COASTAL ENGINEERING SOLUTIONS

NELLY BAY SHORELINE EROSION MANAGEMENT PLAN

FINAL REPORT

prepared for

Townsville City Council

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The Nelly Bay foreshore offers a diversity of seascapes and landscapes - providing extensive recreational and lifestyle opportunities to residents and visitors that are enhanced by considerable environmental, social and cultural values.

The complex interaction of waves, tides, winds and creek flows have continually shaped and reshaped the shoreline of Nelly Bay. The dynamic nature of the coastal environment means that sections of the foreshore are experiencing erosion which is threatening essential infrastructure and adversely affecting social and environmental values.

In recognition of the need to preserve this foreshore as a natural resource and to accommodate the ever increasing pressures of urban development on an eroding shoreline, Townsville City Council has commissioned this *Shoreline Erosion Management Plan*.

OBJECTIVES

The objectives of the Shoreline Erosion Management Plan are:

- to enable the Townsville City Council to proactively plan for erosion management in a way that is consistent with all relevant legislation (Commonwealth, State and Local) as well as all relevant coastal and environmental policies;
- to investigate and address the underlying causes of shoreline erosion and its likely future progression at the local scale;
- to determine cost effective and sustainable erosion management strategies that maintain natural coastal processes and resources; and
- to consider community needs in both the short- and long-term.

RECOMMENDED SHORELINE EROSION MANAGEMENT STRATEGY

Following a review of the prevailing coastal processes, risks and values of the Nelly Bay foreshore the following activities are recommended by this Shoreline Erosion Management Plan:

Beach Nourishment

- Beach nourishment is recommended at the northern end of Nelly Bay beach. The extent of the work is shown in the Figure on page iv.
- Place sand as initial nourishment on the shoreline along the Esplanade ocean frontage. The sand quantities required will depend upon the location of a Coastal Defence Line nominated by Council; and the degree of protection required (ie. the selected Design Event). Some guidance on the quantities of sand required in erosion buffers is provided in this Shoreline Erosion Management Plan.

- It is recommended that the sand for this initial nourishment be sourced from the accumulation of sand in the lower reaches of Gustav Creek.
- The location and operation of the extraction process require further consideration before implementation. This will require consideration of the findings of previous studies as well as the objectives of the *Gustav Creek Management Plan* prepared by Townsville City Council in 2005.
- Implement appropriate dune management practices on the newly nourished foreshore. As a minimum, this entails the planting and protection of native dune vegetation, the ongoing clearing of noxious weed species and ensuring adequate controlled access is maintained through new dune areas.
- Undertake ongoing beach renourishment along the Esplanade ocean frontage through the annual placement of 1,000 m^3 of sand sourced from the lower reaches of Gustav Creek. This is simply providing a mechanical means of reinstating the natural littoral supply processes that nourished Nelly Bay beach prior to the construction of Nelly Bay Harbour.
- Again the location and extraction of this renourishment sand is to be confirmed by investigations and consideration of the catchment management plan for the creek.
- Annual volumes may need to be amended in response to the results of ongoing monitoring of beach performance.

Training Works for Tidal Flows at the Breakwater Bridge

- It is recommended that a training wall for managing the flow of tidal water around the landward end of the southern breakwater of Nelly Bay Harbour be constructed. The proposed arrangement is shown conceptually in the Figure on page iv. The proposed structure will also assist in retaining a stable beach along this section of foreshore.
- Implement a trial of tidal training works alongside the breakwater bridge. This is to facilitate the permanent flow of tidal waters around the landward end of the breakwater. It is to be implemented either by using sand-filled geotextile bags (requiring approximately 580 m^3 of sand to fill) or by using existing precast concrete cubes to initially construct the training wall.
- The wall should extend approximately 70m beyond the toe of the newly nourished beach; and be aligned parallel to but 30 metres to 40 metres from the toe of the southern breakwater.
- Place sand to create a stable beach orientation in a fillet of sand against the southern flank of the training wall. Approximately 1,750 m^3 is estimated as being required for this purpose. The sand for this initial creation of the fillet should be sourced from the accumulation of sand in the lower reaches of Gustav Creek. The location and operation of this sand extraction process requires further consideration before implementation.
- Implement appropriate dune management practices on the newly created sand fillet.
- Monitor the effectiveness of training works alongside the bridge, making any alterations to the length and height of the wall if appropriate.

- Upon successful completion of the trial, armour the temporary training wall for a more permanent arrangement. Alternatively completely remove the sand-filled geotextile bags or concrete blocks that constitute the wall, allowing sand to return to the beach system.

Project Monitoring

- Establish and undertake initial pre-project monitoring survey on approximately twelve beach transects to be located on the Nelly Bay shoreline.
- Undertake surveys twice annually on these transects, with additional surveys immediately after major erosion events.
- All surveys are to extend offshore for a minimum distance of 200m from the line of mean sea level on the beach.
- The exception to this is the initial pre-project survey which should extend at least 500 metres offshore of the seaward edge of the reef flat into deep water (ie. 500 metres seaward of the reef crest).

Project Design and Approvals

- Townsville City Council (in consultation with other stakeholders) to select the Design Event for which the erosion mitigation strategies recommended by this Shoreline Erosion Management Plan are to accommodate. This requires consideration and acceptance of the risk that such an event will occur (or be exceeded) within a 50 year planning period. Guidance on risk is offered in this Shoreline Erosion Management Plan. Nominating the Design Event simply requires selecting the Average Recurrence Interval (ARI) cyclone for which immunity is required.
- Townsville City Council (in consultation with other stakeholders) to select the alignment of an appropriate Coastal Defence Line along the Nelly Bay shoreline. Throughout the 50 year planning period, property and infrastructure landward of the Coastal Defence Line remain protected from long-term erosion effects; short-term erosion caused by the Design Event; and recession as a consequence of future climate change. Foreshore areas seaward of the Coastal Defence Line lie within the active beach system (ie. within the erosion buffers).
- Undertake engineering designs for works associated with the initial beach nourishment along the Esplanade ocean frontage.
- Undertake engineering designs for works associated with the trial of a training wall alongside the breakwater bridge opposite Kelly Street; and for the initial beach nourishment to create the sand fillet in the beach/training wall corner.
- Prepare and submit appropriate approval applications based on designs for the proposed works.

Recommended Shoreline Erosion Management Plan

ESTIMATED COSTS

The estimated costs associated with the above recommended strategies are summarised below.

At this early stage, these estimates must be considered as indicative only - since no detailed design has been undertaken. They have been based on an approximation of sand volumes for initial beach nourishment to provide a buffer to an assumed Coastal Defence Line - the location of which requires confirmation or amendment by the project's stakeholders.

SEMP component	Cost	On-going Cost
Project Design and Approvals		
Design of trial training wall at the breakwater bridge	$10,000	
Design of initial beach nourishment	$10,000	
Obtain appropriate approvals	$20,000	
Project Monitoring		
Establish & undertake initial pre-project surveys	$24,000	
Twice annual beach transect survey		$18,000
Beach Nourishment		
Implementation of initial beach nourishment :		
for 50 year ARI immunity	*$237,000*	
for 100 year ARI immunity	*$252,000*	
for 200 year ARI immunity	*$280,000*	
for 500 year ARI immunity	*$305,000*	
for 1,000 year ARI immunity	*$312,000*	
On-going renourishment with sand from Gustav Creek		$25,000
Implementation / maintenance of dune management program	$80,000	$12,000
Maintain Tidal Flow at Southern Breakwater		
Implementation of trial training wall (2 years)	$220,000	
Convert to permanent training wall	$110,000	
Maintenance of training walls		$5,000
Totals (for various initial beach nourishment options)		
for 50 year ARI immunity	**$711,000**	**$60,000**
for 100 year ARI immunity	**$726,000**	**$60,000**
for 200 year ARI immunity	**$754,000**	**$60,000**
for 500 year ARI immunity	**$779,000**	**$60,000**
for 1,000 year ARI immunity	**$786,000**	**$60,000**

1 INTRODUCTION

The complex interaction of waves, tides, winds and creek flows have continually shaped and reshaped the shoreline of Nelly Bay. The dynamic nature of the coastal environment means that sections of the foreshore are experiencing erosion which is threatening essential infrastructure and adversely affecting social and environmental values.

In recognition of the need to preserve this foreshore as a natural resource and to accommodate the ever increasing pressures of urban development on an eroding shoreline, Townsville City Council has commissioned this *Shoreline Erosion Management Plan*. Its purpose is to provide a framework for the sustainable use, development and management of foreshore land vulnerable to erosion.

This is to be achieved through appropriate consideration of local environmental, social and economic values as well as the physical coastal processes shaping the Nelly Bay shoreline. Figure 1.1 illustrates the extent of the area considered by this Shoreline Erosion Management Plan.

Figure 1.1 : Study Area for this Shoreline Erosion Management Plan[1]

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[1] The extent of the study is defined in *"Part 2 Specification"* of the Terms of Reference prepared by Townsville City Council for this Shoreline Erosion Management Plan.

1.1 Regional and Local Setting

Nelly Bay is located on the south-eastern shores of Magnetic Island, some 8kms offshore of Townsville - the largest city in North Queensland.

As illustrated in Figure 1.2, the study area is located on the western shores of Cleveland Bay - which is an approximately 15km wide and 15km long coastal embayment. Cape Cleveland forms its eastern boundary and Magnetic Island forms its western boundary. Both of these topographical features play an important role in defining the wave climate, tidal hydrodynamics and ocean water levels on the foreshores and nearshore regions throughout the Bay.

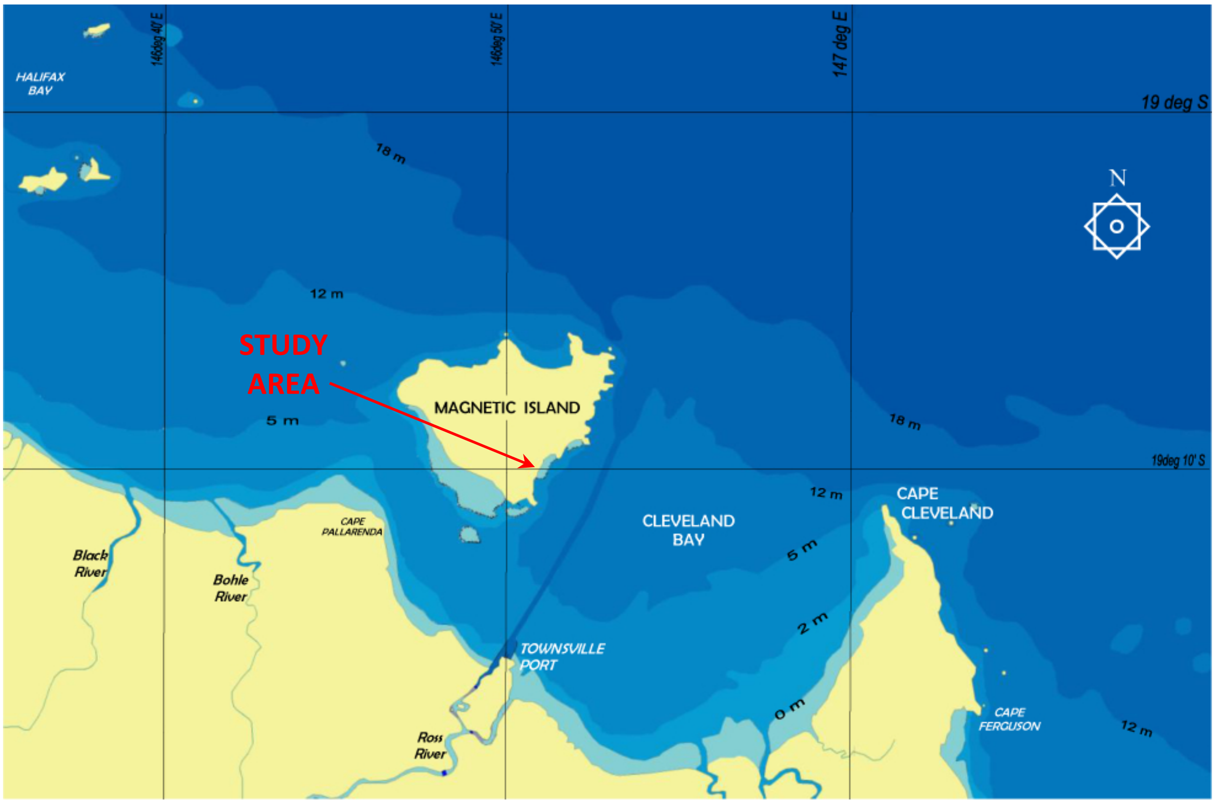

Figure 1.2 : Location of the Study Area in the Regional Context

Cleveland Bay is a somewhat shallow embayment facing north-east onto the broad open waters between the mainland and the Great Barrier Reef. At its seaward limit, the Bay is only some 12 metres deep (below the level of the Lowest Astronomical Tide).

The seabed approach slopes onto local foreshores are therefore very flat. These flat shallow approach slopes, in conjunction with the surrounding land features of Magnetic Island and Cape Cleveland, provide natural protection and wave energy attenuation for the eastern foreshores of Magnetic Island - particularly during extreme storms and tropical cyclones.

Nevertheless, the fetches to the north-east and east of Cleveland Bay are quite long, with the main Great Barrier Reef system being some 70kms offshore. It is from across these open north-east and east fetches that the largest waves can propagate into Cleveland Bay.

1.2 The Erosion Problem

The prevailing coastal processes in Nelly Bay result in a north-to-south transport of sand along the foreshore between Bright Point and Hawkings Point. Historically the supply of sand to the northern end of this coastal reach came from Gustav Creek. However the recent Nelly Bay Harbour development has resulted in changes to this supply of sand. Gustav Creek now discharges into the sheltered waters of the harbour.

A sedimentation basin was constructed in the lower reaches of the creek to intercept sand delivered by Gustav Creek - so that it did not spill into the harbour and could be used to nourish the downdrift foreshores of Nelly Bay Beach.

Whilst this basin has been successful in trapping most of this sand, its clearance and placement on the downdrift foreshore has not been effective. The longshore transport mechanisms on Nelly Bay Beach have still been moving sand along the beach at the same rate as previously. However because of the diminished supply from Gustav Creek, the longshore sand transport rates are greater than the rate that sand is now being supplied.

Consequently the beach has been steadily eroding and is particularly vulnerable during the storms of the north Queensland wet season.

Since the prevailing sand transport is from north towards south, the diminished supply has resulted in the northern section of Nelly Bay near the harbour being the first to experience erosion. The extent of this erosion is expected to gradually migrate southwards, threatening local infrastructure and foreshore amenity.

This erosion is caused by the steady removal of sand by longshore sand transport mechanisms, thereby reducing sand reserves in the upper beach area which would otherwise provide an erosion buffer during severe storms and tropical cyclones.

This increasing erosion threat has resulted in some beach nourishment works being implemented along the affected shoreline to reinstate the erosion buffer. Most of this sand placement has occurred in conjunction with the annual clearing of the “sand trap” located beneath the road bridge linking the harbour breakwater to the island. However this work does not address the underlying cause of erosion - which is the inadequate supply of sand that used to be delivered to the shores of Nelly Bay by Gustav Creek prior to harbour construction.

1.3 Objectives of this Shoreline Erosion Management Plan

The objectives of this Shoreline Erosion Management Plan are:

- to enable the Townsville City Council to proactively plan for erosion management in a way that is consistent with all relevant legislation (Commonwealth, State and Local) as well as all relevant coastal and environmental policies;
- to investigate and address the underlying causes of shoreline erosion and its likely future progression at the local scale;
- to determine cost effective and sustainable erosion management strategies that maintain natural coastal processes and resources; and
- to consider community needs in both the short- and long-term.

Shoreline Erosion Management Plans (SEMP's) are the Department of Environment and Resource Management's preferred method to address shoreline erosion issues at the local government level.

1.4 Structure of this Shoreline Erosion Management Plan

The Shoreline Erosion Management Plan has been structured as follows:

- This Section 1, which consists of an introduction and provides some background to the need and development of the Plan.
- Section 2 provides an assessment of the environmental and social "values" of the Nelly Bay coastal reach.
- Then in Section 3 the natural physical processes that have in the past, are currently, and will in the future, shape the project shoreline are discussed.
- This is followed in Section 4 by a discussion of the risks that these various natural processes represent to local coastal values and infrastructure.
- Section 5 then offers a number of potential strategies to mitigate these risks, then provides a ranking of each - leading to the establishment of a preferred erosion management strategy.
- Section 6 provides details as to the recommended erosion mitigation strategy, including its costs.
- The process of implementing the preferred strategy is then briefly presented in Section 7.
- Appendices to support the technical content of the Plan are then included. These include an outline of the planning and legislative framework affecting implementation of the Plan; detailed assessments of the local marine and terrestrial environments; historical beach surveys; and plots of the predicted shoreline recession and erosion vulnerability.

2 COASTAL VALUES

The Nelly Bay foreshore offers a diversity of seascapes and landscapes - providing extensive recreational and lifestyle opportunities to residents and visitors that are enhanced by considerable environmental, social and cultural values.

2.1 The Marine Environment

A technical and more detailed appraisal of the marine environment of Nelly Bay which was undertaken by C&R Consulting specifically for this Shoreline Erosion Management Plan is presented in Appendix B. However a discussion of the more important aspects is offered here.

The local nearshore marine environment of Nelly Bay is characterised by an extensive fringing reef consisting of five distinct reef zones. These are shown conceptually in Figure 2.1 and are listed in Table 2.1. (from Lewis, 1999).

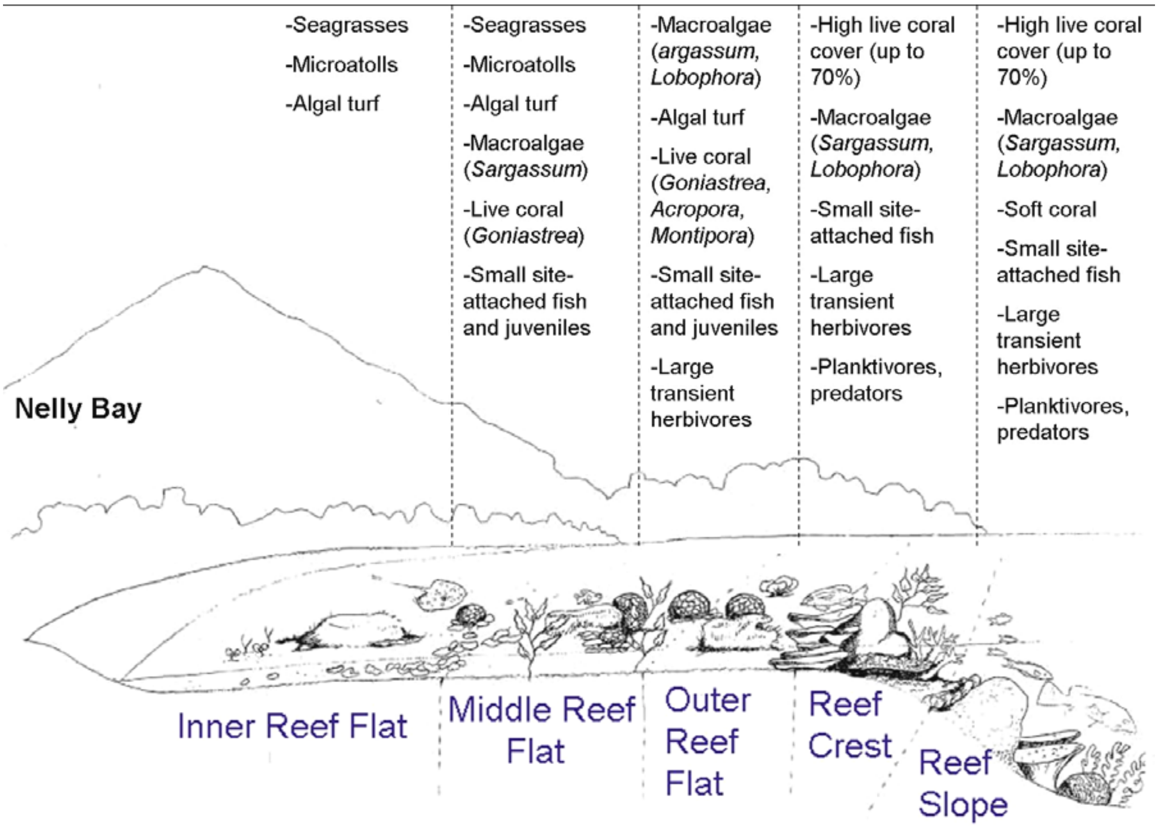

Figure 2.1 : Schematic representation of marine communities across Nelly Bay

Zone	Characteristics
Inner Reef Flat	Initially more than 60% sand cover, contains some rubble and flat-topped dead micro-atolls. Towards the outer edge of the zone, rubble cover increases to almost 100% and contains some large rocks and some live massive corals (mostly *Goniastrea* spp.)
Middle Reef Flat	Alternating dominance of rubble and rock. Many rocks recognizable as dead corals. Rocks are large boulders overgrown with dense stands of *Sargassum* spp. Colonies of *Goniastrea* spp. are larger and more abundant.
Outer Reef Flat	Over 60% dead coral or rock. Most dead coral maintains original form to some degree and indicates large previous stands of foliaceous *Montipora* spp. Heavy overgrowth of *Sargassum* spp. in the summer months, *Lobophora* spp. more prevalent in winter months.
Crest	High live coral cover. Almost no rubble. Some dense stands of *Sargassum* spp. The crest structure is broken up by large outcrops.
Slope	High live coral cover. Occasional gullies of sand and rubble breaking up the reef framework. Benthos dominated by *Padina* and *Lobophora* spp. Towards the base, the reef framework begins to break up, giving way to soft sediment communities including soft, fungid and gorgonian corals.

Table 2.1 : Categorisation of substratum zones

The distance between the toe of the beach and the reef crest at the seaward edge of the reef flat varies from about 400 metres at the northern end of the beach to only some 80 metres at its southern end.

Most surfaces on the inner reef flat are covered by thin turf and macroalgae. Fleshy macroalgae increases in cover across the reef flat - occupying some 30% of the available space on the inner reef flat, increasing to around 70% cover on the outer reef flat. Declines in macroalgal cover on the crest and reef slope is consistent with the higher coverage of live coral in these zones. Live coral is present in very low abundance on the reef flat, but covers some 40% of the reef crest and 30% of the reef slope.

Of the five most common algal genera, *Sargassum* clearly dominates every reef zone. Its presence increases significantly with increasing distance from the shore, before eventually declining on the crest and slope. There is a strong seasonal pulse in this cover of *Sargassum*, it blooms in summer and dies off in winter. The blooms are more pronounced on the mid- and outer reef flat than in other zones.

The coral community in Nelly Bay has adapted to conditions of high exposure to south-easterly trade winds and to high water turbidity. The community is dominated by fast-growing species that recover rapidly after disturbance. This may be one of the reasons for the high resilience documented in Nelly Bay - with coral cover plummeting after disturbances such as cyclones and bleaching events, and subsequently recovering to previous levels (Ayling & Ayling 2005).

Fish species in Nelly Bay are typical of those of inshore coral reefs. A range of groups is represented, including planktivores, territorial and roving herbivores, benthic invertebrate feeders and predators. The abundance of predators such as sharks, coral trout, snappers and emperors is likely to be reduced because Nelly Bay is open to fishing and is subject to baited drumlines under Queensland's Shark Control Program.

A number of migratory wading birds are also present at times, including the ruddy turnstone, sharp-tailed sandpiper and the whimbrel. The endangered[2] little tern is also known to occur in Nelly Bay.

Green turtles (*Chelonia mydas*) are frequently observed by divers in Nelly Bay, and nest annually on the Nelly Bay beach (Magnetic Times 2002; 2007). Endangered flatback turtles have also been recorded as nesting in Nelly Bay. Unfortunately turtles nesting on the beach bring them in close contact with local traffic; nevertheless several successful hatchings have been recorded.

Since 2002 sea turtles have nested primarily at the southern end of the beach, but in 2008 there were many turtles nesting more broadly across the bay (QPWS, pers. comm.), indicating that the entire Nelly Bay beach very likely provides a suitable nesting habitat. Turtle nesting and hatching activities typically occur each year from October to March. Consequently the implementation of any erosion mitigation strategy needs to consider such activities.

Estuarine crocodiles transit through the Cleveland Bay area on an irregular basis (QPWS, 2007) and are occasionally sighted from Townsville beaches and in the waters around Magnetic Island. However, Nelly Bay is not considered a regular habitat for crocodiles. They have never been recorded as using Nelly Bay as a haul-out site.

Clearly the rich diversity of habitats and their associated marine flora and fauna in the Nelly Bay area represents environmental resources and values that require protection and careful management. This is recognised through the designation of the surrounding waters as a Habitat Protection (Dark Blue) Zone of the Great Barrier Reef Marine Park.

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[2] Listed under the Nature Conservation (Wildlife) Regulation 2006 of the Nature Conservation Act 1992.

When considering appropriate erosion management strategies in Nelly Bay it is necessary to consider the following specific issues relating to the local marine environment:

- the proximity of nearshore habitats to the beach;
- proximity of nearshore reef systems;
- activities of sea birds and shorebirds;
- sea turtle nesting and hatching activities.

2.2 The Terrestrial Environment

A detailed and more technical appraisal of the terrestrial environment of Nelly Bay which has been undertaken specifically for this Shoreline Erosion Management Plan by C&R Consulting is presented in Appendix C. Nevertheless a discussion of the more important characteristics is offered below.

The terrestrial values study has been expanded beyond the boundaries nominated for this Shoreline Erosion Management Plan so as to include areas which may be impacted by coastal erosion processes. It therefore incorporates Rocky Bay, just to the south of Nelly Bay beach.

This includes areas designated as Land Zones 2, 3 and 12. A Land Zone is a simplified geology/substrate landform classification that is utilised throughout Queensland. Land Zones are used for Regional Ecosystem Classification, and are combined with details of different vegetation types within a particular bioregion to give a Regional Ecosystem description to a particular patch of vegetation, on a particular substrate in that bioregion. A total of five regional ecosystems occur within the study area - reflecting the wide diversity of the local coastal ecosystem. Three of these ecosystems are listed as “of concern” under the Vegetation Management Act 1999 (DERM 2009).

The highly modified foredune has traces of remnant herbland and grassland, with some elements of *Casuarina* open-forest to woodland remnants in places. Other scattered trees or shrubs occur along the foreshore, including very small stands of mangroves. A number of introduced and invasive plant species have also established along the foredune. Several large Banyan Figs (*Ficus benghalensis*) occur along the foreshore parkland. These iconic trees are of heritage, aesthetic and social value.

Directly behind the foredune, an extensive road and infrastructure network has been established in Nelly Bay. Two roads of particular relevance to this project are Nelly Bay Road and the Esplanade, which run parallel to the foreshore along the base of the beach dune. This dune system has been heavily modified by development along the northern end of the bay. However, a small patch of remnant dune vegetation mapped as Regional Ecosystem 11.2.2 and 11.2.3 (DERM 2009) has been maintained and protected as the *Nelly Bay Habitat Reserve*.

The Habitat Reserve was established in 1996 as a Conservation Reserve by Townsville City Council with the help of community efforts (Townsville City Council 2009). The Habitat Reserve maintains high levels of ecological and conservation values by providing a protected area that links Nelly Bay's highlands and lowlands with the Great Barrier Reef Marine Park, which is part of the Great Barrier Reef World Heritage Area.

The reserve is a coastal nature conservation project that was developed to protect and manage the remnant native vegetation communities and wildlife - such as the pied imperial pigeon and the bush stone curlew which inhabit the area.

The Reserve itself contains nine slightly different vegetation communities producing an array of native vegetation species and providing homes to many native fauna (Townsville City Council 2009). These communities include bloodwood, casuarina and eucalyptus woodlands, open scrub and grassland on foredunes, littoral rainforest, littoral scrub, mangroves, melaleuca / pandanus wetlands and melaleuca scrub.

At the southern end of the Bay, Nelly Bay Road runs directly behind the narrow foredune. It is located at the base of a high natural scarp, where granitic boulders rise rapidly in elevation. In this area the vegetation communities comprise several species of *Acacia*, a number of *Eucalyptus* species and *Corymbia* species. Hoop pines also occur in the granitic hills and on the rocky outcrop at the southern end of Nelly Bay. Koalas are known to occur in this area (DERM, pers. comm.).

Figure 2.2 illustrates conceptually the nature and extent of the terrestrial values of the local foreshore.

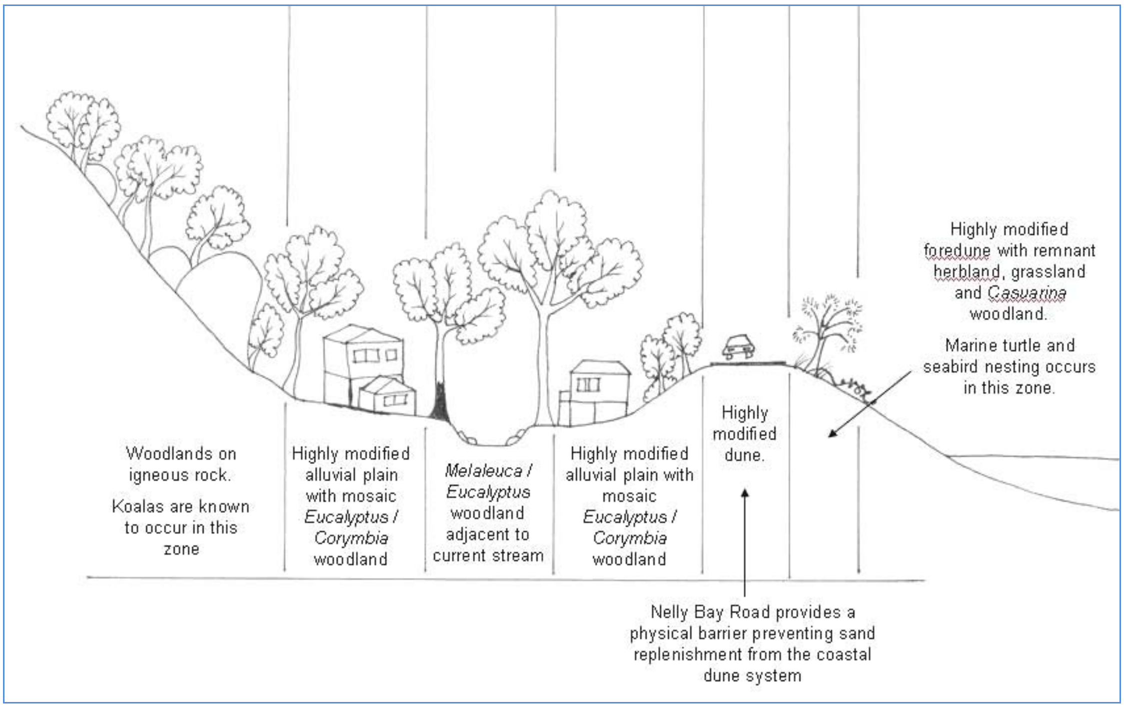

Figure 2.2 : Extent and types of local terrestrial vegetation

2.3 The Social Environment

The traditional owners are the Wulgurukaba people, who are the first known inhabitants of Magnetic Island.

Nowadays Nelly Bay is a suburb of the City of Townsville - and is the most populated bay on Magnetic Island (MICDA 2004). The island offers a quiet and less crowded opportunity to enjoy the natural environment of the Great Barrier Reef World Heritage Area, but is nevertheless within close proximity to Townsville's CBD. Consequently it contributes significantly to public recreation, relaxation and enjoyment – not only for the local population of approximately 2,500 but also to the many Townsville residents and tourists who visit the island.

Townsville is one of the State's two fastest growing Local Government Areas outside of southeast Queensland. Magnetic Island's unique character and environmental values, in conjunction with its close proximity to Townsville, means that it too is increasingly coming under development pressures.

Nelly Bay Road provides the only road access to communities further to the south and west of Magnetic Island - including those at Picnic Bay, Cockle Bay and West Point. This road is located immediately behind and parallel to the low foredune at the southern end of Nelly Bay. This approximately 450 metre length of road is therefore particularly vulnerable to erosion and inundation during severe storm events.

At the northern end of the beach, foreshore parkland is located between the foredune and the sealed Esplanade road. Private residences are located on the landward side of the Esplanade. It is this northern section of foreshore fronting the park and private landholdings which is most at risk of erosion. The foreshore is shaded by numerous trees, including large banyan fig trees alongside sheltered barbeque facilities. The erosion has been adversely affecting the visual and public amenity of the foreshore as well as threatening private and community infrastructure.

When considering appropriate erosion management strategies it is necessary to consider the following specific issues relating to the social environment of Nelly Bay:

- maintaining existing public use and access to the beaches and foreshore areas;
- maintaining the high visual amenity of the foreshore.

3 PHYSICAL PROCESSES ANALYSIS

The coastal environment responds continually to the ever-changing influences of waves, tides, ocean currents, winds and the supply of littoral sediments. Collectively these complex and dynamic coastal processes shape the physical environment of the Nelly Bay foreshore.

This section of the Shoreline Erosion Management Plan defines and quantifies the natural processes that are contributing to the existing and future erosion threats on this shoreline.

3.1 Sediment Supply and Transport Mechanisms

Beach sands on Nelly Bay are composed predominantly of quartz, and have been derived from the weathering of the igneous rocks of Magnetic Island - which have then been delivered to the coastal environment through local streams and creeks.

Whilst tidal currents can potentially initiate and sustain movement of the fine offshore sediments in Cleveland Bay, they are not of sufficient strength to move the coarse sand that exists along the land/sea boundary that constitutes the Nelly Bay foreshore (refer to later discussions in Section 3.2.2). It is wave action that moves this sand.

Tides play an indirect role - in that the variable ocean levels allow waves to access various parts of the beach face. Also, since the amount of wave energy that reaches the beach is determined by the depth of water over the fringing reef flats (by causing larger waves in the sea state to break before reaching the beach) tides play another indirect role by influencing the rate at which waves will move beach sand.

3.1.1 Historical Processes

Prior to the recent construction of the marina and ferry terminal adjacent to Bright Point, the natural supply of sand to the Nelly Bay foreshore was derived from sediments being delivered by Gustav Creek - primarily during flows induced by heavy rainfall events. Sand from the creek's steep inland catchment was delivered into the shoals at the creek entrance alongside Bright Point.

The competing influences of creek flows and longshore sand transport historically saw Gustav Creek meander somewhat as it approached its entrance to Nelly Bay. In the past, the seaward-most reach of the creek flowed northward almost parallel to the water's edge behind a low spit of sand before discharging in the northern-most corner of the beach against the rocky flank of Bright Point. This creek entrance arrangement is evident on historical surveys - as illustrated in Figure 3.1.

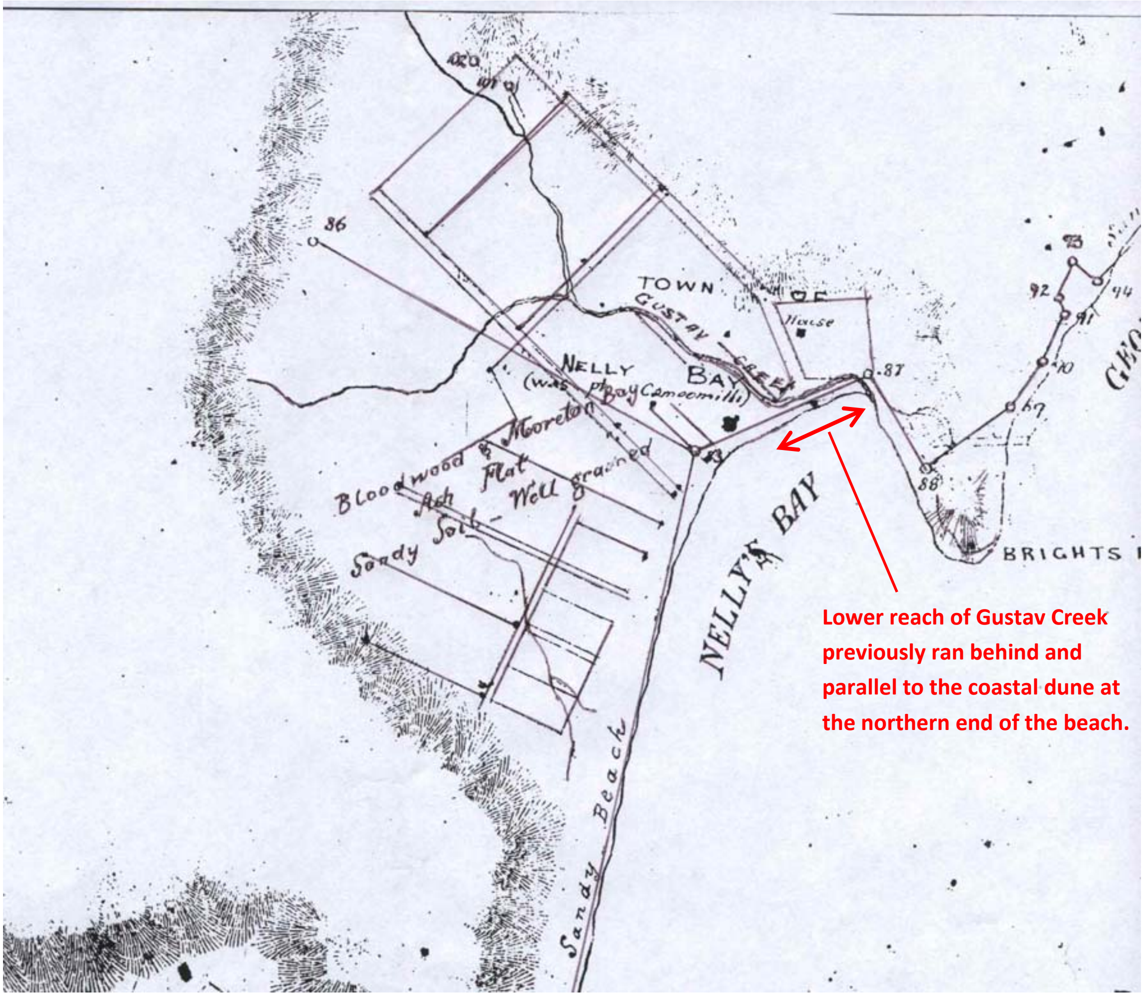

Figure 3.1 : Historical Location of Gustav Creek Entrance (circa 1886)

This sand was then transported off the entrance shoals by waves. The prevailing coastal processes in Nelly Bay result in primarily a north-to-south transport of sand along the foreshore between Bright Point and Hawkings Point (apart from in the northern corner where the creek originally discharged into Nelly Bay).

