Willing and Partners, 1989a)

This report by Willing and Partners reviewed present and future flooding conditions for Joes Creek as a result of the proposed George Bass Drive extension. Joes Creek catchment has an area of 536 ha, discharges under Beach Road and terminates at Corrigans Beach. The RAFTS numerical model was used to simulate the 5, 20, 50 and 100 year ARI rainfall events. Modelling was undertaken with three different tail water conditions: 0.94 m AHD (High High Water Solstices Springs tidal level which occurs approximately 3 times per year), 2.25 m AHD and 2.55 m AHD. The latter two tail water conditions included wave setup and were derived from the Batemans Bay Oceanic Inundation Study (NSW PWD, 1989). Peak flood levels were determined for a number of outlet configurations before and after the road alignment for George Bass Drive.

A.18 Short Beach Creek Flood Study (Willing and Partners, 1989b)

Short Beach Creek catchment has an area of 350 ha and an outlet at the southern end of Caseys Beach. A tributary to Short Beach Creek flows past a caravan park (Caseys Beach Holiday Park) and joins the creek approximately 200 m upstream of the outlet at the beach. After recent flooding, this report by Willing and Partners was initiated to investigate the sufficiency of five pipe culverts under Sunshine Bay Road and also consider the future effects of the proposed George Bass Drive extension. The RAFTS numerical model was again used to simulate the 5, 20, 50 and 100 year ARI rainfall events. Modelling was again undertaken with three different tail water conditions: 0.94 m AHD, 2.43 m AHD and 2.70 m AHD. It was noted that the bridge over Short Beach Creek acts as a control point for upstream water levels. Modelling also considered the build-up of sand blocking the outlet with sand bar elevations between 1.40 and 3.20 m AHD considered. The bar was expected to scour out during minor floods and hence the risk of Beach Road acting as an overland spillway is minimal. It was noted that tail water conditions lower than 0.94 m AHD did not affect upstream water levels as critical depth is achieved immediately downstream of the bridge. A range of short and long term flood mitigation options were set out for reducing post-development flows to pre-development values.

A.19 Batemans Bay Oceanographic and Meteorological Data (MHL, 1990)

This report by Manly Hydraulics Laboratory describes a range of data collected at Batemans Bay between 1986 and 1989 for the Batemans Bay Oceanic Inundation Study (1989). The data collection project involved commissioning a network of data recorders to measure offshore and inshore waves, offshore and inshore tides, wave runup and wind data. Waves were recorded at the newly installed offshore buoy and inshore on a Zwarts pole near Snapper Island. Tides were measured near the Tollgate Islands, Snapper Island and at Princess Jetty (CBD). Poles were used to measure wave runup at Long and Surfside Beaches. It was found that the tides recorded at Princess Jetty correlated well to Snapper Island except during floods and within periods with strong onshore winds where higher tidal anomalies were recorded at the CBD. Generally, the tide at Snapper Island leads Princess Jetty by approximately 22 minutes with a slight reduction in amplitude due to energy loss over the sand shoals. The most intense storm during the data collection period occurred on 23-24 May 1988 during a neap tidal cycle. The tidal anomaly was 0.23 m offshore and 0.15 m inshore. The deep water H_S was 3.9 m and 2.1 m at Snapper Island. However, the maximum wave runup level recorded at Surfside Beach during this storm was only 1.0 m AHD.

A.20 Behaviour of Beach Profiles During Accretion and Erosion Dominated Periods (Thom and Hall, 1991)

This journal paper discussed beach surveys undertaken at Bengello Beach from January 1972 to December 1987. Analysis from January 1972 to October 1974 was presented in WRL's reviews of Thom et al (1973) and McLean and Thom (1975) and is not reproduced for brevity. It was noted that beach surveys had been undertaken fortnightly up until January 1976, after which time they were undertaken monthly. An erosion dominant period including the May/June storms of 1974 extended to June 1978 (when the beach reached its most eroded state since measurements commenced) after which Bengello Beach returned to an accretion dominated period up until the latest available surveys (December 1987). The maximum accretionary rate was 0.419 m^3/m/day but 0.120 m^3/m/day was typical. It was noted that the subaerial beach volume had remained approximately constant from 1981 to 1987. The maximum change in beach volume above -0.94 m AHD varied between 279 and 298 m^3/m between 1972 and 1987.

The authors asserted that the pre-1974 beach may not have been indicative of a long-term equilibrium beach. It was suggested that the mean beach volume in 1981 was approximately equivalent to the mean beach volume in 1973. A small amount of additional accretion from 1981 to 1987 was attributed to sediment contributions from offshore of Bengello Beach. The authors noted that additions to the compartment's total sand store from external sources (e.g. the Moruya River or alongshore) were considered insignificant but that further work was required to conclusively determine this. The Moruya River, which terminates at the southern end of Bengello Beach, experienced large-scale flooding in 1975 and 1976.

A.21 Reed Swamp – Long Beach Flood Study (Willing and Partners, 1991)

Reed Swamp is located behind Sandy Place at Long Beach. It has a catchment area of 136 ha and a wetland which occupies 33 ha of which 5.4 ha is a permanent lagoon. This report by Willing and Partners revised the flood levels presented in previous studies. The existing culverts under Sandy Place were found to be inadequate to discharge a design flood event within the existing drainage channels. The study estimated the 5, 20 and 100 year flood levels and investigated upgrade options for the culverts including protection and augmentation. In June 1991, high flows (estimated to be greater than a 20 year ARI rainfall event) bypassed the culvert and flowed through adjacent properties to Long Beach. It was noted that the outflow from Reed Swamp is primarily governed by downstream tail water levels.

A.22 Land at Cullendulla Creek, Surfside (Patterson, Britton and Partners, 1992)

This report by Patterson, Britton and Partners reviewed oceanic inundation, beach stability and stormwater drainage at Cullendulla Beach. It is an engineering assessment concerning a proposed caravan park development in the lee of the beach. Specifically it reviewed the results of a Local Environmental Study (LES) commissioned by ESC (Kinhill Engineers, 1990).

The LES found that flood flows from Cullendulla Creek were not sufficient to generate water surface gradients and increase tailwater levels under oceanic inundation. The coastal engineering report commented that wave setup at Cullendulla Creek was expected to be lower than on the adjacent beach. The report also discussed at length the 0.7 m difference in design inundation levels between Surfside and Cullendulla Beaches (PWD, 1989) and the potential for overland flow between the two. It was asserted that the Cullendulla Creek estuary essentially behaves as a flood storage basin. The potential for an increase in storage level is determined by the discharge capacity of the Cullendulla Creek outlet relative to overland flow from Surfside Beach. It was concluded that since the Cullendulla Creek outlet is very efficient, the rise in water level from any overland flow would be less than a few millimetres.

With regard to beach stability, the report commented that the inner part of Batemans Bay is essentially a closed sediment system. It asserted that the exchange of sediments between the inner bay and the outer bay is not significant except for very fine to fine sand transported into the outer bay during flood events. Historically, the inner bay may actually have been a mud basin separated from the ocean by a barrier. Approximately 3,000 years before present, this barrier failed and the inner bay was connected to the ocean. The report considered sediments from Cullendulla Creek to be a minor if not insignificant source of sediment for the Square Head shoal seaward of the eastern end of the beach. The main contributors to sediment at Cullendulla Beach were deemed to be the Clyde River and shells produced offshore. The report hypothesised that Cullendulla Creek receives less sediment than the adjoining Surfside Beach, with little littoral exchange between the two. During storms, it was postulated that a mega-rip would tend to form against the Square Head shoal. Westerly winds were deemed to be very effective at generating littoral drift between the western end of Cullendulla Beach and the Square Head shoal. The report asserted that the historical connection of Hawkes Nest to the western end of Cullendulla Beach was not the cause of ongoing recession as progradation had previously occurred between 1864 and 1930 under this arrangement. From 1930 to 1990, Cullendulla Beach receded by 40-60 m (typical) and up to 100 m its eastern end. The report noted that the 1990 shoreline position was still located seaward of the 1864 shoreline. A review of photogrammetric data between 1942 and 1990 indicated typical recession of 1-1.2 m per year. Recession for the western and central parts of the beach (0.4-0.5 m per year) was lower than at the eastern end (1.0-2.0 m per year). Also, recent recession in the western and central parts of the beach was lower than the long term average, whereas the rate at the eastern end was consistent over the analysis period. It was asserted that erosion in the western and central parts of the beach were dominated by storm (swell) waves. Erosion in the eastern part was contended to be from local south-westerly and westerly wind waves. The annual total sediment loss from Cullendulla Beach was estimated to be 3,000 m^3 per year (1,000 m^3 per year above 0 m AHD). The report concluded that in the absence of a major flood or a series of smaller floods, Cullendulla Beach would continue to recede due to swell and wind wave attack. A beach management concept design involving a groyne field and nourishment was also set out. The preferred fill source for beach nourishment was sand extracted from the Square Head shoal.

Finally, the report undertook a preliminary review of stormwater drainage for the proposed development and noted that the detailed design should maximise natural infiltration and recommended that drainage be directed towards Cullendulla Creek and/or the wetland. It was noted that water quality control ponds would be required prior to drainage into the wetland.

A.23 Coastal Engineers Report, Timbara Crescent (Patterson, Britton and Partners, 1994)

This letter report by Patterson, Britton and Partners addresses the coastal hazards relevant to a private property at Timbara Crescent on the northern shoreline of the inner bay. A 50 year planning period was adopted and as no photogrammetry existed, the storm demand for the site was conservatively estimated to be 20 m^3/m. A conservative profile when the beach was slightly eroded (December 1986) was used as the average profile for determination of the hazard lines. It was noted that the present day sediment processes were both event driven (flood and coastal storms) and responsive to relatively sustained periods of accumulation or loss (over several decades). No long term recession was observed at the site. The 50 year design water level was adopted as 2.3 m AHD (from the Batemans Bay Oceanic Inundation Study, less the 0.3 m uncertainty allowance). Under these conditions, the relevant property would be inundated by water to a depth of up to 1.3 m with maximum breaking wave heights of 1.0 m. The best estimate of sea level rise for 2045 at the time of writing was 0.24 m and the Bruun rule was applied to estimate recession at the site. However, it was noted that the ongoing supply of sand from the Clyde River and offshore shell production may nullify shoreline recession due to sea level rise. The letter report recommended that development on the property should consider raised floor levels, structural members designed for wave loadings, the addition of a wall between the adjacent property to the east to prevent wave reflection impacts and preparation of a flood evacuation plan.

A.24 Coastal Processes of Cullendulla Creek (Short, 1995a)

This report is the first of two by Short concerning a revised tourism development proposal at Cullendulla Beach. It was commissioned by the NSW state government. This report discusses the coastal processes operating in the area and the impact of the proposed development on the natural processes. Cullendulla Creek is described as a barrier estuary containing a tidal creek, flats and delta together with a chenier beach ridge sequence and the modern beach. It was noted that oceanic inundation of the entire site will occur approximately every 20 years with an oceanic water level of 1.8 m AHD. Cullendulla Beach has a relatively steep reflective high tide beach (3°) fronted by a wide, low gradient low tide beach/terrace (1°). Maxima for recession were noted to occur at both the western and eastern ends of the beach (where there is shoreline instability from the creek entrance) with a minimum in the lee of the western side of the ebb tide delta. The author reviewed previous work in the area but asserted that there is insufficient information on coastal processes operating in the inner bay and at Cullendulla Beach to conclusively attribute the exact cause of recession and its future rate and duration. However, it is likely to be related to both wave and tidal current impacts on sediments in the inner bay. Recession was considered likely to continue for the next few years to decades. The report asserted that cycles of recession and progradation at Cullendulla Beach were in the order of hundreds of years. The author also contended that a mega-rip would not tend to form against the Square Head shoal. Instead, if a mega-rip does occur, it was more likely to occur at the western end of Cullendulla Beach. The report concluded that the proposed development and its protective works were not in accord with the goals of the NSW Coastal Policy.

A.25 Geomorphology of Cullendulla Creek (Short, 1995b)

This report is the second of two by Short concerning a revised tourism development at Cullendulla Beach. This report discusses the impact of the proposed development on the geomorphology of the system, in particular the outer beach ridges. Cullendulla Creek is the only known chenier site in NSW and one of only two known and documented sites in southern Australia. Cheniers are defined as low, shore linear, swash deposited sand and shell that overlie and are separated by inter-tidal and sub-tidal mud. They represent episodic wave deposition in a muddy tidal flat environment. Such sites are rare in NSW due to the lack of pre-existing fine sediments and high wave energy which removes any fine sediments from the shoreline. The entire system represents a unique coastal system and preserves an excellent record of sea level rise, estuary infilling and shoreline progradation over the past 10,000 years. The author asserts that the cheniers and beach ridges clearly and dramatically illustrate past positions of the shoreline. The report describes the nature of fluvial and marine sediments and the infilling sequence of the creek in six phases. The present geomorphology was categorised into the following major terrain units: outer beach ridge and cheniers, inner beach ridge and cheniers, tidal creeks, a tidal delta and shore platforms. The area also contains numerous Aboriginal occupation sites. The report contended that Cullendulla Beach has the best developed ebb tide delta in NSW. The entire system was asserted to be of additional importance due to its occurrence in a relatively small area (180 ha) with good access from a major town (Batemans Bay) and highway. The report concluded that the proposed development would completely cover and "destroy" the outer beach ridges and thereby severely downgrade the scientific and natural integrity of the entire system. It was also asserted that there was no practicable way that the development could be modified to mitigate its impacts.

A.26 Batemans Bay Vulnerability Study (NSW DLWC, 1996)

The Federal Government was interested in documenting examples of typical climate change vulnerability in each state of Australia. Batemans Bay was selected as the representative site for NSW. The project was jointly funded by ESC, the NSW Government and the Commonwealth Government. The study by the NSW Department of Land and Water Conservation adopted a 50 year planning horizon and a mid-range sea level rise projection of 0.24 m in 2045. Impact assessments were then prepared for beaches, buildings and habitats. The impacts of climate change quantitatively considered included sea level rise, sea surface temperature, rainfall and runoff, storm wave heights and suspended sediment yield from the catchment. Storminess and shoreline re-alignment were also considered qualitatively. Photogrammetry was used to estimate storm demand and long term recession.

The report noted that a low carbonate content of sand in the inner bay appeared to suggest accretion due to fluvial infilling. Maloneys and Long Beaches were characterised by onshore/offshore sand transport only. In contrast, Cullendulla, Surfside and Corrigans Beaches responded to a combination of onshore/offshore and longshore sediment transport. Aeolian losses were not considered to be a major issue as most beaches had well developed dune vegetation. Human intervention in the coastal zone included the rock training wall, dune reconstruction at the northern end of Corrigans Beach in 1988, dredging and terminal revetments at Long, Corrigans and Caseys Beaches. As a result of the intervention at Corrigans Beach, photogrammetry was analysed separately and normalised prior to 1988 and post 1988. The report noted that five major storms occurred in the photogrammetry between 1972 and 1977 at Cullendulla and Corrigans Beaches. However, photogrammetry was only available between 1972 and 1990 at Maloneys, Long, and Surfside Beaches. It was noted that a flood in February 1992 brought a large amount of debris and sediment onto Corrigans Beach.