These littoral drift processes slowly carried the sand from the entrance area southward along the Nelly Bay Beach. At the southern extent of the beach, the fringing reef is very narrow. Consequently whenever sand is transported offshore during storms or strong wave activity at this location, some of it spills over the edge of the reef into the deep water immediately off Rocky Bay and Hawkings Point. This permanently removes that sand from the active beach system of Nelly Bay.

Nevertheless the natural ongoing supply of sand from Gustav Creek to its northern end has historically kept the foreshore of Nelly Bay nourished with sand.

It has been estimated that the annual supply of sediments from the Gustav Creek catchment to its lower reaches is of the order of approximately 600 to 3,600 m^3 - averaging around 1,600 m^3 /year (WBM Oceanics, 1995a). The wide variability in the annual rate is attributed to the considerable variability in annual creek flows as a consequence of rainfall events. Of this volume, some is expected to be retained by channel vegetation and deposited within depressions in the creek bed, thereby contributing to an accumulation of sediment in the lower reaches.

However major flood events scour this material and deliver it to the entrance shoals. During extreme flood events it is possible that some 500 - 1,000 m^3 of sand could be swept out of the creek by a single event (WBM Oceanics, 1995a). Nevertheless the average yield of sand to the creek entrance shoals has been estimated at around 325 to 830 m^3/year (WBM Oceanics, 1995b).

3.1.2 Recent Changes to Supply and Transport Processes

As a consequence of harbour construction works commenced in the late 1980's, the natural ongoing supply of sand to local foreshores has been interrupted. Gustav Creek now discharges into the sheltered waters of the Nelly Bay Harbour.

A sedimentation basin was constructed in the lower reaches of Gustav Creek at Sooning Street to intercept sand delivered by the creek - so that it did not just spill into the harbour basin, but could be used to nourish the downdrift foreshores of Nelly Bay Beach. Whilst this basin has been successful in trapping most of this sand, its clearance and placement on the downdrift foreshore (thereby replicating natural supply mechanisms prior to harbour construction) has not been effective.

The longshore transport processes on Nelly Bay Beach have still been moving sand naturally southward along the beach at the same rate as previously. However because of the diminished supply from Gustav Creek, the longshore sand transport is greater than the rate that sand is now being supplied. Consequently the beach has been steadily eroding. It is now particularly vulnerable to erosion by the storms and cyclones that occur during the North Queensland wet season.

Since the prevailing sand transport is from north towards south, the diminished supply has resulted in the northern section of Nelly Bay being the first to experience erosion. The entire ocean frontage of the Esplanade is currently most at risk. Unless mitigating measures are implemented, the extent of this erosion is expected to gradually migrate southwards, further threatening local infrastructure and foreshore amenity.

In addition to inhibiting the natural supply of sand to Nelly Bay beach, the new harbour has altered the wave climate and longshore sand transport regime on the northern end of the beach. As a consequence of the southern breakwater, there are localised wave diffraction processes that now move some sand northwards along the beach towards the road bridge at the end of Kelly Street (that connects to the breakwater).

This sand movement causes a build up of a sand "fillet" in the beach/breakwater corner which fills the channel under the road bridge - thereby blocking tidal flow between the reef flat and the sheltered harbour waters.

However the Marine Parks Permit issued for the construction, maintenance and operation of Nelly Bay Harbour states:

> *"The Permittee must maintain water flow at Mean Low Water Mark under the breakwater bridge and around the breakwater on all sides with connection to the ocean and must ensure that such water flow is maintained continuously thereafter, ….."*[3]

Consequently Queensland's Department of Main Roads and Transport undertakes annual clearance of sand from this area to ensure that the required tidal flows are reinstated beneath the road bridge by 01st July of each year. The removed sand is placed on Nelly Bay beach.

There is no doubt that this annual relocation of sand onto the threatened foreshore provides a temporary improvement to local erosion buffers. However it does not address the issue of an ongoing inadequate supply of sand to replace sand transported southwards along the beach - and to prevent it from gradually eroding.

The recent changes to sand supply and transport processes are illustrated conceptually in Figure 3.2.

3.1.3 Broad Summary of Supply and Transport Processes

The broad scale sediment supply and longshore transport regime in Nelly Bay can be summarised as follows:

- Historically sand has been delivered to the coastal environment of Nelly Bay primarily by Gustav Creek.
- It is estimated by previous studies that the average supply rate to the coast was around 325 m^3 /year to 830 m^3 /year.
- However this annual rate of sand supply was highly variable, as it is significantly affected by rainfall/runoff events - with major floods in particular flushing large quantities of sand from out of the creek's lower reaches.
- Once delivered into the shoals near the entrance to the creek, sand was then worked by littoral drift processes that slowly carried the sand southward along Nelly Bay beach towards Hawkings Point.
- At the southern end of Nelly Bay beach the fringing reef is quite narrow - resulting in sand being swept over the seaward edge of the reef flat into the deeper water offshore during storms. This then permanently removes that sand from the active Nelly Bay beach system.

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[3] Clause 27 of Marine Parks Permit No G03/2321.1. Issued on 01st June 2003 under the then Great Barrier Reef Marine Park Regulations 1983 (Commonwealth) and Marine Parks Regulations 1990 (Queensland).

Figure 3.2 : Recent Changes to Sand Supply and Transport Processes

- Nevertheless the natural ongoing supply of sand to its northern end from Gustav Creek has historically kept the shores of Nelly Bay nourished with sand.
- Following the construction of the Nelly Bay Harbour, Gustav Creek now discharges into the sheltered waters of the harbour rather than directly into the active beach system. Clearance of a sediment trap near the creek entrance and placement of sand to renourish Nelly Bay beach has not been undertaken effectively. Consequently the supply of sand from the creek to the beach has diminished.
- The longshore sand transport on the beach has remained substantially unchanged, so the lack of adequate sand supply has resulted in the beach eroding.
- Some localised changes to the wave climate adjacent to the harbour's southern breakwater results in accumulation of sand beneath the road bridge leading onto the breakwater. This necessitates annual removal of this sand in

order to comply with the conditions of the Marine Parks Permit originally issued for Nelly Bay Harbour.

- Unless an appropriate long-term supply of sand to the northern end of Nelly Bay is re-established, the erosion trends currently being experienced will continue and indeed will migrate southwards.

3.2 Local Coastal Processes

The preceding Section 3.1 provides an overview of broad scale regional sand supply and transport mechanisms.

However along the Nelly Bay foreshore there are subtle variations in the coastal processes that shape this shoreline and it is important to have an understanding of these more intricate local processes. Otherwise there is the very real risk that any future strategies to mitigate local erosion will be ineffectual, costly and potentially compromise the environmental and social values of the area.

The term "*coastal processes*" refers to the complex interaction of ocean water levels, currents and waves that drive the transport of coastal sediments – including the sand on beaches. Some discussion of each of these individual influences is offered in the following sections.

3.2.1 Ocean Water Levels

When considering the processes that shape shorelines it is necessary to consider the ocean water levels that prevail from time to time. This appreciation not only relates to the day-to-day tidal influences, but also to the storm surges which occur as a result of extreme weather conditions. The expected impacts of climate change on sea level also need to be considered.

Ocean water levels will have a considerable influence on the wave climate of Nelly Bay. As ocean waves propagate shoreward into shallower water, they begin to "feel" the seabed. The decreasing depths cause the waves to change direction so as to become aligned to the seabed contours and to also shoal up in height until such time as they may break - dissipating their energy as they do so.

Just how much wave energy reaches the shoreline is therefore determined largely by the depth of water over the seabed approaches. Ocean water levels and the seabed bathymetry are important aspects in this process of wave energy transmission.

Consequently it is necessary to have a thorough understanding of the following ocean levels on local foreshores:

Astronomical Tide - this is the "normal" rising and falling of the oceans in response to the gravitational influences of the moon, sun and other astronomical bodies. These effects are predictable and consequently the astronomical tide levels can be forecast with confidence.

Storm Tide - this is the combined action of the astronomical tide and any storm surge that also happens to be prevailing at the time. Surge is the rise above normal water level as a consequence of surface wind stress and atmospheric pressure fluctuations induced by severe synoptic events (such as tropical cyclones).

3.2.1.1 Astronomical tides

The tidal rising and falling of the oceans is in response to the gravitational influences of the moon, sun and other astronomical bodies. Whilst being complex, these effects are nevertheless predictable, and consequently past and future astronomical tide levels can be forecast with confidence at many coastal locations. Tidal planes have been published for Magnetic Island (MSQ, 2009) and these are presented in Table 3.1 below.

Tidal Plane	to AHD	to Chart Datum
Highest Astronomical Tide (HAT)	2.04 metres	3.88 metres
Mean High Water Springs (MHWS)	1.13 metres	2.97 metres
Mean High Water Neaps (MHWN)	0.29 metres	2.13 metres
Mean Sea Level (MSL)	0.07 metres	1.91 metres
Mean Low Water Neaps (MLWN)	-0.31 metres	1.53 metres
Mean Low Water Springs (MLWS)	-1.13 metres	0.71 metres
Lowest Astronomical Tide (LAT)	-1.84 metres	0.00 metres

Table 3.1 : Tidal Planes at Magnetic Island

In a lunar month the highest tides occur at the time of the new moon and the full moon (when the gravitational forces of sun and moon are in line). These are called "*spring*" tides and they occur approximately every 14 days. Conversely "*neap*" tides occur when the gravitational influences of the sun and moon are not aligned, resulting in high and low tides that are not as extreme as those during spring tides.

As can be seen in Table 3.1, the maximum possible astronomical tidal range at Nelly Bay is 3.88 metres, with an average range during spring tides of 2.26 metres and 0.60 metres during neap tides.

Spring tides tend to be higher than normal around the time of the Christmas / New Year period (ie. December - February) and also in mid-year (ie. around May - July). The various occurrences of particularly high spring tides are often referred to in lay terms as "*king tides*" - in popular terminology meaning any high tide well above average height.

The widespread notion is that king tides are the very high tides which occur early in the New Year. However, equally high tides occur in the winter months, but these are typically at night and therefore are not as apparent as those during the summer holiday period - which generally occur during daylight hours.

However since tidal predictions are computed on the basis of astronomical influences only, they inherently discount any meteorological effects that can also influence ocean water levels from time to time. When meteorological conditions vary from the average, they can cause a difference between the predicted tide and the actual tide. This occurs at Magnetic Island to varying degrees. The deviations from predicted astronomical tidal heights are primarily caused by strong or prolonged winds, and/or by uncharacteristically high or low barometric pressures.

Differences between the predicted and actual times of low and high water are primarily caused by wind. A strong wind blowing directly onshore will "pile up" the water and cause tides to be higher than predicted, while winds blowing off the land will have the reverse effect. Clearly the occurrence of storm surges associated with tropical cyclones can significantly influence ocean water levels.

3.2.1.2 Storm tide

The level to which ocean water can rise on a foreshore during the passage of a cyclone or an extreme storm event is typically a result of a number of different effects. The combination of these various effects is known as *storm tide*. Figure 3.3 illustrates the primary water level components of a storm tide event. A brief discussion of each of these various components is offered below.

- Astronomical Tide

As discussed earlier, the astronomical tide is the normal day-to-day rising and falling of ocean waters in response to the gravitational influences of the sun and the moon. The astronomical tide can be predicted with considerable accuracy.

Astronomical tide is an important component of the overall storm tide because if the peak of the storm/cyclone were to coincide with a high spring tide for instance, severe flooding of low lying coastal areas can occur and the upper sections of coastal structures can be subjected to severe wave action.

The quite high spring tides that typically occur in summer are of particular interest since they occur during the local cyclone season.

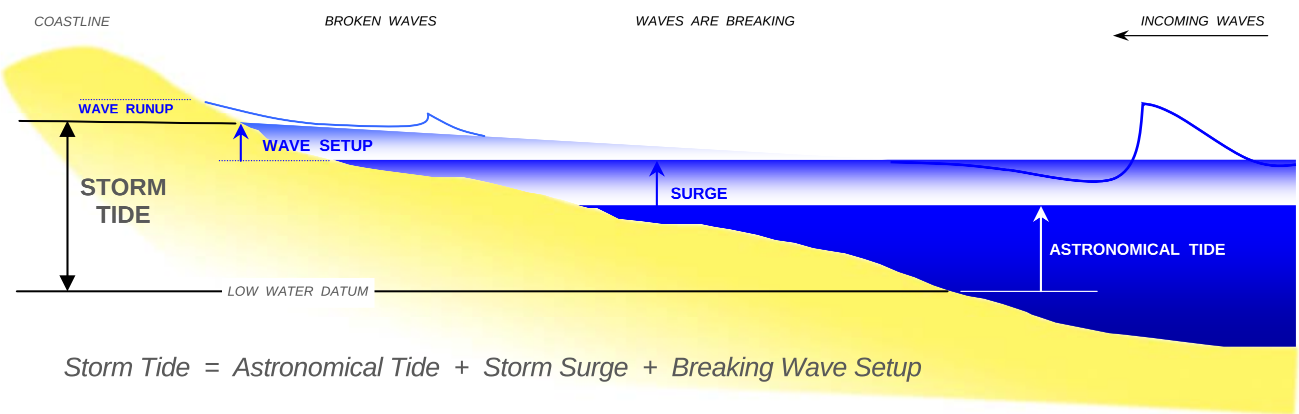

Figure 3.3 : Components of a Storm Tide Event

- Storm Surge

This increase in the ocean water level is caused by the severe atmospheric pressure gradients and the high wind shear induced on the surface of the ocean by a tropical cyclone. The magnitude of the surge is dependent upon a number of factors such as the intensity of the cyclone, its overall physical size, the speed at which it moves, the direction of its approach to the coast, as well as the specific bathymetry of the coastal regions affected.

In order to predict the height of storm surges, these various influences and their complex interaction are typically replicated by numerical modelling techniques using computers.

- Breaking Wave Setup

The strong winds associated with cyclones or severe storms generate waves which themselves can be quite severe. As these waves propagate into shallower coastal waters, they begin to shoal and will break as they encounter the nearshore region. The dissipation of wave energy during the wave breaking process induces a localised increase in the ocean water level shoreward of the breaking point which is called *breaking wave setup*.

Through the continued action of many breaking waves, the setup experienced on a foreshore during a severe wave event can be sustained for a significant timeframe and needs to be considered as an important component of the overall storm tide on a foreshore.

- Wave Runup

Wave runup is the vertical height above the local water level up to which incoming waves will rush when they encounter the land/sea interface. The level to which waves will run up a structure or natural foreshore depends significantly on the nature, slope and extent of the land boundary, as well as the characteristics of the incident waves. For example, the wave runup on a gently sloping beach is quite different to that of say a near-vertical impermeable seawall.

Consequently because this component is very dependent upon the local foreshore type, it is not normally incorporated into the determination of the storm tide height. Nevertheless it needs to be considered separately during the assessment of the storm tide vulnerability of the Nelly Bay foreshore.

- *Storm Tide Events at Townsville*

A number of studies have previously been undertaken with regard to storm tides that may occur in the Townsville region. The most recently published being the *Townsville - Thuringowa Storm Tide Study* (GHD Pty Ltd, 2007). That study also addresses the effect of enhanced Greenhouse conditions on sea level rise and tropical cyclone occurrences.

The storm tides reported by that regional study have been used in the preparation of this Shoreline Erosion Management Plan and are summarised in Table 3.2 for the present day climate scenario.

Average Recurrence Interval[4]	RL to AHD <u>without</u> Breaking Wave Setup
50 years[5]	2.13 metres
100 years	2.25 metres
200 years	2.50 metres
500 years	2.70 metres
1,000 years	3.00 metres

Table 3.2 : Storm Tide Levels at Nelly Bay

These levels are without the effects of breaking wave setup, since this particular component varies along the length of the Nelly Bay foreshore. Its value is determined for this Shoreline Erosion Management Plan in later considerations of storm tide influences.

The duration of the storm tide is also a critical consideration when determining effects on sandy shorelines in Cleveland Bay. The surge component of the storm tide typically builds to a peak over several hours, then drops away over a similar or even shorter timeframe as the cyclone influences pass.

3.2.2 Ocean Currents

Ocean currents in Cleveland Bay are predominantly driven by tides and winds. Over the years there have been many studies of ocean circulation in the Bay. These have typically been numerical modelling studies augmented with some field measurements to assist in verify the modelling predictions.

Whilst these various studies have invariably been comprehensive, they define the structure and magnitude of tidal currents in the deeper waters of Cleveland Bay (or in the immediate vicinity of the port) rather than on the land/sea interface that constitutes the sandy shoreline of Nelly Bay. Nearshore current speeds are considerably less than those offshore because the wide shallow reef flat that exists along the shoreline significantly inhibits tidal flows in these areas.

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[4] Average Recurrence Interval (ARI) is a statistical estimate of the average period in years between the occurrences of an event of a particular size. For example, a 100 year ARI event will occur on average once every 100 years. Such an event would have a 1% probability of occurring in any particular year.

[5] For ARI of around 50 years and less, the maximum local storm tide level may not necessarily be associated with tropical cyclones. Other more frequent meteorological or synoptic events may combine with high spring tides to result in potentially greater levels than that listed here for 50 year ARI.

Consideration of the physical characteristics of the sand on Nelly Bay beach indicates that bed shear stresses of around 0.2 N/m^2 are required to initiate movement of the sand. If this was to be achieved by ocean currents alone, then average tidal velocities of at least 0.35 m/sec would need to flow against the beach.

However field measurements undertaken in nearshore waters during the various investigations and studies for the environmental approvals of the Nelly Bay Harbour development indicate that velocities on the reef flat of Nelly Bay never exceed 0.25 m/sec (McIntyre & Associates, 1986 and Parnell, et al., 1988).

Consequently it is evident that tidal currents alone do not contribute to sand movement on the beach at Nelly Bay. It is waves that play the dominant role in sand transport.

3.2.3 Wave Climate

Given that sand is primarily transported by wave action on this foreshore, the wave characteristics in Nelly Bay are critical considerations in the understanding of local coastal processes. However before describing the local wave climate, it would be informative to firstly outline how waves move sand on shorelines.

3.2.3.1 Effects of waves on sand transport

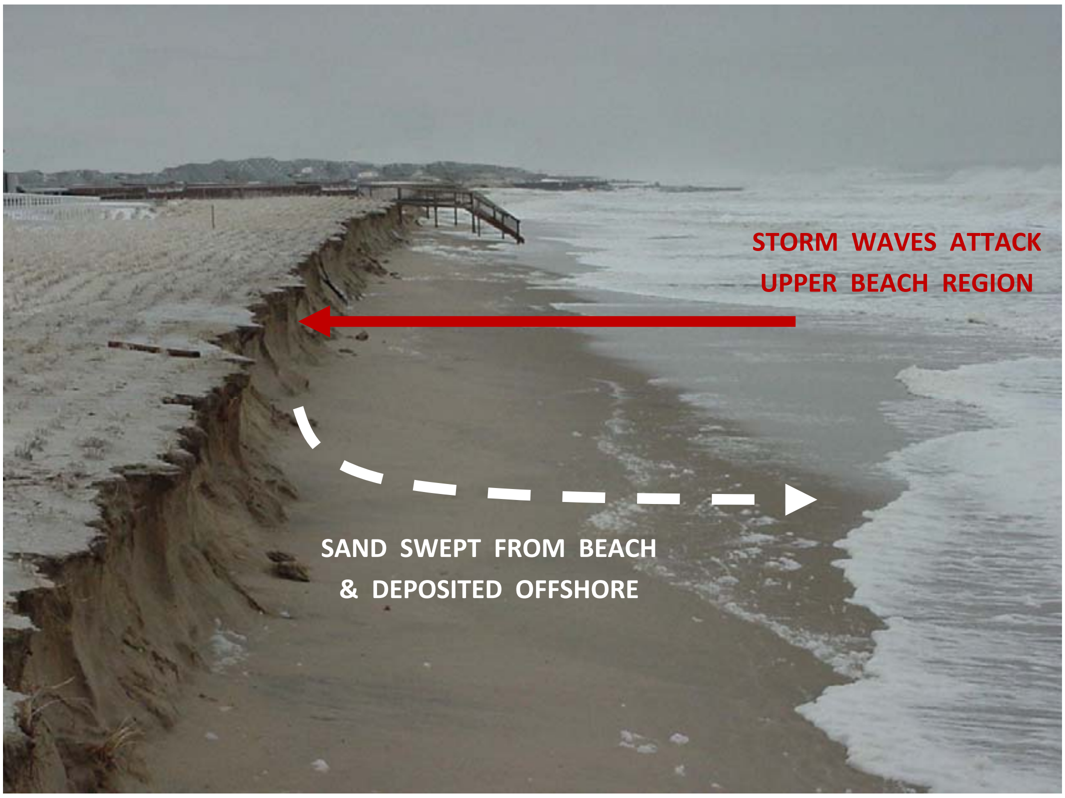
Waves move sand in two fundamental ways; by cross-shore transport and by longshore transport. These are illustrated conceptually in Figure 3.4. Both processes can occur simultaneously, but both vary significantly in their intensity and direction in response to prevailing wave conditions.

- Cross-shore transport

This is the movement of sand perpendicular to the beach – in other words, onshore/offshore movement. Whilst this washing of sand up and down the beach profile occurs during ambient conditions (ie. the normal day-to-day conditions), it is during severe storms or cyclones that it becomes most evident and most critical.

Strong wave action and elevated ocean water levels during such events can cause severe erosion of the beach as sand is removed from the dunes and upper regions of the profile. The eroded sand is moved offshore during the storm to create a sand bank near the seaward edge of the surf zone. Subsequent milder wave conditions can return this sand back onto the beach, where waves and onshore winds then re-work it to establish the pre-storm beach condition.

During particularly severe storms very significant erosion of sand from the upper beach can occur in only a few hours; whereas recovery of the beach by onshore transport processes may take many years.



(a) Cross-shore Sand Transport

(b) Longshore Sand Transport

Figure 3.4 : Wave-induced Sand Transport Mechanisms

- Longshore transport

This is the movement of sand along the beach and occurs predominantly within the surf zone. Of all the various processes that control beach morphology, longshore sand transport is probably the most influential. It determines in large part whether shorelines erode, accrete or remain stable. Consequently an understanding of longshore sand transport is essential to sound coastal management practice.

Waves arriving with their crests at an angle to the plan alignment of the shoreline create an alongshore current which initiates and maintains sand transport along the beach.

The angle at which the incoming waves act on the beach face may only be very small (as may be the waves themselves), nevertheless their continual and relentless action is sufficient to account for notable volumes of sand to be moved annually on local shorelines.

On most coasts, waves arrive at the beach from a number of different offshore directions - producing day-to-day and seasonal reversals in transport direction. At a particular beach location, transport may be to the left (looking seaward) during part of the year and to the right during other times of the year. If the volumes of transport are equal in each direction then there is no net change in the beach position over annual timeframes. However this is not often the case.

Typically longshore movement is greater in one direction than the other – which results in a net annual longshore movement. Certainly this is the case for Nelly Bay beach where the net transport rate is towards the south.

Whilst there may be a net longshore transport along a section of foreshore, this does not mean that sand is being lost and therefore the beach is eroding. So long as sand is being supplied at the same rate as it is being transported along the shore at any particular location, then there will be no net change to the beach over annual timeframes. As discussed in Section 3.1.2, the supply of sand to Nelly Bay has been significantly diminished in recent times. Consequently the annual rate of sand supply does not match the longshore transport rate– therefore the beach is eroding.

The erosion has commenced on the northern shores of this coastal reach since it is this area that historically received the supply of sand from Gustav Creek. At the present time the foreshore further south of this eroding section is receiving sand at a rate that is similar to the longshore transport rate and is therefore not eroding. However that sand supply is derived from the eroding foreshores opposite the Esplanade.

The importance of cross-shore and longshore sand transport to the development and implementation of foreshore management strategies can perhaps best be summarised as:

- Cross-shore transport needs to be understood so that appropriate sand reserves are maintained on a foreshore to act as an erosion buffer during severe storms or tropical cyclones.
- Longshore transport needs to be understood so that the sand supply to a foreshore is maintained at a rate that will continue to naturally sustain the sand reserves acting as the erosion buffer. Where natural supply is deficient, it may need to be augmented with placement of extra sand through beach nourishment works.

3.2.3.2 Types of waves affecting local sand transport mechanisms

Waves arrive in the nearshore waters around Nelly Bay as a consequence of several phenomena, namely;

- Swell waves - generated by weather systems in the distant waters of the Coral Sea and Pacific Ocean out beyond the Great Barrier Reef. In order to propagate into Cleveland Bay, these waves must pass through and over the extensive reefs and shoals that constitute the Barrier Reef. There is considerable attenuation of wave energy during this propagation process.
- Distant Sea waves - generated by winds blowing across the open water fetches between the mainland and the outer Great Barrier Reef system (some 70 kms offshore). This includes the fetches south-east of Cape Cleveland (from which waves are then refracted as they propagate shoreward to the project site).
- Local Sea waves - generated by winds blowing across the open waters of Cleveland Bay, between Magnetic Island and the mainland.

Waves from these various sources can occur simultaneously. Given that sand transport processes are primarily driven by waves, a significant focus of the work undertaken for this Shoreline Erosion Management Plan has been the determination of the ambient (ie. the “day-to-day”) wave climate - as well as the extreme wave climate (ie. due to cyclones and severe storms). Because of the complex nature of the wave and sand transport processes, the work has utilised numerical modelling techniques.

Following sections of this report provide some details as to the methodology and the results of that modelling. However some comment is warranted with respect to the various types of waves that can affect sand transport on Nelly Bay beach.

- Swell waves

As swell waves generated by weather systems out in the Coral Sea propagate shoreward, the Great Barrier Reef significantly inhibits the passage of its energy. Nevertheless, whilst inshore swell wave heights are quite low, because of their relatively long wave periods (typically in excess of around 12 seconds) they contribute to local sediment transport processes.

- Distant Seas

The significant distances between the mainland and the Great Barrier Reef means that quite sizeable waves can be generated by winds blowing across these fetches - particularly during cyclones which are a common synoptic event in these waters. To the north-east and east of Cleveland Bay there are very long open water fetches across which winds can generate significant wave energy. It is from this sector that the largest waves can approach the entrance to Cleveland Bay.

Whilst the project site is sheltered by Cape Cleveland from the direct effects of waves generated out of the south-east quadrant, these waves can diffract and refract around the northern tip of the Cape and propagate shoreward to Nelly Bay. The attenuating effects of diffraction and refraction mean that the energy of these waves is diminished.

Nevertheless, because they are driven by the predominant seasonal weather systems, waves from the south-east and east sectors represent an important component of the ambient wave climate within Cleveland Bay. Their persistent nature and relatively long periods (typically greater than 8 seconds) mean that they strongly influence beach processes in the region.

- Local Seas

The same winds that blow across the open water fetches between the mainland and the Great Barrier Reef (to generate Distant Seas) also blow across the enclosed waters of Cleveland Bay. Consequently they generate waves within the Bay itself – these waves are called Local Seas.

Whilst the fetches are relatively short and shallow, they still enable substantial wave energy to be generated and propagate to Nelly Bay. They play an important role in the longshore transport of sand on this shoreline.

3.2.3.3 Numerical modelling of waves

The generation of the various wave types and how they are modified by wave refraction, diffraction, seabed friction, shoaling and breaking as they propagate from their offshore generation areas to the Nelly Bay beach is very complex. In the absence of any site specific long-term directional wave measurements, the only way of obtaining an appreciation of the wave climate on the beach is to apply numerical modelling techniques.

This approach has been adopted when preparing this Shoreline Erosion Management Plan - so as to obtain an understanding of waves and wave-induced sand transport when determining appropriate foreshore management strategies.

The coastal processes model used to support this Shoreline Erosion Management Plan is the same as that originally used for the investigative studies and engineering designs for the Strand beach and headland system, for which construction was completed in 1999 (Coastal Engineering Solutions, 1998).

Since that time, the regional coastal process model has been progressively but significantly upgraded. This improvement to the model has not only come about by the increased computing power that has developed in recent years, but more significantly due to the model's improved resolution and representation of the seabed and shoreline features throughout Cleveland Bay and offshore regions. The most recent application of the model was for the coastal engineering studies to support the EIS for the Townsville Ocean Terminal Project (Coastal Engineering Solutions, 2007).

A detailed and comprehensive technical discussion of the model and the methodology of its application are not suited for inclusion in this Shoreline Erosion Management Plan, however such information is available from reports pertaining to previous projects and coastal process studies in the Townsville region (Coastal Engineering Solutions, 1998, 2007). The model uses the following data and information:

- wave characteristics recorded by a Waverider station (established in July 1975) which is currently maintained and operated by the Department of Environment and Resource Management;
- hindcasts for waves generated by winds blowing across local Cleveland Bay fetches have been produced using standard mathematical techniques. This requires the use of directional wind data - as measured by the Bureau of Meteorology at local anemometer sites.
- cyclone wave information in the deep waters offshore of Townsville has been extracted from data generated for the *Atlas of Tropical Cyclone Waves in the Great Barrier Reef* (MMU, 2001);
- storm tide levels during extreme events utilises the results of previous modelling of storm tides in the Townsville region (DNRM, 2004) and (GHD Pty Ltd, 2007).

The outcome of the numerical modelling of waves undertaken for the Shoreline Erosion Management Plan consists of time series of wave height, period and direction every hour over timeframes of up to 13 years as well as the cyclone wave characteristics associated with 50, 100, 200, 500 and 1,000 year ARI events. These various wave time series have been established at three locations along the Nelly Bay foreshore.

The numerical modelling of waves provides a description of the wave climate along the Nelly Bay foreshore. This has then been utilised for subsequent numerical modelling of longshore and cross-shore sand transport processes.

3.2.4 Longshore Sediment Transport

As discussed in the preceding Section 3.1, the primary cause of the erosion problems being experienced in Nelly Bay is the inadequate supply of sand to match the longshore transport rates that are removing sand from this foreshore. There have been a number of previous studies and data collection exercises undertaken that provide useful technical background and insight with regard to longshore transport processes.

This, in conjunction with numerical modelling of waves and sand transport along the Nelly Bay foreshore undertaken for this Shoreline Erosion Management Plan, provide the necessary understanding of local sand transport rates.

3.2.4.1 Existing data and previous studies

As part of a comprehensive state-wide program of surveying cross-shore profiles at coastal locations throughout Queensland, the Beach Protection Authority established a number of transect lines on the shores of Magnetic Island. The intent being to undertake repeated surveys on these transects to provide quantitative information regarding shoreline change - which could then assist in determining sand transport processes.

The first surveys of these profiles were undertaken by the Beach Protection Authority in March 1982, with one subsequent survey undertaken in January 1983. Other beach transect lines were established in April 2004, with approximately annual surveys since that time. The locations of these transects are shown on Figure 3.5.

A survey on some of these lines had previously been undertaken in June 1989 - just before construction of the Nelly Bay Harbour was commenced. The results of these various annual surveys (up to April 2009) are shown plotted in Appendix D.

Figure 3.5 : Location of Beach Transect Survey Lines

It is evident from the surveys that since harbour construction commenced in 1989 the northern part of Nelly Bay beach has receded by approximately 12 metres, equating to an average recession rate of around 0.6m/year.

Records of the annual clearance of the sand beneath the road bridge leading onto the harbour's southern breakwater also provides valuable information with regard to recent longshore transport rates at the very northern end of the beach. The volumes removed from this area are listed in Table 3.3 below, which suggests approximately 3,000 to 4,000 m^3 of sand moves northwards along the beach into the beach/breakwater corner each year.

Date of clearance	sand volume
July 2004	4,000 m^3
June 2005	4,000 m^3
June 2006	4,000 m^3
June 2007	3,500 m^3
June 2008	2,500 m^3
August 2009	2,265 m^3

Table 3.3 : Volumes of sand cleared from breakwater sand trap

3.2.4.2 Numerical modelling of longshore sediment transport

Numerical modelling of waves and sand transport processes was undertaken specifically for this Shoreline Erosion Management Plan using an existing model. Longshore sediment transport rates over a thirteen year timeframe have been established at locations along the Nelly Bay foreshore. A summary of the results are shown on Figure 3.6. The rates shown in the figure are the net average longshore transport rates of sand per year.

There are a number of informative characteristics of the longshore sand transport regime that emerge from this modelling, namely:

- Approximately 1,000 m^3/year is moved along the entire Nelly Bay beach from north towards south. This is made up of approximately 3,000 m^3/year that is moved primarily by Distant Sea southwards and approximately 2,000 m^3/year moved mostly by Local Sea towards the north.
- This net longshore transport rate along the beach is similar in magnitude to the average rate of sand that was supplied to the northern end of the beach by Gustav Creek. This suggests an approximate balance between sand volumes supplied to the beach from the creek; and the sand volumes swept southward along the beach by waves.

- The harbour's southern breakwater starts to have an effect on longshore transport processes for locations north of around Yates Street. The effect is to reduce the southward component of sand transport due to its sheltering of the northern part of the beach from Distant Seas which would ordinarily move sand southward. However the northerly movement by Local Seas across Cleveland Bay fetches is unaffected.
- There is a "null point" just to the north of Yates Street where the net longshore transport rate is approximately zero. This does not imply that there is no sand being moved along the shore at this location, but that the amount being moved southwards each year is balanced by an equal volume of sand being moved northwards. The modelling suggests that on average this is around 2,000 m^3/year in each direction.
- Immediately north of the null-point the local net transport is towards the north - into the beach/breakwater corner. Whereas this northward component is around 2,000 m^3/year at the null point, its rate increases somewhat to around 3,500 m^3/year towards the breakwater. This increase is caused by waves that approach Nelly Bay from the north-easterly and easterly sectors being diffracted around the southern harbour breakwater, thereby arriving on this northernmost part of the beach with an orientation so as to enhance the northwards longshore transport component (refer to Figure 3.2).

  This model prediction of 3,500 m^3/year transport towards the breakwater correlates well with the actual amounts of sand that have had to be cleared annually from beneath the road bridge in the beach/breakwater corner (refer Table 3.3).

For the purposes of considering the longshore sand transport regime, it is useful to consider the Nelly Bay foreshore as consisting of two coastal reaches - one to the north of the null point near Yates Street, the other to the south of this location near Yates Street.

This separation into coastal reaches does not imply that the coastal processes within each are in any way compartmentalised. They are by no means isolated or discrete sections of shoreline, since the processes affecting one have an influence on the other. However this partitioning lends itself to a better description and appreciation of longshore sand transport processes in Nelly Bay.

Northern Reach (north of Yates Street)

Sand moves northwards along this approximately 300m long section of shoreline. Consequently sand accumulates as a fillet in the beach/breakwater corner opposite Kelly Street. However every year the accumulated sand is removed by the Department of Main Roads and Transport as a requirement of the Marine Park Permit to operate the Nelly Bay Harbour.