In comparison to the Batemans Bay Oceanic Inundation Study, a lower uncertainty level of 0.2 m was adopted in the design still water levels. In comparison with the previous study, design water levels on the northern side of Batemans Bay increased by approximately 0.1 m and there was also a small decrease (< 0.1 m) on the southern side. This change was only due to variations between the bathymetric surveys used to develop meshes for the numerical models. The boundary conditions derived for the revised model were also based on wave data from Batemans Bay rather than from Jervis Bay and Botany Bay. On the basis that either bathymetry condition was possible, the study applied the higher design water level of the two studies at each site.

For the 50 year planning period, the study adopted increased design rainfall projections. As such, a hydraulic flood model was constructed to model the increased flood levels from this runoff under climate change. The report commented that suspended sediment load in Batemans Bay is proportional to discharge and rainfall erosivity and speculated that there would likely be a small increase in sediment supply to the bay under climate change. It was also speculated that any damage to seagrass beds in Batemans Bay would lead to increased wave heights at the shoreline. Climate change may cause damage to the seagrass beds by salinity change, sediment smothering following floods, higher waves and sea temperature change. Limited data was available at the time of writing regarding future changes in wind patterns under climate change, although speculative commentary was provided.

Hazard lines at each site were determined from storm demand and recession due to sea level rise using the Bruun rule. Ongoing long term recession was noted at Maloneys, Long and

Cullendulla Beaches and included in the respective hazard lines. Surfside Beach also included an additional parameter, an erosion escarpment, in determination of its hazard line to account for mid-term shoreline fluctuations. The applicability of the Bruun Rule at Maloneys, Long and Surfside Beaches was questioned due to the presence of rock reef nearshore.

Site specific management options considering environmental planning, development controls and protection works were set out for each site around Batemans Bay. Cullendulla Beach was characterised by its lack of an incipient dune and vegetation due to ongoing long term recession. Cullendulla Creek was described as a barrier estuary containing a tidal creek, tidal flats and an ebb tide delta. Long term recession at Cullendulla Beach will likely lead to the loss of a vehicle track, a Telstra cable and a rising main. The dune at Surfside Beach was considered stable except at the northern end which was recently eroded (at the time of writing) with a 1 m high scarp. The beach there appeared to be stable as a result of waves moving flood deposited sand onshore. The report indicated that the revetment around the CBD was necessary primarily for protection against flood flows rather than for protection against the structural impacts of waves. The northern end of Corrigans Beach was accreting due to flood deposition and longshore sediment transport (northward) being trapped against the training wall. A sewage pumping station at the southern end of Caseys Beach was also considered to be at risk from coastal hazards.

Finally, the report reproduced the findings of Short (1995b), who noted that to fully understand the processes operating in the inner bay and at Cullendulla Creek, accurate information regarding the following processes is required:

- transport of Clyde River sediment into, within and through the inner bay, particularly associated with major floods;
- transport of marine sands from the outer bay to inner bay;
- the impact of major storm wave events on sediment transport within the inner bay and the impact of the waves and associated setup and runup on bay shores;
- the sequential modification of the depth and morphology of the bay associated with such events
- the impact of modification of adjacent coastal processes and sedimentation;
- the impact of the southern training wall on processes and sedimentation within the inner bay; and
- the interaction of all these processes within the inner bay over years and decades.

A.27 Batemans Bay Wave Penetration and Run-Up Study (Lawson and Treloar, 1996)

This study by Lawson and Treloar was commissioned as a sub-component of the Batemans Bay Vulnerability Study. It was intended to recalculate the wave propagation, wave runup and design still water levels (including setup) at 17 selected sites (as with previous Inundation Study) with updated bathymetric data. The report examined changes in bathymetry between 1987 and 1995. The training wall was extended in 1987 leading to accretion at the northern end of Corrigans Beach. The bathymetry adjacent to Acheron Ledge (separating Maloneys and Long Beaches) had also changed between 1987 and 1995 and affected propagation to the northern shoreline. The study adopted the same tide and storm surge levels as in the previous study. A reverse ray frequency-direction spectral wave refraction method was used to developed nearshore wave coefficients (RAYTRK). It was not possible to propagate waves seaward of Cullendulla Beach, Wharf Road and the CBD at mean sea level. The study found that Caseys and Corrigans Beaches were more sheltered from the southerly sector than determined previously and Maloneys, Long and Surfside Beaches were similarly more exposed. Design still water levels included an uncertainty allowance of 0.2 m. Overall design still water level changes were in the order of 0.1 m. The 100 year ARI design still water level (without sea level rise) varied between 2.2 and 3.0 m AHD around the selected sites of Batemans Bay.

A.28 Drainage Report Wharf Road-Surfside (ESC, 1997)

This report by ESC reviewed the existing drainage in the Wharf Road catchment and considered mitigation options for minor flooding. Rainfall and runoff modelling was undertaken with the XP RAFTS model which was setup with six separate sub-catchments. The hydraulic grade line method was used for hydraulic modelling with a tail water level of 0.6 m AHD (approximately mean high water). The study considered the effects of localised flooding in isolation of oceanic inundation levels. However, the effects of oceanic inundation on the site based on still water levels presented in the Batemans Bay Vulnerability Study were qualitatively discussed.

A.29 The Impact of a Major Storm Event on Entrance Conditions of Four NSW South Coast Estuaries (McLean and Hinwood, 1999)

This conference paper discussed the effects of a major storm event on 8-13 May 1997 on four estuaries, one of which was the Tomaga River. The Tomaga River was described as being a permanently open, elongated coastal river with no associated lake. Under typical conditions the authors indicated that it has an area of 1.6 km^2 and a catchment of 98 km^2. At each estuary, the influx of sand through storm induced washover deposits provided a noticeable change (restriction) to pre-existing entrance conditions. Analysis of the water level inside the Tomaga River indicated that immediately following the storm, the mean water level increased by 0.033 m. Weak changes to the tidal constituents within Tomaga River as result of the storm were detected (reduced tidal amplitude and increased phase lag). The modified regime persisted for less than a week following the major storm event. The authors concluded that a dominant negative feedback mechanism in the Tomaga River encouraged the rapid recovery of pre-storm flows and amplitudes. This negative feedback mechanism was the increased still water level which promoted higher efflux velocities and bed shear stresses. At the same time, a positive feedback mechanism existed in the reduced tidal amplitude. The balance between these two mechanisms at Tomaga River was biased towards the negative feedback allowing relatively rapid "recovery" from a major storm event.

A.30 Batemans Bay Primary School Relocation Surfside Stormwater Drainage Study (ESC, 2000)

This report by ESC considered stormwater drainage for the proposed Batemans Bay primary school relocation site at Surfside. It superseded an earlier drainage study undertaken in 1986. The catchment is immediately upstream of the culverts under Wharf Road. Rainfall and runoff modelling was undertaken with the XP RAFTS model for the 1, 20 and 100 year ARI events. The one-dimensional HEC-RAS surface profile model was used to estimate water surface levels. Four different tail water conditions were considered: 0.6, 1.1, 1.5 and 2.3 m AHD. Calculations were undertaken with unblocked and blocked culverts. The report concluded that the effect of the primary school relocation on stormwater would be minimal and that the benefits exceeded a slight rise (0.1 m) in flood levels at Wharf Road in a 20 year ARI event.

A.31 Batemans Bay/Clyde River Estuary Processes Study (WBM Oceanics, 2000)

This study by WBM Oceanics addressed the water quality and sedimentation aspects of the estuary and associated catchment.

A two-dimensional (2D) RMA hydrodynamic model was developed for the area downstream of Nelligen. Flows from smaller tributaries were defined using the AQUACM-XP model. The RMA advection-dispersion module was also used. The model was calibrated and validated to available data on water levels and flows in the estuary for a range of measurement sites. Tidal water level data from Eden was determined to be most representative of the tide across the entrance to Batemans Bay. The report notes that the ocean tide attenuates slightly (approximately 10%) between the entrance and the highway bridge. It was also noted that the annual median rainfall over the Clyde River coastal plain varies between 900 and 1,150 mm. The highest daily rainfall (24 hours to 9 AM) on record at Batemans Bay was 363 mm on 9 April 1945. Preliminary (un-calibrated) water quality modelling was also undertaken using a module in the MIKE11 model. Predictive assessments for sewer spill scenarios and land use changes with water quality impacts were simulated.