The removed sand has been relocated within the Nelly Bay beach system - either by placing it on the eroding foreshore in the general vicinity of Yates Street, or on the foreshore further south (adjacent to the Nelly Bay Habitat Reserve - some 500 metres south of Yates Street)

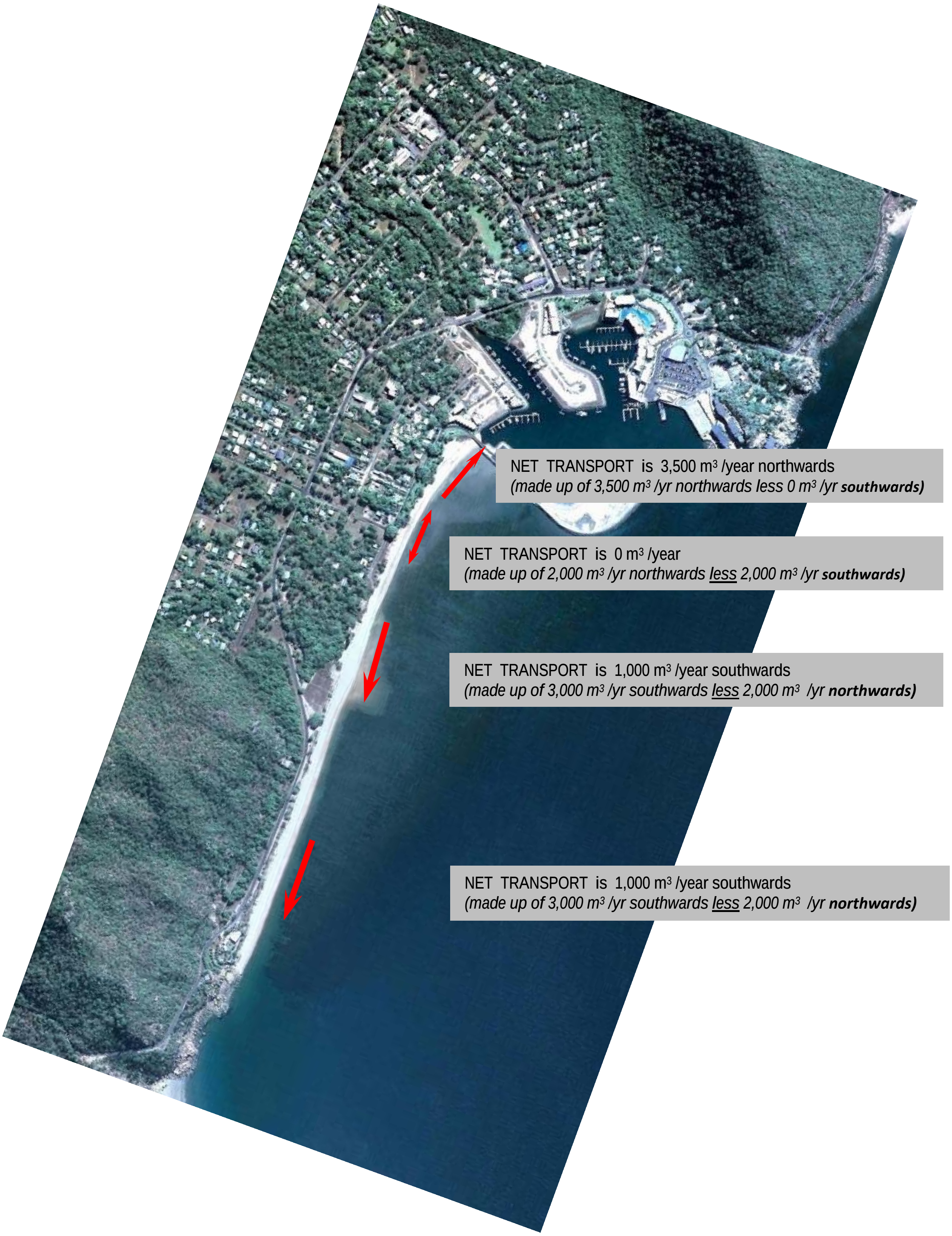


Figure 3.6 : Summary of Modelling Results for Annual Longshore Sand Transport

Placements near Yates Street benefit the Northern Reach, since a large portion of that sand remains on this foreshore. Following its placement it is simply transported northwards, back into the beach/breakwater corner. In doing so, it maintains the width of the beach and recharges the erosion buffers of the northern reach. Consequently the annual relocation of sand from beneath the breakwater bridge to Yates Street is the "mechanical" half of a sand circulation process, the other half of which is the natural northerly transport of sand from Yates Street back to the breakwater bridge.

This is an effective means of reinforcing the present condition of the northern reach and its erosion buffers - indeed it is a widely used foreshore management practice known as "back-passing". However whilst providing temporary benefits, it does not address the ongoing erosion problem of inadequate supply of sand to Nelly Bay.

Southern Reach (south of Yates Street)

This is the much longer 1,125 metre southern section of Nelly Bay beach which is south of Yates Street. The net longshore sand transport along this entire section is approximately 1,000 m^3/year towards the south.

The region around and to the immediate south of Yates Street is experiencing steady ongoing erosion of around 0.6 metres/year. This is because waves are transporting sand off this section of foreshore at around 1,000 m^3/year; however there is no sand being supplied into the northern end to compensate for this removal.

Prior to the construction of the Nelly Bay Harbour, there was no sand deficit because Gustav Creek provided an adequate supply to the northern end. Consequently the foreshore did not experience any long-term / ongoing recession. Foreshore widths at that time provided sufficient buffers to accommodate the erosion associated with intermittent storm/cyclone events (and the subsequent natural beach rebuilding processes) without threatening foreshore infrastructure or values.

However the ongoing recession that has been occurring over the last twenty years since harbour construction commenced has depleted the erosion buffers. This has occurred to the extent that infrastructure and property that was once set back from storm and cyclone erosion are now under threat.

3.2.5 Cross-shore Sediment Transport

In addition to transporting sand along the Nelly Bay shoreline, waves move sand in a cross-shore direction. It is during storms and cyclones that this type of sand transport becomes critical.

Severe wave conditions in conjunction with elevated ocean water levels enable large waves to access higher levels of the beach profile - resulting in significant erosion of the beach and dunes. Sand is removed from this upper region of the profile and is deposited offshore - resulting in recession of the shoreline and the creation of small low sandbanks immediately offshore.

If the storm or cyclone is particularly severe, the erosion may threaten or damage foreshore infrastructure.

The erosion buffers along the Esplanade of Nelly Bay are currently such that even reasonably moderate wave events can cause worrying erosion damage if accompanied by particularly high tides or surges. Such events occurred in January 2009 and January 2010.

3.2.5.1 Beach Response Modelling

Technical work undertaken for this Shoreline Erosion Management Plan included application of the SBEACH proprietary mathematical model to predict the response of the beach profile to a number of different cyclone scenarios. The 50, 100, 200, 500 and 1,000 year ARI storm conditions were investigated at three locations along the Nelly Bay foreshore.

The fundamental approach to this beach response modelling has been to:

- utilise cyclone wave information for the deep waters offshore of Cleveland Bay using data generated for the *Atlas of Tropical Cyclone Waves in the Great Barrier Reef* (MMU, 2001);
- utilise storm tide levels for extreme events which has been previously determined by modelling of storm tides in the Townsville region (DNRM, 2004 and GHD Pty Ltd, 2007);
- transform these offshore cyclone wave and storm tide conditions to each of three locations on the Nelly Bay shoreline using wave transformation modelling; then
- apply the local wave / storm tide conditions and the most recent beach transect surveys as input to the SBEACH model to determine the eroded profile at each location.

Figure 3.7 illustrates a typical outcome of the SBEACH modelling, namely the pre-storm profile and post-storm profiles for a location at transect Line 1 (opposite Yates Street) for the selected range of cyclone scenarios.

As can be seen, sand is eroded from the upper beach area, typically from above RL+1.0m AHD. This sand is then deposited offshore of the toe of the beach, thereby flattening the slope. This cross-shore erosion process is typical of that along the entire Nelly Bay foreshore.

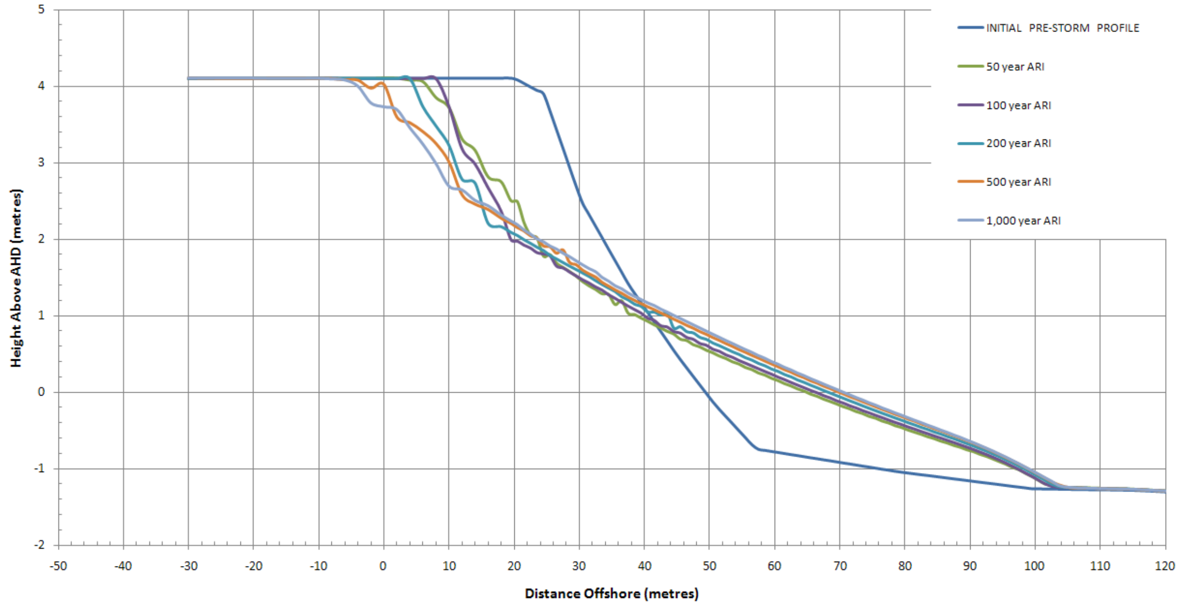


Figure 3.7 : Predicted Beach Response at Yates Street for Various Cyclone Events

The results of the beach response modelling for three locations on the Nelly Bay foreshore are summarised in Table 3.4 and Table 3.5. The volume of sand removed from the upper beach by various cyclone scenarios is presented in Table 3.4 - whereas the distance that the shoreline recedes as a consequence of these same cyclones is shown in Table 3.5.

Some discussion is offered later regarding the phenomena of *overwash*, which influences the predicted profile response for cyclones greater than approximately 100 years ARI.

Foreshore Precinct	Beach Erosion Volumes for Various ARI Storms				
	50 year	100 year	200 year	500 year	1000 year
opposite Yates Street	34.7m^3	37.0m^3	41.0m^3	44.2m^3	45.7m^3
opposite Habitat Reserve	47.2m^3	51.1m^3	55.4m^3	57.3m^3	58.8m^3
southern end of beach	42.4m^3	45.9m^3	50.0m^3	51.0m^3	52.0m^3

Table 3.4 : Predicted Erosion Volumes for Various ARI Cyclone Events

It is evident that the central section of the beach in the vicinity of the Habitat Reserve will experience the greatest sand loss from the upper beach in the event of a major cyclone event. For example, the 100 year ARI cyclone event removes around 51m^3 of sand from each metre length of foreshore in the vicinity of the Nelly Bay Habitat Reserve (refer Table 3.4). This equates to a shoreline recession of about 33m at this location (refer Table 3.5).

Foreshore Precinct	Beach Recession Distances for Various ARI Storms				
	50 year	100 year	200 year	500 year	1000 year
opposite Yates Street	18m	18m	21m	31m	35m
opposite Habitat Reserve	17m	33m	39m	29m	30m
southern end of beach	15m	30m	37m	41m	42m

Table 3.5 : Predicted Shoreline Recessions for Various ARI Cyclone Events

Along the Esplanade (in the general vicinity of Yates Street) that same 100 year ARI cyclone would remove around $37m^3$/metre length of the beach, causing shoreline recession of approximately 18 metres. This would remove most of the Esplanade pavement width and the foreshore trees at this location.

3.2.5.2 Overwash

The eroded volumes and shoreline recessions discussed above and listed in Table 3.4 and Table 3.5 need to be considered with some caution for events more severe than around 100 year ARI. During such storms, there is considerable overwash of the Nelly Bay foreshore. This phenomenon occurs when the storm tide builds during the cyclone to be so great that waves no longer dissipate their energy directly on the beach slope or on the dunes - ocean water levels are such that the waves wash over the beach slope since it is substantially submerged.

Once overwash commences further recession of the foreshore still occurs. However instead of being carried offshore, sand in the upper beach is swept up over the slope and carried inshore. There can be devastating consequences to foreshore areas during overwash since the foreshore is not only inundated by storm surge, but destructive cyclonic waves can wash over the dunes and penetrate inland.

Unfortunately the extent of profile change and damage caused by overwash cannot be confidently predicted by current mathematical modelling techniques. Consequently the erosion characteristics summarised in Table 3.4 and Table 3.5 should be considered as indicative only when overwash occurs.

Nevertheless to assist in obtaining an appreciation of the possible extent of overwash, Table 3.6 shows the SBEACH model's prediction of the level to which storm tide and wave effects (including wave setup) can occur at each of the three locations on the Nelly Bay foreshore.

As can be seen from this figure, the levels vary only slightly along the shoreline. The differences are due to the variation in wave setup that occurs on the different width of reef flat at each location.

Foreshore Precinct	Level of Storm Tide & Wave Effects for Various ARI Storms				
	50 year	100 year	200 year	500 year	1000 year
opposite Yates Street	RL+3.27m	RL+3.64m	RL+4.17m	RL+4.52m	RL+4.74m
opposite Habitat Reserve	RL+3.33m	RL+3.63m	RL+4.17m	RL+4.44m	RL+4.73m
southern end of beach	RL+3.30m	RL+3.58m	RL+3.99m	RL+4.41m	RL+4.72m

Table 3.6 : Predicted Wave & Surge Influences for Various ARI Cyclone Events[6]

3.3 Implications to Erosion Buffers

As well as offering considerable environmental and social benefits, the sandy foreshores of Nelly Bay serve as erosion buffers, protecting valuable foreshore infrastructure and property. Preceding sections of this Shoreline Erosion Management Plan provided discussion on the longshore and cross-shore sand transport mechanisms that affect these sand reserves.

It is evident that the cross-shore sand transport processes during severe storms and cyclones can cause rapid depletion of the erosion buffers. To ensure that adequate protection is afforded to foreshore infrastructure, the volumes of sand and the minimum buffer widths required seaward of such infrastructure are summarised in Table 3.4 and Table 3.5.

Maintaining these buffers ensures that foreshore assets are located a sufficient distance inland so as not to be damaged by storm erosion.

Longshore sand transport also plays an important role, since it is the means by which the erosion buffers are kept naturally recharged with sand. Provided the supply of sand matches the rate at which sand is moved to downdrift foreshores, then local erosion buffers are not adversely affected by longshore transport processes. As was discussed previously, this is not the case for the Nelly Bay shoreline since the supply of sand to the beach has diminished significantly since the construction of the Nelly Bay Harbour (refer Section 3.1). Consequently the erosion buffers are diminishing - particularly at the northern end of Nelly Bay.

Private residences are located some 30 metres from the foredune along the Esplanade. Reference to Table 3.5 indicates that these homes currently have immunity against complete loss by erosion for events up to around 500 year ARI. This immunity will diminish significantly over a 50 year planning period unless erosion mitigation works are implemented.

[6] Levels are referenced to AHD.

3.4 Future Climate Change

The preceding discussions of sand transport rates are based on a present-day climate scenario. Climate change as a consequence of enhanced Greenhouse gas emissions will cause environmental changes to ocean temperatures, rainfall, sea levels, wind speeds and storm systems. If climate changes develop as predicted, the Nelly Bay foreshore will be subjected to potentially greater storm and cyclone energy, higher waves, stronger winds and increased water levels.

In its Fourth Assessment Report released in 2007 the *Intergovernmental Panel on Climate Change* (IPCC, 2007) has presented various scenarios of possible climate change and the resultant sea level rise in the coming century. There is still considerable uncertainty as to which of these various scenarios will occur. The oceanographic and atmospheric processes involved are complex, and numerical modelling of these processes is far from precise.

Because of these complexities, there is a wide range in the predictions of global sea level rise for the coming century. A rise of between 0.18 metres and 0.59 metres by the year 2100 is predicted by the IPCC investigations, with a possible additional contribution of 0.1 to 0.2 metres from melting ice sheets.

At this stage there is no agreed pattern for the longer-term regional distribution of projected sea level rise offered by the IPCC predictions. Nevertheless, in the Australian region a common feature in many model projections of sea level rise is an increase on the east coast of Australia that is potentially higher than the global average. In the Townsville region, this is estimated to be approximately 0.15 metres above global averages (CMAR, 2008).

The projected sea level rise currently adopted for planning purposes by Queensland's *State Coastal Management Plan* is 0.3 metres over 50 years. Whilst this is still within the range of projections in the IPCC Fourth Assessment Report, it is now at the lower end of these recent predictions and is therefore being reviewed. Under the provisions of the Coastal Act, a review of the 2002 *State Coastal Management Plan* was initiated in 2009.

As a consequence of that review, the draft coastal plan has adopted an updated sea level rise of 0.8 metres by the year 2100. This is based on the upper limit of the most recent projections released by the IPCC in its Fourth Assessment Report, in conjunction with the expectation that sea levels along the east coast of Australia will be higher than the global average.

Townsville City Council requires a planning period of 50 years for this Shoreline Erosion Management Plan (ie. to approximately the year 2060). Reference to the upper limit of the range in predictions offered by IPCC (2007) indicates that a 0.4m allowance for Greenhouse-induced sea level rise should therefore be included in current planning for the Shoreline Erosion Management Plan.

In addition to sea level rise, there is speculation that the intensity of tropical cyclones may increase - although it is also acknowledged that there is a possibility that the overall number of cyclones affecting coastal regions may decrease. However estimating any changes to the intensity and occurrence of cyclones is particularly problematic since their formation and subsequent track are dependent upon the complex interaction of a number of natural phenomena (such as the El Nino - Southern Oscillation) which themselves are not yet well understood.

To accommodate any such adverse impacts on future coastal processes when compiling this Shoreline Erosion Management Plan, the effects of a 10% increase in offshore wave heights and a 5% increase in offshore wave periods have been incorporated - along with a 0.4m sea level rise. This increase in wave characteristics equates very approximately to a 10% increase in the intensity of cyclones for any given ARI.

The rate of any sea level rise as a consequence of climate change will be very gradual, and the timescales associated with the coastal processes shaping the nearshore and foreshore regions will keep pace with the slow sea level rise. Consequently the basic form of the beach profile on Nelly Bay will be maintained in relation to the gradually rising sea level in front of it.

Nevertheless, there will be a gradual recession of the position of the shoreline, which will effectively reduce sand buffers in front of existing foreshore infrastructure. The seabed on the wave approaches through Cleveland Bay and across the Nelly Bay reef flat will likely remain at much the same levels and slopes as they are now - which means that waves will be approaching the shore through slightly deeper water.

Numerical modelling indicates that the combination of predicted sea level rise and increased wave energy results in 8% to 12% increase in the longshore sand transport rates reported in Section 3.2.4 for the entire length of the Nelly Bay shoreline.

The ongoing long-term recession of around 0.6m/year currently being experienced on the northern shores of Nelly Bay is likely to increase to approximately 0.7m/year.

Climate change influences may also increase the cross-shore transport rates associated with cyclones. The erosion and recessions along the project foreshore resulting from predicted climate change are listed in Table 3.7 and Table 3.8 respectively.

These have been determined from application of the SBEACH shoreline response model using the expected increases in sea levels rise and more severe wave conditions. In other words, these two tables represent the previous data presented in Table 3.4 and Table 3.5 updated so as to include the expected effects of future climate change.

Foreshore Precinct	Beach Erosion Volumes for Various ARI Storms				
	50 year	100 year	200 year	500 year	1000 year
opposite Yates Street	44.7m^3	47.9m^3	51.3m^3	53.3m^3	54.8m^3
opposite Habitat Reserve	56.5m^3	60.0m^3	64.9m^3	65.5m^3	67.5m^3
southern end of beach	57.0m^3	61.2m^3	65.6m^3	65.8m^3	68.8m^3

Table 3.7 : Predicted Cyclone Erosion Volumes - including climate change effects

Foreshore Precinct	Beach Recession Distances for Various ARI Storms				
	50 year	100 year	200 year	500 year	1000 year
opposite Yates Street	19m	21m	28m	32m	36m
opposite Habitat Reserve	18m	[28m]	[35m]	40m	42m
southern end of beach	18m	[28m]	[37m]	42m	43m

Table 3.8 : Predicted Cyclone Recessions - including climate change effects

The volumes of cross-shore erosion caused by cyclones are generally 25% to 30% higher as a consequence of climate change. However actual shoreline recessions during extreme events are not very much greater than those predicted for present day climate scenario - indeed in some cases it is less. This somewhat unusual result is due to overwash of the foreshore occurring during even quite moderate cyclone events of around 50 year ARI under a future climate change scenario.

As discussed in Section 3.2.5.2, overwash occurs when the ocean water level during the peak of the storm increases such that waves wash over the beach slope since it is substantially submerged. Instead of being carried offshore, sand in the upper beach is swept up over the slope and carried inshore so shoreline recession is somewhat curtailed. Nevertheless there can be devastating consequences to foreshore areas during overwash since destructive cyclonic waves wash over the beach and penetrate inland.

Given the present uncertainties associated with the extent and nature of future climate change, when developing and assessing appropriate erosion mitigation strategies there is considerable merit in applying strategies that are flexible and can be tailored to suit climate change impacts as they gradually evolve.

4 RISK ASSESSMENT

The preceding sections of this Shoreline Erosion Management Plan quantified long-term foreshore recession (as a consequence of a deficit in the supply of sand) as well as cyclone induced erosion as a consequence of a number of cyclone scenarios.

However it is necessary to relate these shoreline responses to the actual hazard this represents - by considering the extent and nature of "at-risk" property and infrastructure.

4.1 Erosion Threat

4.1.1 Designated Erosion Prone Areas

The establishment of Erosion Prone Areas along Queensland's coastline has been an intrinsic part of the state's coastal management policy since 1968. The concept is to set aside undeveloped buffer zones thereby implementing a philosophy that biophysical coastal processes should be accommodated rather than prevented. The most basic form of accommodation is to avoid locating development and vital infrastructure within dynamic coastal areas affected by the natural processes of shoreline erosion and accretion.

An adequate buffer zone allows for the maintenance of coastal ecosystems (including within littoral and sublittoral zones), visual amenity, public access and the impacts of natural processes - without the high cost and potentially adverse effects of property protection works.

The Department of Environment and Resource Management currently has an Erosion Prone Area Plan for the Townsville region which was first established by the Beach Protection Authority in December 1984[7]. Its purpose was to define the width of local foreshores that might be susceptible to erosion over the following 50 years. At the time it was prepared, no specific allowances for potential future climate change were directly incorporated into the designated widths, although a 40% factor of safety was applied to the widths calculated by the Beach Protection Authority.

This safety factor was applied in recognition that there are uncertainties and limitations associated with predictions of future foreshore erosion, including those that might arise as a result of what was then identified as emerging Greenhouse effects.

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[7] Plan number SC 3391, titled "Townsville City Erosion Prone Areas"; originally dated 04th December 1984. It has subsequently been amended a number of times to the current Revision E.

Whilst some amendments have been made to the plan since it was established, the designated erosion prone areas along the Nelly Bay foreshore remain as follows:

- From Nelly Bay Harbour's southern breakwater to the un-named ephemeral creek some 550m further south = 95 metres;
- From the un-named creek to the rocky headland at the southern-most end of Nelly Bay beach = 80 metres (or to the location of any outcropping bedrock).

The erosion prone area is measured landward from the seaward toe of the frontal dune, or from the line of permanent terrestrial vegetation if a dune feature is not well established or identifiable.

As with designated erosion prone widths along the entire Queensland coastline, these areas have served in the past as planning and legislative tools when considering development on the state's foreshores.

4.1.2 Planning Period

When preparing a Shoreline Erosion Management Plan it is necessary to select the timeframe (or planning period) over which erosion influences are to be considered. The threat of erosion to most foreshores can be summarised as being a result of:

- long-term erosion – due to a shortfall in sediment supply over time;
- short-term erosion – due to the direct effects of severe cyclone events; and
- future climate change – primarily sea level rise and increased severity/occurrence of cyclones.

The selection of a planning period determines the effects of these phenomena when considering foreshore management options. Some comment is therefore offered in relation to these phenomena.

- Long-term erosion

Long-term erosion manifests itself as a gradual recession of the average position of the shoreline due to a deficit in the supply of sand from updrift foreshores – such as is happening along the shores of Nelly Bay. When considering the threat that this poses and the measures required to mitigate the threat, it is necessary to select a planning period.

For example, the average long-term recession of 0.6m / year that has been occurring along the northern section of the beach in recent years (refer to discussions in Section 3.2.4) represents a potential recession of 30m over a 50 year planning period. A different planning period represents a different recession.

It is therefore necessary to have a planning period established in order to quantify the extent of future long-term erosion and an appropriate strategy to address it.

- Short-term erosion

The selection of a planning period also has an effect on the threat posed by short-term cyclone induced erosion. For example, the likelihood of a 100 year ARI cyclone occurring in (say) a 50 year planning period is quite different to that for shorter or longer timeframes. Consequently when determining risk, the implications of a 100 year ARI cyclone could be considered unlikely for short planning periods – or alternatively, very likely for longer periods.

- Future climate change

The nominated planning period also has implications to the effects of climate change that are to be incorporated into each Shoreline Erosion Management Plan. Current projections of sea level rise and the severity / frequency of cyclones and storm tides vary - depending upon when in the future such issues are considered. Clearly such effects are different in 20 years time as opposed to 50 or 100 years into the future.

The Department of Environment and Resource Management currently uses a planning period of 50 years when considering the requirement for coastal setbacks (ie. erosion prone area widths) under the current State Coastal Management Plan. Indeed this planning period has been the State Government's policy since the establishment of the Beach Protection Authority in 1968. A 50 year planning period was considered appropriate given the practical life of coastal management projects and the maximum reasonable forward projections of present and past erosion trends.

Townsville City Council has nominated a 50 year planning period for this Shoreline Erosion Management Plan.

4.1.3 Probability of Occurrence

The probability of events having various Average Recurrence Intervals occurring or being exceeded within a 50 year planning period can be predicted using established mathematical techniques, thereby quantifying the risk associated with each such event.

Table 4.1 presents these various probabilities of occurrence for cyclones of varying intensities (ie. various Average Recurrence Intervals).

When preparing designs for the implementation of the preferred shoreline management strategy, it will be necessary for Council to consider the above probabilities and nominate an Average Recurrence Interval as the design standard. This then establishes the Design Event when implementing the Shoreline Erosion Management Plan.

ARI of the event	probability of being equalled or exceeded	probability of occurring in any single year
10 years	99.3%	9.5%
20 years	91.8%	4.9%
50 years	63.2%	2.0%
100 years	39.3%	1.0%
200 years	22.1%	0.5%
500 years	9.5%	0.2%
1,000 years	4.9%	0.1%

Table 4.1 : Probability of Occurrence of ARI events in a 50 year Timeframe

4.1.4 Long-term Erosion

As discussed previously, the northern shores of Nelly Bay are experiencing long-term erosion as a result of the inadequate natural supply of sand. The area affected is primarily the ocean frontage of the Esplanade.

This section of foreshore is expected to continue to experience long-term erosion - requiring foreshore management to address adverse effects. The predicted recession rate of 0.6 m/year (increasing gradually to around 0.7 m/year due to climate change) over the 50 year planning period suggests that if left unchecked, the foreshore in this area will recede an additional 32.5m (say 33m) inland.

Furthermore, the effects of long-term erosion at Nelly Bay is expected to extend further southwards over the same planning period - although it is difficult to predict the rate of that migration without recourse to numerical modelling. It is conceivable however that it could extend as far south as the Nelly Bay Habitat Reserve towards the end of the 50 year planning timeframe.

The Nelly Bay shoreline south of the Reserve is not expected to experience any significant long-term erosion during the planning period. The supply of sand to this section of Nelly Bay foreshore will be sufficient to match the local longshore transport rates that are moving sand onwards. The sand supplying this southern section of shoreline would be derived from the eroding foreshore north of the Reserve and around Yates Street in particular.

4.1.5 Short-term Erosion

Sections 3.2.5 and 3.4 provided discussions on cyclone induced erosion under present day and future climate change scenarios respectively. This resulted in predicted shoreline recessions that are summarised in Table 3.5 and Table 3.8 for a range of cyclone ARI.

4.1.6 Overall Erosion Threat

When combining long-term, short-term and climate change influences along the Nelly Bay foreshore for a planning period of 50 years, the following potential shoreline erosion emerge:

Foreshore Precinct	Overall Beach Recession Distances for Various ARI Storms				
	50 year	100 year	200 year	500 year	1000 year
opposite Yates Street	52m	54m	61m	65m	69m
opposite Habitat Reserve	18m	33m	39m	40m	42m
southern end of beach	18m	30m	37m	42m	43m

Table 4.2 : Predicted Foreshore Recession *(metres)* over a 50 Year Planning Period - includes climate change effects

The distances are measured inland from the toe of the frontal dune where such a feature is evident; otherwise it is measured from a line defining the seaward limit of terrestrial vegetation along the shoreline.

As can be seen, erosion is anticipated to be most acute at the northern end of Nelly Bay, in the vicinity of Yates Street.

As discussed previously, the shoreline recessions in Table 4.2 need to be considered with some caution since there is considerable overwash of the foreshore for even the 50 year ARI towards the end of the 50 year planning period. The numerical modelling of erosion mechanisms during such complex overwash processes is unfortunately not particularly reliable at this point in time.

4.2 Threatened Assets

The predicted shoreline recessions under a range of storm conditions over the 50 year planning period have been plotted on recent aerial photographs. These are presented in Appendix E and include the effects of future climate change at the end of the planning period.

The erosion threat is most severe along the ocean frontage of the Esplanade. It is evident from the predicted shoreline recession plots that towards the end of the 50 year planning period, private residents fronting the Esplanade will be threatened by complete loss - even for 50 year ARI events.

Further south where the Nelly Bay Road runs immediately behind the beach crest, the predicted erosion plots show that the road would be significantly threatened by 50 year ARI events - with its complete removal by events of 100 year ARI or greater.

5 SHORELINE EROSION MANAGEMENT OPTIONS

5.1 Guiding Principles

When preparing a Shoreline Erosion Management Plan there are a number of generic solutions and strategies which can be considered for erosion mitigation of shorelines. The *State Coastal Management Plan* provides a logically sound and robust approach to the problem by requiring all planning for Queensland's coastal areas to address potential impacts through the following hierarchy of approaches[8]:

- avoid — focus on locating new development in areas that are not vulnerable to the impacts of coastal processes and future climate change;
- planned retreat — focus on systematic abandonment of land, ecosystems and structures in vulnerable areas;
- accommodate — focus on continued occupation of near-coastal areas but with adjustments such as altered building design; and
- protect — focus on the defence of vulnerable areas, population centres, economic activities and coastal resources.

5.2 Coastal Defence Line

When considering foreshore protection measures, it is necessary to define a Coastal Defence Line which represents the landward limit of acceptable erosion. In other words, it forms the landward boundary of any erosion buffers to protect the Nelly Bay shoreline, or alternatively the alignment of any protection structure such as a seawall.

Property and infrastructure landward of the Coastal Defence Line remains protected throughout the 50 year planning period, whereas foreshore areas seaward of the line lie within the active beach system (ie. within the erosion buffers).

Defining the position of the Coastal Defence Line therefore entails consideration by Council and other stakeholders as to what assets are to be defended. Options could include a Coastal Defence Line on an alignment alongside the seaward edge of the Esplanade and Nelly Bay Road, or along the seaward edge of the foreshore parkland, or even along the toe of the existing dune. This later option would preserve the park and the iconic trees along the northern section of Nelly Bay.

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[8] Required under the current State Coastal Planning Policy 2.2.1 (Adaptation to climate change).

5.3 Generic Erosion Management Options

In essence, erosion mitigation options can be considered as “soft” non-structural solutions, or “hard” structural solutions.

Soft (or non-structural) solutions would typically include:

- Do nothing - allowing coastal processes to take their natural course while accepting the resulting losses;
- Avoiding development - by implementing regulatory controls with regard to building in undeveloped areas;
- Planned retreat - removing the erosion threat by relocating existing development away from the vulnerable area;
- Beach nourishment - rehabilitate eroding foreshores by direct placement of sand onto the beach, thereby providing an adequate erosion buffer;
- Beach scrapping - by using earthmoving plant and equipment to mechanically relocate sand from the inter-tidal zone or nearshore sandbanks into the upper beach or dune, thereby improving erosion buffers on the beach;
- Channel relocation - relocate dynamic river or creek entrances that may be contributing to shoreline erosion so that they have a lesser impact.

Hard (or structural) solutions that can be utilised to mitigate the threat of erosion include:

- Seawalls - which act as physical barriers to prevent shoreline recession;
- Seawalls with beach nourishment - where the seawall defines the inland extent of erosion, whilst sand is intermittently placed in front of the wall for improved beach amenity;
- Groynes / offshore breakwaters - used to inhibit the natural longshore movement of sand, thereby retaining sand on the eroding foreshore for longer periods;
- Groynes / offshore breakwaters with beach nourishment - where the structure assists in maintaining sand on the beach, and beach nourishment reduces the downdrift erosion caused by the groyne’s interruption to longshore sand supply.

In some cases the optimum management strategy may include a combination of “soft” and “hard” solutions.

An appraisal of each generic erosion management option and its potential application to the Nelly Bay shoreline is set out below. This is followed by a summary of the advantages and disadvantages of each.

5.3.1 Non-structural Management Options

5.3.1.1 Do nothing

A "do nothing" strategy of coastal management can be appropriate where foreshore land is undeveloped, or assets and property are of only limited value. It is well suited to situations where available erosion buffers are sufficient to accommodate long-term and short-term erosion over the nominated planning period. However on foreshores where existing development and infrastructure is threatened by erosion, the high social and financial costs associated with their loss are generally unacceptable.

As stated previously, it is the foreshore along the Esplanade frontage of Nelly Bay which is most threatened by erosion in a 50 year planning period. A Do Nothing strategy on this shoreline would potentially lead to the loss of the Esplanade itself along with the front row of private dwellings.

This scenario would therefore lead to considerable social trauma and substantial economic loss. Consequently it is not a viable management option for this erosion prone foreshore.

5.3.1.2 Avoid development

Along sections of the foreshore that remain substantially undeveloped, a key objective would be to prevent an erosion problem from occurring by allowing the natural beach processes of erosion and accretion to occur unimpeded. This would also preserve the natural ecosystem, amenity and character of the beach.

There is scope to implement this option along the foreshore south of the Esplanade since this primarily constitutes undeveloped land which is primarily in public ownership. Because there is no long-term erosion on this section of foreshore, erosion threats over the next 50 years relate primarily to cyclones (with threat levels much as they are now) and any recession due to future climate change.

The implementation of an "avoid development" strategy would require appropriate planning controls to prevent future development and infrastructure occurring in these areas. However such instruments are already in place, through the current designation of the Nelly Bay foreshore as being within 80m wide Erosion Prone Area (refer discussions in Section 4.1.1).

Presently any foreshore protection works or re-zoning applications within designated Erosion Prone Areas trigger an approval requirement from the Department of Environment and Resource Management. Part of this foreshore is also within the Nelly Bay Habitat Reserve and therefore unavailable for development anyway.

5.3.1.3 Planned retreat

The intent of a planned retreat strategy is to relocate existing development outside of the area considered vulnerable to erosion, allowing this previously developed land to function as a future erosion buffer. This approach accommodates natural beach processes without attempting to influence them.

The private properties along a 350m long section of the Esplanade are currently threatened by cyclone events of around 500 year ARI. However because of ongoing long-term erosion, the same threat of loss will be posed by cyclones of around 50 year ARI towards the end of the 50 year planning period.

A planned retreat strategy would require resumption of these private properties and abandonment of them and the Esplanade easement to erosion processes.

The financial costs involved in such a strategy would be considerable given current property values of foreshore land on Magnetic Island. Significant adverse community response to the social cost of a retreat strategy on this foreshore is also very likely.

Nevertheless an aspect of planned retreat which could be implemented relates to any existing power and telecommunications infrastructure that is located within the erosion prone areas. Outages and emergency works could be averted if a strategy of retreat was implemented by power and telecommunication suppliers as part of planned relocation works.

5.3.1.4 Beach nourishment

A strategy of beach nourishment entails the placement of sand directly onto the beach - either by using conventional earthmoving techniques or by pumping - so as to restore an adequate buffer width on the foreshore. The advantages of beach nourishment as an erosion management strategy are that it has no adverse impacts on adjacent foreshores, and it maintains the beach amenity.

It is generally regarded as being the most desirable solution to erosion problems on foreshores where a suitable and economic source of sand is available.

A frequent community criticism of beach nourishment projects is that it does not provide a permanent solution to persistent long-term erosion problems since it requires an ongoing commitment to further renourishment. Nevertheless most other forms of direct intervention (even those of a “hard” structural nature) also require maintenance and a commitment to future costs. When all impacts and costs are taken into account, the requirement for future nourishment campaigns typically does not detract from the cost/benefit advantage of a beach nourishment strategy. This aspect is explored further in Section 5.4 when various generic erosion mitigation options for Nelly Bay are assessed..

The ability to immediately replace sand lost in a storm so as to provide continual protection by an adequate buffer is often a challenging issue under this strategy. This is particularly the case given that there can be several storms or cyclones in any one season; and means that sand may need to be placed on the beach more than once in any cyclone season so as to be completely effective.

Sand used for nourishment is typically sourced from outside of the active beach system to offset any possibility that the benefit to the nourished foreshore is achieved at the expense of beach erosion elsewhere. This places a constraint on prompt restoration of buffers depleted by storm/cyclone events if such sources are not readily to hand.

The requirements for an effective beach nourishment strategy are determined by the local sediment transport regime. The objectives of such a strategy are to establish and maintain adequate erosion buffers. Cross-shore sand transport processes dictate the overall volume of sand required in the buffer so as to accommodate a particular cyclone ARI. On the other hand, longshore transport processes determine the average rate at which sand needs to be added periodically to the buffers so that they are maintained in the long-term.

The buffer characteristics of sand volume and width are basically the volumes and widths that would be removed by short-term erosion processes. These characteristics were presented earlier for present-day climate conditions in Table 3.4 and Table 3.5 (of Section 0).

An appropriate beach nourishment strategy for Nelly Bay would be to initially create the buffers required for present-day conditions and to then continually monitor foreshore performance - increasing buffer volumes/widths as actual climate change conditions manifest themselves.

As discussed previously, it is necessary to define a Coastal Defence Line which under a Beach Nourishment strategy represents the landward limit of acceptable beach fluctuations. In other words, it forms the landward boundary of the sand buffer which is to protect the Nelly Bay shoreline. Property and infrastructure landward of the Coastal Defence Line will remain protected throughout the 50 year planning period, whereas foreshore areas seaward of the line fall within the dynamic erosion buffer.

Clearly such determinations will affect the volume of sand that needs to be initially imported to create the required buffer widths. For example, if the line was to lie immediately alongside the Esplanade and Nelly Bay Road, then much of the existing foreshore between these roads and the beach can be considered as being part of the required buffer. This would need much less sand to be placed than an option that had the line along the toe of the existing foredune, which would then require importing a greater volume of sand to effectively create a completely new buffer.