Batemans Bay was described as having an open funnel shape with its centre-line orientation directed towards the south-east. Direct ocean wave access to the inner bay area is available from a range of ocean wave directions between the east 90° and approximately the south-south-east (150°). Waves from further north and south than this are subject to substantial refraction, diffraction and associated attenuation in propagating to the inner bay. It was noted that the shape of Batemans Bay may exacerbate wind-induced setup in certain conditions. Wave attenuation by bed friction across Batemans Bay causes a tendency for setup to occur further offshore with a slightly lower resultant setup at the shore. Where much wave refraction occurs in offshore areas, the same wave setup tendencies may also result. As part of the study, 2D preliminary (un-calibrated) wave propagation modelling was undertaken to derive refraction, diffraction and shoaling characteristics for several representative wave cases. The modelling of wave induced currents was used to infer indicative sand transport patterns. Wave related radiation stresses within the inner bay were found to induce significant current circulations including a consistent clockwise current circulation in the deeper regions (especially significant for accretion at the northern end of Corrigans Beach) and westward current flow across the ramp margin shoals past the Wharf Road area to the main river channel.

The study provides an excellent overview of sediment transport processes within Batemans Bay including Holocene sediment supply, river delta morphology, shoreline evolution and historical bathymetric changes. With respect to sedimentation aspects of the estuary, the annual average flood fluvial sand supply at the highway bridge was calculated to be approximately 22,000 m^3 per year. A substantial proportion of this volume is transported by the most infrequent flood events. The seabed across the inner bay was described as being highly mobile over a wide area out to and beyond Square Head and Snapper Island. Since 1898, approximately 800,000 m^3 of sand has accumulated on Corrigans Beach. The extent of accretion on Corrigans Beach is largely determined by the length of the training wall. The study noted that tidal currents act with wave action to move sand on the river bar, the ramp margin shoals and the Wharf Road area. The study described the Wharf Road area as having two fundamental configuration categories for the shoreline and shoals. The first is a nearshore current dominated configuration with a shoreline shape which runs approximately east-west. The second is a wave dominated shoreline evolution forming a well-established sand spit alignment approximately parallel to wave crests in the area.

In general, it was asserted that sand movement is westwards at Wharf Road. Only infrequent floods were deemed to have capacity for substantial reworking of the Wharf Road shoals seaward to the Surfside Beach nearshore area.

Finally, the study documented several important changes introduced to the Batemans Bay area. In response to progressive erosion of the northern end of Surfside Beach commencing around 1991, 12,000 m^3 of sand was placed on the beach in 1996. The sand for this beach nourishment exercise was sourced from the hind-dune area of Corrigans Beach. This was in turn replaced by sand removed from the marina basin during maintenance dredging. The report also noted that the highway bridge was constructed between 1951 and 1956, replacing the ferry crossing which had operated since the 1800s.

A.32 Moruya Odyssey: Beach Change at Moruya, 1972-2000 (Shen, 2001)

This conference paper discussed beach surveys undertaken at Bengello Beach from January 1972 to December 2000. Analysis from January 1972 to December 1987 was presented in WRL's reviews of Thom et al (1973), McLean and Thom (1975) and Thom and Hall (1991) and is not reproduced for brevity. It was noted that beach surveys had been undertaken fortnightly between January 1972 and January 1976, monthly between February 1976 and January 1989 and approximately every six weeks between February 1989 and December 2000. An accretion dominant period extended from June 1978 to January 1993 after which Bengello Beach entered a period of gradual erosion up until the latest available surveys (December 2000). The author noted that Bengello Beach had not yet experienced a full low-frequency cycle of erosion and accretion since monitoring commenced in 1972.

A.33 Batemans Bay Waterway Infrastructure Strategy (Webb, McKeown and Associates, 2002)

This report by Webb, McKeown and Associates formed part of the Estuary Processes Study and its outcomes would be included in the Estuary Management Plan for Batemans Bay. It considered the long term planning for, and provision and management of public waterway infrastructure. Specifically it assessed the current condition of public wharves and jetties, boat launching/retrieval facilities, car parking and other land based facilities, fish cleaning tables and boat access for persons with a disability. A 25 year planning timeframe was adopted with the greatest population growth in the area expected at Long Beach. The boat ramp at Maloneys Beach was considered to be dangerous as it often had a drop-off at the seaward end of the ramp due to erosion. Permanent waterway facilities at Cullendulla Beach, Surfside Beach and Wharf Road would be subject to shoaling and erosion which require extensive maintenance. Beach accretion around such facilities was noted to be just as significant for maintenance as erosion. Facilities constructed at Maloneys Beach, Long Beach, Surfside Beach, the northern end of Corrigans Beach and Caseys Beach would also be vulnerable to storm damage from wave action. Unofficial boat launching at the southern end of Corrigans Beach was noted to have caused damage to the dune back beach area. The report proposed that a boat harbour could be created at the eastern end of Long Beach with the construction of a breakwater.

A.34 McLeods Beach [Surfside Beach (West)] Emergency Response Plan - Draft (WBM Oceanics, 2003)

Following more than a decade of accretionary trends on the northern shoreline of the inner bay, severe erosion of the foreshore in December 2001 led to initiation of an Emergency Response Plan for Surfside Beach (West), also known as McLeods Beach. The storm had a peak H_S of

4.0 m coinciding with a spring tide and storm surge of approximately 0.4 m. This report by WBM Oceanics prepared management options for irregular and severe erosion at the site.

It was noted that sand transport is dominated by tidal currents on a day-to-day basis and wave induced currents when swell propagates into the bay. Erosion of the foreshore is dependent on the location and volume of sand in the shoals offshore of the beach, the volume of sand on the beach and the location of the Surfside Creek outlet (which is intermittently closed). The sediment at Surfside Beach (West) is dominated by flood and non-flood cycles. During major floods, scour processes deposit sand offshore of Wharf Road and offshore of Surfside Beach (East). Flooding may cause erosion or accretion at Surfside Beach (West). During periods of high waves (without flooding), strong westward longshore transport from Surfside Beach (East) occurs along the Wharf Road foreshore. This wave action generally causes accretion at Surfside Beach (West). The natural recovery of Surfside Beach was noted to be dependent on major floods to provide new sand deposits offshore. The report concluded that there are no theories or models which can reproduce or represent the processes over the timeframe of natural changes for the northern shoreline of Batemans Bay. Paradoxically, if a significant flood or large wave event does not take place for several years, persistent beach erosion may be apparent in some areas of the inner bay.

The study commented that a seawall (preferably composed of sand-filled geotextile containers) positioned landward of the historical eroded foreshore alignment should have a minimal probability of adversely affecting coastal processes. Sand nourishment was considered as an emergency response option combined with monthly monitoring. An alert was to be noted when the beach scarp came within 5 m of private property boundaries and nourishment was to commence if the scarp reached the boundaries. The construction of a groyne field was also appraised. The preferred solution set out in the report was immediate construction of a seawall composed of 2 tonne sand-filled geotextile containers. It was also recommended that sand build-up at the Surfside Creek outlet be monitored and relocated to adjacent beaches when necessary.