Reference to discussions in Section 3.2.4 indicates that the average net longshore sand transport rates along this section of foreshore are typically around 1,200 m^3/year. Since there is no longer an adequate supply of sand from Gustav Creek to meet this demand, renourishment of the shoreline at this average annual rate would be required to maintain the necessary erosion buffers.

5.3.1.5 Beach scrapping

The concept of beach scrapping entails moving sand from lower levels of the cross-shore beach profile (typically from tidal flats immediately in front of a beach) up onto the beach slope or into the dune system. In essence it is simply redistributing sand that is already within the active beach profile and as such does not provide a net long-term benefit - particularly on foreshores that are experiencing long-term recession, such as those on Nelly Bay.

Beach scrapping can be beneficial in reinstating or reshaping the dune following a storm event, thereby assisting and accelerating natural processes that would otherwise rebuild the eroded dune system over much longer timeframes. However since scrapping would simply lower and/or steepen the Nelly Bay beach which provides very little benefit.

It is not considered a viable strategy for mitigating erosion on Nelly Bay beach.

5.3.1.6 Channel relocation

In some cases foreshore erosion can be attributed in varying degrees to the dynamic nature of river or creek entrances. The sandbanks and shoals at the mouth of these natural waterways can affect tidal currents and wave patterns which can have an adverse effect on nearby shorelines. In some of those instances the problem can be alleviated somewhat by the planned relocation of the entrance or main channel flow.

There is an un-named ephemeral creek which at times discharges across the foreshore approximately midway along the beach. However it does not contribute significantly to local erosion problems. Consequently there is no merit in considering any relocation of this creek entrance.

5.3.2 Structural Management Options

5.3.2.1 Seawalls

Seawalls are commonly used to provide a physical barrier to continuing shoreline recession. Properly designed and constructed seawalls can be very effective in protecting foreshore assets by stopping any further recession. Consequently if such a strategy was to be implemented along the Nelly Bay foreshore, it would be constructed along the alignment of a nominated Coastal Defence Line.

However seawalls significantly interfere with natural beach processes by separating the active beach from sand reserves stored in beach ridges and dunes. In other words, seawalls can protect property behind the wall, but they do not prevent in any way the erosion processes continuing on the beach in front of them. In fact they very often exacerbate and accelerate the erosion.

Typically the effect of seawall construction on actively eroding shores is for the level of the beach in front of it to steadily lower - until the beach reaches a new equilibrium profile.

This lowering is primarily caused by wave action washing against the wall causing a high degree of turbulence in front of the structure - which scours the beach material. Wave energy reflected from the seawall also contributes to these scour and beach lowering processes. In many cases this lowering continues until the level of the beach is below prevailing tide levels, in which case the ocean simply washes against the face of the seawall and there is no beach for part (or possibly for all) of the tide cycle. The amenity of the beach and foreshore is therefore significantly degraded in order for the seawall to protect the area behind it.

This lowering of the sand level in front of seawalls can also present problems for the overall stability of the structure. Unless appropriate foundation and toe arrangements are constructed, the seawall can fail by undermining. Even if only damaged, it is extremely difficult and very expensive to repair existing seawalls that have been damaged by undermining. Indeed frequently the most cost effective solution is to demolish the structure and rebuild it with deeper and more robust foundations.

Another typically adverse impact of seawalls is that the original erosion problem that they were meant to solve is simply relocated further along the shore. Natural beach processes can no longer access the sand reserves in the upper part of the active beach that are behind the seawall. Consequently this sand cannot be moved downdrift by longshore sand transport processes to replenish the sand that these same processes are moving along the shoreline beyond the end of the seawall.

The deficit in sand supply to these downdrift sections initiates greater erosion, ultimately requiring extension of the seawall along the entire downdrift shoreline in order to protect it.

Seawalls have an effect on the visual amenity of a shoreline, and this can be quite adverse if the wall is high - or if it becomes so as a consequence of natural beach lowering in front of it. Such walls also inhibit easy public access across the foreshore onto the beach. Typically access stairways or ramps need to be provided on seawalls to ensure the safety of beach access by pedestrians.

Along urban foreshores, seawalls can offer sheltered habitats for vermin such as feral cats and rodents. This can adversely affect natural coastal flora and fauna values.

Appropriately designed and constructed seawalls are relatively expensive and they do not always compare favourably with the cost of other alternatives. However many seawalls constructed in Queensland have been built of rock during or immediately following severe sea conditions and significant cyclone erosion events. Under such circumstances appropriate design and construction of these walls may not have been implemented. Consequently most of the rock walls constructed in this manner require significant maintenance to prevent structural failure and the re-establishment of the original erosion problem.

Despite their disadvantages, rock seawalls are probably the most commonly used method in Queensland for protecting foreshore assets against the threat of erosion. This can probably be attributed to their versatility. They are relatively easy to construct using conventional earthmoving plant and equipment; and this is often accomplished by simply dumping rock on a prepared slope rather than applying more appropriate construction practises to create a robust structure.

Such adhoc methods can be used to not only protect long sections of foreshore, but also individual private properties. The substantial and solid appearance of rock walls can provide owners of foreshore assets with a sense of security - which unfortunately is frequently misguided given the often inadequate design and construction of these structures. Their subsequent failure or damage can not only lead to the re-establishment of the original erosion problem, but the scattering of removed rocks can adversely affect foreshore use and visual amenity.

If a rock seawall was to be constructed on a Coastal Defence Line along the at-risk section of the Nelly Bay foreshore, it would need to be constructed of two layers of approximately 3tonne rocks overlying two layers of smaller rocks of around 0.25 tonne each. This armoured slope should be no steeper than 1 vertical to 1.5 horizontal; and founded on what is expected to be the reef pavement buried beneath the existing beach.

The rock seawall could initially be constructed along the shores of Nelly Bay which are immediately threatened by erosion. However the accelerated erosion processes would soon require the wall to be extended further south. The location of the Coastal Defence Line with respect to the active beach would determine when this extension would be required. However eventually it will be necessary to construct the seawall along the entire foreshore of Nelly Bay.

This 1.3km long seawall would require some 40,000 to 55,000 tonnes of armour rock and cost around $4million to build.

Because of there would be no natural supply of sand to recharge the beach in front of the seawall, over time the beach level would drop until there was no beach in front of the seawall - tides would wash directly against the wall. Whilst this erosion mitigation strategy would prevent any recession of the shoreline, it would have significant adverse impacts on the foreshore amenity of Nelly Bay.

5.3.2.2 Seawalls with beach nourishment

To mitigate some of the disadvantages of seawalls, beach nourishment can also be undertaken to create a beach amenity in front of the structure. This sand placement also provides a reservoir of sand to feed the downdrift foreshore which would otherwise be starved of sand by the wall.

At Nelly Bay, the seawall would be built along the entire frontage of the Esplanade and serve as the primary defence against erosion; and must be designed and constructed accordingly. The amount of sand initially placed as beach nourishment will depend on both where the Coastal Defence Line is located within the active beach profile and the extent of the amenity to be provided.

For example, if the Coastal Defence Line was located some distance inland (say, along the seaward kerb of the Esplanade) then the existing foreshore between the seawall and the beach could be considered as the beach nourishment. Nevertheless, regular sand placement would be required to maintain the beach amenity, as well as prevent migration of the initial erosion problem southward along the shore. This intermittent renourishment would need to at least match the average net longshore sand transport rate of around 1,200 m^3 /year.

Assuming that no initial sand placement is required (due to an inland Coastal Defence Line), then costs would therefore be approximately $1.5million to construct the wall and approximately 1,200 m^3 annually (at present day rates) for renourishing the beach in front of it.

5.3.2.3 Groynes

The longshore transport of sand on an eroding shoreline can be impeded by constructing groynes across the active beach. A groyne functions as a physical barrier by intercepting sand moving along the shore. Sand is gradually trapped against the updrift side of the structure, resulting in a wider beach on this "supply-side" of the structure. However the downdrift beach is deprived of the sand trapped by the groyne and therefore it erodes.

This process of updrift entrapment and downdrift erosion continues until such time as sand has accumulated on the updrift side of the groyne to the extent that it starts to feed around its seaward end. Sand supply is then reinstated to the downdrift foreshore; however this then simply maintains the shoreline on its eroded alignment.

Groynes cannot prevent the significant cross-shore erosion that typically occurs during cyclones. Nevertheless they have an indirect effect in that by having trapped sand on their updrift side, they have created a wider beach and an enhanced erosion buffer on that section of foreshore. However on the depleted downdrift side, the foreshore is more susceptible to cyclone erosion due to the depleted beach/buffer width.

Consequently the construction of a groyne does not in itself resolve the erosion problem, but merely transfers it further along the beach.

The same effect of impeding the longshore transport of sand by a groyne can also be achieved by a structure built offshore of the beach, but not connected to it. Such structures a called *offshore breakwaters* and function by casting a “wave shadow” onto the shoreline in its lee.

The reduced wave energy landward of the offshore breakwater means that the ability of the waves to keep moving sand along the shoreline is reduced. Consequently the supply of sand from the updrift shoreline is greater than that at which it can be moved out of the wave shadow. Sand therefore accumulates in the lee of the structure. However, as is the case with a conventional groyne, the shoreline downdrift of the wave shadow is deprived of sand and therefore erodes.

At Nelly Bay, a groyne solution would entail the construction of a groyne (or shore-parallel offshore breakwater) on the foreshore near the southern end of the Esplanade. This would retain sand to its north, thereby maintaining the current beach width on this northern section of the beach. However the shoreline to the south of the groyne would start to experience erosion since it was no longer receiving the eroding sand from in front of the Esplanade. In other words, the erosion problem along the Esplanade would be alleviated by simply transferring it southward.

5.3.2.4 Groynes with beach nourishment

The downdrift erosion caused by groynes can be compensated to a large extent by incorporating beach nourishment into the strategy. This is achieved by placing sand against the updrift side of the groyne immediately after it is constructed so that it is “filled”. Any additional sand moved against this side of the structure by natural processes can therefore be carried around the end of the groyne to supply the downdrift shoreline.

The length of updrift shoreline that benefits from such groyne and beach nourishment is somewhat limited. Therefore if long sections of shoreline require protection then a number of groynes can be built at intervals along the shoreline. This is typically called a *groyne field*.

The length and spacing of such groynes depend to a large degree on the local longshore sand transport regime; and in particular the naturally preferred stable orientation of the beach. Their length and spacing are also somewhat dependent upon each other. Under any given longshore transport regime, it is possible to achieve a similar degree of protection by using short closely spaced groynes, or longer more widely spaced structures. Such issues can only be resolved by further detailed study and design.

Nevertheless such intervention will have a significant impact on the visual amenity of the Nelly Bay foreshore. Structures such as groynes that cross the shore can also have an adverse impact on beach use since walking along the beach will entail crossing over the groynes. This experience is also potentially marred by the different beach levels on the updrift and downdrift sides.

It is for these reasons alone that a management strategy that entails a groyne field along Nelly Bay beach is unlikely to have appeal.

5.3.3 Advantages and Disadvantages of Generic Options

As discussed above, there are a number of generic erosion management strategies which could be implemented under this Shoreline Erosion Management Plan. Some options are better suited than others. To assist in evaluating these in the context of the Nelly Bay foreshore, a summary of the advantages and disadvantages of the various strategies has been prepared in Table 5.1 (for non-structural options) and Table 5.2 (for structural options).

5.4 Assessment of Shoreline Management Options

When considering appropriate erosion management options along the Nelly Bay foreshore it is evident that the shoreline can be considered in two coastal precincts, namely

- Northern Reach : north of around Yates Street; and
- Southern Reach : south of around Yates Street.

This separation into coastal reaches does not imply that the coastal processes within each are in any way compartmentalised. They are by no means isolated or discrete sections of shoreline, since the processes affecting each have considerable influence on the other. However this partitioning lends itself to the development of viable erosion management strategies that integrate well over the entire Nelly Bay coastal reach.

An assessment of potential management strategies for each of these two coastal precincts is presented in the following sections. In order to rate the various options, a score is intuitively assigned to each option using a numerical scale ranging from 1 (exceptionally poor) to 10 (excellent). Therefore the higher the score, the more appropriate or desirable is the option's outcome.

It is acknowledged that there is a degree of subjectivity in such an approach, and that even amongst experienced coastal management practitioners there is likely to be some differing opinions as to overall and relative scores. As will be seen, preferred strategies nevertheless strongly emerge from this process.

Erosion Management Option	Advantages	Disadvantages
Do Nothing	Maintains existing undeveloped foreshores in their natural state. Coastal processes proceed unimpeded by erosion mitigation works. Could be applied to existing foreshore south of the Esplanade.	Considerable loss of private landholdings and dwellings along the Esplanade. Loss of essential community infrastructure, including the Esplanade road reserve, recreational reserves, stormwater drainage system, Loss of foreshore land south of the Esplanade if implemented in this area. Significant adverse impact on visual amenity. Expected erosion of foreshore will result in considerable loss of important terrestrial values. Will cause significant social trauma.
Avoid Development	Maintains existing undeveloped foreshores in their natural state. Coastal processes proceed unimpeded by erosion mitigation works. Planning controls to achieve outcomes are substantially in place.	Does not resolve current erosion problems at the northern end of Nelly Bay - where existing development and assets are located within foreshore areas prone to erosion.
Planned Retreat	Maintains existing undeveloped foreshores in their natural state. Coastal processes proceed unimpeded by erosion mitigation works. Minimal disturbance to visual amenity.	Does not ensure that existing terrestrial values are protected. Loss of existing foreshore flora and fauna habitats. Requires resumption of foreshore properties along the Esplanade. Requires abandoning the Esplanade road reserve & resumed properties to the effects of erosion processes.
Beach Nourishment	Coastal processes can proceed unhindered, with no adverse impacts on adjacent foreshores. Maintains existing beach amenity and public access. Minimal disturbance to visual amenity. Cost of initial sand placement and renourishment can be low if appropriate sand sources are close-by. A flexible solution that can be tailored to suit the currently uncertain effects of future climate change as they actually emerge.	Requires on-going commitment to annual sand re-nourishment to recharge erosion buffers. Cost of initial sand placement and renourishment can be medium/high if appropriate sand sources are a long way away.
Beach Scrapping	None	Does not resolve long-term erosion problems at northern end of Nelly Bay where existing assets are located within foreshore areas prone to erosion. Unlikely to achieve the volumes of sand required to create and maintain buffers. Adverse impacts likely on intertidal flora and fauna. Adverse impacts on visual amenity during scrapping activities.
Channel Relocation	None	Does not resolve long-term erosion problems at northern end of Nelly Bay where existing assets are located within foreshore areas prone to erosion.

Table 5.1 : Non-structural Erosion Management Options

Erosion Management Option	Advantages	Disadvantages
Seawalls	Provides robust physical barrier to halt shoreline recession.	High construction cost. Adverse affect on local coastal processes - causing loss of beach in front of the structure. Does not solve the existing erosion problem at the northern end of Nelly Bay, it simply transfers the problem further south. Will need to continually extend the seawall along the shore to accommodate the ongoing southward migration of the erosion. To accomodate expected erosion influences over the entire planning period, it is likely to have to extend the seawall along the entire 1.3km Nelly Bay foreshore. Significant adverse impact on visual amenity. Adversely affects beach amenity by inhibiting easy access across the foreshore onto the beach. May require stairways/ramps to provide safe access onto the beach.
Seawalls and Beach Nourishment	Provides robust physical barrier to halt shoreline recession. Under most ambient conditions, coastal processes proceed unimpeded by erosion mitigation works. Maintains existing beach amenity and public access. Minimal disturbance to visual amenity. A flexible solution that can be tailored to suit the currently uncertain effects of future climate change as they actually emerge.	High construction cost. Requires ongoing financial and works commitment to future sand placements in order to assure beach amenity.
Groynes	Retains sand on presently eroding foreshores for longer periods.	Medium / High construction cost. Does not solve the existing erosion problem at the northern end of Nelly Bay, it simply transfers the problem further south. Will need to continually extend the number of groynes along the shore to accommodate the ongoing southward migration of the erosion. To accomodate expected erosion influences over the entire planning period, it is likely to have extend the groyne field along the entire 1.3km Nelly Bay foreshore. Significant adverse impact on visual amenity. Adversely affects beach amenity by inhibiting access along the shore.
Groynes and Beach Nourishment	Retains sand on presently eroding foreshores.	High construction cost. Requires ongoing financial and works commitment to future sand placements in order to assure beach amenity.

Table 5.2 : Structural Erosion Management Options

5.4.1 Northern Reach

As shown in Figure 5.1, the northern reach of the Nelly Bay shoreline nominated for inclusion in this Shoreline Erosion Management Plan extends from the Nelly Bay Harbour's southern breakwater to a location near Yates Street.

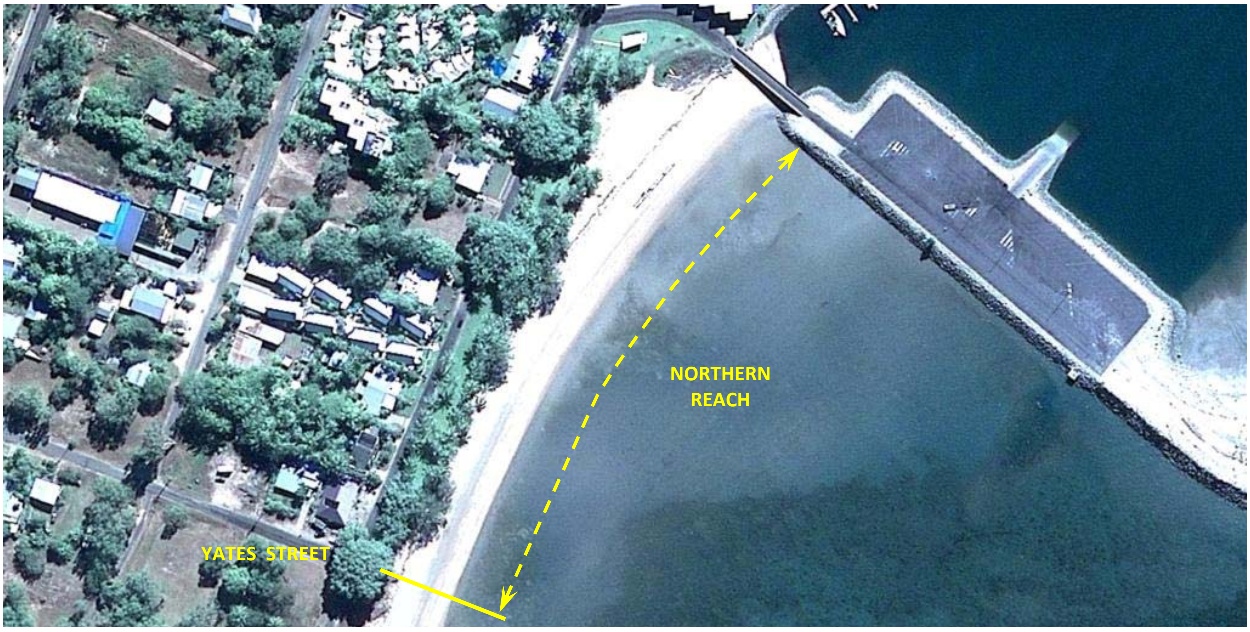

Figure 5.1 : Northern Reach of the Nelly Bay Shoreline

This ocean frontage of the Esplanade experiences a predominantly northwards littoral transport. The foreshore erosion buffer has benefited from the annual relocation of sand from beneath the breakwater road bridge opposite Kelly Street.

The shoreline can be considered as being a "developed foreshore" since it consists of an intensely managed and highly utilised public park. Private landholdings and residences on the landward side of the Esplanade are also included in the area prone to erosion and therefore require protection.

Options for providing this erosion protection have been subjectively assessed in Table 5.3 - from which it is evident that a Beach Nourishment strategy is the most effective.

Clearly the options of Do Nothing and Planned Retreat rate poorly due to the considerable adverse social and financial costs. Structural management options (such as a seawall or groynes - with/without supplementary beach nourishment) also rate poorly. This is due to their adverse impacts on prevailing coastal processes and coastal values, along with their high financial costs.

However to optimise the benefits of this preferred solution, it will be necessary to incorporate considerations of its influence on the requirement to maintain tidal flows beneath the breakwater bridge opposite Kelly Street. These aspects are discussed in more detail in the following section of this report.

Generic Management Options

Assessment Criteria	Do Nothing	Avoid Development	Planned Retreat	Beach Nourishment	Beach Scrapping	Seawalls	Seawalls & Nourishment	Groynes	Groynes & Nourishment
Compliance with State Coastal Policy	6	*NOT APLICABLE*	6	8	3	2	4	2	4
Maintaining coastal processes	8		8	9	4	2	6	3	6
Maintenance of Marine Values	6		6	9	2	3	7	3	6
Maintenance of Terrestrial Values	1		1	9	5	6	8	5	7
Maintenance of Social Values	1		1	9	3	3	7	3	7
Visual amenity	1		1	9	4	2	7	2	3
Beach access and amenity	2		2	9	4	2	8	4	3
Initial financial cost (direct & indirect)	1		1	6	8	2	2	3	3
Ongoing financial cost (direct & indirect)	2		2	5	6	5	3	4	3
TOTAL SCORE	**28**		**28**	**73**	**39**	**27**	**52**	**29**	**42**

Table 5.3 : Option Assessment - Northern Reach of Nelly Bay

5.4.2 Southern Reach

The southern reach of the Nelly Bay shoreline extends southwards from around Yates Street to the rocky outcrops at the very southern end of the beach (near the backpacker resort). Its extent is shown on Figure 5.2.

It is along the northern section of this coastal reach that the erosion problem is most acute. As is the case for the northern reach, the annual relocation of sand from beneath the breakwater bridge onto this section of the Nelly Bay beach has assisted considerably in maintaining an erosion buffer along the Esplanade. Previous emergency beach nourishment campaigns undertaken in recent years by Townsville City Council following major erosion events have also been effective in reducing the threat posed to local infrastructure.

However whilst providing valuable temporary and short-term benefits, the annual relocation of sand from beneath the breakwater bridge does not resolve the ongoing erosion threat posed by inadequate supply of sand to Nelly Bay shores.

Options to mitigate this threat have been subjectively assessed in Table 5.4. It is evident that a Beach Nourishment strategy is again the most effective solution for this reach.

Figure 5.2 : Southern Reach of the Nelly Bay Shoreline

Assessment Criteria	Do Nothing	Avoid Development	Planned Retreat	Beach Nourishment	Beach Scrapping	Seawalls	Seawalls & Nourishment	Groynes	Groynes & Nourishment
	Generic Management Options								
Compliance with State Coastal Policy	7	*NOT APLICABLE*	6	8	3	2	4	2	4
Maintaining coastal processes	8		8	9	4	2	6	3	6
Maintenance of Marine Values	7		7	9	2	3	7	3	6
Maintenance of Terrestrial Values	7		6	9	5	6	8	5	7
Maintenance of Social Values	5		5	9	3	3	7	3	7
Visual amenity	7		5	9	3	2	7	2	3
Beach access and amenity	6		5	9	4	2	8	4	3
Initial financial cost (direct & indirect)	4		4	6	8	2	2	3	3
Ongoing financial cost (direct & indirect)	7		4	5	5	5	3	4	3
TOTAL SCORE	**58**		**50**	**73**	**37**	**27**	**52**	**29**	**42**

Table 5.4 : Option Assessment - Southern Reach of Nelly Bay

A Do Nothing strategy would result in the loss of some private landholdings and residences (as well as the Esplanade road reserve) south of Yates Street. Under such a scenario the erosion would gradually migrate southwards to threaten the foreshores of the Nelly Bay Habitat Reserve. It therefore rates poorly, as does the Planned Retreat philosophy - primarily because of the adverse financial and social costs.

Again structural management options (such as a seawall or groynes - with/without supplementary beach nourishment) also rate poorly. As is the case for the developed shoreline north of Yates Street, this is due to adverse impacts on prevailing coastal processes and coastal values, along with their high financial costs.

5.4.3 Maintaining Flow Beneath the Breakwater Bridge

The implementation of a beach nourishment strategy for Nelly Baywill establish and maintain natural erosion buffers along foreshore sections that are threatened by erosion over the 50 year planning period. However the local coastal processes are such that some of the placed sand will be transported into the beach/breakwater corner opposite Kelly Street. As discussed previously, there is a requirement to maintain tidal flow under the road bridge that connects to the southern harbour breakwater opposite Kelly Street (refer discussions in Section 3.1.2).

Consequently to be effective, the beach nourishment strategy recommended for Nelly Bay must accommodate this requirement. There are two alternative solutions to this issue, namely:

- interception of the northward moving sand and the creation of a stable sand “fillet” by construction of a training wall alongside the southern breakwater. This will facilitate the tidal flow in the channel beneath the bridge; or alternatively
- relocation of sand which is deposited in the beach/breakwater corner by means of back-passing operations (similar to the management strategy currently being applied by the Queensland Department of Main Roads and Transport).

Comments are offered in relation to both of these options. This is followed by an Options Assessment similar to that used to assess generic shoreline management options.

5.4.3.1 Training Wall

As an alternative to the current practice of recycling sand from the channel beneath the breakwater bridge, a training wall could be constructed immediately updrift of this location. The wall would intercept the northward transport of sand which would otherwise fill the flow channel beneath the bridge. The concept is illustrated in Figure 5.3.

A stable orientation of the sand fillet that forms against this training wall would be such that it faced out towards the south-easterly fetches that exist across Cleveland Bay towards Townsville. The shoreline of the fillet would align itself with the predominant wave energy - which in this northern corner of the beach would be towards the south-east.

The training wall would need to be of a sufficient length to hold this fillet in place without any sand spilling around its offshore end, which would otherwise compromise the tidal flows beneath the breakwater bridge.

It is estimated that the training wall would need to extend approximately 70 metres beyond the toe of the existing beach to achieve this outcome. It is further estimated that the wall should be parallel to, and around 30 metres to 40 metres from, the toe of the southern breakwater.

Figure 5.3 : Training Wall Adjacent to Southern Breakwater

The construction of the training wall provides the added benefit of confining the tidal flow on its approach through the area beneath the bridge. This means that the main flow channel is more likely to be naturally maintained by the scouring effect of tidal flows.

Rather than allow natural processes to fill the fillet against the southern flank of the training wall over time (and thereby deplete the sand reserves of the adjacent beach in doing so) it is more appropriate to use imported sand to create the sand fillet. It is estimated that approximately 1,750 m^3 of sand would be required to create the necessary fillet.

Detailed coastal processes modelling could be undertaken prior to the implementation phase of the project to more accurately determine the length of the training wall. The particularly complex natural processes are such that any predicted outcomes of the modelling would nevertheless have to be treated with some caution. Greater confidence in outcomes would be achieved by application of a prototype trial for the training works.

It is recommended that a temporary training wall be constructed at the approximate location and alignment shown in Figure 5.3.

Details need to be confirmed by an engineering design phase prior to the trial. However it is envisaged that this wall could be constructed of sand filled geotextile bags; or alternatively by using large precast concrete cubes that the Department of Main Roads and Transport have in store. These blocks were surplus to the construction of the sand weirs associated with the sand-trap beneath breakwater bridge. Approximately 580 m^3 of sand would be required for filling the geotextile bags and this could be sourced from Gustav Creek.

The training wall would be placed on its estimated optimum alignment and length; then its effectiveness monitored during the trial. As the performance of the temporary training wall became evident, changes to its length, height and even its location could be implemented with reasonable ease during the trial. The results obtained from monitoring an actual prototype scenario are likely to provide greater accuracy than any numerical modelling - at a similar cost.

Once the optimum training wall arrangement has been determined by the trial, the temporary wall could be made more permanent by placing armour rock over it. If for some unforseen reason, the trial indicated that training of the tidal flow beneath the bridge was not appropriate, then the temporary training wall can be readily removed. An excavator fitted with a ripping-tyne can easily tear open and remove any geotextile bags, allowing the filling sand to spill back into the active littoral system. Alternatively the precast concrete cubes would simply be removed.

The implementation costs associated with a training wall entail:

- establishment of the trial program;
- operation of the trial, with amendments and refinements as necessary;
- adapt/convert trial arrangements to a permanent system; and
- operation of the permanent system.

These costs are summarised below in Table 5.5 and are on the basis of sand filled geotextile bags forming the temporary training wall.

Assuming a two year trial, the overall capital cost would be approximately $220,000; followed by approximately $110,000 to implement a permanent arrangement, then around $5,000 per year for maintenance and monitoring.

Activity	Capital Cost	Annual Cost
Establish Trial Program	$190,000	
Operation of the Trial		$15,000
Convert to a Permanent System	$110,000	
Operation of the Permanent System		$5,000

Table 5.5 : Estimated Current Costs for Training Wall

5.4.3.2 Sand Back-passing

The annual relocation of sand from beneath the breakwater bridge at the northern-most end of Nelly Bay beach is essentially "sand back-passing".

Sand back-passing operations simply redistribute sand within a local littoral system. It involves the mechanical transport of sand from one section of foreshore back onto an updrift sediment-starved beach. This method is often utilised in locations where coastal processes are such that sand from an eroding foreshore moves alongshore and is deposited in a more sheltered area. This is indeed the case along the northern shores of Nelly Bay, where sand is moved along the beach in the general vicinity of Yates Street and deposited in the more sheltered beach/breakwater corner, filling the channel beneath the bridge as it does so

Back-passing "recycles" the sand back onto the eroding beach. If the sand volumes are moderate and the haul distances are short, the practice can provide a very cost-effective scheme for better managing the erosion problems on the updrift beach.

As discussed, it will not on its own resolve the erosion problem since that is due to inadequate supply of sand to Nelly Bay to compensate for the 1,000 m^3 /year net longshore drift. Nevertheless it will serve the dual purpose of periodic clearing of the tidal channel at the bridge and assist in maintaining erosion buffers along the northern end of the beach.

The back-passing operations would best deliver the cleared sand to the foreshore just to the north of Yates Street, thereby recycling it within the reach that has a predominantly northerly transport. The concept is shown in Figure 5.4.

The back-passing operation itself could be implemented in one of two ways:

- by conventional earthmoving equipment; or
- by using a hydraulic "sand shifter".

Figure 5.4 : Conceptual Layout of Sand Back-passing on the Northern End of Nelly Bay Beach

Conventional earthmoving equipment

This technique is currently used to clear the channel beneath the breakwater bridge and to renourish the Nelly Bay beach. Its future application would entail use of equipment such as an excavator and front-end loader to remove sand from the extraction site beneath the bridge and load trucks - which then haul the sand along the Esplanade for placement and spreading by a loader on the target shoreline just north of Yates Street.

The annual relocation of around 3,000 to 4,000 m^3/year can be achieved in timeframes of only a few weeks. Nevertheless it requires fairly intensive construction traffic on the Esplanade during this time. The exercise typically costs around \$12.50/m^3 - resulting in an annual back-passing cost of approximately \$50,000.

Sand shifter

An alternative to earthmoving equipment is the application of a sand shifter. Such equipment has been successfully used for sand bypassing and back-passing operations to manage eroding coastlines elsewhere in Australia.

However given the relatively small annual volumes of sand back-passing, it is more expensive than the option of using conventional earthmoving equipment - but will have somewhat less social and environmental impacts.

The sand shifter is based on a fluidising principle which enables sand to be recovered from below the seabed over a distance equivalent to the length of the sand shifter unit. This unit is essentially a submerged sand pump mounted on a frame. When operating, pressurised sea water is delivered to the unit through three pipelines:

- a temporary pipe to fluidise the seabed beneath the legs of the support frame, enabling it to bury itself in the seabed;
- a permanent pipe to fluidise the sand under the buried sand shifter unit; and
- another permanent pipeline to transfer the fluidised sand to shore.

Sand is drawn down towards the sand shifter, creating a hole in the beach which is replenished by the natural longshore transport of sand. When the hole is refilled with sand, pumping recommences.

Once onshore, the sand slurry is then pumped through a pipeline to the discharge point on the foreshore where sand renourishment is required. Therefore the sand shifter unit is supplemented by shore-based facilities such as:

- a pump that supplies the pressurised seawater;
- pumps, trash rack and hopper to ensure the consistency of the sand slurry and to boost the sand discharge through the pipeline to the delivery point; and
- delivery pipelines.

A permanent installation would utilise solar and/or electrical power to operate the pumps - which could also be run automatically at night to use off-peak power.

The onshore facilities can be housed in a permanent pump station and operated automatically or remotely. The delivery pipeline from the supply point to the target foreshore near Yates Street could be buried within the foreshore reserve.

The self-burying sand shifter unit would be placed beneath the breakwater bridge opposite Kelly Street. The concept is illustrated in the images presented in Figure 5.5 which are of back-passing operations larger than would be required for Nelly Bay.

Because the recovery of sand at the extraction point relies on the prevailing coastal processes to bring sand to the unit, the rate at which sand is extracted and delivered to the eroding shoreline matches the natural rate that sand is moved off the eroding foreshore by these processes.

In other words, there is no large single annual placement of sand for renourishment purposes. Instead sand can be delivered steadily throughout the year to the foreshore that requires it.

A potential shortcoming of the system relates to recharging the erosion buffers on the northern shores of Nelly Bay following a severe cyclone event. The system can only supply sand that is brought alongshore to recharge the hole created by the sand shifter. This may not necessarily be at a rate that enables the system to quickly recharge the erosion buffers.

sand shifter unit:
on a beach prior to location on site

sand shifter unit:
in the process of self submerging at the selected sourcing site

temporary onshore pump and slurry systems for transfer of extracted sand to the foreshore requiring renourishment.

Figure 5.5 : Images of Sand Shifters Used for Sand Back-passing Operations

Prior to considering the sand shifter option it will be necessary to undertake some preliminary design - including some probing of the subsurface at the bridge. It may be that the depth of sand for creating the hole beneath the bridge is too shallow. The rocky reef flat may be located near the surface, thereby restricting the ability of the sand shifter to self-bury.

Even if such geotechnical investigations indicate that a sand shifter system could be implemented, rather than commit to a permanent installation, a trial of the sand shifter system could be implemented. The purpose of the trial would be to tailor the equipment and operations to suit the local longshore transport regime.

For the trial, the pumps might be diesel operated with subsequent conversion to solar/electric once the trail has confirmed the arrangements and operations of a permanent system.

The cost of ongoing renourishment by a sand shifter arrangement is related to the establishment of the back-passing system and its subsequent running costs. The implementation costs for ongoing renourishment by this method can therefore be considered to entail:

- establishment of the trial program;
- operation of the trial, with amendments and refinements as necessary;
- adapt/convert trial arrangements to a permanent system; and
- operation of the permanent system.

These costs are summarised below in Table 5.6. Assuming a two year long trial, the cost would be approximately \$340,000 (ie. around \$42.50/m^3) - with costs reducing to around \$40,000 per year (ie. at approximately \$10/m^3) and an initial one-off conversion cost of around \$90,000 should a permanent system be subsequently installed.

Activity	Capital Cost	Annual Cost
Establish Trial Program	\$120,000	-
Operation of the Trial	-	\$110,000
Convert to a Permanent System	\$90,000	-
Operation of the Permanent System	-	\$35,000

Table 5.6 : Estimated Costs for Renourishment by Sand Shifter

There is an initial establishment cost to set up and operate a trial of the system and clearly these establishment costs are much higher than those for sand back-passing using conventional earthmoving plant and equipment. However the sand shifter system would be mostly automated, and would not require truck movements on the Esplanade.

If a permanent installation is confirmed by the trial and then implemented, annual costs are then comparable to those of an operation using conventional earthmoving equipment.

5.4.3.3 Recommended Strategy

In order to assess the strategies of maintaining tidal flow beneath the breakwater bridge opposite Kelly Street, an option assessment similar to that used to assess the generic shoreline management options for Nelly Bay has been applied. The outcome is presented below in Table 5.7. From which it is evident that all three options are similar in terms of outcomes - but with the Training Wall option providing a better overall strategy.

	Strategy Alternatives		
Assessment Criteria	Training Wall	Backpassing - earthmoving equipment	Backpassing - sand shifter
Compliance with State Coastal Policy	7	7	7
Maintaining coastal processes	9	6	7
Maintenance of Marine Values	7	6	6
Maintenance of Terrestrial Values	7	7	7
Maintenance of Social Values	6	5	6
Visual amenity	5	6	7
Beach access and amenity	7	7	7
Initial financial cost (direct & indirect)	6	7	3
Ongoing financial cost (direct & indirect)	9	7	5
TOTAL SCORE	**63**	**58**	**55**

Table 5.7 : Option Assessment - Maintaining flow beneath the bridge

6 RECOMMENDED SHORELINE EROSION MANAGEMENT

6.1 Beach Nourishment

It is recommended that the future management of the Nelly Bay shoreline is achieved through Beach Nourishment.

The strategy basically consists of:

- Initial Nourishment - through the placement of a sufficient volume of sand to establish the sand buffers that are necessary to accommodate erosion caused by a nominated Design Event.
- Ongoing Renourishment - given that the nourished foreshore experiences long-term erosion processes, it will be necessary to recharge these erosion buffers by periodic placement of additional sand.

It is evident from the understanding of local coastal processes that has emerged when compiling this Shoreline Erosion Management Plan, that a successful beach nourishment solution will also need to address the issue of maintaining tidal flows beneath the road bridge opposite Kelly Street (that leads onto the southern breakwater of Nelly Bay Harbour). This aspect was discussed in the preceding Section 5.4.3, from which it emerged that the best option would be to construct a training wall to assist in maintaining the flows.

Prior to discussing the application of the overall Beach Nourishment strategy for Nelly Bay, it is appropriate to first consider an appropriate source of sand for this work.