A.35 Batemans Bay and Clyde River Estuary Management Study (WBM Oceanics, 2004a)

This report by WBM Oceanics considered the current uses and values of the estuary and provided strategies for addressing issues and conflicts. Significantly, it found that the Clyde River is one of the few coastal rivers in NSW known to deliver significant sand to the coastal zone. The chenier sand plain forming part of the Cullendulla Wetlands was considered to be of national scientific significance. The report noted that this sand plain provides one of the few remaining intact sites which demonstrate shoreline evolution. It cautioned that development in the Surfside Creek catchment would increase discharge volumes (and hence sediments) if not carefully managed. This would increase the frequency at which the Surfside Creek outlet is blocked. One of the management strategies proposed was to undertake a cost-benefit analysis of dredging the Clyde River bar. It also recommended that additional technical studies regarding the bar be commissioned in parallel with ongoing monitoring of its elevation.

A.36 Batemans Bay and Clyde River Estuary Waterway User Management Plan (WBM Oceanics, 2004b)

This study by WBM Oceanics was commissioned as a sub-component of the Estuary Management Plan which was forthcoming at the time of writing. The plan was designed to protect recreational and environmental values of the waterway and ensure boating practices which maximised user safety and enjoyment. The report concluded that the boat ramp at Maloneys Beach (composed of board and chain) was no longer usable. It speculated that the impact of boat wash on bank erosion was minimal.

A.37 Background Information Document for Joes, Wimbie, Short Beach and Surfside Creeks (WBM Oceanics, 2004c)

This report is the first of three by WBM Oceanics concerning four creeks in the Batemans Bay area. It provides relevant technical information to inform subsequent reports. It was noted that breaching of entrance barriers at the four creeks is periodically undertaken by ESC to alleviate odour problems, as flood prevention strategy or to mitigate water quality issues. The creeks in the study are all small Intermittently Closed and Open Lakes and Lagoons (ICOLLs). Each creek has a relatively high catchment runoff to estuary volume ratio.

While not examined in this report, it was noted that within Eurobodalla Shire there are approximately 30 ICOLLs, of between 200 metres and 1 km in length and less than 20 to 40 m in width, which have lagoons located behind the beach berm.

Surfside Creek has a catchment area of 2.1 km^2. The creek extends 400 m from the opening where it joins the southern extent of a freshwater wetland. This wetland is protected from tidal flushing by a bund wall. The entrance to this creek requires relatively frequent opening by ESC. Scour of the beach is dependent on the beach condition and the volume of water in the creek when it is opened. The elevation of the berm seaward of the outlet causing complete blockage is estimated to be 1.62 m AHD.

A.38 Creek Management Policies for Joes, Wimbie, Short Beach and Surfside Creeks (WBM Oceanics, 2004d)

This report is the second of three by WBM Oceanics concerning four creeks in the Batemans Bay area. It presents the adopted creek management policies. The adopted policy for Surfside Creek is to excavate sand blocking the culvert when the upstream water level reaches 1.5 m AHD.

A.39 Review of Environmental Factors for Joes, Wimbie, Short Beach and Surfside Creeks Creek Management Policies (WBM Oceanics, 2004e)

This report is the third of three by WBM Oceanics concerning four creeks in Eurobodalla Shire. It documents the magnitude and nature of potential environmental impacts associated with entrance management policies. It is considered that artificial opening of the creeks is merely an early facilitation of a natural process to temporarily re-establish a tidal connection between the creeks the ocean. The study discusses the natural berm elevation variability without human intervention. It concluded that the creek management policies are unlikely to have significant environmental impacts upon the respective ecosystems in the short term.

A.40 Comprehensive Coastal Assessment #06: New South Wales Coastal Lands Risk Assessment – Draft Issue 3 (Patterson, Britton and Partners, 2005)

This report by Patterson, Britton and Partners developed a whole-of-coast comparative risk assessment, identifying those parts of the NSW coastal zone that are at risk from a range of coastal hazards for one probability scenario (1% AEP) in 2005 and in the future (2015). The project was funded by the NSW Department of Infrastructure, Planning and Natural Resources. The results were intended to alert local councils and state agencies to areas requiring more detailed scrutiny when planning future land use. "Broad-brush" methodologies were developed and used for all localities regardless of whether or not detailed coastal processes investigations had previously been completed. That is, the output from this report at any on locality includes greater uncertainties than a coastal hazard study focused only on that locality. A total of 99 discrete coastal "localities" were broadly assessed in Eurobodalla Shire including 46 open beaches, 10 pocket beaches and 43 cliffs/bluffs. Note that areas within tidal rivers/estuaries and the inner part of Batemans Bay; Central Business District, Boat Harbour West and Boat Harbour East, were not included. The coastal hazards considered included erosion, recession, cliff instability and overwash potential (dynamic inundation). The primary coastal vegetation line was used as a baseline for mapping coastal hazard lines as it was considered to be representative of an erosion escarpment during past erosion events. This line was defined as the distinct sand/vegetation interface (i.e. the edge of significant vegetation rather than sparse dunal vegetation) and was manually digitised for the NSW coastline using aerial photographs. Unfortunately, the coastal hazard figures for each of the localities within Eurobodalla Shire were not available for review by WRL (report text available only). The key assumptions in the "broad-brush" assessment are presented below:

- Present Day Setbacks from the Primary Coastal Vegetation Line (storm bite distance)
  - Pocket Beach: 10 m
  - Open, Exposed Beach, Dune Elevation > 8 m AHD: 15 m
  - Open, Exposed Beach, Dune Elevation 6-8 m AHD: 20 m
  - Open, Exposed Beach, Dune Elevation < 6 m AHD: 25 m
  - Open, Sheltered Beach, Dune Elevation > 8 m AHD: 10 m
  - Open, Sheltered Beach, Dune Elevation 6-8 m AHD: 15 m
  - Open, Sheltered Beach, Dune Elevation < 6 m AHD: 20 m
- Underlying recession rate: 0.3 m/year
- Recession due to sea level rise
  - Bruun Factor: 50
  - Sea Level Rise (Relative to 1990 MSL): 0.50 m (2105)
- Present Day Wave Runup level: 6 m AHD

A.41 Batemans Bay Wharf Road Development - Soft Option Coastal Engineering Assessment (Webb, McKeown and Associates, 2005a)

This report by Webb, McKeown and Associates concerns a residential development at Wharf Road on the northern shoreline of Batemans Bay. Three structures up to 4.5 storeys high were proposed, with a total of 33 residential units. The development application required a coastal engineer to demonstrate that the site would be secure from flooding and coastal processes and not impact upon flooding and coastal processes. The proponent wished to install a buried seawall with a wave return wall along the 100 % historical line (the most eroded beach alignment on record). However, ESC requested that a "soft option" without a seawall be considered by the proponent.

The report considered that 1964 was the most eroded beach state between 1898 and 1999 and this was adopted as the 100 % historical line. For erosion beyond this line to occur, the report speculated that a very large flood would have to occur when the main channel and margin shoals were highly shoaled. Such conditions would direct flood flows into the Wharf Road area, particularly if combined with a low tide. Peak flood velocities would be in the order of 2 to 4 m/s. While the report acknowledged that the effect of climate change on sediment movement along Wharf Road is not clear, it was speculated that the probability of future erosion extending beyond the 100 % historical line was small. Despite this assertion, the report applied the Bruun rule to estimate recession beyond the 100 % historical line due to sea level rise (0.2 m) in 2050. No additional storm demand was allowed for in these calculations. The report concluded that the development could proceed if structural members were designed for wave loading and inundation, and beach nourishment was planned following any major erosion events.

A.42 Addendum to Batemans Bay Wharf Road Development Soft Option - Coastal Engineering Assessment (Webb, McKeown and Associates, 2005b)

Further to the previous study, this report by Webb, McKeown and Associates considered additional requests from ESC regarding the development at Wharf Road. It was noted that the present vegetation line (2005) was actually located up to 15 m landward of the 100 % historical line (1964). The report also considered impacts on the proposed development from recent coastal protection in its vicinity. Upstream of the development, the foreshore revetment in front of the caravan park had been extended by 5 m in early 2005. Immediately downstream of the development a temporary rock wall had also been constructed in May 2005.