6.1.1 Recommended Source of Sand for Nourishment Works

As stated many times elsewhere in this Shoreline Erosion Management Plan, the primary cause of the erosion problems currently being experienced on Nelly Bay beach is the obstruction of the natural renourishing supply of sand from Gustav Creek that has occurred following construction of Nelly Bay Harbour.

As part of the harbour works, a sedimentation basin was created just upstream of where the creek now enters the sheltered waters of the harbour. This occurs at the Sooning Road bridge. The intent of the basin was to intercept the sand that was previously delivered to the shoreline for two reasons:

- to prevent this sand from creating a siltation problem in the harbour;
- to enable the sand to be removed from the sediment basin and placed on the downdrift Nelly Bay beach. This in effect replaced the natural process of creek supply to the coast with a “mechanical” process.

In recent times, the sedimentation basin has proved reasonably effective in alleviating any major problems associated with harbour siltation, however its clearance for the nourishment of Nelly Bay beach has not been effectively undertaken.

In addition to capturing sediments delivered to the coast from the Gustav Creek catchment, the Sooning Street bridge culverts have reduced the flood velocities in the lower reaches of the creek. This has reduced the capacity of the creek system to flush the accumulating sediments through these lower reaches and into the sedimentation basin downstream at Sooning Street (SKM, 2001).

Consequently the lower reaches have been slowly accreting, leading to local flooding issues - with properties along Mango Parkway being particularly vulnerable to inundation during high creek flows.

Another effect of this accumulation of sediments in the creek's lower reaches is that fine material from the catchment makes its way in suspension to the sedimentation basin. Once in the basin these fine fractions settle out, thereby contributing to a high percentage of fine material in the basin itself - which is not necessarily suitable for subsequent extraction and placement on Nelly Bay beach as intended. Aquatic flora and fauna have established in the basin, reputedly increasing the nutrient content of its sediments, thereby potentially compromising its suitability for beach nourishment even further.

However the sand that has accumulated immediately upstream of the sedimentation basin (ie. alongside the Mango Parkway easement) is much coarser and is very suitable for beach nourishment. It consists of native sand brought down off the Gustav Creek catchment. Indeed this same accumulation of sand in the lower reaches of Gustav Creek was part of the natural littoral supply process prior to harbour construction, only now this sand cannot be flushed out by flood events as readily; and has therefore built up to a significant degree.

It is very likely that the physical characteristics of the coarse sand in the lower reaches of Gustav Creek is the same as that of the sand that accumulated in this area before being flushed into the active beach system of Nelly Bay prior to harbour construction.

It is therefore recommended that all sand for the initial nourishment of Nelly Bay beach (to create the necessary erosion buffers) as well as for the ongoing renourishment (to maintain the buffers) be sourced from the lower reaches of Gustav Creek. This is simply providing a mechanical means of reinstating the natural littoral supply processes that nourished Nelly Bay beach prior to the construction of Nelly Bay Harbour.

The precise location and operation of the extraction process requires further consideration before implementation. This would require consideration of the findings of previous studies (Cairns, et.al., 2000) as well as the Gustav Creek Management Plan (Townsville City Council, 2005).

6.1.2 Initial Nourishment

The extent of buffers required to accommodate various Design Events along the Nelly Bay shoreline have been discussed previously. Under the present day climate scenario, the shoreline most at risk extends along the entire ocean frontage of the Esplanade. The required buffer widths seaward of a designated Coastal Defence Line along this section of shoreline are presented in Table 6.1.

Transect Location	Average Recurrence Interval (ARI) 50 year	100 year	200 year	500 year	1000 year
opposite Yates Street	18	18	21	31	35
opposite Habitat Reserve	17	33	39	29	30
southern end of beach	15	30	37	41	42

Table 6.1 : Overall Buffer Widths Required by Beach Nourishment (*metres*)

As climate change influences manifest themselves, additional widths will be required. The recommended strategy for initial beach nourishment is to establish the necessary buffers for present-day conditions; and to gradually increase these widths as actual climate change effects become apparent. Such effects would be identified by regularly survey and monitoring of buffer performance.

When establishing sand buffers, the primary objective is to ensure that there is a sufficient volume of sand available to accommodate the expected erosion. Simply stating a buffer width does not guarantee that the required volumes are achieved. To do so requires that the crest level to which the sand buffer is placed is also defined.

The level of the buffer should be no lower than the foreshore area immediately behind the beach slope. In fact a slightly elevated dune would best be created where such a feature no longer naturally exists. Typically the dune crest should be 0.5m to 1.0m higher than the foreshore behind - thereby creating a swale that can intercept and disperse any shoreward flow of runoff during severe rainfall events. A typical nourishment profile is shown conceptually on Figure 6.1.

It is evident by reference to this figure that the location of the Coastal Defence Line will have a significant bearing on the volume of sand that needs to be initially placed to form the required erosion buffer. A more seaward location will require more imported sand than a more landward location - since sand already on the foreshore can be considered as being part of the required buffer.

Whilst it is acknowledged that the location of the Coastal Defence Line is a matter for Council and other stakeholders, for the purposes of illustrating and quantifying works under this Shoreline Erosion Management Plan a location along the rear of the existing foredune is adopted.

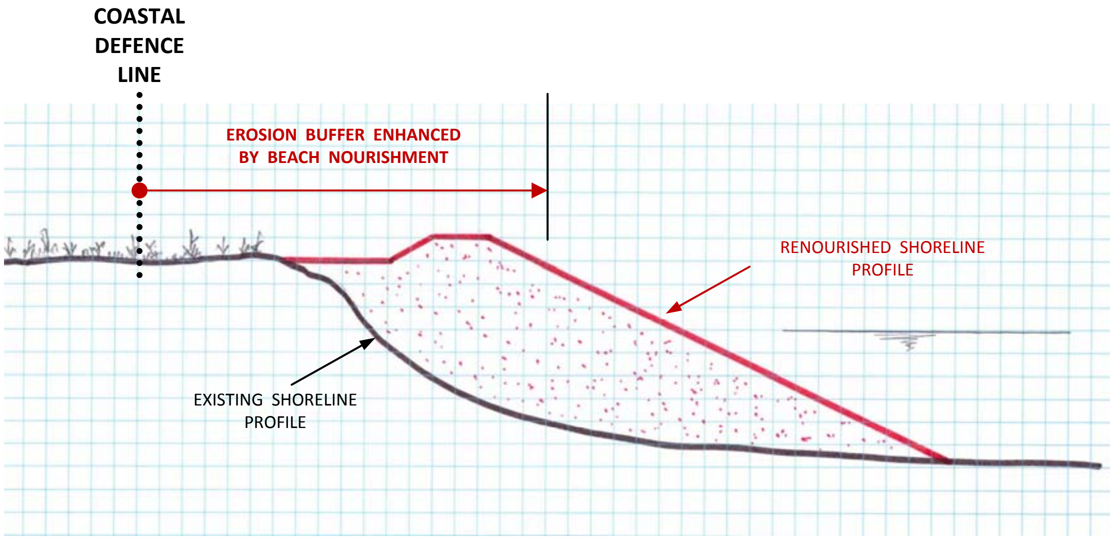

Figure 6.1 : Typical Initial Nourishment Profile

The location of the assumed Coastal Defence Line is shown in Figure 6.2. This is shown overlain on beach transect Line 2 - which is just to the south of Yates Street. The initial placement of sand to create the necessary erosion buffers seaward of this assumed Coastal Defence Line requires the volumes listed in Table 6.2.

It is interesting to note that the placement of sand to establish an erosion buffer that can accommodate a 100 year ARI event would basically be reinstating the foreshore condition that existed in June 1989 - which was just prior to construction works commencing on Nelly Bay Harbour. It was at that point in time that the natural supply of sand to the beach from Gustav Creek was obstructed and long-term erosion processes commenced.

6.1.3 Ongoing Renourishment

As discussed previously, the long-term erosion on the northern shores of Nelly Bay caused by the deficit in natural sand supply is expected to continue. This means that the erosion buffers created by the initial sand nourishment will gradually be depleted - thereby diminishing the protection that they afford.

Ongoing renourishment will therefore be required to recharge the buffers with sand. This should not be construed as a “failure” of beach nourishment, as it is typically an integral component of successful beach nourishment strategies worldwide.

Renourishment rates should at least match the net longshore transport rates along the foreshore. To the south of Yates Street the historical surveys and numerical modelling indicate that currently this renourishment rate should average around 1,000 m^3/year.

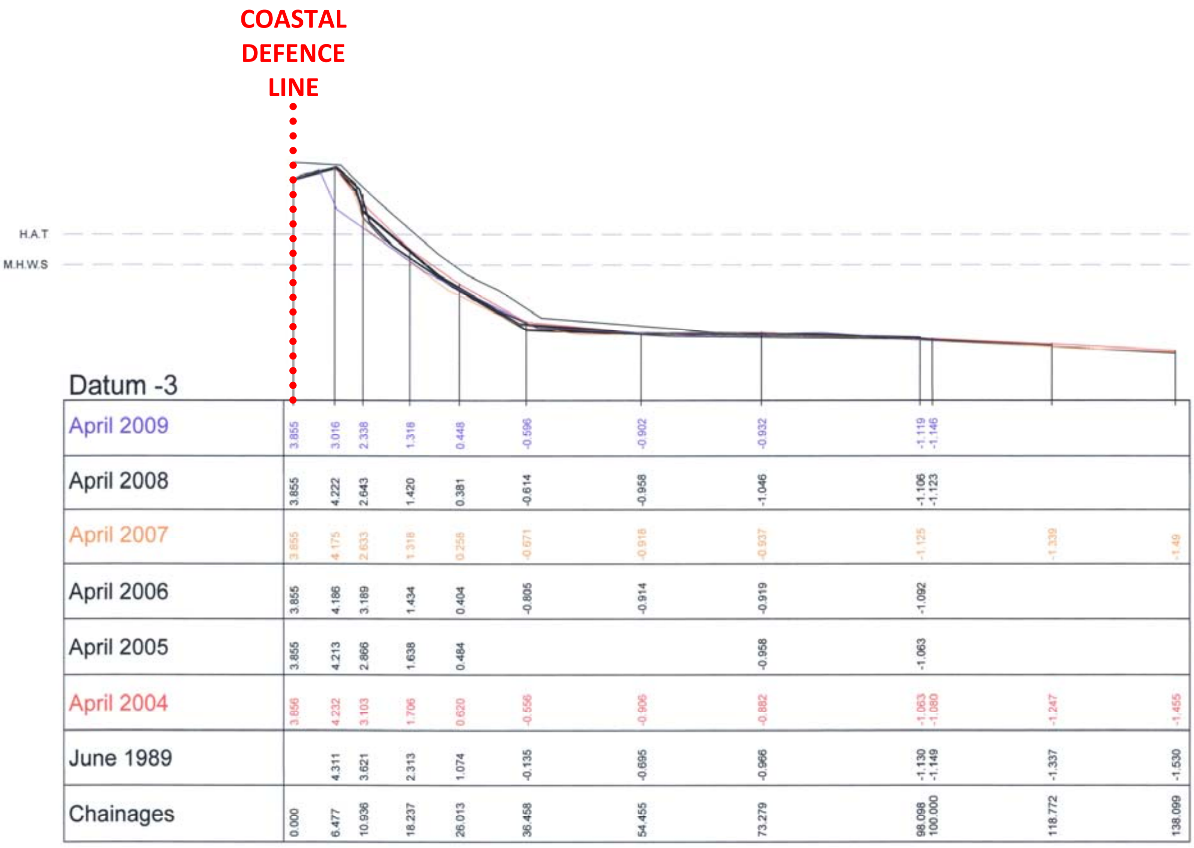

Figure 6.2 : Assumed Location of the Coastal Defence Line at Nelly Bay[9]

Foreshore Precinct	Required Buffer Volumes for Various ARI Storms				
	50 year	100 year	200 year	500 year	1000 year
Line 12	3,300m^3	3,570m^3	4,010m^3	4,370m^3	4,530m^3
Line 1	3,400m^3	3,680m^3	4,140m^3	4,500m^3	4,670m^3
Line 2	2,700m^3	2,870m^3	3,180m^3	3,430m^3	3,540m^3
Line 3	3,130m^3	3,310m^3	3,640m^3	3,920m^3	4,040m^3
Line 4	2,270m^3	2,470m^3	2,810m^3	3,130m^3	3,270m^3
subtotals	*14,800m^3*	*15,900m^3*	*17,800m^3*	*19,350m^3*	*20,050m^3*

Table 6.2 : Sand Volumes Required for Initial Beach Nourishment *(m^3)*

[9] Base survey information taken from Townsville City Council Infrastructure Services' Drawing "*Nelly Bay Beach X-Sections Kelly Street to Old Helipad*" Drawing No. SV11180/1-2-RevA; dated 08th May 2009.

Given the requirement to also ensure that erosion buffers are fully recharged prior to the likelihood of any cyclone erosion, it is recommended that the beach renourishment should be completed prior to the onset of each cyclone season. Sea turtle nesting activities commence around October each year, so it is further recommended that renourishment work be completed by the end of September so as not to interfere with this activity.

6.1.4 Estimated Costs of Beach Nourishment Activities

The costs associated with a beach nourishment option relate primarily to the initial nourishment campaign to create the necessary erosion buffers and the ongoing renourishment to recharge these buffers. Estimates of these costs are provided below.

6.1.4.1 Initial beach nourishment

As discussed previously, there are a number of aspects which determine the extent of sand to be provided to create the necessary erosion buffers. Firstly there is the degree of protection required by Council and other stakeholders (ie. what Average Recurrence Interval is to be adopted as the Design Event). Secondly there is the location of the Coastal Defence Line. The more seaward is the location, the more sand that is required to create the necessary buffer.

For the purposes of preparing cost estimates, a range of ARI events are considered. However the location of the Coastal Defence Line is assumed to be as shown earlier in Figure 6.2

The cost estimates in Table 6.3 are based on estimated unit rates for the supply of sand from the lower reaches of Gustav Creek, and its placement on Nelly Bay beach just to the south of Yates Street.

The costs associated with this initial placement will depend upon the location of the extraction point in Gustav Creek. For the purposes of preparing cost estimates, it has been assumed that this will be from the reach alongside Mango Parkway. Controlled and appropriate access across the creek banks and along Mango Parkway itself would need to be carefully considered and implemented.

ARI	Volume of Sand[10]	Estimated Cost
50 years	14,800 m^3	$237,000
100 years	15,900 m^3	$252,000
200 years	17,800 m^3	$280,000
500 years	19,350 m^3	$305,000
1,000 years	20,050 m^3	$312,000

Table 6.3 : Estimated Costs for Initial Beach Nourishment

[10] Refer to Table 6.2 for overall buffer volumes to accommodate the various ARI storms.

6.1.4.2 Ongoing renourishment

As is the case for the initial placement of sand to create the erosion buffers on Nelly Bay beach, the cost of ongoing nourishment using sand obtained from Gustav Creek will depend upon the location of the extraction point. Again it has been assumed that this will be along the reach opposite Mango Parkway.

Approximately 1,000 m^3/year will need to be extracted and placed on the Nelly Bay beach south of Yates Street to accommodate losses caused by the net southward transport of sand along this foreshore.

The cost of this ongoing renourishment is estimated to be around $25,000 / year.

6.2 Maintenance of Tidal Flow at the Breakwater Bridge

As discussed in Section 5.4.3, it is recommended that tidal flows beneath the bridge to the southern harbour breakwater be maintained through the construction of a training wall. The costs are summarised previously in Table 5.5. On the basis of sand filled geotextile bags forming the temporary training wall for a two year successful trial period, the overall capital cost would be approximately $230,000 to implement the permanent arrangement, then around $5,000 per year for maintenance.

6.3 Management of Sand Dunes

The dune system established by beach nourishment needs to be effectively managed in a manner consistent with natural processes. Appropriate management will assist in maintaining their natural ecosystem and ensure their structural integrity as erosion buffers. Dune vegetation traps wind-blown sand on foreshore dunes which might otherwise be blown inland. Therefore rather than being permanently lost from erosion buffers (and potentially creating a nuisance to road and stormwater drainage systems), such trapped sand remains within the natural beach system.

Appropriate dune management will include the planting and protection of native dune vegetation, the clearing of weeds and other noxious species from the area, and the provision of controlled access through the dunes onto the beach.

The Department of Environment and Resource Management offers valuable information and recommendations regarding the stabilisation of coastal dunes which should be applied to local foreshores enhanced by beach nourishment.

Where foredunes are naturally created by sand transport processes along the southern shores of Nelly Bay, stabilisation of these important features with primary vegetation species and controlled access is recommended

6.4 Monitoring Surveys

Once implemented, monitoring of the performance of the Shoreline Erosion Management Plan ensures that potential threats to project outcomes can be addressed in a proactive manner.

Given that a primary objective of the Shoreline Erosion Management Plan is to manage erosion along the Nelly Bay shoreline, regular surveys of this foreshore should be undertaken as part of the Plan.

Beach transect lines were established on this shoreline immediately prior to the construction of the Nelly Bay Harbour. The first cross-shore surveys were undertaken in June 1989 with others taken at various intervals since that time. Since April 2004 Council has undertaken surveys on an annual basis. It is strongly recommended that this annual survey campaign be maintained and extended as follows:

- the eight transects currently established along the foreshore (north from around the Nelly Bay Habitat Reserve) should be surveyed twice per year - at least in the first few years on beach nourishment. This should occur at the same time every year, typically in April and in November.
- the foreshore south of the Esplanade to the end of Nelly Bay beach should also be surveyed at the same time twice each year. This would entail monitoring four additional transect lines established at approximately 200 metre spacings.
- all beach transect surveys should extend well beyond the toe of the beach to ensure that the entire littoral system is captured by the survey. Typically the surveys should extend at least 200 metres offshore of the beach.
- the monitoring surveys should commence prior to implementation of any activities recommended by this Shoreline Erosion Management Plan, thereby providing a pre-project foreshore condition as a baseline reference. This initial pre-project survey of each transect line should extend across the reef flat and over the edge of the reef crest into deep water (for a minimum distance of 500 metres from the reef crest). This initial pre-project survey will therefore require a bathymetric survey component.
- Transects should be surveyed immediately following major erosion events to determine the condition of erosion buffers and their ability to accommodate another storm event.

As discussed in Section 3.4, in coming decades the Nelly Bay foreshore is likely to experience the effects of climate change - which may see gradual increases in sea level and greater volumes of sand being transported by natural processes. There remains considerable uncertainty about the scale and effect of such processes.

The monitoring of future shoreline response by a regular program of foreshore surveys therefore serves an important role in assessing the effectiveness of the recommended erosion management strategy in coming years and to guide future action.

6.5 Recommended Shoreline Erosion Management Plan

Following a review of the prevailing coastal processes, risks and values of the Nelly Bay foreshore the following activities are recommended by this Shoreline Erosion Management Plan:

Project Design and Approvals

- Townsville City Council (in consultation with other stakeholders) to select the Design Event for which the erosion mitigation strategies recommended by this Shoreline Erosion Management Plan are to accommodate. This requires consideration and acceptance of the risk that such an event will occur (or be exceeded) within a 50 year planning period. Guidance on risk is offered in Section 4.1.3 of this Shoreline Erosion Management Plan. Nominating the Design Event simply requires selecting the Average Recurrence Interval (ARI) cyclone for which immunity is required.
- Townsville City Council (in consultation with other stakeholders) to select the alignment of an appropriate Coastal Defence Line along the Nelly Bay shoreline. Throughout the 50 year planning period, property and infrastructure landward of the Coastal Defence Line remain protected from long-term erosion effects; short-term erosion caused by the Design Event; and recession as a consequence of future climate change. Foreshore areas seaward of the Coastal Defence Line lie within the active beach system (ie. within the erosion buffers).
- Undertake engineering designs for works associated with the initial beach nourishment along the Esplanade ocean frontage.
- Undertake engineering designs for works associated with the trial of a training wall alongside the breakwater bridge opposite Kelly Street; and for the initial beach nourishment to create the sand fillet in the beach/training wall corner.
- Prepare and submit appropriate approval applications based on designs for the proposed works.

Beach Nourishment

- Beach nourishment is recommended at the northern end of Nelly Bay beach. The extent of the work is shown on Figure 6.3.
- Place sand as initial nourishment on the shoreline along the Esplanade ocean frontage. The sand quantities required will depend upon the location of a Coastal Defence Line nominated by Council; and the degree of protection required (ie. the selected Design Event). Some guidance on the quantities of sand required in erosion buffers is provided in Table 6.2 of this Shoreline Erosion Management Plan.
- It is recommended that the sand for this initial nourishment be sourced from the accumulation of sand in the lower reaches of Gustav Creek.
- The location and operation of the extraction process require further considerations before implementation. This will require consideration of the findings of previous studies as well as the objectives of the *Gustav Creek Management Plan* prepared by Townsville City Council in 2005.

- Implement appropriate dune management practices on the newly nourished foreshore. As a minimum, this entails the planting and protection of native dune vegetation, the ongoing clearing of noxious weed species and ensuring adequate controlled access is maintained through new dune areas.
- Undertake ongoing beach renourishment along the Esplanade ocean frontage through the annual placement of 1,000 m^3 of sand sourced from the lower reaches of Gustav Creek. This is simply providing a mechanical means of reinstating the natural littoral supply processes that nourished Nelly Bay beach prior to the construction of Nelly Bay Harbour.
- Again the location and extraction of this renourishment sand is to be confirmed by investigations and consideration of the catchment management plan for the creek.
- Annual volumes may need to be amended in response to the results of ongoing monitoring of beach performance.

Training Works for Tidal Flows at the Breakwater Bridge

- It is recommended that a training wall for managing the flow of tidal water around the landward end of the southern breakwater of Nelly Bay Harbour be constructed. The proposed arrangement is shown conceptually on Figure 6.3. The proposed structure will also assist in retaining a stable beach along this section of foreshore.
- Implement a trial of tidal training works alongside the breakwater bridge. This is to facilitate the permanent flow of tidal waters around the landward end of the breakwater. It is to be implemented either by using sand-filled geotextile bags (requiring approximately 580 m^3 of sand to fill) or by using existing precast concrete cubes to initially construct the training wall.
- The wall should extend approximately 70m beyond the toe of the newly nourished beach; and be aligned parallel to but 30 metres to 40 metres from the toe of the southern breakwater.
- Place sand to create a stable beach orientation in a fillet of sand against the southern flank of the training wall. Approximately 1,750 m^3 is estimated as being required for this purpose. The sand for this initial creation of the fillet should be sourced from the accumulation of sand in the lower reaches of Gustav Creek. The location and operation of this sand extraction process requires further consideration before implementation.
- Implement appropriate dune management practices on the newly created sand fillet.
- Monitor the effectiveness of training works alongside the bridge, making any alterations to the length and height of the wall if appropriate. Upon successful completion of the trial, armour the temporary training wall for a more permanent arrangement. Alternatively completely remove the sand-filled geotextile bags or concrete blocks that constitute the wall, allowing sand to return to the beach system.

Project Monitoring

- Establish and undertake initial pre-project monitoring survey on approximately twelve beach transects to be located on the Nelly Bay shoreline.
- Undertake surveys twice annually on these transects, with additional surveys immediately after major erosion events.
- All surveys are to extend offshore for a minimum distance of 200m from the line of mean sea level on the beach.
- The exception to this is the initial pre-project survey which should extend at least 500 metres offshore of the seaward edge of the reef flat into deep water (ie. 500 metres seaward of the reef crest).

Figure 6.3 : Recommended Shoreline Erosion Management Strategy

6.6 Estimated Costs

The estimated costs associated with the recommended strategies under this Shoreline Erosion Management Plan are summarised below.

At this early stage these estimates must be considered as indicative only since no detailed design has been undertaken. They have been based on an approximation of sand volumes for initial beach nourishment to provide a buffer to a Coastal Defence Line on the general alignment previously shown in Figure 6.2.

SEMP component	Cost	On-going Cost
Project Design and Approvals		
Design of trial training wall at the breakwater bridge	$10,000	
Design of initial beach nourishment	$10,000	
Obtain appropriate approvals	$20,000	
Project Monitoring		
Establish & undertake initial pre-project surveys	$24,000	
Twice annual beach transect survey		$18,000
Beach Nourishment		
Implementation of initial beach nourishment :		
for 50 year ARI immunity	*$237,000*	
for 100 year ARI immunity	*$252,000*	
for 200 year ARI immunity	*$280,000*	
for 500 year ARI immunity	*$305,000*	
for 1,000 year ARI immunity	*$312,000*	
On-going renourishment with sand from Gustav Creek		$25,000
Implementation / maintenance of dune management program	$80,000	$12,000
Maintain Tidal Flow at Southern Breakwater		
Implementation of trial training wall (2 years)	$220,000	
Convert to permanent training wall	$110,000	
Maintenance of training walls		$5,000
Totals (for various initial beach nourishment options)		
for 50 year ARI immunity	**$711,000**	**$60,000**
for 100 year ARI immunity	**$726,000**	**$60,000**
for 200 year ARI immunity	**$754,000**	**$60,000**
for 500 year ARI immunity	**$779,000**	**$60,000**
for 1,000 year ARI immunity	**$786,000**	**$60,000**

7 IMPLEMENTATION OF THE STRATEGY

7.1 Approvals Process

The planning and legislative framework associated with coastal protection on Queensland's shorelines is discussed in Appendix A of this Shoreline Erosion Management Plan. The specific approvals that are likely to be required under the recommended strategies of this Shoreline Erosion Management Plan are shown below.

LEGISLATIVE / PLANNING INSTRUMENT	LIKELY	POSSIBLE	UNLIKELY
State Coastal Management Plan	✓		
Great Barrier Reef Marine Park Act 1975	✓		
Queensland Marine Parks Act 2004	✓		
Queensland Environmental Protection Act 1994	✓		
Sustainable Planning Act 1997	✓		
Townsville Planning Scheme	✓		
Aboriginal Cultural Heritage Act 2003		✓	
Nature Conservation Act 1992	✓		
Fisheries Act 1994	✓		
Vegetation Management Act 1999		✓	
Local Government Act 1993		✓	
Environmental Protection and Biodiversity Conservation Act 1999	✓		
Land Act 1994	✓		

7.2 Implementation Plan

As noted in Section 6, the recommended future management of the Nelly Bay shoreline incorporates Beach Nourishment.

The implementation of the Beach Nourishment strategy can be tailored to suit available funding. Ideally the initial nourishment to provide the erosion buffers necessary to provide immunity for the Design Event would be undertaken in a single campaign as soon as possible.

However a staged approach whereby the buffers are created over a number of (possibly annual) nourishment campaigns might offer a more financially viable implementation. Under such an approach, the annual renourishment requirement of 1,000 m^3/year would need to be included in the volumes of each progressive sand placement.

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APPENDIX A

- **PLANNING & LEGISLATIVE FRAMEWORK**

A. PLANNING AND LEGISLATIVE FRAMEWORK

To ensure that the proposed management options are consistent with planning and legislative requirements of Commonwealth, State and Local governments it is necessary to have appropriate regard for the full range of legislation that controls activities in the coastal zone.

Local, state and federal governments all have a vested interest in the management of Magnetic Island and its surrounding areas. The island is a suburb of the City of Townville, and as such is managed under Townsville City Council municipal laws and regulations. More than half of the island is National Park under the stewardship of the Queensland State Government. Magnetic Island is also listed as a World Heritage area – protected by the Commonwealth.

This appendix of the Shoreline Erosion Management Plan outlines the relevant planning and legislative framework that will influence the development, assessment and implementation of appropriate erosion mitigation measures on the Nelly Bay shoreline. The specific requirements for the recommended strategy developed by this Shoreline Erosion Management Plan are discussed in Section 7 relating to the implementation of that strategy.

A.1 Queensland Coastal Legislation and Planning Instruments

The Queensland Government has developed a coastal management framework which includes specific legislation, policies and support tools to direct sustainable planning, development and management decisions. The *Coastal Protection and Management Act 1995 (Qld)* (hereafter referred to as, the Coastal Act) provides a comprehensive framework for the coordinated management of a diverse range of coastal resources and values in the coastal zone.

Fundamental tools to implement the Coastal Act are the State Coastal Management Plan and regional coastal management plans. The *Coastal Protection and Management Act 1995 (Qld)* provides for the appropriate management of Queensland's coastal zone. The Act recognises the diverse range of resources and values of:

"coastal waters and all foreshore areas in which there are physical features, ecological or natural processes or human activities that affect, or potentially affect, the coast or coastal resources."[11]

[11] s3 Coastal Protection and Management Act 1995 (Qld)

In 2001 the State Coastal Management Plan was developed in accordance with the requirements of the Coastal Act and serves as a statutory instrument under that Act.

A.1.1 State Coastal Management Plan

The *State Coastal Management Plan* was reviewed in 2009 and at the time of preparing this Shoreline Erosion Management Plan, that review has been completed and a *Draft State Coastal Management Plan* is currently in the public domain for review and comment. Until such time as the public review and subsequent drafting of a new Queensland Coastal Plan is completed, the existing State Coastal Management Plan remains in force. Once the new Queensland Coastal Plan has been finalised and approved, the current State Coastal Management Plan will be repealed.

This Shoreline Erosion Management Plan will provide strategic direction for the sustainable management of the Nelly Bay shoreline, and ensure shoreline protection management actions are consistent with the State Coastal Management Plan. A 50 year planning horizon is applied to such considerations.

In particular, the Shoreline Erosion Management Plan will provide a non-statutory shoreline erosion management strategy that will detail the existing and likely future sediment transport processes, erosion trends and geomorphological processes. It will describe and compare management options for coastal erosion - in terms of environmental sustainability, community priorities and cost effectiveness.

Queensland's State Coastal Management Plan (SCMP) aims to protect and manage the state's coastal resources and values by providing an overarching framework for coastal management. It is founded on the following ten management topics:

- coastal use and development
- physical coastal processes
- public access to the coast
- water quality
- indigenous traditional owner cultural resources
- cultural heritage
- coastal landscapes
- conserving nature
- coordinated management
- research and information

Specific principles and policies have been developed within each of these issues so as to achieve defined coastal management outcomes. These topics are considered by the Shoreline Erosion Management Plan for Nelly Bay when assessing appropriate erosion management options.

The State Coastal Management Plan provides five policies under the topic *"Physical Coastal Processes"* that relate to the management of coastal erosion. These being:

Policy 2.2.1 Adaptation to climate change;
Policy 2.2.2 Erosion prone areas;
Policy 2.2.3 Shoreline erosion management;

Policy 2.2.4 Coastal hazards; and
Policy 2.2.5 Beach protection structures.

Comment on these policies and their relevance to the preparation of this Shoreline Erosion Management Plan are offered below.

A.1.1.1 Policy 2.2.1 Adaptation to climate change

Consideration must be given to the local implications of possible future climate change, including sea level rise and increased climatic variability. When developing the Shoreline Erosion Management Plan for Nelly Bay a hierarchical approach must be applied as follows:

- *Avoid* - to focus on locating new development in areas not vulnerable to the impacts of climate change;
- *Planned retreat* - to focus on systematic abandonment of land, structures and ecosystems in vulnerable areas;
- *Accommodate* - to focus on continued occupation of coastal areas but with adjustments such as altered building design;
- *Protect* - to focus on the defence of vulnerable areas, population centres, economic activities and coastal resources.

When assessing potential erosion mitigation options for the Nelly Bay foreshore this ranking of preferred approaches to future climate change is applied.

A.1.1.2 Policy 2.2.2 Erosion prone areas

Under this policy the State Coastal Management Plan recognises the important role of erosion prone areas as natural coastal buffers. Wherever practical, erosion prone areas are to remain undeveloped - except for temporary or relocatable structures.

In areas that have already been developed and are now in designated erosion prone areas, future use should not be at a scale or intensity greater than the existing development. Nor should such future development extend further seaward than the current alignment of buildings or services.

Retreat from the erosion prone area is the preferred strategy, but it is acknowledged that coastal protection works may be necessary to defend existing land uses and infrastructure. In such circumstances intervention by way of physical barriers (such as seawalls) should only be considered as a last resort where the threat to public safety or property is immediate and the infrastructure is not expendable. Coastal defence works are not to adversely affect coastal processes and environmental values.

Where erosion mitigation measures are required, the State Coastal Management Plan specifies the following hierarchy of actions (in order of decreasing preference):

- Remove, relocate or resume development from the threatened location; or
- Undertake beach nourishment to increase the width of the erosion buffer; or
- Push sand up from the intertidal zone onto the beach so as to provide short-term protection from erosion influences, provided such work will have only minor and temporary impacts on intertidal ecology; or

- Construct groynes or offshore breakwaters to impede longshore sand transport and increase the accumulation of sand on the eroding coast - subject to acceptable impacts on downdrift shoreline; or
- Construct a revetment / seawall as a physical barrier to permanently stop erosion and protect development; provided that such works are located as far landward as possible so as not to isolate important sand reserves from the active beach system - again subject to acceptable impacts on downdrift shoreline.

When assessing potential erosion mitigation options for the Nelly Bay foreshore this ranking of preferred measures is applied.

A.1.1.3 Policy 2.2.3 Shoreline erosion management

Areas that are to be considered as priorities for erosion management must be taken into account when considering:

- applications for renewal or conversion of leases for leasehold land on the coast;
- issuing approvals for coastal protection works; and
- assessing proposals for funding proposals for coastal management programs.

A.1.1.4 Policy 2.2.4 Coastal hazards

Coastal hazards on the Nelly Bay foreshore not only include the threat of erosion but also damage and inundation by storm tides. Under the State Coastal Management Plan wherever possible areas identified as being at risk of coastal hazards should remain undeveloped. In developed areas that are vulnerable to coastal hazards, further development must address vulnerability to storm tide inundation - including protection of evacuation routes.

Areas within the Nelly Bay coastal precinct that are vulnerable to storm tide effects have been identified in the *Townsville - Thuringowa Storm Tide Study* (GHD, 2007). Appropriate erosion mitigation options in these inundation prone areas will be considered when preparing this Shoreline Erosion Management Plan.

A.1.1.5 Policy 2.2.5 Beach protection structures

The State Coastal Management Plan states under this policy that the construction of beach protection structures (such as seawalls) will only be approved where:

- there is a demonstrated need in the public interest; and
- comprehensive investigation has been carried out and it can be demonstrated that:
    - there would not be any significant adverse impact on longshore transport of sediments; and
    - there would be no increase in coastal hazards for neighbouring foreshores.

A.1.2 Regional Coastal Management Plan

A requirement under Section 2.2.3 of the State Coastal Management Plan is that *Regional Coastal Management Plans* (RCMP) identify any priority areas for erosion management. Regional plans are required to be consistent with and/or set more detailed requirements compared with the State Coastal Management Plan (SCMP). RCMP's implement the SCMP at the regional level and also identify key coastal sites at the regional level that require specific management interventions.

The SCMP identifies eleven coastal regions in Queensland. The Nelly Bay shoreline is included in Dry Tropical Coast Region. However work on the preparation of a RCMP for this area has halted whilst the review of the SCMP has been underway. However it is now understood that the regional plan will no longer be prepared (Queensland Department for Premier and Cabinet, 2009; Webbe & Weller, 2009).

A.2 Great Barrier Reef Marine Park Act

The Great Barrier Reef Marine Park Act 1975 is the primary Act in respect of the Great Barrier Reef Marine Park. It includes provisions which:

- Establish the Great Barrier Reef Marine Park itself;
- Establish the Great Barrier Reef Marine Park Authority (GBRMPA), a Commonwealth authority responsible for the management of the Marine Park;
- Provide a framework for planning and management of the Marine Park, including through zoning plans, plans of management and a system of permissions ;
- Prohibit mining operations (which includes prospecting or exploration for, as well as recovery of, minerals) in the Great Barrier Reef Region (unless authorised to carry out the operations by a permission granted under the Regulations, for the purpose of research or investigations relevant to the conservation of the Marine Park);
- Require compulsory pilotage for certain ships in prescribed areas of the Great Barrier Reef Region;
- Provide for regulations, collection of Environmental Management Charge, enforcement etc.

As a consequence of the findings of a review of the Act in 2006, amendments to the Act were made by the Australian Government in 2008, which came into force in two stages in 2008 and 2009. The purpose of the amendments was to update the Act, and better integrate it with other legislation in order to provide an effective framework for the protection and management of the Marine Park.

Within the study area of this Shoreline Erosion Management Plan, the Park's landward boundary is along the low water mark. Mean low water mark at the Nelly Bay Harbour is defined as RL-0.696m (to AHD)[12].

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[12] Definitions p3. Marine Parks Permit No G03/2321.1 for Nelly Bay Harbour; issued on 01st July 2003 under the then current Great Barrier Reef Marine Park Regulations 1983 (Commonwealth) and Marine Parks Regulations 1990 (Queensland).

Zoning plans prepared in accordance with the *Great Barrier Reef Marine Park Act* define activities that may be undertaken within specific zones. In the vicinity of Nelly Bay the adjoining area of the Park is predominantly Habitat Protection (Dark Blue) Zone.

When assessing erosion management strategies for this Shoreline Erosion Management Plan, the permissible activities within this zone must be taken into account. Consideration of other zones in the Park may be required if sand sourcing or other activities associated with erosion mitigation for Nelly Bay are undertaken within those zones.

A permit for certain activities within the Park is required under the Act and its regulations; *Great Barrier Reef Marine Park Regulations 1983* and the *Great Barrier Reef Marine Park Zoning Plan 2003*.

A.3 Queensland Marine Parks Act

In Queensland, the State's main legislation and regulation pertaining to marine parks are the *Marine Parks Act 2004 (Act)* and the *Marine Parks Regulation 2006 (Regulation)*. These are designed to complement the Commonwealth's *Great Barrier Reef Marine Park Act 1975*, indeed the zoning plan for the State Marine Park is the same as the zoning plan for the Great Barrier Reef Marine Park.

The *Marine Parks (Great Barrier Reef Coast) Zoning Plan 2004 (Zoning Plan)* defines the zoning arrangements, including the objectives for each zone, the allowable and prohibited activities, and those that require a marine park permit.