A.43 From Foreshore to Foredune: Foredune Development Over the Last 30 Years at Moruya Beach, New South Wales, Australia (McLean and Shen, 2006)

This journal paper discussed beach surveys undertaken at Bengello Beach from January 1972 to June 2004. Analysis from January 1972 to December 2000 was presented in WRL's reviews of Thom et al (1973), McLean and Thom (1975), Thom and Hall (1991) and Shen (2001) and is not reproduced for brevity. A period of gradual erosion extended from 1993 to 1999 after which Bengello Beach entered a period of gradual accretion up until mid-2001. From this time up until the latest available surveys (June 2004), Bengello Beach has been relatively stable. At this time, the beach was considered to be in a well-nourished state. The maximum change in beach volume above 0 m AHD (averaged across the four profiles) was an increase of 210 m^3/m between 1975 and 1994. The authors also noted that during the 7 weeks from 6 May to 21 June 1974, 95 m^3/m of sand above 0 m AHD (averaged across the four profiles) was eroded (2 m^3/m/day).

A.44 Flood Risk Assessment (URS, 2006)

This report by URS presents findings and recommendations on Floodplain Risk Management within ESC. It is a strategic document for the development of more specific floodplain risk management studies and plans within the local government area. The report recommended that after a flood has occurred, flood damage and other data should be collected as quickly as possible. Potential flood prone properties were noted at Maloneys Beach (5), Long Beach (65), Surfside Beach and Wharf Road (180), the CBD and boat harbour (200), Corrigans and Caseys Beaches (100), Malua Bay (20), Rosedale Beach (15), Guerilla Bay (2), Tomakin Cove and Beach (60) and Broulee Beach (10).

A.45 Batemans Bay Coastline Hazard Management Plan (Webb, McKeown and Associates, 2006)

This report by Webb, McKeown and Associates reviewed the findings of the Batemans Bay Vulnerability Study and further reports since this time (including the Clyde River/Batemans Bay

Estuary Processes Study) to determine hazard management options for the region. The study area was the same as that for the present Coastal Hazard Zone Management Plan. The study did not consider rocky foreshores as they were not deemed to be significantly affected by coastal hazards. The present value of likely damage due to inundation was estimated using an Average Annual Damage approach. This estimated the damage for each event multiplied by its probability of occurrence.

Revetment stability was also assessed in the study. Small seawalls at Long Beach and Corrigans Beach were not considered to have the ability to withstand a major storm. After damage sustained in a severe storm in the early 1990s, the seawall at Caseys Beach was topped up with 0.6 to 0.9 m size granite.

The report reviewed water level records during three recent severe storms in the area. On 9-11 May 1997, a maximum water level of 1.08 m AHD was measured at Princess Jetty tide gauge with a maximum anomaly of 0.32 m. On 22-25 June 1998, a maximum water level of 1.25 m AHD was measured with a maximum anomaly of 0.51 m. On 6-10 August 1998, a maximum water level of 1.07 m AHD was measured with a maximum anomaly of 0.35 m.

The study adopted sea level rise projections of 0.2 m in 2050 and 0.5 m in 2100. Since flooding and storm surge are not entirely mutually dependent, the study combined a 20 year ARI flood with 100 year ARI storm surge in determination of 100 year ARI oceanic still water levels in the inner bay. At most, flooding contributed 0.1 m to these design water levels. Unlike the Batemans Bay Oceanic Inundation and Vulnerability Studies, no uncertainty allowance was included in these levels. A hydrodynamic model was set-up for the CBD only to examine the combined effects of local runoff and oceanic inundation. Storm demands were calculated in a different manner to those in the Batemans Bay Vulnerability Study (DLWC, 1996), but not consistently based on an eroded volume above 0 m AHD. The storm demand for Cullendulla Beach was estimated in an unconventional manner and assumed to be equivalent to the volume of sand removed by ongoing recession over 5 years. The Bruun rule was applied to determine recession due to sea level rise, but these estimates were considered to be conservative.

The following recommended coastal hazard management options were presented for each part of Batemans Bay:

Maloneys Beach: No major recommendations.
Long Beach: Continue and strengthen existing development controls.
Cullendulla Beach: Relocate assets when required in the medium term.
Surfside Beach: Continue minimum floor level policy but large scale land filling is not feasible.
Wharf Road: Continue existing development controls but large scale land filling is not feasible.
CBD: Continue and strengthen existing development controls.
Boat Harbour West: Continue existing minimum floor level policy.
Boat Harbour East: Consider construction of a levee around the caravan park.
Corrigans Beach: Continue minimum floor level policy with planned retreat.
Caseys Beach: Sustain ongoing maintenance and possible upgrade of the seawall.

A.46 Southern Rivers Catchment Action Plan (SRCMA, 2006)

This plan by the Southern Rivers Catchment Management Authority broadly addresses six subregions from Stanwell Park to the Victorian Border of which Eurobodalla is one. It identifies the desired condition of natural resources and sets out priority targets towards achieving this condition over 10 years. Adaptive management is considered an important principle to deal with fire, flood, drought, storms and climate change. The main threats to the quality of ecosystems were deemed to come from historic and current impacts. Ecologically sustainable development principles and climate change impacts were taken into account in development of the Catchment Action Plan. Specifically, it targets the identification, auditing and rehabilitation of erosion "hotspots".

A.47 South Coast Regional Strategy 2006-31 (NSW Department of Planning, 2007)

This strategy by the NSW Department of Planning represents an agreed NSW government position on the future of the south coast to complement and inform other state government planning documents. Batemans Bay is identified as a major regional centre in the document, while Moruya and Narooma are identified as major towns. Its purpose is to ensure the adequate and appropriately located supply of land to sustainably accommodate housing and employment needs over 25 years. Various adaptation strategies for climate change were presented. Future urban development will not be located in high risk areas from natural hazards (flooding, inundation, erosion and recession). The strategy deems that Local Environmental Plans should provide adequate setbacks in high risk areas. The document specifically identified Long Beach and Malua Bay as an area potentially suitable for future urban growth. However, future development in northern Batemans Bay was preferred in the first instance due to its proximity to the CBD.

A.48 Projected Changes in Climatological Forcing for Coastal Erosion in NSW (McInnes et al, 2007)

This report is the first of two by CSIRO concerning climate changes projections in the Batemans Bay area. This study demonstrates the expected range of variability of climate parameters that influence coastal erosion in Batemans Bay. Two high resolution regional climate models were forced with the same greenhouse gas emission scenarios with markedly different responses. Depending on the model considered, a climate variable may both increase or decrease such that the range of possible changes spans zero. This was an artefact of the differences in the formulation of the models and their treatment of physical processes. Both models were forced with the IPCC A2 scenario which is considered to be a sufficiently conservative future scenario to base risk averse planning decisions on.

Wave growth and propagation were not included in the regional climate models but were inferred from the wind outputs with application of desktop wave hindcast techniques. These techniques treated waves with a fetch less than 200 km as locally generated and waves with a fetch between 200 and 500 km as swell.

Conclusions were drawn from comparison of the two models based on whether a trend (i.e an increase or decrease) was consistent for each variable between both models over the projected period. Sea level rise was expected to be 0-4 cm greater than the global mean at Batemans Bay in 2030 and 4-12 cm greater in 2070. Projected changes to wind speed, direction and frequency were inconclusive. Correspondingly, the projected changes to mean wave climate (height, direction and period) were considered small to negligible. Changes to extreme wave climate and storm surge behaviour were also inconclusive.

A.49 Climate Change Projections for the Wooli Wooli Estuary and Batemans Bay (Macadam et al, 2007)

This report is the second of two by CSIRO concerning climate changes projections in the Batemans Bay area. This study complements the previous report but examines additional variables with two different global mean temperature increases (low and high) for the same two regional climate models. The annual average maximum temperature at Batemans Bay was found to increase by 0.5 to 1.1° in 2030 and 1.1 to 4.6° in 2070. The annual average minimum temperature was found to also increase by 0.4 to 1.0° in 2030 and 1.0 to 4.3° in 2070. The annual average solar radiation was found to increase by 0.1 to 0.3% in 2030 and 0.2 to 0.8% in 2070. Projected changes to annual average rainfall, extreme rainfall and extreme drought were inconclusive.

A.50 Wharf Road Coastal Hazard Assessment and Hazard Management Plan (BMT WBM, 2009)

This report by BMT WBM was commissioned to consider the extent of coastline hazards effecting beachfront properties in the eastern end of Wharf Road. The area was subdivided in 1883 and is currently zoned for residential and tourism development. 80 per cent of the original subdivision is now below the high water mark. At the time of writing, coastal hazards were managed with minimum floor levels and additional development control. As a result of the construction of the training wall, the report asserted that 80 per cent of the sand supplied by the Clyde River into the inner bay had accreted on Corrigans Beach. It was speculated that this has reduced the supply of fluvial sediment to Cullendulla Beach, Surfside Beach and Wharf Road. It was noted that the northern end of Corrigans Beach had nearly accreted to the end of the training wall and its capacity as a sediment sink would correspondingly reduce. Extreme water levels were derived from the Princess Jetty tide gauge (including wave set-up and flood effects). A groyne constructed on private land without approval from ESC had maintained the updrift (eastern) shoreline position but exacerbated downdrift (western) shoreline erosion between 2005 and 2007.

In contrast to two previous studies of the area, the 100 % historical line (the most eroded beach alignment on record) was identified as having occurred in 1977. The extent of maximum erosion had previously been nominated to have occurred in 1964 or 2005. A smooth equilibrium planform was also fitted through this 1977 foreshore alignment. The Bruun rule was also applied to estimate the recession due to sea level rise beyond the 1977 vegetation line.

The suitability of a range of management options including environmental planning, development control conditions, "soft" protective works, "hard" protective works and "hybrid" protective works were considered. It was determined that any structural protection works or mitigation options would only be able to use a small amount of backfill due to its impacts on stormwater drainage. The report concluded that a second groyne or extension of the seawall fronting the caravan park would be required to offset the downdrift erosion caused by the unapproved groyne. However, it was considered unlikely that such "hard" protective works would satisfy ecologically sustainable development principles and so the recommended management option was rezoning of the Wharf Road area with possible voluntary resumption.

A.51 Eurobodalla Interim Sea Level Rise Adaptation Policy (ESC, 2010)

This policy by ESC initiates the process of providing long term management options for the ESC coastline under sea level rise projections and gives guidance on how development applications will be assessed until the Coastal Zone Management Plan is completed. Coastal risk areas are defined as those deemed to be at risk in a coastal hazard or floodplain study or within 100 m of the 1% still water level (1.435 m AHD) and/or at an elevation less than or equal to 5 m AHD. A 100 year planning period was used for residential land and a 50 year period for commercial or public facilities. The policy adopted the now withdrawn NSW sea level rise benchmarks of 0.4 m rise by 2050 and 0.9 m rise by 2100 relative to 1990 levels. The degree of risk was discretised as follows: immediate risk (at risk to the current 1% AEP event), high risk (at risk to 1% AEP event by 2050), medium risk (at risk to 1% AEP event from 2050 to 2100) and low risk (at risk to 1% AEP event after 2100). ESC promotes a policy of planned retreat for sites with immediate, high and medium risk (i.e. those sites at risk to 1% AEP event before 2100). New developments in the coastal zone must not create community risk, manage coastal hazard risk, not require protection works, not create community cost and be able to be removed or relocated at no cost to the community. As such, the policy noted that compliance with engineered property protection works is difficult to achieve. It was noted that planning control exclusions may be modified for coastal erosion protection in the CBD, the boat harbour (east and west) and the northern end of Corrigans Beach.

A.52 Concept Plan for the Batemans Bay Coastal Headlands Walking Trail (Gondwana Consulting, 2010)

This report by Gondwana Consulting presented a concept plan to guide the planning and development of a three phase formal walking trail linking the coastal headlands and beaches of the southern shoreline of Batemans Bay (Observation Head to Pretty Point). Parts of the trail are in the Coastal Hazard Assessment study area and include Caseys Beach, Sunshine Bay and Malua Bay. Acid sulphate soils were noted to occur along and landward of Sunshine Bay (west of Beach Road) and landward of Malua Bay (and along Reedy Creek).

In the first phase, the works proposed at each of the coastline sub-sections within the Coastal Hazard Assessment study area are minimal (i.e. addition of signage, drainage treatments and upgrade of existing walking track surfaces). The exception to this is at Caseys Beach, where a new footpath is to be built on the western side of Beach Road to allow travel between the northern end of Caseys Beach and Short Beach Creek before crossing back to the eastern side of the Beach Road. This footpath is to be constructed to avoid wave impacts on walkers under high tides and/or storm conditions.

During the second phase, the following significant works are proposed:

- picnic furniture is to be installed at the southern end of Caseys Beach;
- picnic furniture is to be installed at Sunshine Bay; and
- a footbridge is to be built over Reedy Creek at the northern end of Malua Bay.

In the third phase, it is proposed that Beach Road may be converted to a one-way road system at Caseys Beach and a foreshore reserve be established for the trail.

A.53 Eurobodalla Shire Coastal Hazards Scoping Study (SMEC, 2010)

This report by SMEC reviewed all existing coastal hazard studies for the whole of the ESC local government area and provided recommendation for future studies. The review specifically focused on the findings of previous reports with regard to current climate change projections. Specifically, it was commented that the Batemans Bay Vulnerability Study (DLWC, 1996) should have considered the 2100 planning period. It was noted that the storm demand values derived in that study appeared to be generally too low. The review found that there is a lack of coastal hazard information for the shire outside of Batemans Bay. It recommended that given the length of coastline and vast network of estuaries, beaches and lagoons within the shire, there is a need to target comprehensive coastal hazard investigations to priority areas. This report identified the priority areas for targeted assessments, as well as critical data acquisition requirements for the development of a Coastal Management Program for the entire coastline.

This scoping study analysed photogrammetry to estimate storm demand and long term recession at Maloneys Beach, Long Beach, Cullendulla Beach, Surfside Beach and Barlings Beach based on the storms of May-June 1974 and May 1978. Estimates for storm demand at other beaches were also presented based on approximate wave climate exposure. A small amount of recession was noted at Maloneys Beach and Barlings Beach, but it was speculated that this may be the result of sea level rise and not a sediment transport imbalance, and hence the long term recession at this beach was considered to be nil. Long term recession at Cullendulla Beach was not analysed. It was assumed that the median sand grain size for the beaches was 0.25 mm.

It was noted that the Bruun rule is a two-dimensional model which does not take into account three-dimensional effects. However, due to the lack of a more satisfactory model at the time of writing, it had been assumed that the Bruun rule could be applied uniformly along the beaches. However, the beaches within estuaries such as Cullendulla Beach, Wharf Road and the CBD would not undergo sea level rise recession that could be accurately calculated using the Bruun rule. It was asserted that this was because their offshore profiles are dominated by the dynamics of the tidal delta and three-dimensional sediment transport processes. Bruun factors were calculated from bathymetric and topographic data for Maloneys, Long and Surfside Beaches. A Bruun factor of 50 was specifically adopted for Barlings Beach as bathymetric data was unavailable. Bruun factors for the remaining beaches were approximated with more limited data. As the study concerned the whole of the local government area, the extreme water level estimates were generic in nature. However, the 1,000 year ARI water level was used for maximum wave runup calculations. Hazard lines were plotted for Maloneys, Long, Surfside, Barlings and Moruya Heads Beaches.