Whereas the landward boundary of the Great Barrier Reef Marine Park is low water mark, the landward boundary of the State Marine Park is the high water mark. The Department of Environment and Resource Management defines high water as:

"…high water means the mean height of the highest high water at spring tide." [13]

When considering erosion mitigation strategies for this Shoreline Erosion Management Plan, it is likely that any works or activities below the high water line (and therefore within the State Marine Park) will require approval under the State *Marine Parks Act 2004*.

A.4 Queensland Environmental Protection Act

The primary objective of the *Environmental Protection Act 1994* is to safeguard Queensland's natural environment whilst allowing for development in an ecologically sustainable manner. It is administered by the Department of Environment and Resource Management.

[13] Marine Parks (Great Barrier Reef Coast) Zoning Plan 2004 "*Schedule 11 Dictionary*" p 132.

The Act establishes a general environmental duty that requires any erosion mitigation works on foreshores to be undertaken such that all reasonable and practical steps are taken to prevent or minimise environmental harm.

Environmentally relevant activities (ERAs) are authorised by an administering authority. Schedule 2 of the *Environmental Protection Regulation 2008* lists all ERAs. Included in that schedule are "Extractive and screening activities" of which ERA 16 (relating to extracting material from the bed of any State waters) may be relevant to strategies developed by the Shoreline Erosion Management Plan.

Specific environmental protection policies (EPPs) currently exist and others may be prepared under the Act to protect or enhance the environment. The EPP most relevant to considerations of erosion mitigation measures under this Shoreline Erosion Management Plan is the *Environmental Protection (Water) Policy 2009*.

The intent of this policy is to achieve ecologically sustainable development with regard to Queensland waters - including those of coastal ecosystems. It provides a framework for appropriate management of environmental impacts by identifying environmental values and presents guidelines to protect and maintain the State's water environment.

A.5 Sustainable Planning Act

New planning and development laws recently came into effect in Queensland with *the Sustainable Planning Act 2009* replacing the *Integrated Planning Act 1997*. This new legislation seeks to achieve sustainable planning outcomes through:

- managing the process by which development takes place;
- managing the effects of development on the environment;
- continuing the coordination and integration of local, regional and state planning.

Development approval of foreshore protection works may be required under the Integrated Development Assessment System (IDAS). Specifically the instruments may include but not be limited to:

- *Coastal Protection and Management Act*
- *Fisheries Act*
- State Planning Policy 2/02 (SPP 2/02) - *Planning and Managing Development Involving Acid Sulfate Soils*.
- *Vegetation Management Act 1999*.

A.6 Townsville City Plan 2005

The *Townsville City Plan* aims to implement the vision for the City to achieve ecologically sustainable development. It provides a robust, responsive and transparent environment for simplified development assessment reflecting the aspirations of the local community.

At the time of preparing this Shoreline Erosion Management Plan, a new planning scheme for the entire local government area is in the process of being created. This will be in line with information provided by Queensland's Department of Infrastructure and Planning on how new planning schemes are to be formatted and what they are to include. Areas that have been identified by Council as needing to be addressed include climate change and impacts of natural hazards - and in particular how they relate to existing coastal communities, infrastructure and future development in coastal areas.

Until such time as that new scheme is finalised, the current planning scheme remains in force.

The erosion mitigation strategies recommended in this Shoreline Erosion Management Plan will need to be appropriately designed during subsequent implementation phases to ensure that the proposed works comply with the relevant assessment criteria in the Specific Outcomes of relevant codes.

A.7 Land Act

The Land Act applies to all land in Queensland - including that below high-water mark. Its administration requires that land to which this Act applies must be managed for the benefit of the people of Queensland by having regard to the following principles:

- Sustainability - Requires sustainable resource use and development so as to ensure that existing needs are met, and the State's resources are conserved for the benefit of future generations.
- Evaluation - Requires that land evaluation is based on the appraisal of land capability and the consideration and balancing of the different economic, environmental, cultural and social opportunities and values of the land.
- Development - Requires allocation of land for development in the context of the State's planning framework, and applying contemporary best practice in design and land management. When land is made available for development, it is allocated to persons who will facilitate its most appropriate use; and that use supports the economic, social and physical wellbeing of the people of Queensland.
- Community purpose - If land is needed for community purposes, the retention of such land is to be in a way that protects and facilitates the community purpose.
- Protection - Requires the protection of environmentally and culturally valuable and sensitive areas and features.
- Consultation - Requires consultation with community groups, industry associations and authorities as an important part of any decision making process.
- Administration - Requires that administration of the Act is consistent, impartial, efficient, open and accountable. A market approach is applied in land dealings, adjusted when appropriate for any community benefits arising from the dealing.

Erosion mitigation measures proposed by this Shoreline Erosion Management Plan on Unallocated State Land and other State Land will require a resource entitlement permit where there are direct implications (such as sand extraction activities) or indirect implications (e.g. impact on access). These provisions are also covered through the IDAS process.

A.8 Indigenous Cultural Heritage Act

Legislation exists under a number of Commonwealth and State Acts to protect Aboriginal and Torres Strait Islander cultural heritage. To ensure compliance with the *Aboriginal Cultural Heritage Act 2003*, when implementing erosion mitigation works Council must take all reasonable and practical measures to ensure that such works do not harm Aboriginal cultural heritage. This may include:

- following the statutory "duty of care" guidelines, which may require consultation with the relevant Aboriginal party; or
- development and approval of a Cultural Heritage Management Plan.
- The State's *Native Title (Queensland) Act 1993* and the Commonwealth's *Native Title Act 1993* should both be considered when planning foreshore protection works.

A.9 Nature Conservation Act

The *Nature Conservation Act 1992* maintains biological diversity and ecologically sustainable development within areas established and managed under the Act. The Regulations under the Act that are of relevance to the Shoreline Erosion Management Plan are as follows:

- *Nature Conservation (Protected Areas) Regulation 1994* : which nominates declared protected areas such as National Parks and conservation parks - such as the Townsville Town Common Conservation Park which is in the study area covered by this Shoreline Erosion Management Plan;
- *Nature Conservation (Wildlife) Regulation 2006* : which identifies management intent and principles associated with certain significant species. It is read in conjunction with:
- Nature Conservation (Administration) Regulation 2006.

Any disturbance of areas so as to provide access for implementing erosion mitigation works will require assessment as to whether the area is an "essential habitat" for fauna species listed under the Act. For example, such species may include nesting habitats for listed sea turtle species if these are found to be in the area.

A.10 Fisheries Act

The *Fisheries Act 1994* provides for the management, use, development and protection of fisheries resources and fish habitats throughout Queensland. Approvals are required for marine plant disturbance, works in a declared fish habitat area or constructing or raising a waterway barrier.

Mangroves & Marine Plants

Tidal inundation of a coastal area generally indicates the presence of marine plants on a site protected under Section 8 of the *Fisheries Act 1994*. The definition of the term Marine Plant includes the following:

- A plant (a tidal plant) that usually grows on, or adjacent to, tidal land, whether it is living, dead, standing, or fallen. Material of a tidal plant, or other plant material on tidal land.

- A plant, or material of a plant, prescribed under a regulation or management plan to be a marine plant.

Areas within and adjoining the area covered by this Shoreline Erosion Management Plan contain vegetation that are protected in accordance with Section 123 of the *Fisheries Act*; and as such any disturbance (trimming or removal) to these areas would require approval from the Department of Employment, Economic Development and Innovation (DEEDI).

Limited removal or trimming works on mangroves and associated marine plants may be undertaken for maintenance works on existing lawful structures or works on farm drains as per Marine Plant Code 02 and 03. However, any removal or trimming required for new construction works directly related to a development will require a development approval.

Any activities associated with the implementation of the Shoreline Erosion Management Plan that may require the removal or harm to marine plants will require an approval from the DEEDI.

A.11 Local Government Act

The high water mark is the seaward extent of Townsville City Council's jurisdiction under the *Local Government Act 2009*. Nevertheless the Act enables local government authorities to obtain specific jurisdiction from the State with regard to the beach between the high and low water lines for special purposes - typically for beach nourishment.

Local government authorities control land use and activities under the local planning scheme (via the *Sustainable Planning Act 2009*) and Local Laws (via the *Local Government Act 2009*).

With regard to coastal management, local government has responsibilities relating to:

- land use control;
- recreational planning;
- management of local reserves;
- environmental protection and rehabilitation;
- monitoring.

A.12 Vegetation Management Act

The purpose of the *Vegetation Management Act* 1999 (VMA) is to regulate clearing of remnant vegetation on freehold and leasehold land by:

- Preserving remnant endangered, of concern and not of concern Regional Ecosystems and vegetation in areas of high nature conservation value; and

- Considering the preservation of vegetation in areas vulnerable to land degradation.

The definition of the term *Vegetation* under the Act includes the following:

- Native tree; or
- Native plant, other than a grass or mangrove.

Since the remnant vegetation identified within the study area of the Shoreline Erosion Management Plan comprises marine plants and tidal grasses it is not consistent with the definition of vegetation under the Act. Consequently no approvals are likely to be required under the VMA.

A.13 Environment Protection and Biodiversity Conservation Act

The Commonwealth Department of the Environment, Water, Heritage and Arts administers the *Environment Protection and Biodiversity Conservation Act 1999.* Referral to the Department is required for actions that have (or are likely to have) a significant impact on a matter of national environmental significance.

These include;

- World Heritage properties
- National Heritage places
- Wetlands of international importance
- Migratory species
- Nationally threatened species and ecological communities
- The Commonwealth marine area
- Nuclear matters.

The issues potentially relevant to activities prescribed by the Shoreline Erosion Management Plan include the world and national heritage values of the Great Barrier Reef World Heritage Area; migratory species such as bird species listed under international agreements (JAMBA and CAMBA); and nationally threatened species and ecological communities.

If erosion mitigation works recommended by this Shoreline Erosion Management Plan are declared a "*controlled action*", approval will be required under the Act before works can commence. The Commonwealth and Queensland governments have a bilateral agreement under the Act that controlled actions requiring environmental impact assessment (EIA) may be assessed in accordance to the EIA processes under Queensland law.

Appendix B

- **ASSESSMENT OF THE LOCAL MARINE ENVIRONMENT BY C&R CONSULTING**

Nelly Bay

The marine environment of Nelly Bay is characterised by an extensive fringing reef, consisting of an inner sedimentary accumulation zone and a typical reef flat habitat. The distance between the reef crest and the beginning of the inner sedimentary accumulation zone ranges from approximately 200m to 400m. The seagrasses *Halodule uninervis* and *Halophila ovalis* dominate the benthic biota in the sedimentary accumulation zone, with macroalgae restricted to banks of rubble and dead microatolls interspersed within the zone. On the reef flat proper, the community structure is dominated by fleshy macroalgae such as *Sargassum* spp. (Morrissey 1980; Mapstone et al. 1989; Vuki & Price 1994). Coral cover is higher on the reef slope than on the reef flat, *Montipora* and *Turbinaria* spp. being the most abundant and widespread coral genera (Mapstone et al. 1989). The distribution of macroalgae and corals on reef flats and reef slopes in Nelly Bay has previously been documented in a baseline study conducted in response to a proposed development in Nelly Bay (Mapstone et al. 1989). Detailed physical and biological information exists for Geoffrey Bay, Magnetic Island (Morrissey 1980). Nelly Bay is subject to similar physical conditions, as it has a similar orientation and terrestrial geological features. Five distinct reef zones have been recognized (Lewis 1999, Table 1).

Table 1: Categorisation of substratum zones (from Lewis 1999). See also Figure 1

Zone	Characteristics
Inner Reef Flat	Initially more than 60% sand cover, contains some rubble and flat-topped dead micro-atolls. Towards the outer edge of the zone, rubble cover increases to almost 100% and contains some large rocks and some live massive corals (mostly *Goniastrea* spp.)
Middle Reef Flat	Alternating dominance of rubble and rock. Many rocks recognizable as dead corals. Rocks are large boulders overgrown with dense stands of *Sargassum* spp. Colonies of *Goniastrea* spp. are larger and more abundant.
Outer Reef Flat	Over 60% dead coral or rock. Most dead coral maintains original form to some degree and indicates large previous stands of foliaceous *Montipora* spp. Heavy overgrowth of *Sargassum* spp. in the summer months, *Lobophora* spp. more prevalent in winter months.
Crest	High live coral cover. Almost no rubble. Some dense stands of *Sargassum* spp. The crest structure in broken up by large outcrops.
Slope	High live coral cover. Occasional gullies of sand and rubble breaking up the reef framework. Benthos dominated by *Padina* and *Lobophora* spp. Towards the base the reef framework begins to break up, giving way to soft sediment communities including soft, fungid and gorgonian corals.

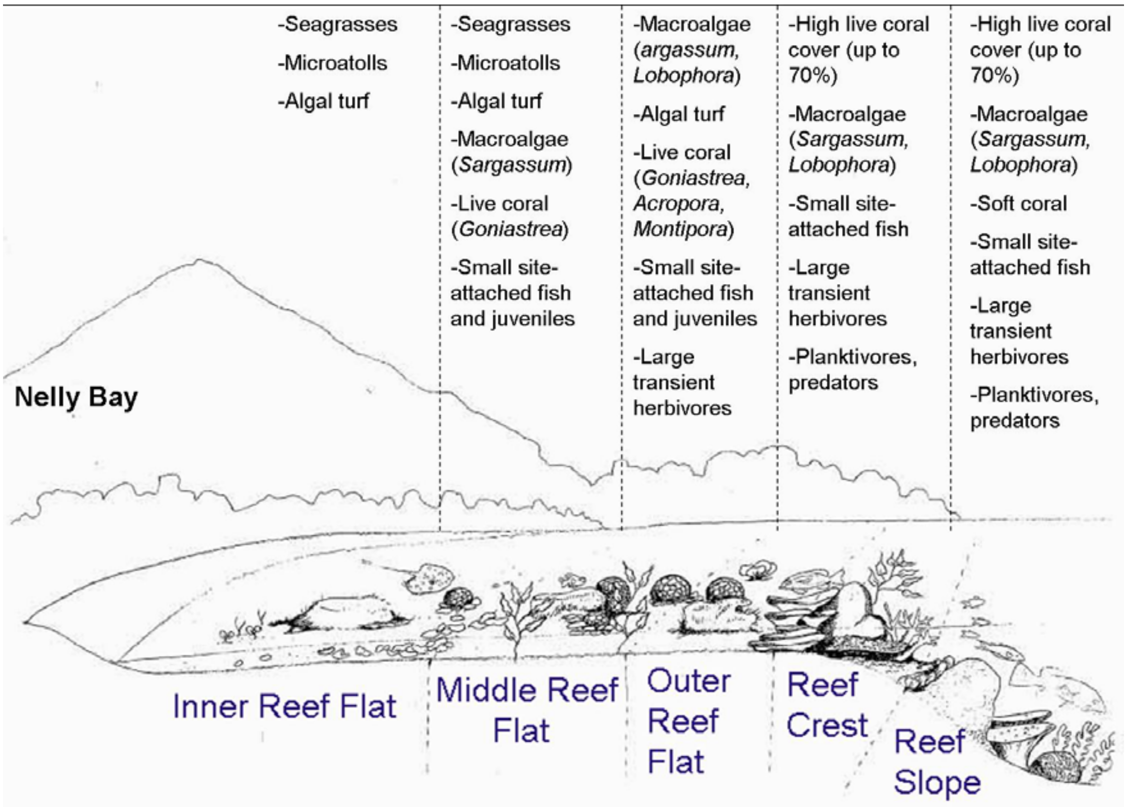

Figure 1. Schematic diagram of the zonation of marine communities across Nelly Bay. Not to scale.

Benthic biota

Benthic community structure is organized along a clear zonation pattern. Most surfaces on the inner reef flat are covered by thin turf and macroalgae. The cover of thin turf declines across the reef as other organisms became more abundant. Fleshy macroalgae increases in cover across the reef flat, occupying ~30% of the available space on the inner reef flat and reaching ~70% cover on the outer reef flat. The decline in macroalgal cover on the crest and slope is concurrent with the higher live coral cover in these zones. Live coral is present in very low abundance on the reef flat, but covers ~ 40% of the reef crest, and 30% of the reef slope.

Of the five most common algal genera, *Sargassum* spp. clearly dominates every reef zone. It increases significantly with increasing distance from the shore, before eventually declining on the crest and slope. *Lobophora* and *Colpomenia* are less abundant but also follow this trajectory. *Padina* and *Dictyota pardalis* are most abundant on the inner reef flat and decline to very low cover on the reef crest and slope (Phillips & Price 1997). There is a strong seasonal pulse was found in the cover of *Sargassum* spp., which blooms in summer and dies off in winter. The blooms are more pronounced on the mid and outer reef flat than in other zones. A sparse seagrass bed composed primarily of *Halophila* *ovalis* and *Halodule uninervis* occupies the intertidal sandflat of the northern end of the bay. A recent seagrass survey of Cleveland Bay and Magnetic Island documented a meadow of thin *Halodule uninervis* on the Nelly Bay reef flat (Figure 2). They measured approximately 9.5 hectares of patchy seagrass at an average biomass of 4.1gDWm^{-2} (Taylor & Rasheed 2008).

The coral community beyond the zones of high macroalgal cover in Nelly Bay is adapted to conditions of both high exposure to south-easterly trade winds and high water turbidity. The community is dominated by fast-growing foliaceous species (*Montipora* and *Turbinaria* spp.) that recover rapidly after disturbance (Ayling & Ayling 2005). Research has shown that individual species can adapt to turbid conditions by increasing ingestion and assimilation rates of food particles, as opposed to relying on photosynthetic products of zooxanthellae (Anthony 2000). This may be one of the key factors in the high resilience documented in Nelly Bay, with coral cover plummeting after disturbances such as cyclones and bleaching evens, and subsequently recovering to previous levels (Ayling & Ayling 2005).

Fauna inhabiting Nelly Bay includes soft-bottom and coral reef invertebrates, fish and reptiles. Benthic invertebrate communities vary according to the primary habitat. Soft-sediment habitats support abundant worms and gastropods, while rubble and seagrass areas provide habitat for a wider range of taxa, including crustaceans and cephalopods. Echinoderms such as starfish and sea cucumbers are found throughout all habitats. The herbivorous sea urchins *Diadema* can be found among the more consolidated rubble zones just inside the reef crest.

The fish community in Nelly Bay is typical of inshore coral reefs. The full complement of functional groups is represented, including planktivores, territorial and roving herbivores, benthic invertebrate feeders and predators. The abundance of predators such as sharks, coral trout, snappers and emperors is likely to be reduced because Nelly Bay is open to fishing and is subject to baited drumlines under Queensland's Shark Control Program.

Green turtles (*Chelonia mydas*) are frequently observed by divers in Nelly Bay, and nest annually on the Nelly Bay beach (Magnetic Times 2002; 2007). Endangered flatback turtles have also been recorded to nest in Nelly Bay. Unfortunately this brings them in close contact with traffic, but several successful hatchings have been recorded. Since 2002, the turtles have nested primarily at the southern end of the bay, but 2008 a 'bumper year' for turtle nesting was recorded (QPWS, pers. comm.). Nesting locations were spread more broadly across the bay (Figure 3), indicating that the entire Nelly Bay beach most probably provides nesting habitat.

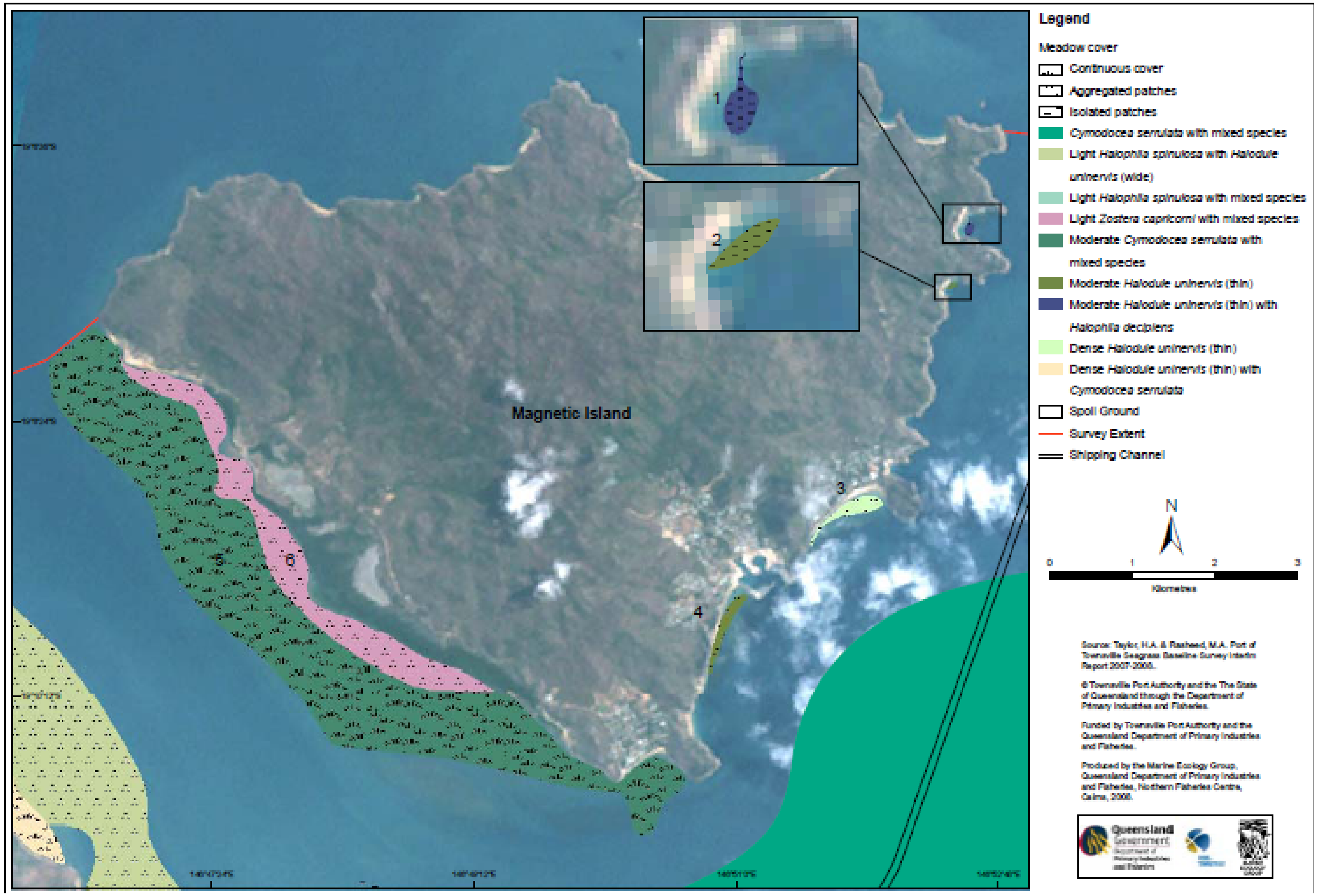

Figure 2. Map of seagrass meadows recorded around Magnetic Island in 2007-2008. Nelly Bay is identified as the number ‘4’. From Taylor and Rasheed (2008).

Figure 3. Turtle nesting sites recorded in Nelly Bay in 2008.

Estuarine crocodiles transit through the Cleveland Bay area on an irregular basis (QPWS 2007). Nelly Bay is not considered a regular habitat for crocodiles, and they have never been recorded as using Nelly Bay beach as a haul-out site. However, crocodiles have been observed periodically in waters around Magnetic Island (Bateman 2008).

Figure 4. Turtle nesting in Nelly Bay in 2008. From left to right: Turtle digging nesting pit; laying eggs, and the QPWS barricade erected around the nest near The X Base Backpackers Hostel at the southern end of the beach. Images supplied by QPWS.

Potential impacts of proposed mitigating devices – seawalls, groynes, beach replenishment

Seawalls and groynes – Constructing seawalls and groynes to capture longshore sand drift is unlikely to cause widespread ecological damage. While some studies exist on the sediment and fauna characteristics around established structures, no data exist for the immediate impact of constructing the structures and how these effects may change over time (Walker et al. 2008). Seawalls and groynes built perpendicular to the beach will cause accumulation on one side and some erosion on the other. Localised burial of nearshore seagrasses, macroalgae and infauna may result through the accumulation of sediment, and the structure is likely to cause changes in the benthic communities within a localised area (Walker et al. 2008). Localised burial of nearshore seagrasses, macroalgae and infauna may result through the accumulation of sediment. Given the low incidence of turtle nesting on this beach, seawalls and groynes are unlikely to have a large impact on nesting turtles. The expected footprint of sediment accumulation is likely to be small and therefore should not significantly affect food resources (seagrasses) of dugongs and turtles.

Beach replenishment – Widespread burial of nearshore benthic invertebrates and increased turbidity of shallow water is likely to result from beach replenishment. Construction equipment can crush beach invertebrates and disturb nesting turtles. The extent of this damage depends on the extent of the beach to be replenished. However, replenishment will need to be repeated periodically, as its benefits are temporary. The ability of the affected nearshore benthic communities to return to their pre-impact state is unknown.

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Appendix C

- **ASSESSMENT OF THE LOCAL TERRESTRIAL ENVIRONMENT BY C&R CONSULTING**

Nelly Bay

The most populated bay on Magnetic Island (MICDA 2004), Nelly Bay contains a large residential population, a retail precinct and several major tourism developments concentrated in the northern end of the bay. Contemporary development is centred around a large harbour and marina including ferry and barge terminals and an emergency services helipad (GBRMPA, 1999). The majority of development has occurred on the alluvial plain and on coastal dune systems. Remnant vegetation remaining within the coastal environment of Nelly Bay, which for the purposes of this study consists of Land Zone 2, 3 and 12 and the foreshore immediately south of the marina to the rocky headland between Nelly Bay and Picnic Bay, comprises five Regional Ecosystems (Table 1), three of which are listed as 'of concern' under the *Vegetation Management Act 1999* (DERM 2009a). The geomorphic zonations within Land Zones 2 and 3 include coastal dunes and beach ridges, sand plains, swales and wetlands and alluvial systems. Small areas of rocky lowlands, hills and outcrops also occur (Land Zone 12). These areas affect the distribution and successional status of vegetation across the undeveloped areas of Nelly Bay. For the purpose of the terrestrial assessment, the area originally delineated for investigation has been expanded to include terrestrial environments which may potentially be influenced by coastal erosion processes (Figure 1). This area includes Rocky Bay.

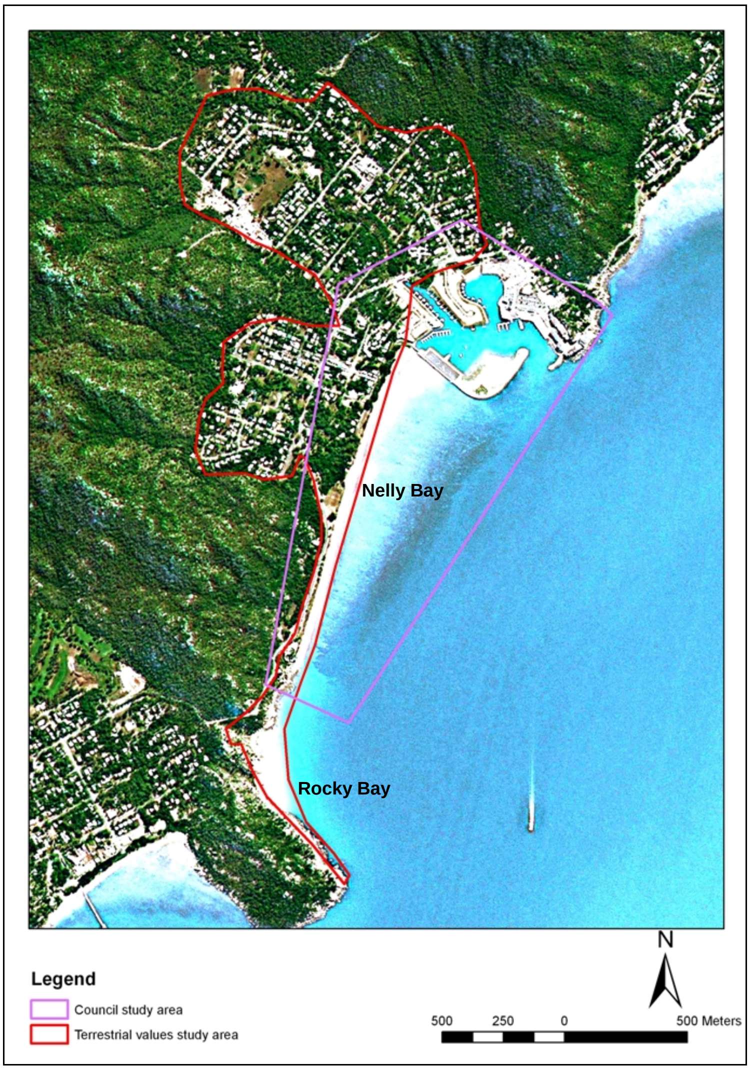

Figure 1: Nelly Bay terrestrial values study area, overlaid onto original Nelly Bay study area plan.

The foreshore of Nelly Bay extends almost one and a half kilometres along the south-eastern side of Magnetic Island. The highly modified fore dune, subject to salt-laden winds, has traces of remnant herbland and grassland with some elements of *Casuarina* open-forest to woodland remnants in places. Other scattered trees or shrubs occur along the foreshore in places, including very small stands of mangroves. A number of introduced and invasive plant species have also established along the fore dune. At least two marine turtle species are known to nest along this foreshore, including the green turtle (*Chelonia mydas*) and the Flatback turtle (*Natator depressus*). These species are listed as vulnerable under both State and Commonwealth legislation (DERM 2009b; TCC 2009a). The little tern (*Sterna albifrons*), listed as endangered under the Nature Conservation (Wildlife) Regulation 2006 of the Nature Conservation Act 1992, is also known to occur in Nelly Bay. A number of migratory wading birds are also present at times, including the ruddy turnstone (*Arenaria interpres*), sharp-tailed sandpiper (*Calidris acuminata*) and the whimbrel (*Numenius phaeopus*).

Directly behind the fore dune, an extensive road and infrastructure network has been established in Nelly Bay. Two roads of particular relevance to this project are Nelly Bay Road and the Esplanade, which run parallel to the foreshore, along the base of the beach dune. This dune system has been heavily modified by development in the northern end of the bay. However, a small patch of remnant dune vegetation mapped as Regional Ecosystem 11.2.2 and 11.2.3 (DERM 2009a) has been maintained and protected as the Nelly Bay Habitat Reserve. In addition, the aforementioned road infrastructure forms a significant barrier preventing sand re-nourishment from the dunes.

The Habitat Reserve was established in 1996 as a Conservation Reserve by the Townsville City Council with the help of community efforts (TCC 2009b). The Habitat Reserve boasts high levels of ecological and conservation values by providing a protected area that links Nelly Bay's highlands and lowlands to join with the Great Barrier Reef Marine Park, part of the Great Barrier Reef World Heritage Area. The reserve is a coastal nature conservation project that was developed to protect and manage the remnant native vegetation communities and wildlife such as the pied imperial pigeon (*Ducula bicolor*) and the bush stone curlew (*Burhinus grallarius*) which inhabit the area.

The Reserve itself contains nine slightly different vegetation communities producing an array of native vegetation species and providing homes to many native fauna (TCC 2009b). These communities include bloodwood, casuarina and eucalyptus woodlands, open scrub and grassland on foredunes, littoral rainforest, littoral scrub, mangroves, melaleuca / pandanus wetlands and melaleuca scrub.

At the southern end of the Bay, Nelly Bay Road runs directly behind the narrow foredune, parallel to the base of scarp, where granitic boulders rise rapidly in elevation. In this area, vegetation communities comprise several species of *Acacia,* a number of *Eucalyptus* species and *Corymbia* species. Hoop pines (*Araucaria cunninghamii*) also occur in the granitic hills and on the rocky outcrop at the southern end of Nelly Bay. Koalas (*Phascolarctos cinereus*) are known to occur in this area (DERM, Pers. comm.).

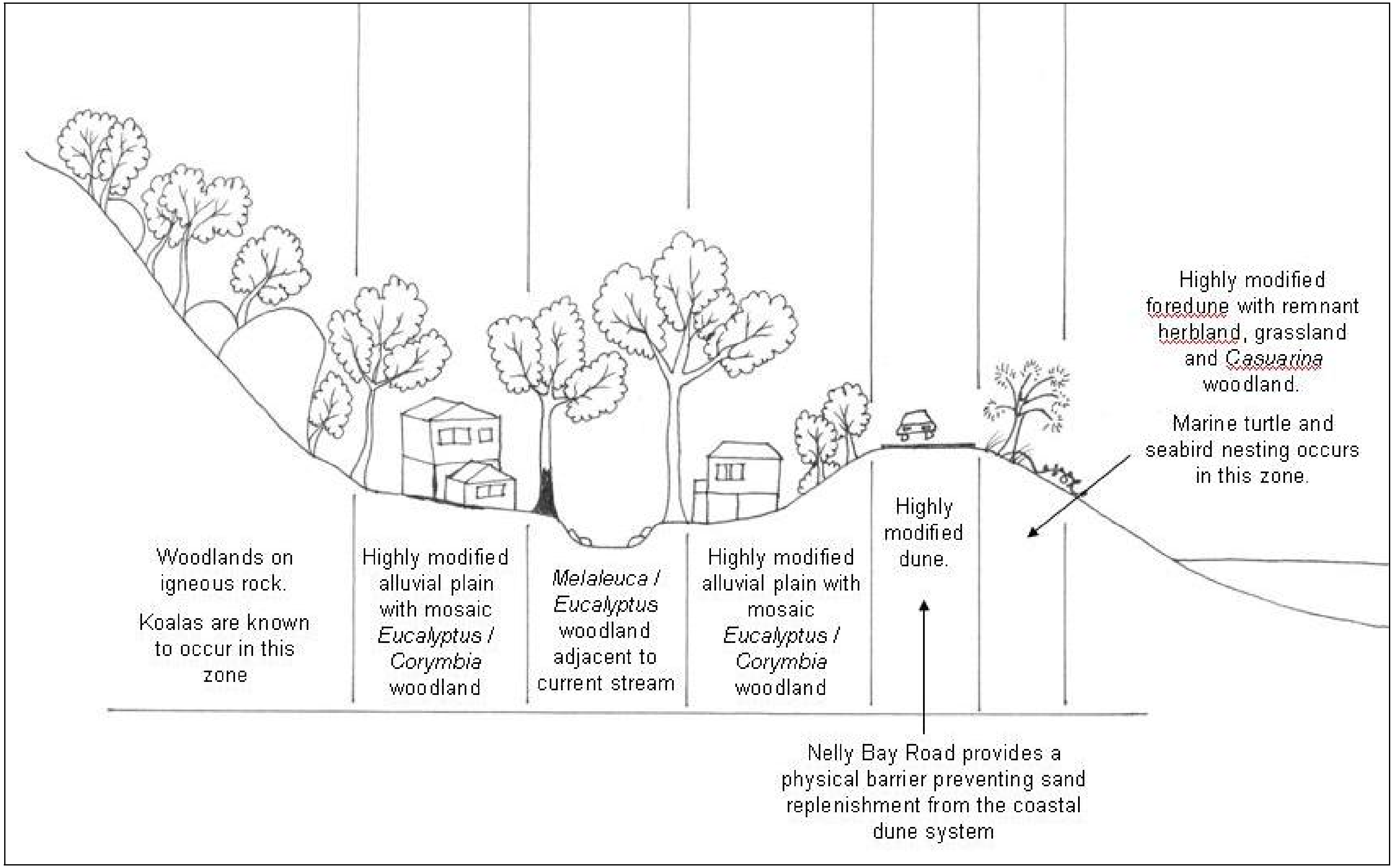

Figure 2: Simplified cross-section diagram of the terrestrial environment of Nelly bay

Table 1: Regional Ecosystems occurring in Nelly Bay

Regional Ecosystem No.	Status under the VMA 1999	Description
11.2.2	Of concern	*Ipomoea pes-caprae* and *Spinifex sericeus* grassland ± *Casuarina equisetifolia*. *Casuarina equisetifolia* varies from clumps of open-forest, to woodland, to isolated trees. Other scattered trees or shrubs may be present including *Pandanus tectorius*, *Hibiscus tiliaceus*, *Terminalia muelleri*, *Alphitonia excelsa*, *Caesalpinia bonduc* and *Cupaniopsis anacardioides*. The ground layer is quite dense, and includes *Ipomoea pes-caprae*, *Cyperus pedunculatus*, *Bulbostylis barbata*, *Aphyllodium biarticulatum* (prostrate form), and *Spinifex sericeus*. Several species are prostrate, but the only climbing vine is *Cassytha pubescens*. Occurs on Quaternary coastal fore dunes and beaches. Major vegetation communities include: 11.2.2a: Grassland with *Heteropogon triticeus*, various other grasses and herbaceous spp. Includes narrow prostrate strandline vegetation. 11.2.2b: Complex of vegetation on Quaternary coastal dunes and beaches. Characterised by *Casuarina equisetifolia*, which varies in structure from clumps of open-forest, to woodland, to isolated trees. Other scattered trees may be present including *Pandanus tectorius*, *Hibiscus tiliaceus*, *Terminalia muelleri*, *Alphitonia excelsa*, and *Cupaniopsis anacardioides*. There may be a shrublayer of *Clerodendrum spp*., *Caesalpinia bonduc*, *Vitex trifolia* and/or *Scaevola taccada*. The ground layer usually includes *Eragrostis interrupta*, *Thuarea involuta*, *Eriachne triodioides*, *Spinifex sericeus*, Ip*omoea pes-caprae*, *Canavalia rosea* and *Cyperus pedunculatus*. There is usually a distinct zonation along the strandline. On gentle to moderately sloping foredunes and immediate swales, usually within 200 m of the high tide mark. Occurs in environments subject to salt-laden winds. Associated with exposed and loose aeolian (wind-transported) pale siliceous sands.
11.2.3	Of concern	Microphyll/notophyll vineforest to semi-deciduous vine thicket on Quaternary coastal dunes. Commonly consists of several of the following trees: *Pleiogynium timorense*, *Mimusops elengi*, *Cupaniopsis anacardioides*, *Exocarpos latifolius*, *Pouteria sericea* and *Diospyros geminata*. In dry, exposed and windswept locations, this RE may only reach 4-5 m, and include deciduous emergent species such as *Gyrocarpus americanus* and *Brachychiton australis*. At its best development this formation grows to 15 m and includes further species such as *Ficus virens*, *Aglaia brownii*, *Polyalthia nitidissima*, *Canarium australianum*, *Miliusa brahei* and *Ficus spp*. A shrub layer may be present with *Carissa ovata*, *Capparis sepiaria*, *Eugenia reinwardtiana*, *Drypetes deplanchei* and *Aidia racemosa*. Vines are common, including *Sarcostemma viminale subsp. australe*, *Jasminum didymum*, *J. simplicifolium*, *Abrus precatorius* and *Cissus spp*. A ground layer is sparse or absent. Occurs on Quaternary coastal dunes and adjacent swales. Best developed on secondary dune swales and areas protected from strong winds. Soils are fine to coarse beach sands possibly enriched by calcareous sediments.
11.3.9	Not of concern	*Eucalyptus platyphylla* ± *Corymbia clarksoniana* ± *C. intermedia* ± *E. tereticornis* ± *Lophostemon suaveolens* woodland. This association has a grassy groundlayer, with species including