Run-up and overtopping areas were plotted for the following coastline sub-sections:

- Durras Beach (south);
- Maloneys Beach;
- Long Beach;
- Surfside Beach;
- Wharf Road and the CBD;
- Corrigans Beach;
- Caseys Beach and Sunshine Bay;
- Denhams, Surf and Wimbie Beaches;
- Mosquito Bay and Garden Bay;
- Malua Beach;
- Rosedale Beach;
- Guerrilla Bay;
- Barlings Beach;
- Tomakin Cove and Beach;
- Broulee Beach;
- Bengello Beach;
- Moruya Heads Beach;
- Congo Beach;
- Tuross Beach;
- Potato Point;
- Yabbara, Dalmeny and Kianga Beaches;
- Bar Beach;
- Narooma Beach; and
- Mystery Bay.

A risk assessment indicated that extreme (immediate) risk was present for the eastern end of Long Beach (inundation and erosion), Surfside Beach (West) (inundation), the CBD (inundation), Caseys Beach (erosion) and the southern end of Tomakin Beach (inundation). It was also noted that the Durras Creek, Maloneys Creek, Surfside Creek and Short Beach Creek outlets are constricted, which may cause issues under significant flows.

Finally, the report concluded that at the time of writing, future studies would require an updated bathymetric survey of Batemans Bay, ongoing LIDAR collection and ongoing photogrammetry collection. It was noted that gaps existed in the historical photogrammetry record which could not be retrospectively filled. The report also recommended that a wave climate study of Batemans Bay be undertaken to update the previous analysis conducted for the Vulnerability Study in 1996.

A.54 Beach Change at Bengello Beach, Eurobodalla Shire, New South Wales: 1972-2010 (McLean, Shen and Thom, 2010)

This conference paper discussed beach surveys undertaken at Bengello Beach from January 1972 to October 2010. Analysis from January 1972 to June 2004 was presented in WRL's reviews of Thom et al (1973), McLean and Thom (1975), Thom and Hall (1991), Shen (2001) and McLean and Shen (2006) and is not reproduced for brevity. A period of relative beach stability (consistent mean volume) in a well-nourished state continued from mid-2001 up until October 2010, albeit with high variations in sand volume. Important erosional events occurred in July 2001, October 2004, July 2005, June-July 2007, October 2009 and May-June 2010. The most significant of these events was in June-July 2007 when the mean sea level intercept moved 20-30 m landward leaving a 1.5 to 2 m high vertical scarp. The post-storm state of Bengello Beach was approximately equivalent to when surveys commenced in January 1972. However, within a year of the June-July 2007 event, the beach had recovered to its pre-storm state and continued accreting to reach its most accreted state since surveys commenced.

A.55 The Cause of Breaks in Holocene Beach Ridge Progradation at Bengello Beach (Rae, 2011)

This postdoctoral thesis evaluated whether any, if not all, of the breaks in beach ridge progradation at Bengello Beach throughout the Late Holocene, from approximately 7,000 years before present (BP) to the present, may have been caused by possible sea level, sediment supply and/or wave climate changes.

Bengello Beach was described as a transgressive-regressive barrier infilling part of a drowned river valley. Between 10,000 to 8,500 years BP, a low relief barrier existed 30-40 m below the present sea level,. A rapid marine transgression between 8,000 to 6,000 years BP caused Bengello Beach valley to flood. Open-ocean sand gradually blocked off the drowned valley causing estuarine mud to accumulate. The low-gradient coastal embayment and an excess of sediment caused episodic beach ridge progradation to occur, mostly between 6,000 to 2,500 years BP, thereby blocking several small drainage basins to create Waldrons Swamp. This resulted in the formation of 40-50 parallel beach ridges, each of which represent a former shoreline position. The source of this infilling sediment was concluded to be the offshore shelf deposit as the bounding headlands exclude littoral inputs of sediments and sediment input from the Moruya River was not considered significant. It was asserted that analysis of these beach ridges may be used as an indicator of the future response of Bengello Beach to changes in sea level and wave climate.

Hand augering of the beach ridges indicated that median sand grain size increased with depth. The Bruun Rule (Bruun Factor approximately 72) was used to estimate recession distances at Bengello Beach at three periods during the Holocene when the sea level rose. An analysis of aerial photographs of Bengello Beach indicated that there has been no significant changes in the orientation of the ridges along the centre of the embayment. However, to the south, the ridges curved to a common point along the airport indicating that this was the edge of the Bengello Beach barrier prior to draining (sea level fall) around 2,000 years BP. It was noted that Moruya airport was constructed in 1942.

It was concluded that the causes of the breaks in the beach ridges were attributed to a combination of wave climate and sea level changes and not sediment supply. Wave energy changes effecting the beach ridges were considered to include periods of increased wave heights and periods but without wave direction changes. The use of ground penetrating radar also indicated that a previous erosion event, approximately 1,900 years BP, had resulted in a 5 m scarp at the beach face. Since modern monitoring began in 1972, observed beach scarps have not exceeded 2 m in height.

A.56 Review of Environmental Factors for Clyde River Entrance Bar Maintenance Dredging and Beach Nourishment, Batemans Bay (NSW Department of Primary Industries, 2011)

This report by the NSW Department of Primary Industries documents the magnitude and nature of potential environmental impacts associated with dredging of the Clyde River bar and nourishment of Corrigans Beach. At the time of writing, shallowing of the entrance bar had limited the ability of recreational and commercial boats to safely cross the bar. NSW Crown Lands proposed to undertake dredging of the bar to maintain public safety and amenity followed by placement of sand on Corrigans Beach to minimise wave overtopping during storm conditions. 10,000 m^3 of sand is to be dredged from the bar to the east of the end of the training wall. The dredged sand is to be placed at two different sites. 7,500 m^3 sand is to be placed seaward of Batemans Bay resort at Corrigans Beach. This is to form a 320 m long dune with a maximum elevation of 3.7 m AHD. Placement of this sand at other beaches such as Long, Surfside and Caseys Beaches was considered and rejected. The remaining sand is to be placed at a second site seaward of the Hanging Rock playing fields. This sand will be stored at this location for future nourishment use as required elsewhere in Batemans Bay.

The report noted that on the opposite side of the bay, there was little movement of sediment around Square Head into Cullendulla Beach. It was noted that the 1989 extension of the training wall (by 150 m) was intended to prevent leakage of sand from Corrigans Beach past the training wall tip, along the channel and into the boat harbour ramp area. Ongoing beach accretion will eventually lead to repetition of this process.

The dredged depth was not to exceed approximately -2.8 m AHD to minimise the rate of infilling. It was speculated that dredging to a greater depth (say -3.3 m AHD) would result in faster infilling of the dredged area.

A.57 Eurobodalla Local Environmental Plan (ESC, 2012)

This plan by ESC aims to restrict development of land subject to flooding, coastal hazards, bush fire and land slip. It embraces ecologically sustainable development principles and aims to minimise any off and on site impacts on biodiversity, water resources and natural landforms. There are 22 different land zonings stipulated in the Local Environment Plan. Zone E2 is entitled Environmental Conservation and one of its objectives is to identify those areas at risk from coastline hazards, including sea level rise. Section 5.5 specifically discussed development within the coastal zone. New development must not be significantly affected by coastal hazards, have a significant impact on coastal hazards or increase the risk of coastal hazards in relation to any other land. Section 5.7 identifies that any development carried out below the high water mark requires consent. Section 6.5 discusses the development of land subject to flooding. The flood planning level was identified as being the 100 year ARI flood level with an additional 0.5 m freeboard. If such land is also affected by coastal hazards, the authority must consider the potential to relocate, modify or remove the development.