Regional Ecosystem No.	Status under the VMA 1999	Description
		Heteropogon contortus, *Sorghum nitidum*, *Chrysopogon fallax*, *Alloteropsis semialata* and *Aristida holathera*, or with heavier grazing short grasses such as *Chloris spp*., *Fimbristylis dichotoma*, *Cyperus spp*., *Schizachyrium fragile* and *Ectrosia leporina*. Occurs on Cainozoic alluvial plains, on sandy surface with clay subsoil. Usually with "wet" influence, either closely adjacent to major river, or undergoes inundation relatively frequently. May occur in wet depressions. Major vegetation communities include: 11.3.9a: *Eucalyptus acmenoides* ± *E. drepanophylla*, ± *E. platyphylla* woodland.
11.3.25	Not of concern	*Eucalyptus camaldulensis* or *E. tereticornis* open-forest to woodland. Other tree species such as *Casuarina cunninghamiana*, *E. coolabah*, *Melaleuca bracteata*, *Melaleuca viminalis*, *Livistona spp*. (in north), *Melaleuca spp*. and *Angophora floribunda* are commonly present and may be locally dominant. An open to sparse, tall shrub layer is frequently present dominated by species including *Acacia salicina*, *A. stenophylla* or *Lysiphyllum carronii*. Low shrubs are present, but rarely form a conspicuous layer. The ground layer is open to sparse and dominated by perennial grasses, sedges or forbs such as *Imperata cylindrica*, *Bothriochloa bladhii*, *B. ewartiana*, *Chrysopogon fallax*, *Cyperus dactylotes*, *C. difformis*, *C. exaltatus*, *C. gracilis*, *C. iria*, *C. rigidellus*, *C. victoriensis*, *Dichanthium sericeum*, *Leptochloa digitata*, *Lomandra longifolia* or *Panicum spp*.. Occurs on fringing levees and banks of major rivers and drainage lines of alluvial plains throughout the region. Soils are very deep, alluvial, grey and brown cracking clays with or without some texture contrast. These are usually moderately deep to deep, soft or firm, acid, neutral or alkaline brown sands, loams or black cracking or non-cracking clays, and may be sodic at depth (Burgess 2003). Major vegetation communities include: 11.3.25a: Riverine wetland or fringing riverine wetland. *Eucalyptus raveretiana* (sometimes emergent), *Melaleuca fluviatilis* woodland. A range of other species may be present including *Melaleuca leucadendra*, *Corymbia clarksoniana*, *Casuarina cunninghamiana*, *Melaleuca viminalis* and *Nauclea orientalis.* There is often a dense low tree layer dominated by species such as *Acacia salicina*, *Geijera salicifolia*, *Diospyros humilis* and *Mallotus philippensis*. 11.3.25b: Riverine wetland or fringing riverine wetland. *Melaleuca leucadendra* and/or *M. fluviatilis*, *Nauclea orientalis* open forest. A range of other canopy or sub canopy tree species also occur including *Pandanus tectorius*, *Livistona spp., Eucalyptus tereticornis*, *Corymbia tessellaris*, *Millettia pinnata*, *Casuarina cunninghamiana*, *Livistona decora*, *Lophostemon suaveolens* or *L. grandiflorus*, rainforest species and, along drainage lines, *Eucalyptus camaldulensis* or *E. tereticornis*. A groundlayer of tall grasses such as *Chionachne cyathopoda*, *Mnesithea rottboellioides* or *Heteropogon triticeus* may be present. Often occurs on coarse sand spits and levees within larger river channels. 11.3.25c: Riverine wetland or fringing riverine wetland. *E. camaldulensis* or *E. tereticornis* open-forest to woodland. Occurs fringing drainage lines derived from Serpentinite. 11.3.25d: Riverine wetland or fringing riverine wetland. *Melaleuca bracteata* woodland to open-forest. Occurs on

Regional Ecosystem No.	Status under the VMA 1999	Description
		fringing alluvial soils or near-channel levees on heavy wet clays. 11.3.25e: Riverine wetland or fringing riverine wetland. *Eucalyptus camaldulensis*, *E. tereticornis* woodland fringing larger, permanent water courses. A range of other tree species commonly occur including *Melaleuca trichostachya*. *Casuarina cunninghamiana*, and *Melaleuca viminalis*. Ground layer is composed of grasses and forbs. Occurs fringing permanent water courses. 11.3.25f: Riverine wetland or fringing riverine wetland. Main river channels. Open water or exposed stream bead and bars. Usually devoid of emergent vegetation although scattered trees and shrubs such as *Melaleuca viminalis* or *Melaleuca spp.* may be present and aquatic species may be abundant particularly in water holes and lagoons. Occurs on river channels. 11.3.25g: Riverine wetland or fringing riverine wetland. Vegetation is seasonal and may consist of open water and/or a range of mainly aquatic species such as *Nymphoides crenata*, *Chara sp*, *Nitella sp,* or *Hydrilla verticillata*. Often with fringing woodland, commonly *E. camaldulensis* or *E. coolabah* and a ground layer that may include species such as *Pseudoraphis spinescens*, *Marsilea drummondii*, *M. mutica*, *Persicaria subsessilis* and *Eleocharis spp*. Occurs on waterholes in larger drainage lines and rivers. 11.3.25h: Riverine wetland or fringing riverine wetland. Low open-forest or low woodland of *Melaleuca viminalis*, often in association with *Melaleuca trichostachya*, occasionally with *Cryptocarya triplinervis*, and sometimes with emergent layer of *Eucalyptus tereticornis* or *Casuarina cunninghamiana*. The shrub layer is sparse but includes *Ficus opposita*. The ground layer includes *Lomandra hystrix* and *Oplismenus aemulus*. Occurs fringing drainage lines.
11.12.16	Of concern	Mixed low woodland to shrubland. Canopy species include *Acacia spirorbis subsp. solandri*, *A. leptostachya*, *Lophostemon grandiflorus*, *Canarium australianum* ± *Eucalyptus drepanophylla* ± *Cochlospermum gillivraei* ± *Corymbia tessellaris* and semi-evergreen vine thicket species. Ground layer is often dominated by *Triodia stenostachya*. Occurs on coastal ranges formed on Mesozoic to Proterozoic igneous rocks. Major vegetation communities include: 11.12.16a: *Acacia julifera* shrubland ± *Eucalyptus drepanophylla*. 11.12.16d: Grassland with scattered shrubs or trees or very open shrubland / low woodland with *Triodia stenostachya*, *Heteropogon contortus*, *H. triticeus*, *Cymbopogon bombycinus, C. ambiguus +/- Cochlospermum gillivraei +/- Araucaria cunninghamii +/- Corymbia dallachiana +/- C. tessellaris* 11.12.16x1: Grassland with scattered shrubs to low very open scrub. Various grasses may be dominate: *Heteropogon contortus*, *H. triticeus*, *Themeda triandra*, *Sarga plumosum*, *Cymbopogon bombycinus*, *C. ambiguus*, *Eriachne mucronata* and *Triodia stenostachya*. Occurs on rhyolite or granite hills, headlands and islands.

Table 2: Rare and threatened species, listed under the Environmental Protection and Biodiversity (EPBC) Act 1999 and the Nature Conservation (Wildlife) Regulation 2006 of the Nature Conservation Act 1992, occurring or potentially occurring in Nelly Bay (E: Endangered; V: Vulnerable; R: Rare). Likelihood of occurrence is based on EPBC protected matters search tool data and records obtained through the Wildlife Online database. Likelihood of direct impact from coastal processes is based local knowledge and expertise of the consultant.

Group	Common name	Species name	Status EPBC	Status NCA	Likelihood of occurrence	Likelihood of direct impact from coastal erosion processes
Birds	Australian swiftlet	*Aerodramus terraereginae*		R	One confirmed sighting within the area	Species or species habitat unlikely to be significantly impacted by coastal erosion processes along Nelly Bay.
	Black-necked stork	*Ephippiorhynchus asiaticus*		R	Two confirmed sightings within the area	Species or species habitat unlikely to be significantly impacted by coastal erosion processes in this area.
	Little tern	*Sterna albifrons*		E	One confirmed sighting within the area	Species or species habitat likely to be impacted as a result of coastal erosion processes along Nelly Bay foreshore. Confirmed sightings of this species have been made in this area.
	Macleay's fig-parrot	*Cyclopsitta diophthalma*		V	Confirmed records in Nelly Bay	Species or species habitat may be impacted by coastal erosion processes in Nelly Bay, particularly where habitat (fig) trees are disturbed or destroyed as a result of erosion processes.
Mammals	Spectacled flying fox	*Pteropus conspicillatus*	V		Species or species habitat may occur within the area	Species or species habitat considered very unlikely to be significantly impacted coastal erosion processes along Nelly Bay. No confirmed sightings of this species have been recorded within this area. This species prefers rainforest habitats.
	Water mouse	*Xeromys myoides*	V		Species or species habitat may occur within the area	Species or species habitat considered very unlikely to be significantly impacted coastal

Group	Common name	Species name	Status EPBC	Status NCA	Likelihood of occurrence	Likelihood of direct impact from coastal erosion processes
						erosion processes along Nelly Bay. No confirmed sightings of this species have been recorded on Magnetic Island.
Reptiles	Loggerhead turtle	*Caretta caretta*	E		Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat may be impacted as a result of coastal erosion processes
	Green turtle	*Chelonia mydas*	V	V	One confirmed sighting within the area. Breeding occurs in this area.	Species or species terrestrial (breeding) habitat likely to be impacted as a result of coastal erosion processes. Nesting occurs in the area.
	Leatherback turtle	*Dermochelys coriacea*	E		Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat may be impacted as a result of coastal erosion processes. However, no confirmed breeding records exist for this area
	Hawksbill turtle	*Eretmochelys imbricata*	V		Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat unlikely to be impacted as a result of coastal erosion processes. No confirmed breeding records occur in this area
	Olive Ridley turtle	*Lepidochelys olivacea*	E		Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat may be impacted as a result of coastal erosion processes. However, no confirmed breeding records exist for this area
	Flatback turtle	*Natator depressus*	V	V	Confirmed sightings and breeding within this area.	Species or species terrestrial (breeding) habitat likely to be impacted as a result of coastal erosion processes. Nesting is known to occur in Nelly Bay
	Striped-tailed delma	*Delma labialis*	V	V	One confirmed sighting within this area.	Species or species habitat unlikely to be directly impacted by coastal

Group	Common name	Species name	Status EPBC	Status NCA	Likelihood of occurrence	Likelihood of direct impact from coastal erosion processes
						erosion processes
	Yakka skink	*Egernia rugosa*	V		Species or species habitat likely to occur within the area	Species or species habitat unlikely to be directly impacted by coastal erosion processes
	Common death adder	*Acanthophis antarcticus*		R	Confirmed records in Nelly Bay	Species or species habitat unlikely to be directly impacted by coastal erosion processes, due to preferred habitat of this species.
	Saxicoline sun skink	*Lampropholis mirabilis*		R	Confirmed records in Nelly Bay	Species or species habitat unlikely to be directly impacted by coastal erosion processes, due to preferred habitat of this species.
Plants	Minute orchid	*Taeniophyllum muelleri*	V		Species or species habitat may occur within the area	Species or species habitat unlikely to be directly impacted by coastal erosion processes. There are no confirmed records of this species within the area.
	-	*Leucopogon cuspidatus*	V		Species or species habitat likely to occur within the area	Species or species habitat unlikely to be directly impacted by coastal erosion processes. There are no confirmed records of this species within the area.

Table 3: **Migratory species, listed under the Environmental Protection and Biodiversity (EPBC) Act 1999, occurring or potentially occurring in Nelly Bay. Likelihood of occurrence is based on EPBC protected matters search tool data and records obtained through the Wildlife Online database. Likelihood of direct impact from coastal processes is based local knowledge and expertise of the consultant.**

Group	Common name	Species name	Likelihood of occurrence	Likelihood of direct impact from coastal erosion processes
Terrestrial Birds	White-bellied sea-eagle	*Haliaeetus leucogaster*	Species or species habitat likely to occur within the area	Species or species habitat may be directly impacted by coastal erosion processes in Nelly Bay, particularly if habitat (nesting) trees

Group	Common name	Species name	Likelihood of occurrence	Likelihood of direct impact from coastal erosion processes
				are disturbed. This species is also known to occasionally nest on the ground. The white-bellied sea-eagle returns to the same nest site each breeding season, and will therefore suffer direct impacts if nesting sites are damaged or destroyed as a result of coastal erosion processes
	White-throated needletail	*Hirundapus caudacutus*	Species or species habitat may occur within the area	Species of species habitat unlikely to be significantly impacted coastal erosion processes in Nelly Bay
	Barn swallow	*Hirundo rustica*	Species or species habitat may occur within the area	Species of species habitat unlikely to be significantly impacted coastal erosion processes in Nelly Bay
	Satin flycatcher	*Myiagra cyanoleuca*	Confirmed records in Nelly bay	Species of species habitat unlikely to be significantly impacted coastal erosion processes in Nelly Bay
	Oriental cuckoo	*Cuculus saturatus*	Confirmed records in Nelly Bay	Species of species habitat unlikely to be significantly impacted coastal erosion processes in Nelly Bay
	Fork-tailed swift	*Apus pacificus*	Confirmed records in Nelly Bay	Species of species habitat unlikely to be significantly impacted coastal erosion processes in Nelly Bay
	Black-faced monarch	*Monarcha melanopsis*	Confirmed records in Nelly Bay	Species of species habitat unlikely to be significantly impacted coastal erosion processes in Nelly Bay
	Spectacled monarch	*Monarcha trivirgatus*	Confirmed records in Nelly Bay	Species of species habitat unlikely to be significantly impacted coastal erosion processes in Nelly Bay
Wetland birds	Latham's snipe, Japanese snipe	*Gallinago hardwickii*	Species or species habitat may occur within the area	Species or species habitat may be impacted by coastal erosion processes in Nelly Bay
	Ruddy turnstone	*Arenaria interpres*	Confirmed records in Nelly Bay	Species or species habitat may be impacted as a result of coastal erosion processes, particularly processes potentially impacting the mangrove forests and wetland areas.
	Sharp-tailed	*Calidris acuminata*	Confirmed records in Nelly Bay	Species or species habitat may be impacted

Group	Common name	Species name	Likelihood of occurrence	Likelihood of direct impact from coastal erosion processes
	sandpiper			as a result of coastal erosion processes, particularly processes potentially impacting the mangrove forests and wetland areas.
	Whimbrel	*Numenius phaeopus*	Confirmed records in Nelly Bay	Species or species habitat may be impacted as a result of coastal erosion processes, particularly processes potentially impacting the mangrove forests and wetland areas.
Reptiles	Loggerhead turtle	*Caretta caretta*	Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat unlikely to be impacted as a result of coastal erosion processes. However, no confirmed breeding records occur in this area
	Green turtle	*Chelonia mydas*	Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat likely to be impacted as a result of coastal erosion processes. Nesting occurs in the area.
	Estuarine crocodile	*Crocodylus porosus*	Species or species habitat likely to occur within the area	Species or species habitat likely to be impacted by coastal erosion processes in Nelly Bay. This species is known to occur in this area. However, no confirmed nesting has been recorded.
	Leatherback turtle	*Dermochelys coriacea*	Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat unlikely to be impacted as a result of coastal erosion processes. However, no confirmed breeding records occur in this area
	Hawksbill turtle	*Eretmochelys imbricata*	Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat unlikely to be impacted as a result of coastal erosion processes. However, no confirmed breeding records occur in this area
	Olive Ridley turtle	*Lepidochelys olivacea*	Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat may be impacted as a result of coastal erosion processes. However, no confirmed breeding records exist for this area
	Flatback turtle	*Natator depressus*	Breeding likely to occur within the area	Species or species terrestrial (breeding) habitat likely to be impacted as a result of coastal erosion processes. Nesting is known

Group	Common name	Species name	Likelihood of occurrence	Likelihood of direct impact from coastal erosion processes
				to occur in Nelly Bay

Rowes Bay

For the purpose of this study, the extent of the terrestrial, coastal environment of Rowes Bay has been limited to areas of Land zones 1 and 2 and small areas of Land zone 3 that may be directly influenced by coastal erosion processes along Rowes Bay beach. The terrestrial values study area has been expanded to include terrestrial environments which may be impacted by coastal erosion processes (Figure 3). Land zones 1 and 2 include mangroves, saltpans, tidal flats and tidal beaches, coastal dunes and beach ridges, sand plains and swales, lakes and swamps enclosed by dunes. Land zone 3 comprises alluvial systems, including floodplains, alluvial plains, alluvial fans, terraces, levees, swamps, channels, closed depressions and fine textured palaeo-estuarine deposits. The terrestrial environment extends approximately 2km inland from the Rowes Bay foreshore. A total of seven regional ecosystems occur within this area (Table 4).

Figure 3: **Rowes Bay terrestrial values study area, overlaid onto the original Rowes Bay study area plan.**

The foreshore of Rowes Bay, subject to salt-laden winds, comprises a moderately sloping, highly modified foredune mapped as non-remnant vegetation, with elements of remnant herbland and grassland that are quite dense in areas. Some *Casuarina* open-forest to woodland remnants consistent with the 'of concern' Regional Ecosystem 11.2.2 occur along the 10km stretch of foreshore, and along the eastern side of Cape Pallarenda. Other scattered trees or shrubs also occur along the foreshore. A number of introduced and invasive plant species have also established along the foredune.

Anecdotal evidence suggests that marine turtles, including the green turtle (*Chelonia mydas*) nest above high water mark along Rowes Bay beach, and a number of sea birds and shorebirds, including some threatened species such as the little tern (*Sterna albifrons*) and the beach stone curlew (*Esacus neglectus*) are known to occur along the beach (Table 5). A number of migratory species listed under various international treaties, including JAMBA and CAMBA are also known to occur (Table 6).

In addition to the environmental value of Rowes Bay, the foreshore holds much social value for Townsville residents and visitors alike. A number of public parklands and associated infrastructure have been established along the foreshore, including car parks, barbeque areas and picnic facilities. Rowes Bay also provides one of a limited number of dog-friendly beaches in Townsville.

Directly behind the foredune, a bitumen bicycle path runs parallel to Heatleys Parade and Cape Pallarenda Road, traversing the coastal dune from Kissing Point to Cape Pallarenda. This road and related infrastructure provide sole access to the suburb of Pallarenda, the Rowes Bay Golf Course, Rowes Bay Caravan Park and the Townsville Town Common Conservation Park. This infrastructure currently serves as a linear disturbance affecting the zonation of coastal vegetation, preventing tertiary successional species from gaining any foothold on areas to the east of the road.

A highly modified urban environment occurs on the coastal dune system immediately to the west of Rowes Bay foreshore. Residential development is expanding in this area, and an appealing mix of seaside (Rowes Bay) and mountainside (Cape Pallarenda) residential offerings has been described as the catalyst for accelerating and affluent residential development in the suburbs of both Rowes Bay and Pallarenda (http://en.wikipedia.org/wiki/Rowes_Bay,_Queensland).

Immediately to the west of the coastal fore dune a series of mangrove forests, saltpans and wetlands occur (Figure 4). These areas comprise the Regional Ecosystems 11.1.1, 11.1.2, 11.1.4 and 11.2.5 which are listed as not of concern under the *Vegetation Management Act 1999*, and small areas of Regional Ecosystem 11.2.2 listed as of concern. Marine couch wetlands dominated by almost pure stands of *Sporobolus virginicus* with a wide range of other species present as scattered individuals occur on supratidal flats which are often only inundated by highest spring tides. These wetland areas are in places dissected by small tidal channels. Small areas of mangrove forest also occur along or in close proximity to the small tidal creeks and channels.

Samphire forbland, bare mud-flats and saltpans also occur throughout this section. Similarly, these ares are only inundated during the highest spring tides.

A series of dunes and swales occur at the western extent of the Rowes Bay environment, comprising old beach ridge open-woodland, with *Melaleuca dealbata* dominating swale vegetation. This community is mapped as the Regional Ecosystem 11.2.5, listed as not of concern under the *Vegetation Management Act 1999*.

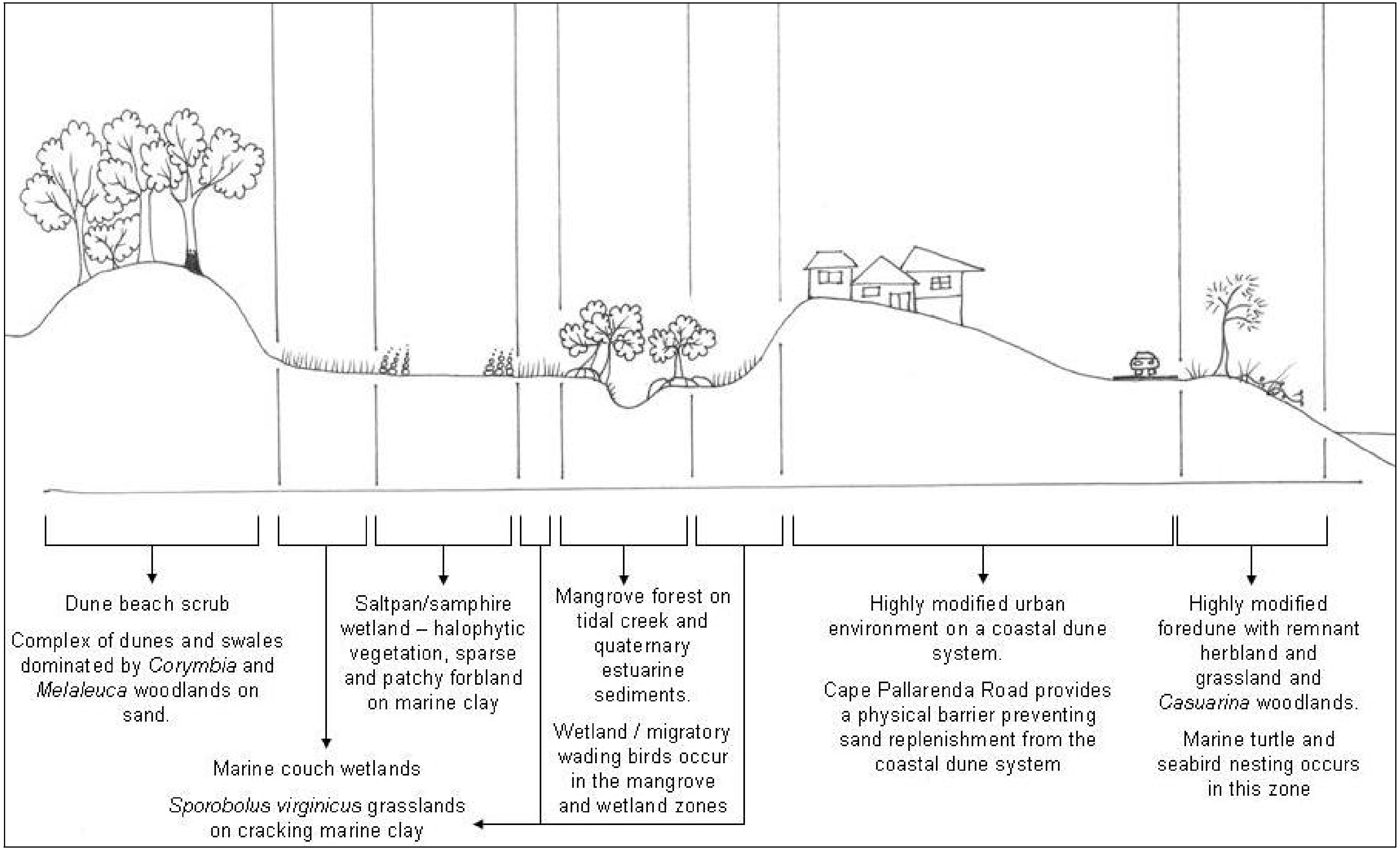

Figure 4: Simplified cross-section diagram of the terrestrial environment of Rowes Bay.

Table 4: Regional Ecosystems occurring in Rowes Bay

Regional Ecosystem No.	Status under the VMA 1999	Description
11.2.5	Not of concern	Corymbia-Melaleuca woodland complex of beach ridges and swales. Beach ridge woodland with *Melaleuca dealbata* in swales and *Corymbia tessellaris* woodland on Quaternary dune systems. Ridges: Usually a woodland to open forest of *Corymbia tessellaris* with occasional *Acacia crassicarpa*, *Cupaniopsis anacardioides*, *Pleiogynium timorense* and *Terminalia muelleri*. A sparse to dense shrublayer may include Acacia oraria, A. crassicarpa, *Planchonia careya*, *Alphitonia excelsa*, *Exocarpos latifolius*, *Senna surattensis* and *Dodonaea viscosa*. Groundlayer includes *Aphyllodium biarticulatum*, *Themeda triandra*, *Heteropogon contortus*, *Elionurus citreus*, *Aristida holathera*, *Cymbopogon refractus* and *Perotis rara*. Swales: Open forest of *Melaleuca dealbata*, (sometimes *M. leucadendra* or *M. viridiflora*), *Livistona drudei* or *L. decora*, with shrubs of *Pandanus spiralis*. Groundlayer of *Chrysopogon filipes*, *Imperata cylindrica*, *Sporobolus virginicus* and *Lepturus repens*. In some areas sedges are common, including *Cyperus javanicus*, *Fimbristylis dichotoma*, *F. polytrichoides*. Small vines are commonly present including *Cynanchum carnosum*, *Abrus precatorius*, and *Jasminum didymum*. Occurs on Quaternary undulating stabalised dunes with narrow linear depressions. Associated soils are generally well drained siliceous sands, swales with humic hydrosols Major vegetation communities include: 11.2.5a: Woodland to open forest of *E. tereticornis* x *platyphylla* with *Corymbia tessellaris* and occasional *M viridiflora* 11.2.5b: Palustrine wetland (e.g. vegetated swamp). Swales: Open forest of *Melaleuca dealbata*, (sometimes *M. leucadendra* or *M. viridiflora*), *Livistona drudei* or *L. decora*, with shrubs of *Pandanus spiralis*. Groundlayer of *Chrysopogon filipes*, *Imperata cylindrica*, *Sporobolus virginicus* and *Lepturus repens*. In some areas sedges are common, including *Cyperus javanicus*, *Fimbristylis dichotoma*, *F. polytrichoides*. Small vines are commonly present including *Cynanchum carnosum*, *Abrus precatorius* and *Jasminum didymum.*
11.2.2	Of concern	*Ipomoea pes-caprae* and *Spinifex sericeus* grassland ± *Casuarina equisetifolia*. *Casuarina equisetifolia* varies from clumps of open-forest, to woodland, to isolated trees. Other scattered trees or shrubs may be present including *Pandanus tectorius*, *Hibiscus tiliaceus*, *Terminalia muelleri*, *Alphitonia excelsa*, *Caesalpinia bonduc* and *Cupaniopsis anacardioides*. The ground layer is quite dense, and includes *Ipomoea pes-caprae*, *Cyperus pedunculatus*, *Bulbostylis barbata*, *Aphyllodium biarticulatum* (prostrate form), and *Spinifex sericeus*. Several species are prostrate, but the only climbing vine is *Cassytha pubescens*. Occurs on Quaternary coastal fore dunes and beaches. Major vegetation communities include: 11.2.2a: Grassland with *Heteropogon triticeus*, various other grasses and herbaceous spp. Includes narrow prostrate strandline vegetation. 11.2.2b: Complex of vegetation on Quaternary coastal dunes and beaches. Characterised by *Casuarina equisetifolia*, which varies in structure from clumps of open-forest, to woodland, to isolated trees. Other scattered trees

Regional Ecosystem No.	Status under the VMA 1999	Description
		may be present including *Pandanus tectorius*, *Hibiscus tiliaceus*, *Terminalia muelleri*, *Alphitonia excelsa*, and *Cupaniopsis anacardioides*. There may be a shrublayer of *Clerodendrum spp*., *Caesalpinia bonduc*, *Vitex trifolia* and/or *Scaevola taccada*. The ground layer usually includes *Eragrostis interrupta*, *Thuarea involuta*, *Eriachne triodioides*, *Spinifex sericeus*, Ip*omoea pes-caprae*, *Canavalia rosea* and *Cyperus pedunculatus*. There is usually a distinct zonation along the strandline. On gentle to moderately sloping foredunes and immediate swales, usually within 200 m of the high tide mark. Occurs in environments subject to salt-laden winds. Associated with exposed and loose aeolian (wind-transported) pale siliceous sands.
11.1.1	Not of concern	*Sporobolus virginicus* grassland on Quaternary estuarine deposits. *Sporobolus spp*. usually dominates pure stands although a wide range of other species may be present as scattered individuals including *Fimbristylis ferruginea*, *Cyperus victoriensis*, *C. scariosus*, and sometimes *Eleocharis spiralis*, *Mnesithea rottboellioides*, *Marsilea mutica*, *Cynanchum carnosum*, *Ischaemum australe*, *Cyperus polystachyos*, *Ceratopteris thalictroides* and *Leptochloa fusca*. Occasional emergent stunted mangroves, usually *Avicennia marina* or *Ceriops tagal*, may occur as isolated individuals or along small channels. There may also be a minor presence of salt-tolerant forbs such as *Suaeda australis*, *S. arbusculoides*, *Sarcocornia quinqueflora subsp. quinqueflora* or *Tecticornia australasica*. Occurs on supratidal flats which are often only inundated by highest spring tides. Often occurs on the landward side of intertidal flats; seaward margins irregularly inundated with tidal waters and dissected by small tidal channels. Formed from Quaternary estuarine sediments with deep grey or black and grey saline cracking clays with occasional mottling, minor gilgai occasionally present.
11.1.2	Not of concern	Samphire forbland or bare mud-flats on Quaternary estuarine deposits. Mainly saltpans and mudflats with clumps of saltbush including one or several of the following species; *Halosarcia spp*. (e.g. *Halosarcia indica subsp. julacea*, *Halosarcia indica subsp*. l*eiostachya*), *Sesuvium portulacastrum*, *Sarcocornia quinqueflora subsp. quinqueflora*, *Suaeda australis*, *S. arbusculoides*, *Tecticornia australasica*, *Salsola kali*, algal crusts and the grass *Sporobolus virginicus*. Sedges are also common. Occurs on supratidal flats with deep saline clay soils and formed from Quaternary estuarine sediments. Occurs along the landward edge of the intertidal zone in a hypersaline environment that is only inundated by the highest spring tides. Soils are grey mottled clays with a crusting surface, and are highly saline. Major vegetation communities include: 11.1.2a: Estuarine wetlands (e.g. mangroves). Bare mud flats on Quaternary estuarine deposits, with very isolated individual stunted mangroves such as *Avicennia marina* and/or *Ceriops tagal*. May have obvious salt crusts on the soil surface. 11.1.2b: Estuarine wetlands (e.g. mangroves). Samphire forbland on Quaternary estuarine deposits. Mainly saltpans and mudflats with clumps of saltbush including one or several of the following species; *Halosarcia spp*. (e.g. *Halosarcia indica subsp. julacea*, *Halosarcia indica subsp. leiostachya*),

Regional Ecosystem No.	Status under the VMA 1999	Description
		Sesuvium portulacastrum, *Sarcocornia quinqueflora subsp. quinqueflora, Suaeda australis, S. arbusculoides, Tecticornia australasica*, *Scleria ciliaris*, *Marsilea mutica*, *Salsola kali*, algal crusts and the grass *Sporobolus virginicus*. Sedges may be common.
11.1.4	Not of concern	Mangrove low forest on Quaternary estuarine deposits. Low open-shrubland to closed forest of mangrove species forming a variety of associations, depending on position in relation to salt water inundation. *Avicennia marina* is the most common dominant but also other trees such as *Aegiceras corniculatum*, *Rhizophora spp*. and *Ceriops tagal* dominate often in pure stands. There is often a shrub layer consisting of juvenile plants of the above species. Other species such as *Excoecaria agallocha*, *Bruguiera spp*., *Lumnitzera racemosa* and *Alchornea ilicifolia* may also occur. Occurs on intertidal flats which are often dissected by tidal streams. Soils are usually deep saline clays. Major vegetation communities include: 11.1.4a: Estuarine wetlands (e.g. mangroves). *Rhizophora spp*. open-forest on Quaternary estuarine deposits. This may include *Rhizophora stylosa* or *R. apiculata* as dominants, with occasional *Avicennia marina* as emergents, and subdominant *Bruguiera gymnorhiza* and/or *Ceriops tagal*. In northern areas, occasional *Xylocarpus moluccensis* may also occur. A shrub layer is usually not present. Occurs on fringing waterways low in intertidal zone, with roots submerged during high tides (Danaher 1995) 11.1.4b: Estuarine wetlands (e.g. mangroves). *Avicennia marina* low open-shrubland to closed forest on Quaternary estuarine deposits. There may be occasional *Ceriops tagal*, *Rhizophora spp*., *Bruguiera spp*., *Excoecaria agallocha* or *Lumnitzera spp*. An occasional presence of species such as *Aegialitis annulata* and/or *Aegiceras corniculatum* may occur. Open-shrublands of *Avicennia marina* may have a sparse presence of samphires such as *Suaeda spp*., *Tecticornia australasica* and *Sarcocornia spp*. Occurs in all intertidal environments from the seaward edge (as a pioneer) to accreting banks (as a fringe), to the landward edge adjacent to claypans (Bruinsma 2000; Danaher 1995) 11.1.4c: Estuarine wetlands (e.g. mangroves). *Ceriops tagal*, +/- *Avicennia marina* open forest on Quaternary estuarine deposits. Other mangrove species may be present as occasional individuals including *Rhizophora spp*., *Bruguiera spp*., *Lumnitzera spp*., and *Sonneratia spp*. A shrub layer is not usually present. Occurs on upstream creek edges, and toward the landward edge of the upper intertidal limit. Only inundated by spring tides (Bruinsma 2000). 11.1.4d: Estuarine wetlands (e.g. mangroves). Dominated by a range of species from genera such as from *Avicennia sp., Ceriops sp., Rhizophora sp.* and *Bruguiera sp*. which form a closed forest. A low shrub layer composed of species such as *Acanthus ilicifolius*, *Acrostichum speciosum*, *Crinum pedunculatum* or juvenile canopy species is often present. Epiphytes on the canopy are common. Occurs on the landward edge of the tidal flats and in the upper tidal reaches of creeks and rivers where there is a high freshwater influence. 11.1.4e: Estuarine wetlands (e.g. mangroves). *Avicennia marina* usually dominates the canopy which forms an open-forest

Regional Ecosystem No.	Status under the VMA 1999	Description
		although may vary from a low open-forest to a woodland or shrubland. *Ceriops tagal* sometimes occurs as a codominant. Occurs on intertidal flats which are often dissected by tidal streams. Occurs on the seaward edge of the tidal flats as a pioneer and on landward edge in areas bordering saltpans and that are inundated by the highest spring tides.
11.3.27	Not of concern	Freshwater wetlands. Vegetation is variable including open water with or without aquatic species and fringing sedgelands and eucalypt woodlands. Occurs in a variety of situations including lakes, billabongs, oxbows and depressions on floodplains. Major vegetation communities include: 11.3.27a: Lacustrine wetland (e.g. lake). Vegetation ranges from open water ± aquatics and emergents such as *Chara spp*. *Nitella spp*., *Myriophyllum verrucosum*, *Nymphaea violacea*, *Potamogeton javanicus*, *P. crispus, P. tricarinatus*, *Ottelia ovalifolia*, *Vallisneria caulescens* and *Nymphoides indica*, A narrow fringing woodland commonly dominated by *E. camaldulensis* or *E. coolabah* but also a range of other tree species may be present. Larger ephemeral - permanent water bodies (lakes). 11.3.27b: Palustrine wetland (e.g. vegetated swamp). Vegetation ranges from open water ± aquatics and emergents such as *Potamogeton crispus*, *Myriophyllum verrucosum*, *Chara spp*., *Nitella spp*, *Nymphaea violacea*, *Ottelia ovalifolia*, *Nymphoides indica*, *N. crenata*, *Potamogeton tricarinatus*, *Cyperus difformis*, *Vallisneria caulescens* and *Hydrilla verticillata*. Often with fringing woodland, commonly *Eucalyptus camaldulensis* or *E. coolabah* but also a wide range of other species including *Eucalyptus platyphylla*, *E. tereticornis*, *Melaleuca spp., Acacia holosericea* or other *Acacia spp*. Occurs on billabongs no longer connected to the channel flow. 11.3.27c: Palustrine wetland (e.g. vegetated swamp). Mixed grassland or sedgeland with areas of open water +/- aquatic species. Dominated by a range of species including *Eleocharis spp*., *Nymphoides spp*. and sometimes *Phragmites australis*. Occurs on closed depressions on alluvial plains that are intermittently flooded in inlands parts of the bioregion. 11.3.27d: Palustrine wetland (e.g. vegetated swamp). *Eucalyptus camaldulensis* and/or *E. tereticornis* woodland. A range of sedges and grasses occur in the ground layer including *Fimbristylis vagans*, *Myriophyllum striatum*, *Nitella pseudoflabellata* and *Pseudoraphis sp.* Occurs fringing larger lakes and billabongs. 11.3.27e: Palustrine wetland (e.g. vegetated swamp). Vegetation ranges from open water ± aquatics sometimes with fringing trees and shrubs. Fringing tree species include *Melaleuca dealbata*, *Nauclea orientalis*, *M. leucadendra*, *Lophostemon suaveolens* and *Corymbia tessellaris*. Shrub layers are usually absent although scattered *Pandanus spp.* may be present. The ground layer is often open water with emergent aquatic species or sedges and grasses including *Leersia hexandra, Cyperus dactylotes*, *Cyperus lucidus*, *Nymphaea spp*. and *Gymnanthera oblonga*. Occurs on billabongs and oxbows with permanent to ephemeral water regime. 11.3.27f: Palustrine wetland (e.g. vegetated swamp). *Eucalyptus coolabah* and/or *E. tereticornis* open woodland to woodland fringing swamps. Ground layer and treeless areas range from open water ± aquatics and

Regional Ecosystem No.	Status under the VMA 1999	Description
		emergents such as *Potamogeton crispus*, *Myriophyllum verrucosum*, *Chara spp*., *Eleocharis spp*., *Nitella spp*, *Cyperus difformis*, *Hydrilla verticillata*. Occurs on closed depressions on floodplains associated with old drainage courses that are intermittently flooded. 11.3.27g: Palustrine wetland (e.g. vegetated swamp). *Eucalyptus coolabah* fringing lakes with open water. Occurs on closed depressions on floodplains associated with old drainage courses. 11.3.27h: Lacustrine wetland (e.g. lake). Lakes with mainly open water or bare lake bed. May be *Muehlenbeckia florulenta* low shrubland ± scattered *E. coolabah* trees fringing or scattered across the area. Occurs on floodplains. Seasonally dry. 11.3.27i: Palustrine wetland (e.g. vegetated swamp). *Eucalyptus camaldulensis* woodland to open-woodland with sedgeland ground layer. Other tree species such as *E, coolabah, E. tereticornis* and *E. largiflorens* may be present or locally dominant. Ground layer dominated by *Eleocharis spp*, *Juncus spp*., *Marsilea spp*. etc Occurs in depressions on floodplains. 11.3.27j: Palustrine wetland (e.g. vegetated swamp). *Acacia stenophylla* and other shrubby species Occurs in frequently flooded depression on floodplains. 11.3.27x1a: Palustrine wetland (e.g. vegetated swamp). Sedgelands to grasslands on old marine planes. Often occurs as an *Eleocharis spp*. (*E. dulcis*, *E. sphacelata*) sedgeland but a variety of other species dominate in local areas including *Typha orientalis*, *Cyperus alopecuroides*, *Phragmites australis* and *Ludwigia octovalvis*. A range of other sedges, grasses small shrubs and herbs (<40 cm) are abundant, and include *Ammannia multiflora*, *Cyperus polystachyos*, *Sporobolus virginicus*, *Chloris virgata*, *Fimbristylis ferruginea*, *Ceratopteris thalictroides*, *Phyla nodiflora var. nodiflora* and *Persicaria attenuata.* The vines *Passiflora foetida* may occur in some areas. Trees and large shrubs are generally absent. Occurs in depressions on Quaternary estuarine deposits which are seasonally inundated with fresh water. 11.3.27x1b: Palustrine wetland (e.g. vegetated swamp). Sedgelands to grasslands on Quaternary deposits. Often occurs as an *Eleocharis dulcis* sedgeland but a variety of other species dominate in local areas including *Typha orientalis* and *Phragmites australis*. Trees and large shrubs are generally absent. Occurs on broad drainage depressions situated on old alluvial plains. 11.3.27x1c: Palustrine wetland (e.g. vegetated swamp). Sedgelands to grasslands on Quaternary deposits. Sedgeland areas typically dominated by *Schoenoplectus litoralis* although a range of other sedges and grasses may also dominate localised areas. Other dominant species include the sedges *Eleocharis philippinensis, Cyperus alopecuroides*, *C. scariosus* and *C. iria* and the grasses *Phragmites australis*, *Sporobolus virginicus* and *Paspalum vaginatum*. Other typical species in shallower margins include *Fimbristylis ferruginea*, *Phyla nodiflora* and *Cyperus polystachyos*. Occasional twiners such as *Cynanchum carnosum* may be present. Occurs in depressions on old Quaternary estuarine deposits. These are seasonally inundated with fresh water but become more brackish as they dry. Dry out completely before the next season's rain.

Table 5: Rare and threatened species, listed under the Environmental Protection and Biodiversity (EPBC) Act 1999 and the Nature Conservation (Wildlife) Regulation 2006 of the Nature Conservation Act 1992, occurring or potentially occurring in Rowes Bay (E: Endangered; V: Vulnerable; R: Rare). Likelihood of occurrence is based on EPBC protected matters search tool data and records obtained through the Wildlife Online database. Likelihood of direct impact from coastal processes is based local knowledge and expertise of the consultant.

Group	Common name	Species name	Status EPBC	Status NCWR	Likelihood of occurrence	Likelihood of direct impact from coastal erosion processes
Birds	Red goshawk	*Erythrotriorchis radiatus*	V	E	One confirmed sighting within the area; Species or species habitat likely to occur within the area	Species or species habitat considered unlikely to be significantly impacted coastal erosion processes along Rowes Bay
	Grey goshawk	*Accipiter novaehollandiae*		R	Three confirmed sightings within the area	Species or species habitat considered unlikely to be significantly impacted coastal erosion processes along Rowes Bay
	Grey falcon	*Falco hypoleucos*		R	One confirmed sighting within the area	Species or species habitat considered unlikely to be significantly impacted coastal erosion processes along Rowes Bay
	Star finch (eastern), Star finch (southern)	*Neochmia ruficauda ruficauda*	E		Species or species habitat likely to occur within the area	Species or species habitat considered unlikely to be significantly impacted coastal erosion processes along Rowes Bay
	Black-throated finch (southern)	*Poephila cincta cincta*	E		Species or species habitat likely to occur within the area	Species or species habitat considered unlikely to be significantly impacted coastal erosion processes along Rowes Bay
	Crimson finch	*Neochmia phaeton*		V	Five confirmed sightings within the area	Species or species habitat considered unlikely to be significantly impacted coastal erosion processes along Rowes Bay
	Australian painted snipe	*Rostratula australis*	V		Species or species habitat may occur within the area	Species or species habitat may be impacted as a result of coastal erosion processes, particularly processes potentially impacting the mangrove forests, saltpans and mud

Group	Common name	Species name	Status EPBC	Status NCWR	Likelihood of occurrence	Likelihood of direct impact from coastal erosion processes
						flats to the west of the fore dune
	Square-tailed kite	*Lophoictinia isura*		R	Two confirmed sightings within the area	Species or species habitat considered unlikely to be significantly impacted coastal erosion processes along Rowes Bay
	Cotton pygmy-goose	*Nettapus coromandelianus*		R	Five confirmed sightings within the area	Species or species habitat may be impacted as a result of coastal erosion processes, particularly processes potentially impacting the mangrove forests, saltpans and mud flats to the west of the fore dune
	Major Mitchell's cockatoo	*Lophochroa leadbeateri*		V	One confirmed sighting within this area. *Note: This sighting is considered likely to be an aviary escapee, as the species is not known to occur within this area.*	Species or species habitat considered very unlikely to be significantly impacted coastal erosion processes along Rowes Bay. This species does not occur naturally within this area
	Black-necked stork	*Ephippiorhynchus asiaticus*		R	Forty-six confirmed sightings within the area	Species or species habitat may be impacted as a result of coastal erosion processes, particularly processes potentially impacting the mangrove forests, saltpans and mud flats to the west of the fore dune
	Little tern	*Sterna albifrons*		E	Two confirmed sightings within the area	Species or species habitat likely to be impacted as a result of coastal erosion processes along Rowes Bay foreshore. Confirmed sightings of this species have been made in this area
	Southern giant petrel	*Macronectes giganteus*	E	E	One confirmed sighting within the area	Species or species habitat considered very unlikely to be significantly impacted coastal erosion processes along Rowes Bay. This species is very uncommon in the tropics

Group	Common name	Species name	Status EPBC	Status NCWR	Likelihood of occurrence	Likelihood of direct impact from coastal erosion processes
	Eastern curlew	*Numenius madagascariensis*		R	Six confirmed sightings within the area	Species or species habitat likely to be impacted as a result of coastal erosion processes along Rowes Bay foreshore
	Macleay's fig-parrot	*Cyclopsitta diophthalma macleayana*		V	One confirmed sighting within the area	Species or species habitat may be impacted by coastal erosion processes along Rowes Bay, where habitat trees such as figs and *Elaeocarpus* trees occur.
	Rufous owl (southern)	*Ninox rufa queenslandica*		V	One confirmed sighting within the area	Species or species habitat considered very unlikely to be significantly impacted coastal erosion processes along Rowes Bay. This species prefers dense woodland, river margins and rainforest habitat.
Mammals	Northern quoll	*Dasyurus hallucatus*	E		Species or species habitat likely to occur within the area; One confirmed sighting within the area	Species or species habitat considered unlikely to be significantly impacted coastal erosion processes along Rowes Bay
	Semon's leaf-nosed bat	*Hipposideros semoni*	E		Species or species habitat may occur within the area	Species or species habitat considered unlikely to be significantly impacted coastal erosion processes along Rowes Bay. This species prefers tropical rainforest, monsoon forest and wet sclerophyll forest.
	Greater large-eared horseshoe bat	*Rhinolophus philippinensis*	E		Species or species habitat may occur within the area	Species or species habitat considered very unlikely to be significantly impacted coastal erosion processes along Rowes Bay. No confirmed sightings of this species have been recorded within this area. This species prefers rainforest habitats.
	Spectacled flying	*Pteropus*	V		Species or species habitat may	Species or species habitat

Group	Common name	Species name	Status EPBC	Status NCWR	Likelihood of occurrence	Likelihood of direct impact from coastal erosion processes
	fox	*conspicillatus*			occur within the area	considered very unlikely to be significantly impacted coastal erosion processes along Rowes Bay. No confirmed sightings of this species have been recorded within this area. This species prefers rainforest habitats.
	Water mouse	*Xeromys myoides*	V		Species or species habitat may occur within the area	Species or species habitat considered very unlikely to be significantly impacted coastal erosion processes along Rowes Bay. No confirmed sightings of this species have been recorded within 100km of this area.
Reptiles	Loggerhead turtle	*Caretta caretta*	E		Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat may be impacted as a result of coastal erosion processes
	Green turtle	*Chelonia mydas*	V	V	Species or species habitat may occur within the area; One confirmed sighting within the area	Species or species terrestrial (breeding) habitat may be impacted as a result of coastal erosion processes
	Leatherback turtle	*Dermochelys coriacea*	E		Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat unlikely to be impacted as a result of coastal erosion processes. No confirmed breeding records occur in this area
	Hawksbill turtle	*Eretmochelys imbricata*	V		Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat unlikely to be impacted as a result of coastal erosion processes. No confirmed breeding records occur in this area
	Olive Ridley turtle	*Lepidochelys olivacea*	E		Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat unlikely to be impacted as a result of coastal

Group	Common name	Species name	Status EPBC	Status NCWR	Likelihood of occurrence	Likelihood of direct impact from coastal erosion processes
						erosion processes. No confirmed breeding records occur in this area
	Flatback turtle	*Natator depressus*	V		Breeding likely to occur within the area.	Species or species terrestrial (breeding) habitat may be impacted as a result of coastal erosion processes
	Striped-tailed delma	*Delma labialis*	V	V	Species or species habitat likely to occur within the area; One confirmed sighting within this area	Species or species habitat unlikely to be directly impacted by coastal erosion processes
	Yakka skink	*Egernia rugosa*	V		Species or species habitat likely to occur within the area	Species or species habitat unlikely to be directly impacted by coastal erosion processes
	Yellow-naped snake	*Furina barnardi*		R	One confirmed sighting within this area	Species or species habitat unlikely to be directly impacted by coastal erosion processes
	Rusty monitor	*Varanus semiremex*		R	One confirmed sighting within the area	Species or species habitat unlikely to be directly impacted by coastal erosion processes
Plants	Frogbit	*Hydrocharis dubia*	V		Species or species habitat likely to occur within the area	Species or species habitat unlikely to be directly impacted by coastal erosion processes. There are no confirmed records of this species within the area.
		Leucopogon cuspidatus	V		Species or species habitat likely to occur within the area	Species or species habitat unlikely to be directly impacted by coastal erosion processes. There are no confirmed records of this species within the area.

Table 6: **Migratory species, listed under the Environmental Protection and Biodiversity (EPBC) Act 1999, occurring or potentially occurring in Rowes Bay. Likelihood of occurrence is based on EPBC protected matters search tool data and records obtained through the Wildlife Online database. Likelihood of direct impact from coastal processes is based local knowledge and expertise of the consultant.**

Group	Common name	Species name	Likelihood of occurrence	Likelihood of direct impact from coastal erosion processes
Terrestrial Birds	White-bellied sea-eagle	*Haliaeetus leucogaster*	Species or species habitat likely to occur within the area	Species or species habitat may be directly impacted by coastal erosion processes in Rowes Bay, particularly if habitat (nesting) trees are disturbed. This species is also known to occasionally nest on the ground. The white-bellied sea-eagle returns to the same nest site each breeding season, and will therefore suffer direct impacts if nesting sites are damaged or destroyed as a result of coastal erosion processes.
	White-throated needletail	*Hirundapus caudacutus*	Species or species habitat may occur within the area	Species of species habitat unlikely to be significantly impacted coastal erosion processes in Rowes Bay.
	Barn swallow	*Hirundo rustica*	Species or species habitat may occur within the area	Species of species habitat unlikely to be significantly impacted coastal erosion processes in Rowes Bay.
	Rainbow bee-eater	*Merops ornatus*	Species or species habitat may occur within the area	Species or species habitat may be directly impacted by coastal erosion processes in Rowes Bay, particularly where nesting tunnels may be disturbed.
	Black-faced monarch	*Monarcha melanopsis*	Breeding may occur within the area	Species or species habitat unlikely to be directly impacted by coastal erosion processes in Rowes bay. This species nests above ground and prefers rainforest and other similar habitats.
	Spectacled monarch	*Monarcha trivirgatus*	Breeding likely to occur within the area	Species or species habitat unlikely to be directly impacted by coastal erosion processes in Rowes bay. This species nests above ground and prefers rainforest and other similar habitats.

Group	Common name	Species name	Likelihood of occurrence	Likelihood of direct impact from coastal erosion processes
	Satin flycatcher	*Myiagra cyanoleuca*	Species or species habitat likely to occur within the area	Species of species habitat unlikely to be significantly impacted coastal erosion processes in Rowes Bay
	Rufous fantail	*Rhipidura rufifrons*	Breeding may occur within the area	Species or species habitat unlikely to be directly impacted by coastal erosion processes in Rowes bay. This species nests above ground and prefers rainforest, woodland and other similar habitats.
Wetland birds	Great egret	*Ardea alba*	Species or species habitat may occur within the area	Species or species habitat may be impacted by coastal processes in Rowes bay, particularly where wetland and creek habitats are disturbed.
	Cattle egret	*Ardea ibis*	Species or species habitat may occur within the area	Species or species habitat may be impacted by coastal processes in Rowes bay, particularly where wetland and creek habitats are disturbed.
	Latham's snipe, Japanese snipe	*Gallinago hardwickii*	Species or species habitat may occur within the area	Species or species habitat may be impacted by coastal erosion processes in Rowes Bay
	Australian cotton pygmy-goose	*Nettapus coromandelianus albipennis*	Species or species habitat may occur within the area	Species or species habitat may be impacted as a result of coastal erosion processes, particularly processes potentially impacting the mangrove forests, wetlands, saltpans and mud flats to the west of the fore dune
	Painted snipe	*Rostratula benghalensis s. lat*	Species or species habitat may occur within the area	Species or species habitat may be impacted as a result of coastal erosion processes, particularly processes potentially impacting the mangrove forests, wetlands, saltpans and mud flats to the west of the fore dune
Marine birds	Little tern	*Sterna albifrons*	Species or species habitat may occur within the area	Species or species habitat likely to be impacted as a result of coastal erosion processes along Rowes Bay foreshore. Confirmed sightings of this species have been made in this area
Reptiles	Loggerhead turtle	*Caretta caretta*	Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat unlikely to be impacted as a result of

Group	Common name	Species name	Likelihood of occurrence	Likelihood of direct impact from coastal erosion processes
				coastal erosion processes. However, no confirmed breeding records occur in this area
	Green turtle	*Chelonia mydas*	Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat likely to be impacted as a result of coastal erosion processes. Nesting occurs in the area.
	Estuarine crocodile	*Crocodylus porosus*	Species or species habitat likely to occur within the area	Species or species habitat likely to be impacted by coastal erosion processes in Rowes Bay. This species is known to occur in this area. However, no confirmed nesting has been recorded.
	Leatherback turtle	*Dermochelys coriacea*	Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat unlikely to be impacted as a result of coastal erosion processes. However, no confirmed breeding records occur in this area
	Hawksbill turtle	*Eretmochelys imbricata*	Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat unlikely to be impacted as a result of coastal erosion processes. However, no confirmed breeding records occur in this area
	Olive Ridley turtle	*Lepidochelys olivacea*	Species or species habitat may occur within the area	Species or species terrestrial (breeding) habitat may be impacted as a result of coastal erosion processes. However, no confirmed breeding records exist for this area
	Flatback turtle	*Natator depressus*	Breeding likely to occur within the area	Species or species terrestrial (breeding) habitat likely to be impacted as a result of coastal erosion processes. Nesting is known to occur in Rowes Bay

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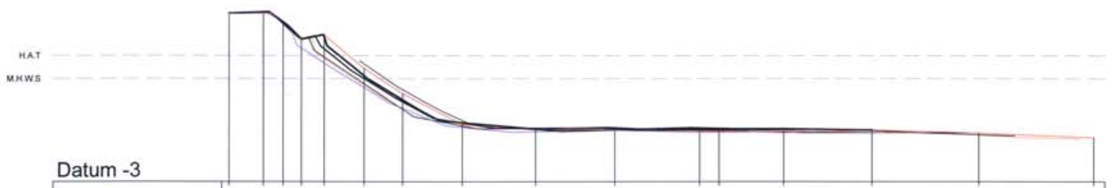
Appendix D

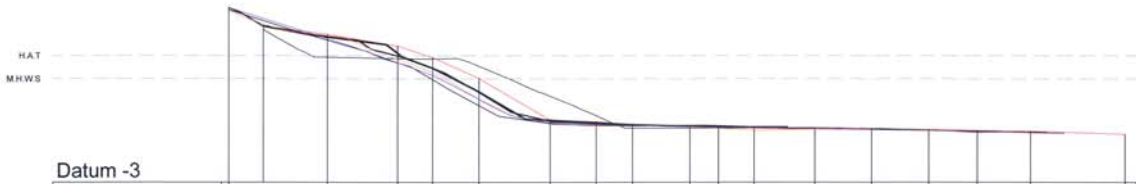
- **RESULTS OF BEACH TRANSECT SURVEYS**

Location of Beach Transect Lines



Datum -3																
April 2009	3.858	3.877	3.425	2.461	1.854	0.855	0.009	-0.776	-0.954	-0.899	-0.973	-0.974	-0.952	-0.987		
April 2008	3.858	3.939	3.444	2.825	2.093	1.011	-0.037	-0.717	-0.823	-0.778	-0.895	-0.897	-0.887	-0.907	-1.075	
April 2007	3.888	3.93	3.429	2.854	2.64	0.341	0.035	-0.66	-0.822	-0.884	-0.948		-0.935	-0.96	-1.082	
April 2006	3.888	3.940	3.457	2.845	2.433	1.228	0.278	-0.598	-0.807	-0.820	-0.854	-0.856				
April 2005	3.888	3.927	3.527	2.836	2.914	1.340	0.360				-0.805					
April 2004	3.888	3.951	3.565	2.805	3.005	1.643	0.611	-0.653	-0.885	-0.863	-0.900	-0.921	-0.903	-0.884	-1.003	-1.199
June 2003						1.818	0.770	-0.493	-0.835	-0.876	-0.904	-0.922	-0.975	-1.000		
Chainages	0.000	7.000	11.036	14.761	19.421	27.550	35.420	47.595	62.559	78.738	96.031	100.000	113.185	131.204	153.002	176.477

Line 12



Datum -3																		
April 2009	4.016	3.579	2.767	1.785	1.278	0.304	-0.657	-0.744	-0.772	-0.818	-0.841	-0.863	-0.866	-0.909	-0.980	-0.991		
April 2008	4.016	3.573	2.785	1.865	1.181	0.123	-0.610	-0.675	-0.703	-0.684	-0.698	-0.744	-0.796	-0.813	-0.885	-0.947	-0.960	
April 2007		3.448	2.971	2.021	1.472	0.365	-0.537	-0.702	-0.706	-0.743		-0.86	-0.834	-0.819	-0.845	-0.977		
April 2006	4.103	3.371	2.933	2.146	1.648	0.669	-0.509	-0.609	-0.662	-0.712	-0.737	-0.747						
April 2005		3.356	2.921	2.257	1.653	0.691	-0.473	-0.579	-0.661	-0.722								
April 2004		3.356	3.025	2.556	2.096	1.235	-0.403	-0.525	-0.648	-0.728		-0.800 -0.801	-0.841	-0.838	-0.842	-0.888	-0.918	-1.035
June 2003		3.229	2.089	2.038	2.026	1.723	0.504	-0.289	-0.800	-0.800		-0.800 -0.800	-0.826	-0.856	-0.893	-0.931	-0.973	
Chainages	0.000	7.076	20.179	34.492	41.629	51.128	65.642	75.067	82.462	94.194	100.000	107.285	119.694	131.293	142.960	152.894	163.738	183.052

Line 13

12d Model - A3
Horizontal Scale 1:500
Vertical Scale 1:100

REF.	REVISIONS	BY	CKD.	DATE
A	ORIGINAL ISSUE			

DRAWING SCALES

City of Townsville

ASSOCIATED DRAWINGS

LEVEL DATUM	SURVEY INDEX NO.
A.H.D.	SV 11180
SERVICE LOCATIONS	TCC REFERENCE
n/a	-

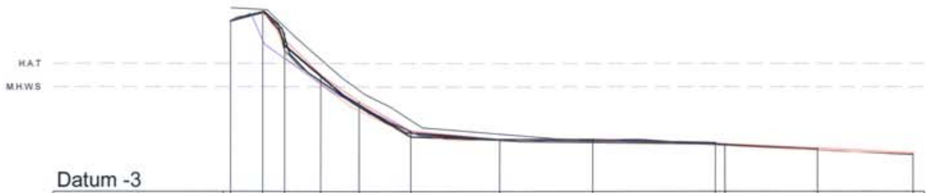
INFRASTRUCTURE SERVICES

APPROVED
Original signed by
MANAGER
Original signed by
ENGINEER

DES.	JYP
DRN.	JYP
CHK.	
COORD.	

Nelly Bay Beach
X-Sections
Kelly Street to Old Helipad
April 2009

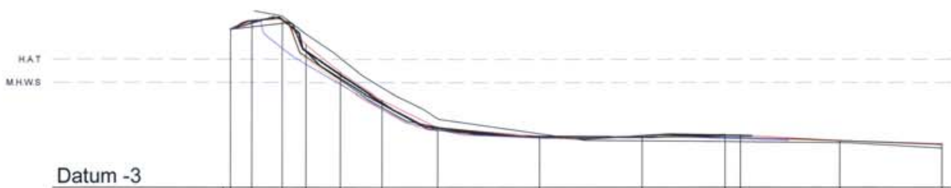
DATE	SHEET	DRAWING NO.	REV.
8/5/2009	1 OF 4	SV11180/12 -13	A



Datum -3

	0.000	6.477	10.936	18.237	26.013	36.458	54.455	73.279	98.098	100.000	118.772	138.099
April 2009	3.855	3.016	2.338	1.318	0.448	-0.596	-0.902	-0.932	-1.119	-1.146		
April 2008	3.855	4.222	2.643	1.420	0.381	-0.614	-0.958	-1.046	-1.106	-1.123		
April 2007	3.855	4.175	2.632	1.218	0.256	-0.871	-0.918	-0.937	-1.129		-1.338	-1.49
April 2006	3.855	4.186	3.189	1.434	0.404	-0.805	-0.914	-0.919	-1.092			
April 2005	3.855	4.213	2.866	1.638	0.484			-0.958	-1.063			
April 2004	3.856	4.232	3.103	1.706	0.820	-0.556	-0.906	-0.882	-1.063	-1.080	-1.247	-1.455
June 1989		4.311	3.621	2.313	1.074	-0.135	-0.695	-0.966	-1.130	-1.149	-1.337	-1.530
Chainages	0.000	6.477	10.936	18.237	26.013	36.458	54.455	73.279	98.098	100.000	118.772	138.099

Line 2



Datum -3

	0.000	4.300	10.450	15.246	22.208	30.658	41.894	62.494	83.236	100.000	103.145	123.233	143.883
April 2009	3.356	3.637	2.604	1.962	1.147	0.167	-0.659	-1.003	-0.941	-1.023	-1.041		
April 2008	3.356	3.456	3.599	2.260	1.309	0.227	-0.567	-0.974	-0.971	-0.987	-1.001	-1.118	-1.273
April 2007	3.356	3.722	3.727	2.19	1.196	0.163	-0.686	-0.969	-0.932		-0.993	-1.131	-1.267
April 2006	3.356	3.611	3.738	2.473	1.378	0.363	-0.683	-0.976	-0.916	-0.899	-0.911		
April 2005	3.356	3.701	3.750	2.483	1.522	0.412	-0.600		-0.972	-0.894			
April 2004	3.356	3.716	3.767	2.744	1.834	0.517	-0.589	-0.900	-0.964	-0.884	-0.862	-1.110	-1.232
June 1989			3.893	3.168	2.206	1.010	-0.223	-0.834	-1.122	-1.153	-1.159	-1.197	-1.418
Chainages	0.000	4.300	10.450	15.246	22.208	30.658	41.894	62.494	83.236	100.000	103.145	123.233	143.883

Line 1

12d Model - A3
Horizontal Scale 1:500
Vertical Scale 1:100

REF.	REVISIONS	BY	CKD.	DATE
A	ORIGINAL ISSUE			

DRAWING SCALES

City of Townsville

ASSOCIATED DRAWINGS

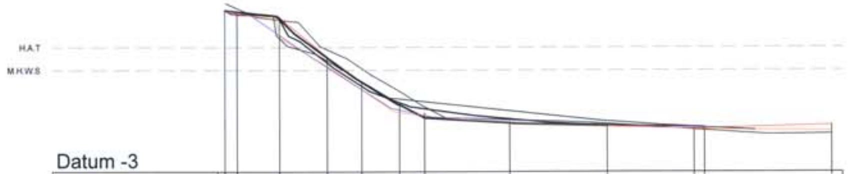
LEVEL DATUM	SURVEY INDEX NO.
A.H.D.	SV 11180
SERVICE LOCATIONS	TCC REFERENCE
n/a	-

INFRASTRUCTURE SERVICES

APPROVED		
Original signed by	DES.	JYP
MANAGER	DRN.	JYP
Original signed by	CHK.	
ENGINEER	COORD.	

Nelly Bay Beach
X–Sections
Kelly Street to Old Helipad
April 2009

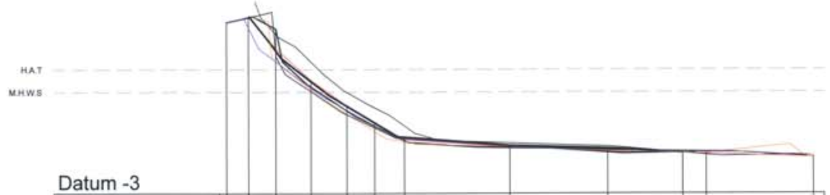
DATE	SHEET	DRAWING NO.	REV.
8/5/2009	2 OF 4	SV11180/1 – 2	A



Datum -3

	0.000	2.585	11.397	21.337	28.523	36.429	41.627	59.372	79.718	97.830	100.000	126.523
April 2009	3.669	3.593	2.669	1.343	0.427	-0.435	-0.655	-0.859	-1.060	-1.152	-1.158	
April 2008	3.669	3.515	2.530	1.602	0.748	0.015	-0.096	-0.477	-0.905	-1.137	-1.160	
April 2007	3.669	3.555	2.744	1.381	0.438	-0.535	-0.684	-0.889	-1.129	-1.219		-1.304
April 2006	3.669	3.618	3.312	1.520	0.556	-0.127	-0.380	-0.806	-1.064	-1.139		
April 2005	3.669	3.613	3.342	1.729	0.717	-0.219	-0.765	-0.980	-1.103			
April 2004	3.667	3.487	3.398	1.765	0.744	-0.169	-0.765	-0.948	-1.116	-1.207	-1.196	-1.053
June 1989		3.758	3.282	2.066	1.285	0.339	-0.301	-0.842	-1.009	-1.247	-1.276	-1.425
Chainages	0.000	2.585	11.397	21.337	28.523	36.429	41.627	59.372	79.718	97.830	100.000	126.523

Line 4



Datum -3

	0.000	4.613	10.287	17.613	25.108	30.896	37.097	59.057	79.467	96.087	100.000	122.373
April 2009	4.101	3.887	2.496	1.397	0.471	-0.172	-0.739	-1.037	-1.262	-1.285	-1.289	
April 2008	4.101	4.295	2.854	1.241	0.278	-0.275	-0.729	-1.049	-1.209	-1.249	-1.262	
April 2007	4.101	4.298	2.505	1.325	0.313	-0.418	-0.849	-1.062	-1.237	-1.324		-1.435
April 2006	4.101	4.307	3.832	1.431	0.439	-0.192	-0.803	-1.101	-1.298	-1.302		
April 2005	4.101	4.331	2.922	1.656	0.628	-0.067	-0.662	-1.010	-1.138	-1.321		
April 2004	4.102	4.326	3.033	1.719	0.653	-0.048	-0.753	-1.064	-1.164	-1.321	-1.362	-1.483
June 1989			3.614	2.469	1.208	0.567	-0.188	-0.903	-1.046	-1.312	-1.398	-1.441
Chainages	0.000	4.613	10.287	17.613	25.108	30.896	37.097	59.057	79.467	96.087	100.000	122.373

Line 3

12d Model - A3
Horizontal Scale 1:500
Vertical Scale 1:100

REF.	REVISIONS	BY	CKD.	DATE
A	ORIGINAL ISSUE			

DRAWING SCALES

City of Townsville

ASSOCIATED DRAWINGS

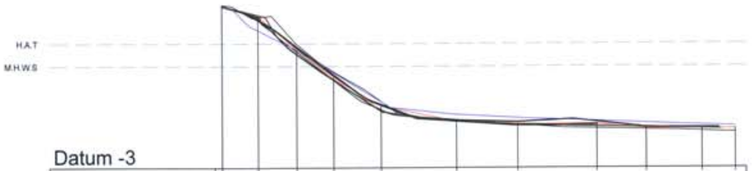
LEVEL DATUM	SURVEY INDEX NO.
A.H.D.	SV 11180
SERVICE LOCATIONS	TCC REFERENCE
n/a	-

INFRASTRUCTURE SERVICES

APPROVED Original signed by MANAGER	DES.	JYP
	DRN.	JYP
Original signed by ENGINEER	CHK.	
	COORD.	

Nelly Bay Beach
X–Sections
kelly Street to Old Helipad
April 2009

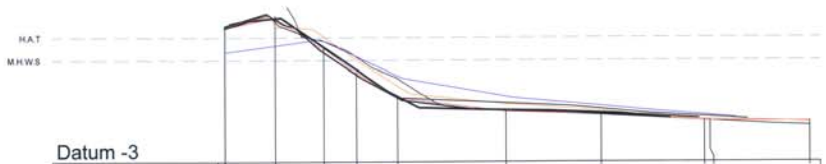
DATE	SHEET	DRAWING NO.	REV.
8/5/2009	3 OF 4	SV11180/3 – 4	A



Datum -3

April 2009	3.687	2.703	1.887	0.949	-0.260	-0.793	-0.935	-1.064	-1.148	-1.234	-1.280
April 2008	3.687	3.327	1.815	0.632	-0.599	-1.085	-1.231	-1.301	-1.344	-1.392	
April 2007	3.687	3.3	1.942	0.795	-0.58	-1.088	-1.164	-1.249	-1.298		-1.423
April 2006	3.687	3.245	1.717	0.643	-0.656	-1.034	-1.109	-1.104	-1.325	-1.348	
April 2005	3.687	3.171	2.051	0.894	-0.343	-1.017	-1.187	-1.181			
April 2004	3.687	3.391	1.902	0.705	-0.430	-1.079	-1.204	-1.181	-1.377	-1.382	-1.386
June 1989	3.736	3.230	2.134	0.991	-0.251	-1.014	-1.207	-1.379	-1.422	-1.488	-1.541
Chainages	0.000	7.534	15.578	23.251	33.126	48.657	61.603	78.114	88.400	100.000	106.964

Line 6



Datum -3

April 2009	1.542	1.824	2.011	1.375	0.575	-0.281	-0.674	-1.047	-1.066	
April 2008	2.538	2.815	1.774	0.834	-0.334	-0.553	-0.801	-1.122	-1.136	
April 2007	2.538	2.837	2.2	1.242	0.167	-0.581	-0.873	-1.235		-1.348
April 2006	2.538	2.825	1.459	0.537	-0.411	-0.910	-1.034			
April 2005	2.538	2.947	1.759	0.827	-0.280		-1.004			
April 2004	2.616	3.062	1.724	0.702	-0.322	-0.901	-1.034	-1.288	-1.302	-1.315
June 1989			2.007	1.355	0.463	-0.678	-1.055	-1.288	-1.300	-1.500
Chainages	0.000	10.506	20.645	27.440	35.998	58.631	78.470	100.000	101.168	121.970

Line 5

12d Model - A3
Horizontal Scale 1:500
Vertical Scale 1:100

REF.	REVISIONS	BY	CKD.	DATE
A	ORIGINAL ISSUE			

DRAWING SCALES

City of Townsville

ASSOCIATED DRAWINGS	
LEVEL DATUM	SURVEY INDEX NO.
A.H.D.	SV 11180
SERVICE LOCATIONS	TCC REFERENCE
n/a	-

INFRASTRUCTURE SERVICES

APPROVED		
Original signed by MANAGER	DES.	JYP
	DRN.	JYP
Original signed by ENGINEER	CHK.	
	COORD.	

Nelly Bay Beach
X-Sections
kelly Street to Old Helipad
April 2009

DATE	SHEET	DRAWING NO.	REV.
8/5/2009	4 OF 4	SV11180/5 - 6	A

Appendix E

- **EROSION RECESSION LINES**


LEGEND FOR RECESSION LINES :
50 YEAR A RI
100 YEAR A RI
200 YEAR ARI
500 YEAR ARI
1,000 YEAR ARI
SHEET 1


YATES
STREET
LEGEND FOR RECESSION LINES :
50 YEAR A RI
100 YEAR A RI
200 YEAR ARI
500 YEAR ARI
1,000 YEAR ARI
SHEET 2

THE ESPLANADE
LEGEND FOR RECESSION LINES :
50 YEAR A RI
100 YEAR A RI
200 YEAR ARI
500 YEAR ARI
1,000 YEAR ARI
SHEET 3


LEGEND FOR RECESSION LINES :
50 YEAR A RI
100 YEAR A RI
200 YEAR ARI
500 YEAR ARI
1,000 YEAR ARI
SHEET 4


Insufficient survey information in this area
NELLY BAY ROAD
HELIPAD
LEGEND FOR RECESSION LINES :
50 YEAR A RI
100 YEAR A RI
200 YEAR ARI
500 YEAR ARI
1,000 YEAR ARI
SHEET 5

LEGEND FOR RECESSION LINES :
50 YEAR A RI
100 YEAR A RI
200 YEAR ARI
500 YEAR ARI
1,000 YEAR ARI
NELLY BAY ROAD
Recession limited by presence of rock in the slope
SHEET 6


LEGEND FOR RECESSION LINES :
50 YEAR A RI
100 YEAR A RI
200 YEAR ARI
500 YEAR ARI
1,000 YEAR ARI
NELLY BAY ROAD
Recession limited by presence of rock in the slope
SHEET 7


LEGEND FOR RECESSION LINES :
50 YEAR A RI
100 YEAR A RI
200 YEAR ARI
500 YEAR ARI
1,000 YEAR ARI
Recession limited by presence of rock in the slope
SHEET 8


NELLY
BAY
ROAD
Recession limited
by presence of
rock in the slope
Insufficient
survey
LEGEND FOR RECESSION LINES :
50 YEAR A RI
100 YEAR A RI
200 YEAR ARI
500 YEAR ARI
1,000 YEAR ARI
SHEET 9